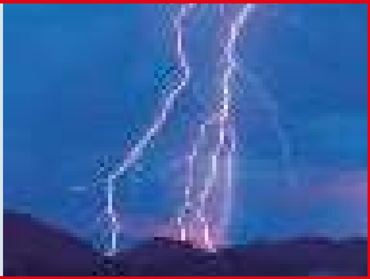
LIGHTNING PROTECTION GUIDE

3rd updated Edition



DEHN

LIGHTNING PROTECTION GUIDE

3rd updated Edition

DEHN + SÖHNE – Lightning Protection Guide
3rd updated edition
as of December 2014

ISBN 978-3-9813770-1-9

Surge Protection
Lightning Protection / Earthing
Safety Equipment

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Publication No. DS702/E/2014

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Preface

Since its foundation in 1980, the "Lightning Protection" Technical Committee IEC TC81 of the International Electrotechnical Commission (IEC) has published numerous standards on the topics of lightning protection for buildings, protection of electronic systems, risk analysis and simulation of lightning effects. Parts 1 to 4 of the international IEC 62305 standard series, which was published in 2006, laid the foundation for lightning protection standards and their application. This standard series was published almost at the same time as the European lightning protection standard series EN 62305 Parts 1 to 4. The entire IEC standard series was further developed between 2006 and 2010 and was finally published as IEC 62305 Parts 1 to 4:2010-12 (edition 2) in December 2010. While the adaptations were internationally accepted, only Parts 1, 3 and 4 were accepted on the European level and were published as EN documents in October 2011. Part 2, however, was adapted to European requirements, improved and finally published as a European standard in March 2012.

When designing and installing lightning protection systems, contractors will have to observe the IEC 62305 (EN 62305) standard series to comply with the state of the art. To this end, they must make themselves familiar with the content of the new lightning protection standards.

European treaties require that countries completely adopt European standards on the national level (not only in the field of lightning protection). Therefore, additional information is provided in the form of national supplements. These supplements are not contradictory to the actual standard and are only informative from a legal point of view. Since these supplements were prepared by different experts, many aspects from science as well as from the design, installation and inspection of lightning protection systems were taken into account. The supplements are state of the art and must be observed.

This revised and considerably extended edition of the Lightning Protection Guide is supposed to make experts in this field (designers or installers) familiar with the new IEC 62305 (EN 62305) standard series. For this purpose, our Lightning Protection Guide includes comprehensive practical solutions for different applications. It also provides general information on the wide-ranging field of lightning and surge protection which is a major business area of DEHN where the fourth generation is now in charge.

At this point we would like to thank Mr Thomas Dehn, former DEHN Managing Partner of the third generation, for his longstanding commitment to science, research and education. This book would not have been published without him.

The third edition of our Lightning Protection Guide is now available and we hope that this guide will be useful to you. We kindly ask you to help us improve our Lightning Protection Guide. Please do not hesitate to send your corrections and suggestions to lightning.protection.guide@dehn.de. We are looking forward to your feedback and we will do our best to consider it in the next edition.

DEHN + SÖHNE, December 2014

DEHN + SÖHNE, Neumarkt

1

State of the art for the installation of lightning protection systems

1.1 Installation standards

With the new IEC 62305 (EN 62305) standard series, the state of the art in the field of lightning protection is incorporated in a uniform and updated international (European) standard. The actual lightning protection standards (IEC 62305-3 (EN 62305-3) and IEC 62305-4 (EN 62305-4)) are preceded by two general standard parts (IEC 62305-1 (EN 62305-1) and 62305-2 (EN 62305-2)) (**Table 1.1.1**). The supplements to the German standards include important national information (**Table 1.1.2**).

IEC 62305-1 (EN 62305-1): General principles

This part contains information about the risk of lightning strikes, lightning characteristics and the resulting parameters for simulating the effects of lightning strikes. In addition, an overview of the IEC 62305 (EN 62305) standard series is given. Procedures and protection principles, which form the basis for the following parts, are explained.

IEC 62305-2 (EN 62305-2): Risk management

Risk management in accordance with IEC 62305-2 (EN 62305-2) includes a risk analysis to determine whether lightning protection is required. A technically and economically optimum protection measure is then defined. Finally, the remaining residual risk is determined. Starting with the unprotected state of the building, the remaining risk is reduced and reduced until it is below the tolerable risk. This method can be both used for a simple determination of the class of LPS in accordance with IEC 62305-3 (EN 62305-3) and to establish a complex protection system against lightning electromagnetic impulses (LEMP) in accordance with IEC 62305-4 (EN 62305-4).

Supplement 1 of the German DIN EN 62305-2 standard (Supplement 1 of the German VDE 0185-305-2 standard): Lightning threat in Germany

This supplement includes a map of the ground flash density N_g in Germany. N_g is required for a risk analysis according to IEC 62305-2 (EN 62305-2).

Supplement 2 of the German DIN EN 62305-2 standard (Supplement 2 of the German VDE 0185-305-2 standard): Calculation assistance for assessment of risk for structures

This supplement includes a calculation assistance for assessing the risk according to IEC 62305-2 (EN 62305-2) to protect structures and persons according to IEC 62305-3 (EN 62305-3) as well as electrical and electronic systems in structures according to IEC 62305-4 (EN 62305-4).

Classification	Title
IEC 62305-1 (EN 62305-1):2010-12	Protection against lightning Part 1: General principles
IEC 62305-2 (EN 62305-2):2010-12	Protection against lightning Part 2: Risk management
IEC 62305-3 (EN 62305-3):2010-12	Protection against lightning Part 3: Physical damage to structures and life hazard
IEC 62305-4 (EN 62305-4):2010-12	Protection against lightning Part 4: Electrical and electronic systems within structures

Table 1.1.1 Lightning protection standards valid since December 2010

Standard	Supplement	Title
DIN EN 62305-2	1	Lightning threat in Germany
	2	Calculation assistance for assessment of risk for structures
	3	Additional information for the application of DIN EN 62305-2 (VDE 0185-305-2)
DIN EN 62305-3	1	Additional information for the application of DIN EN 62305-3 (VDE 0185-305-3)
	2	Additional information for special structures
	3	Additional information for the testing and maintenance of lightning protection systems
	4	Use of metallic roofs in lightning protection systems
	5	Lightning and overvoltage protection for photovoltaic power supply systems
DIN EN 62305-4	1	Sharing of the lightning current

Table 1.1.2 Supplements to the German DIN EN 62305 standard

Supplement 3 of the German DIN EN 62305-2 standard (Supplement 3 of the German VDE 0185-305-2 standard): Additional information for the application of DIN EN 62305-2 (VDE 0185-305-2)

This supplement includes information and figures to make it easier to use and understand the standard and considers new findings.

IEC 62305-3 (EN 62305-3): Physical damage to structures and life hazard

This part deals with the protection of structures and persons from material damage and life-threatening situations caused by the effects of lightning currents or dangerous sparking, especially in the event of direct lightning strikes. A lightning protection system comprising external lightning protection (air-termination system, down-conductor system and earth-termination system) and internal lightning protection (lightning equipotential bonding and separation distance) serves as a protection measure. The lightning protection system is defined by its class of LPS, class of LPS I being more effective than class of LPS IV. The class of LPS required is determined with the help of a risk analysis carried out in accordance with IEC 62305-2 (EN 62305-2), unless otherwise laid down in regulations (e.g. building regulations).

Supplement 1 of the German DIN EN 62305-3 standard (Supplement 1 of the German VDE 0185-305-3 standard): Additional information for the application of DIN EN 62305-3 (VDE 0185-305-3)

Supplement 1 provides more detailed information on Annex E "Guidelines for the design, construction, maintenance and inspection of lightning protection systems" of the standard. It focuses on the dimensioning of the air-termination system, use of metal components, positioning of air-termination conductors and rods, use of protected volumes, etc. Moreover, information on the fire behaviour of construction materials and components is provided. To define the scope of the standard, the fields where special regulations apply are listed (e.g. railway systems, electrical transmission, distribution and generation systems outside a structure, pipelines, vehicles, ships, aircrafts and offshore systems).

Moreover, different terms and definitions were defined more exactly (e.g. down-conductor system, earth electrode, lightning equipotential bonding) and notes on the correct use of aluminium conductors mounted on, in or under the surface, mortar and concrete were added. The note that it is **basically** not allowed to use aluminium in the ground is paramount.

The use of connecting lines for single earth electrodes is explained based on several sample figures.

Protection measures against touch and step voltage and the use of gutters, downpipes and steel columns, natural earth electrodes, manually or industrially produced components and corrosion protection measures were also added or illustrated in figures.

Supplement 2 of the German DIN EN 62305-3 standard (Supplement 2 of the German VDE 0185-305-3 standard): Additional information for special structures

This supplement includes information on special structures such as hospitals, sports grounds, swimming baths, silos with potentially explosive areas, high-rack warehouses, sewage plants and biogas plants, thus taking into account the technological development over the last years.

Supplement 3 of the German DIN EN 62305-3 standard (Supplement 3 of the German VDE 0185-305-3 standard): Additional information for the testing and maintenance of lightning protection systems

This supplement gives information on the inspection of lightning protection systems and provides flow charts. Moreover, terms and their meaning (e.g. lightning protection specialist) are defined. This supplement includes figures on the different measuring methods for inspecting lightning protection systems (contact resistance, earth resistance) and information on the documentation.

Supplement 4 of the German DIN EN 62305-3 standard (Supplement 4 of the German VDE 0185-305-3 standard): Use of metallic roofs in lightning protection systems

Metallic roofs can be used as a natural component of a lightning protection system. The aim of this supplement is to provide additional information on the use of metallic roofs according to the IEC 62305 (EN 62305) standard.

Supplement 5 of the German DIN EN 62305-3 standard (Supplement 5 of the German VDE 0185-305-3 standard): Lightning and overvoltage protection for photovoltaic power supply systems

This supplement describes the protection of photovoltaic power supply systems in case of lightning interference and surges of atmospheric origin. The requirements and measures for ensuring the protection, operation and availability of photovoltaic power supply systems are described.

IEC 62305-4 (EN 62305-4): Electrical and electronic systems within structures

This part deals with the protection of structures with electrical and electronic systems against the effects of the lightning electromagnetic impulse. Based on the protection measures according to IEC 62305-3 (EN 62305-3), this standard also considers the effects of electrical and magnetic fields as well as induced voltages and currents caused by direct and indirect lightning strikes.

The importance and necessity of this standard derive from the increasing use of different electrical and electronic systems, which are referred to as information systems. To protect these information systems, the structure is divided into lightning protection zones (LPZs). This allows to consider local differences in number, type and sensitivity of the electrical and electronic devices when choosing the protection measures. For each lightning protection zone, a risk analysis in accordance with IEC 62305-2 (EN 62305-2) is performed to select those protection measures which provide optimum protection at minimum cost.

The IEC 62305 (EN 62305) standards Parts 1 to 4 can be used to design, install, inspect and maintain lightning protection systems for structures, their installations, their contents and the persons within.

1.2 Work contracts

A work contractor is fundamentally liable for ensuring that his service is free of deficiencies. Compliance with the recognised engineering rules is the decisive starting point for work and service free of deficiencies. Relevant national standards are used here in order to fill the factual characteristic of the "recognised engineering rules" with life. If the relevant standards are complied with, it is presumed that the work and service is free of deficiencies. The practical significance of such a prima facie evidence lies in the fact that a customer who lodges a complaint of non-conform service by the work contractor (for example for the installation of a lightning protection system) has basically little chance of success if the work contractor can show that he complied with the relevant technical standards. As far as this effect is concerned, standards and preliminary standards carry equal weight. The effect of the presumption of technical standards is removed, however, if either the standards are withdrawn, or it is proven that the actual standards no longer represent the state of the art. Standards cannot statically lay down the state of the recognised engineering rules in tablets of stone as technical requirements and possibilities are continually changing. If standards are withdrawn and replaced with new standards or preliminary standards, it is primarily the new standards which correspond to the state of the art. National supplements reflect the recognised state of the art.

Contractors and those placing an order for work regularly agree that the work must conform to the general state of the art without the need to make specific mention of this. If the work shows a negative deviation from this general state of the art, it is faulty. This can result in a claim being made against the contractor for material defect liability. The material defect liability only exists, however, if the work was already faulty at the time of acceptance! Circumstances occurring subsequently – such as a further development of the state of the art – do not belatedly make the previously accepted, defect-free work faulty!

For the question of the deficiency of work and service, the state of the recognised engineering rules at the time of the acceptance is the sole deciding factor.

Since, in the future, only the new lightning protection standards will be relevant at the time of completion and acceptance of lightning protection systems, they have to be installed in accordance with these standards. It is not sufficient that the service conformed to the engineering rules at the time it was provided, if, between completion of a contract, service provision and acceptance of the construction work, the technical knowledge and hence the engineering rules have changed.

Thus, works which have been previously installed and already accepted under the old standards do not become defective because, as a result of the updating of the standards, a "higher technical standard" is demanded.

With the exception of lightning protection systems for nuclear facilities, lightning protection systems have only to conform to the state of the art at the time they are installed, i.e. they do not have to be updated to the latest state of the art. Existing systems are inspected in the course of maintenance tests according to the standards in force at the time they were installed.

1.3 Product standards

Materials and components for lightning protection systems must be designed and tested for the electrical, mechanical and chemical stress (e.g. corrosion) which has to be expected during use. This affects both the components of the external and internal lightning protection system.

IEC 62561-1 (EN 62561-1): Lightning protection system components (LPSC) – Requirements for connection components

This standard describes test procedures for metal connection components. Components falling within the scope of this standard are:

- Clamps
- Connectors
- Connection components
- Bridging components
- Expansion pieces
- Test joints

DEHN clamps and connectors meet the requirements of this test standard.

IEC 62561-2 (EN 62561-2): Lightning protection system components (LPSC) – Requirements for conductors and earth electrodes

This standard specifies the requirements on conductors, air-termination rods, earth lead-in rods and earth electrodes.

IEC 62561-3 (EN 62561-3): Lightning protection system components (LPSC) – Requirements for isolating spark gaps (ISG)

IEC 62561-4 (EN 62561-4): Lightning protection system components (LPSC) – Requirements for conductor fasteners

IEC 62561-5 (EN 62561-5): Lightning protection system components (LPSC) – Requirements for earth electrode inspection housings and earth electrode seals

IEC 62561-6 (EN 62561-6): Lightning protection system components (LPSC) – Requirements for lightning strike counters (LSC)

IEC 62561-7 (EN 62561-7): Lightning protection system components (LPSC) – Requirements for earthing enhancing compounds

IEC 61643-11 (EN 61643-11): Surge protective devices connected to low-voltage power systems – Requirements and test methods

This standard describes the requirements on, and inspections of, surge protective devices (SPDs) to ensure protection against the effects of indirect and direct lightning strikes or other transients.

IEC 61643-12 (CLC/TS 61643-12): Surge protective devices connected to low-voltage power distribution systems – Selection and application principles

This standard / technical specification must be used together with the IEC 61643-11 (EN 61643-11) standard and includes information on parameters which are required for the correct selection of surge protective devices. It also provides information on the selection and coordination of SPDs. In this context, the entire operating environment of the SPDs used such as equipment to be protected, system properties, insulation levels, types of surges, installation methods, place of installation of SPDs, coordination of SPDs, types of faults of SPDs and the consequences in case of failure of the equipment to be protected must be taken into account. The standard / technical specification describes the principles for the selection, operation, place of installation and coordination of SPDs connected to 50/60 Hz a.c. systems and equipment with nominal voltages up to 1000 V (r.m.s. value). This standard / technical specification only covers SPDs in electrical installations of buildings. Surge protective devices installed in devices are not taken into account.

IEC 61643-21 (EN 61643-21): Surge protective devices connected to telecommunications and signalling networks

This standard describes the performance requirements and test procedures for surge protection devices used for the protection of telecommunications and signalling networks including

- Data networks
- Voice transmission networks
- Emergency alarm systems and
- Automation systems

IEC 61643-22 (CLC/TS 61643-22): Low-voltage surge protective devices – Surge protective devices connected to telecommunications and signalling networks – Selection and application principles

This standard / technical specification describes the principles for the selection and application of surge protective devices (SPDs) used to protect telecommunications and signalling networks.

IEC 61663-1 (EN 61663-1): Lightning protection – Telecommunication lines – Fibre optic installations

IEC 61663-2 (EN 61663-2): Lightning protection – Telecommunication lines – Lines using metallic conductors

Supplement 1 of the German DIN VDE 0845 standard (Supplement 1 of the German VDE 0845 standard): Overvoltage protection of information technology equipment (IT installations)

This supplement provides additional information on how to protect IT installations against surges. Normative requirements are included in IEC 61663-1 (EN 61663-1), IEC 61663-2 (EN 61663-2) and IEC 61643-21 (EN 61643-21).

2

Characteristics of lightning current

2.1 Lightning discharge and lightning current curves

Every year, an average of around 1.5 million lightning strikes discharges over Germany. For an area of 357,042 km^2 this corresponds to an average flash density of 4.2 lightning discharges per square kilometre and year. The actual flash density, however, depends to a large extent on geographic conditions. An initial overview can be obtained from the flash density map contained in **Figure 3.2.3.1**. The higher the sub-division of the flash density map, the more accurate the information it provides about the actual lightning frequency in the area under consideration.

Using the BLIDS (lightning information service by Siemens) lightning detection system, it is now possible to locate lightning within 200 m in Germany. For this purpose, 145 measuring stations are spread throughout Europe. They are synchronised by means of the highly accurate time signal of the global positioning system (GPS). The measuring stations record the time the electromagnetic wave produced by the lightning discharge arrives at the receiver. The point of strike is calculated from the differences in the times of arrival of the electromagnetic wave recorded by the various receivers and the corresponding differences in the times it takes the electromagnetic wave to travel from the location of the lightning discharge to the receivers. The data determined in this way are filed centrally and made available to the user in form of various packages. Further information on this service can be obtained from www.siemens.de/blids (German website).

Thunderstorms come into existence when warm air masses containing sufficient moisture are transported to great altitudes. This transport can occur in a number of ways. In the case of heat thunderstorms, the ground is heated up locally by intense insolation. The layers of air near the ground heat up and rise. For frontal thunderstorms, the invasion of a cold air front causes cooler air to be pushed below the warm air, forcing it to rise. Orographic thunderstorms are caused when warm air near the ground is lifted up as it crosses rising ground. Additional physical effects further increase the vertical upsurge of the air masses. This forms updraught channels with vertical speeds of up to 100 km/h, which create towering cumulonimbus clouds with typical heights of 5 to 12 km and diameters of 5 to 10 km.

Electrostatic charge separation processes, e.g. friction and sputtering, are responsible for charging water droplets and particles of ice in the cloud.

Positively charged particles accumulate in the upper part and negatively charged particles in the lower part of the thundercloud. In addition, there is again a small positive charge centre at the bottom of the cloud. This originates from the corona discharge which emanates from sharp-pointed objects on the ground underneath the thundercloud (e.g. plants) and is transported upwards by the wind.

If the space charge densities, which happen to be present in a thundercloud, produce local field strengths of several 100 kV/m, leader discharges are formed which initiate a lightning discharge. Cloud-to-cloud flashes result in charge neutralisation between positive and negative cloud charge centres and do not directly strike objects on the ground in the process. The lightning electromagnetic impulses (LEMP) they radiate must be taken into consideration, however, because they endanger electrical and electronic systems.

Flashes to earth lead to a neutralisation of charge between the cloud charges and the electrostatic charges on the ground. We distinguish between two types of lightning flashes to earth:

- Downward flash (cloud-to-earth flash)
- Upward flash (earth-to-cloud flash)

In case of downward flashes, leader discharges pointing towards the ground guide the lightning discharge from the cloud to the earth. Such discharges usually occur in flat terrain and near low buildings. Cloud-to-earth flashes can be recognised by the branching (**Figure 2.1.1**) which is directed to earth. The most common type of lightning is a negative downward flash where a leader filled with negative cloud charge pushes its way from the thundercloud to earth (**Figure 2.1.2**). This leader propagates as a stepped leader with a speed of around

Figure 2.1.1 Downward flash (cloud-to-earth flash)

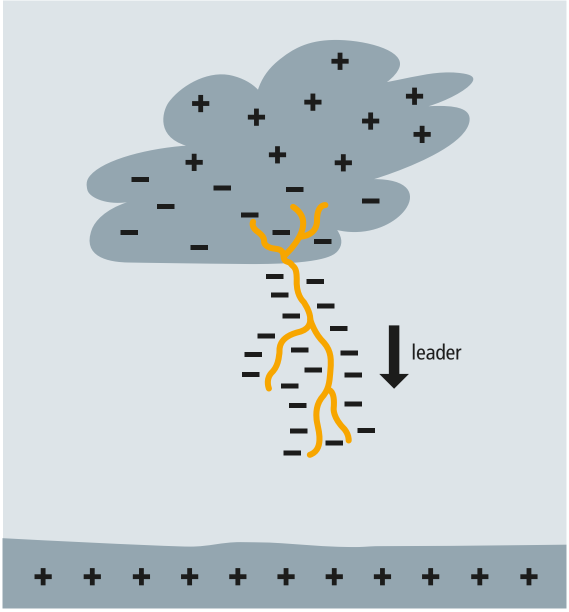


Figure 2.1.2 Discharge mechanism of a negative downward flash (cloud-to-earth flash)

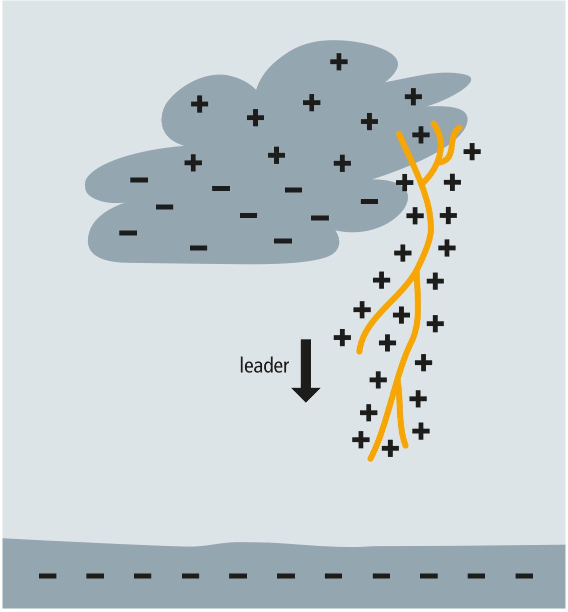


Figure 2.1.3 Discharge mechanism of a positive downward flash (cloud-to-earth flash)

300 km/h in steps of a few 10 m. The interval between the jerks amounts to a few 10 µs. When the leader has drawn close to the earth (a few 100 m to a few 10 m), it causes the strength of the electric field of objects on the surface of the earth in the vicinity of the leader (e.g. trees, gable ends of buildings) to increase. The increase is great enough to exceed the dielectric strength of the air. These objects involved reach out to the leader by growing positive streamers which then meet up with the leader, initiating the main discharge.

Positive downward flashes can arise out of the lower, positively charged area of a thundercloud (**Figure 2.1.3**). The ratio of the polarities is around 90 % negative lightning to 10 % positive lightning. This ratio depends on the geographic location.

On very high, exposed objects (e.g. wind turbines, radio masts, telecommunication towers, steeples) or on the tops of mountains, upward flashes (earth-to-cloud flashes) can occur. It can be recognised by the upwards-reaching branches of the lightning discharge (**Figure 2.1.4**). In case of upward flashes, the high electric field strength required to trigger a leader is not achieved in the cloud, but rather by the distortion of the electric field on the exposed object and the associated high strength of the electric field. From this location, the leader and its charge channel propagate towards the cloud. Upward flashes occur with both negative polarity (**Figure 2.1.5**) and with positive polarity (**Figure 2.1.6**). Since, with upward flashes, the leaders propagate from the exposed object on the surface of the earth to the cloud, high objects can be struck several times by one lightning discharge during a thunderstorm.

Depending on the type of flash, each lightning discharge consists of one or more partial lightning strikes. We distinguish between short strokes with a duration of less than 2 ms and long strokes with a duration of more than 2 ms. Further distinctive features of partial lightning strikes are their polarity (negative or positive) and their temporal position in the lightning discharge (first, subsequent or superimposed). The possible

Figure 2.1.4 Upward flash (earth-to-cloud flash)

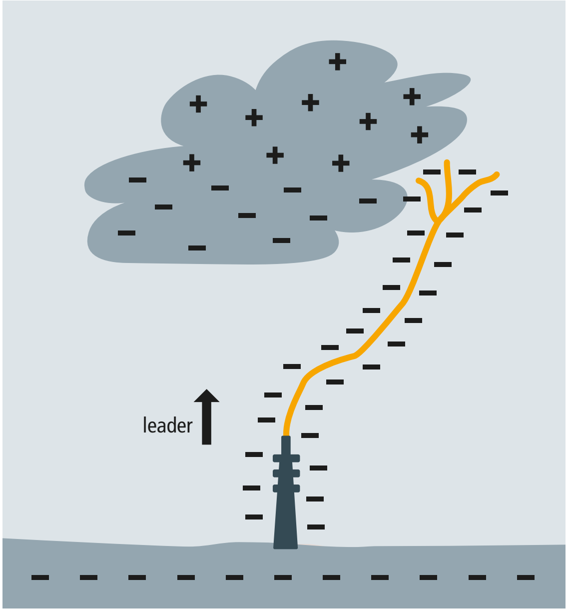


Figure 2.1.5 Discharge mechanism of a negative upward flash (earth-to-cloud flash)

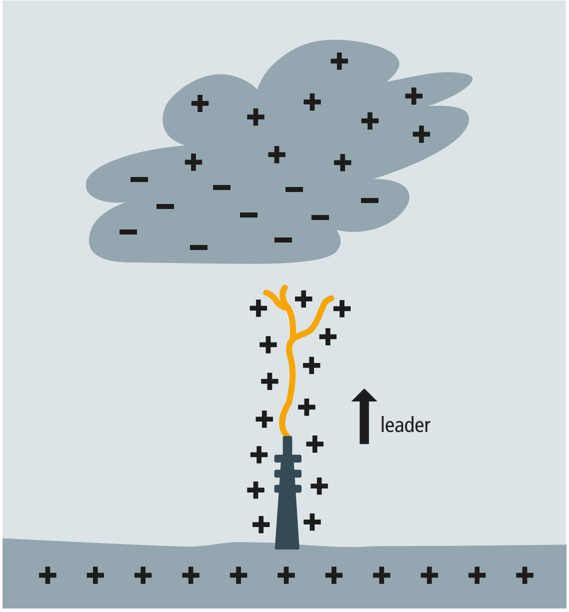


Figure 2.1.6 Discharge mechanism of a positive upward flash (earth-to-cloud flash)

combinations of partial lightning strikes are shown in **Figure 2.1.7** for downward flashes, and in **Figure 2.1.8** for upward flashes.

The lightning currents consisting of both short strokes and long strokes are impressed currents, i.e. the objects struck have no effect on the lightning currents. Four parameters which are important for lightning protection can be obtained from the lightning current curves shown in **Figures 2.1.7 and 2.1.8**:

- The peak value of the lightning current I
- The charge of the lightning current Q_{flash} consisting of the charge of the short stroke Q_{short} and the charge of the long stroke Q_{long}
- The specific energy W/R of the lightning current
- The steepness di/dt of the lightning current rise.

The following chapters show which of the individual parameters are responsible for which effects and how they influence the dimensioning of lightning protection systems.

2.2 Peak value of the lightning current

Lightning currents are impressed currents, in other words a lightning discharge can be considered to be an almost ideal current source. If an impressed electric current flows through conductive parts, a voltage drop across the part carrying the current occurs due to the amplitude of the current and the impedance of the conductive part carrying the current. In the simplest case, this relationship can be described using Ohm´s Law.

$$U = I \cdot R$$

I	Peak value of the lightning current
R	Earth resistance

If a current is formed at a single point on a homogeneously conducting surface, a potential gradient area arises. This effect also occurs when lightning strikes homogeneous ground (**Figure 2.2.1**). If living beings (persons or animals) are inside this potential gradient area, step voltage is formed which can cause electric shock (**Figure 2.2.2**). The higher the conductivity of the ground, the flatter is the potential gradient area. The risk of dangerous step voltages is thus also reduced.

If lightning strikes a building which is already equipped with a lightning protection system, the lightning current flowing via the earth-termination system of the building causes a voltage drop across the earth resistance R_E of the earth-termination system of the building (**Figure 2.2.3**). As long as all exposed conductive parts in the building are raised to the same high potential, persons inside the building are not in danger. There-

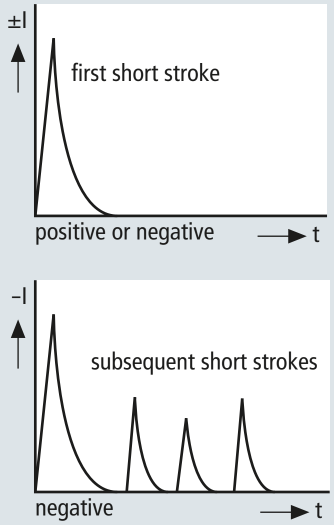


Figure 2.1.7 Possible components of a downward flash

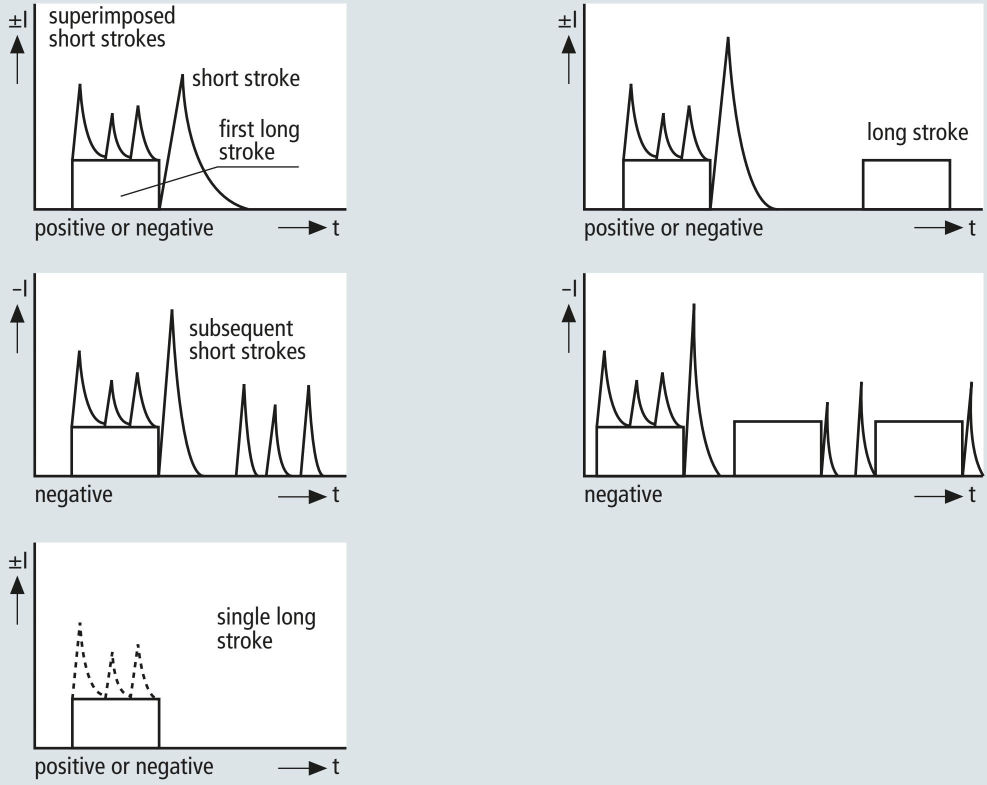


Figure 2.1.8 Possible components of an upward flash

fore, it is necessary to establish equipotential bonding for all exposed conductive parts in the building and all extraneous conductive parts entering the building. If this is disregarded, dangerous touch voltages may occur in case of a lightning strike.

The rise in potential of the earth-termination system as a result of the lightning current also creates a hazard for electrical installations (**Figure 2.2.4**). In the example shown, the operational earth of the low-voltage supply system is located outside the potential gradient area caused by the lightning current. If lightning strikes the building, the potential of the operational earth R_B is therefore not identical with the earth potential of the consumer's installation inside the building. In the example, the difference is 1000 kV. This endangers the insulation of the electrical installation and the equipment connected to it.

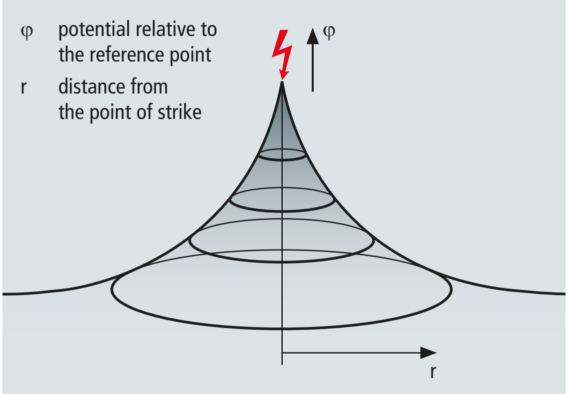


Figure 2.2.1 Potential distribution in case of a lightning strike to homogenous ground

Figure 2.2.2 Animals killed by electric shock due to step voltage

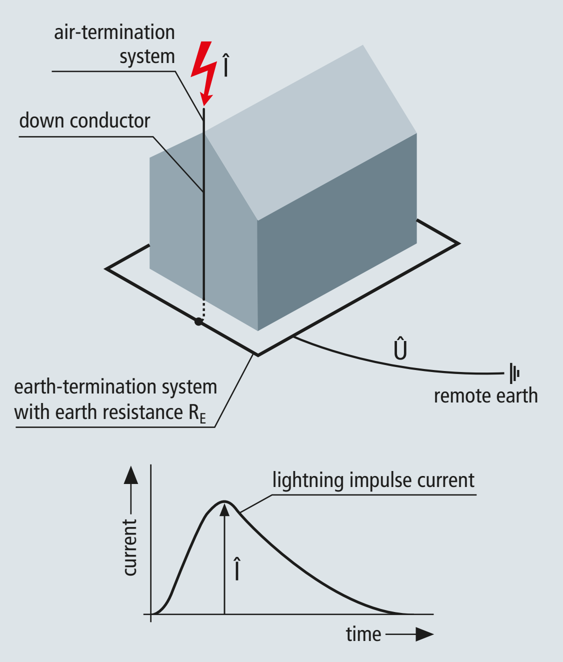


Figure 2.2.3 Potential rise of the building's earth-termination system with respect to the remote earth caused by the peak value of the lightning current

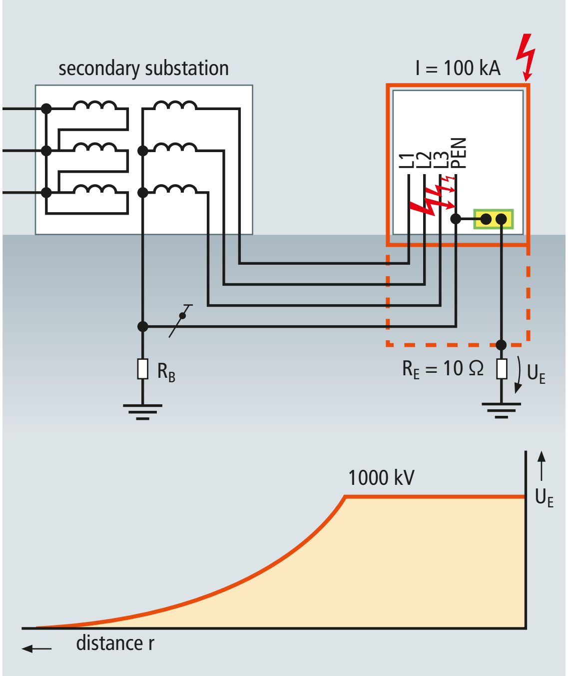


Figure 2.2.4 Risk for electrical installations resulting from a potential rise of the earth-termination system

2.3 Steepness of the lightning current rise

The steepness of lightning current rise $\Delta i/\Delta t$, which is effective during the interval Δt, defines the intensity of the electromagnetically induced voltages. These voltages are induced in all open or closed conductor loops located in the vicinity of conductors carrying lightning current. **Figure 2.3.1** shows possible configurations of conductor loops in which lightning currents could induce voltages. The square wave voltage U induced in a conductor loop during the interval αt is:

$$U = M \cdot \frac{\Delta i}{\Delta t}$$

M	Mutual inductance of the loop
$\Delta i/\Delta t$	Steepness of the lightning current rise

As already described, lightning discharges consist of a number of partial lightning strikes. As far as the temporal position is concerned, a distinction is made between first and subsequent short strokes within a lightning discharge. The main difference between these two types of short strokes is that, due to the formation of a lightning channel, the lightning current rise in case of a first stroke is not as steep as that of the subsequent stroke, which can use an existing conductive lightning channel. The steepness of the lightning current rise of the subsequent stroke is therefore used to assess the maximum induced voltage in conductor loops. **Figure 2.3.2** shows an example of how to assess the induced voltage in a conductor loop.

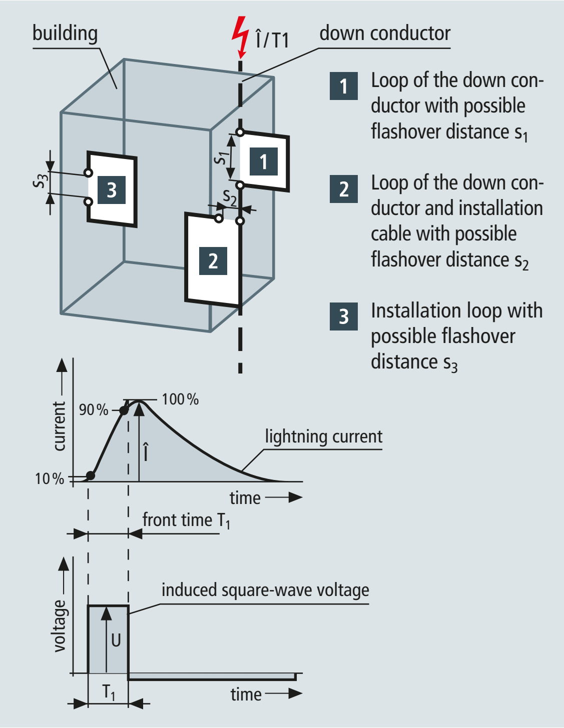


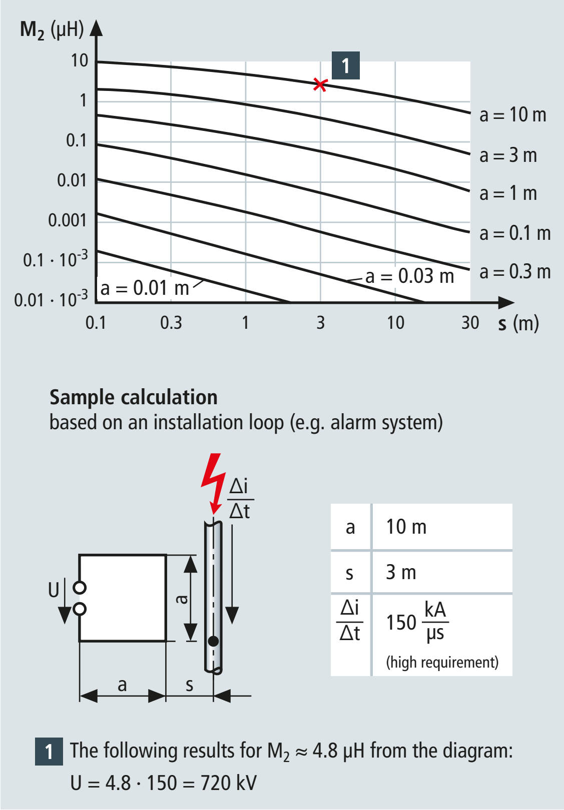
Figure 2.3.1 Square-wave voltage induced in loops due to the current steepness $\Delta i/\Delta t$ of the lightning current

2.4 Charge of the lightning current

The charge Q_{flash} of the lightning current consists of the charge Q_{short} of the short stroke and the charge Q_{long} of the long stroke. The charge

$$Q = \int i dt$$

of the lightning current is decisive for the energy conversion at the exact point of strike and at all points where the lightning current occurs in the form of an arc along an insulating clearance. The energy W converted at the base point of the arc is the



Sample calculation
based on an installation loop (e.g. alarm system)

a	10 m
s	3 m
$\frac{\Delta i}{\Delta t}$	$150 \ \frac{kA}{\mu s}$ (high requirement)

1 The following results for $M_2 \approx 4.8$ µH from the diagram:
$U = 4.8 \cdot 150 = 720$ kV

Figure 2.3.2 Sample calculation for induced square-wave voltages in squared loops

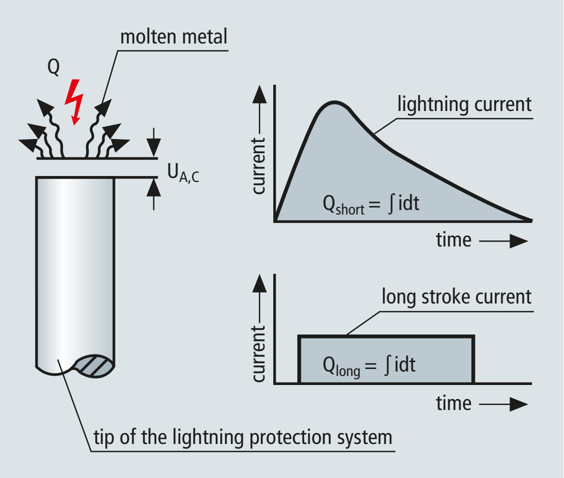
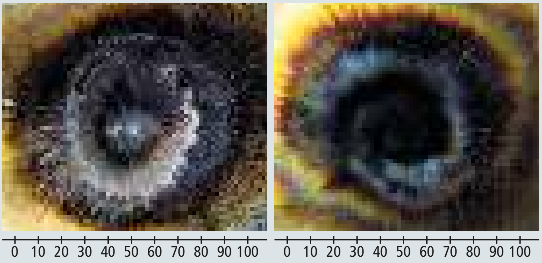


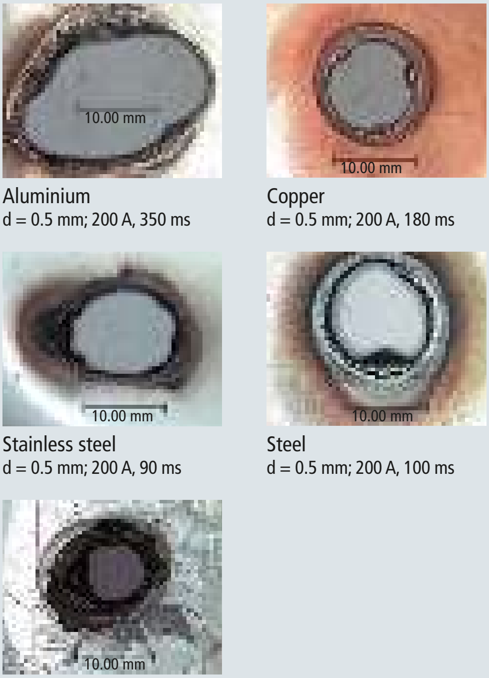
Figure 2.4.1 Energy conversion at the point of strike due to the charge of the lightning current



Galvanised steel
100 kA (10/350 µs)

Copper
100 kA (10/350 µs)

Figure 2.4.2 Effect of a short stroke arc on a metal surface



Aluminium
d = 0.5 mm; 200 A, 350 ms

Copper
d = 0.5 mm; 200 A, 180 ms

Stainless steel
d = 0.5 mm; 200 A, 90 ms

Steel
d = 0.5 mm; 200 A, 100 ms

Galvanised steel
d = 0.5 mm; 200 A, 100 ms

Figure 2.4.3 Plates perforated by the effects of long stroke arcs

product of the charge Q and the anode/cathode drop voltage $U_{A,C}$, which is in the micrometre range (**Figure 2.4.1**). The average value of $U_{A,C}$ is some 10 V and depends on influences such as the current intensity and wave form:

$$W = Q \cdot U_{A,C}$$

Q Charge of the lightning current

$U_{A,C}$ Anode/cathode drop voltage

Consequently, the charge of the lightning current causes the components of the lightning protection system directly struck by lightning to melt and also stresses isolating and protective spark gaps as well as spark-gap-based surge protective devices. Recent tests have shown that, because the arc persists for a longer time, it is mainly the long stroke charge Q_{long} which is capable of melting or vaporising large volumes of material. **Figures 2.4.2 and 2.4.3** show a comparison between the effects of the short stroke charge Q_{short} and the long stroke charge Q_{long}.

2.5 Specific energy

The specific energy W/R of a short stroke is the energy the short stroke converts into a resistance of 1 Ω. This energy conversion is the integral of the square of the short stroke over time for the duration of the short stroke:

$$\frac{W}{R} = \int i^2 dt$$

Therefore, this specific energy is frequently referred to as current square impulse. It is relevant for the temperature rise in conductors carrying lightning impulse currents as well as for the force exerted between conductors carrying lightning impulse currents (**Figure 2.5.1**).

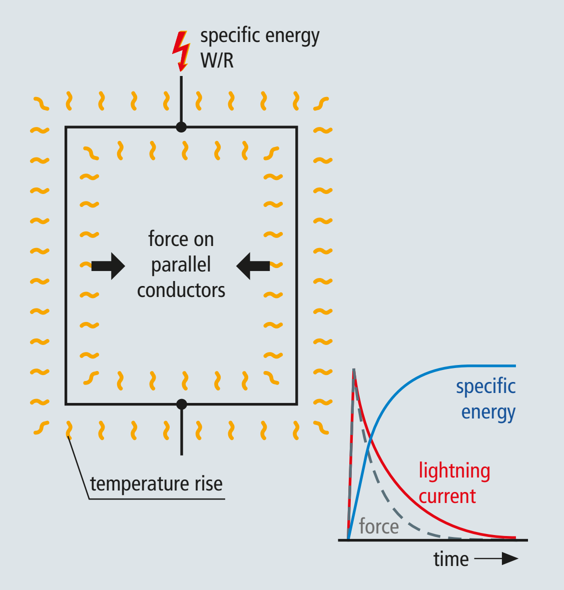


Figure 2.5.1 Temperature rise and force resulting from the specific energy of the lightning current

For the energy W converted in a conductor with resistance R we have:

$$W = R \cdot \int i^2 dt = R \cdot \frac{W}{R}$$

R	(Temperature-dependent) d.c. resistance of the conductor
W/R	Specific energy

The calculation of the temperature rise of conductors carrying lightning impulse currents may be required if the risks to persons and the risks from fire and explosion have to be taken into account during the design and installation of lightning protection systems. The calculation assumes that all the thermal energy is generated by the ohmic resistance of the components of the lightning protection system. Furthermore, it is assumed that there is no perceptible heat exchange with the surroundings due to the short duration of the process. **Table 2.5.1** lists the temperature rises of different lightning protection materials as well as their cross-sections as a function of the specific energy.

The electrodynamic forces F generated by a current i in a conductor with a long, parallel section of length l and a distance d (**Figure 2.5.2**) can be calculated as an approximation using the following equation:

Cross-section [mm^2]			4	10	16	25	50	100
Material	**Aluminium** W/R [MJ/Ω]	2.5	–	564	146	52	12	3
		5.6	–	–	454	132	28	7
		10	–	–	–	283	52	12
	Iron W/R [MJ/Ω]	2.5	–	–	1120	211	37	9
		5.6	–	–	–	913	96	20
		10	–	–	–	–	211	37
	Copper W/R [MJ/Ω]	2.5	–	169	56	22	5	1
		5.6	–	542	143	51	12	3
		10	–	–	309	98	22	5
	Stainless steel W/R [MJ/Ω]	2.5	–	–	–	940	190	45
		5.6	–	–	–	–	460	100
		10	–	–	–	–	940	190

Table 2.5.1 Temperature rise ΔT in K of different conductor materials

$$F(t) = \frac{\mu_0}{2\pi} \cdot i^2(t) \cdot \frac{l}{d}$$

F(t)	Electrodynamic force
i	Current
μ_0	Magnetic field constant in air ($4\,\pi \cdot 10^{-7}$ H/m)
l	Conductor length
d	Distance between the parallel conductors

The force between the two conductors is attractive if the currents flow in the same direction and repulsive if the currents flow in opposite directions. It is proportional to the product of the currents in the conductors and inversely proportional to the distance of the conductors. Even in the case of a single, bent conductor, a force is exerted on the conductor. In this case, the force is proportional to the square of the current in the bent conductor.
Thus, the specific energy of the short stroke defines the stress which causes reversible or irreversible deformation of components and arrangements of a lightning protection system. These effects are considered in the test setups of the product standards concerning the requirements made on lightning protection components for lightning protection systems.

Annex D of IEC 62305-1 describes in detail in which way the lightning current parameters relevant to the point of strike are important for the physical integrity of an LPS. As explained above, these are in general the peak current I, the charge Q, the specific energy W/R, the duration T and the average steepness of the current di/dt. Each parameter tends to dominate a different failure mechanism as analysed in detail above.

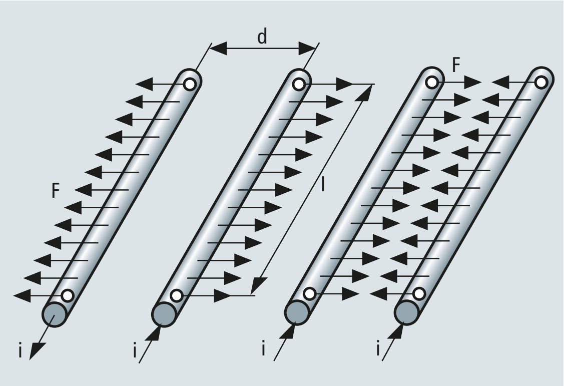


Figure 2.5.2 Electrodynamic force between parallel conductors

2.6 Lightning current components

Figures 2.1.7 and 2.1.8 show the fundamental lightning current curves and the possible components of upward and downward flashes as described in the IEC 62305-1 lightning protection standard.

The total lightning current can be subdivided into individual lightning current components:

- First positive short stroke
- First negative short stroke
- Subsequent short stroke
- Long stroke

Maximum values are assigned to the individual lightning protection components depending on the lightning protection level (LPL). The time characteristic of the lightning current plays an important role for most of the lightning effects described before. Therefore, time parameters are defined for the individual lightning current components in the lightning protection standards. These wave forms are also used for analysis and as test parameters for simulating the lightning effects on LPS components. In the latest version of the IEC 62305-2 (EN 62305-2) standard, the first negative short stroke is introduced as a new lightning current component. The first negative short stroke is currently only used for calculations and is the highest risk for some induction effects. **Table 2.6.1** gives an overview of the maximum parameters according to the lightning protection level as well as the wave form for the individual lightning current components defined in the standard.

First positive stroke	**Lightning protection level (LPL)**			
Parameters	**I**	**II**	**III**	**IV**
Peak current I [kA]	200	150	100	
Short stroke charge Q_{short} [C]	100	75	50	
Specific energy W/R [MJ/Ω]	10	5.6	2.5	
Wave form T_1/T_2 [μs/μs]	10/350			
First negative stroke	**LPL**			
Parameters	**I**	**II**	**III**	**IV**
Peak current I [kA]	100	75	50	
Average steepness di/dt [kA/μs]	100	75	50	
Wave form T_1/T_2 [μs/μs]	1/200			
Subsequent stroke	**LPL**			
Parameters	**I**	**II**	**III**	**IV**
Peak current I [kA]	50	37.5	25	
Average steepness di/dt [kA/μs]	200	150	100	
Wave form T_1/T_2 [μs/μs]	0.25/100			
Long stroke	**LPL**			
Parameters	**I**	**II**	**III**	**IV**
Long stroke charge Q_{long} [C]	200	150	100	
Time T_{long} [s]	0.5			
Flash	**LPL**			
Parameters	**I**	**II**	**III**	**IV**
Flash charge Q_{flash} [C]	300	225	150	

Table 2.6.1 Maximum lightning current parameters and wave forms for the different lightning current components

2.7 Assignment of lightning current parameters to lightning protection levels

Lightning protection levels I to IV are laid down to define lightning as a source of interference. Each lightning protection level requires a set of

- Maximum values (dimensioning criteria which are used to design lightning protection components in such a way that they meet the requirements expected) and
- Minimum values (interception criteria which are necessary to be able to determine the areas which are sufficiently protected against direct lightning strikes (rolling sphere radius)).

Lightning protection level	Maximum values (dimensioning criteria)	
	Maximum peak value of the lightning current	Probability that the actual lightning current is smaller than the maximum peak value of the lightning current
I	200 kA	99 %
II	150 kA	98 %
III	100 kA	95 %
IV	100 kA	95 %

Table 2.7.1 Maximum lightning current parameter values and their probabilities

Lightning protection level	Minimum values (dimensioning criteria)		
	Minimum peak value of the lightning current	Probability that the actual lightning current is greater than the minimum peak value of the lightning current	Rolling sphere radius
I	3 kA	99 %	20 m
II	5 kA	97 %	30 m
III	10 kA	91 %	45 m
IV	16 kA	84 %	60 m

Table 2.7.2 Minimum lightning current parameter values and their probabilities

Tables 2.7.1 and 2.7.2 show the assignment of the lightning protection levels to the maximum and minimum values of the lightning current parameters.

2.8 Lightning current measurements for upward and downward flashes

In general, it is assumed that downward flashes (cloud-to-earth flashes) place a greater stress on objects hit by lightning than upward flashes (earth-to-cloud flashes), particularly with regard to short strokes. In the majority of cases, downward flashes are to be expected in flat terrain and near low structures. If, however, structures are situated in an exposed location and / or are very high, upward flashes typically occur. The parameters defined in the lightning protection standards generally apply to upward and downward flashes. In case of upward flashes, especially the long stroke with or without superimposed impulse currents must be considered.

A more exact determination of the lightning current parameters and their mutual dependence for upward and downward flashes is in preparation. Therefore, lightning current measurements for scientific fundamental research are performed on different lightning measuring stations throughout the world. **Figure 2.8.1** shows the lightning measuring station operated by the Austrian research group ALDIS on the Gaisberg mountain near Salzburg / Austria. Since 2007, DEHN has been performing lightning current measurements on this measuring station by means of a mobile lightning current detection unit. The results of these comparison measurements basically confirm the lightning current parameters as described in the latest IEC 62305-1 (EN 62305-1) standard. The high number of superimposed impulse currents in case of upward flashes is

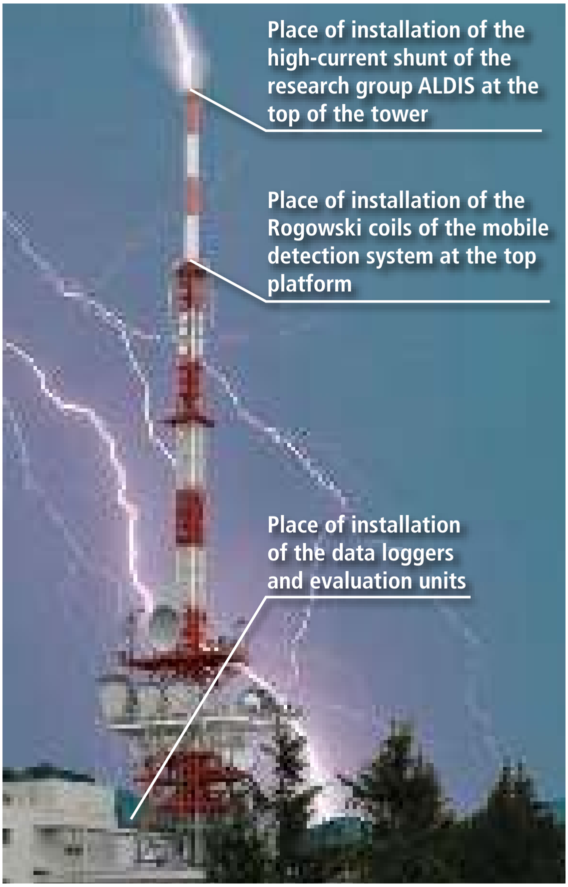


Figure 2.8.1 Lightning current measurements by the Austrian lightning research group ALDIS and DEHN at the ORS transmission mast on top of the Gaisberg mountain near Salzburg

particularly remarkable. With an average of 8 short strokes (either superimposed on the long stroke or subsequent to the long stroke), considerably more impulse currents were recorded than the 3 to 4 subsequent strokes which typically occur in case of downward flashes. Thus, the 3 to 4 impulse discharges per flash stated in the lightning protection standards only apply to downward flashes.

For 10 years (2000 to 2009), ALDIS has been recording 10 flashes with total charges exceeding the maximum charge value of 300 As depending on the lightning protection level (LPL). These high charge values were recorded only during winter thunderstorms. In the first measuring period, the mobile system also recorded long strokes during winter thunderstorms with higher charges than the charges specified for LPL I. **Figure 2.8.2** shows a long stroke with a charge of 405 As recorded in January 2007. These extreme loads, which exceed the charge value of 300 As of LPL I, may have to be taken into account when taking lightning protection measures for high structures at exposed locations such as wind turbines and transmitters.

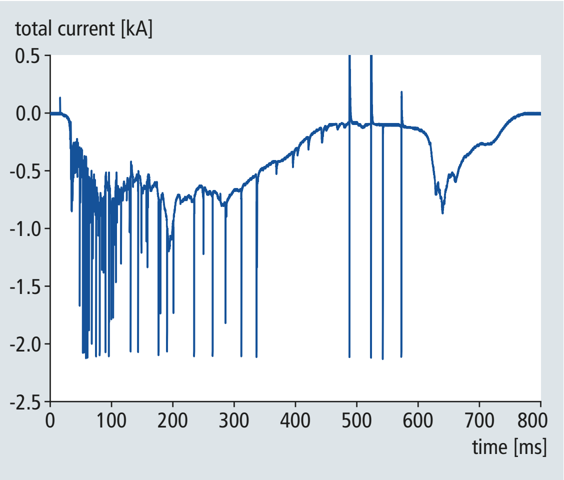


Figure 2.8.2 Long stroke with superimposed impulse currents of an upward flash with a total charge of approximately 405 As – recorded at the Gaisberg transmission mast during a winter thunderstorm

Negative downward flash and the associated partial lightning current

A negative cloud-to-earth flash was recorded during the lightning current measurements. Compared to the previously described upward flashes, this downward flash is characterised by a considerably higher short strokes value. The detected negative downward flash has a maximum current of about 29 kA and a charge of about 4.4 As. **Figure 2.8.3** shows a comparison between the current curves recorded by the scientific ALDIS measuring system and the mobile lightning current detection system. Both current curves are in good agreement. Another slowly increasing negative lightning current of about 5 kA is superimposed on the decreasing short stroke. In lightning research, this characteristic lightning current component is referred to as M-component. In the second measuring period, the mobile lightning current detection system also recorded partial currents in one of the low-voltage cables installed between the platform at a height of 80 m and the operations building at the foot due to the high number of measuring channels. Between these two installation points, there are numerous parallel discharge paths for the lightning current. The lightning current splits between the metal mast structure and the numerous power supply, data and antenna cables. Thus, the measured absolute value of the partial lightning current in a single low-voltage cable does not provide any useful information. However, it was verified that the partial lightning current in the low-voltage cable under consideration has the same polarity as well as a wave form and current flow duration comparable to the primary lightning current at the top of the tower. Consequently, a surge protective device installed to protect this cable must be capable of discharging partial lightning currents.

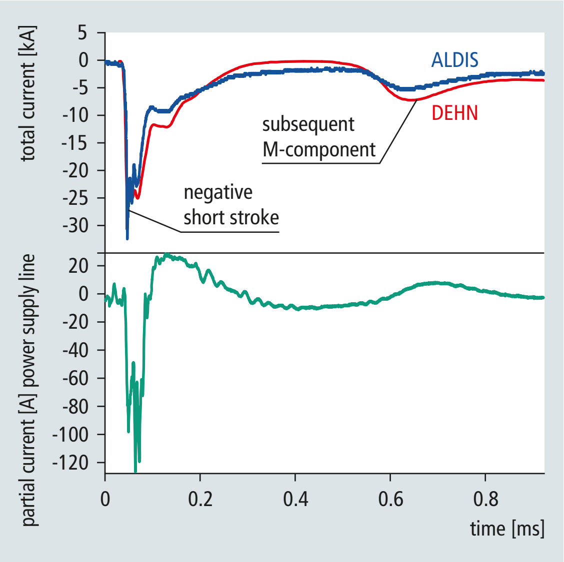


Figure 2.8.3 Negative downward flash with M-component (top) and partial lightning current in a power supply line (below) – recorded at the Gaisberg transmission mast

Designing a lightning protection system

3.1 Necessity of a lightning protection system – Legal regulations

The purpose of a lightning protection system is to protect buildings from direct lightning strikes and possible fire or from the consequences of lightning currents (non-igniting flash).

If national regulations such as building regulations, special regulations or special directives require lightning protection measures, they must be implemented.

If these regulations do not specify a class of LPS, a lightning protection system which meets the requirements of class of LPS III according to IEC 62305-3 (EN 62305-3) is recommended as a minimum. In principle, a risk analysis, which is described in the IEC 62305-2 (EN 62305-2) standard (see chapter 3.2.1), should be performed for an overall assessment.

In Germany, the

- VdS 2010 guideline "Risikoorientierter Blitz- und Überspannungsschutz, Richtlinien zur Schadenverhütung" ["Risk-oriented lightning and surge protection, guideline for damage prevention"]

can be used to determine the class of LPS.

For example, the Bavarian building regulations (BayBO) state that permanently effective lightning protection systems must be installed when lightning can easily strike a structure or can have serious consequences due to:

- Its location,
- Its type of construction or
- Its use

This means: **A lightning protection system must be installed even if only one of the requirements is met.**

A lightning strike can have particularly **serious consequences** for structures due to their location, type of construction or use.

A nursery school, for example, is a structure where a lightning strike can have serious consequences due to its use.

The interpretation of this statement is made clear in the following court judgement:

Extract from the Bavarian Administrative Court, decision of 4 July 1984 – No. 2 B 84 A.624.

1. A nursery school is subject to the requirement to install effective lightning protection systems.
2. The legal requirements of the building regulations for at least fire-retardant doors when designing staircases and exits also apply to a residential building which houses a nursery school.

For the following reasons: According to article 15, section 7 of the Bavarian building regulations (valid section at the time of the court decision), structures where a lightning strike can easily occur or can have serious consequences due to their location, type of construction or use must be equipped with permanently effective lightning protection systems. Thus, effective protective devices are required in two cases. In the first case, the structures are particularly susceptible to lightning strikes (e.g. due to their height or location); in the other case, a lightning strike (e.g. due to the type of construction or use) can have particularly serious consequences. The plaintiff´s building falls under the latter category since it is used as a nursery school. A nursery school is a structure where a lightning strike can have serious consequences due to its use. The fact that nursery schools are not expressly mentioned in the examples of structures which are particularly at risk in the notes of the Bavarian building regulations does not make any difference. The risk of serious consequences if lightning hits a nursery school results from the fact that, during day time, a large number of children under school age are present at the same time. The fact that the rooms where the children spend their time are on the ground floor and that the children could escape through several windows – as put forward by the plaintiff – is not decisive. In the event of fire, there is no guarantee that children of this age will react sensibly and leave the building through the windows, if necessary. In addition, the installation of sufficient lightning protection equipment is not too much to expect of the operator of a nursery school. Article 36, section 6 of the Bavarian building regulations (valid section at the time of the court decision) requires that, amongst other things, staircases must have entrances to the basement which have self-closing doors which are, at least, fire-retardant. This requirement does not apply to residential buildings with up to two flats (article 36, section 10 of the Bavarian building regulations (valid section at the time of the court decision)). The defendant only made the demand when the plaintiff converted the building, which was previously used as a residential building, into a nursery school in accordance with the authorised change of use. The exemption provision of article 36, section 10 of the Bavarian building regulations (valid section at the time of the court decision) cannot be applied to buildings which were built as residential buildings with up to two flats, but which now (also) serve another purpose which justifies the application of the safety requirements in article 36, section 1 to 6 of the Bavarian building regulations (valid section at the time of the court decision). This is the case here.

Serious consequences (panic) can also arise when lightning hits places of public assembly, schools and hospitals. For these reasons, it is necessary that all endangered structures are equipped with permanently effective lightning protection systems.

Lightning protection systems required

Structures where a lightning protection system must be typically installed because, in these cases, the law has affirmed the need, are:

1. Places of public assembly with stages or covered areas and places of public assembly for showing films if the associated assembly rooms, individually or together, accommodate more than 200 visitors;
2. Places of public assembly with assembly rooms which, individually or together, accommodate more than 200 visitors; in case of schools, museums and similar buildings, this regulation only applies to the inspection of technical installations in assembly rooms which individually accommodate more than 200 visitors and their escape routes;
3. Sales areas with sales rooms of more than 2000 m^2 of floor space;
4. Shopping streets with several sales areas which are connected to each other either directly or via escape routes and whose sales rooms individually have less than 2000 m^2 of floor space and have a total floor space of more than 2000 m^2;
5. Exhibition areas whose exhibition rooms, individually or together, have more than 2000 m^2 of floor space;
6. Restaurants with more than 400 seats or hotels with more than 60 beds;
7. High-rise buildings (depending on the federal state);
8. Hospitals and other structures of a similar purpose;
9. Medium-sized and large-scale garages (depending on the federal state);
10. Structures

10.1 Containing explosives, such as ammunition factories, ammunition and explosive stores,

10.2 Containing hazardous locations such as varnish and paint factories, chemical factories, large warehouses containing flammable liquids and large gas tanks,

10.3 Particularly at risk of fire such as
   - Large woodworking factories,
   - Buildings with thatched roofs,
   - Warehouses and production facilities with a high fire load,

10.4 For a large number of persons such as
   - Schools,
   - Homes for the elderly and children´s homes,
   - Barracks,
   - Correctional facilities,
   - Railway stations,

10.5 With cultural heritage such as
   - Buildings of historic interest,
   - Museums and archives,

10.6 Protruding above their surroundings such as
   - High chimneys,
   - Towers,
   - High buildings.

The following list provides an overview of the relevant “General provisions” which deal with the necessity, design and inspection of lightning protection systems.

General international and national provisions:

DIN 18384:2012 (German standard)
German construction contract procedures (VOB) – Part C: General technical specifications in construction contracts (ATV) – Installation of lightning protection systems

Lightning protection systems

IEC 62305-1:2010 (EN 62305-1:2011)
General principles

IEC 62305-2:2010 (EN 62305-2:2012)
Risk management

Supplement 1 of the German DIN EN 62305-2 standard:2013
Lightning threat in Germany

Supplement 2 of the German DIN EN 62305-2 standard:2013
Calculation assistance for assessment of risk for structures

Supplement 3 of the German DIN EN 62305-2 standard:2013
Additional information for the application of DIN EN 62305-2 (VDE 0185-305-2)

IEC 62305-3:2010 (EN 62305-3:2011)
Physical damage to structures and life hazard

Supplement 1 of the German DIN EN 62305-3 standard:2012
Additional information for the application of DIN EN 62305-3 (VDE 0185-305-3)

Supplement 2 of the German DIN EN 62305-3 standard:2012
Additional information for special structures

Supplement 3 of the German DIN EN 62305-3 standard:2012
Additional information for the testing and maintenance of lightning protection systems

Supplement 4 of the German DIN EN 62305-3 standard:2008
Use of metallic roofs in lightning protection systems

Supplement 5 of the German DIN EN 62305-3 standard:2014
Lightning and overvoltage protection for photovoltaic power supply systems

IEC 62305-4:2010 (EN 62305-4:2011)
Electrical and electronic systems within structures

IEC 62561-1:2012 (EN 62561-1:2012)
Requirements for connection components
This standard describes the requirements for metal connection components such as connectors, connecting and bridging components, expansion pieces and test joints for lightning protection systems.

IEC 62561-2:2012 (EN 62561-2:2012)
Requirements for conductors and earth electrodes
This standard specifies e.g. the dimensions and tolerances for metal conductors and earth electrodes as well as the test requirements for the electrical and mechanical values of the materials.

IEC 62561-3:2012 (EN 62561-3:2012)
Requirements for isolating spark gaps

IEC 62561-4:2010 (EN 62561-4:2011)
Requirements for conductor fasteners

IEC 62561-5:2011 (EN 62561-5:2011)
Requirements for earth electrode inspection housings and earth electrode seals

IEC 62561-6:2011 (EN 62561-6:2011)
Requirements for lightning strike counters

IEC 62561-7:2011 (EN 62561-7:2012)
Requirements for earthing enhancing compounds

DIN V VDE V 0185-600:2008 (German standard)
Testing of the suitability of coated metallic roofs as a natural components of the lightning protection system

Special standards for earth–termination systems

DIN 18014:2007 (German standard)
Foundation earth electrode – General planning criteria

DIN VDE 0151:1986 (German standard)
Material and minimum dimensions of earth electrodes with respect to corrosion

IEC 61936-1:2010 (EN 61936-1:2010)
Power installations exceeding 1 kV a.c.

EN 50522:2010
Earthing of power installations exceeding 1 kV a.c.

DIN VDE 0141:2000 (German standard)
Earthing system for special power installations with nominal voltages above 1 kV

EN 50341-1:2012
Overhead electrical lines exceeding AC 1 kV

EN 50162:2004
Protection against corrosion by stray current from direct current systems

Special standards for internal lightning and surge protection, equipotential bonding

IEC 60364-4-41:2005 (HD 60364-4-41:2007)
Low-voltage electrical installations – Part 4-41: Protection for safety - Protection against electric shock

IEC 60364-4-44:2001 (HD 60364-4-443:2006)
Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances – Clause 443: Protection against overvoltages of atmospheric origin or due to switching

IEC 60364-4-44:2007 (HD 60364-4-444:2010)
Low-voltage electrical installations – Part 4-444: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances

IEC 60364-5-53:2002 (HD 60364-5-534:2008)
Low-voltage electrical installations – Selection and erection of electrical equipment – Isolation, switching and control – Clause 534: Devices for protection against overvoltages

This standard deals with the use of class I, II and III surge protective devices in low-voltage consumer's installations for the protection against indirect contact.

IEC 60364-5-54:2011 (HD 60364-5-54:2011)

Low-voltage electrical installations
Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors
This standard includes provisions for the installation of earth-termination systems and equipotential bonding measures.

IEC 60664-1:2007 (EN 60664-1:2007)

Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests
This standard defines the minimum clearances, their selection and the rated impulse withstand voltages for overvoltage categories I to IV.

VDN guideline:2004 (German guideline)

Surge Protective Devices Type 1 – Guideline for the use of surge protective devices (SPDs) Type 1 in main power supply systems.
This guideline describes the use and installation of type 1 surge protective devices upstream of the meter.

Special standards for PV systems

IEC 60364-7-712:2002 (HD 60364-7-712:2005)

Solar photovoltaic (PV) power supply systems

CLC/TS 50539-12:2010

SPDs connected to photovoltaic installations

Special standards for electronic systems such as television, radio, data systems (telecommunications systems)

DIN VDE 0800-1:1989 (German standard)

General concepts requirements and tests for the safety of facilities and apparatus

DIN V VDE V 0800-2:2011 (German standard)

Information technology – Part 2: Equipotential bonding and earthing
Part 2 summarises all earthing and equipotential bonding requirements for the operation of a telecommunications system.

DIN VDE 0800-10:1991 (German standard)

Transitional requirements on erection and operation of installations
Part 10 includes requirements for the erection, extension, modification and operation of telecommunication systems. Section 6.3 calls for surge protection measures.

EN 50310:2010

Application of equipotential bonding and earthing in buildings with information technology equipment

IEC 61643-21:2000 (EN 61643-21:2001)

Low voltage surge protective devices – Part 21: Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods

IEC 61643-22:2004 (CLC/TS 61643-22:2006)

Surge protective devices connected to telecommunications and signalling networks – Selection and application principles

IEC 60728-11:2010 (EN 60728-11:2010)

Cable networks for television signals, sound signals and interactive services – Part 11: Safety
Part 11 requires measures to protect against atmospheric discharges (earthing of the antenna support, equipotential bonding).

DIN VDE 0855-300:2008 (German standard)

Transmitting / receiving systems, safety requirements
Section 12 of Part 300 describes lightning / surge protection and earthing for antenna systems.

IEC 61663-1:1999 (EN 61663-1:1999)

Telecommunication lines – Part 1: Fibre optic installations
This standard describes a method for calculating possible damage and for selecting adequate protection measures and specifies the permissible frequency of damage. However, only primary faults (interruption of operations) and no secondary faults (damage to the cable sheath (hole formation)) are considered.

IEC 61663-2:1999 (EN 61663-2:1999)

Telecommunication lines – Part 2: Lines using metallic conductors
This standard must only be applied to the lightning protection of telecommunication and signal lines with metal conductors which are located outside buildings (e.g. access networks of landline providers, lines between buildings).

Special installations

EN 1127-1:2011

Explosion prevention and protection – Part 1: Basic concepts and methodology

This standard is a guideline on how to prevent explosions and to protect against the effects of explosions by taking measures during the design and installation of devices, protection systems and components.

Section 5.7 and 6.4.8 require protection against the effects of a lightning strike if the installations are at risk.

IEC 60079-14:2007 (EN 60079-14:2008)

Electrical installations design, selection and erection

It is pointed out that the effects of lightning strikes must be observed. The standard requires comprehensive equipotential bonding in all Ex zones.

VDE series 65

Elektrischer Explosionsschutz nach DIN VDE 0165; VDE Verlag Berlin, Anhang 9: PTB-Merkblatt für den Blitzschutz an eigensicheren Stromkreisen, die in Behälter mit brennbaren Flüssigkeiten eingeführt sind [Electrical explosion protection according to DIN VDE 0165, Annex 9: PTB bulletin for protecting intrinsically safe circuits installed in tanks with flammable liquids against lightning strikes]

In Germany, standards can be obtained from:

VDE VERLAG GMBH
Bismarckstr. 33
10625 Berlin
Germany
Phone: +49 30 34 80 01-0
Fax: +49 30 341 70 93
eMail: vertrieb@vde-verlag.de
Internet: www.vde-verlag.de

or: Beuth-Verlag GmbH
Burggrafenstr. 6
10787 Berlin
Germany
Phone: +49 30 2601-0
Fax: +49 30 2601-1260
Internet: www. beuth.de

3.2 Explanatory notes on the IEC 62305-2 (EN 62305-2) standard: Risk management

Risk management with foresight includes calculating the risks for a company. It provides the basis for taking decisions on how to limit these risks and it makes clear which risks should be covered by insurance. However, it should be borne in mind that insurance is not always a suitable means of achieving certain aims (e.g. maintaining the ability to deliver). The probabilities that certain risks will occur cannot be changed by insurance.

Manufacturing companies using extensive electronic installations or companies providing services (and nowadays this applies to most companies) must also give special consideration to the risk presented by lightning strikes. It must be observed that the damage caused by the non-availability of electronic installations, production and services, and also the loss of data, is often far greater than the physical damage to the hardware of the installation affected.

The aim of a risk analysis is to objectify and quantify the risk to structures and their contents as a result of direct and indirect lightning strikes. This new way of thinking is embodied in the international standard IEC 62305-2:2006 or the European standard EN 62305-2:2006 which has been revised in 2010.

The risk analysis presented in IEC 62305-2 (EN 62305-2) ensures that it is possible to draw up a lightning protection concept which is understood by all parties involved and which meets optimum technical and economic requirements, which means that the necessary protection can be ensured with as little expenditure as possible. A detailed description of the protection measures resulting from the risk analysis can be found in Part 3 and 4 of the IEC 62305 (EN 62305) standard series.

3.2.1 Sources of damage, types of damage and types of loss

The actual **sources of damage** are lightning strikes that are subdivided into four groups depending on the point of strike (**Table 3.2.1.1**):

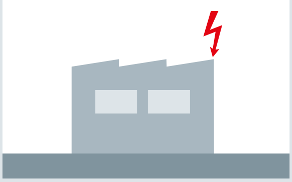
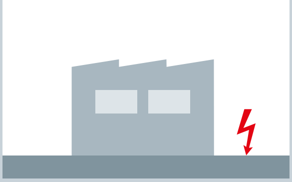
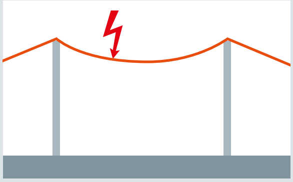
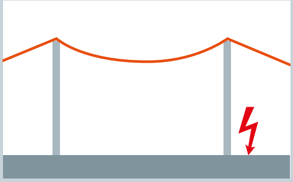
S1 Direct lightning strike to a structure;
S2 Lightning strike near a structure;
S3 Direct lightning strike to an incoming line;
S4 Lightning strike near an incoming line.

These sources of damage may result in different **types of damage** which cause the loss. The standard specifies three types of damage:

D1 Injury to living beings by electric shock as a result of touch and step voltage;
D2 Fire, explosion, mechanical and chemical reactions as a result of the physical effects of the lightning discharge;
D3 Failure of electrical and electronic systems as a result of surges.

Depending on the type of construction, use and substance of the structure, the relevant loss can be very different. IEC 62305-2 (EN 62305-2) specifies the following **four types of loss**:

L1 Loss of human life (injury to or death of persons);
L2 Loss of service to the public;
L3 Loss of cultural heritage;
L4 Loss of economic value.

Point of strike	Example	Type of damage	Type of loss
Structure S1		D1 D2 D3	L1, L4[b] L1, L2, L3, L4 L1[a], L2, L4
Near structure S2		D3	L1[a], L2, L4
Incoming line S3		D1 D2 D3	L1, L4[b] L1, L2, L3, L4 L1[a], L2, L4
Near incoming line S4		D3	L1[a], L2, L4

[a] For hospitals and other structures where failures of internal systems immediately endangers human life and structures with a risk of explosion.

[b] For agricultural properties (loss of animals)

Table 3.2.1.1 Sources of damage, types of damage and types of loss depending on the point of strike

These types of loss can arise as a result of different types of damage. The types of damage thus literally represent the "cause" in a causal relationship, the type of loss the "effect" (**Table 3.2.1.1**). The possible types of damage for one type of loss can be manifold. It is therefore necessary to first define the relevant types of loss for a structure before defining the types of damage to be determined.

3.2.2 Fundamentals of risk analysis

According to IEC 62305-2 (EN 62305-2), the risk R that lightning damage occurs is the sum of all risk components R_x relevant to the particular type of loss. The individual risk components R_x are derived from the following equation:

$$R_x = N_x \cdot P_x \cdot L_x$$

where

N_x is the number of dangerous events, i.e. the frequency of lightning strikes causing damage in the area under consideration (How many dangerous events occur each year?);

P_x is the probability of damage (What is the probability that a dangerous event causes certain damage?);

L_x is the loss factor, i.e. the quantitative evaluation of damage (What are the effects, amount of loss, extent and consequences of a certain damage?).

Therefore, the function of a risk analysis is to determine the three parameters N_x, P_x and L_x for all relevant risk components R_x. A comparison of the risk R with a tolerable risk R_T provides information on the requirements for and dimensioning of lightning protection measures.

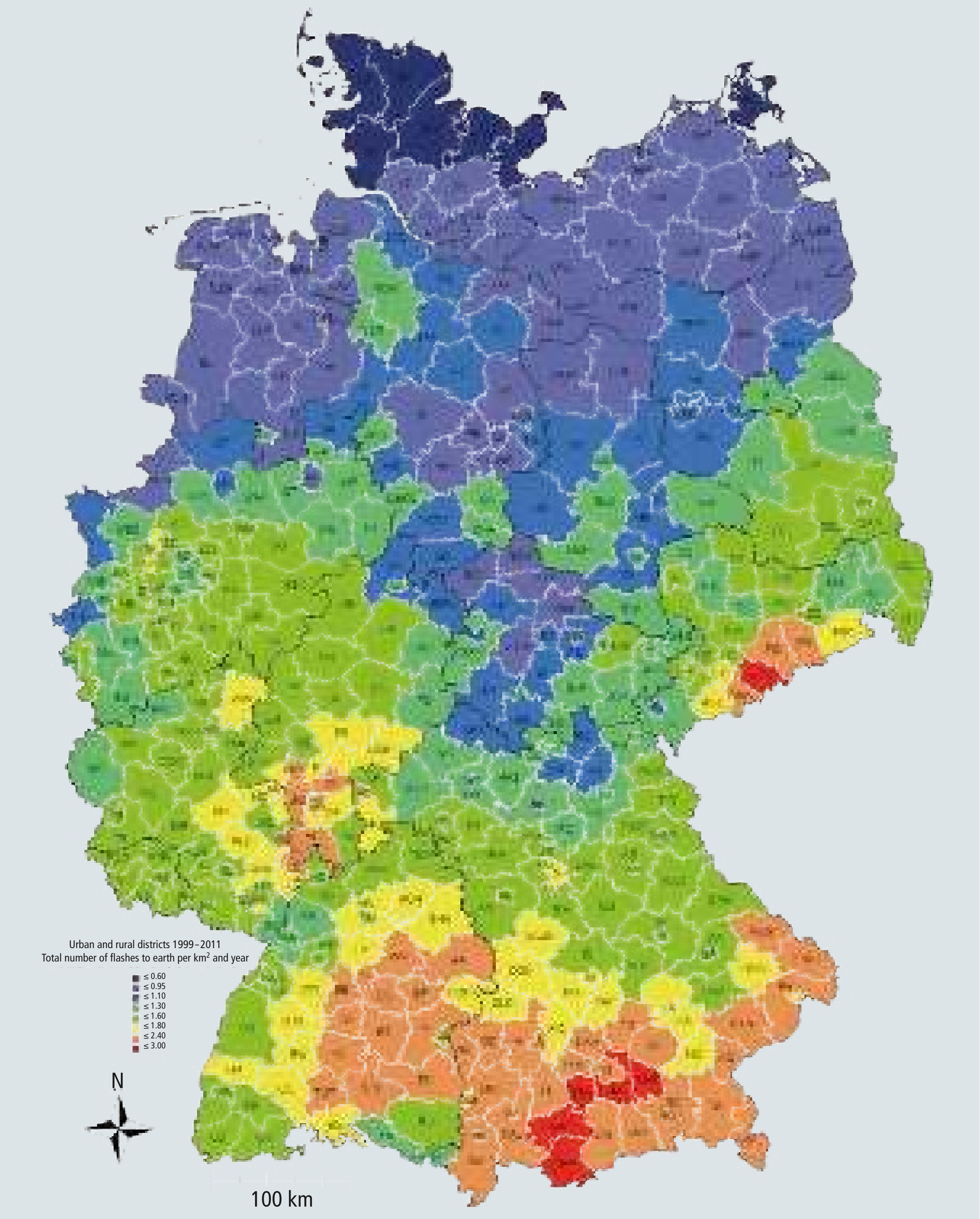


Figure 3.2.3.1 Flash density in Germany (average from 1999 to 2011) according to Supplement 1 of DIN EN 62305-2 Ed. 2:2013 (source: Blitz-Informations-Dienst by Siemens)

The loss of economic value forms an exception. For this type of loss, protection measures should be based on economic considerations. If the data for this analysis are not available, the representative value of tolerable risk $R_T = 10^{-3}$ specified in the IEC standard may be used.
In the EN standard, there is no tolerable risk R_T. Therefore, it is advisable to perform a cost benefit analysis.

3.2.3 Frequency of dangerous events

The following frequencies of dangerous events can be relevant for a structure:

- N_D Caused by direct lightning strikes to a structure;
- N_M Caused by nearby lightning strikes with magnetic effects;
- N_L Caused by direct lightning strikes to incoming lines;
- N_I Caused by lightning strikes near incoming lines.

A detailed calculation can be found in Annex A of IEC 62305-2 (EN 62305-2).
The average annual number N of dangerous events resulting from lightning strikes influencing a structure to be protected depends on the thunderstorm activity of the region where the structure is located and on the structure's physical characteristics. To calculate the number N, the ground flash density N_G should be multiplied by an equivalent collection area of the structure, taking into account correction factors for the structure's physical characteristics. The ground flash density N_G is the number of lightning strikes per km^2 per year (e.g. **Figure 3.2.3.1**).
This value is available from ground flash location networks in many areas of the world. If a map of N_G is not available, in temperate regions it may be estimated by:

$$N_G \approx 0.1 \cdot T_D$$

where T_D is the thunderstorm days per year (which can be obtained from isokeraunic maps).

Direct lightning strikes

For direct lightning strikes to the structure we have:

$$N_D = N_G \cdot A_D \cdot C_D \cdot 10^{-6}$$

A_D is the equivalent collection area of the isolated structure in m^2 (**Figure 3.2.3.2**). C_D is a location factor which considers the influence of the surroundings (buildings, terrain, trees, etc.) (**Table 3.2.3.1**).
The collection area for an isolated rectangular structure with a length L, width W and height H on a plane surface is calculated as follows:

$$A_D = L \cdot W + 2 \cdot (3 \cdot H) \cdot (L + W) + \pi \cdot (3 \cdot H)^2$$

Nearby lightning strikes

For nearby lightning strikes with magnetic effects we have:

$$N_M = N_G \cdot A_M \cdot 10^{-6}$$

A_M is obtained from drawing a line around the structure at a distance of 500 m (**Figure 3.2.3.3**). Lightning strikes to the area A_M magnetically induce surges in installation loops in the structure.

Lightning strikes to lines

For direct lightning strikes to an incoming line we have:

$$N_L = N_G \cdot A_L \cdot C_I \cdot C_E \cdot C_T \cdot 10^{-6}$$

where N_L is the annual number of surges on the line section with a maximum value of at least 1 kV.
C_I is the installation factor of the line (**Table 3.2.3.2**) which takes into account whether an overhead line or a buried cable is used. If a medium-voltage line is installed in the area A_L rather than a low-voltage line, the required transformer reduces the surges at the entry point into the structure. In such cases, this is taken into account by the line type factor C_T (**Table 3.2.3.3**). C_E is the environmental factor (**Table 3.2.3.4**) which defines the "building density" near the line and thus the probability of a lightning strike.
For the collection area for direct lightning strikes to the line (**Figure 3.2.3.3**) we have:

$$A_L = 40 \cdot L_L$$

where L_L is the length of the line section. If the length of the line section is unknown, a worst case value of L_L = 1000 m should be assumed.
As a rule, lightning strikes within the area A_L lead to a high-level discharge which can cause fire, explosion or a mechanical or chemical reaction in the relevant structure. Therefore, the frequency N_L does not only include surges resulting in faults on or damage to the electrical and electronic systems, but also in mechanical and thermal effects which arise in case of lightning interference.

For lightning strikes near an incoming line with a maximum value of at least 1 kV, which cause surges on this line, we have:

$$N_I = N_G \cdot A_I \cdot C_I \cdot C_E \cdot C_T \cdot 10^{-6}$$

where the same boundary conditions and correction factors (**Tables 3.2.3.2 to 3.2.3.4**) apply as in case of direct lightning strikes.

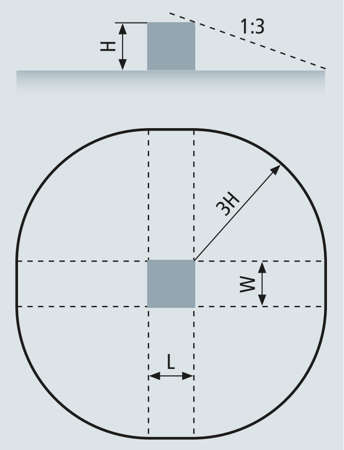


Figure 3.2.3.2 Equivalent collection area A_D for direct lightning strikes to an isolated structure

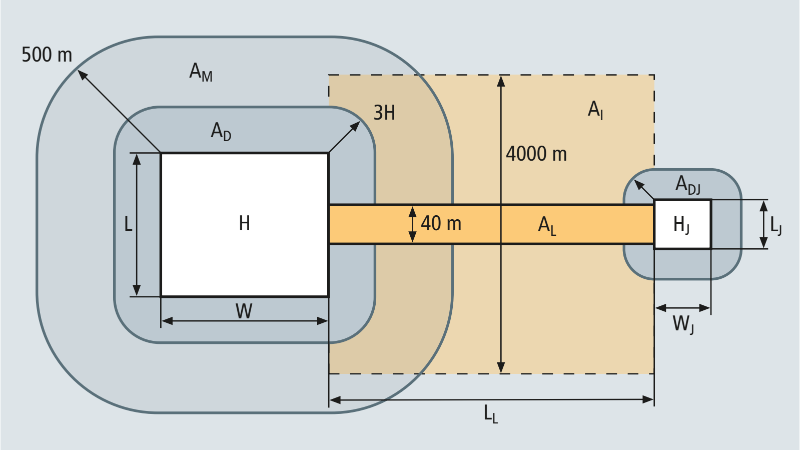


Figure 3.2.3.3 Equivalent collection area A_M, A_L, A_I for indirect lightning strikes to the structure

Relative location of the structure	**C_D**
Structure surrounded by higher objects	0.25
Structure surrounded by objects of the same height or smaller	0.5
Isolated structure: no other objects in the vicinity (within a distance of 3H)	1
Isolated structure on a hilltop or a knoll	2

Table 3.2.3.1 Location factor C_D

Routing	**C_I**
Overhead line	1
Buried	0.5
Buried cables running entirely within a meshed earth-termination system (see 5.2 of IEC 62305-4 (EN 62305-4))	0.01

Table 3.2.3.2 Installation factor C_I

Transformer	**C_T**
Low-voltage power, telecommunication or data line	1
High-voltage power line (with high-voltage / low-voltage transformer)	0.2

Table 3.2.3.3 Line type factor C_T

Environment	**C_E**
Rural	1
Suburban	0.5
Urban	0.1
Urban with tall buildings (higher than 20 m)	0.01

Table 3.2.3.4 Environmental factor C_E

For the collection area for lightning strikes near a line we have (**Figure 3.2.3.3**):

$$A_I = 4000 \cdot L_L$$

where L_L is the length of the line section. If the length of the line section is unknown, a worst case value of L_L = 1000 m should be assumed.

If the line has more than one section, the values of N_L and N_I must be calculated for each relevant line section. The sections between the structure and the first node must be considered (maximum distance from the structure must not exceed 1000 m).

If more than one line enters the structure on different paths, each line must be calculated individually. However, if more than one line enters the structure on the same path, only the line with the most unfavourable properties must be calculated, in other words the line with the maximum N_L and N_I values connected to the internal systems with the lowest insulation strength (telecommunication line opposite to power line, unshielded line opposite to shielded line, low-voltage power line opposite to high-voltage power line with high-voltage / low-voltage transformer, etc.). If the collection areas of lines overlap, the overlapped areas should only be considered once.

3.2.4 Probabilities of damage

The parameter "probability of damage" defines the probability that a dangerous event causes certain damage. The probability of damage may have a maximum value of 1 (meaning that every dangerous event causes damage). There are the following eight probabilities of damage:

In case of a direct lightning strike to a structure (S1):

P_A	Injury to living beings by electric shock
P_B	Physical damage (fire, explosion, mechanical and chemical reactions)
P_C	Failure of electrical / electronic systems

In case of a lightning strike to the ground near a structure (S2):

P_M	Failure of electrical / electronic systems

In case of a direct lightning strike to an incoming line (S3):

P_U	Injury to living beings by electric shock
P_V	Physical damage (fire, explosion, mechanical and chemical reactions)
P_W	Failure of electrical / electronic systems

In case of a direct lightning strike to the ground near an incoming line (S4):

P_Z	Failure of electrical / electronic systems

A detailed description of these probabilities of damage can be found in Annex B of IEC 62305-2 (EN 62305-2). The probabilities of damage can be either selected from tables or they result from a combination of different influencing factors. In this context, it must be observed that, as a general rule, other deviating values are possible if they are based on detailed examinations or assessments. In the following, a short overview of the individual probabilities of damage is given. More detailed information can be found in IEC 62305-2 (EN 62305-2).

Probabilities of damage in case of direct lightning strikes

The values of the probability of damage P_A that living beings are injured by electric shock due to touch and step voltage caused by a direct lightning strike to the structure depend on the type of lightning protection system and additional protection measures:

$$P_A = P_{TA} \cdot P_B$$

P_{TA} describes the typical protection measures against touch and step voltages (**Table 3.2.4.1**). P_B depends on the class of LPS as per IEC 62305-3 (EN 62305-3) (**Table 3.2.4.2**).
If more than one protection measure is taken, the value of P_{TA} is the product of the corresponding values. Moreover, it must be observed that the protection measures to reduce P_A are only effective in structures which are protected by a lightning protection system (LPS) or which consist of a continuous metal or reinforced concrete framework acting as a natural LPS provided that equipotential bonding and earthing requirements as per IEC 62305-3 (EN 62305-3) are fulfilled. Chapter 5 provides more detailed information on protection measures.
The probability of physical damage P_B (fire, explosion, mechanical or chemical reactions inside or outside a structure as a result of a direct lightning strike) can be selected from **Table 3.2.4.2**.
The probability P_C that a direct lightning strike to a structure will cause failure of internal systems depends on the coordinated SPDs installed:

$$P_C = P_{SPD} \cdot C_{LD}$$

P_{SPD} depends on the coordinated SPD system according to IEC 62305-4 (EN 62305-4) and on the lightning protection level (LPL) for which the SPDs are dimensioned. The values of P_{SPD} are given in **Table 3.2.4.3**. A coordinated SPD system only reduces P_C if the structure is protected by an LPS or if the structure consists of a continuous metal or reinforced concrete framework acting as a natural LPS provided that the equipotential bonding and earthing requirements as per IEC 62305-3 (EN 62305-3) are observed. The values of P_{SPD} may be reduced if the selected SPDs have better protection characteristics (higher current carrying capability I_N, lower voltage protection level U_P, etc.) than required for lightning protection level I at the relevant places of installation (see Table A.3 of IEC 62305-1 (EN 62305-1) for information on the current carrying capabilities, Annex E of IEC 62305-1 (EN 62305-1) and Annex D of IEC 62305-4 (EN 62305-4) for lightning current distribution). The same annexes can also be used for SPDs with higher probabilities of P_{SPD}.

The factor C_{LD} considers the shielding, earthing and insulation conditions of the line connected to the internal system. The values of C_{LD} are given in **Table 3.2.4.4**.

Probabilities of damage in case of nearby lightning strikes

The probability P_M that a lightning strike near a structure will cause failure of internal systems in the structure depends on the protection measures taken for the electrical and electronic

Additional protection measures	P_{TA}
No protection measures	1
Warning notices	10^{-1}
Electrical insulation (e.g. at least 3 mm cross-linked polyethylene) of exposed parts (e.g. down conductors)	10^{-2}
Effective potential control in the ground	10^{-2}
Physical restrictions or building framework used as down conductor	0

Table 3.2.4.1 Values of probability P_{TA} that a lightning strike to a structure will cause electric shock to living beings due to dangerous touch and step voltages

Properties of the structure	Class of LPS	P_B
Structure is not protected by an LPS	–	1
Structure is protected by an LPS	IV	0.2
	III	0.1
	II	0.05
	I	0.02
Structure with an air-termination system conforming to class of LPS I and a continuous metal (or reinforced concrete) framework acting as a natural down-conductor system		0.01
Structure with a metal roof and an air-termination system, possibly including natural components, with complete protection of any roof installations against direct lightning strikes and a continuous metal (or reinforced concrete framework) acting as a natural down-conductor system		0.001

Table 3.2.4.2 Probability of damage P_B describing the protection measures against physical damage

LPL	P_{SPD}
No coordinated SPD system	1
III – IV	0.05
II	0.02
I	0.01
Surge protective devices with better protection characteristics than required for LPL I (higher lightning current carrying capability, lower voltage protection level, etc.)	0.005 – 0.001

Table 3.2.4.3 Probability of damage P_{SPD} describing the protection measure "coordinated surge protection" depending on the lightning protection level (LPL)

Type of external line	Connection at entrance	C_{LD}	C_{LI}
Unshielded overhead line	Undefined	1	1
Unshielded buried line	Undefined	1	1
Power line with multi-grounded neutral conductor	None	1	0.2
Shielded buried line (power or telecommunication line)	Shields not bonded to the same equipotential bonding bar as equipment	1	0.3
Shielded overhead line (power or telecommunication line)	Shields not bonded to the same equipotential bonding bar as equipment	1	0.1
Shielded buried line (power or telecommunication line)	Shields bonded to the same equipotential bonding bar as equipment	1	0
Shielded overhead line (power or telecommunication line)	Shields bonded to the same equipotential bonding bar as equipment	1	0
Lightning protection cable or wiring in lightning protection cable ducts, metallic conduit or metallic tubes	Shields bonded to the same equipotential bonding bar as equipment	0	0
(No external line)	No connection to external lines (stand-alone systems)	0	0
Any type	Isolating interfaces acc. to IEC 62305-4 (EN 62305-4)	0	0

Table 3.2.4.4 Values of factors C_{LD} and C_{LI} depending on shielding, earthing and insulation conditions

installations (SPM). A grid-like lightning protection system, shielding measures, installation principles for the cables, an increased rated impulse withstand voltage, isolating interfaces and coordinated SPD systems are suitable protection measures to reduce P_M. The probability P_M is calculated as follows:

$$P_M = P_{SPD} \cdot P_{MS}$$

P_{SPD} can be selected from **Table 3.2.4.3** provided that a coordinated SPD system which meets the requirements of IEC 62305-4 (EN 62305-4) is installed. The values of the factor P_{MS} are determined as follows:

$$P_{MS} = (K_{S1} \cdot K_{S2} \cdot K_{S3} \cdot K_{S4})^2$$

where

K_{S1}	is the shielding effectiveness of the structure, LPS or other shields at the boundaries LPZ 0/1;
K_{S2}	is the shielding effectiveness of internal shields of the structure at the boundaries LPZ X/Y (X > 0, Y > 1);
K_{S3}	stands for the properties of the internal cabling (**Table 3.2.4.5**);
K_{S4}	is the rated impulse withstand voltage of the system to be protected.

If equipment with isolating interfaces consisting of insulation transformers with an earth shield between the windings, optical fibre cables or optocouplers is used, it can be assumed that $P_{MS} = 0$.

The factors K_{S1} and K_{S2} for LPS or grid-like spatial shields can be assessed as follows:

$$K_{S1} = 0.12 \cdot w_{m1}$$

$$K_{S2} = 0.12 \cdot w_{m2}$$

where w_{m1} (m) and w_{m2} (m) are the mesh sizes of the grid-like spatial shields or the mesh sizes of the meshed down conductors of the LPS or the distance between the metal rods of the structure or the distance between the reinforced concrete structure acting as a natural LPS.

The factor K_{S4} is calculated as follows:

$$K_{S4} = \frac{1}{U_W}$$

where U_W is the rated impulse withstand voltage of the system to be protected in kV. The maximum value of K_{S4} is 1. If equipment with different impulse withstand voltage values is installed in an internal system, the factor K_{S4} must be selected according to the lowest value of the impulse withstand voltage.

Type of internal wiring	K_{S3}
Unshielded cable – no routing precaution in order to avoid loops (loops formed by conductors with different routing in large buildings, meaning a loop surface of about 50 m^2)	1
Unshielded cable – routing precaution in order to avoid large loops (loops formed by conductors routed in the same installation tube or loops formed by conductors with different installation paths in small buildings, meaning a loop surface of about 10 m^2)	0.2
Unshielded cable – routing precaution in order to avoid loops (loops formed by conductors routed in the same cable, meaning a loop surface of about 0.5 m^2)	0.01
Shielded cables and cables running in metal conduits (the cable shields and metal conduits are connected to the equipotential bonding bar on both ends and equipment is connected to the same bonding bar)	0.0001

Table 3.2.4.5 Value of the factor K_{S3} depending on internal wiring

Probabilities of damage in case of direct lightning strikes to lines

The values of the probability P_U that human beings in the structure will be injured by touch voltages resulting from a direct lightning strike to a line entering the structure depend on the shielding properties of the line, impulse withstand voltage of the internal systems connected to the line, protection measures (physical restrictions or warning notices) and isolating interfaces or SPDs at the entry point into the structure according to IEC 62305-3 (EN 62305-3):

$$P_U = P_{TU} \cdot P_{EB} \cdot P_{LD} \cdot C_{LD}$$

P_{TU} describes the protection measures against touch voltages such as physical restrictions and warning notices (**Table 3.2.4.6**). If more than one protection measure is taken, the value of P_{TU} is the product of the relevant values.

P_{EB} is the probability which depends on the lightning equipotential bonding as per IEC 62305-3 (EN 62305-3) and the lightning protection level (LPL) for which the SPDs are dimensioned (**Table 3.2.4.7**). The values of P_{EB} may also be reduced if the selected SPDs have better protection characteristics (higher current carrying capability I_N, lower voltage protection level U_P, etc.) than required for LPL I at the relevant places of installation. A coordinated SPD system according to IEC 62305-4 (EN 62305-4) is not required to reduce P_U; SPDs as per IEC 62305-3 (EN 62305-3) are sufficient.

P_{LD} is the probability that internal systems will fail as a result of a lightning strike to a connected line depending on the properties of the line (**Table 3.2.4.8**). The factor C_{LD}, which considers the shielding, earthing and insulation conditions of the line, can be selected from **Table 3.2.4.4**.

The values of probability P_V that **physical damage** will occur due to a lightning strike to a line entering the structure also depend on the shielding properties of the line, impulse withstand voltage of the internal systems connected to the line and the isolating interfaces or SPDs at the entry point into the structure as per IEC 62305-3 (EN 62305-3) (also in this case a coordinated SPD system according to IEC 62305-4 (EN 62305-4) is not required):

$$P_V = P_{EB} \cdot P_{LD} \cdot C_{LD}$$

The values of probability P_W that a lightning strike to a line entering a structure will cause **failure of internal systems** depend on the shielding properties of the line, impulse

Protection measure	P_{TU}
No protection measure	1
Warning notices	10^{-1}
Electrical insulation	10^{-2}
Physical restrictions	0

Table 3.2.4.6 Values of probability P_{TU} that a flash to an entering line will cause electric shock to living beings due to dangerous touch voltages

LPL	P_{EB}
No SPD	1
III – IV	0.05
II	0.02
I	0.01
Surge protective devices with better protection characteristics than required for LPL I (higher lightning current carrying capability, lower voltage protection level, etc.)	0.005 – 0.001

Table 3.2.4.7 Probability of damage P_{EB} describing the protection measure "lightning equipotential bonding" depending on lightning protection level (LPL)

Line type	**Routing, shielding and equipotential bonding**		**Impulse withstand voltage U_W in kV**				
			1	**1.5**	**2.5**	**4**	**6**
Power or telecommunication lines	Overhead or buried line, unshielded or shielded, whose shield is not bonded to the same equipotential bonding bar as the equipment		1	1	1	1	1
	Shielded overhead or buried line whose shield is bonded to the same equipotential bonding bar as the equipment	5 Ω/km < RS ≤ 20 Ω/km	1	1	0.95	0.9	0.8
		1 Ω/km < RS ≤ 5 Ω/km	0.9	0.8	0.6	0.3	0.1
		RS ≤ 1 Ω/km	0.6	0.4	0.2	0.04	0.02

Table 3.2.4.8 Values of the probability P_{LD} depending on the resistance of the cable shield R_S and the impulse withstand voltage U_W of the equipment

withstand voltage of the internal systems connected to the line and the isolating interfaces or SPDs as per IEC 62305-4 (EN 62305-4) (in this case, a coordinated SPD system is required):

$$P_W = P_{SPD} \cdot P_{LD} \cdot C_{LD}$$

The values of P_{EB}, P_{SPD}, P_{LD} and C_{LD} can be selected from **Tables 3.2.4.3, 3.2.4.4, 3.2.4.7 and 3.2.4.8**.

Probabilities of damage in case of indirect lightning strikes to lines

The line is not directly hit; the point of strike is near the line. In this process, it can be excluded that high-level partial lightning currents are injected into the line. Nevertheless, voltages can be magnetically induced on the line.

The values of probability P_Z that lightning strikes near a line entering a structure will cause failure of internal systems depend on the shielding properties of the line, impulse withstand voltage of the internal systems connected to the line and the isolating interfaces or SPDs as per IEC 62305-4 (EN 62305-4):

$$P_Z = P_{SPD} \cdot P_{LI} \cdot C_{LI}$$

P_{SPD} can be selected from **Table 3.2.4.3**. P_{LI} is the probability of failure of internal systems due to a lightning strike near a connected line and depends on the properties of the line (**Table 3.2.4.9**). The factor C_{LI} (**Table 3.2.4.4**) considers the shielding, earthing and insulating properties of the line.

3.2.5 Loss

If a certain damage occurs in a structure, the consequences of this damage must be assessed. A fault on or damage to an information technology system, for example, can have different consequences. If no business-specific data is lost, only hardware damage of some thousand euros may occur. If, however, the entire business activities of a company depend on the permanent availability of the information technology system (call centre, bank, automation technology), a significantly higher consequential damage occurs in addition to the hardware damage (e.g. customer dissatisfaction, loss of customers, loss of business, production downtime). The loss L (this term used in IEC 62305-2 (EN 62305-2) is an unfortunate choice; damage factor or loss value would be more appropriate) allows to assess the consequences of damage. In this context, losses are subdivided according to the types of damage (D1 to D3):

L_t	Loss due to injuries caused by electric shock resulting from touch and step voltages (D1);
L_f	Loss due to physical damage (D2);
L_o	Loss due to the failure of electrical and electronic systems (D3).

Depending on the type of loss L1 to L4, the extent, costs and consequences of damage are assessed. Annex C of the IEC 62305-2 (EN 62305-2) standard includes the calculation bases for the loss of the four types of loss. In the next sections, this loss will be shortly described after the reduction and increase factors and the parameters and equations for the different zones of a structure will be defined. However, all structures can also be described by a single zone, meaning that the entire structure consists of one zone.

Reduction and increase factors

In addition to the actual loss factors, Annex C includes three reduction factors and one increase factor:

Line type	**Impulse withstand voltage U_W in kV**				
	1	**1.5**	**2.5**	**4**	**6**
Power lines	1	0.6	0.3	0.16	0.1
Telecommunication lines	1	0.5	0.2	0.08	0.04

Table 3.2.4.9 Values of the probability P_{LI} depending on the line type and the impulse withstand voltage U_W of the equipment

Type of surface	Contact resistance kΩ [a]	r_t
Agricultural, concrete	≤ 1	10^{-2}
Marble, ceramic	1 – 10	10^{-3}
Gravel, moquette, carpets	10 – 100	10^{-4}
Asphalt, linoleum, wood	≥ 100	10^{-5}

[a] Values measured between a 400 cm^2 electrode compressed with a force of 500 N and a point of infinity.

Table 3.2.5.1 Values of the reduction factor r_t depending on the type of surface of the ground or floor

Measures	r_p
No measures	1
One of the following measures: fire extinguishers, fixed manually operated fire extinguishing installations, manual alarm installations, hydrants, fire compartments, escape routes	0.5
One of the following measures: fixed automatically operated fire extinguishing installations, automatic alarm installations	0.2

Table 3.2.5.2 Values of the reduction factor r_p depending on the measures taken to reduce the consequences of fire

Risk	Type of risk	r_f
Explosion	Zone 0, 20 and solid explosives	1
	Zone 1, 21	10^{-1}
	Zone 2, 22	10^{-3}
Fire	High	10^{-1}
	Ordinary	10^{-2}
	Low	10^{-3}
Explosion or fire	None	0

Table 3.2.5.3 Values of the reduction factor r_f depending on the risk of fire of a structure

Type of special risk	h_z
No special risk	1
Low risk of panic (e.g. structures limited to two floors with up to 100 persons)	2
Average level of panic (e.g. structures for cultural and sport events with 100 to 1000 visitors)	5
Difficulty of evacuation (e.g. structures with immobile persons, hospitals)	5
High risk of panic (e.g. structures for cultural and sport events with more than 1000 visitors)	10

Table 3.2.5.4 Values of the factor h_z which increases the relative value of a loss for type of loss L1 (loss of human life) in case of a special risk

r_t Factor reducing the effects of touch and step voltages depending on the type of ground outside the structure or type of floor inside the structure (**Table 3.2.5.1**);

r_p Factor reducing the measures taken to reduce the consequences of fire (**Table 3.2.5.2**);

r_f Factor reducing the risk of fire and explosion of the structure (**Table 3.2.5.3**);

h_z Factor increasing the relative value in case of loss of human life (L1) due to the level of panic (**Table 3.2.5.4**).

Loss of human life (L1)

Loss must be determined for each risk component relevant to the structure. Moreover, the structure can be subdivided into several zones so that the losses must be assigned to the individual zones.

Thus, the loss value depends on the properties of the zone which are defined by increase factors (h_z) and reduction factors (r_t, r_p, r_f). In other words, the loss value depends on the relation between the number of persons in the zone (n_z) and the total number of persons in the structure (n_t) and between the time in hours per year during which persons stay in the zone (t_z) and the 8760 hours per year. Thus, there are up to eight loss values:

$$L_A = L_U = \frac{r_t \cdot L_T \cdot n_Z}{n_t} \cdot \frac{t_z}{8760}$$

$$L_B = L_V = \frac{r_p \cdot r_f \cdot h_Z \cdot L_F \cdot n_Z}{n_t} \cdot \frac{t_z}{8760}$$

$$L_C = L_M = L_W = L_Z = \frac{L_O \cdot n_Z}{n_t} \cdot \frac{t_z}{8760}$$

where

L_T is the typical mean percentage of victims injured by electric shock (D1) due to a dangerous event;

L_F	is the typical mean percentage of victims injured by physical damage (D2) due to a dangerous event;
L_O	is the typical mean percentage of victims injured by failure of internal systems (D3) due to a dangerous event;
r_t	is a factor reducing the loss of human life depending on the type of ground or floor;
r_p	is a factor reducing the loss due to physical damage depending on the measures taken to reduce the consequences of fire;
r_f	is a factor reducing the loss due to physical damage depending on the risk of fire or explosion of the structure;
h_z	is a factor increasing the loss due to physical damage when a special hazard is present;
n_z	is the number of persons in the zone;
n_t	is the total number of persons in the structure;
t_z	is the time in hours per year during which persons stay in the zone.

IEC 62305-2 (EN 62305-2) specifies typical mean values for L_T, L_F and L_O for roughly classified structures (**Table 3.2.5.5**). These values can be modified and adapted for specific structures provided that the number of possibly affected persons, their independent mobility and their exposition to lightning effects are considered. For the values stated in **Table 3.2.5.5**, it is assumed that persons permanently stay in the structure.

A detailed assessment of L_F and L_O may be required for structures with a risk of explosion. In this context, the type of structure, risk of explosion, division into explosion protection zones and measures to reduce the risk must be observed.

If the risk for persons resulting from a direct lightning strike to a structure also affects surrounding structures or the environment (e.g. in case of chemical or radioactive emissions), the additional loss of human life due to physical damage (L_{BE} and L_{VE}) should be taken into account when assessing the total loss (L_{BT} and L_{VT}):

$$L_{BT} = L_B + L_{BE}$$

$$L_{VT} = L_V + L_{VE}$$

$$L_{BE} = L_{VE} = \frac{L_{FE} \cdot t_e}{8760}$$

L_{FE}	Loss due to physical damage outside the structure;
t_e	Time during which person stay in dangerous places outside the structure.

If the time t_e is unknown, $t_e/8760 = 1$ is to be assumed. L_{FE} should be provided by the body preparing the explosion protection documents.

Unacceptable loss of service to the public

Loss of service to the public is defined by the properties of the structure or its zones. These properties are described by means of reduction factors (r_p, r_f). Moreover, the relation between the number of served users in the zone (n_z) and the total number of served users in the structure (n_t) is important. There are up to six loss values:

$$L_B = L_V = \frac{r_p \cdot r_f \cdot L_F \cdot n_Z}{n_t}$$

$$L_C = L_M = L_W = L_Z = \frac{L_O \cdot n_Z}{n_t}$$

L_F	is the typical mean percentage of unserved users due to physical damage (D2) in case of a dangerous event;
L_O	is the typical mean percentage of unserved users due to failure of internal systems (D3) in case of a dangerous event;

Type of damage	Typical loss value		Type of structure
D1: Injuries	L_T	10^{-2}	All types
D2: Physical damage	L_F	10^{-1}	Risk of explosion
		10^{-1}	Hospital, hotel, school, public building
		$5 \cdot 10^{-2}$	Building with entertainment facility, church, museum
		$2 \cdot 10^{-2}$	Industrial structure, economically used plant
		10^{-2}	Others
D3: Failure of internal systems	L_O	10^{-1}	Risk of explosion
		10^{-2}	Intensive care unit and operating section of a hospital
		10^{-3}	Other areas of a hospital

Table 3.2.5.5 Type of loss L1: Typical mean values for L_T, L_F and L_O

r_p is a factor reducing the loss due to physical damage depending on the measures taken to reduce the consequences of fire;

r_f is a factor reducing the loss due to physical damage depending on the risk of fire or explosion of the structure;

n_z is the number of served users in the zone;

n_t is the total number of served users in the structure.

IEC 62305-2 (EN 62305-2) specifies typical mean values for L_F and L_0 depending on the type of service (**Table 3.2.5.6**). These values also provide information on the significance of the type of service to the public. If required, they can be modified and adapted for specific structures provided that the exposition to lightning effects and deviating significances are considered.

Loss of cultural heritage (L3)

Loss of cultural heritage is defined by the properties of the structure or its zones. These properties are described by means of reduction factors (r_p, r_f). Moreover, the relation between the value of the zone (c_z) and the total value (building and content) of the entire structure (c_t) is important. There are two loss values:

$$L_B = L_V = \frac{r_p \cdot r_f \cdot L_F \cdot c_Z}{c_t}$$

L_F is the typical mean percentage of the value of all goods damaged by physical damage (D2) in case of a dangerous event;

r_p is a factor reducing the loss due to physical damage depending on the measures taken to reduce the consequences of fire;

r_f is a factor reducing the loss due to physical damage depending on the risk of fire or explosion of the structure;

c_z is the value of the cultural heritage in the zone;

c_t is the total value of the building and content of the structure (sum of all zones).

IEC 62305-2 (EN 62305-2) specifies a typical mean value for L_F (**Table 3.2.5.7**). This value can be modified and adapted for specific structures provided that the exposition to lightning effects is considered.

Loss of economic value

Loss of economic value is also defined by the properties of the zone which are described by means of reduction factors (r_t, r_p, r_f). Moreover, the relation between the decisive value in the zone and the total value (c_t) of the entire structure is required to assess the damage in a zone.

The total value of a structure may include animals, buildings, contents and internal systems including their activities. The decisive value depends on the type of damage (**Table 3.2.5.8**). Thus, there are up to eight loss values:

Type of damage	Typical loss value		Type of service
D2: Physical damage	L_F	10^{-1}	Gas, water, power supply
		10^{-2}	TV, telecommunication
D3: Failure of internal systems	L_O	10^{-2}	Gas, water, power supply
		10^{-3}	TV, telecommunication

Table 3.2.5.6 Type of loss L2: Typical mean values for L_F and L_O

Type of damage	Typical loss value		Type of service
D2: Physical damage	L_F	10^{-1}	Museum, gallery

Table 3.2.5.7 Type of loss L3: Typical mean values for L_F

Type of damage	Meaning	Value	Meaning
D1	Injury of animals due to electric shock	c_a	Value of animals
D2	Physical damage	$c_a + c_b + c_c + c_s$	Value of all goods
D3	Failure of internal systems	c_s	Value of internal systems and their activities

Table 3.2.5.8 Type of loss L4: Relevant values depending on the type of loss

$$L_A = L_U = \frac{r_t \cdot L_T \cdot c_a}{c_t}$$

$$L_B = L_V = \frac{r_p \cdot r_f \cdot L_F \cdot (c_a + c_b + c_c + c_s)}{c_t}$$

$$L_C = L_M = L_W = L_Z = \frac{L_O \cdot c_s}{c_t}$$

L_T	is the typical mean percentage of the economic value of all goods damaged by electric shock (D1) in case of a dangerous event;
L_F	is the typical mean percentage of the economic value of all goods damaged by physical damage (D2) in case of a dangerous event;
L_O	is the typical mean percentage of the economic value of all goods damaged by failure of internal systems (D3) in case of a dangerous event;
r_t	is a factor reducing the loss of animals depending on the type of ground or floor;
r_p	is a factor reducing the loss due to physical damage depending on the measures taken to reduce the consequences of fire;
r_f	is a factor reducing the loss due to physical damage depending on the risk of fire or explosion of the structure;
c_a	is the value of the animals in the zone;
c_b	is the value of the building related to the zone;
c_c	is the value of the content in the zone;
c_s	is the value of the internal systems in the zone including their activities;
c_t	is the total value of the structure (sum of all zones for animals, buildings, contents and internal systems including their activities).

IEC 62305-2 (EN 62305-2) specifies typical mean values for L_T, L_F and L_O depending on the type of structure (**Table 3.2.5.9**). These values can be modified and adapted for specific structures provided that the exposition to lightning effects and the probability of damage are considered.

Section 3.2.5 only defines the loss values. The further procedure for examining whether protection measures make economic sense is discussed in section 3.2.9.

If the loss of economic value of a structure resulting from a lightning strike also affects surrounding structures or the environment (e.g. in case of chemical or radioactive emissions), the additional loss due to physical damage (L_{BE} and L_{VE}) should be taken into account when assessing the total loss (L_{BT} and L_{VT}):

$$L_{BT} = L_B + L_{BE}$$

$$L_{VT} = L_V + L_{VE}$$

$$L_{BE} = L_{VE} = \frac{L_{FE} \cdot c_e}{c_t}$$

L_{FE}	Loss due to physical damage outside the structure;
c_e	Total value of goods at dangerous locations outside the structure.

Type of damage	Typical loss value		Type of structure
D1: Injuries due to electric shock	L_T	10^{-2}	All types
D2: Physical damage	L_F	1	Risk of explosion
		0.5	Hospital, industrial structure, museum, agriculturally used plant
		0.2	Hotel, school, office building, church, building with entertainment facility, economically used plant
		0.1	Others
D3: Failure of internal systems	L_O	10^{-1}	Risk of explosion
		10^{-2}	Hospital, industrial structure, office building, hotel, economically used plant
		10^{-3}	Museum, economically used plant, school, church, building with entertainment facility
		10^{-4}	Others

Table 3.2.5.9 Type of loss L4: Typical mean values for L_T, L_F and L_O

Source of damage Type of damage	S1 Lightning strike to a structure	S2 Lightning strike near a structure	S3 Lightning strike to an incoming line	S4 Lightning strike near an incoming line
D1: Injury of living beings due to electric shock	$R_A = N_D \cdot P_A \cdot L_A$		$R_U = (N_L + N_{DJ}) \cdot P_U \cdot L_U$	
D2: Physical damage	$R_B = N_D \cdot P_B \cdot L_B$		$R_V = (N_L + N_{DJ}) \cdot P_V \cdot L_V$	
D3: Failure of electrical and electronic systems	$R_C = N_D \cdot P_C \cdot L_C$	$R_M = N_M \cdot P_M \cdot L_C$	$R_W = (N_L + N_{DJ}) \cdot P_W \cdot L_W$	$R_Z = N_I \cdot P_Z \cdot L_Z$
	$R_d = R_A + R_B + R_C$	$R_i = R_M + R_U + R_V + R_W + R_Z$		
Note: For risk components R_U, R_V and R_W, not only the frequency of direct lightning strikes to the line N_L are important, but also the frequency of direct lightning strikes to the connected structure N_{DJ} (see Figure 3.2.3.3)				

Table 3.2.6.1 Risk components for different points of strike (sources of damage) and types of damage

L_{FE} should be provided by the body preparing the explosion protection documents.

3.2.6 Relevant risk components for different types of lightning strikes

There is a close correlation between the type of damage, the type of loss and the resulting relevant risk components. Depending on the sources of damage S1 to S4 (or on the point of strike), there are the following risk components (**Table 3.2.6.1**):

In case of a direct lightning strike to a structure (S1):

R_A Risk of injury to living beings caused by electric shock;

R_B Risk of physical damage;

R_C Risk of failure of electrical and electronic systems.

In case of a lightning strike to the ground near a structure (S2):

R_M Risk of failure of electrical and electronic systems

In case of a direct lightning strike to an incoming line (S3):

R_U Risk of injury to living beings caused by electric shock;

R_V Risk of physical damage;

R_W Risk of failure of electrical and electronic systems

In case of a lightning strike to the ground near an incoming line (S4):

R_Z Risk of failure of electrical and electronic systems.

The eight risk components can also be defined according to the point of strike:

R_d Risk due to a direct lightning strike to a structure (S1);

R_i Risk due to all indirect lightning strikes related to a structure (S2 to S4);

Type of loss	R_T (1/year)
L1: Loss of human life or permanent injury	10^{-5}
L2: Loss of service to the public	10^{-3}
L3: Loss of cultural heritage	10^{-4}
L4: Loss of economic value (only IEC 62305-2)	10^{-3}

Table 3.2.7.1 Typical values for the tolerable risk R_T

3.2.7 Tolerable risk of lightning damage

When selecting lightning protection measures, it must be examined whether the risk R determined for the relevant types of loss exceeds a tolerable value R_T. For a structure which is sufficiently protected against the effects of a lightning strike we have:

$$R \leq R_T$$

Table 3.2.7.1 shows the values of R_T listed in IEC 62305-2 (EN 62305-2) for these three types of loss.

3.2.8 Selection of lightning protection measures

Lightning protection measures are supposed to limit the risk R to values below the tolerable risk R_T. By using a detailed calculation of the risks for the relevant types of loss and by classifying them into the individual risk components R_A, R_B, R_C, R_M,

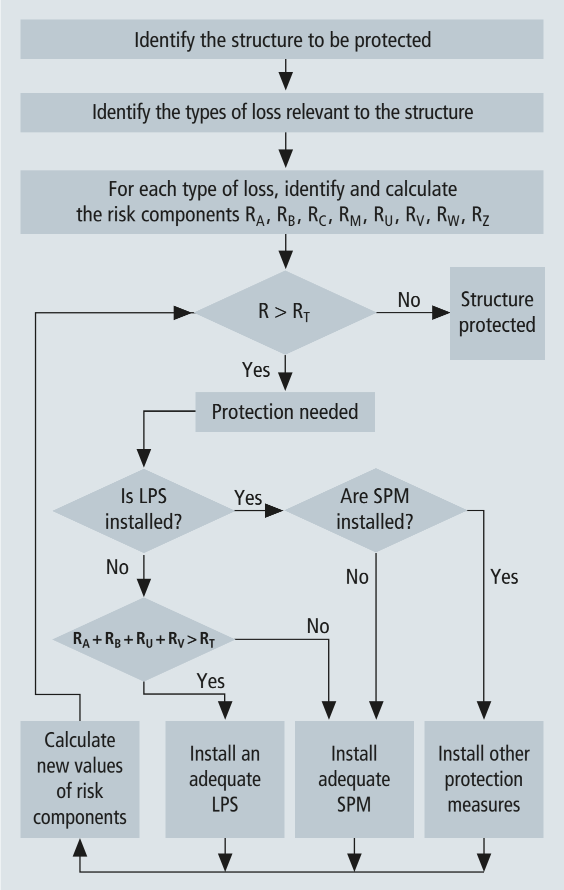


Figure 3.2.8.1 Flow diagram for determining the need of protection and for selecting protection measures in case of types of loss L1 to L3

R_U, R_V, R_W and R_Z, it is possible to specifically select lightning protection measures for a particular structure. The flow chart in IEC 62305-2 (EN 62305-2) (**Figure 3.2.8.1**) illustrates the procedure. If it is assumed that the calculated risk R exceeds the tolerable risk R_T, it must be examined whether the risk of electric shock and physical damage caused by a direct lightning strike to the structure and the incoming lines ($R_A + R_B + R_U + R_V$) exceeds the tolerable risk R_T. If this is the case, an adequate lightning protection system (external and / or internal lightning protection) must be installed. If $R_A + R_B + R_U + R_V$ is sufficiently small, it must be examined whether the risk due to the lightning electromagnetic pulse (LEMP) can be sufficiently reduced by additional protection measures (SPM).

If the procedure according to the flow diagram is observed, protection measures which reduce such risk components with relatively high values can be selected, namely protection measures with a comparatively high effectiveness in the examined case. **Table 3.2.8.1** gives an overview of typical lightning and surge protection measures and their impact on the risk components.

3.2.9 Loss of economic value / Profitability of protection measures

In addition to the types of loss of public interest L1 to L3, the type of loss L4 (loss of economic value) is relevant for many structures. It has to be compared whether the protection measures make economic sense, namely if they are profitable.

Thus, the standard of comparison is not an absolute parameter like the specified tolerable risk R_T, but a relative parameter: Different states of protection of the structure are compared and the optimum state of protection (costs of damage resulting from lightning strikes are as low as possible) is implemented. Several possibilities can and should be examined. The flow chart according to IEC 62305-2 (EN 62305-2) (**Figure 3.2.9.1**) shows the basic procedure.

The costs of the total loss C_L in the structure are calculated by the sum of the loss in the individual zones C_{LZ}:

$$C_{LZ} = R_{4Z} \cdot c_t$$

where

R_{4Z} is the risk related to the loss of value in the zone without protection measures;

c_t is the total value of the structure (animals, building, contents and internal systems including their activities in currency) (see section 3.2.5).

If protection measures are taken, the loss is reduced. However, it is never reduced to zero since there is a residual risk. The costs C_{RL} for the total residual loss in the structure in spite of protection measures are calculated by the sum of the remaining loss in the individual zones C_{RLZ}:

$$C_{RLZ} = R'_{4Z} \cdot c_t$$

where

R'_{4Z} is the risk related to loss of value in the zone with protection measures.

In case of a single zone, the following applies:

$$C_L = C_{LZ} \text{ or } C_{RL} = C_{RLZ}$$

The annual costs C_{PM} for protection measures can be calculated by means of the following equation:

$$C_{PM} = C_P \cdot (i + a + m)$$

Properties of the structure or internal systems – Protection measures	R_A	R_B	R_C	R_M	R_U	R_V	R_W	R_Z
Physical restrictions, insulation, warning notice, potential control on the ground	●				●			
Lightning protection system (LPS)	●	●	●	● [a]	● [b]	● [b]		
Surge protective device for lightning equipotential bonding	●	●			●	●		
Isolating interfaces			● [c]	● [c]	●	●	●	●
Coordinated SPD system			●	●			●	●
Spatial shielding			●	●				
Shielding of external lines					●	●	●	●
Shielding of internal lines			●	●				
Routing precautions			●	●				
Equipotential bonding network			●					

[a] Only for grid-like external LPS
[b] Due to equipotential bonding
[c] Only if they belong to equipment to be protected

Table 3.2.8.1 Lightning and surge protection measures and their influences on the individual risk components

where

C_P	stands for the costs of protection measures;
i	is the interest rate (for financing the protection measures);
a	is the amortisation rate (calculated by the service life of the protection measures);
m	is the maintenance rate (also includes inspection and maintenance costs).

Thus, the procedure assumes that costs can be (roughly) estimated before actually planning lightning and surge protection measures. (General) information on interest rates, amortisation of protection measures and planning, maintenance and repair costs must also be available. Protection makes economic sense if the annual saving S_M is positive:

$$S_M = C_L - (C_{PM} + C_{RL})$$

Depending on the size, construction, complexity and use of the structure and the internal systems, different protection measures can be taken. Thus, there are several possibilities to protect the structure. The profitability of protection measures can therefore be further examined even if an economically sound solution has already been found since there might be an even better solution. Consequently, an economically optimal solution can and should be achieved.
For examining the profitability of protection measures as described in this chapter, possible damage, namely the loss in

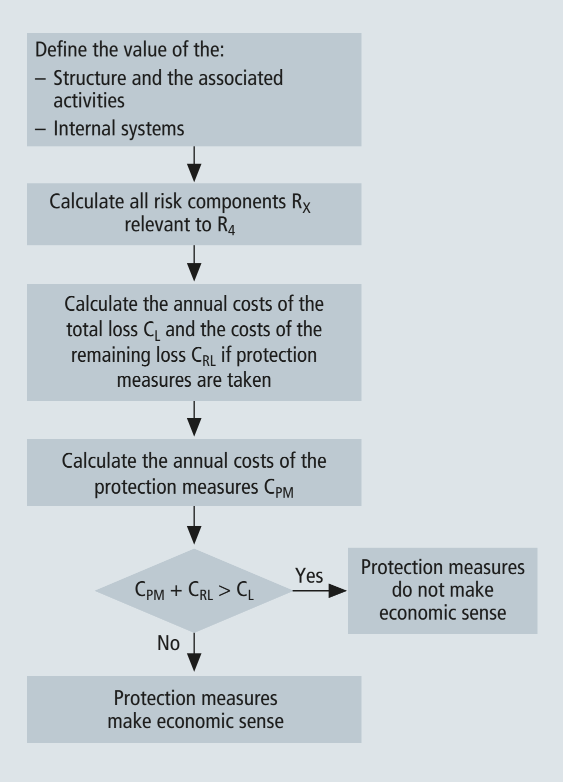


Figure 3.2.9.1 Flow diagram for selecting protection measures in case of loss of economic value

case of lightning effects, must be assessed. To this end, the values of risk R_4, which are determined according to section 3.2.5, are required. For this purpose, the values of the structure c_b, of the content c_c, of the internal systems (including their failure) c_s and of animals c_a, if any, must be known and divided in zones. These values are typically provided by the planner of the protection measures and / or by the owner of the structure. In many cases, these values are not available or it is difficult to obtain these values (e.g. the owner does not want to provide these values). In case of industrial structures or administration buildings with sensitive production or work processes, the transparency required for the reasonable implementation of the risk management stands in contrast to the necessity of confidentiality of sensitive economic data. In other cases, the acquisition of these data is too complex.

EN 62305-2 includes a simplified procedure to implement the risk management for the type of loss L4 in cases where it is difficult to assess possible damage sums resulting from lightning effects.

The total value c_t of the structure is determined according to **Table 3.2.9.1** based on the volume of the structure (in case of non-industrial structures) and the number of full-time jobs (in case of industrial structures). The values in percent specified in **Table 3.2.9.2** are used to assign this total value to the individual categories (animals: c_a, buildings: c_b, contents: c_c, internal systems: c_s). For these values, it must be observed that the possible malfunction of electrical and electronic systems (internal systems) and the resulting follow-up costs are only included in the values for industrial structures, but not in the values for non-industrial structures.

If the structure is divided into several zones, the relevant values c_a, c_b, c_c and c_s can be subdivided according to the share of the volume of the relevant zone in the total volume (in case of non-industrial structures) or the share of the jobs in the relevant zone in the total number of jobs (in case of industrial structures).

Thus, the simplified procedure according to EN 62305-2 follows the only reasonable procedure for examining the profitability of protection measures, namely a comparison based on exclusively economic data. Only the total value of the structure (c_t) and the values c_a, c_b, c_c, c_s are determined according to a simplified method. However, if exact data is available for the stated values, these values should be used.

In addition to type of loss L4, one or more other types of loss L1 to L3 are typically relevant to a structure. In these cases, the procedure described in 3.2.8 must be used first, in other words it must be examined whether protection measures are required and the risk R must be smaller than the tolerable risk R_T for the types of loss L1 to L3. If this is the case, the profitability of the planned protection measures is examined according to **Figure 3.2.9.1** in a second step. Also in this case, several protection measures are possible and the economically optimum measure should be taken provided that the following applies to all relevant types of loss of public interest L1 to L3:

$$R < R_T$$

A lightning protection system according to IEC 62305-3 (EN 62305-3) often sufficiently ensures that persons in the structure are protected (type of loss L1). In case of an office and administration building or an industrial structure, types of

Type of structure	Reference values		Total value of c_t	
Non-industrial structures	Total reconstruction costs (do not include possible malfunction)	Low	c_t per volume (€/m^3)	300
		Ordinary		400
		High		500
Industrial structures	Total value of the structure including buildings, installations and contents (includes possible malfunction)	Low	c_t per employee (k€/AP)	100
		Ordinary		300
		High		500

Table 3.2.9.1 Values for assessing the total value c_t (EN 62305-2)

Condition	Portion for animals c_a/c_t	Portion for the building c_b/c_t	Portion for the content c_c/c_t	Portion for internal systems c_s/c_t	Total for all goods $(c_a+c_b+c_c+c_s)/c_t$
Without animals	0	75 %	10 %	15 %	100 %
With animals	10 %	70 %	5 %	15 %	100 %

Table 3.2.9.2 Portions to assess the values c_a, c_b, c_c, c_s (EN 62305-2)

loss L2 and L3 are not relevant. Consequently, other protection measures (e.g. surge protection) can only be justified by examining their profitability. In these cases, it quickly becomes evident that loss of economic value can be significantly reduced by using coordinated SPD systems.

3.2.10 Calculation assistances

The IEC 62305-2 (EN 62305-2) standard includes procedures and data for calculating the risk in case of lightning strikes to structures and for selecting lightning protection measures.
The procedures and data listed in the standard are often complex and difficult to implement in practice. This, however, should and must not stop lightning protection specialists, in particular planners, to deal with this topic. The quantitative assessment of the risk of lightning damage for a structure is a significant improvement compared to the previous situation where decisions in favour of or against lightning protection measures were often based on subjective considerations which were not understood by all parties involved.
Thus, such a quantitative assessment is an important prerequisite for the decision whether, to what extent and which lightning protection measures must be taken for a structure. This ensures that lightning protection is widely accepted and prevents damage in the long term.
It is virtually impossible to apply the procedure stated in the standard without tools, namely without software tools. The structure and contents of the IEC 62305-2 (EN 62305-2) standard are so complex that tools are indispensable if the standard is supposed to gain ground on the market. Such a software tool is e.g. Supplement 2 of the German DIN EN 62305-2 standard, which includes a calculation assistance based on an EXCEL sheet with print option. Moreover, commercial programs based on databases are available, which also reflect the full functionality of the standard and allow to edit and store additional project data and other calculations, if any.

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3.3 DEHNsupport Toolbox design assistance

A computer-aided solution makes it easier to design a lightning protection system for structures.
The DEHNsupport Toolbox software offers a number of calculation options in the field of lightning protection based on the requirements of the IEC 62305-x (EN 62305-x) standard series. In addition to international requirements, country-specific adaptations are integrated in the software and are constantly updated. The software, which is available in different languages, is a tool for specifically defining and implementing lightning and surge protection measures (**Figure 3.3.1**).

The following design assistances are available:

- DEHN Risk Tool; risk analysis according to IEC 62305-2 (EN 62305-2)
- DEHN Distance Tool; calculation of the separation distance according to IEC 62305-3 (EN 62305-3)
- DEHN Earthing Tool; calculation of the length of earth electrodes according to IEC 62305-3 (EN 62305-3)
- DEHN Air-Termination Tool; calculation of the length of air-termination rods according to IEC 62305-3 (EN 62305-3)

3.3.1 DEHN Risk Tool; risk analysis according to IEC 62305-2 (EN 62305-2)

The DEHN Risk Tool considerably facilitates the complex and difficult method of assessing the risk for structures. The ground flash density N_G in the area where the object to be protected is located can be determined in the integrated customer/project management.
In addition to the ground flash density, the calculation basis must be selected in the DEHNsupport customer/project management. To this end, different countries and their country-specific standard designations are available. This selection does not only define the standard designation for the printout of the calculations, but also activates country-specific calculation parameters. As soon as a calculation is opened for the first time, the defined calculation basis cannot be changed any more.

Figure 3.3.1 Start screen of the DEHNsupport Toolbox software

After the user has created a customer/project, the risks to be considered must be selected. Four risks are available for a risk analysis:

- Risk R_1, Risk of loss of human life
- Risk R_2, Risk of loss of service to the public
- Risk R_3, Risk of loss of cultural heritage
- Risk R_4, Risk of loss of economic value

The competent body is responsible for defining the values for the tolerable risks. It is advisable to accept the normative values without changes.

When performing a risk analysis by means of the Risk Tool, the actual state must be considered without selecting protection measures. In a second step, a desired state where the existing risk is minimised by specific protection measures so that it is less than the tolerable risk specified in the standard is created by using the copy function, which can be found in the "Building" tab. This procedure should always be used.

In addition to the ground flash density and the environment of the building, the collection areas for direct/indirect lightning strikes must be calculated in the "Building" tab. Three types of buildings can be used for the calculation:

- Simple structure
- Building with high point
- Complex structure (**Figure 3.3.1.1**).

In case of "Building with high point", the distance between +/–0.00 m ground level as well as the top edge (highest point) must be defined for "Highest point". In this case, the position is irrelevant. "Complex structure" allows to simulate an interconnected building structure as exact as possible and to calculate its collection area.

When calculating the collection areas and when performing risk analyses, it must be observed that only interconnected building parts can be assessed. If a new building is added to an existing structure, it can be considered in the risk analysis as a single object. In this case, the following normative requirements must be met on site:

- Both building parts are separated from each other by means of a vertical fire wall with a fire resistance period of 120 min (REI 120) or by means of equivalent protection measures.
- The structure does not provide a risk of explosion.
- Propagation of surges along common supply lines, if any, is avoided by means of SPDs installed at the entry point of such lines into the structure or by means of equivalent protection measures.

If these requirements are not fulfilled, the dimensions and the necessary protection measures must be determined for the complete building complex (old and new building). Thus, the grandfathering clause does not apply. As a result, a lightning protection system on an existing building may have to be tested for a comprehensive consideration.

Figure 3.3.1.1 Calculation of the collection area

The "Zones" tab (**Figure 3.3.1.2**) allows the user to divide a building into lightning protection zones and these lightning protection zones into individual zones. These zones can be created according to the following aspects:

- Type of soil of floor
- Fireproof compartments
- Spatial shields
- Arrangement of internal systems
- Existing protection measures or protection measures to be taken
- Loss values

The division of the structure into zones allows the user to consider the special characteristics of each part of the structure when assessing the risk and to select adequate "made-to-measure" protection measures. Consequently, the total costs of protection measures can be reduced.

In the "Supply lines" tab, all incoming and outgoing supply lines of the structure under consideration are defined. Pipes do not have to be assessed if they are connected to the main earthing busbar of the structure. If this is not the case, the risk of incoming pipes must also be considered in the risk analysis. Parameters such as

- Type of line (overhead line/buried line)
- Length of the line (outside the building)
- Environment
- Connected structure
- Type of internal cabling and
- Lowest rated impulse withstand voltage

Figure 3.3.1.2 DEHN Risk Tool, division into zones

Figure 3.3.1.3 DEHN Risk Tool, evaluation

must be defined for every supply line. These parameters are included in the line-related risks for the structure. If the line length is unknown, the standard recommends to use a line length of 1000 m for calculation. The line length is defined from the entry point into the object to be protected to the connected structure or a node. A node is, for example, a distribution point of a power supply line on a HV / LV transformer or in a substation, a telecommunication exchange or a piece of equipment (e.g. multiplexer or xDSL device) in a telecommunication line.

In addition to line-related parameters, the properties of the building must also be defined. For example, the following factors are important:

- External spatial shielding
- Spatial shielding in the building
- Floor properties inside / outside the structure
- Fire protection measures and
- Risk of fire

The risk of fire is an important decision criterion and basically defines whether a lightning protection system must be installed and which class of LPS is required. The risk is assessed according to the specific fire load in MJ/m^2. The following definitions are provided in the standard:

- Low risk of fire: Specific fire load $\leq$ 400 MJ/m^2
- Ordinary risk of fire: Specific fire load $>$ 400 MJ/m^2
- High risk of fire: Specific fire load $\geq$ 800 MJ/m^2
- Explosion zone 2, 22
- Explosion zone 1, 21
- Explosion zone 0, 20 and solid explosives

To complete the risk analysis, possible losses must be selected. Losses are subdivided according to the type of loss:

- L1; Loss of human life
- L2; Loss of service to the public
- L3; Loss of cultural heritage
- L4; Loss of economic value

When defining the losses, it must be observed that losses always refer to the relevant type of loss. Example: Loss of economic value (risk R_4) due to touch and step voltage only applies to the loss of animals, not to the loss of persons.

In the DEHN Risk Tool the result of a risk analysis is displayed in the form of graphics (**Figure 3.3.1.3**). Thus, it can be seen immediately and at any time how high the relevant risks are. Blue stands for the tolerable risk, red or green for the calculated risk of the structure to be protected. To be able to correctly assess the risk potential for a structure, the risk components of the relevant risk must be considered in detail. Each component describes a risk potential. The aim of a risk analysis is to specifically reduce the main risks by means of reasonably chosen measures.

Each risk component can be influenced (reduced or increased) by different parameters. The measures shown in **Table 3.3.1.1** make it easier to select protection measures. The user must make this selection and activate the protection measures in the software.

To calculate the risk R_4 "Loss of economic value", costs must be calculated according to IEC 62305-2 (EN 62305-2). To this end, the actual state (without protection measures) and the desired state (with protection measures) must be considered. The following costs (in €) must be defined for calculation:

- Costs of animals c_a
- Costs of the building c_b
- Costs of internal systems including their activities c_s

Properties of the structure or internal systems Protection measures	R_A	R_B	R_V
Physical restrictions, insulation, warning notice, potential control on the ground	●		
Lightning protection system (LPS)	●	●	●[b]
Surge protective devices for lightning equipotential bonding	●	●	●
[b] Due to equipotential bonding			

Table 3.3.1.1 DEHN Risk Tool, measures (excerpt)

- Costs of the content c_c
- Total costs of the structure $(c_a + c_b + c_c + c_s)$ c_t

It must be observed that the costs also include replacement costs, downtime costs and follow-up costs. These costs must be evenly allocated to the types of costs.

The EN 62305-2 standard allows to define these values according to tables if they are unknown. The following procedure must be observed:

- Assessment of the total value c_t of the structure (**Table 3.2.9.1**)
- Proportional assessment of the values of c_a, c_b, c_c and c_s based on c_t (**Table 3.2.9.2**)

In addition to c_a, c_b, c_c and c_s, the costs of protection measures c_p must also be defined. To this end, the

- Interest rate i
- Maintenance rate m and
- Amortisation rate a

must be defined.

The result of the consideration of loss of economic value is:

- Costs of the total loss C_L without protection measures
- Remaining loss costs C_{RL} despite of protection measures
- Annual costs C_{PM} of the protection measures
- Savings

The calculated values are displayed in €/year.
If the assessment leads to positive savings S_M, the protection measures make economic sense. If it leads to negative savings S_M, the protection measures do not make economic sense. After performing a risk analysis, a detailed report or a summary can be printed (rtf file).

3.3.2 DEHN Distance Tool; calculation of the separation distance according to IEC 62305-3 (EN 62305-3)

The DEHN Distance Tool is another module of the DEHNsupport Toolbox software. In addition to the conventional calculation formulas for determining the separation distance and thus the partitioning coefficient k_c, more exact calculations can be performed according to the standard. The calculation of the separation distance is based on nodal analysis.

3.3.2.1 Nodal analysis

Kirchhoff's first law defines that at any node the sum of the currents flowing into that node is equal to the sum of currents flowing out of that node (nodal rule) (**Figure 3.3.2.1.1**).
This rule can also be used for buildings with external lightning protection system. In case of a simple building with one air-termination rod (**Figure 3.3.2.1.2**), the lightning current is distributed at the base in the event of a lightning strike to the air-termination rod. This lightning current distribution depends on the number of down conductors, also referred to as current paths. **Figure 3.3.2.1.2** shows a node with four conductors (current paths).
In case of a meshed external lightning protection system with down conductors, the lightning current is distributed in each junction and at the connection point of the air-termination system. To this end, a clamp connection according to IEC 62305-3 (EN 62305-3) is required.
The closer the mesh or the higher the number of nodes, the better is the lightning current distribution. The same applies to the entire conductor routing (**Figure 3.3.2.1.3**).
Nodal analysis is used to calculate the exact lightning current distribution and the resulting separation distances. This method is used for network analysis in electrical engineering and is a transmission line method. If nodal analysis is used for a building with external lightning protection system, each line (current path) is shown in the form of a resistor. Thus, the variety of meshes and down conductors in a lightning protection system forms the basis for nodal analysis. The lines of a lightning protection system, for example of a mesh, are typically divided into many individual line sections by means of nodes (junctions). Each line section represents an electric resistance R (**Figure 3.3.2.1.4**). When using nodal analysis, the reciprocal value of the resistance, also referred to as conductance G, is used for calculation:

$$R = \frac{1}{G} \quad \Rightarrow \quad G = \frac{1}{R}$$

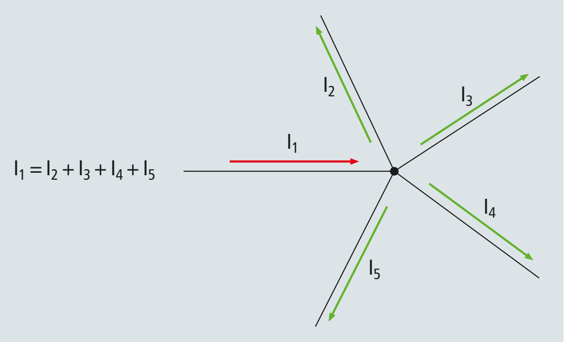


Figure 3.3.2.1.1 Kirchhoff's law with nodes

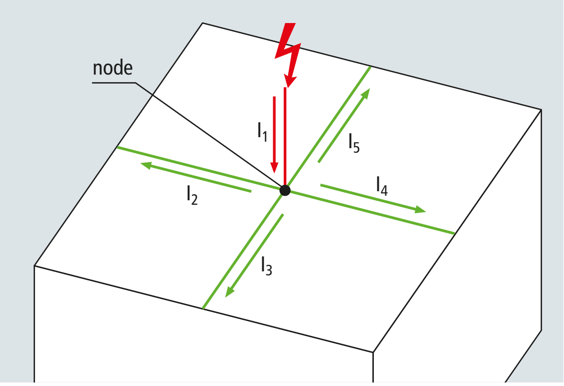


Figure 3.3.2.1.2 Kirchhoff's law: Example of a building with a mesh on the roof

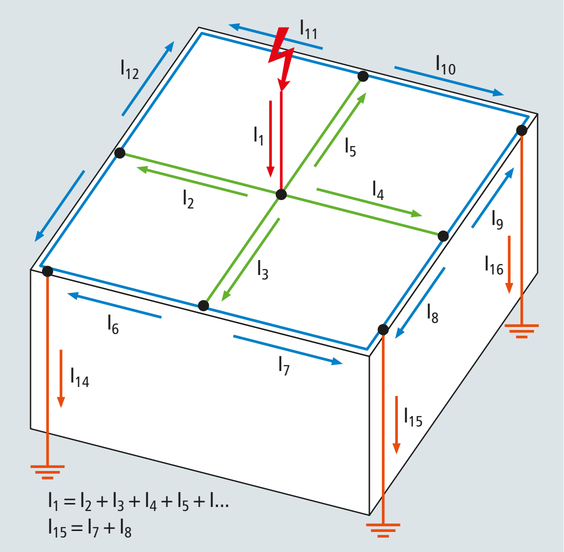


Figure 3.3.2.1.3 Kirchhoff's law: Example of a building with air-termination system

The conductance G is calculated from a current and voltage value or a resistance value R. The conductivity refers to the conductance G of a material with specific dimensions, e.g.:

- Length = 1 m
- Cross-section = 1 mm^2
- Material

The conductance of a conductor can be calculated from these values without requiring current and voltage values. When positioning the lightning protection system according to **Figure 3.3.2.1.4**, a distinction is made between self-conductance and mutual conductance.

- **Self-conductance:** Conductance of all conductances connected at one point I (example: Corner of a flat roof: Self-conductance consists of the sum of the conductances of the down conductors in the corner and the conductance of the two air-termination conductors of the mesh).

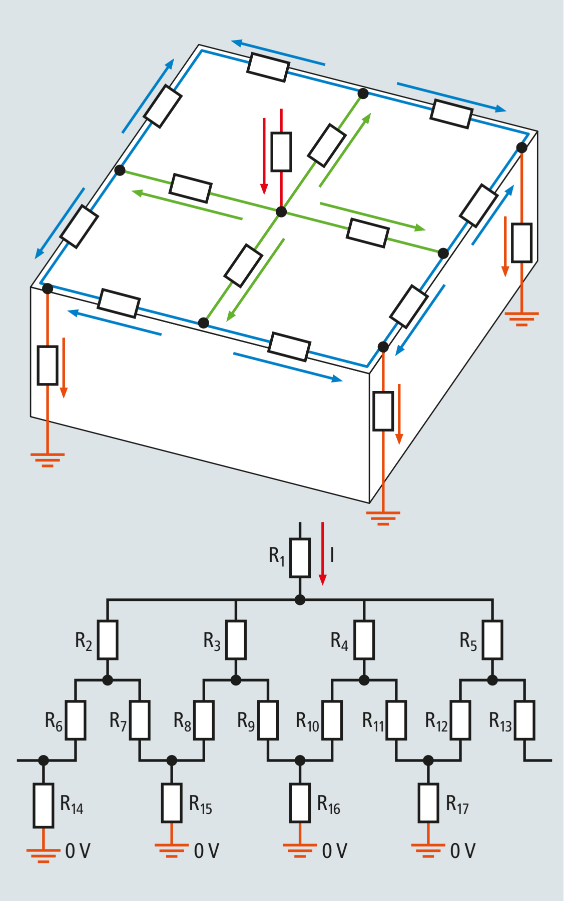
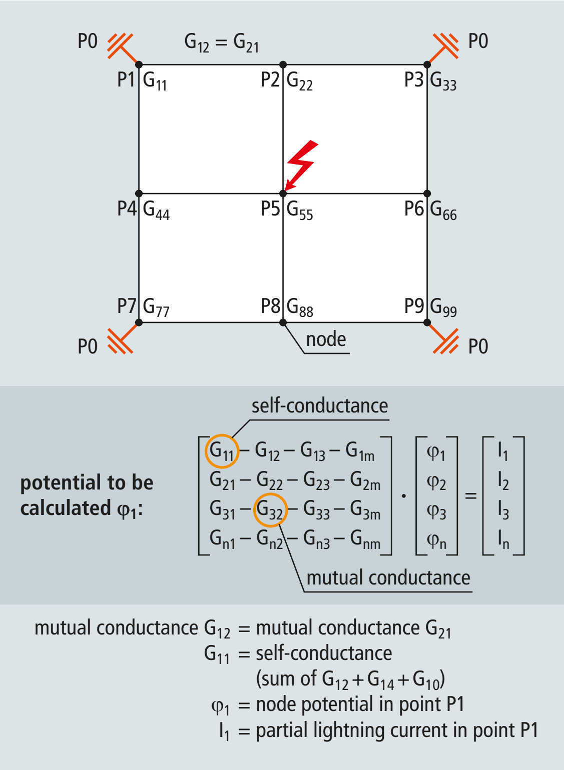


Figure 3.3.2.1.4 Resistors of the building

- **Mutual conductance:** Conductance between two points (example: Conductance between two opposite points (clamping points) of a mesh on a flat roof (without branches)). The following steps are required to calculate the separation distances in case of a building with external lightning protection system (see also **Figure 3.3.2.1.5**):

1. Define 0 V potentials (φ_0 in P0)
2. Define potentials (φ_1 in P1, …)
3. Define self-conductances (G_{11}, G_{22}, G_{nn})
4. Define mutual conductances (G_{12}, G_{23}, G_{nm})
5. Define point of strike
6. Prepare equations for nodal analysis (matrix)

After preparing the node equations, the potential at a certain point such as φ_1 can be calculated. Since the matrix includes many unknown variables, the equation must be solved accordingly. If all potentials of the meshed network are determined, the lightning current distribution and thus the k_c values are derived from these potentials. Based on these values, the separation distances can be determined using the equation specified in the standard.



$$\begin{bmatrix} G_{11} - G_{12} - G_{13} - G_{1m} \\ G_{21} - G_{22} - G_{23} - G_{2m} \\ G_{31} - G_{32} - G_{33} - G_{3m} \\ G_{n1} - G_{n2} - G_{n3} - G_{nm} \end{bmatrix} \cdot \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_n \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_n \end{bmatrix}$$

mutual conductance G_{12} = mutual conductance G_{21}
G_{11} = self-conductance (sum of $G_{12} + G_{14} + G_{10}$)
φ_1 = node potential in point P1
I_1 = partial lightning current in point P1

Figure 3.3.2.1.5 Node equation

Almost equal earth resistances (type B earth-termination system) form the basis for this type of calculation of separation distances for a lightning protection system.

3.3.2.2 Information on the DEHN Distance Tool

Since the calculation by means of nodal analysis is very complex, the simple and time-saving DEHN Distance Tool calculation module can be used. This module allows to simulate the current flow in a meshed network and to calculate the separation distances based on this simulation.

3.3.3 DEHN Earthing Tool; calculation of the length of earth electrodes according to IEC 62305-3 (EN 62305-3)

The Earthing Tool of the DEHNsupport software can be used to determine the length of earth electrodes as per IEC 62305-3 (EN 62305-3). To this end, a distinction is made between the different types of earth electrodes (foundation earth electrode, ring earth electrode and earth rod).

In addition to the class of LPS, the earth resistivity must be defined for single earth electrodes (type A earthing arrangement). These values are used to calculate the length of the earth electrode (in m) (**Figure 3.3.3.1**).

To determine the length of a ring or foundation earth electrode, the class of LPS, the surface enclosed by the earth electrode and the soil resistivity must be defined. The result shows whether the earth-termination system is sufficiently dimensioned or whether additional earthing measures must be taken.

For more detailed information, please see chapter 5.5 "Earth-termination systems".

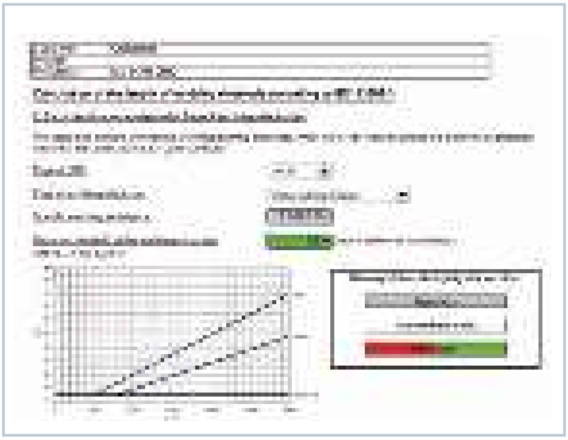


Figure 3.3.3.1 DEHN Earthing Tool, type A earth-termination system

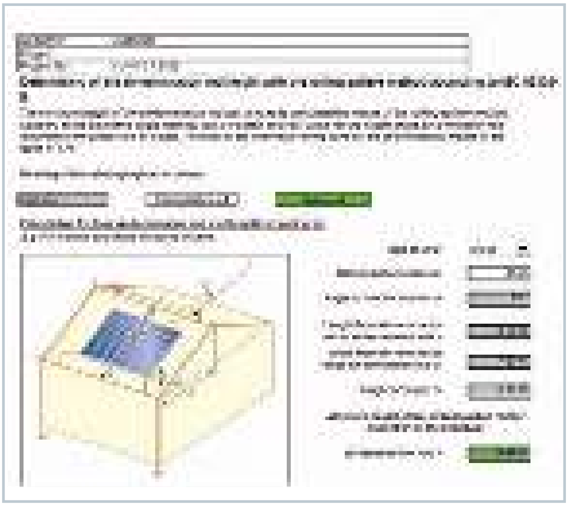


Figure 3.3.4.1 DEHN Air-Termination Tool, gable roof with PV system

3.3.4 DEHN Air-Termination Tool; calculation of the length of air-termination rods according to IEC 62305-3 (EN 62305-3)

Air-termination rods allow to integrate large areas in the protected volume of LPZ 0_B. In some cases, graphics, which must be created depending on the class of LPS, are required to determine the height of the air-termination rod. To facilitate work for qualified personnel, calculations for different kinds of graphics are integrated in the DEHN Air-Termination Tool of the DEHNsupport Toolbox software. The user must define the class of LPS, the length, width and height of the building and the separation distance. Depending on whether the protective angle or rolling sphere method is used, the length of the air-termination rods to be installed can be calculated from these values. In case of calculations with several air-termination rods, the lateral sag of the rolling sphere must also be considered in the calculation (**Figure 3.3.4.1**).

The aim is to ensure a technically correct external lightning protection system.

3.4 Inspection and maintenance

3.4.1 Types of inspection and qualification of inspectors

To ensure that the structure, the persons therein and the electrical and electronic systems are permanently protected, the mechanical and electrical characteristics of a lightning protection system must remain completely intact for the whole of its service life. To ensure this, a coordinated inspection and maintenance programme for the lightning protection system should be laid down by an authority, the designer or installer of the lightning protection system and the owner of the structure. If defects are found during the inspection of a lightning protection system, the operator / owner of the structure is responsible for the immediate rectification of the defects. The inspection of the lightning protection system must be carried out by a lightning protection specialist. A lightning protection specialist (according to Supplement 3 of the German DIN EN 62305-3 standard) is able to design, install and inspect lightning protection systems due to his technical training, knowledge, experience and familiarity with applicable standards. Evidence can be provided by regular participation in national training courses.

The criteria (technical training, knowledge and experience) are usually fulfilled after several years of work experience and current occupation in the field of lightning protection. The design, installation and inspection of lightning protection systems require different skills from the lightning protection specialist, which are listed in Supplement 3 of the German DIN EN 62305-3 standard.

A lightning protection specialist is a competent person who is familiar with the relevant safety equipment regulations, directives and standards to the extent that he is in a position to judge if technical work equipment is in a safe condition. In Germany, a training course leading to recognition as a lightning protection specialist (competent person for lightning and surge protection as well as for electrical installations conforming to EMC (EMC approved expert)) is offered by the Association of Damage Prevention (VdS), which is part of the German Insurance Association (GDV e.V.), in conjunction with the Committee for Lightning Protection and Lightning Research of the Association for Electrical, Electronic & Information Technologies (ABB of the VDE).

Attention: A *competent person* is not an *expert*!

An *expert* has special knowledge in the field of technical work equipment which requires testing due to his technical training and experience. He is familiar with the relevant safety equipment regulations, directives and standards to the extent that he is in a position to judge if complex technical equipment is in a safe condition. He should be able to inspect technical work equipment and provide an expert opinion. Experts are, for example, engineers at the German Technical Inspectorates or other specialist engineers. Installations requiring inspection generally have to be inspected by *experts* or competent persons.

Regardless of the qualifications required from the inspectors, the inspections should ensure that the lightning protection system protects living beings, contents, technical equipment in the structure, safety systems and the structure from the effects of direct and indirect lightning strikes and maintenance and repair measures should be taken, if required. A report of the lightning protection system containing the design criteria, design description and technical drawings should therefore be available to the inspector. The inspections to be carried out are distinguished as follows:

Inspection at the design stage

The inspection at the design stage should ensure that all aspects of the lightning protection system with its components correspond to the state of the art in force at the design stage and must be carried out before the service is provided.

Inspections during the construction phase

Parts of the lightning protection system which will be no longer accessible when the construction work is completed must be inspected as long as this is possible. These include foundation earth electrodes, earth-termination systems, reinforcement connections, concrete reinforcements used as room shielding as well as down conductors and their connections laid in concrete. The inspection comprises checking of technical documents, on-site inspection and assessment of the work carried out (see Supplement 3 of the German DIN EN 62305-3 standard).

Acceptance test

The acceptance test is carried out when the lightning protection system has been completed. Compliance with the protection concept (design) conforming to the standard and the work performed (technical correctness taking into consideration the type of use, the technical equipment of the structure and the site conditions) must be thoroughly inspected.

Maintenance test

Regular maintenance tests are the prerequisite for a permanently effective lightning protection system. In Germany they should be carried out every 1 to 4 years. **Table 3.4.1.1** includes recommendations for the intervals between the complete test of a lightning protection system under average environmental conditions. The test intervals specified in regulatory requirements or regulations have to be considered as minimum requirements. If regulatory requirements prescribe that the electrical installation in the structure must be regularly tested, the effectiveness of the internal lightning protection measures should be checked during this test.

Visual inspection

Lightning protection systems of structures and critical sections of lightning protection systems (e.g. in case of considerable influence from aggressive environmental conditions) must undergo a visual inspection between maintenance tests (**Table 3.4.1.1**).

Additional inspection

In addition to the maintenance tests, a lightning protection system must be inspected if fundamental changes in use, modification to the structure, restorations, extensions or repair have been carried out on a protected structure. These inspections should also be carried out when it is known that lightning has struck the lightning protection system.

3.4.2 Inspection measures

The inspection comprises checking of technical documents, on-site inspection and measurements.

Checking of technical documents

The technical documents must be checked to ensure they are complete and comply with the standards.

On-site inspection

It must be checked whether:

Class of LPS	Visual inspection (year)	Complete Inspection (year)	Complete inspection of critical situations [a) b)] (year)
I and II	1	2	1
III and IV	2	4	1

[a)] Lightning protection systems utilised in applications involving structures with a risk caused by explosive materials should be visually inspected every 6 months. Electrical testing of the installation should be performed once a year. An acceptable exception to the yearly test schedule would be to perform the tests on a 14 to 15 month cycle where it is considered beneficial to conduct earth resistance testing over different times of the year to get an indication of seasonal variations.

[b)] Critical situations could include structures containing sensitive internal systems, office blocks, commercial buildings or places where a high number of people may be present.

Table 3.4.1.1 Maximum period between inspections of an LPS according to Table E.2 of IEC 62305-3 (EN 62305-3)

- The complete system complies with the technical documentation,
- The complete external and internal lightning protection system is in good order and condition,
- There are loose connections and interruptions in the conductors of the lightning protection system,
- All earth connections (if visible) are in good order and condition,
- All conductors and system components are properly installed and parts which provide mechanical protection are in good order and condition,
- Modifications requiring additional protection measures have been made to the protected structure,
- The surge protective devices installed in power installations and information systems are correctly installed,
- There is any damage or tripped surge protective devices,
- Upstream overcurrent protective devices of surge protective devices have tripped,
- Lightning equipotential bonding has been established for new supply connections or extensions, which have been installed inside the structure since the last inspection,
- Equipotential bonding connections are installed in the structure and are intact,
- Measures required for proximities between the lightning protection system and installations have been taken.

Measurements

Measurements are used to test the continuity of the connections and the condition of the earth-termination system.

They must be made to check whether all connections of air-termination systems, down conductors, equipotential bonding conductors, shielding measures etc. have a low-impedance continuity. The recommended value is $< 1\ \Omega$.

The contact resistance to the earth-termination system at all test joints must be measured to establish the continuity of the lines and connections (recommended value $< 1\ \Omega$). Furthermore, the continuity with respect to the metal installations (e.g. gas, water, ventilation, heating), the total earth resistance of the lightning protection system and the earth resistance of single earth electrodes and partial ring earth electrodes must be measured. The results of the measurements must be compared with the results of earlier measurements. If they significantly deviate from the earlier measurements, additional examinations must be performed.

Note: In case of existing earth-termination systems which are older than 10 years, the condition and quality of the earthing conductor and its connections can only be visually inspected by exposing it at certain points.

3.4.3 Documentation

A report must be prepared for each inspection. This must be kept together with the technical documents and reports of previous inspections at the installation / system operator´s premises or at the offices of the relevant authority.

The following technical documents must be available to the inspector when assessing the lightning protection system: Design criteria, design descriptions, technical drawings of the external and internal lightning protection system as well as reports of previous maintenance and inspection.

A report should contain the following information:

- **General:** Owner and address, manufacturer of the lightning protection system and address, year of construction
- **Information on the structure:** Location, use, type of construction, type of roofing, lightning protection level (LPL)
- **Information on the lightning protection system**
  - Material and cross-section of the conductors
  - Number of down conductors, e.g. test joints (designation according to the information in the drawing); separation distance calculated
  - Type of earth-termination system (e.g. ring earth electrode, earth rod, foundation earth electrode), material and cross-section of the connecting lines between the single earth electrodes
  - Connection of the lightning equipotential bonding system to metal installations, electrical installations and existing equipotential bonding bars
- **Fundamentals of inspection**
  - Description and drawings of the lightning protection system
  - Lightning protection standards and provisions at the time of installation
  - Further fundamentals of inspection (e.g. regulations, requirements) at the time of installation
  - Ex zone plan
- **Type of inspection**
  - Inspection at the design stage, inspection during the construction phase, acceptance test, maintenance test, additional inspection, visual inspection
- **Result of the inspection**
  - Any modifications to the structure and / or the lightning protection system
  - Deviations from the applicable standards, regulations, requirements and application guidelines applicable at the time of installation
  - Defects found

  - Earth resistance or loop resistance at the individual test joints with information on the measuring method and the type of measuring device
  - Total earth resistance (measurement with or without protective conductor and metal building installation)
- **Inspector:** Name of the inspector, inspector´s company / organisation, name of person accompanying the inspector, number of pages of the report, date of inspection, signature of the inspector´s company / organisation

Sample test reports according to the requirements of Supplement 3 of the German DIN EN 62305-3 standard are available at www.dehn-international.com.

- For general installations: Test report No. 2110
- For installations located in hazardous areas: Test report No. 2117

3.3.4 Maintenance

Maintenance and inspection of lightning protection systems must be coordinated. In addition to the inspections, regular maintenance routines should therefore also be defined for all lightning protection systems. The frequency of maintenance work depends on the following factors:

- Loss of quality related to the weather and ambient conditions
- Effects of direct lightning strikes and resulting possible damage
- Class of LPS required for the structure under consideration

Maintenance measures should be individually determined for each lightning protection system and become an integral part of the complete maintenance programme for the structure.

A maintenance routine should be prepared. This allows a comparison between the latest results and those from an earlier maintenance. These values can also be used for comparison for a later inspection.

The following measures should be included in a maintenance routine:

- Inspection of all conductors and components of the lightning protection system
- Measuring the continuity of the installations of the lightning protection system
- Measuring the earth resistance of the earth-termination system
- Visual inspection of all surge protective devices (relates to surge protective devices installed on the incoming lines of the power installation and information system) to detect whether they are damaged or have tripped
- Fixing components and conductors again
- Inspection to ascertain that the effectiveness of the lightning protection system is unchanged after additional installations or modifications to the structure

Complete records should be kept of all maintenance work. They should contain modification measures which have been or must be carried out.

These records make it easier to assess the components and installations of the lightning protection system. They can be used to examine and update a maintenance routine. The maintenance records should be retained together with the design and the inspection reports of the lightning protection system for future reference.

4

Lightning protection system

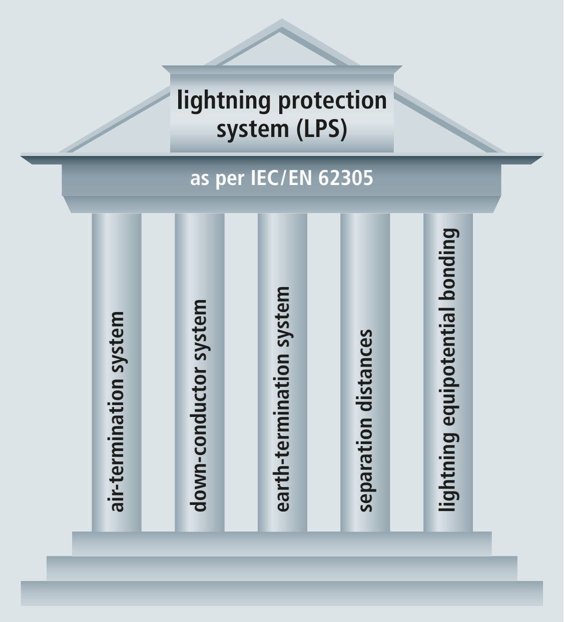


Figure 4.1 Components of a lightning protection system

The function of a lightning protection system is to protect structures from fire or mechanical destruction and persons in the buildings from injury or even death.
A lightning protection system consists of an external and an internal lightning protection system (**Figure 4.1**).

The functions of the external lightning protection system are:

- To intercept direct lightning strikes via an air-termination system
- To safely conduct the lightning current to the ground via a down-conductor system
- to distribute the lightning current in the ground via an earth-termination system

The function of the internal lightning protection system is:

- To prevent dangerous sparking inside the structure. This is achieved by establishing equipotential bonding or maintaining a separation distance between the components of the lightning protection system and other electrically conductive elements inside the structure.

Lightning equipotential bonding reduces the potential differences caused by lightning currents. This is achieved by connecting all isolated conductive parts of the installation directly by means of conductors or surge protective devices (SPDs) (**Figure 4.2**).

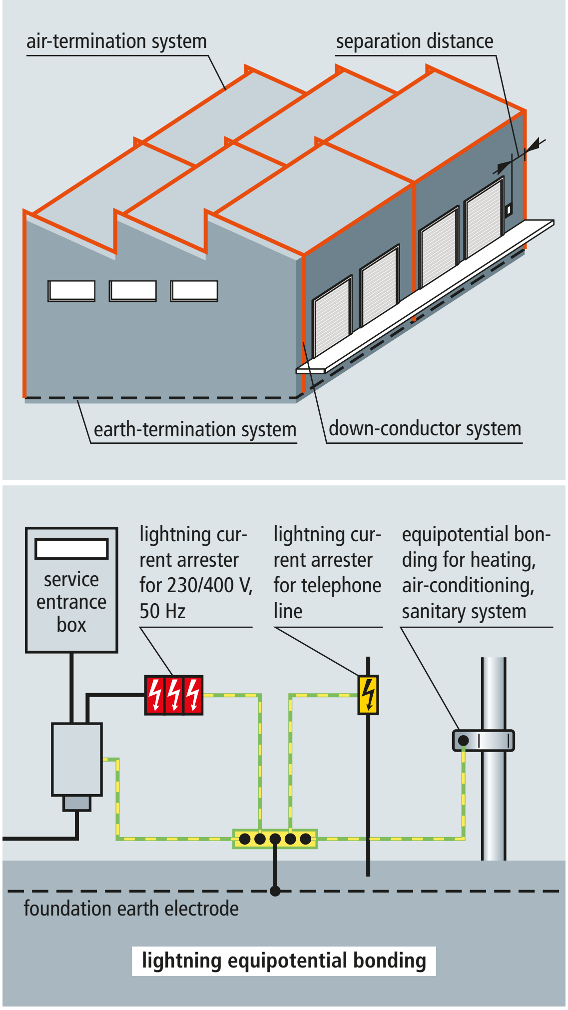


Figure 4.2 Lightning protection system (LPS)

The four classes of LPS I, II, III and IV are determined using a set of construction rules including dimensioning requirements which are based on the relevant lightning protection level. Each set comprises class-dependent (e.g. radius of the rolling sphere, mesh size) and class-independent (e.g. cross-sections, materials) requirements.

To ensure permanent availability of complex information technology systems even in case of a direct lightning strike, additional measures, which supplement the lightning protection measures, are required to protect electronic systems against surges. These comprehensive measures are described in chapter 7 (lightning protection zone concept).

5

External lightning protection

5.1 Air-termination systems

The function of the air-termination systems of a lightning protection system is to prevent that direct lightning strikes damage the volume to be protected. They must be designed to avoid uncontrolled lightning strikes to the building / structure to be protected.
Correct dimensioning of the air-termination systems allows to reduce the effects of a lightning strike to a structure in a controlled way.

Air-termination systems can consist of the following components and can be combined with each other as required:

- Rods
- Spanned wires and cables
- Meshed conductors

When determining the position of the air-termination systems of the lightning protection system, special attention must be paid to the protection of corners and edges of the structure to be protected. This particularly applies to air-termination systems on the surfaces of roofs and the upper parts of façades. Most importantly, air-termination systems must be mounted at corners and edges.
The following three methods can be used to determine the arrangement and the position of the air-termination systems (**Figure 5.1.1**):

- Rolling sphere method
- Mesh method
- Protective angle method

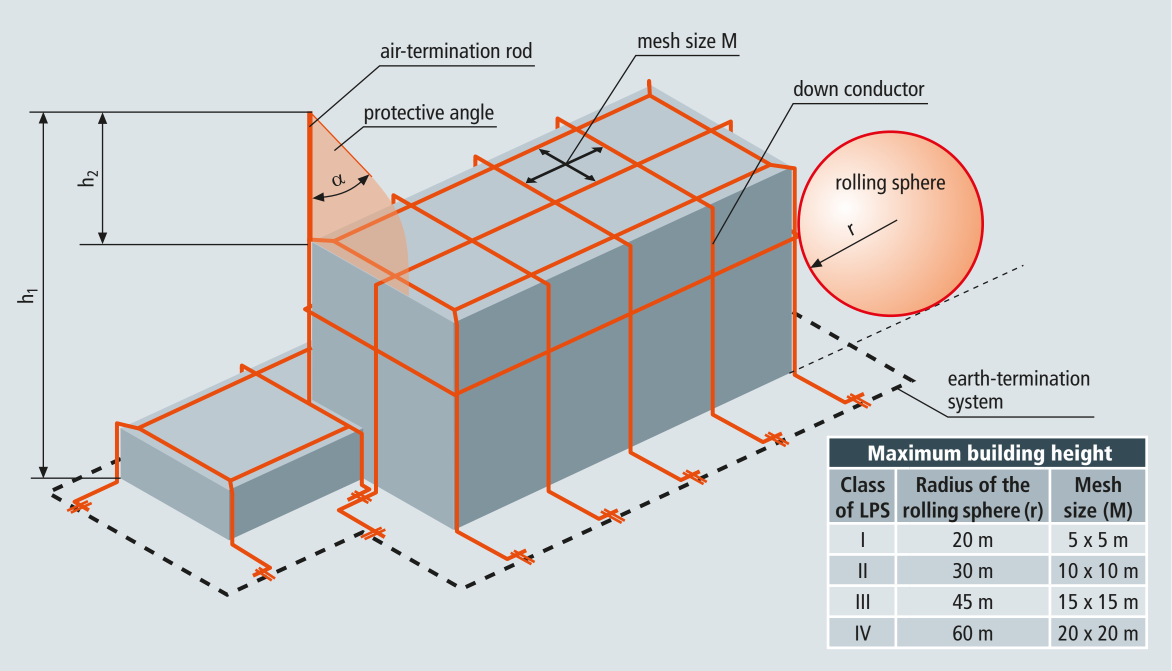
The rolling sphere method is the universal method of design particularly recommended for geometrically complicated applications.

The three different methods are described below.

5.1.1 Types of air-termination systems and design methods

Rolling sphere method – Electro-geometric model
For cloud-to-earth flashes, a downward leader grows step-by-step in a series of jerks from the cloud towards the earth. When the downward leader has got close to the earth within a few tens, to a few hundreds of metres, the electrical insulation strength of the air near the ground is exceeded. A further "leader" discharge similar to the downward leader begins to grow towards the head of the downward leader: The upward leader. This defines the point of strike of the lightning strike (**Figure 5.1.1.1**).

The starting point of the upward leader and hence the subsequent point of strike is determined mainly by the head of the



Maximum building height		
Class of LPS	Radius of the rolling sphere (r)	Mesh size (M)
I	20 m	5 x 5 m
II	30 m	10 x 10 m
III	45 m	15 x 15 m
IV	60 m	20 x 20 m

Figure 5.1.1 Method of designing air-termination systems for high buildings

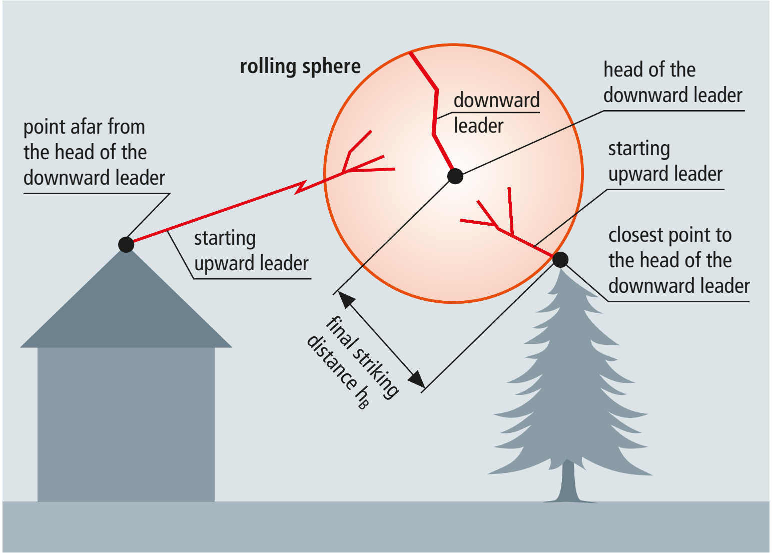


Figure 5.1.1.1 Starting upward leader defining the point of strike

A rolling sphere cannot only touch the steeple, but also the nave of the church at multiple points, as this model experiment shows. All these points are potential points of strike.

Figure 5.1.1.2 Model of a rolling sphere; source: Prof. Dr. A. Kern, Aachen

downward leader. The head of the downward leader can only approach the earth within a certain distance. This distance is defined by the continuously increasing electrical field strength of the ground as the head of the downward leader approaches. The smallest distance between the head of the downward leader and the starting point of the upward leader is called the final striking distance h_B (corresponds to the radius of the rolling sphere).

Immediately after the electrical insulation strength is exceeded at one point, the upward leader, which leads to the final strike and manages to cross the final striking distance, is formed. Observations of the protective effect of earth wires and pylons were used as the basis for the so-called **electro-geometric model**.

This is based on the hypothesis that the head of the downward leader approaches the objects on the ground, unaffected by anything, until it reaches the final striking distance.

The point of strike is then determined by the object closest to the head of the downward leader. The upward leader starting from this point "forces its way through" (**Figure 5.1.1.2**).

Classes of LPS and radius of the rolling sphere

As a first approximation, a proportionality exists between the peak value of the lightning current and the electrical charge stored in the downward leader. Furthermore, the electrical field strength of the ground as the downward leader approaches is also linearly dependent on the charge stored in the downward leader, to a first approximation. Thus there is a proportionality between the peak value I of the lightning current and the final striking distance h_B (= radius of the rolling sphere):

$$r = 10 \cdot I^{0.65}$$

r in m
I in kA

The protection of buildings against lightning is described in the IEC 62305-1 (EN 62305-1) standard. Among other things, this standard defines the classification into the individual lightning protection levels/classes of LPS and stipulates the resulting lightning protection measures.

It differentiates between four classes of LPS. Class of LPS I provides the most protection and a class of LPS IV, by comparison, the least. The interception effectiveness E_i of the air-termination systems is concomitant with the class of LPS, i.e. which percentage of the prospective lightning strikes is safely controlled by the air-termination systems. From this, the final striking distance and hence the radius of the rolling sphere is obtained. The relationships between lightning protection level/class of LPS, interception effectiveness of the air-termination systems, final striking distance/radius of the rolling sphere and current peak value are shown in **Table 5.1.1.1**.

Taking as a basis the hypothesis of the electro-geometric model that the head of the downward leader approaches the objects on the earth in an arbitrary way, unaffected by anything, until it reaches the final striking distance, a general method can be derived which allows the volume to be protected of

Lightning protection level LPL	Probabilities for the limits of the lightning current parameters		Radius of the rolling sphere (final striking distance h_B) r in m	Minimum peak value of current I in kA
	> minimum values	< maximum values		
IV	0.84	0.95	60	16
III	0.91	0.95	45	10
II	0.97	0.98	30	5
I	0.99	0.99	20	3

Table 5.1.1.1 Relation between lightning protection level, interception probability, final striking distance h_B and minimum peak value of current I; source: Table 5 of IEC 62305-1 (EN 62305-1)

any arrangement of objects to be investigated. A scale model (e.g. on a scale of 1:100) of the object to be protected, which includes the external contours and, where applicable, the air-termination systems, is required to carry out the rolling sphere method. Depending on the location of the object under investigation, it is also necessary to include the surrounding buildings and objects since these could act as "natural protection measures" for the object under examination.

Furthermore, a true-to-scale sphere with a radius corresponding to the final striking distance (depending on the class of LPS, the radius r of the rolling sphere must correspond true-to-scale to the radii 20, 30, 45 or 60 m) is required for the class of LPS. The centre of the rolling sphere used corresponds to the head of the downward leader towards which the respective upward leaders will approach.

The rolling sphere is now rolled around the object under examination and the contact points which represent potential points of strike are marked in each case. The rolling sphere is then rolled over the object in all directions. All contact points are marked again. All possible points of strike are thus shown on the model; it is also possible to determine the areas which can be hit by side flashes. The naturally protected volumes resulting from the geometry of the object to be protected and its surroundings can also be clearly seen. Air-termination conductors are not required at these points (**Figure 5.1.1.3**).

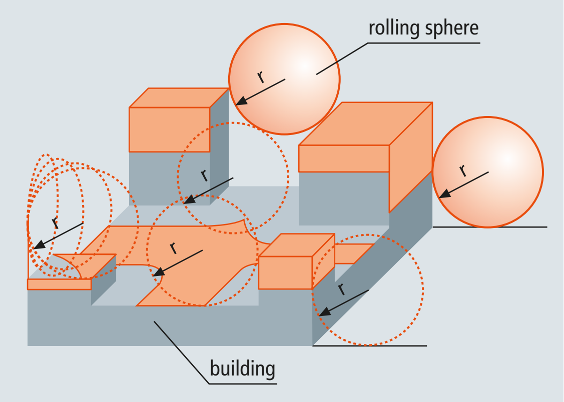


Figure 5.1.1.3 Schematic application of the rolling sphere method at a building with very irregular surface

However, it must be observed that lightning footprints have also been found on steeples in places which were not directly touched as the rolling sphere rolled over. This, among other things, is due to the fact that in the event of multiple lightning strikes, the base of the lightning strike moves because of the wind conditions. Consequently, an area of approximately one metre can come up around the point of strike determined where lightning strikes can also occur.

Example 1: New administration building in Munich

At the design stage of the new administration building, the complex geometry led to the decision to use the rolling sphere method for identifying the areas threatened by lightning strikes.

This was possible because an architectural model of the new building was available on a scale of 1:100.

It was determined that class of LPS I was required, i.e. the radius of the rolling sphere in the model was 20 cm (**Figure 5.1.1.4**).

The points where the rolling sphere touches parts of the building can be hit by a direct lightning strike with a corresponding minimum current peak value of 3 kA (**Figure 5.1.1.5**). Consequently, adequate air-termination systems were required at these points. If, in addition, electrical installations were localised at these points or in their immediate vicinity (e.g. on the roof of the building), additional air-termination measures were taken at these locations.

The application of the rolling sphere method meant that air-termination systems were not installed where protection was not required. On the other hand, at locations where the pro-

Figure 5.1.1.4 New administration building: Model with rolling sphere according to class of LPS I; source: WBG Wiesinger

Figure 5.1.1.5 New DAS administration building: Areas threatened by lightning strikes for class of LPS I, top view (excerpt); source: WBG Wiesinger

Figure 5.1.1.6 Aachen Cathedral: Model with surroundings and rolling spheres of classes of LPS II and III; source: Prof. Dr. A. Kern, Aachen

tection against direct lightning strikes needed to be improved, this could be done (**Figure 5.1.1.5**).

Example 2: Aachen Cathedral

The cathedral stands in the middle of the old quarter of Aachen surrounded by several high buildings. Adjacent to the cathedral is a scale model (1:100) whose purpose is to make it easier for visitors to understand the geometry of the building.

The buildings surrounding Aachen Cathedral provide a degree of natural protection against lightning strikes. To demonstrate the natural protection and the effectiveness of lightning protection measures, a model of the most important elements of the surrounding buildings was made on the same scale (1:100) (**Figure 5.1.1.6**).

Figure 5.1.1.6 also shows rolling spheres for classes of LPS II and III (i.e. with radii of 30 cm and 45 cm) on the model.
The aim here was to demonstrate the increasing requirements on the air-termination systems as the radius of the rolling sphere decreases, i.e. which areas of Aachen Cathedral had additionally to be considered at risk from lightning strikes if a class of LPS II providing a higher degree of protection was used.
The rolling sphere with the smaller radius (according to a class of LPS providing a higher lightning protection level) naturally also touches the model at all points already touched by the rolling sphere with the larger radius. It is thus only necessary to determine the additional contact points.
As demonstrated, the sag of the rolling sphere is decisive when dimensioning the air-termination system for a structure or a roof-mounted structure.

The following formula can be used to calculate the penetration depth p of the rolling sphere when the rolling sphere rolls “on rails”, for example. This can be achieved by using two spanned wires, for example.

$$p = r - \sqrt{r^2 - \left(\frac{d}{2}\right)^2}$$

r	Radius of the rolling sphere
d	Distance between two air-termination rods or two parallel air-termination conductors

Figure 5.1.1.7 illustrates this approach.
Air-termination rods are frequently used to protect the surface of a roof or roof-mounted structures against a direct lightning strike. The square arrangement of the air-termination rods, over which no cable is generally spanned, means that the sphere

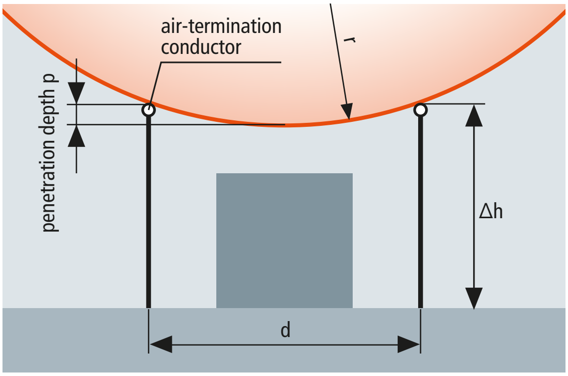


Figure 5.1.1.7 Penetration depth p of the rolling sphere

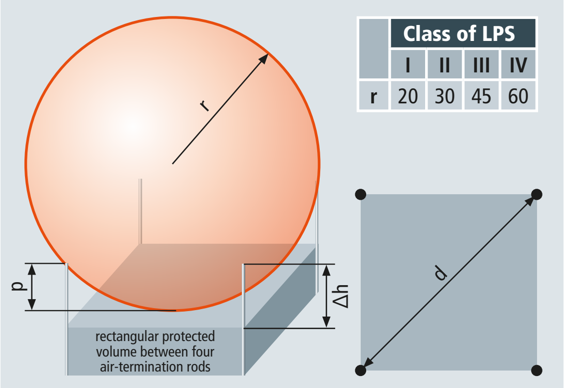


Figure 5.1.1.8 Air-termination system for roof-mounted structures and their protected volume

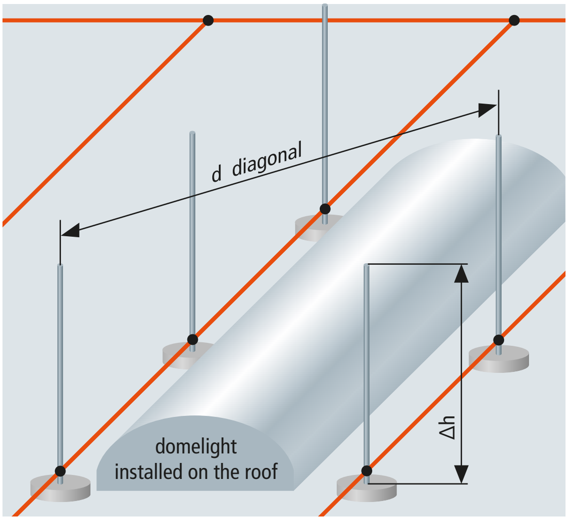


Figure 5.1.1.9 Calculation of Δh for several air-termination rods according to the rolling sphere method

d	**Sag of the rolling sphere [m] (rounded up)**			
Distance between the air-termination rods [m]	**Class of LPS with rolling sphere radius [m]**			
	I (20 m)	**II (30 m)**	**III (45 m)**	**IV (60 m)**
2	0.03	0.02	0.01	0.01
4	0.10	0.07	0.04	0.03
6	0.23	0.15	0.10	0.08
8	0.40	0.27	0.18	0.13
10	0.64	0.42	0.28	0.21
12	0.92	0.61	0.40	0.30
14	1.27	0.83	0.55	0.41
16	1.67	1.09	0.72	0.54
18	2.14	1.38	0.91	0.68
20	2.68	1.72	1.13	0.84
23	3.64	2.29	1.49	1.11
26	4.80	2.96	1.92	1.43
29	6.23	3.74	2.40	1.78
32	8.00	4.62	2.94	2.17
35	10.32	5.63	3.54	2.61

Table 5.1.1.2 Sag of the rolling sphere in case of two air-termination rods or two parallel air-termination conductors

does not “roll on rails” but “sits deeper” instead, thus increasing the penetration depth of the sphere (**Figure 5.1.1.8**).

The height of the air-termination rods Δh must always be greater than the value of the penetration depth p determined, and hence greater than the sag of the rolling sphere. This additional height of the air-termination rod ensures that the rolling sphere does not touch the object to be protected.

Another way of determining the height of the air- termination rods is to use **Table 5.1.1.2**. The penetration depth of the rolling sphere is governed by the largest distance of the air-termination rods from each other. Using the greatest distance, the penetration depth p (sag) can be read off from the table. The air-termination rods must be dimensioned according to the height of the roof-mounted structures (in relation to the location of the air-termination rod) and also the penetration depth (**Figure 5.1.1.9**).

If, for example, a total air-termination rod height of 1.15 m is either calculated or obtained from the table, an air-termination rod with a standard length of 1.5 m is normally used.

Class of LPS	Mesh size
I	5 x 5 m
II	10 x 10 m
III	15 x 15 m
IV	20 x 20 m

Table 5.1.1.3 Mesh size

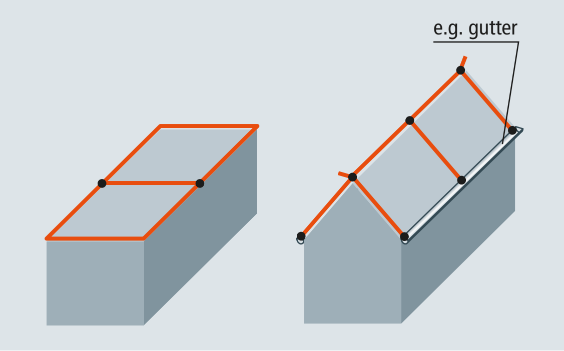


Figure 5.1.1.10 Meshed air-termination system

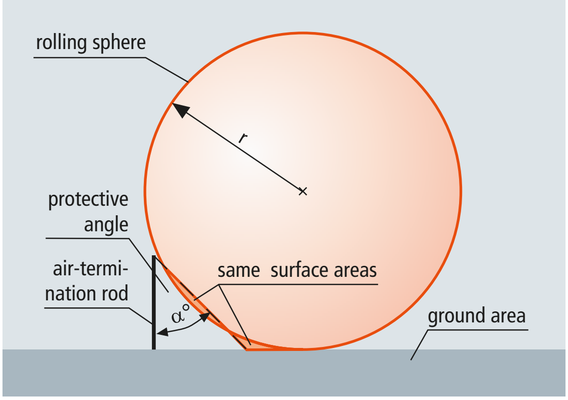


Figure 5.1.1.11 Protective angle and comparable radius of the rolling sphere

Mesh method

A "meshed" air-termination system can be used universally regardless of the height of the building and shape of the roof. A meshed air-termination network with a mesh size according to the class of LPS is arranged on the roofing (**Table 5.1.1.3**).

To simplify matters, the sag of the rolling sphere is assumed to be zero for a meshed air-termination system.
By using the ridge and the outer edges of the building as well as the metal natural parts of the building serving as an air-termination system, the individual meshes can be positioned as desired.
The air-termination conductors on the outer edges of the structure must be laid as close to the edges as possible.

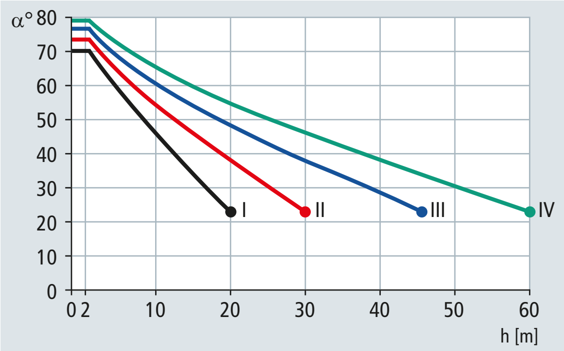


Figure 5.1.1.12 Protective angle α as a function of height h depending on the class of LPS

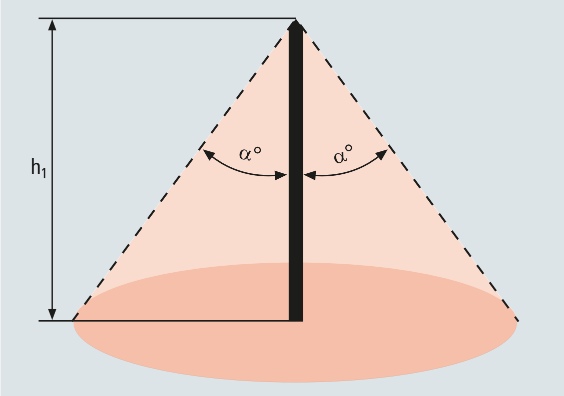


Figure 5.1.1.13 Cone-shaped protected volume

The metal capping of the roof parapet can serve as an air-termination conductor and / or a down conductor if the required minimum dimensions for natural components of the air-termination system are complied with (**Figure 5.1.1.10**).

Protective angle method

The protective angle method is derived from the electric-geometric lightning model. The protective angle is determined by the radius of the rolling sphere. The protective angle, which is comparable with the radius of the rolling sphere, is given when a slope intersects the rolling sphere in such a way that the resulting areas have the same size (**Figure 5.1.1.11**).
This method must be used for buildings with symmetrical dimensions (e.g. steep roof) or roof-mounted structures (e.g. antennas, ventilation pipes).

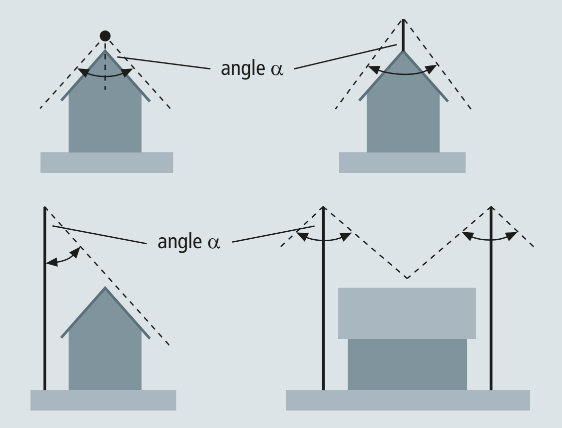
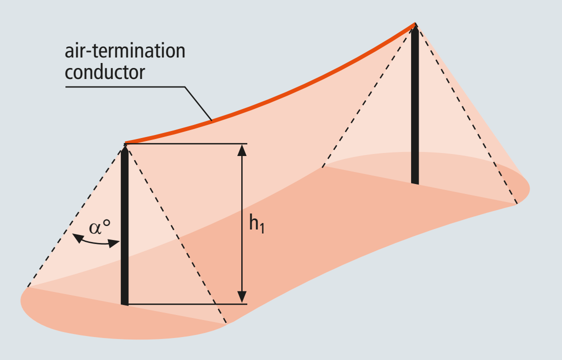
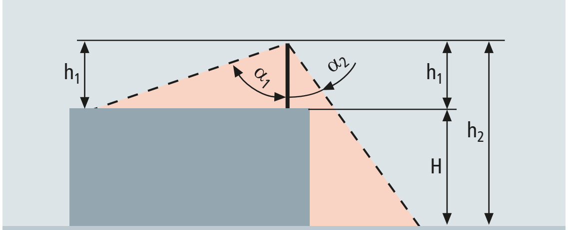


Figure 5.1.1.14 Example of air-termination systems with protective angle α



Angle α depends on the class of LPS and the height of the air-termination conductor above ground

Figure 5.1.1.15 Volume protected by an air-termination conductor



h_1: Physical height of the air-termination rod

Note:
Protective angle α_1 refers to the height of the air-termination system h_1 above the roof surface to be protected (reference plane).
Protective α_2 refers to the height $h_2 = h_1 + H$, where the earth surface is the reference plane.

Figure 5.1.1.16 Volume protected by an air-termination rod

The protective angle depends on the class of LPS and the height of the air-termination system above the reference plane (**Figure 5.1.1.12**).

Air-termination conductors, air-termination rods, masts and wires should be arranged in such a way that all parts of the structure to be protected are situated within the protected volume of the air-termination system.

The protected volume can be "cone-shaped" or "tent-shaped", if a cable, for example, is spanned over it (**Figures. 5.1.1.13 to 5.1.1.15**).
If air-termination rods are installed on the surface of the roof to protect roof-mounted structures, the protective angle α can be different. In **Figure 5.1.1.16**, the reference plane for protective angle α_1 is the roof surface. The protective angle α_2 has the ground as its reference plane and therefore the angle α_2 according to **Figure 5.1.1.12** and **Table 5.1.1.4** is less than α_1.
Table 5.1.1.4 provides the corresponding protective angle for each class of LPS and the corresponding distance (protected volume).

Protective angle method for isolated air-termination systems on roof-mounted structures

Special problems occur when roof-mounted structures, which are often installed at a later date, protrude from the protected volumes of the mesh. If, in addition, these roof-mounted structures contain electrical or electronic equipment such as roof-mounted fans, antennas, measuring systems or TV cameras, additional protection measures are required.

If such equipment is connected directly to the external LPS, partial currents are conducted into the building in the event of a lightning strike. This could result in the destruction of surge-sensitive equipment. Direct lightning strikes to such structures protruding above the roof can be prevented by isolated air-termination systems.
Air-termination rods as shown in **Figure 5.1.1.17** are suitable for protecting smaller roof-mounted structures (with electrical equipment).
They form a "cone-shaped" protected volume and thus prevent a direct lightning strike to the roof-mounted structure.

The separation distance s must be taken into account when dimensioning the height of the air- termination rod (see chapter 5.6).

Isolated and non-isolated air-termination systems

When designing the external lightning protection system of a building, we distinguish between two types of air-termination system:

Height of the air-termination rod h in m	Class of LPS I		Class of LPS II		Class of LPS III		Class of LPS IV	
	Angle α	Distance a in m	Angle α	Distance a in m	Angle α	Distance a in m	Angle α	Distance a in m
1	71	2.90	74	3.49	77	4.33	79	5.14
2	71	5.81	74	6.97	77	8.66	79	10.29
3	66	6.74	71	8.71	74	10.46	76	12.03
4	62	7.52	68	9.90	72	12.31	74	13.95
5	59	8.32	65	10.72	70	13.74	72	15.39
6	56	8.90	62	11.28	68	14.85	71	17.43
7	53	9.29	60	12.12	66	15.72	69	18.24
8	50	9.53	58	12.80	64	16.40	68	19.80
9	48	10.00	56	13.34	62	16.93	66	20.21
10	45	10.00	54	13.76	61	18.04	65	21.45
11	43	10.26	52	14.08	59	18.31	64	22.55
12	40	10.07	50	14.30	58	19.20	62	22.57
13	38	10.16	49	14.95	57	20.02	61	23.45
14	36	10.17	47	15.01	55	19.99	60	24.25
15	34	10.12	45	15.00	54	20.65	59	24.96
16	32	10.00	44	15.45	53	21.23	58	25.61
17	30	9.81	42	15.31	51	20.99	57	26.18
18	27	9.17	40	15.10	50	21.45	56	26.69
19	25	8.86	39	15.39	49	21.86	55	27.13
20	23	8.49	37	15.07	48	22.21	54	27.53
21			36	15.26	47	22.52	53	27.87
22			35	15.40	46	22.78	52	28.16
23			36	16.71	47	24.66	53	30.52
24			32	15.00	44	23.18	50	28.60
25			30	14.43	43	23.31	49	28.76
26			29	14.41	41	22.60	49	29.91
27			27	13.76	40	22.66	48	29.99
28			26	13.66	39	22.67	47	30.03
29			25	13.52	38	22.66	46	30.03
30			23	12.73	37	22.61	45	30.00
31					36	22.52	44	29.94
32					35	22.41	44	30.90
33					35	23.11	43	30.77
34					34	22.93	42	30.61
35					33	22.73	41	30.43
36					32	22.50	40	30.21
37					31	22.23	40	31.50
38					30	21.94	39	30.77
39					29	21.62	38	30.47
40					28	21.27	37	30.14
41					27	20.89	37	30.90
42					26	20.48	36	30.51
43					25	20.05	35	30.11
44					24	19.59	35	30.81
45					23	19.10	34	30.35
46							33	29.87
47							32	29.37
48							32	29.99
49							31	29.44
50							30	28.87
51							30	29.44
52							29	28.82
53							28	28.18
54							27	27.51
55							27	28.02
56							26	27.31
57							25	26.58
58							25	27.05
59							24	26.27
60							23	25.47

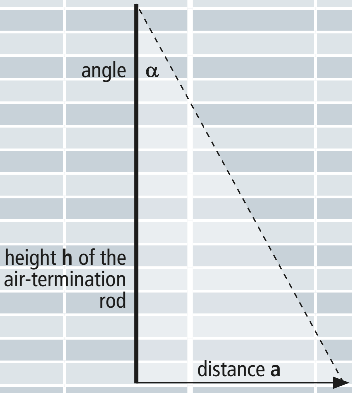


Table 5.1.1.4 Protective angle α depending on the class of LPS

Figure 5.1.1.17 Protection of small-sized roof-mounted structures against direct lightning strikes by means of air-termination rods

Figure 5.1.1.18 Gable roof with conductor holder

Figure 5.1.1.19 Flat roof with air-termination rods and conductor holders: Protection of the domelights

- Isolated
- Non-isolated

The two types can be combined.

The air-termination systems of a **non-isolated** external lightning protection system of a structure can be installed in the following ways:

- If the roof is made of non-flammable material, the conductors of the air-termination system can be installed on the surface of the structure (e.g. gable or flat roof). Non-flammable building materials are commonly used. The components of the external lightning protection system can therefore be mounted directly on the structure (**Figures 5.1.1.18 and 5.1.1.19**).
- If the roof is made of highly flammable material (class B 3 building material, see Supplement 1 of the German DIN EN 62305-3 standard) e.g. thatched roofs, the distance between the flammable parts of the roof and the air-termination rods, air-termination conductors or air-termination meshes of the air-termination system must not be less than 0.4 m. Highly flammable parts of the structure to be protected must not be in direct contact with parts of the external lightning protection system. Neither may they be located under the roofing, which can be punctured in the event of a lightning strike (see also chapter 5.1.5 Thatched roofs).

Isolated air-termination systems protect the complete structure against a direct lightning strike by means of air-termination rods, air-termination masts or masts with cables spanned over them. When installing the air-termination systems, the separation distance s from the building must be maintained (**Figures 5.1.1.20 and 5.1.1.21**).

Isolated air-termination systems are frequently used when the roof is covered with flammable material (e.g. thatched roof) or also for systems located in hazardous areas (e.g. tanks) (see also chapter 5.1.5 "Air-termination system for buildings with thatched roofs").

A further method of designing isolated air-termination systems is to use electrically insulating materials such as GRP (glass-

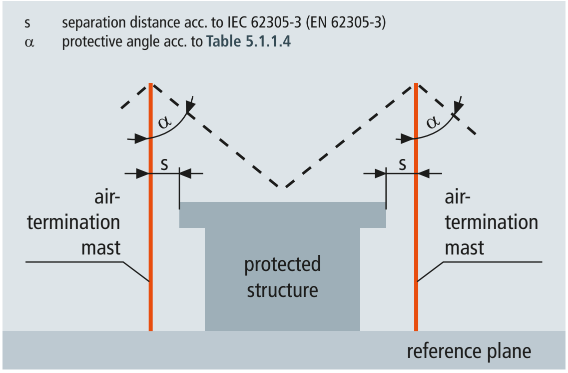


Figure 5.1.1.20 Isolated external lightning protection system with two separate air-termination masts according to the protective angle method: Projection on a vertical surface

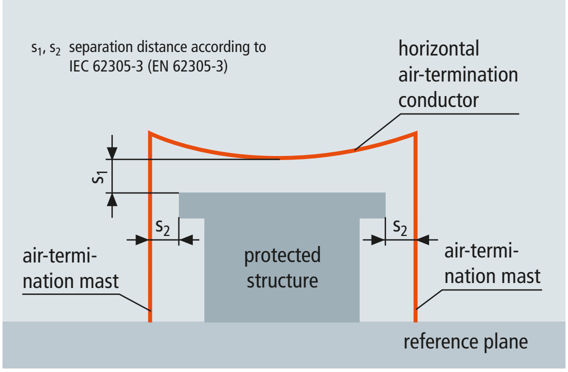


Figure 5.1.1.21 Isolated external lightning protection system consisting of two separate air-termination masts connected by a horizontal air-termination conductor: Projection on a vertical surface via the two masts (vertical section)

Class of LPS	Material	Thickness [a] t [mm]	Thickness [b] t' [mm]
I to IV	Lead	–	2.0
	Steel (stainless, galvanised)	4	0.5
	Titanium	4	0.5
	Copper	5	0.5
	Aluminium	7	0.65
	Zinc	–	0.7

[a] t prevents puncture

[b] t` only for sheet metal if puncture, overheating and ignition does not have to be prevented

Table 5.1.1.5 Minimum thickness of sheet metal

fibre reinforced plastic) to secure the air-termination systems (air-termination rods, conductors or cables) at the object to be protected.

This form of isolation can be limited to local use or applied to whole parts of the installation. It is often used for roof-mounted structures such as ventilation systems or heat exchangers which have an electrically conductive connection into the building (see also chapter 5.1.8).

Natural components of air-termination systems

Metal structural parts such as roof parapets, gutters, railings or claddings can be used as natural components of an air-termination system.

If a building has a steel frame construction with a metal roof and façade made of conductive material, these parts can be used for the external lightning protection system, under certain circumstances.

Sheet metal claddings at or on top of the building to be protected can be used if the electrical connection between the different parts is permanent. These permanent electrical connections can be made by e.g. soldering, welding, pressing, screwing or riveting. Qualified persons may also establish connections by means of soft-soldering. The continuously soldered surface of the connection must be at least 10 cm^2 with a width of at least 5 mm.

If there is no electrical connection, these elements must be additionally connected e.g. by means of bridging braids or bridging cables.

If the thickness of the sheet metal is not less than the value t' in **Table 5.1.1.5** and if melting of the sheets at the point of strike or the ignition of flammable material under the cladding does not have to be taken into account, such sheets can be used as an air-termination system. The material thicknesses are not distinguished according to the class of LPS.

If it is, however, necessary to take precautionary measures against melting or intolerable heating at the point of strike, the thickness of the sheet metal must not be less than value t in **Table 5.1.1.5**.

The required thicknesses t of the materials can generally not be complied with, for example, in case of metal roofs.

For pipes or containers, however, it is possible to comply with these minimum thicknesses (wall thicknesses). If, though, the temperature rise (heating) on the inside of the pipe or tank represents a hazard for the medium contained therein (risk of fire or explosion), these must not be used as air-termination systems (see also chapter 5.1.4).

If the requirements concerning the appropriate minimum thickness are not met, the components, e.g. pipes or containers, must be situated in an area protected from direct lightning strikes.

A thin coat of paint, 1 mm bitumen or 0.5 mm PVC, cannot be regarded as insulation in the event of a direct lightning strike. Such coatings are punctured when subjected to the high energies deposited during a direct lightning strike.

If conductive parts are located on the surface of the roof, they can be used as a natural air-termination system if there is no conductive connection into the building.

By connecting e.g. pipes or incoming electrical conductors, partial lightning currents can enter the structure and interfere with or even destroy sensitive electrical / electronic equipment.

Figure 5.1.2.1 Air-termination system on a gable roof

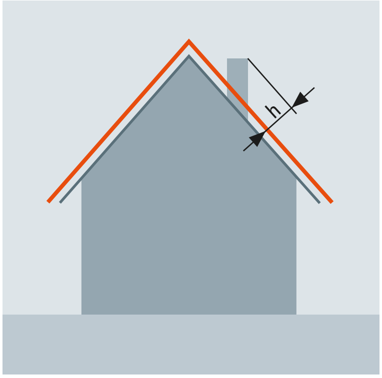


Figure 5.1.2.2 Height of a roof-mounted structure made of non-conductive material (e.g. PVC), h ≤ 0.5 m

Figure 5.1.2.3 Additional air-termination system for vent pipes

In order to prevent these partial lightning currents, isolated air-termination systems must be installed for such roof-mounted structures.
The isolated air-termination system can be designed using the rolling sphere or protective angle method. An air-termination system with a mesh size according to the class of LPS used can be installed if the whole arrangement is elevated (isolated) by the required separation distance s.

A universal component system for installing isolated air-termination systems is described in chapter 5.1.8.

5.1.2 Air-termination systems for buildings with gable roofs

Air-termination systems on roofs include all metal components, e.g. air-termination conductors, air-termination rods, air-termination tips.
The parts of the structure typically hit by lightning strikes such as gable peaks, chimneys, ridges and arrises, the edges of gables and eaves, parapets and other protruding structures mounted on the roof must be equipped with air-termination systems.

Normally, a meshed air-termination network is installed on the surface of gable roofs with a mesh size according to the class of LPS (e.g. mesh size of 15 m x 15 m for class of LPS III) (**Figure 5.1.2.1**).
By using the ridge and the outer edges as well as the metal parts serving as an air-termination system, the individual meshes can be positioned as desired. The air-termination conductors on the outer edges of the building must be installed as close to the edges as possible.

Generally, the metal gutter is used for closing the "mesh" of the air-termination system on the roof surface. If the gutter itself is connected in such a way that it is conductive, a gutter clamp is mounted at the cross point between the air-termination system and the gutter.

Roof-mounted structures made of **non-conductive** material (e.g. PVC vent pipes) are considered to be sufficiently protected if they do not protrude more than h = 0.5 m from the plane of the mesh (**Figure 5.1.2.2**).

If such a roof-mounted structure protrudes more than h = 0.5 m, it must be equipped with an air-termination system (e.g. air-termination tip) and connected to the nearest air- termination conductor. To this end, a wire with a diameter of 8 mm up to a maximum free length of 0.5 m can be used as shown in **Figure 5.1.2.3**.

Metal roof-mounted structures without conductive connection into the structure do not have to be connected to the air-termination system if all of the following conditions are fulfilled:

- Roof-mounted structures may protrude a maximum distance of 0.3 m from the roof level
- Roof-mounted structures may have a maximum enclosed area of 1 m^2 (e.g. dormers)
- Roof-mounted structures may have a maximum length of 2 m (e.g. sheet metal roofing)

Only if all three conditions are met, no connection is required. Furthermore, the separation distance to the air-termination and down conductors must be maintained for the above mentioned conditions (**Figure 5.1.2.4**).

Figure 5.1.2.4 Building with photovoltaic system and sufficient separation distance; source: Blitzschutz Wettingfeld, Krefeld

Figure 5.1.2.5 Antenna with air-termination rod and spacer

Air-termination rods for chimneys must be installed to ensure that the entire chimney is located in the protected volume. The protective angle method is used to dimension the air-termination rods.
If the chimney is brick-built or constructed with preformed sections, the air-termination rod can be directly mounted on the chimney.
If there is a metal pipe in the interior of the chimney, e.g. if an old building is renovated, the separation distance to this conductive part must be maintained. To this end, isolated air-termination systems are used and the air-termination rods are installed by means of spacers. The metal pipe must be connected to the equipotential bonding system.

The assembly to protect parabolic antennas is similar to that to protect chimneys with a metal pipe.

In the event of a direct lightning strike to antennas, partial lightning currents can enter the building to be protected via the shields of the coaxial cables and cause the interference

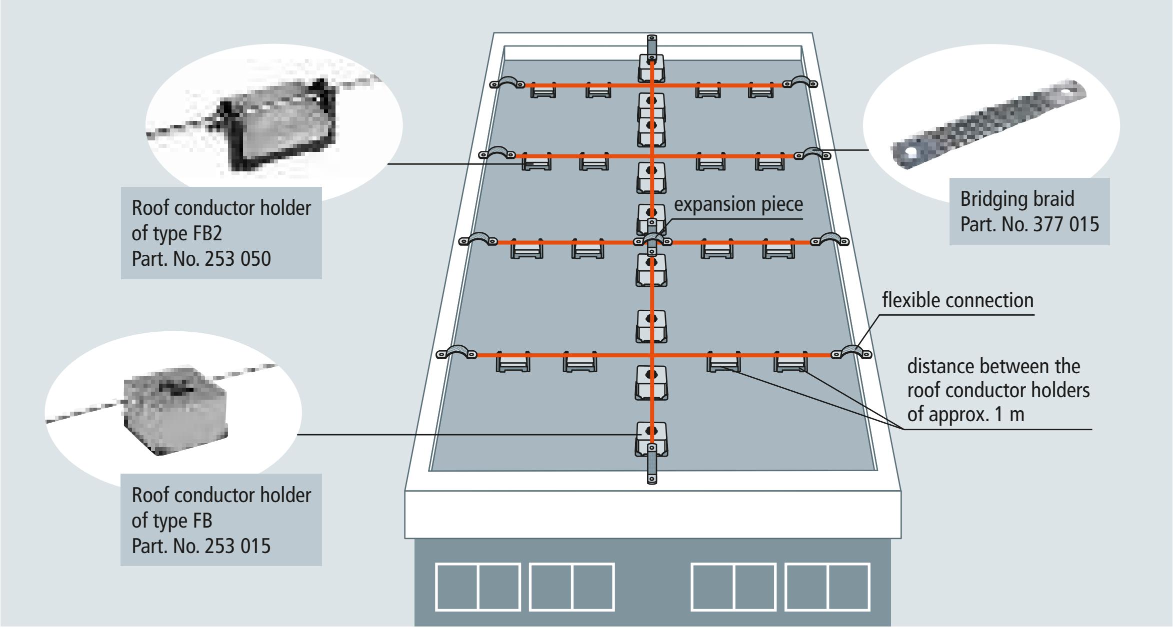


Figure 5.1.3.1 Air-termination system on a flat roof

and destruction described before. To prevent this, antennas are equipped with isolated air-termination systems (e.g. air-termination rods) (**Figure 5.1.2.5**).

Air-termination systems on the ridge have a tent-shaped protected volume (according to the protective angle method). The angle depends on the height above the reference plane (e.g. surface of the earth) and the selected class of LPS.

5.1.3 Air-termination systems for buildings with flat roofs

The mesh method is used to design an air-termination system for buildings with flat roofs (**Figure 5.1.3.1**). A meshed air-termination network with a mesh size according to the class of LPS is arranged on the roofing (**Table 5.1.1.3**).

Figure 5.1.3.2 illustrates the practical application of the meshed air-termination system in combination with air-termination rods to protect the structures mounted on the roof, e.g. domelights, photovoltaic modules or fans. Chapter 5.1.8 shows how to deal with these roof-mounted structures.

Roof conductor holders on flat roofs are laid at intervals of approximately 1 m. The air-termination conductors are connected to the roof parapet which is used as a natural component of the air-termination system. As the temperature changes, so does the length of the materials used for the roof parapet. Therefore, the individual segments must be equipped with "slide sheets".

If the roof parapet is used as an air-termination system, these individual segments must be permanently interconnected so as to be electrically conductive without restricting their ability to expand. This can be achieved by means of bridging braids, brackets or cables (**Figure 5.1.3.3**).

The changes in length resulting from changes in temperature must also be taken into account for air-termination conductors and down conductors (see chapter 5.4.1).

A lightning strike to the roof parapet can melt the material used. If this is not acceptable, an additional air-termination system, e.g. with air-termination tips, must be installed using the rolling sphere method (**Figure 5.1.3.4**).

Conductor holders for flat roofs, homogeneously welded

Under wind conditions, roof sheetings can horizontally move across the roof surface if they are not properly fixed/laid on the surface. To ensure that conductor holders for air-termination systems are not displaced on the smooth surface, the air-termination conductor must be fixed. Conventional roof

Figure 5.1.3.2 Practical use of air-termination rods

Figure 5.1.3.3 Bridging braid used for the roof parapet

Figure 5.1.3.4 Example how to protect the metal capping of the roof parapet if melting is not allowed (front view)

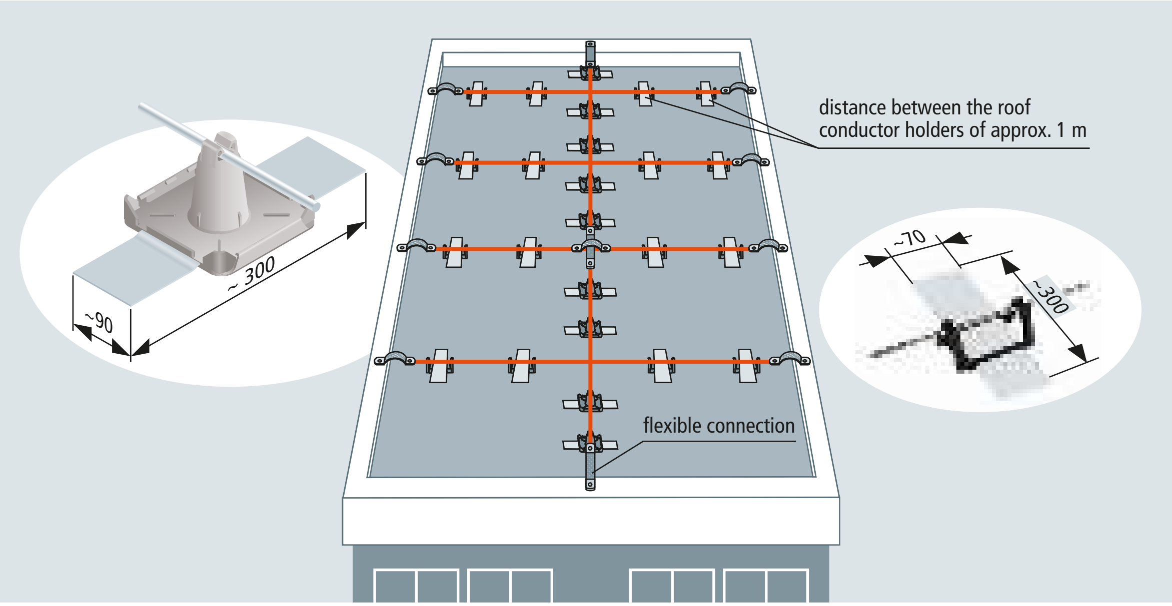


Figure 5.1.3.5 Plastic flat roof sheetings – Roof conductor holder of type KF / KF2

conductor holders cannot be permanently bonded to roof sheetings since they usually do not permit the application of adhesives.

A simple and safe way of fixing air-termination conductors is to use roof conductor holders of type KF in combination with strips (strips must be cut to the desired length) made of the roof sheeting material. The strip is clamped into the plastic holder and both sides are welded onto the sealing. Holder and strip should be positioned directly next to a roof sheeting joint at a distance of approximately 1 m. The membrane strip is welded to the roof sheeting according to the roof sheeting manufacturer's instructions. This prevents air-termination conductors from being displaced on flat roofs.

If the slope of the roof is greater than 5 °, every roof conductor holder must be fixed, if it is smaller than 5 °, only every second conductor holder must be fixed. If the slope of the roof is greater than 10 °, the roof conductor holder may not be suitable any more depending on the installation situation.

If the plastic roof sheetings are mechanically fixed, the roof conductor holders must be arranged in the immediate vicinity of the mechanical fixing.

When carrying out this work, it must be observed that the roofer is liable for welding and bonding work on the sealing.

Therefore, the work may only be carried out in agreement with the roofer responsible for the particular roof or must be carried out by himself (**Figure 5.1.3.5**).

5.1.4 Air-termination systems on metal roofs

Modern industrial and commercial buildings often have metal roofs and façades. The metal sheets and plates on the roofs are usually 0.7 to 1.2 mm thick.

Figure 5.1.4.1 shows an example of the construction of a metal roof. When such a roof is hit by a direct lightning strike, melting or vaporisation at the point of strike can leave a hole in the roof. The size of the hole depends on the energy of the lightning strike and the material properties of the roof (e.g. thickness). The biggest problem is the subsequent damage, e.g. ingress of moisture, at this point. Days or weeks can pass before this damage is noticed. The roof insulation gets damp and / or the ceiling gets wet and is thus no longer rainproof.

One example of damage which was assessed using the Siemens Lightning Information Service (Blitz-Informations Dienst von Siemens (BLIDS)) illustrates this problem (**Figure 5.1.4.2**). A current of approximately 20,000 A struck the sheet metal and left a hole there (**Figure 5.1.4.2: Detail A**). Since the sheet metal was not earthed by a down conductor, flashover to natural metal parts in the wall occurred in the area around the fascia (**Figure 5.1.4.2: Detail B**) which also left a hole.

To prevent such kind of damage, a suitable external lightning protection system with lightning current carrying wires and clamps must be installed even on a “thin” metal roof. The

Figure 5.1.4.1 Types of metal roofs, e.g. roofs with round standing seam

Figure 5.1.4.2 Example of damage: Sheet metal

IEC 62305-3 (EN 62305-3) lightning protection standard clearly illustrates the risk for metal roofs. Where an external lightning protection system is required, the metal sheets must have the minimum values stated in **Table 5.1.1.5**.

The thicknesses t are not relevant for roofing materials. Metal sheets with a thickness t' may only be used as a natural air-termination system if puncture, overheating and melting is accepted. The owner of the structure must agree to accept this type of roof damage since the roof will no longer be rainproof.

If the owner does not accept damage to the roof in the event of a lightning strike, a separate air-termination system must be installed on a metal roof so that the rolling sphere (radius r according to the class of LPS) does not touch the metal roof (**Figure 5.1.4.3**).

In this case, an air-termination system with many air-termination tips is recommended.

The heights of air-termination tips in **Table 5.1.4.1** have proven effective in practice, regardless of the class of LPS.

When fixing the conductors and air-termination tips, no holes may be drilled into the metal roof. A number of conductor holders is available for the different types of metal roofs (round standing seam, standing seam, trapezoidal). **Figure 5.1.4.4a** shows adequate conductors for a metal roof with round standing seam. If conductor holders with lightning current carrying clamp are used, an air-termination tip can be directly fixed.

It must be observed that e.g. on a trapezoidal roof the conductor in the conductor holder located at the highest point of the roof must be fixed, whereas the conductors in all other conductor holders must be routed loosely due to the length compensation resulting from the changes in temperature (**Figure 5.1.4.4b**).

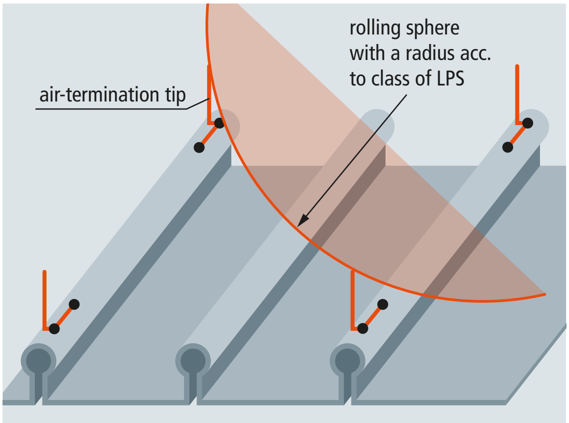
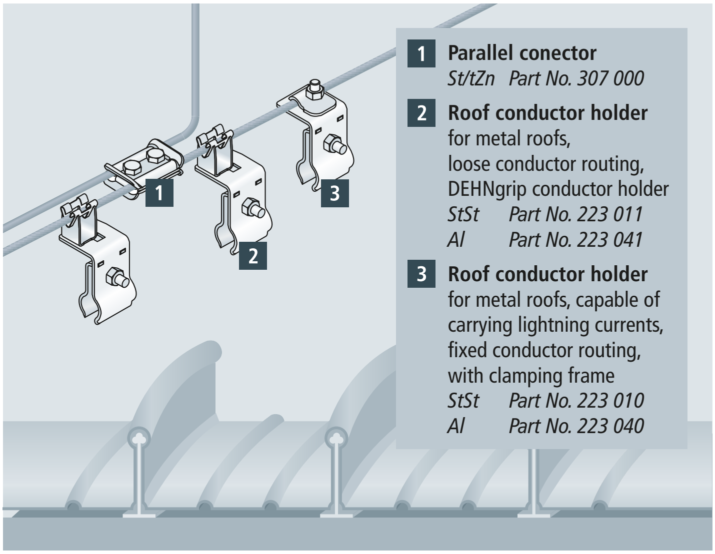


Figure 5.1.4.3 Air-termination system on a metal roof – Protection against puncture

Suitable for all classes of LPS	
Distance of the horizontal conductors	**Height of the air-termination tip*)**
3 m	0.15 m
4 m	0.25 m
5 m	0.35 m
6 m	0.45 m
*) recommended values	

Table 5.1.4.1 Lightning protection for metal roofs – Height of the air-termination tips

Figure 5.1.4.5 shows a conductor holder with fixed conductor routing and an air-termination tip on a trapezoidal roof. To reliably prevent the ingress of moisture, the conductor holder must be hooked into the fixing screw above the cover plate for the drill hole.



1 **Parallel conector**
St/tZn Part No. 307 000

2 **Roof conductor holder**
for metal roofs,
loose conductor routing,
DEHNgrip conductor holder
StSt Part No. 223 011
Al Part No. 223 041

3 **Roof conductor holder**
for metal roofs, capable of
carrying lightning currents,
fixed conductor routing,
with clamping frame
StSt Part No. 223 010
Al Part No. 223 040

Figure 5.1.4.4a Conductor holders for metal roofs – Round standing seam

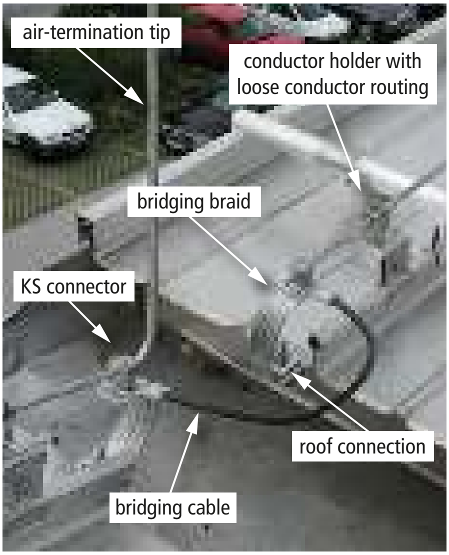


Figure 5.1.4.4b Conductor holder for metal roofs – Round standing seam

Figure 5.1.4.5 Sample construction o a trapezoidal sheet roof, conductor holder with clamping frame

Figure 5.1.4.6 Sample construction on a standing seam roof

Figure 5.1.4.7 Air-termination rod for a domelight on a round standing seam roof

Figure 5.1.4.6 shows a conductor holder with loose conductor routing on a standing seam roof.

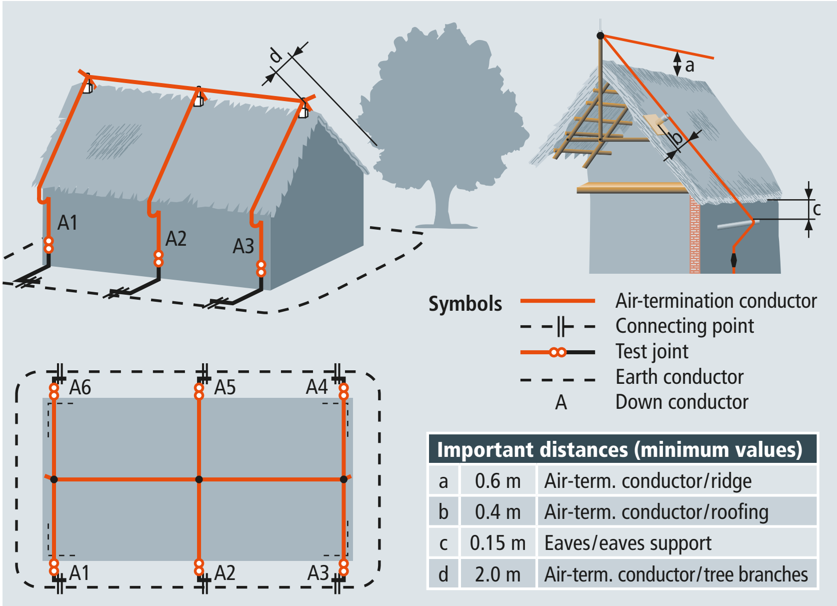
Figure 5.1.4.6 also shows the current carrying connection to the standing seam roof at the edge of the roof. Unprotected installations protruding above the roof such as domelights and smoke vents are exposed to lightning strikes. In order to prevent these installations from being struck by direct lightning strikes, air-termination rods must be installed next to the installations protruding above the roof (**Figure 5.1.4.7**). The height of the air- termination rod depends on the protective angle α.

5.1.5 Air-termination system for buildings with thatched roof

In general, class of LPS III is suited for such a structure. In individual cases, a risk analysis based on IEC 62305-2 (EN 62305-2) can be performed.

Section 4.3 of Supplement 2 of the German DIN EN 62305-3 standard places special requirements on the installation of the air-termination system for buildings with thatched roof.

The air-termination conductors on such roofs made of thatch, straw or reed must be fastened across insulating supports so



Important distances (minimum values)		
a	0.6 m	Air-term. conductor/ridge
b	0.4 m	Air-term. conductor/roofing
c	0.15 m	Eaves/eaves support
d	2.0 m	Air-term. conductor/tree branches

Figure 5.1.5.1 Air-termination system for buildings with thatched roofs

that they are free to move. Certain distances must also be maintained around the eaves.

When a lightning protection system is installed on a roof at a later date, the distances must be increased so that when re-roofing is carried out, the necessary minimum distances are maintained at any time.

For a class of LPS III, the typical distance of the down conductors is 15 m.

The exact distance of the down conductors from each other can be determined by calculating the separation distance s in accordance with IEC 62305-3 (EN 62305-3).

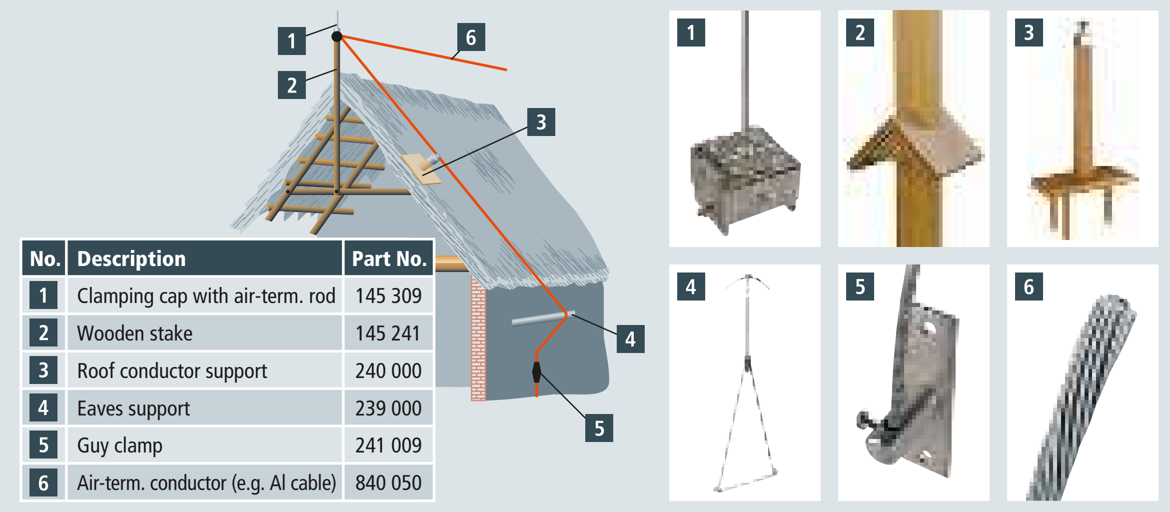
The calculation of the separation distance is described in chapter 5.6.

Ideally, ridge conductors should have a span width up to about 15 m and down conductors up to about 10 m without additional supports.

Span stakes must be firmly connected to the roof structure (rafters and crossbars) by means of anchor bolts and washers (**Figures 5.1.5.1 to 5.1.5.3**).

Metal parts situated on the roof surface (such as wind vanes, irrigation systems, antennas, sheet metal, conductors) must be completely located in the protected volume of isolated air-termination systems.

If this is not possible, efficient lightning protection must be ensured in these cases. To this end, an isolated external lightning protection system with air-termination rods next to the structure, air-termination conductors or air-termination networks between masts next to the building must be installed.



No.	Description	Part No.
1	Clamping cap with air-term. rod	145 309
2	Wooden stake	145 241
3	Roof conductor support	240 000
4	Eaves support	239 000
5	Guy clamp	241 009
6	Air-term. conductor (e.g. Al cable)	840 050

Figure 5.1.5.2 Components for thatched roofs

Figure 5.1.5.3 Thatched roof

Figure 5.1.5.4 Historical farmhouse with external lightning protection system; source: Hans Thormählen GmbH & Co.KG.

If a thatched roof is situated next to metal roofing material and if the building has to be equipped with an external lightning protection system, a non-conductive roofing material with a width of at least 1 m, e.g. made of plastic, must be inserted between the thatched roof and the rest of the roof.

Tree branches must be kept at least 2 m away from a thatched roof. If trees are very close to, and higher than, a building, an air-termination conductor must be mounted on the edge of the roof facing the trees (edge of the eaves, gable) and connected to the lightning protection system. The necessary distances must be maintained.

Another possibility to protect thatched buildings from lightning strikes is to install air-termination masts which ensure that the entire building is located in the protected volume.

This is described in chapter 5.1.8 "Isolated air-termination systems" (telescopic lightning protection masts).

A new and architecturally appealing possibility to install an isolated lightning protection system is to use insulated down conductors.

Figure 5.1.5.4 shows insulated down conductors installed on a historical farmhouse.

A lightning protection system according to class of LPS III was installed on the historical farmhouse. This meets the normative requirements for buildings with thatched roof (IEC 62305-3 (EN 62305-3)).

The ridge of the object is made of heather and is protected by a plastic meshed network to prevent birds from taking away the heather.

When planning the air-termination system, the rolling sphere method must be used to determine the protected volumes. Ac-

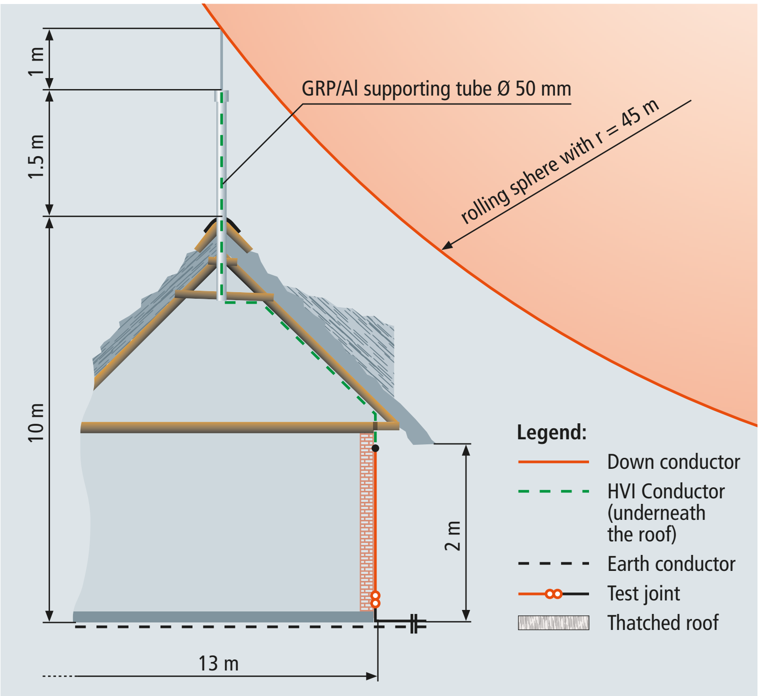


Figure 5.1.5.5 Sectional view of the main building

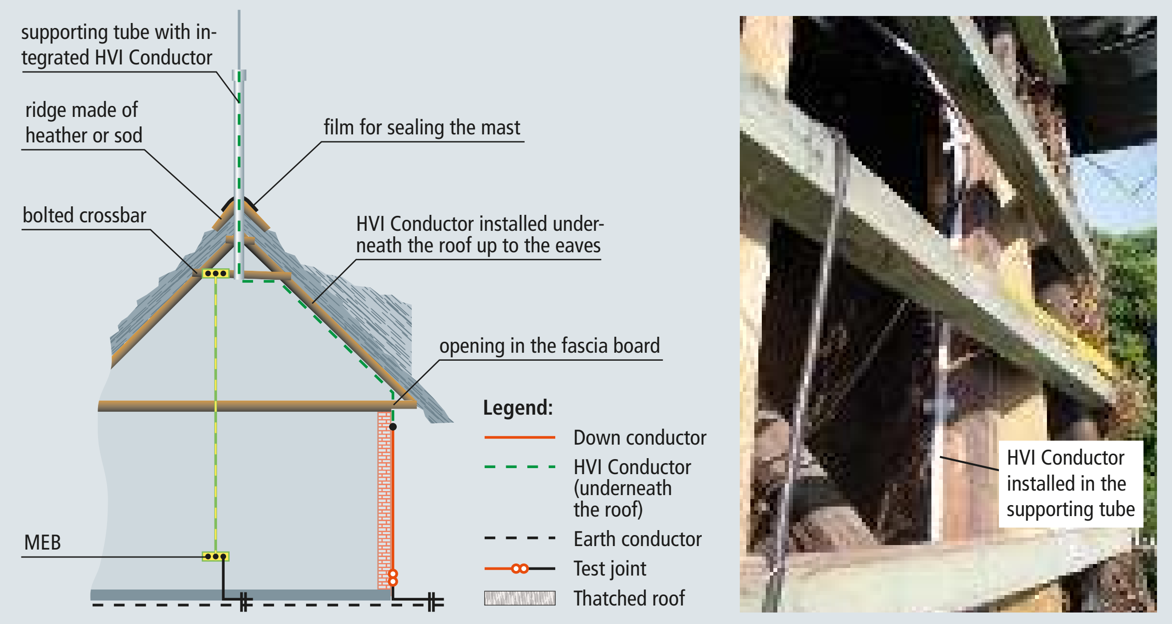


Figure 5.1.5.6 Schematic diagram and picture of the installation of the down conductor at the rafter

cording to the standard, a rolling sphere radius of 45 m must be used for class of LPS III. In our example, the height of the air-termination system is 2.30 m. This height ensures that the two chimneys at the ridge and the three new dormers on the roof are located in the protected volume (**Figure 5.1.5.5**).

A supporting tube made of GRP (**g**lass-fibre **r**einforced **p**lastic) was chosen to elevate the air-termination system and to accept the insulated down conductors. The lower part of the supporting tube is made of aluminium to ensure mechanical stability. Unwanted sparking may occur in this section as a result of the induction effects on adjacent parts. To avoid this, no earthed parts or electrical equipment may be located at a distance of 1 m around the aluminium tube. Therefore, e.g. nylon tie wires should be used for ridges made of heather or sod. Electrical isolation between air-termination systems and down conductors and between the metal installations to be protected and equipment of power supply and information technology systems in the structure requiring protection can be achieved by maintaining a separation distance s between these conductive parts. This separation distance must be determined according to the IEC 62305-3 (EN 62305-3) standard. The high-voltage-resistant, insulated HVI Conductor has an equivalent separation distance of s = 0.75 m (air) or s = 1.50 m (solid material). **Figure 5.1.5.6** shows the arrangement of the down conductor.

The HVI Conductor is installed in the supporting tube and connected via a central earthing busbar. Equipotential bonding is established by means of a flexible conductor H07V-K 1 x 16 mm^2. The supporting tube is fixed at a special construction (crossbar) and the down conductors are routed along the rafters of the roof construction underneath the battens (**Figure 5.1.5.6**). At the eaves, the HVI Conductors are led through the fascia board (**Figure 5.1.5.7**).

For architectural reasons, down conductors are installed in aluminium further down. The transition of the HVI Conductor to the uninsulated, bare down conductor near the earth-termination system and the installation of HVI Conductors are described in the relevant installation instructions. A sealing end is not required in this case.

Figure 5.1.5.7 HVI Conductor led through the fascia board

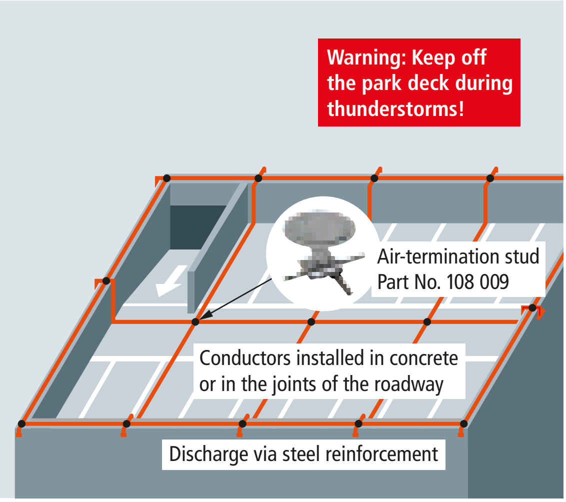


Figure 5.1.6.1 Lightning protection system for a car park roof – Protection of the building

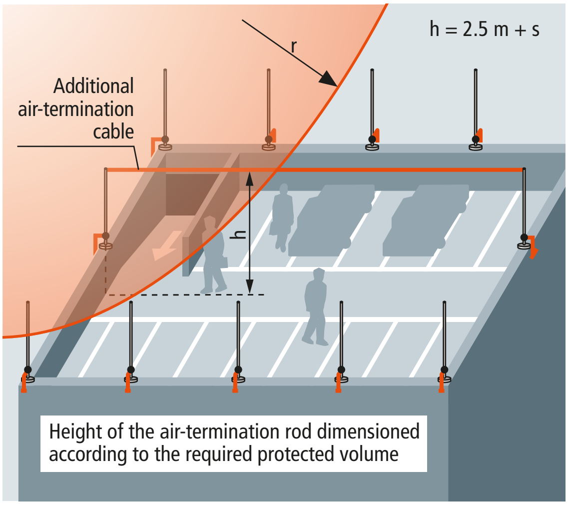


Figure 5.1.6.2 Lightning protection system for a car park roof – Protection of the building and persons (IEC 62305-3 (EN 62305-3); Annex E)

5.1.6 Accessible roofs

It is not possible to mount air-termination conductors (e.g. with concrete blocks) on roofs which are accessible by vehicles. One possible solution is to install the air-termination conductors in either concrete or in the joints between the decks. If the air-termination conductor is installed in these joints, air-termination studs are fixed at the intersections of the meshes as defined points of strike.
The mesh size must not exceed the value specified for the relevant class of LPS (see chapter 5.1.1, **Table 5.1.1.3**).

If it is ensured that persons do not stay in this area during a thunderstorm, it is sufficient to take the measures described above.
Persons who have access to the parking deck must be informed by a notice that they must immediately clear this parking deck when a thunderstorm occurs and not return for the duration of the storm (**Figure 5.1.6.1**).

If it is likely that persons stay on the roof surface during a thunderstorm, the air-termination system must be designed to protect these persons from direct lightning strikes, assuming they have a height of 2.5 m (with stretched arm). The rolling sphere or the protective angle method can be used to dimension the air-termination system according to the class of LPS (**Figure 5.1.6.2**).

These air-termination systems can consist of spanned cables or air-termination rods. The air-termination rods are fixed to e.g. structural elements such as parapets or the like.

Furthermore, e.g. lighting masts can also be used as air-termination rods to prevent life hazards. In this case, however, the partial lightning currents which may enter the structure via the power lines must be observed. Therefore, it is imperative to establish lightning equipotential bonding for these lines.

5.1.7 Air-termination system for green and flat roofs

Green roofs can make economic and ecological sense since they provide noise insulation, protect the roofing, suppress dust from the ambient air, provide additional heat insulation, filter and retain rainwater and are a natural way of improving the living and working atmosphere. Moreover, green roofs are publically funded in many regions. A distinction is made between so-called extensive and intensive green roofing. Extensive green roofing requires little effort, in contrast to intensive green roofing which requires fertiliser, irrigation and cutting. For both types of green roofing, either earth substrate or granulate must be laid on the roof.
It is even more complicated if the granulate or substrate has to be removed due to a direct lightning strike.
If no external lightning protection system is installed, the roof sealing can be damaged at the point of strike.

Experience has shown that, regardless of the effort required, the air-termination system of an external lightning protection system can and should be installed on the surface of a green roof.

Figure 5.1.7.1 Green roof

Figure 5.1.7.2 Air-termination system on a green roof

Figure 5.1.7.3 Conductor routing above the cover layer

If a meshed air-termination system is used, the IEC 62305-3 (EN 62305-3) lightning protection standard requires a mesh size which depends on the relevant class of LPS (see chapter 5.1.1, **Table 5.1.1.3**). An air-termination conductor installed inside the cover layer is difficult to inspect after some years because the air-termination tips or studs are overgrown and no longer recognisable and frequently damaged during maintenance work. Moreover, air-termination conductors installed inside the cover layer are susceptible to corrosion. Conductors of air-termination meshes installed evenly on top of the cover layer are easier to inspect even if they are overgrown and the air-termination system can be elevated by means of air-termination tips and rods and thus "grow" with the plants on the roof. Air-termination systems can be designed in different ways. A meshed air-termination network with a mesh size of 5 m x 5 m (class of LPS I) up to a maximum mesh size of 15 m x 15 m (class of LPS III) is typically installed on the roof surface, regardless of the height of the building. The mesh is to be preferably installed on the external edges of the roof and on any metal structures serving as air-termination system.
Stainless steel (V4A, e.g. material No. AISI/ASTM 316 Ti) has proven to be a good wire material for air-termination systems on green roofs.
Aluminium wires must not be used for installing conductors in the cover layer (in the earth substrate or granulate) (**Figures 5.1.7.1 to 5.1.7.3**).

5.1.8 Isolated air-termination systems

Roof-mounted structures such as air-conditioning and cooling systems, e.g. for mainframes, are frequently installed on the roofs of large office and industrial buildings. These roof-mounted systems must be treated like antennas, electrically controlled domelights, advertising signs with integrated lighting and all other protruding roof-mounted structures because they typically have a conductive connection into the building, e.g. via electrical lines or ducts.

According to the state of the art of lightning protection technology, such roof-mounted structures are protected against direct lightning strikes by means of separately mounted air-termination systems. This prevents partial lightning currents from entering the building where they would interfere with or even destroy sensitive electrical / electronic equipment.

In the past, these roof-mounted structures were directly connected so that parts of the lightning current were conducted into the building. Later, roof-mounted structures were indirectly connected via a spark gap. This meant that direct lightning strikes to the roof-mounted structure could still flow through the "internal conductor" although the spark gap should not reach the sparkover voltage in the event of a more remote lightning strike to the building. This voltage of approximately 4 kV was almost always reached and thus partial lightning currents were also injected into the building via the electrical cable, for example, which led to interference with the electrical or electronic installations.

The only way of preventing that these currents are injected into the building is to use isolated air-termination systems which ensure that the separation distance s is maintained.

Figure 5.1.8.1 shows partial lightning currents entering the structure.

The different roof-mounted structures can be protected by various types of isolated air- termination systems.

Air-termination rods

Small roof-mounted structures (e.g. small fans) can be protected by individual air-termination rods or a combination of several air-termination rods. Air-termination rods up to a height of 2.0 m can be fixed by means of one or two concrete bases piled on top of each other (e.g. Part No. 102 010) so that they are isolated (**Figure 5.1.8.2).**

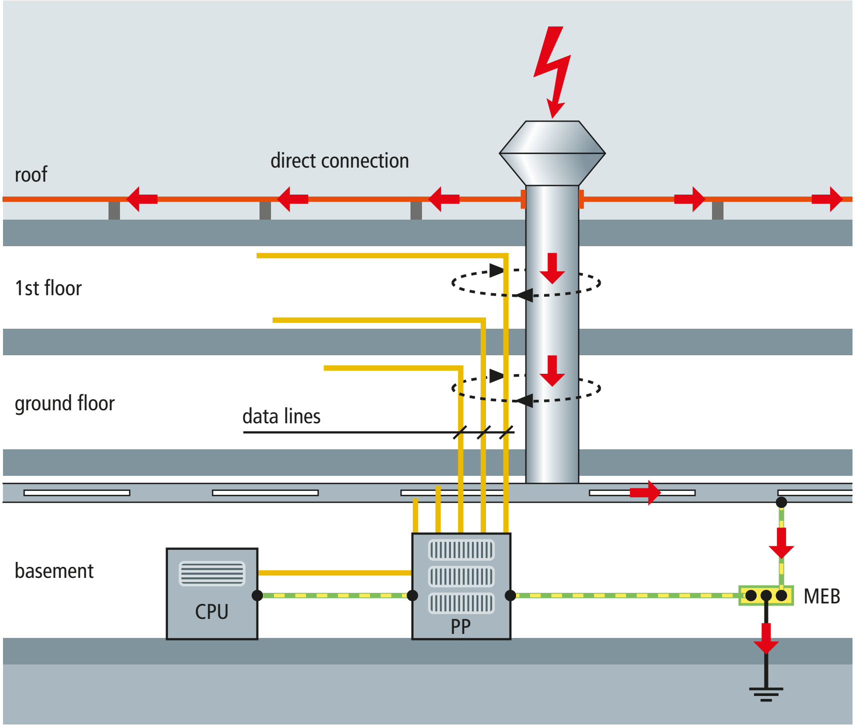


Figure 5.1.8.1 Risk posed by directly connected roof-mounted structures

Air-termination rods with a height between 2.5 m and 3.0 m must be fixed at the object to be protected by means of spacers made of electrically insulating material (e.g. DEHNiso spacer) (**Figure 5.1.8.3**).

Angled supports are a practical solution when air- termination rods also have to be protected against the effects of side winds (**Figures 5.1.8.4 and 5.1.8.5**).

If higher air-termination rods are required, e.g. for larger roof-mounted structures where nothing can be fixed, these air-termination rods can be provided with special stands.

Self-supporting air-termination rods up to a height of 14 m can be installed using a tripod. These stands are fixed on the floor by means of standard concrete bases (stacked on top of each other). Additional supports are required for a free height of 6 m and more in order to withstand the wind loads.

These self-supporting air-termination rods can be used for a wide range of applications (e.g. antennas, PV systems). Their advantage is the short installation time since no holes must be drilled and only few elements need to be screwed together (**Figures 5.1.8.6 and 5.1.8.7**).

Lightning protection masts are used to protect complete buildings or installations (e.g. free field PV systems, ammunition

Figure 5.1.8.2 Isolated air-termination system – Protection by an air-termination rod

Figure 5.1.8.3 Air-termination rod with spacer

Figure 5.1.8.4 Angled support for an air-termination rod

Figure 5.1.8.5 Supporting element for an air-termination rod

Figure 5.1.8.6 Isolated air-termination system of a photovoltaic system

depots) by means of air-termination rods. These masts are installed in a bucket foundation or on-site concrete foundation. A foundation basket is facotory-installed in the bucket foundation or inserted into the concrete foundation on site. Free heights of about 25 m above ground level or higher (customised versions) can be achieved. The standard lengths of the steel telescopic lightning protection masts are supplied in sections, thus offering enormous advantages for transport.

Figure 5.1.8.7 Isolated air-termination system for roof-mounted structures

Figure 5.1.8.8 Installation of a telescopic lightning protection mast

More detailed information (e.g. installation, assembly) on these steel telescopic lightning protection masts can be found in installation instructions No. 1729 (**Figures 5.1.8.8**).

Spanned by cables or conductors

According to IEC 62305-3 (EN 62305-3), air-termination conductors can be installed above the structure to be protected. The air-termination conductors generate a tent-shaped protected volume at the sides and a cone-shaped protected volume at the ends. The protective angle α depends on the class of LPS and the height of the air-termination systems above the reference plane.

Figure 5.1.8.9 Elevated air-termination system; source: Blitzschutz Wettingfeld, Krefeld

Figure 5.1.8.10 Tripod for isolated supporting tubes

Conductors or cables can also be dimensioned using the rolling sphere method (radius of the rolling sphere according to the class of LPS).

A meshed air-termination system can also be used if a sufficient separation distance s is maintained between the parts of the installation and the air-termination system. In such cases, e.g. isolating spacers are vertically installed in concrete bases, thus elevating the mesh (**Figure 5.1.8.9**).

DEHNiso Combi

The DEHNiso Combi portfolio offers a user-friendly way of installing conductors or cables according to the three different design methods for air-termination systems (rolling sphere, protective angle, mesh method).

The cables are led through aluminium supporting tubes with an "insulating clearance" (GRP – glass-fibre reinforced plastic), which are fixed on the object to be protected or in a tripod. Subsequently, they are routed separately to the down conductors or air-termination systems (e.g. mesh) by means of GRP spacers.

Figure 5.1.8.11 Isolated air-termination system with DEHNiso Combi

Figure 5.1.8.12 Rail fixing clamp for DEHNiso Combi supporting tube

Figure 5.1.8.13 Isolated air-termination system with DEHNiso Combi

More detailed information on the application of DEHNiso Combi can be found in brochure DS151/E and in installation instructions No. 1475.

The methods described above can be combined with each other as required to adapt the isolated air-termination system to the local conditions (**Figures 5.1.8.10 to 5.1.8.13**).

5.1.9 Air-termination system for steeples and churches

External lightning protection system

According to section 18.1 of Supplement 2 of the German DIN EN 62305-3 standard, a lightning protection system according to class of LPS III meets the standard requirements for churches and steeples. In individual cases, for example in case of structures of great cultural importance, a separate risk analysis must be carried out in accordance with IEC 62305-2 (EN 62305-2).

Nave

According to section 18.5 of Supplement 2 of the German DIN EN 62305-3 standard, the nave must be equipped with a separate lightning protection system and, if a steeple is attached, this system must be connected with a down conductor of the steeple along the shortest possible route. In the transept, each end of the air-termination conductor along the transverse ridge must be equipped with a down conductor.

Figure 5.1.9.1 Installation of the down conductor on a steeple

Steeple

Steeples up to a height of 20 m must be equipped with a down conductor. If the steeple and the nave are joined, this down conductor must be connected to the external lightning protection system of the nave along the shortest possible route (**Figure 5.1.9.1**). If the down conductor of the steeple crosses a down conductor of the nave, a common down conductor can be used at this point. According to section 18.3 of Supplement 2 of the German DIN EN 62305-3 standard, steeples with a height of more than 20 m must be provided with at least two down conductors. At least one of these down conductors must be connected with the external lightning protection system of the nave along the shortest possible route.

Down conductors on steeples must be routed to the ground along the outer surface of the steeple. Installation inside the steeple is not allowed (Supplement 2 of the German DIN EN 62305-3 standard). Furthermore, the separation distance s from metal parts and electrical installations in the steeple (e.g. clock mechanisms, belfry) and underneath the roof (e.g. air-conditioning, ventilation and heating systems) must be maintained by a suitable arrangement of the external lightning protection system. The necessary separation distance can be a problem especially at the church clock. In this case, the conductive connection into the building can be replaced by an insulating joint (e.g. a GRP tube) to prevent hazardous sparking in parts of the external lightning protection system.

In more modern churches made of reinforced concrete, the reinforcing steels can be used as down conductors if they have a permanently conductive connection. If pre-cast reinforced concrete parts are used, the reinforcement may be used as a down conductor if connection points are provided on the precast concrete parts to continuously connect the reinforcement.

According to the Supplement 2 of the German DIN EN 62305-3 standard, lightning equipotential bonding / surge protection of the electrical equipment (power installation, telephone and loudspeaker system, etc.) is implemented at the entrance point into the building and for the bell controller in the steeple and at the control system.

5.1.10 Air-termination systems for wind turbines

Lightning protection

The continuous further development of modern wind turbines with tower heights of more than 100 m considerably increases the risk of lightning strikes to a wind turbine. Moreover, the value of wind turbines is increased as a result of the higher generator outputs. Due to the global use of wind turbines, this technology is increasingly used in areas with a high lightning activity. At these heights, fire caused by lightning effects can rarely be extinguished by means of conventional fire-fighting equipment.
International standards follow this trend. The IEC 61400-24 (EN 61400-24) standard (Wind turbines: Lightning protection) requires class of LPS I and therefore, wind turbines must be designed for lightning currents of 200,000 A.

Principle of an external lightning protection system for wind turbines

An external lightning protection system consists of air-termination systems, down conductors and an earth-termination system and protects against mechanical destruction and fire. Since lightning typically strikes the rotor blades of wind turbines, e.g. receptors are integrated in the rotor blades to provide defined points of strike (**Figure 5.1.10.1**).

In order to discharge the injected lightning currents to earth in a controlled way, the receptors in the rotor blades are connected to the hub via a metal connecting cable (flat strip, St/tZn, 30 mm x 3.5 mm, or copper cable, 50 mm^2). Carbon fibre brushes or spark gaps in air bridge the ball bearings in the head of the nacelle to avoid welding of the rotating structural parts. In order to protect structures on the nacelle such as anemometers in the event of a lightning strike, air-termination rods or "air-termination cages" are installed (**Figure 5.1.10.2**).

The metal tower or, in case of a prestressed concrete tower, round wires (St/tZn, Ø 8 ...10 mm) or flat strips (St/tZn, 30 mm x 3.5 mm) embedded in the concrete are used as a down conductor. The wind turbine is earthed by means of a foundation earth electrode in the tower base and the meshed connection to the foundation earth electrode of the operations building or other wind turbines. This creates an "equipotential surface" which prevents potential differences in the event of a lightning strike.

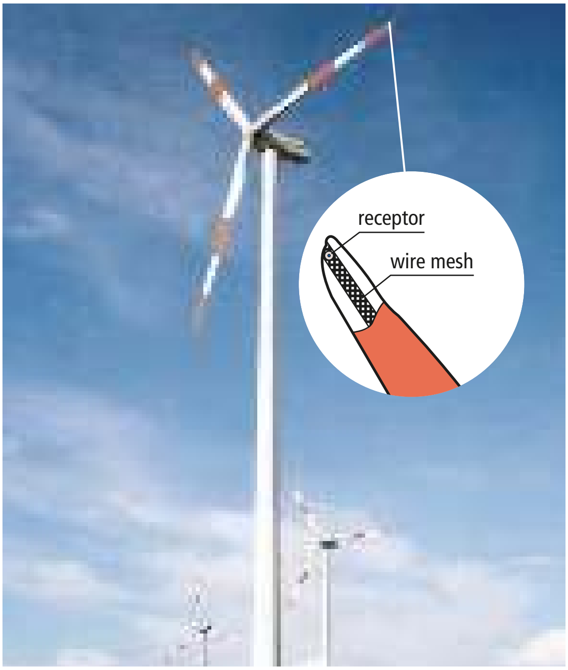


Figure 5.1.10.1 Wind turbine with integrated receptors in the rotor blades

Figure 5.1.10.2 Lightning protection for the anemometers of a wind turbine

Figure 5.1.11.1 Protection against direct lightning strikes by means of self-supporting air-termination rods

5.1.11 Air-termination rods subjected to wind loads

Roofs are used as areas for technical equipment. Especially when extending the technical equipment in the building, extensive installations are sited on the roofs of large office and industrial buildings. In this case, it is essential to protect the different roof-mounted structures such as air-conditioning and cooling systems, antennas of cell sites on rented buildings, lamps, smoke extraction systems and other equipment connected to the electrical low-voltage system (**Figure 5.1.11.1**).

In accordance with the relevant lightning protection standards of the IEC 62305 (EN 62305) series, these roof-mounted structures can be protected from direct lightning strikes by means of isolated air-termination systems. To this end, both the air-termination systems such as air-termination rods, air-termination tips or air-termination meshes and the down conductors are isolated, in other words they have a sufficient separation distance from the roof-mounted structures located in the protected volume. The installation of an isolated lightning protection system creates a volume protected against direct lightning strikes and also prevents partial lightning currents from entering the building. This is important because sensitive electrical / electronic equipment can be interfered with or destroyed by the injected partial lightning currents.

Extended roof-mounted structures are also equipped with a system of isolated air-termination systems. These are connected with each other and with the earth-termination system. The size of the protected volume depends e.g. on the number and height of the air-termination systems installed.

A single air-termination rod is sufficient to provide protection for small roof-mounted structures. To this end, the rolling sphere method in accordance with IEC 62305-3 (EN 62305-3) is used (**Figure 5.1.11.2**).

With the rolling sphere method, a rolling sphere whose radius depends on the class of LPS selected is rolled in all possible directions on and over the structure to be protected. During this procedure, the rolling sphere may only touch the ground (reference plane) and / or the air-termination system.

Max. height of the building		
Class of LPS	Radius of the rolling sphere (r)	Mesh size (M)
I	20 m	5 x 5 m
II	30 m	10 x 10 m
III	45 m	15 x 15 m
IV	60 m	20 x 20 m

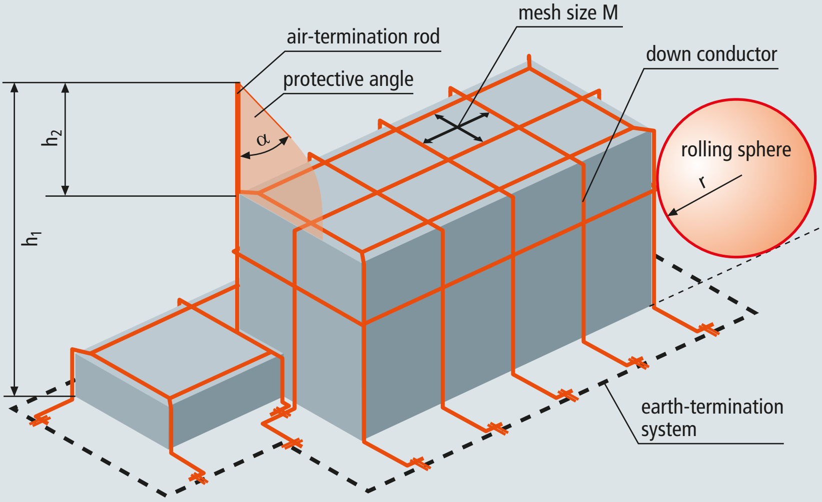


Figure 5.1.11.2 Procedure for installing air-termination systems according to IEC 62305-3 (EN 62305-3)

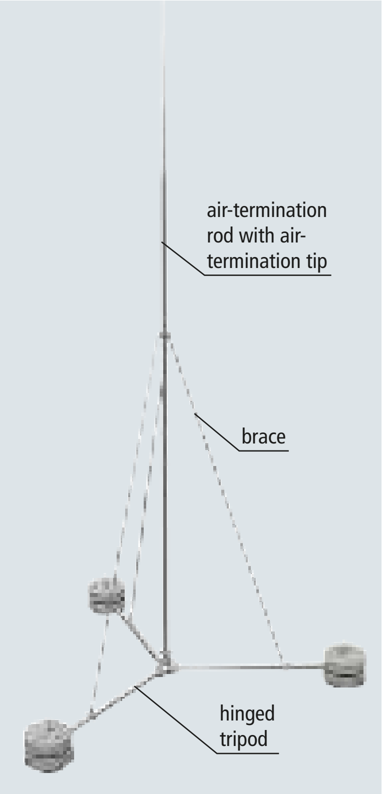


Figure 5.1.11.3 Self-supporting air-termination rod with hinged tripod

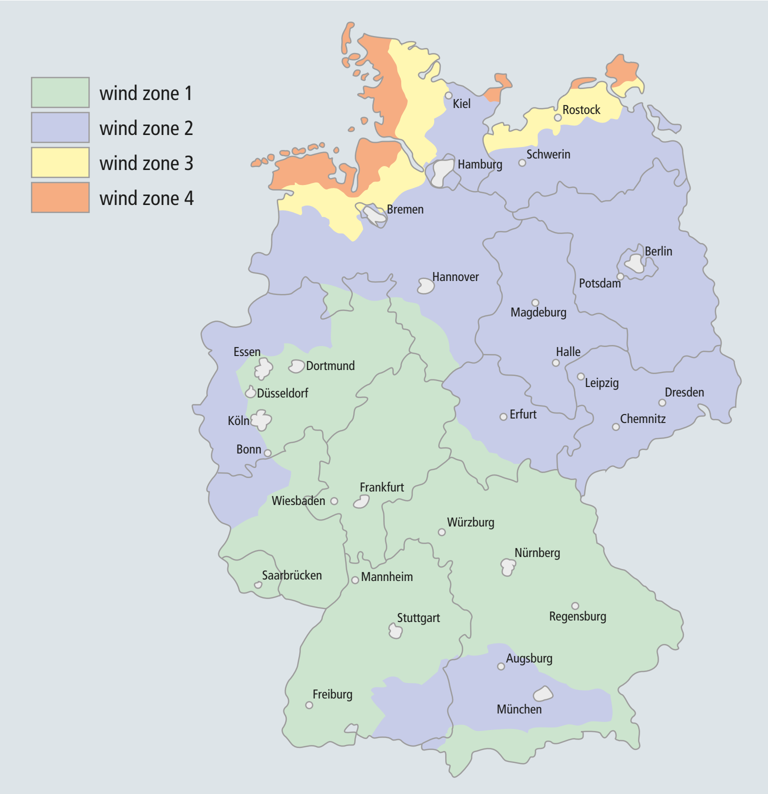


Figure 5.1.11.4 Division of Germany into wind zones; source: DIN EN 1991-1-4/NA: Actions on structures – Part 1-4: General actions – Wind actions

This method creates a protected volume where direct lightning strikes cannot occur.

To achieve the largest possible protected volume or to protect large roof-mounted structures against direct lightning strikes, individual air-termination rods of sufficient height should be installed. To prevent self-supporting air-termination rods from tilting and breaking, a suitable base and additional braces are required (**Figure 5.1.11.3**).

However, the requirement that the self-supporting air-termination rods should be as high as possible leads to a higher stress resulting from the wind loads. At the same time, a lightweight "self-supporting air-termination rod" is required to facilitate transport and installation. The stability of air-termination rods must be verified to ensure safe use on roofs.

Stress caused by wind loads

Since self-supporting air-termination rods are installed at exposed locations (e.g. on roofs), mechanical stress occurs similar to the stress on radio towers due to the comparable place of installation and wind speeds. Isolated air-termination rods must therefore basically meet the same requirements concerning their mechanical stability as set out in EN 1993-3-1, Eurocode 3: Design of steel structures – Part 3-1: Towers, masts and chimneys – Towers and masts.

Germany is divided into four wind zones (**Figure 5.1.11.4**). When calculating the actual wind load stress to be expected, apart from the zone-dependent wind load, the height of the building and the local conditions (detached building in open terrain or embedded in other buildings) must also be observed. **Figure 5.1.11.4** shows that about 95 % of Germany´s surface area is situated in wind zones 1 and 2. Therefore, air-termination rods are generally designed for wind zone 2. The use of self-supporting air-termination rods in wind zones 3 and 4 must be examined for each individual case to take into account the stresses which arise.

When designing self-supporting air-termination rods, the following requirements must be met with regard to the wind load stress:

- ➡ Tilt resistance of the air-termination rods
- ➡ Bending resistance of the rods

- The required separation distance from the object to be protected must be maintained even under wind load (prevention of intolerable bending)

Determination of the tilt resistance

The wind forces acting on the areas of the air-termination rod that are exposed to wind generate a line load q‘ on the surface which generates a corresponding tilting moment M_T on the self-supporting air-termination rod. To ensure stability of the self-supporting air-termination rod, a load torque M_L generated by the post must counteract the tilting moment M_T. The magnitude of the load torque M_L depends on the standing weight and the radius of the post. If the tilting moment is greater than the load torque, the air-termination rod falls over due to the wind load.

The stability of self-supporting air-termination rods is proven in static calculations. In addition to the mechanical characteristics of the materials used, the following is included in the calculation:

- **Area of the air-termination rod exposed to wind**
  Determined by the length and diameter of the individual sections of the air-termination rod.
- **Area of the braces exposed to wind**
  Extremely high self-supporting air-termination rods are stabilised with three braces which are mounted equidistantly around the circumference. The area of these braces that is exposed to wind is equal to the area of these braces projected onto a plane at a right angle to the direction of the wind, in other words the brace lengths are shortened accordingly in the calculation.
- **Weight of the air-termination rod and braces**
  The own weight of the air-termination rod and the braces are taken into account when calculating the load torque.
- **Weight of the post**
  The post is a tripod loaded with concrete blocks. The weight of this post consists of the own weight of the tripod and the individual weights of the concrete blocks.
- **Tilt lever of the post**
  The tilt lever describes the shortest distance between the centre of the tripod and the line or point around which the whole system would tilt.

Stability is proven by comparing the following moments:

- **Tilting moment**
  Formed by the wind-load-dependent force on the air-termination rod, braces and the lever arm of the air-termination rod.
- **Load torque**
  Formed by the weight of the post, the weight of the air-termination rod and braces, and the length of the tilt lever related to the tripod.

Stability is achieved when the ratio between the load torque and the tilting moment is > 1. The following rule applies: The greater the ratio between the load torque and the tilting moment, the greater is the stability.

The required stability can be achieved as follows:

- In order to keep the area of the air-termination rod that is exposed to wind small, the cross-sections used have to be as small as possible. The load on the air-termination rod is reduced, but, at the same time, the mechanical stability of the air-termination rod decreases (risk of breakage). It is therefore vital to make a compromise between the smallest possible cross-section to reduce the wind load and the largest possible cross-section to achieve the required stability.
- The stability can be increased by using larger standing weights and / or larger post radii. This often conflicts with the limited installation space and the general requirement for a low weight and easy transport.

Implementation

In order to provide the smallest possible area exposed to wind, the cross-sections of the air-termination rods were optimised according to the results of the calculation. To facilitate transport and installation, the air-termination rod consists of an aluminium tube (separable, if required) and an aluminium air-termination rod. The post for the air-termination rod is hinged and is available in two sizes. Thus, roof pitches up to 10 ° can be compensated.

Determination of the break resistance

Not only the stability, but also the break resistance of the air-termination rod must be verified since the wind load exerts bending stress on the self-supporting air-termination rod. The bending stress must not exceed the maximum permissible stress and increases if longer air-termination rods are used. The air-termination rods must be designed to ensure that wind loads which can arise in wind zone 2 cannot cause permanent deformation of the rods.

Since both the exact geometry of the air-termination rod and the non-linear performance of the materials used must be taken into account, the break resistance of self-supporting air-termination rods is verified by means of an FEM calculation model. The finite elements method (FEM) is a numerical calculation method for calculating stress and deformation of complex geometrical structures. The structure under examination is divided into so-called “finite elements” using imaginary surfaces and lines and these “finite element” are interconnected via nodes.

The following information is required for calculation:

- **FEM calculation model**
  The FEM calculation model corresponds in a simplified form to the geometry of the self-supporting air-termination rod.

- **Material characteristics**
  The performance of the material is determined by the cross-sectional values, modulus of elasticity, density and lateral contraction.
- **Loads**
  The wind load is applied to the geometric model in the form of a pressure load.

The break resistance is determined by comparing the permissible bending stress (material property) and the maximum bending stress (calculated from the bending moment and the effective cross-section at the point of maximum stress).
Break resistance is achieved if the ratio between the permissible and the actual bending stress is > 1. Basically, the same also applies in this case: The greater the ratio between the permissible and the actual bending stress, the greater is the break resistance.

The FEM calculation model was used to calculate the actual bending moments for two air-termination rods (length = 8.5 m) with and without braces as a function of their height (**Figure 5.1.11.5**). This clearly shows the impact of the braces on the moments. While the maximum bending moment for the air-termination rod without brace is about 1270 Nm in the clamping point, the bending moment for the air-termination rod with brace is reduced to about 460 Nm. This brace allows to reduce the stress in the air-termination rod to such an extent that, for the maximum expected wind loads, the strength of the materials used is not exceeded and the air-termination rod is not destroyed.

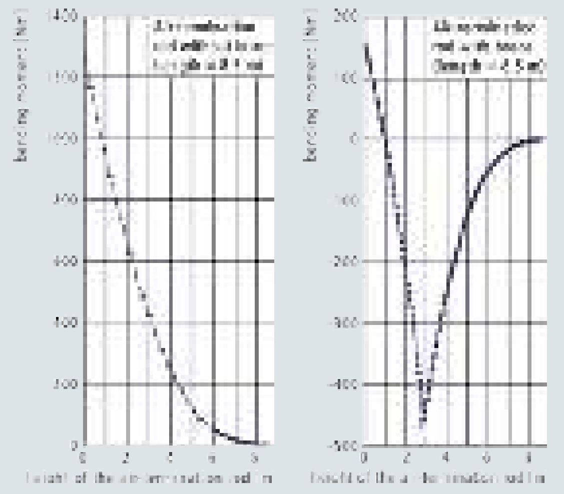


Figure 5.1.11.5 Comparison of the bending moments of self-supporting air-termination rods with and without braces (length = 8.5 m)

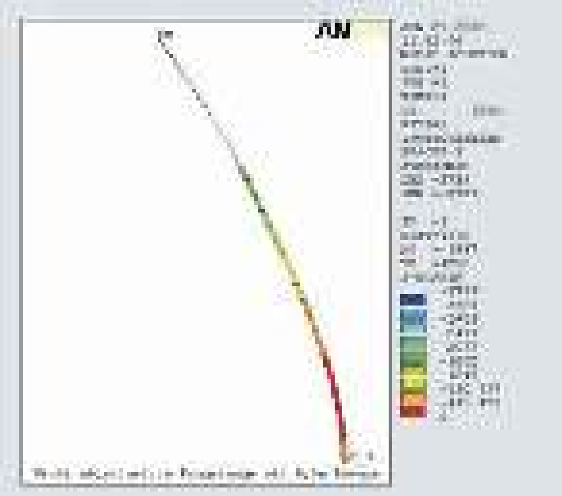


Figure 5.1.11.6 FEM model of a self-supporting air-termination rod without brace (length = 8.5 m)

Implementation

Braces create an additional “supporting point” which significantly reduces the bending stress in the air-termination rod. Without additional braces, the air-termination rods would not withstand the stress of wind zone 2. Therefore, air-termination rods higher than 6 m are equipped with braces.

In addition to the bending moments, the FEM calculation also provides the stress in the braces whose stability must also be proven.

Determination of the wind-load-dependent deflection of the air-termination rod

A further important value to be calculated by means of the FEM model is the deflection of the tip of the air-termination rod. Air-termination rods are deflected by wind loads. This deflection changes the volume to be protected. Objects requiring protection are no longer located in the protected volume and / or proximities can no longer be maintained.
Figures 5.1.11.6 and 5.1.11.7 show the use of the calculation model for a self-supporting air-termination rod with and without braces. In this example, the tip of the air-termination rod with brace is displaced by approximately 1150 mm. Without brace there would be a deflection of about 3740 mm, a theoretical value which exceeds the breaking limit of the air-termination rod under consideration.

Implementation

Above a certain rod height, additional braces significantly reduce this defection and the bending stress on the rod.

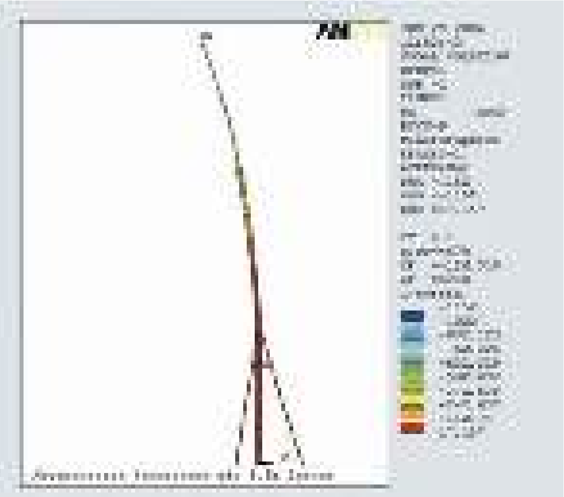


Figure 5.1.11.7 FEM model of a self-supporting air-termination rod with brace (length = 8.5 m)

The tilt resistance, break resistance and deflection are the decisive factors for designing air-termination rods. The post and air-termination rod must be coordinated to ensure that the stress resulting from the wind speed according to wind zone 2 do not cause tilting of the rod and / or damage it.

It must be observed that large deflections of the air-termination rod reduce the separation distance and thus intolerable proximities can occur. Higher air-termination rods require additional braces to prevent such intolerable deflections of the tips of air-termination rods. The measures described above ensure that self-supporting air-termination rods can withstand wind speeds of wind zone 2 when used for their intended purpose.

5.1.12 Safety systems and lightning protection

Service and maintenance work is regularly carried out on the roof surfaces of industrial and commercial buildings. But also e.g. cleaning work on gutters and light strips involves a risk of falling. Therefore, it is quite common today that particularly flat-roofed industrial buildings are equipped with safety rope systems. The service personnel can only be hooked into the personal protective equipment (PPE) of the safety rope system (**Figure 5.1.12.1**) or protected from falling by anchor points. The advantage of a safety rope system over an anchor point is that operators can walk along the rope by hooking the rope guide / rope slide into the safety rope system. Anchoring to the next fixed anchor point is not required. This increases safety at work and the acceptance of such a system.

Figure 5.1.12.1 Safety rope system used on a flat roof

Two different trades, namely the installation of the safety rope system and the installation of the lightning protection system, meet on the roof which must be coordinated at the intersection of these two trades. With respect to personal safety, it can even be dangerous if two different tradesmen work on an "unknown" system. Each of them should work independently and competently and observe the warranty obligation of the other party involved. Therefore, only specialised companies should install safety rope systems and qualified lightning protection specialists should work on external lightning protection systems.

Safety rope systems are prone to lightning strikes since they are installed about 30 m above a common air-termination mesh. Therefore, many manufacturers of safety rope systems point out in their installation instructions that safety rope systems must be checked for lightning strikes and thus possible melting of metal resulting from the injection of lightning currents during their annual inspection. The Central Association of the German Roofing Trade (ZVDH) and the Committee for Lightning Protection and Research (ABB) at the VDE has published a bulletin in German language (Roof and wall-mounted external lightning protection systems).

Figure 5.1.12.2 Incorrect installation: Safety rope system intersects the air-termination system

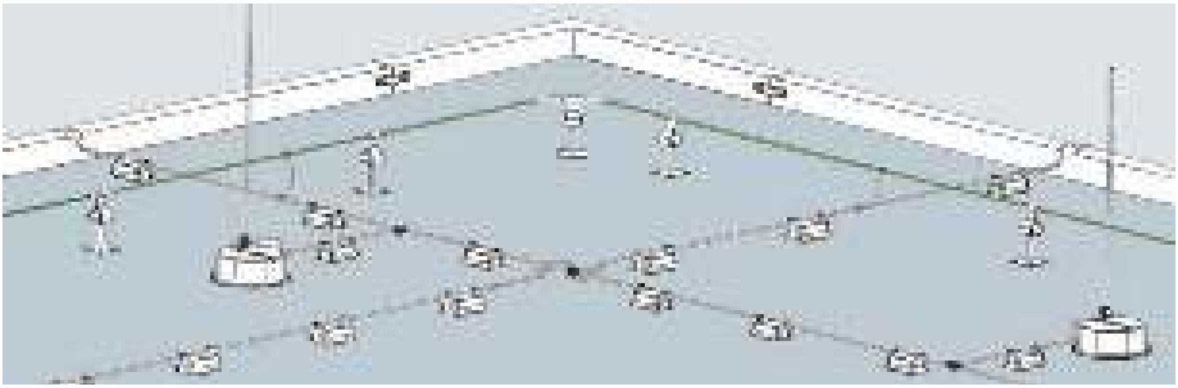


Figure 5.1.12.3 Integration of the safety rope system (fall protection) in the air-termination system

Figure 5.1.12.4 Flat-roofed structure – Detailed view

Incorrect installation

Figure 5.1.12.2 shows a negative example which unfortunately can often be found in practice today. This safety rope system was positioned above the lightning protection system. It is also questionable whether the conventional connecting clamp for contacting the safety rope system used in this example is capable of carrying lightning currents. The cable used to connect the safety rope system and the meshed network is very short. If a person falls from the roof, the safety rope system can be lowered up to 1 m to compensate the fall. The too short connecting cable shown in **Figure 5.1.12.2** would

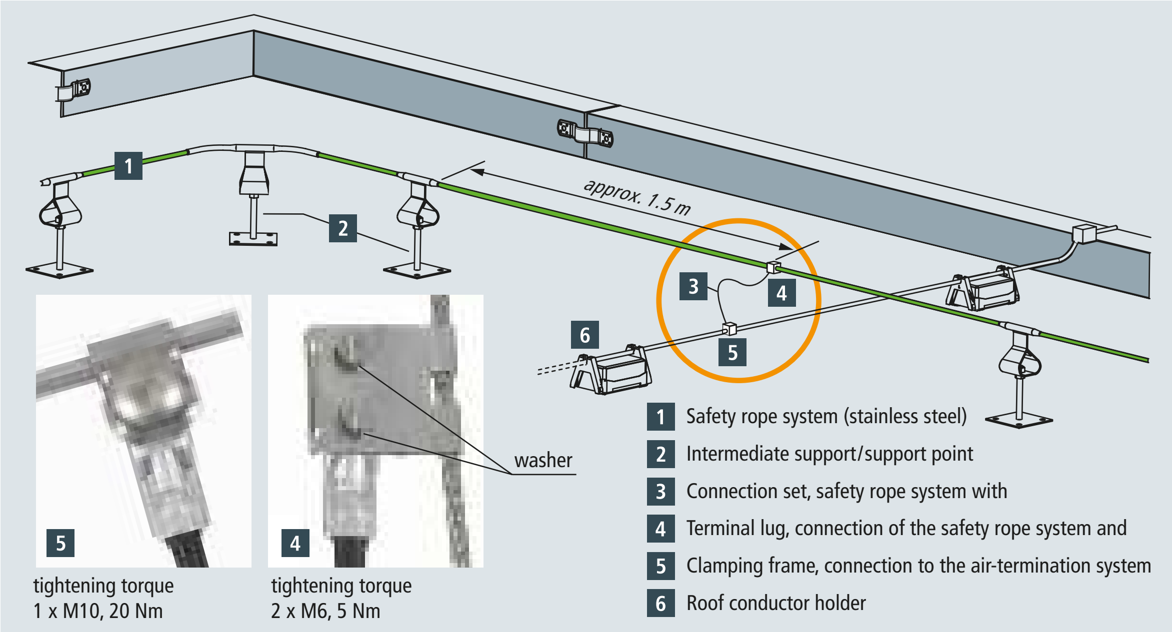


Figure 5.1.12.5 Installation example: Connecting set for safety rope systems

break and considerably affect the compensation effect in case of a fall. This is impermissible.

Lightning protection

The rope of the safety rope system is part of a personal safety system and must not be used as an air-termination system! If lightning current is injected into the safety rope system, the rope may be damaged by melting (reduced rope cross-section / reduced resistance). Therefore, the safety rope system must be integrated in the external lightning protection system. **Figures 5.1.12.3 and 5.1.12.4** show the basic principle.

The safety rope system is located in the protected volume of the air-termination rods. To implement equipotential bonding, an electrically safe connection is established at the intersections between the safety rope system and the lower air-termination mesh.

These connections must be capable of carrying lightning currents and must be established correctly according to the relevant cable diameter. They must also be designed in such a way that they are not crossed by the rope guide / rope slide. The connection set from DEHN specifically developed for this safety rope system provides the required lightning current carrying connection to an existing external lightning protection system. The personal protective equipment does not have to be unhooked, thus ensuring permanent fall protection. **Figure 5.1.12.5** shows an example of a correct installation. The rope connecting clamp / terminal lug is designed in such a way that the rope guide / rope slide of the safety rope system can be passed over the connection without unhooking it. The entire connection set, which forms the connection between the rope system and the meshed network of the external lightning protection system, is positioned to ensure that the rope length can be lowered up to 1 m if a person falls and the connection does not break. To this purpose, the connection set must be provided with a longer connecting cable.

5.2 Down conductors

The down conductor is the electrically conductive connection between the air-termination system and the earth-termination system. The function of a down conductor is to conduct the intercepted lightning current to the earth-termination system without damaging the building e.g. due to intolerable temperature rises.

To avoid damage caused during the lightning current discharge to the earth-termination system, the down conductors must be mounted to ensure that from the point of strike to the earth,

- Several parallel current paths exist,
- The length of the current paths is kept as short as possible (straight, vertical, no loops),
- The connections to conductive parts of the structure are made wherever required.

5.2.1 Determination of the number of down conductors

The number of down conductors depends on the perimeter of the external edges of the roof (perimeter of the projection onto the ground surface). The down conductors must be arranged to ensure that, starting at the corners of the structure, they are distributed as uniformly as possible to the perimeter.

Depending on the structural conditions (e.g. gates, precast components), the distances between the various down conductors can be different. In each case, there must be at least the total number of down conductors required for the respective class of LPS.

The IEC 62305-3 (EN 62305-3) standard specifies typical distances between down conductors and ring conductors for each class of LPS (**Table 5.2.1.1**).

The exact number of down conductors can only be determined by calculating the separation distance s. If the calculated separation distance cannot be maintained for the intended number of down conductors of a structure, one way of meeting this requirement is to increase the number of down conductors. The parallel current paths improve the partitioning coefficient k_c. This measure reduces the current in the down conductors and the required separation distance can be maintained.

Natural components of the structure (e.g. reinforced concrete supports, steel frameworks) can also be used as down conductors if continuous electrical conductivity can be ensured.

By interconnecting the down conductors at ground level (base conductor) and using ring conductors for higher structures, it is possible to balance the lightning current distribution which, in turn, reduces the separation distance s.

The latest IEC 62305 (EN 62305) series attaches great significance to the separation distance. The measures specified allow to reduce the separation distance for structures and thus the lightning current can be safely discharged.

Class of LPS	Typical distance
I	10 m
II	10 m
III	15 m
IV	20 m

Table 5.2.1.1 Distances between down conductors according to IEC 62305-3 (EN 62305-3)

If these measures are not sufficient to maintain the required separation distance, high voltage-resistant, insulated conductors (HVI Conductors) can also be used as an alternative. These are described in chapter 5.2.4.

Chapter 5.6 describes how to exactly determine the separation distance.

5.2.2 Down conductors for a non-isolated lightning protection system

Down conductors are primarily mounted directly onto the building (without separation distance). The reason for installing them directly onto the structure is the temperature rise in the event of lightning striking the lightning protection system.

If the wall is made of flame-resistant or normally inflammable material, the down conductors may be installed directly on or in the wall.

Owing to the specifications in the building regulations of the German federal states, highly combustible materials are generally not used. This means that down conductors can usually be mounted directly on the building.

Wood with a density greater than 400 kg/m^2 and a thickness greater than 2 mm is considered to be normally inflammable. Thus, the down conductor can be directly mounted on wooden poles, for example.

If the wall is made of highly combustible material, the down conductors can be directly installed on the surface of the wall provided that the temperature rise when lightning currents flow through them is not dangerous.

Table 5.2.2.1 shows the maximum temperature rise ΔT in K of the various conductors for each class of LPS. These values mean that it is generally allowed to install down conductors underneath the heat insulation because these temperature rises do not present a fire risk to the insulation materials. This also ensures fire retardation.

When installing the down conductor in or underneath a heat insulation, the temperature rise (on the surface) is reduced if an additional PVC sheath or PVC-sheathed aluminium wire is used.

If the wall is made of highly combustible material and the temperature rise of the down conductors presents a hazard, the down conductors must be mounted in such a way that the distance between the down conductors and the wall is greater than 0.1 m. The fixing elements may touch the wall. The installer of the structure must specify whether the wall on which a down conductor is to be installed is made of combustible material.

In Germany the terms flame-resistant, normally inflammable and highly combustible are exactly defined in Annex E.101 of Supplement 1 of the DIN EN 62305-3 (VDE 0185-305-3) standard.

5.2.2.1 Installation of down conductors

The down conductors must be arranged in such a way that they are the direct continuation of the air-termination conductors. They must be installed vertically in a straight line so that they represent the shortest most direct connection to earth.

Loops, e.g. on projecting eaves or structures, must be avoided. If this is not possible, the distance measured where two points of a down conductor are closest and the length l of the down conductor between these points must fulfil the requirements on the separation distance s (**Figure 5.2.2.1.1**). The separation distance s is calculated by means of the total length $l = l_1 + l_2 + l_3$.

Down conductors must not be installed in gutters and downpipes, even if they are incorporated into an insulating material since the moisture in the gutters would cause corrosion of the down conductors.

If an aluminium down conductor is used, it must neither be installed directly (without separation distance) on, in or under plaster, mortar or concrete nor in the ground. If it is equipped with a PVC sheath, aluminium can be installed in mortar, plaster or concrete if it is ensured that the sheath will not be mechanically damaged and the insulation will not break at low temperatures.

q [mm^2]	Ø [mm]	Class of LPS											
		Aluminium			Iron			Copper			Stainless steel (V4A)		
		III + IV	II	I	III + IV	II	I	III + IV	II	I	III + IV	II	I
16		146	454	*	1120	*	*	56	143	309	*	*	*
50	8 mm	12	28	52	37	96	211	5	12	22	190	460	940
78	10 mm	4	9	17	15	34	66	3	5	9	78	174	310

* melting / vaporisation

Table 5.2.2.1 Maximum temperature rise ΔT in K of different conductor materials

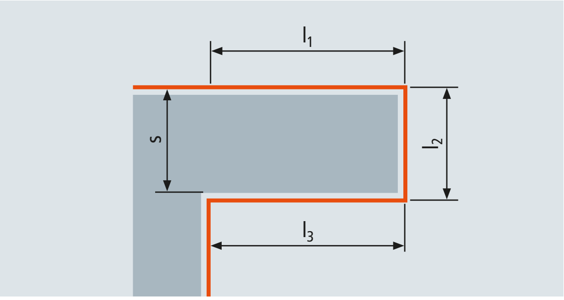


Figure 5.2.2.1.1 Loop in the down conductor

It is recommended to mount down conductors in such a way that the required separation distance s is maintained from all doors and windows (**Figure 5.2.2.1.2**).

Metal gutters must be connected with the down conductors at the points where they intersect (**Figure 5.2.2.1.3**).

The base of metal downpipes must be connected to the equipotential bonding or earth-termination system, even if the downpipe is not used as a down conductor. Since it is connected to the lightning current carrying gutter, the downpipe also carries a part of the lightning current which must be diverted to the earth- termination system. **Figure 5.2.2.1.4** illustrates a possible design.

5.2.2.2 Natural components of a down conductor

When using natural components of the structure as a down conductor, the number of separately installed down conductors can be reduced or, in some cases, no separately installed down conductors are required.

The following parts of a structure can be used as natural components of the down conductor:

- **Metal installations**

  These components can be used as natural down conductors provided that the various parts are safely connected on a permanent basis and their dimensions meet the minimum requirements for down conductors. These metal installations may also be incorporated into insulating material. It is not permitted to use pipelines containing flammable or explosive materials as down conductors if the seals in the flanges / couplings are non-metallic or the flanges / couplings of the connected pipes are not conductively connected in any other way.

- **Metal framework of the structure**

  If the metal framework of steel frame structures or the interconnected reinforcing steel of the structure is used as a down conductor, ring conductors are not required since additional ring conductors would not improve the splitting of the current.

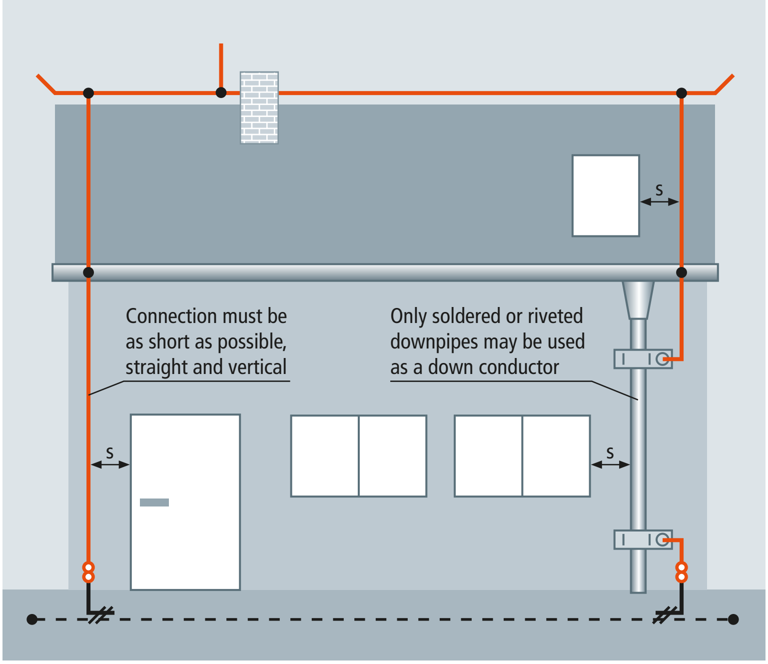


Figure 5.2.2.1.2 Down conductors

Figure 5.2.2.1.3 Air-termination system connected to the gutter

Figure 5.2.2.1.4 Earth connection of a downpipe

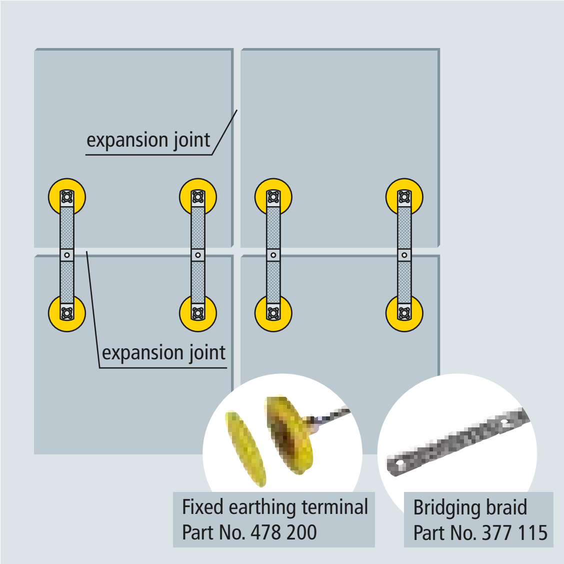


Figure 5.2.2.2.1 Use of natural components – New buildings made of ready-mix concrete

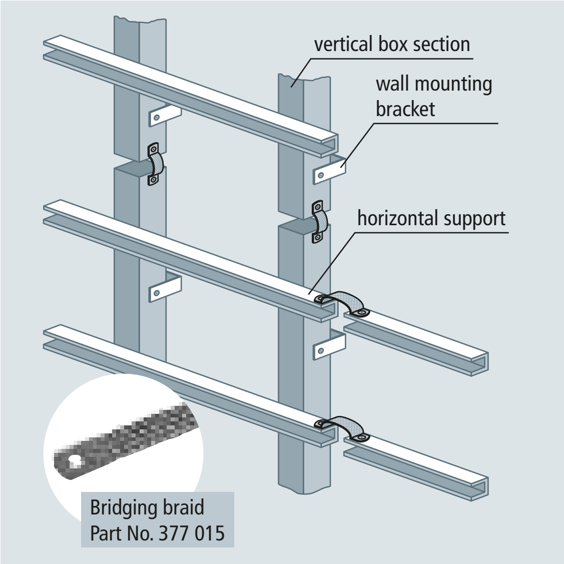


Figure 5.2.2.2.2 Metal substructure, conductively bridged

Figure 5.2.2.2.3 Earth connection of a metal façade

Figure 5.2.2.2.4 Down conductor installed along a downpipe

Figure 5.2.2.3.1 Test joint with number plate

- **Interconnected reinforcement of the structure**
  The reinforcement of existing structures cannot be used as a natural component of the down conductor unless the reinforcement is safely interconnected. Separate external down conductors must be installed.
- **Precast parts**
  Precast parts must be designed to provide connection points for the reinforcement. They must have a conductive connection between all connection points. The individual components must be interconnected on site during installation (**Figure 5.2.2.2.1**).
- **Façade elements, DIN rails and metal sub-structures of façades**
  These components can be used as natural down conductors provided that the dimensions meet the requirements for down conductors (5.6.2 of IEC 62305-3 (EN 62305-3)) and that the thickness is at least 0.5 mm for sheet metal and metal pipes and their conductivity in the vertical direction meets the requirements of 5.5.3 of IEC 62305-3 (EN 62305-3).

Note: In case of prestressed concrete, the particular risk of possible impermissible mechanical effects due to the lightning current and resulting from the connection to the lightning protection system must be observed.

Connections to prestressing bars or cables must only be effected outside the stressed area. The permission of the installer of the structure must be given before using prestressing bars or cables as a down conductor.
If the reinforcement of existing structures is not safely interconnected, it cannot be used as a down conductor. In this case, external down conductors must be installed.
Furthermore, façade elements, DIN rails and metal sub-structures of façades can be used as a natural down conductor provided that:

- The dimensions meet the minimum requirements for down conductors. For sheet metal, the thickness must not be less than 0.5 mm. Their electrical conductivity in the vertical direction must be ensured. If metal façades are used as a down conductor, they must be interconnected to ensure that the individual sheet metal plates are safely interconnected by means of screws, rivets or bridging connections. There must be a safe current carrying connection to the air-termination and earth-termination system.
- If sheet metal plates are not interconnected in accordance with the above requirement, but the substructure is such that they are continuously conductive from the connection to the air-termination system to the connection on the earth-termination system, they can be used as a down conductor (**Figures 5.2.2.2.2 and 5.2.2.2.3**).

Metal downpipes can be used as natural down conductors as long as they are safely interconnected (soldered or riveted joints) and have a minimum wall thickness of 0.5 mm (**Figure 5.2.2.1.2**).
If a downpipe is not safely interconnected, it can be used as a holder for the supplementary down conductor. This type of application is illustrated in **Figure 5.2.2.2.4**. The downpipe must be connected to the earth-termination system in such a way that it can carry lightning currents since the conductor is only connected to the pipe.

5.2.2.3 Test joints

A test joint must be provided at every connection of a down conductor to the earth-termination system (above the earth entry, if practicable).

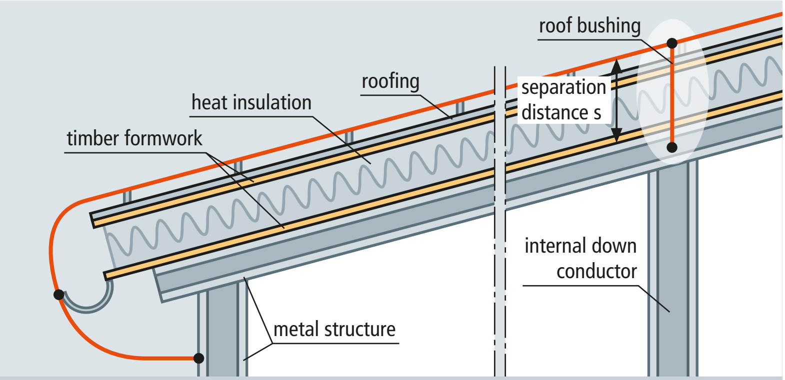
Test joints are required to facilitate the inspection of the following characteristics of the lightning protection system:

- Connections of the down conductors via the air-termination systems to the next down conductor
- Interconnections of the terminal lugs via the earth-termination system, e.g. in case of ring or foundation earth electrodes (type B earth electrodes)
- Earth resistances of single earth electrodes (type A earth electrodes)

Test joints are not required if the structural design (e.g. reinforced concrete or steel frame structure) allows no electrical isolation of the natural down conductor from the earth-termination system (e.g. foundation earth electrode). The test joint may only be opened with the help of a tool for measurement purposes, otherwise it must be closed. Each test joint must be clearly identifiable in the plan of the lightning protection system. Typically, all test joints are marked with numbers (**Figure 5.2.2.3.1**).

5.2.2.4 Internal down conductors

If the edges of the building (length and width) are four times as large as the distance of the down conductors according to the class of LPS, supplementary internal down conductors must be installed (**Figure 5.2.2.4.1**). The grid dimensions for the internal down conductors are about 40 m x 40 m.
Large flat-roofed structures such as large production halls or distribution centres frequently require internal down conductors. In such cases, the ducts through the surface of the roof should be installed by a roofer since he is responsible for rain safety.



If the separation distance is too small, the conductive parts of the building structure must be connected to the air-termination system. The effects of the currents must be taken into account.

Figure 5.2.2.4.1 Air-termination system for large roofs – Internal down conductors

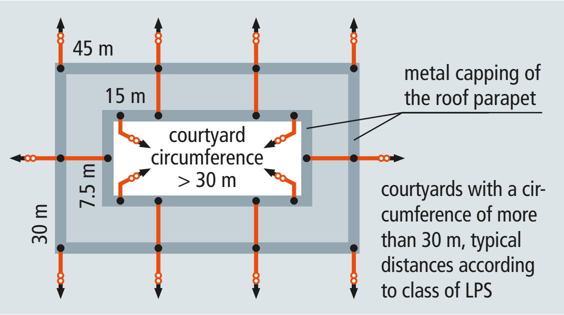


Figure 5.2.2.5.1 Down-conductor systems for courtyards

The effects of partial lightning currents flowing through internal down conductors within the structure must be taken into account. When designing the internal lightning protection system, the resulting electromagnetic field in the vicinity of the down conductors must be considered (observe injection to electrical / electronic systems).

5.2.2.5 Courtyards

Structures with enclosed courtyards with a perimeter of more than 30 m require down conductors with the distances shown in **Table 5.2.1.1** (**Figure 5.2.2.5.1**).

5.2.3 Down conductors of an isolated external lightning protection system

If an air-termination system consists of air-termination rods on isolated masts (or one mast), they assume the function of an air-termination system and down conductor system at the same time (**Figure 5.2.3.1**). Each individual mast must be fitted with at least one down conductor. Steel masts or masts with interconnected reinforcing steel require no additional down conductors. For aesthetic reasons, a metal flag pole, for example, can also be used as an air-termination system.

The separation distance s between the air-termination and down-conductor systems and the structure must be maintained. If the air-termination system consists of one or more spanned wires or cables, each cable end on which the conductors are fixed requires at least one down conductor (**Figure 5.2.3.2**).

If the air-termination system forms an intermeshed network of conductors, i.e. the individual spanned wires or cables are interconnected to form a mesh (cross-linked), there must be at least one down conductor on each cable end on which the conductors are fixed (**Figure 5.2.3.3**).

5.2.4 High voltage-resistant, insulated down conductor – HVI Conductor

The main function of an external lightning protection system is to intercept a lightning strike according to the principle of Benjamin Franklin, discharge it along the building and safely conduct it to the ground. To prevent dangerous flashover between the parts of the external lightning protection system and conductive parts inside the structure (electrical / electronic equipment, pipes, ventilation ducts, etc.) resulting from a direct lightning strike, it is imperative to maintain the separation distance s when designing and installing a lightning protection system.

The separation distance s is calculated according to section 6.3 of the IEC 62305-3 (EN 62305-3) standard.

However, it is often impractical to keep the separation distance in new and existing structures. For aesthetic reasons, modern architecture often does not allow to use GRP spacers to lead the down conductor to the ground. In modern industrial plants, the roof is often the last installation level for equipment such as ventilation and air-conditioning systems, antennas, different pipe systems and cable ladders. In this context, it is imperative to observe lightning protection systems and maintain the necessary separation distances. Direct lightning strikes to structures protruding above the roof can be prevented if air-termination systems dimensioned according to the rolling

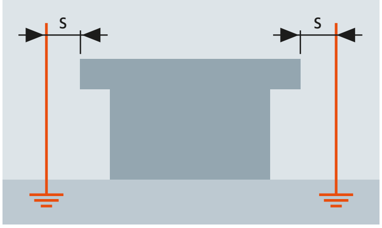


Figure 5.2.3.1 Air-termination masts isolated from the building

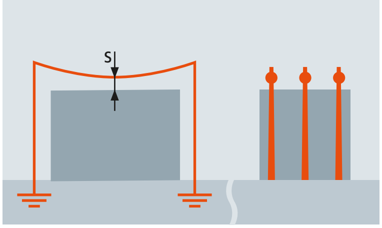


Figure 5.2.3.2 Air-termination masts spanned with cables

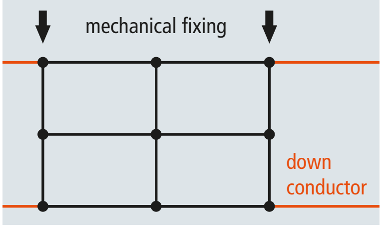


Figure 5.2.3.3 Air-termination masts spanned with cross-linked cables (meshes)

sphere method are ideally positioned. These structures are typically connected to the technical equipment of the building. Discharging the lightning current to earth while maintaining a sufficient separation distance s and ensuring the aesthetical appearance of the building is a special challenge. HVI (High Voltage Insulation) Conductors are an ideal solution.

Separation distance

The calculation of the separation distance forms the basis for the decision whether and which HVI Conductor can be used for the installation. Consequently, the design of an isolated lightning protection system is based on the separation distance. To be able to take adequate protection measures, the separation distance must be already calculated at the design stage. Chapter 5.6 gives a detailed description of the different calculation options for determining the separation distance. The absolute conductor lengths are decisive for calculating the separation distance particularly in case of HVI Conductors. According to IEC 62305-3 (EN 62305-3), the separation distance s for preventing uncontrolled flashover is calculated as follows:

$$s = \frac{k_i \cdot k_c}{k_m} \cdot l$$

s	separation distance
k_i	depends on the selected class of LPS
k_c	depends on the lightning current flowing through the down conductors
k_m	depends on the material of the electrical insulation
l	length along the air-termination system or down conductor in metres from the point where the separation distance is supposed to be determined to the next equipotential bonding or earthing point

The separation distance is determined by means of the length (l) of the down conductor, the class of LPS (k_i), the distribution of the lightning current to different down conductors (k_c) and the material factor (k_m).

Design and functional principle of HVI Conductors

The basic principle of a high-voltage-resistant, insulated down conductor is that a lightning current carrying conductor is covered with insulating material to ensure that the required separation distance s from other conductive parts of the building structure, electrical lines and pipelines is maintained. In principle, a high-voltage-resistant, insulated down conductor must fulfil the following requirements if it is used to prevent impermissible proximities:

- Sufficient electric strength of the insulation in case of lightning voltage impulses along the entire HVI Conductor
- Prevention of creeping discharge
- Sufficient current carrying capability thanks to a sufficient cross-sectional area of the down conductor
- Lightning current carrying connection of the down conductor to the air-termination system (air-termination rod, air-termination conductor, etc.)
- Connection to the earth-termination or equipotential bonding system

If certain high-voltage boundary conditions are fulfilled, the separation distance s can be maintained by covering the down conductor with insulating materials with a high electric strength. However, possible creeping discharge must be prevented! This problem cannot be solved by using a conductor which is covered with insulating materials only.

Creeping discharge near proximities (e.g. between earthed metal conductor holders and the feed point), which may lead to an overall flashover at the surface over great conductor lengths, already occurs in case of relatively low impulse voltages.

Areas where insulating material, metal (at high voltage potential or earthed) and air coincide are critical points where creeping discharge may occur. This environment is highly stressed since creeping discharge can arise and the electric strength can be significantly reduced. Creeping discharge is to be expected when normal components of the electric field strength E (vertical to the surface of the insulating material) exceed the creeping discharge inception voltage and tangential field components (in parallel to the surface of the insulating material) accelerate the propagation of the creeping discharge (**Figure 5.2.4.1**).

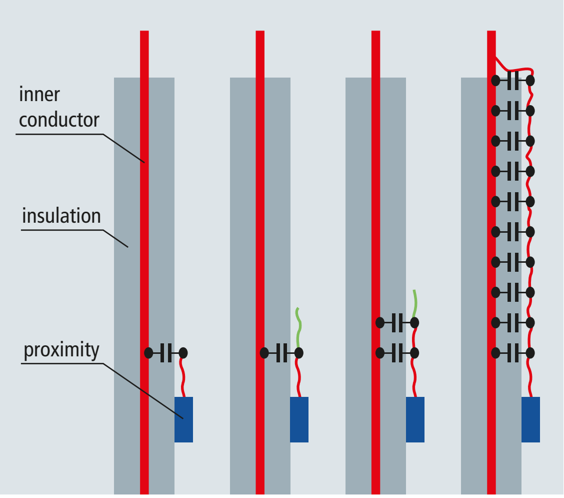


Figure 5.2.4.1 Formation of a creeping discharge at an insulated down conductor without special sheath

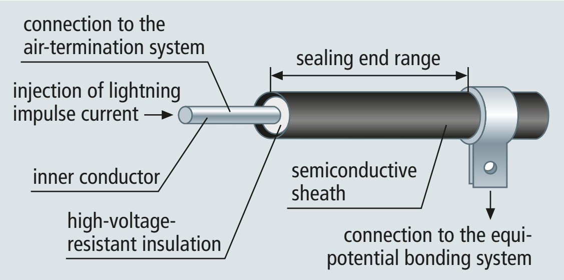


Figure 5.2.4.2 Components of a HVI Conductor

The creeping discharge inception voltage defines the resistance of the entire insulation arrangement and has a lightning impulse voltage between 250 and 300 kV for such arrangements.

Coaxial cables with semi-conductive sheath

The specifically developed single-conductor coaxial cable (HVI Conductor) allows to prevent creeping discharge and to safely discharge the lightning current to the ground (**Figure 5.2.4.2**).

Insulated down conductors with field control via a semi-conductive sheath prevent creeping discharge by specifically influencing the electric field in the sealing end range. Thus, the lightning current is led into the special cable and is safely discharged while maintaining the necessary separation distance s. It must be observed that the magnetic field surrounding the current carrying inner conductor is not interfered with.

A specially adapted sealing end range of the conductor was created by optimising the field control. The length of this sealing end range depends on the type of HVI Conductor. This special sealing end begins at the feed point (connection to the air-termination system) and ends with the equipotential bonding connection element at a defined distance (**Figure 5.2.4.3**).

Based on the necessary separation distance s, the maximum conductor length L_{max} of such an insulated down conductor can be calculated as follows:

$$L_{\max} = \frac{k_m \cdot s}{k_i \cdot k_c}$$

Types of HVI Conductors

HVI Conductors were adapted to meet the constantly growing requirements on the installation environment. Three types of HVI Conductors are available:

- HVI light Conductor, DEHNcon-H
- HVI Conductor, HVI long Conductor
- HVI power Conductor

Each of these types of HVI Conductors (**Figure 5.2.4.4**) has different thicknesses and characteristics and thus different installation requirements. HVI Conductors are available with black and grey sheath. The additional grey sheath allows a more aesthetical installation of the HVI Conductor on the relevant building. The most important parameters of the different HVI Conductors are listed in **Table 5.2.4.1**.

HVI Conductors fulfil the requirements of the IEC 62561-2 (EN 62561-2) standard. In the following, the different types of HVI Conductors will be described in detail.

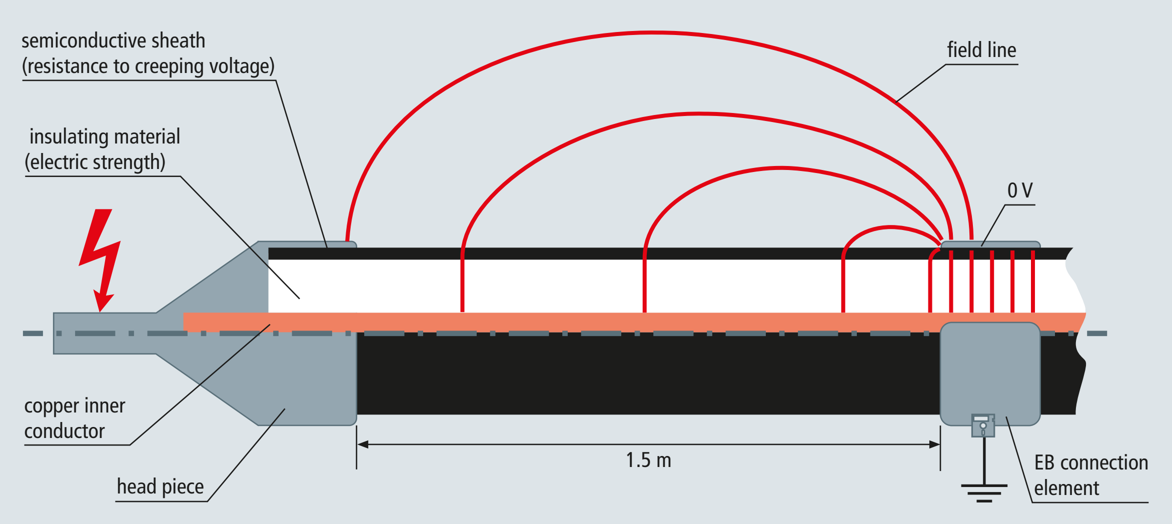


Figure 5.2.4.3 Functional principle sealing end / field control

	s in air	s in case of solid material	Length of the sealing end	Cross-section of the inner conductor (Cu)	Outer diameter	Bending radius
HVI light Conductor, DEHNcon-H, HVI Conductor, HVI long Conductor	s ≤ 0.45 m	s ≤ 0.9 m	≤ 1.2 m	19 mm^2	Grey 20 mm	≥ 200 mm
	s ≤ 0.75 m	s ≤ 1.5 m	≤ 1.5 m	19 mm^2	Black 20 mm Grey 23 mm	≥ 200 mm ≥ 230 mm
HVI power Conductor, HVI power long Conductor	s ≤ 0.90 m	s ≤ 1.8 m	≤ 1.8 m	25 mm^2	Black 27 mm Grey 30 mm	≥ 270 mm ≥ 300 mm

Table 5.2.4.1 Parameters of a HVI Conductor

HVI light Conductor (s ≤ 0.45 m in air, s ≤ 0.9 m in case of solid material)

Irrespective of the hazard of possible lightning strikes, pipelines, electrical and information technology systems as well as PV systems are spread at a large scale across the roof surface. Due to this installation situation and the dimensions of the building, it is almost impractical to maintain the separation distance by means of non-insulated conductors. However, according to the standard, it is imperative to consistently intermesh the air-termination system while maintaining the separation distances.

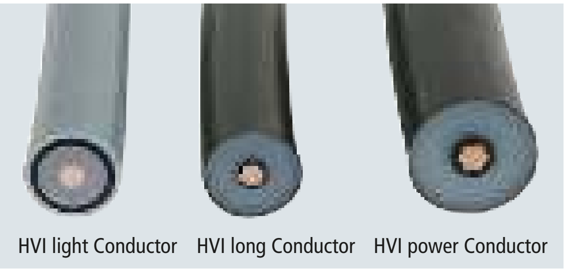


Figure 5.2.4.4 Different types of HVI Conductors

Figure 5.2.4.5 Protection of a PV system by means of a HVI light Conductor

The HVI light Conductor is a system for maintaining the separation distance in case of intermeshed air-termination systems on flat roofs. The high-voltage-resistant insulation of the HVI light Conductor prevents uncontrolled flashover e.g. through the roofing to metal or electric parts underneath it.

This system significantly differs from the standard HVI Conductor due to the fact that no direct connection (no sealing end) to the functional equipotential bonding system of the building must be established. The HVI light Conductor (adjustment range) is connected at the lower part of the supporting tube by means of metal conductor holders, thus facilitating installation (**Figure 5.2.4.5**).

It is equally important that the real conductor lengths of the HVI light Conductor are used to calculate the separation distance. In this context, the conductor length at the supporting tube up to the connecting plate (connection to the air-termination rod) must also be observed.

DEHNcon-H (s ≤ 0.45 m in air, s ≤ 0.9 m in case of solid material)

Particularly in residential and low buildings, it can be problematic to install bare, uninsulated conductors due to proximities. In this case, it is mostly impractical to consistently maintain the necessary separation distances. In addition to the IEC 62305 (EN 62305) lightning protection standard, the IEC 60728-11 (EN 60728-11) standard, which requires that radio towers should be separately integrated in the lightning protection system of buildings, if possible, provides information on separation distances. The DEHNcon-H Conductor is ideally suited for this purpose.

Depending on field of application, two types of DEHNcon-H Conductors (pre-assembled) are available:

- DEHNcon-H, HVI light Conductor I
- DEHNcon-H, HVI light Conductor III

DEHNcon-H, HVI light Conductor I is used if the air-termination system is directly connected to the earth-termination sys-

Figure 5.2.4.6 Connection of DEHNcon-H (HVI light Conductor I) to the earth-termination system

Figure 5.2.4.7 Protection of a residential building by means of DEHNcon-H (HVI light Conductor III)

Figure 5.2.4.8 Protection of a biomethane plant by means of a HVI Conductor I

tem of the building (**Figure 5.2.4.6**). DEHNcon-H, HVI light Conductor III with a sealing end that must be established on site is used if the air-termination system is to be connected to other parts (e.g. connection to the eaves). The separation distance at the connection point is s ≤ 0.175 m in air or is s ≤ 0.35 in case of solid material (**Figure 5.2.4.7**).

HVI Conductor (s ≤ 0.75 m in air, s ≤ 1.5 m in case of solid material)

The standard HVI Conductor offers a wide range of installation options. For example, it protects large roof-mounted structures, antennas and masts including information technology equipment against direct lightning strikes. Moreover, this conductor can be routed up to the earth-termination system. If this is not required, it can be connected to existing conventional lightning protection systems (elevated / isolated ring conductor). Depending on the field of application, two types (preassembled) are available:

- HVI Conductor I
- HVI Conductor III

HVI Conductor I is used if the air-termination system of the external lightning protection system is directly connected to the earth-termination system of the building (**Figure 5.2.4.8**). HVI Conductor III with a fixed sealing end and a sealing end to be established on site is typically used where the total length cannot be exactly determined at the design stage. It is also used if e.g. several parts of the structure to be protected are jointly connected to the earth-termination system of the building via an elevated / isolated ring conductor (**Figure 5.2.4.9**).

Connection to the equipotential bonding system of the building (functional equipotential bonding) is required to establish the sealing end of the HVI Conductor.

HVI long Conductor (s ≤ 0.75 m in air, s ≤ 1.5 m in case of solid material)

Due to unknown and constantly changing building situations, the exact lengths of HVI Conductors for new buildings or buildings in need of renovation can frequently not be determined at the design stage of a lightning protection system. Therefore, the HVI long Conductor can be assembled on site and is available on a reel with a length of 100 m. The installer determines the lengths, strips the conductor and fixes the sealing ends on site.

Connection to the equipotential bonding system of the building (functional equipotential bonding) is required to establish the sealing end of the HVI long Conductor.

HVI power Conductor (s ≤ 0.9 m in air, s ≤ 1.8 m in case of solid material)

The HVI power Conductor is the most powerful type of high-voltage-resistant, insulated HVI Conductors. Compared to the standard HVI Conductor, an equivalent separation distance of 0.9 m in air and 1.8 m in case of solid material can be maintained. The HVI power Conductor and the associated components are tested for a lightning current carrying capability up to 200 kA (10/350 μs) and can therefore be used for all classes of LPS (I – IV).

This type of conductor is particularly installed for buildings such as hospitals, data centres and silos where large separation distances must be maintained due to the building dimensions (heights). Moreover, it allows larger conductor lengths to the earth-termination system (**Figure 5.2.4.10**).

The conductor is installed in the supporting tube. An integrated spring contact automatically establishes functional equipotential bonding for the sealing end. The supporting tube must be connected to the functional equipotential bonding system of the structure.

Functional principle of the sealing end

High impulse voltages cause flashover at the surfaces of insulating material if no additional measures are taken. This effect is also known as creeping flashover. If the creeping discharge inception voltage is exceeded, a surface discharge is initiated which can easily flash over a distance of several metres. To prevent creeping discharge, HVI Conductors feature a special outer sheath which allows to discharge high lightning impulse voltages to a reference potential. For functional reasons, a connection is established in the sealing end range between the semiconductive outer sheath and the equipotential bonding system of the building (no lightning voltage). This connection to the equipotential bonding system can made e.g. on earthed metal roof-mounted structures located in the protected volume of the lightning protection system, earthed parts of the building structure / radio towers that do not carry lightning voltage or the protective conductor of the low-voltage system. **Figure 5.2.4.3** shows the functional principle of field control via the semiconductive sheath of the HVI Conductor.

No conductive or earthed parts such as metal conductor holders, structural parts or reinforcements may be installed in the sealing end range (area between the head piece and the equipotential bonding connection element). **Figure 5.2.4.11** shows the separation distance s in the form of a cylinder.

Installation of the connection elements

Black and grey HVI Conductors are available. When installing the connection elements of HVI Conductors, it is important

Figure 5.2.4.9 Installation of a HVI Conductor III with sealing end

Figure 5.2.4.10 Installation of a HVI power Conductor

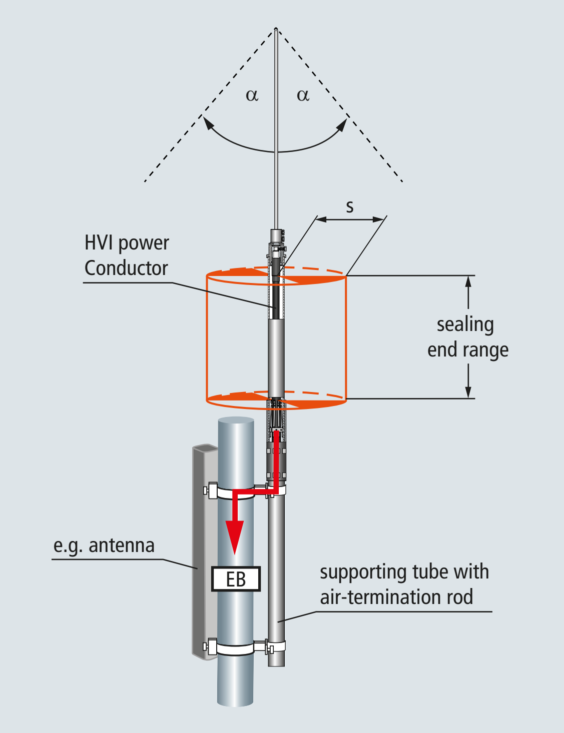


Figure 5.2.4.11 Sealing end range

Figure 5.2.4.12 HVI strip stripping tool

that the high-voltage-resistant insulation is stripped correctly. User-friendly tools are available for this purpose.

If the grey HVI Conductor (exception: HVI light Conductor) is used, the grey sheath must be removed by about 65 mm without damaging the black sheath of the conductor underneath it. After that, the outer sheath and the PE insulation are easily and safely stripped by 35 mm using the HVI strip tool (**Figure 5.2.4.12**) which ensures that the copper conductor underneath them is not damaged.

The connection element is then screwed onto the conductor. It is fixed by means of two threaded pins and is electrically contacted. Finally, a self-adhesive heat-shrinkable sleeve is applied to the conductor by means of a hot air blower. This heat-shrinkable sleeve provides additional mechanical protection and protects the conductor end from the ingress of moisture, thus preventing corrosion of the inner copper conductor.

Installation of the EB connection element

EB connection elements must be installed depending on the type of HVI Conductor, installation conditions and sealing end length according to the separation distance. More detailed information can be found in the relevant installation instructions.

If a grey HVI Conductor is used, the additional grey sheath must be removed to contact the semiconductive sheath underneath it. After that, the EB connection element can be installed.

Use of HVI Conductors for protecting roof-mounted structures

Metal and electrical roof-mounted structures protrude from the roof level and are exposed to lightning strikes. Due to conductive connections into the structure via pipes, ventilation ducts and electrical lines, partial lightning currents may be injected into the structure.

The injection of partial lightning currents into the structure is prevented by connecting an isolated air-termination system to the insulated down conductor which ensures that the entire electrical / metal equipment protruding from the roof is located in the protected volume. The lightning current is led past the structure to be protected and is distributed via the earth-termination system.

Installation of HVI Conductors in façades

It is often a special challenge to inconspicuously integrate a down conductor while maintaining the required separation distance s. In the past, this was achieved by using a round wire which was fixed by DEHNiso spacers. This horizontal distance is often not acceptable although it was required from a technical point of view. HVI Conductors can be directly installed on or in façades and thus open up different design possibilities. This innovative technology combines functionality and design and therefore is an important aspect of modern architecture. HVI Conductors allow to easily discharge the lightning current to the earth-termination system without having to maintain distances from metal and electrical parts.

Use of HVI Conductors for transceivers

Cell sites are often installed on rented roof space. The cell site operator and the building owner usually agree that the instal-

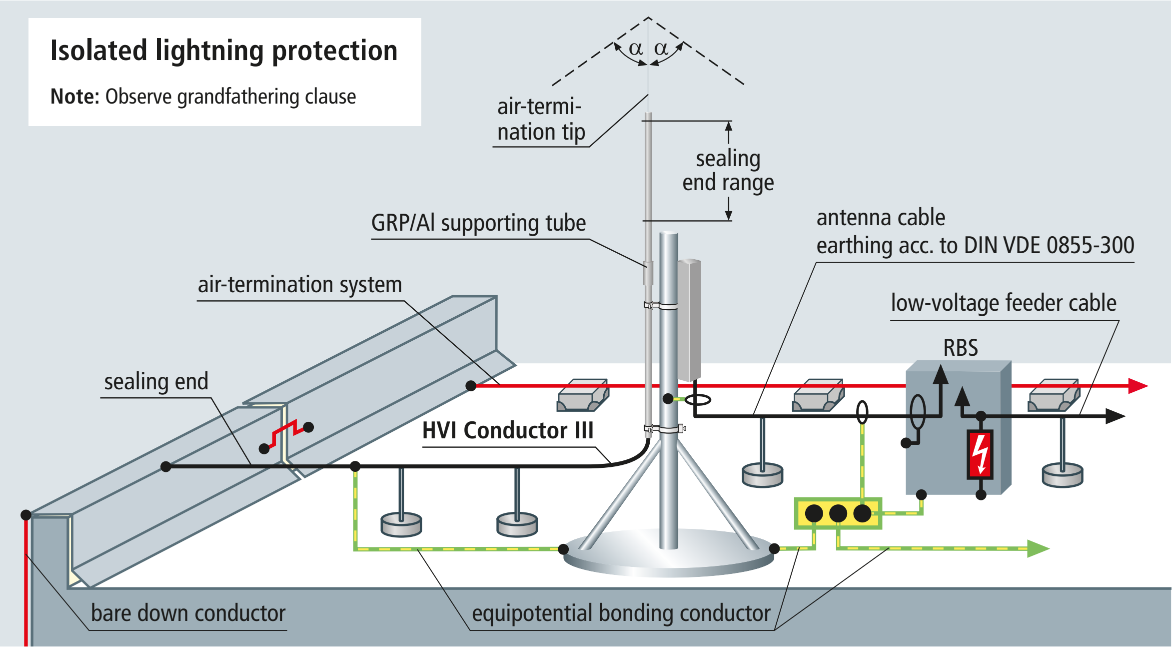


Figure 5.2.4.13 Integration of an antenna in an existing lightning protection system by means of a HVI Conductor

lation of the cell site must not present an additional risk for the building.

For the lightning protection system this means that no partial lightning currents may enter the building in case of a lightning strike to the radio tower since partial lightning currents inside the building would threaten the electrical and electronic devices.
For this reason, the radio tower must be installed in conjunction with an isolated air-termination system and an insulated down conductor (**Figure 5.2.4.13**). Thanks to this structure which is fixed at the antenna standpipe, areas exposed to wind are kept to a minimum (HVI Conductor integrated in the supporting tube) and additional mechanical stress on the antenna standpipe is minimised (**Figure 5.2.4.14**).

Use of HVI Conductors for thatched roof

Due to their specific fire load, thatched and soft roofs pose a special challenge for installing a lightning protection system. If these highly flammable materials are used, separation distances must be maintained from these objects. HVI Conductors are also suited for installation on soft roofs. Uncontrolled flashover to installations is prevented since the lightning current is separately conducted to the earth-termination system. In addition, this solution meets architectural requirements. For more detailed information on thatched roofs, please refer to chapter 5.1.5.

Figure 5.2.4.14 HVI Conductor installed on a radio tower

Use of HVI Conductors for installations with a risk of explosion

Lightning strikes to or near structures and incoming supply lines can damage the structure itself or persons and equipment therein and can also affect and influence the immediate vicinity. There is a particularly high risk when processing flammable substances such as gas, vapour, mist or dust which, when mixed with air, can form an ignitable atmosphere and cause an explosion in combination with an ignition source. From a lightning protection point of view, more detailed information is required on this topic to ensure proper installation of protection systems.

According to the German Ordinance on Industrial Safety and Health (BetrSichV), the operator must create an explosion protection document where the potential risks resulting from the persistence and expansion of explosive atmospheres are assessed and defined in an Ex zone plan. The following Ex zones are distinguished:

Zone 0	Place in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is present continuously, for long periods or frequently
Zone 1	Place in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is likely to occur occasionally in normal operation
Zone 2	Place in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only
Zone 20	Place in which an explosive atmosphere, in the form of a cloud of combustible dust in air, is present continuously, for long periods or frequently
Zone21	Place in which an explosive atmosphere, in the form of a cloud of combustible dust in air, is likely to occur in normal operation occasionally
Zone 22	Place in which an explosive atmosphere, in the form of a cloud of combustible dust in air, is not likely to occur in normal operation but, if it does occur, will persist for a short period only

The division of the relevant structure into Ex zones allows to identify possible ignition sources. In EN 1127-1 or the German TRBS 2152-3, lightning is defined as ignition source in an explosive atmosphere. If lightning strikes an explosive atmosphere, it is ignited. High currents flow away from the point of strike and may generate sparks along the discharge path. Lightning-related ignition sources are, for example:

- Melting at the point of strike
- Heating of discharge paths
- Uncontrolled flashover if the separation distance is not maintained
- Induced voltages in cables and lines
- Lightning strikes to lines entering potentially explosive atmospheres

If lightning protection systems are installed on or in a structure for which potentially explosive atmospheres (zones) are defined, they must meet the requirements of the relevant zones. The division into zones which is required for this purpose is included in the explosion protection document according to the German Ordinance on Industrial Safety and Health. In Ex systems with Ex zone 2 and 22, explosive atmospheres are only to be expected in rare and unpredictable cases. "Persistence of an ignitable explosive atmosphere" in these zones and a lightning strike rarely occur at the same time. Therefore, interception of lightning strikes (lightning strikes to the air-termination system) is permitted in these zones. Nevertheless, uncontrolled flashover resulting from the fact that the separation distance is not maintained and heating of the discharge paths are not acceptable / allowed in all Ex zones.

Electrical isolation of the lightning protection system from conductive parts of the building structure and insulation with respect to the electrical lines in the building prevents flashover and thus dangerous sparking in potentially explosive atmospheres.

The HVI Conductor allows to maintain the separation distance and prevents impermissible heating of the discharge paths. In the high-voltage-resistant, insulated down conductor, the lightning current is directly conducted to the earth-termination system without causing flashover. The HVI Conductor can be directly installed next to metal parts of the building structure or electrotechnical systems (**Figure 5.2.4.15**).

Figure 5.2.4.15 HVI Conductor installed on a gas pressure control and measurement system

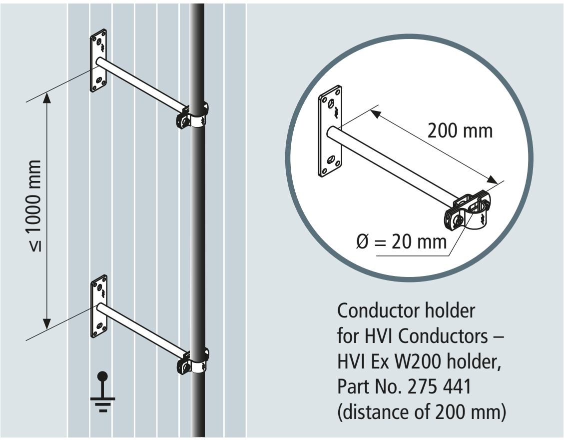


Figure 5.2.4.16 Version for use in hazardous areas 1, metal façade

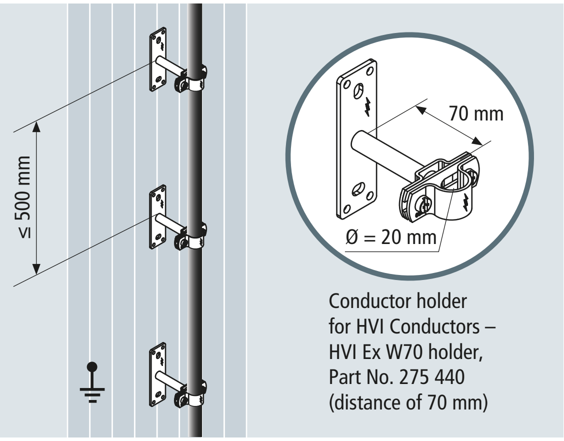


Figure 5.2.4.17 Version for use in hazardous areas 2, metal façade

If lightning currents flow through the HVI Conductor, a potential arises at the outer semiconductive sheath due to the low-power capacitive displacement current at remote earthing points. The shorter the distance between the special conductor holders (functional equipotential bonding) and the semiconductive sheath, the lower is this potential. If these installation instructions are observed when installing the HVI Conductor in Ex zones 1 and 2 or 21 and 22, discharge (sparking) is prevented when lightning current flows through the HVI Conductor. However, the effects of the lightning electromagnetic impulse are not reduced. Two examples of how to install HVI Conductors can be found in **Figures 5.2.4.16 and 5.2.4.17.**

Use of HVI Conductors for biogas plants

When planning lightning protection measures for a biogas plant, an integrated lightning protection concept must be created. In this context, particularly the protection of fermenters, post-fermenters and fermentation tanks, which typically form round containers with a large diameter, poses a challenge. A dome (membrane) made of rubber-like material is mostly located on top of a fermenter. Due to the diameter and height of the fermenter with membrane, extremely high air-termination systems must be installed to protect the entire fermenter from direct lightning strikes. As an alternative to telescopic lightning protection masts, which are installed next to a fermenter with an adequate foundation, air-termination masts with HVI Conductors can be directly installed on the fermenter (**Figure 5.2.4.18**). These air-termination masts with integrated HVI Conductor can be installed up to a free length ≤ 8.5 m.
The air-termination mast can be equipped with one or two HVI Conductors. The number of conductors to be installed depends on the effective conductor length and separation distance. Since the HVI Conductors may have to be installed in explosive areas, the outer sheath of the second conductor must be additionally connected to the equipotential bonding system at a distance ≤ 1000 mm. More detailed information can be found in the relevant installation instructions.

Figure 5.2.4.18 Protection of a biogas fermenter by means of a HVI Conductor

5.3 Materials and minimum dimensions for air-termination and down conductors

Table 5.3.1 gives the minimum cross-sectional area, configuration and material of air-termination systems.
These requirements result from the ability of the materials to electrically conduct the lightning current (temperature rise) and the mechanical stress when in use.
When using a round wire with a diameter of 8 mm as an air-termination tip, a maximum free height of 0.5 m is permitted. The maximum free height of a round wire with a diameter of 10 mm is 1 m.

Note: According to Table 8 of IEC 62305-3 (EN 62305-3), the minimum cross-sectional area for a connecting cable between two equipotential bonding bars is 16 mm^2 (copper).

Material	Configuration	Cross-sectional area in [mm^2]
Copper, tin-plated copper	Solid tape	50
	Solid round [b)]	50
	Stranded [b)]	50
	Solid round [c)]	176
Aluminium	Solid tape	70
	Solid round	50
	Stranded	50
Aluminium alloy	Solid tape	50
	Solid round	50
	Stranded	50
	Solid round	176
Copper coated aluminium alloy	Solid round	50
Hot-dipped galvanised steel	Solid tape	50
	Solid round	50
	Stranded	50
	Solid round [c)]	176
Copper-coated steel	Solid round	50
	Solid tape	50
Stainless steel	Solid tape [d)]	50
	Solid round [d)]	50
	Stranded	50
	Solid round [c)]	176

[a)] Mechanical and electrical properties as well as corrosion resistance properties must meet the requirements of the future IEC 62561 series.

[b)] 50 mm^2 (diameter of 8 mm) may be reduced to 25 mm^2 in certain applications where the mechanical strength is not an essential requirement. In this case, consideration should be given to reduce the spacing between the fasteners.

[c)] Applicable for air-termination rods and earth entry rods. For air-termination rods where mechanical stress such as wind load is not critical, an at least 1 m long rod with a diameter of 9.5 mm may be used.

[d)] If thermal and mechanical considerations are important, these values should be increased to 75 mm^2.

Table 5.3.1 Material, configuration and minimum cross-sectional area of air-termination conductors, air-termination rods, earth entry rods and down conductors [a)] according to Table 6 of IEC 62305-3 (EN 62305-3)

Tests with a PVC-insulated copper conductor and an impulse current of 100 kA (10/350 µs) revealed a temperature rise of 56 K. Thus, e.g. a copper cable NYY 1 x 16 mm^2 can be used as a down conductor or as an aboveground and buried connecting cable. This has been normal installation practice for years, for example when installing down conductors underneath a façade.

This is also pointed out in section 5.6.2 of Supplement 1 of the German DIN EN 62305-3 standard.

5.4 Mounting dimensions for air-termination systems and down conductors

The following dimensions (**Figure 5.4.1**) have proven to be successful in practice and are mainly due to the mechanical forces acting on the components of the external lightning protection system.

These mechanical forces occur not as a result of the electrodynamic forces produced by the lightning currents, but as a result of the compressive and tensile forces, e.g. due to temperature-related changes in length, wind loads or snow loads.

The maximum distance of 1.2 m between the conductor holders primarily refers to St/tZn (relatively rigid). For aluminium, distances of maximum 1 m have proven themselves in practice.

Figures 5.4.1 and 5.4.2 show the mounting dimensions for an external lightning protection system recommended by the IEC 62305-3 (EN 62305-3) standard. Wherever practical, the separation distance s from windows, doors and other apertures should be maintained when installing down conductors.

Figure 5.4.3 shows the use of a down conductor on a flat roof.

Other important mounting dimensions can be found in **Figures 5.4.3 to 5.4.5.**

Surface earth electrodes (e.g. ring earth electrodes) are installed around the building at a depth > 0.5 m and about 1 m away from the structure (**Figure 5.4.4**).

The earth entry rods or connectors of foundation earth electrodes (ring earth electrodes) must be protected against corrosion. Measures such as anticorrosive tapes or PVC-sheathed wires must be taken at least 0.3 m above and below the turf (earth entry) (**Figure 5.4.5**). In many cases, it is easier to use terminal lugs made of stainless steel (V4A). Concrete-encased fixed earthing terminals made of stainless steel (V4A) are an aesthetically acceptable and corrosion-free connection possibility.

The terminal lug for equipotential bonding inside the building must also be protected against corrosion in moist and wet rooms.

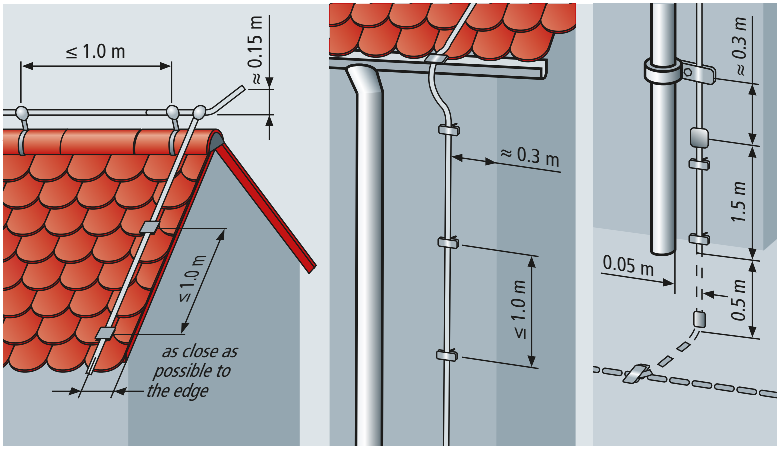


Figure 5.4.1 Examples (details) of an external lightning protection system installed on a building with a sloped tiled roof

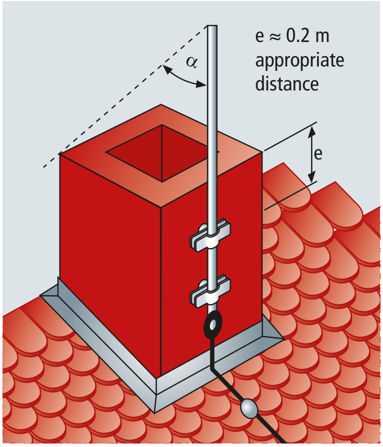


Figure 5.4.2 Air-termination rod for a chimney

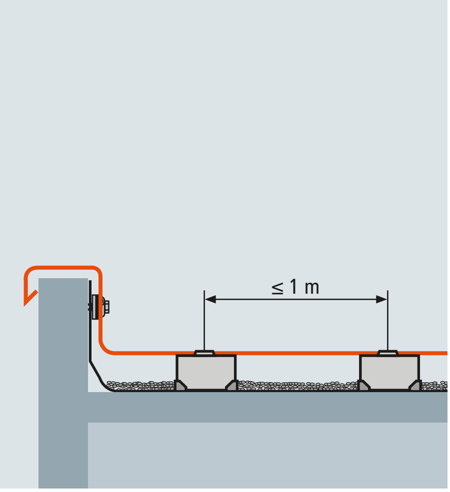


Figure 5.4.3 Application on a flat roof

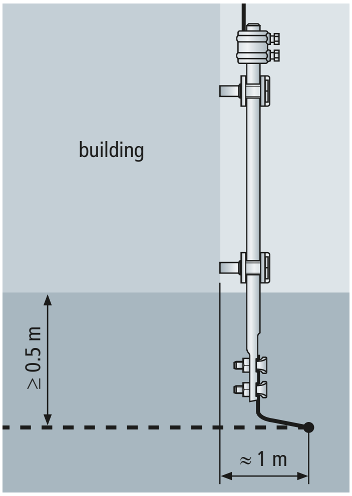


Figure 5.4.4 Dimensions for ring earth electrodes

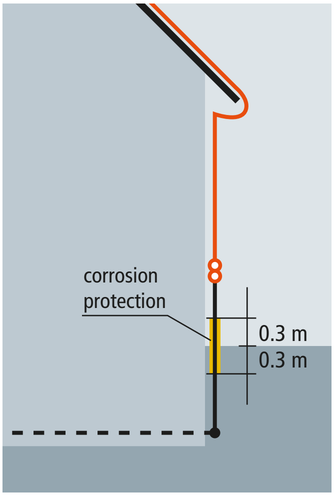


Figure 5.4.5 Points threatened by corrosion

Provided that no particularly aggressive environmental influences must be taken into account, the material combinations (air-termination systems, down conductors and structural parts) according to **Table 5.4.1** have proven to be successful in practice. These values are empirical values.

5.4.1 Changes in length of metal wires

The temperature-related changes in length of air-termination systems and down conductors are often underestimated in practice.

In many cases, older regulations and stipulations generally recommended to install an expansion piece approximately every 20 m. This recommendation was based on the use of steel wires which used to be the usual and sole material. The higher coefficients of linear expansion of stainless steel, copper and especially aluminium were not taken into account.

In the course of the year, temperature changes of 100 K must be expected on and around the roof. The resulting changes in length for the different metal wire materials are shown in **Table 5.4.1.1**. It can be seen that the temperature-related change in length between steel and aluminium differs by a factor of 2.

In practice, the requirements shown in **Table 5.4.1.2** apply to expansion pieces.

When using expansion pieces, it must be observed that they provide flexible length compensation. It is not sufficient to bend the metal wires into an S shape since these manually installed "expansion pieces" are not sufficiently flexible.

When connecting air-termination systems, for example to metal cappings of the roof parapet surrounding the edges of roofs, it should be ensured that there is a flexible connection by means of suitable components or other measures. If this flexible connection is not made, there is a risk that the metal capping of the roof parapet will be damaged by the temperature-related change in length.

To compensate for the temperature-related changes in length of the air-termination conductors, expansion pieces must be used for length compensation (**Figure 5.4.1.1**).

	Steel (tZn)	**Aluminium**	**Copper**	**StSt (V4A)**	**Titanium**	**Tin**
Steel (tZn)	yes	yes	**no**	yes	yes	yes
Aluminium	yes	yes	**no**	yes	yes	yes
Copper	**no**	**no**	yes	yes	**no**	yes
StSt (V4A)	yes	yes	yes	yes	yes	yes
Titanium	yes	yes	**no**	yes	yes	yes
Tin	yes	yes	yes	yes	yes	yes

Table 5.4.1 Material combinations

Material	**Coefficient of linear expansion α** $\frac{1}{10^6}\cdot\frac{1}{K}$	**ΔL** **Calculation formula: ΔL = α · L · ΔT** **Assumed temperature change on the roof: ΔT = 100 K**
Steel	11.5	$\Delta L = 11.5 \cdot 10^{-6} \cdot \frac{1}{K} \cdot 1m \cdot 100K = 0.115\,cm \approx 1.1\frac{mm}{m}$
Stainless steel	16	$\Delta L = 16 \cdot 10^{-6} \cdot \frac{1}{K} \cdot 1m \cdot 100K = 0.16\,cm \approx 1.6\frac{mm}{m}$
Copper	17	$\Delta L = 17 \cdot 10^{-6} \cdot \frac{1}{K} \cdot 1m \cdot 100K = 0.17\,cm \approx 1.7\frac{mm}{m}$
Aluminium	23.5	$\Delta L = 23.5 \cdot 10^{-6} \cdot \frac{1}{K} \cdot 1m \cdot 100K = 0.235\,cm \approx 2.3\frac{mm}{m}$

Table 5.4.1.1 Calculation of the temperature-related change in length ΔL of metal wires for lightning protection systems

Material	**Surface under the fixing of the air-termination system or down conductor**		**Distance of expansion pieces in m**
	soft, e.g. flat roof with bitumen or synthetic roof sheetings	**hard, e.g. pantiles or brickwork**	
Steel	•		≈ 15
		•	≤ 20
Stainless steel / Copper	•		≈ 10
		•	≤ 15
Aluminium	•	•	≤ 10
Use of expansion pieces, if no other length compensation is provided			

Table 5.4.1.2 Expansion pieces in lightning protection – Recommended application

Figure 5.4.1.1 Air-termination system – Expansion compensation by means of a bridging braid

5.4.2 External lightning protection system for an industrial and residential building

Figure 5.4.2.1a shows the design of an external lightning protection system for an industrial building and **Figure 5.4.2.1b** for a residential building with annexed garage. These Figures and the **Tables 5.4.2.1a and 5.4.2.1 b** also show examples of the components used today.

The necessary internal lightning protection measures such as lightning equipotential bonding and surge protection (see also chapter 6) are not taken into account.

Particular attention is drawn to DEHN´s DEHNhold, DEHNsnap and DEHNgrip portfolio of holders.

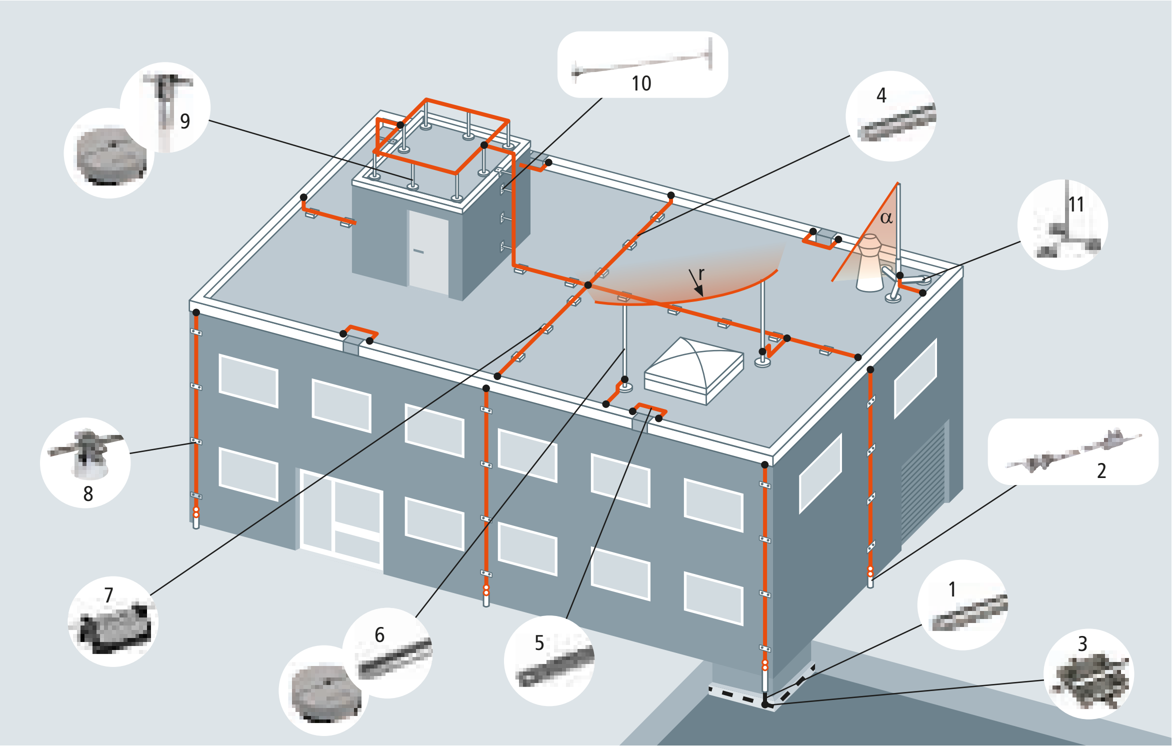


Figure 5.4.2.1a External lightning protection system of an industrial building

No.	Item		Part No.	No.	Item		Part No.
1	Stainless steel wire (Ø 10 mm)	StSt (V4A)	860 010	7	Roof conductor holder for flat roofs		253 050
2	Earth entry rod set	St/tZn	480 150	8	DEHNhold conductor holder		274 160
3	Cross unit	StSt (V4A)	319 209	9	Elevated ring conductor with concrete base with adapted base plate and spacer	StSt (V4A)	102 340 106 160
4	DEHNalu wire (Ø 8 mm)	AlMgSi	840 008				
5	Bridging braid	Al	377 015	10	DEHNiso spacer	ZDC-St/tZn	106 120
6	Air-termination rod with concrete base and adapted base plate	AlMgSi	103 420 102 340	11	Self-supporting air-termination rod		105 500

Table 5.4.2.1a Components for the external lightning protection system of an industrial building

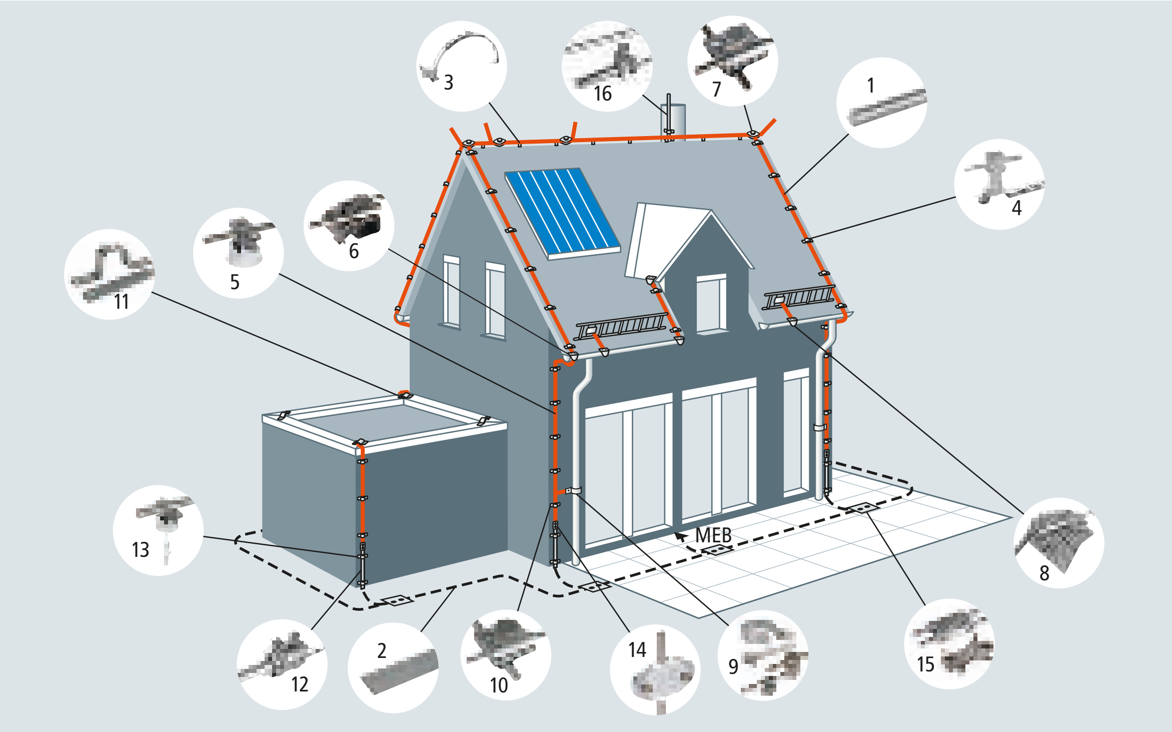


Figure 5.4.2.1b External lightning protection system of a residential building

No.	Item		Part No.
1	DEHNalu wire, semi-rigid (Ø 8 mm)	AlMgSi	840 008
	DEHNalu wire, soft torsionable (Ø 8 mm)	AlMgSi	840 018
2	Steel strip (30 x 3.5 mm)	St/tZn	810 335
	Round wire (Ø 10 mm)	StSt (V4A)	860 010
3	Roof conductor holder for ridge and hip tiles	St/tZn	202 020
		StSt (V4A)	204 109
		StSt (V4A)	204 249
		StSt (V4A)	204 269
		StSt (V4A)	206 109
		StSt (V4A)	206 239
4	Roof conductor holder for conductors on the roof surface	StSt (V4A)	204 149
		StSt (V4A)	204 179
		St/tZn	202 010
		St/tZn	202 050
		St/tZn	202 080
		StSt (V4A)	206 209
		St/tZn	206 309
5	DEHNsnap		204 006
	DEHNgrip		207 009
	DEHNhold conductor holder with plastic base		274 150
	Conductor holder for thermal insulation		273 740
6	Gutter board clamp	St/tZn	339 050
		StSt (V4A)	339 059
		St/tZn	339 060
		StSt (V4A)	339 069
7	MV clamp	St/tZn	390 050
		StSt (V4A)	390 059
8	Snow guard clamp	St/tZn	343 000
9	Downpipe clamp, adjustable for Ø 60–150 mm		423 020
	Downpipe clamp for any cross-section		423 200
	KS connector for connecting conductors		301 000
	KS connector	StSt (V4A)	301 009
10	MV clamp		390 051
11	Bridging bracket	Al	377 006
	Bridging braid	Al	377 015
12	Earth entry rod (Ø 16 mm)		480 150
	complete		480 175
13	Rod holder with plastic base		274 260
14	Number plate for marking test joints		480 006
			480 005
15	Parallel connector		305 000
			306 020
	Cross unit		319 201
	SV clamp	St/tZn	308 220
		StSt (V4A)	308 229
16	Air-termination rod with forged lug		100 100
	Air-termination rod, chamfered on both ends		483 100
	Rod clamp		380 020

Table 5.4.2.1b Components for the external lightning protection system of a residential building

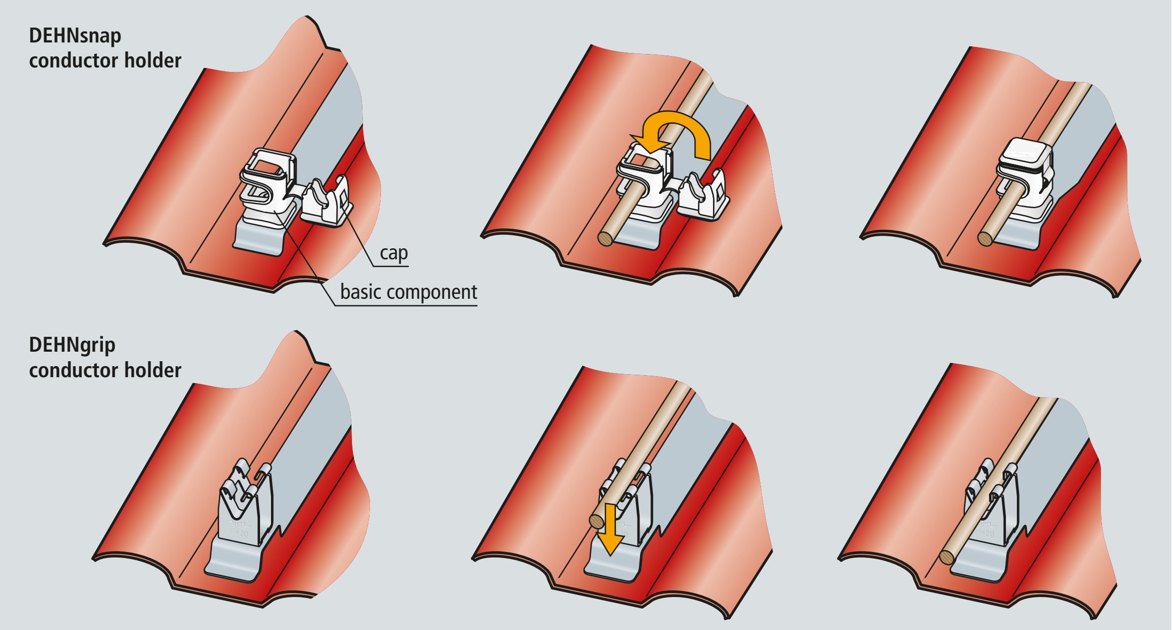


Figure 5.4.2.2 DEHNsnap and DEHNgrip conductor holders

The DEHNhold conductor holder is made of solid stainless steel (V4A) and can be used for different materials such as Al, StSt (V4A), St/tZn and Cu.

The DEHNsnap range of plastic holders (**Figure 5.4.2.2**) is a basic component (roof and wall). The cap simply snaps in and fixes the conductor in the holder, ensuring loose conductor routing. The special snap-in mechanism does not mechanically stress the fastener.

DEHNgrip (**Figure 5.4.2.2**) is a screwless stainless steel (V4A) holder system. This system can be used as a roof and wall conductor holder for conductors with a diameter of 8 mm. The conductor is simply pressed in to fix it in the DEHNgrip (**Figure 5.4.2.2**).

5.4.3 Instructions for mounting roof conductor holders

Ridge and hip tiles

The roof conductor holders are adjusted by means of a locking screw to suit the dimensions of the ridge tile (**Figure 5.4.3.1**).

In addition, conductor holders allow to gradually adjust the conductor routing from the top centre to the lower side (conductor holder can be loosened by either turning the holder or unscrewing the locking screw).

- SPANNsnap roof conductor holder with DEHNsnap plastic conductor holder or DEHNgrip stainless steel (V4A) conductor holder (**Figure 5.4.3.2**). A stainless steel (V4A) tension spring ensures permanent tension. Universal tensioning range from 180 to 280 mm with laterally adjustable conductor routing for 8 mm round conductors.
- FIRSTsnap conductor holder with DEHNsnap plastic conductor holder to be fixed on existing ridge tile clips of dry ridges (**Figure 5.4.3.3**).

The FIRSTsnap conductor holder is snapped on the ridge tile clip of dry ridges and tightened by hand (only turn DEHNsnap).

Interlocking tiles, smooth tiles

UNIsnap roof conductor holders with pre-punched braces are used for roof surfaces. The conductor holder is bent by hand before it is hooked into the pantile (**Figure 5.4.3.4**).

Slated roofs

When used on slated roofs, the inner hook is bent (**Figure 5.4.3.5**) or provided with an additional clamping part (Part No. 204 089).

Interlocking tiles

- FLEXIsnap roof conductor holders for interlocking tiles are directly pressed on the seams (**Figure 5.4.3.6**). The flexible stainless steel (V4A) brace is pushed between the interlock-

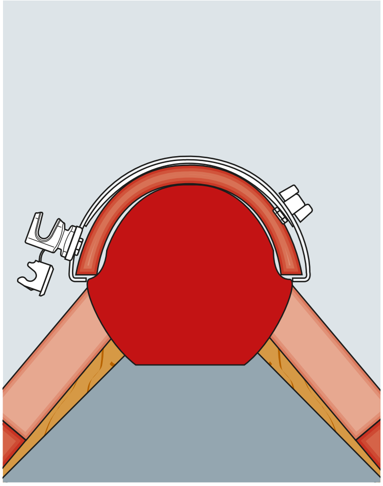


Figure 5.4.3.1 Conductor holder with DEHNsnap for ridge tiles

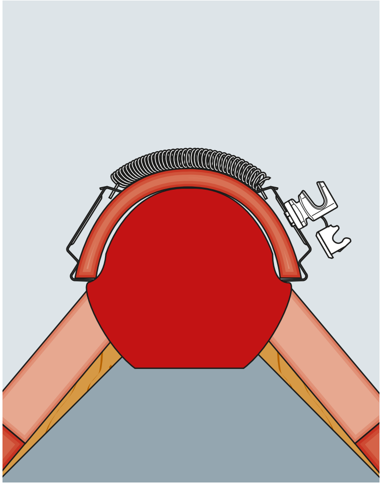


Figure 5.4.3.2 SPANNsnap with DEHNsnap plastic conductor holder

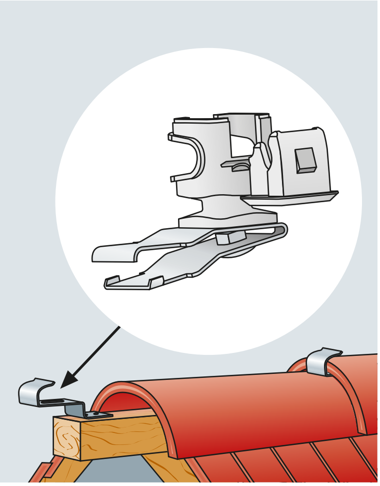


Figure 5.4.3.3 FIRSTsnap for mounting on existing ridge clips

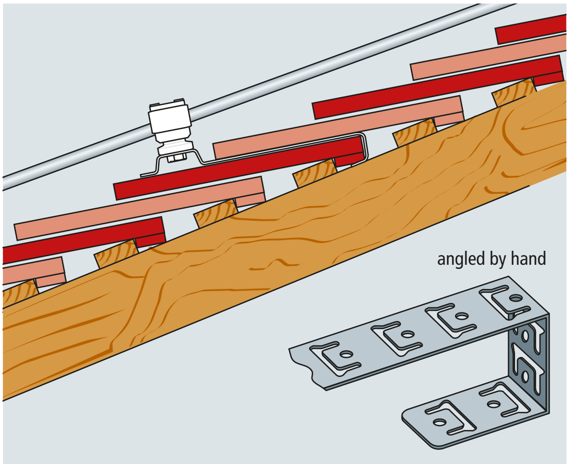


Figure 5.4.3.4 UNIsnap roof conductor holder with pre-punched brace – Used on pantiles and smooth tiles (e.g. pantile roofs)

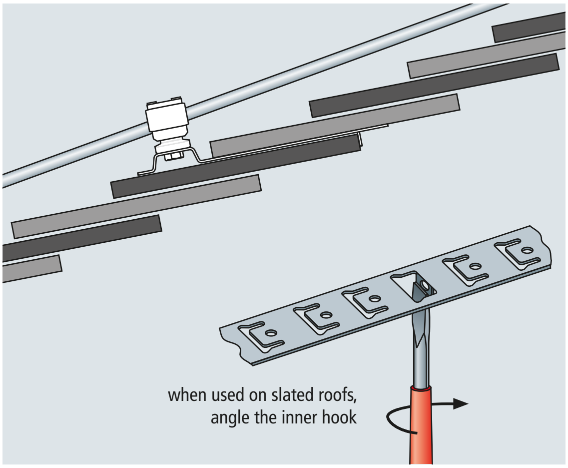


Figure 5.4.3.5 UNIsnap roof conductor holder with pre-punched brace – Used on slated roofs

ing tiles. By pressing on the top interlocking tile, the stainless steel (V4A) brace is deformed and adapts itself to the shape of the seam. Thus, it is tightly fixed under the tile.

➡ Roof conductor holders (Part No. 204 229) with preformed brace are hooked into the lower seam of pantile roofs (**Figure 5.4.3.7**).

Flat tiles or slabs

Together with the DEHNsnap conductor holder, the ZIEGELsnap roof conductor holder is pushed between the flat tiles (e.g. plain tiles) or slabs and is tightened by hand (only turn DEHNsnap) (**Figure 5.4.3.8**).

Overlapped constructions

In case of overlapped constructions (e.g. slabs and natural slate), the DEHNsnap conductor holder (**Figure 5.4.3.9**) is snapped in from the side and fixed by means of a screw driver when the holder is open.

In case of diagonally installed slabs, DEHNsnap can be turned to ensure vertical conductor routing.

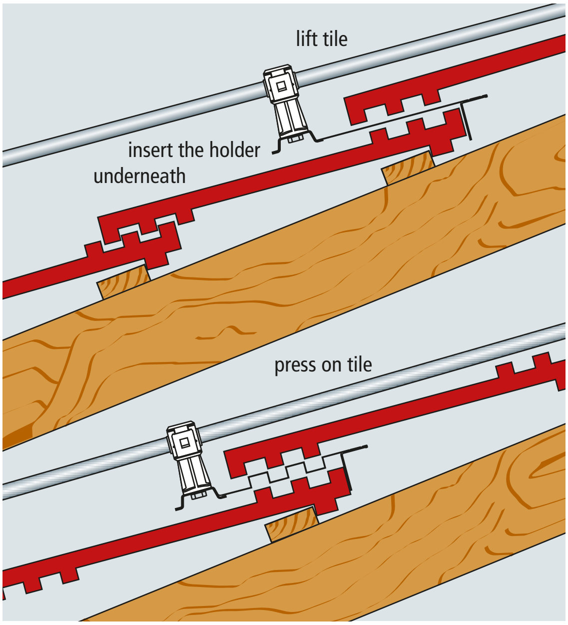


Figure 5.4.3.6 FLEXIsnap roof conductor holder for direct fitting on the seams

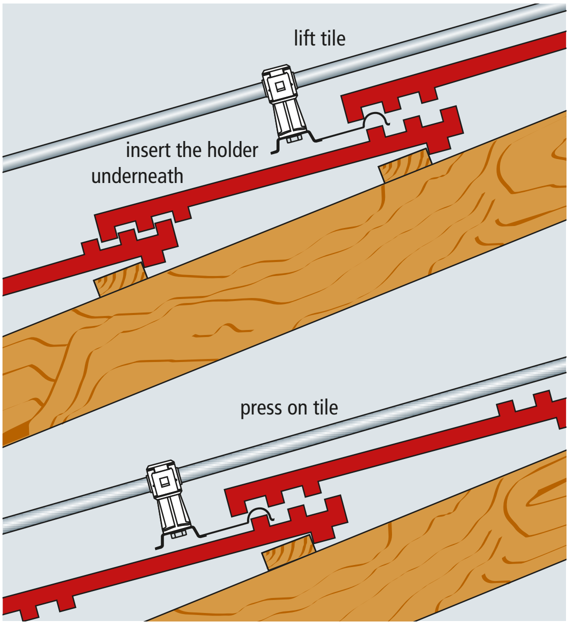


Figure 5.4.3.7 Roof conductor holder for hanging into the lower seam of pantile roofs

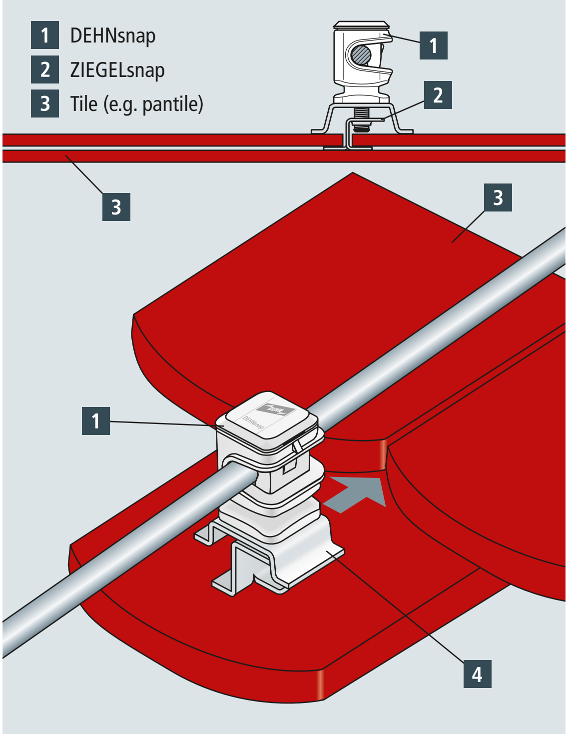


Figure 5.4.3.8 ZIEGELsnap for fixing between flat tiles or slabs

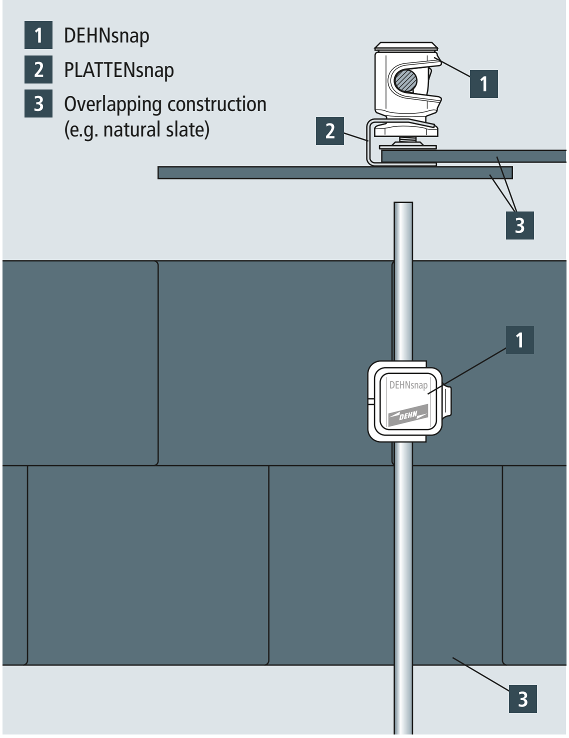


Figure 5.4.3.9 PLATTENsnap roof conductor holder for overlapping constructions

5.5 Earth-termination systems

A detailed description of the terms related to earth-termination systems can be found in IEC 62305-3 (EN 62305-3) "Protection against lightning – Physical damage to structures and life hazard", IEC 61936-1 (EN 61936-1) and EN 50522 "Power installations exceeding 1 kV" as well as IEC 60050-826 and IEC 60364-5-54 (HD 60364-5-54) "Erection of power installations with nominal voltages up to 1000 V". In Germany, DIN 18014 must be additionally observed for foundation earth electrodes. In the following, only the terms are explained which are required to understand this chapter.

Terms and definitions

Earth
is the conductive ground and the part of the earth in electrical contact with an earth electrode whose electric potential is not necessarily zero. The term "earth" also describes both a place and a material, e.g. humus, loam, sand, gravel and rock.

Reference earth
(neutral earth) is the part of the earth, especially the surface of the earth outside the area influenced by an earth electrode or an earth-termination system, in which no perceptible voltages arising from the earthing current occur between two arbitrary points (**Figure 5.5.1**).

Earth electrode
is a conductive part or several conductive parts in electrical contact with earth which provide(s) an electrical connection with the earth (also foundation earth electrodes).

Earth-termination system
all conductively interconnected earth electrodes which are physically separated or metal components acting as such (e.g. reinforcements of concrete foundations, metal cable sheaths in direct contact with earth).

Earthing conductor
is a conductor which connects a system part to be earthed to an earth electrode and which is installed above the ground or insulated in the ground.

Lightning protection earthing
earthing of a lightning protection system to discharge lightning currents to earth.

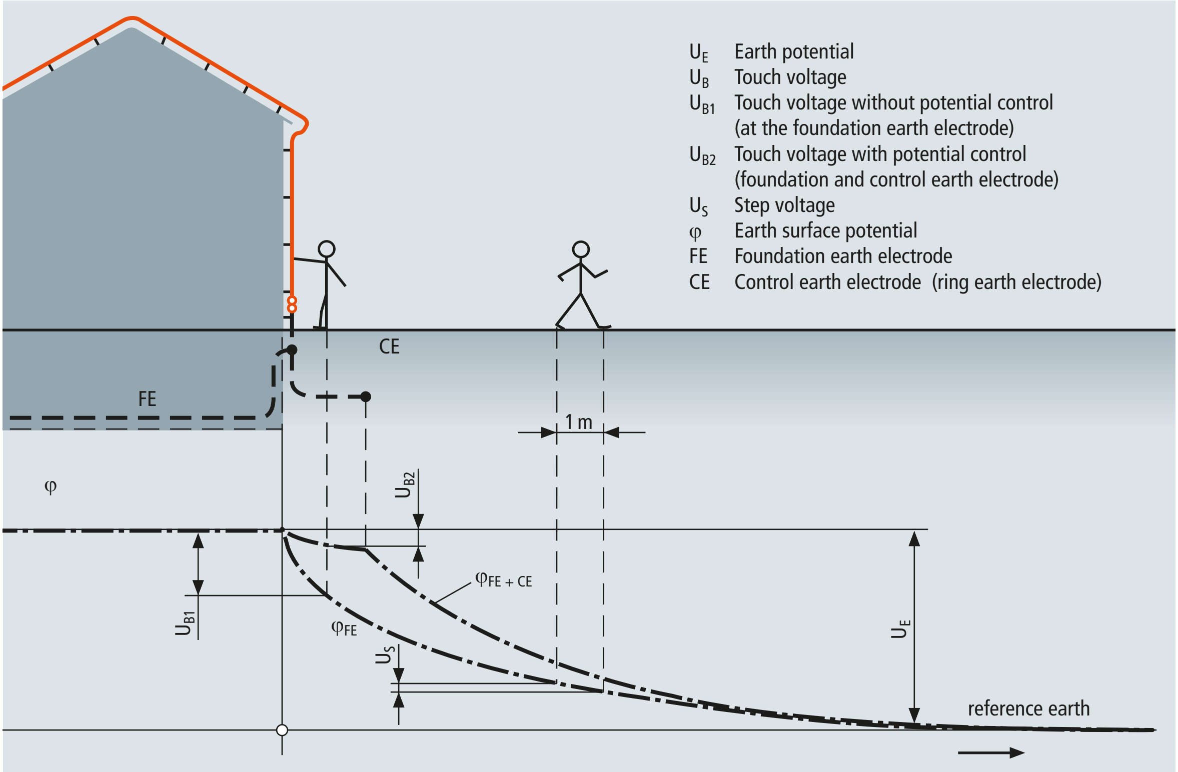


Figure 5.5.1 Earth surface potential and voltages in case of a current carrying foundation earth electrode FE and control earth electrode CE

Some types of earth electrodes and their classification according to their location, shape and profile will be described below.

Classification according to the location of earth electrodes

Surface earth electrode

is an earth electrode that is generally driven into the earth at a depth up to 1 m. It can consist of round material or flat strips and can be designed as a radial, ring or meshed earth electrode or a combination thereof.

Earth rod

is an earth electrode that generally extends vertically into the earth at great depths. It can consist of round material or material with another profile, for example.

Foundation earth electrode

consists of one or several conductors embedded in concrete which are in contact with earth over a large area.

Control earth electrode

is an earth electrode whose shape and arrangement serve more to control the potential than to maintain a certain earth resistance.

Ring earth electrode

earth electrode that forms a closed ring around the structure underneath or on the surface of the earth.

Natural earth electrode

is a metal part in contact with earth or with water either directly or via concrete which is originally not intended for earthing purposes, but which acts as an earth electrode (reinforcements of concrete foundations, pipes, etc.).

Classification according to the shape and profile of earth electrodes

A distinction is made between strip earth electrodes, crossed earth electrodes and earth rods.

Types of resistance

Earth resistivity

ρ_E is the electric resistivity of the earth. It is specified in Ωm and represents the resistance of an earth cube with 1 m long edges between two opposite sides of the cube.

Earth resistance

R_A of an earth electrode is the resistance of the earth between the earth electrode and reference earth. R_A is practically an effective resistance.

Conventional earthing impedance

R_{st} is the resistance as lightning currents flow from one point of an earth-termination system to reference earth.

Voltages in case of current carrying earth-termination systems, potential control

Earth potential

U_E is the voltage occurring between an earth-termination system and reference earth (**Figure 5.5.1**).

Earth surface potential

φ is the voltage between one point of the surface of the earth and reference earth (**Figure 5.5.1**).

Touch voltage

U_B is the part of the earth surface potential which can be bridged by persons (**Figure 5.5.1**), the current path via the human body running from hand to foot (horizontal distance from the touchable part of about 1 m) or from one hand to the other.

Step voltage

U_S is the part of the earth surface potential which can be bridged by persons taking one step of 1 m, the current path via the human body running from one foot to the other (**Figure 5.5.1**).

Potential control

is the influence of earth electrodes on the earth potential, particularly on the earth surface potential (**Figure 5.5.1**).

Equipotential bonding

for lightning protection systems is the connection of metal installations and electrical systems to the lightning protection system via conductors, lightning current arresters or isolating spark gaps.

Earth resistance/earth resistivity

Earth resistance R_A

The lightning current is not conducted to earth at one point via the earth electrode, but rather energises a certain area around the earth electrode.
The shape of the earth electrode and type of installation must be chosen to ensure that the voltages influencing the surface of the earth (touch and step voltages) do not assume hazardous values.
The earth resistance R_A of an earth electrode is best explained with the help of a metal sphere buried in the ground.
If the sphere is buried deep enough, the current discharges radially so that it is uniformly distributed over the surface of the sphere. **Figure 5.5.2a** illustrates this case; in comparison,

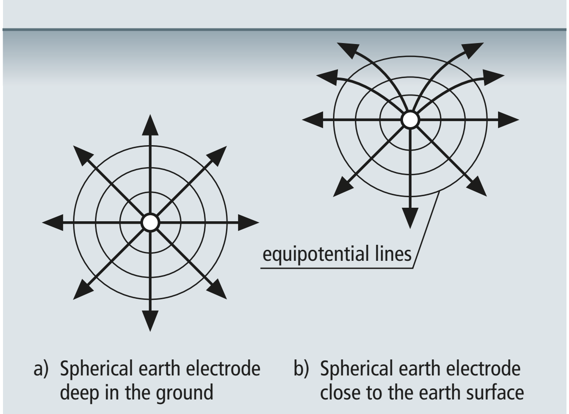


Figure 5.5.2 Current flowing out of a spherical earth electrode

Figure 5.5.2b shows a sphere buried directly below the surface of the earth.

The concentric circles around the surface of the sphere represent a surface of equal voltage. The earth resistance R_A consists of partial resistances of individual sphere layers connected in series. The resistance of such a sphere layer is calculated as follows:

$$R = \rho_E \cdot \frac{l}{q}$$

where

ρ_E is the earth resistivity of the ground, assuming it is homogeneous,

l is the thickness of an assumed sphere layer and

q is the centre surface of this sphere layer

To illustrate this, we assume a metal sphere with a diameter of 20 cm buried at a depth of 3 m in case of an earth resistivity of 200 Ωm.

If the increase in earth resistance is calculated for the different sphere layers, a curve as shown in **Figure 5.5.3** as a function of the distance from the centre of the sphere is achieved.

The earth resistance R_A for the spherical earth electrode is calculated as follows:

$$R_A = \frac{\rho_E \cdot 100}{2\pi \cdot r_K} \cdot \frac{1 + \frac{r_K}{2t}}{2}$$

ρ_E Earth resistivity in Ωm

t Burial depth in cm

r_K Radius of the spherical earth electrode in cm

This formula results in an earth resistance R_A = 161 Ω for the spherical earth electrode.

The curve in **Figure 5.5.3** shows that the largest portion of the total earth resistance occurs in the immediate vicinity of the earth electrode. For example, at a distance of 5 m from the centre of the sphere, 90 % of the total earth resistance R_A has already been achieved.

Earth resistivity ρ_E

The earth resistivity ρ_E, which is decisive for the magnitude of the earth resistance R_A of an earth electrode, depends on the soil composition, moisture in the soil and the temperature. It can fluctuate within wide limits.

Values for various types of soil

Figure 5.5.4 shows the fluctuation ranges of the earth resistivity ρ_E for various types of soil.

Seasonal fluctuations

Extensive measurements have shown that the earth resistivity varies greatly depending on the burial depth of the earth electrode. Owing to the negative temperature coefficient of the ground (α = 0.02 to 0.004), the earth resistivity reaches a maximum in winter and a minimum in summer. It is therefore advisable to convert the measured values obtained from earth electrodes to the maximum prospective values since the permissible values must not be exceeded even under unfavourable conditions (very low temperatures).

The curve of the earth resistivity ρ_E as a function of the time of year (ground temperature) can be represented to a good approximation by a sine curve which has its maximum in mid-February and its minimum in mid-August. Investigations have also shown that, for earth electrodes buried not deeper than

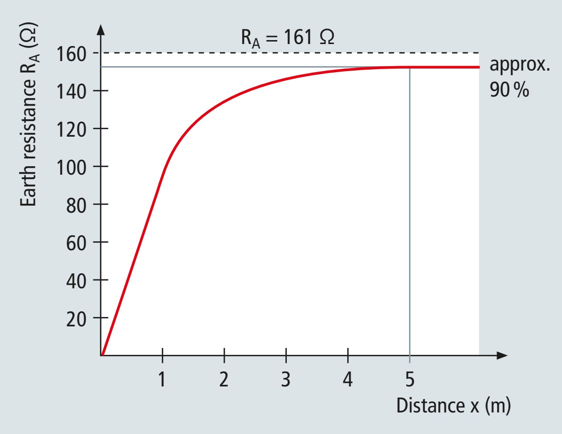


Figure 5.5.3 Earth resistance R_A of a spherical earth electrode with 20 cm, 3 m deep, at ρ_E = 200 Ωm as a function of the distance x from the centre of the sphere

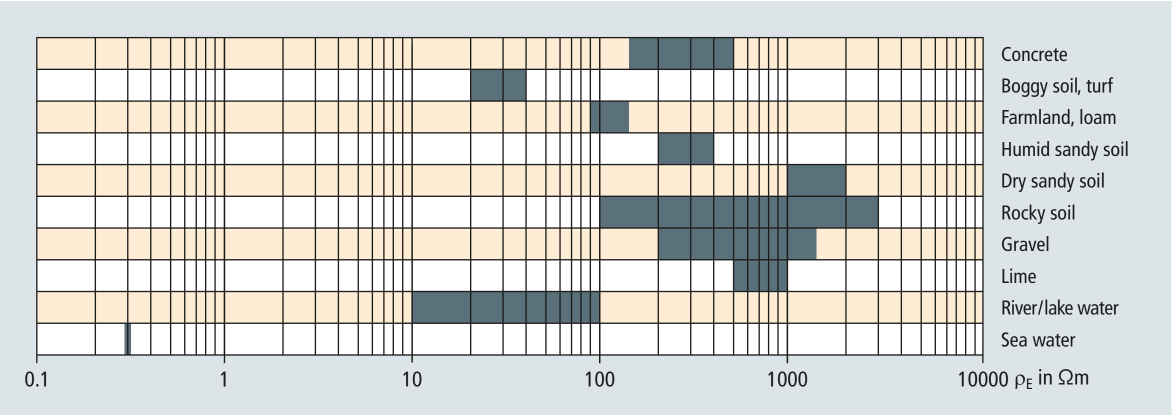


Figure 5.5.4 Earth resistivity ρ_E in case of different types of soil

about 1.5 m, the maximum deviation of the earth resistivity from the average value is about ±30 % (**Figure 5.5.5**).

If earth electrodes (particularly earth rods) are buried deeper, the fluctuation is only ±10 %. From the sine-shaped curve of the earth resistivity in **Figure 5.5.5**, the earth resistance R_A of an earth-termination system measured on a particular day can be converted to the maximum value to be expected.

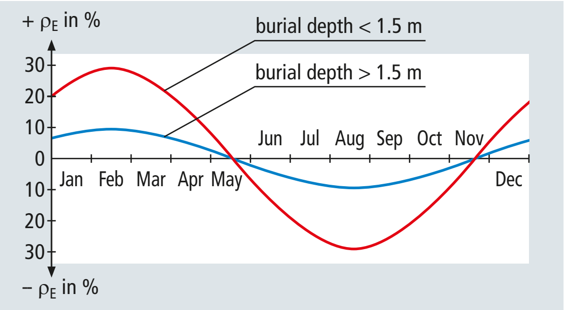


Figure 5.5.5 Earth resistivity ρ_E as a function of the time of year without precipitation effects (burial depth of the earth electrode < 1.5 m)

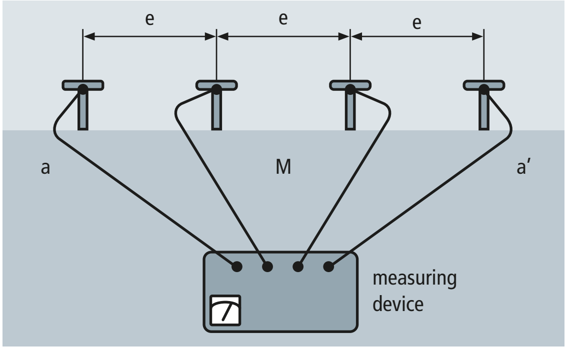


Figure 5.5.6 Determination of the earth resistivity ρ_E by means of a four-terminal measuring method (WENNER method)

Measurement

The earth resistivity ρ_E is determined using an earthing measuring bridge with four clamps (four-conductor method/four-pole measuring method) which operates according to the zero method.

Figure 5.5.6 shows the measurement arrangement of this measuring method named after WENNER. The measurement is carried out from a fixed central point M which is kept for all subsequent measurements. Four measuring probes (30 to 50 cm long earth spikes) are driven into the soil along a line a–a' pegged out in the ground. The earth resistivity ρ_E of the ground can be determined from the measured resistance R:

$$\rho_E = 2\pi \cdot e \cdot R$$

R	Measured resistance in Ω
e	Probe spacing in m
ρ_E	Average earth resistivity in Ωm up to a depth according to the probe spacing e

By increasing the probe spacing e and retuning the earthing measuring bridge, the curve of the earth resistivity ρ_E can be determined as a function of the depth.

Calculation of earth resistances

Table 5.5.1 shows the formulas for calculating the earth resistances of commonly used earth electrodes. In practice, these approximate formulas are quite sufficient. The exact calculation formulas are specified in the following sections.

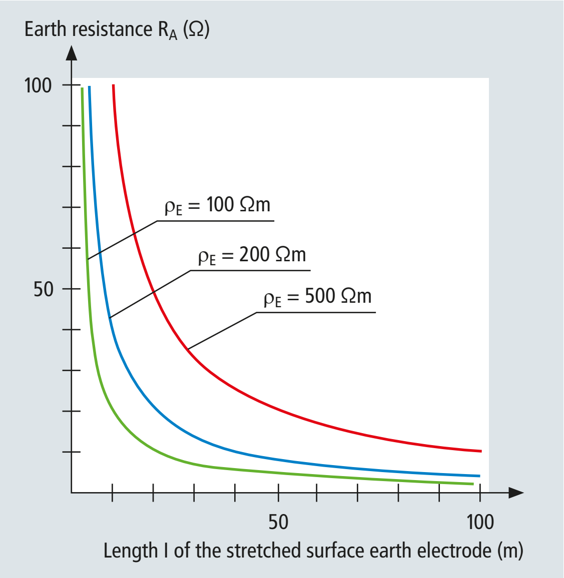


Figure 5.5.7 Earth resistance R_A as a function of length l of the surface earth electrode in case of different earth resistivities ρ_E

Straight surface earth electrode

Surface earth electrodes are typically embedded horizontally in the ground at a depth of 0.5 to 1 m. Since the soil layer above the earth electrode dries out in summer and freezes in winter, the earth resistance R_A of such a surface earth electrode is calculated as if it is installed on the surface of the ground:

$$R_A = \frac{\rho_E}{\pi \cdot l} \cdot \ln \frac{l}{r}$$

R_A	Earth resistance of a stretched surface earth electrode in Ω
ρ_E	Earth resistivity in Ωm
l	Length of the surface earth electrode in m
r	Quarter width of strip steel in m or radius of the round wire in m

Figure 5.5.7 shows the earth resistance R_A as a function of the length of the earth electrode.

Figure 5.5.8 shows the transverse and longitudinal earth potential U_E for an 8 m long strip earth electrode. The effect of the burial depth on the earth potential can be clearly seen.

Figure 5.5.9 illustrates the step voltage U_S as a function of the burial depth.

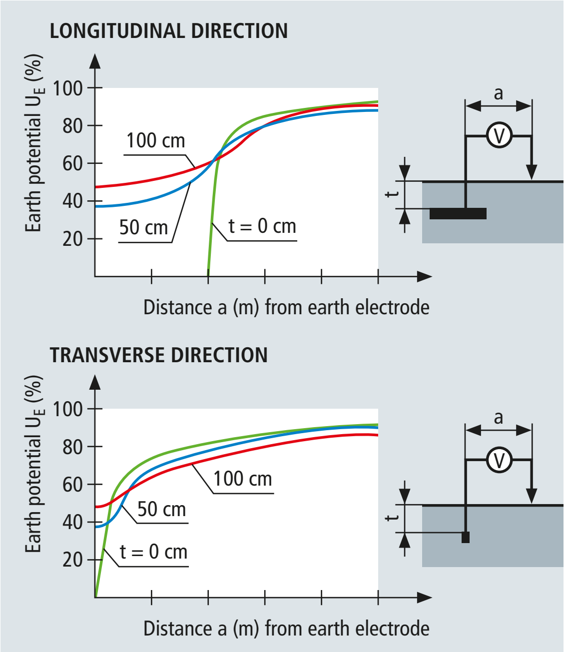


Figure 5.5.8 Earth potential U_E between the supply line of the earth electrode and the earth surface as a function of the distance from the earth electrode in case of an strip earth electrode (8 m long) in different depths

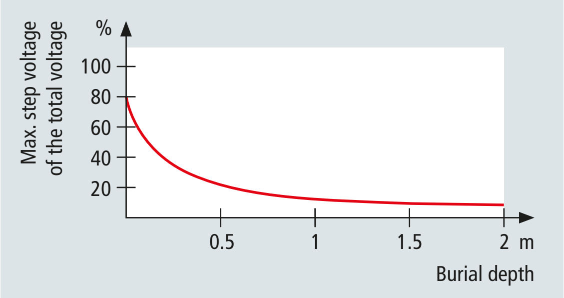


Figure 5.5.9 Maximum step voltage U_S as a function of the burial depth for a stretched strip earth electrode

In practice, it is sufficient to calculate the earth resistance using the approximate formula in **Table 5.5.1**:

$$R_A = \frac{2 \cdot \rho_E}{l}$$

Earth rod

The earth resistance R_A of an earth rod is calculated as follows:

$$R_A = \frac{\rho_E}{2\pi \cdot l} \cdot \ln \frac{2l}{r}$$

R_A Earth resistance in Ω
ρ_E Earth resistivity in Ωm
l Length of the earth rod in m
r Radius of the earth rod in m

As an approximation, the earth resistance R_A can be calculated using the approximate formula given in **Table 5.5.1**:

$$R_A = \frac{\rho_E}{l}$$

Figure 5.5.10 shows the earth resistance R_A as a function of the rod length l and the earth resistivity ρ_E.

Combination of earth electrodes

If several earth rods are installed next to one another (due to the soil conditions), the distance between the earth electrodes should correspond at least to their drive-in depth. The individual earth rods must be interconnected.

Earth electrode	Approximate formula	Auxiliary
Surface earth electrode (radial earth electrode)	$R_A = \frac{2 \cdot \rho_E}{l}$	–
Earth rod	$R_A = \frac{\rho_E}{l}$	–
Ring earth electrode	$R_A = \frac{2 \cdot \rho_E}{3 \cdot d}$	$d = 1.13 \cdot \sqrt[2]{A}$
Meshed earth electrode	$R_A = \frac{\rho_E}{2 \cdot d}$	$d = 1.13 \cdot \sqrt[2]{A}$
Earth plate	$R_A = \frac{\rho_E}{4.5 \cdot a}$	–
Hemispherical / foundation earth electrode	$R_A = \frac{\rho_E}{\pi \cdot d}$	$d = 1.57 \cdot \sqrt[3]{V}$

R_A Earth resistance (Ω)
ρ_E Earth resistivity (Ωm)
l Length of the earth electrode (m)
d Diameter of a ring earth electrode, the area of the equivalent circuit or a hemispherical earth electrode
A Area (m^2) of the enclosed area of a ring or meshed earth electrode
a Edge length (m) of a square earth plate. In case of rectangular plates: a is substituted by $\sqrt{b \cdot c}$, where b and c are the two sides of the rectangle
V Volume of a single foundation earth electrode

Table 5.5.1 Formulas for calculating the earth resistance R_A for different earth electrodes

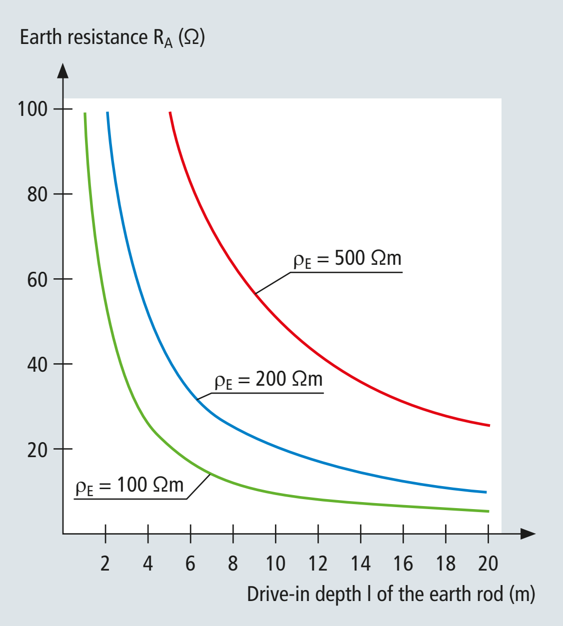


Figure 5.5.10 Earth resistance R_A of earth rods as a function of their length l in case of different earth resistivities ρ_E

The earth resistances calculated using the formulas and the measurement results in the diagrams apply to low-frequency direct current and alternating current provided that the expansion of the earth electrode is relatively small (a few hundred metres). For greater lengths, e.g. in case of surface earth electrodes, the alternating current also has an inductive component.

However, the calculated earth resistances do not apply to lightning currents. In this case, the inductive component plays a role, which can lead to higher values of the conventional earthing impedance in case of a large expansion of the earth-termination system.

Increasing the length of the surface earth electrodes or earth rods to more than 30 m only insignificantly reduces the conventional earthing impedance. It is therefore advisable to combine several short earth electrodes. In such cases, it must be observed that the actual total earth resistance is higher than the value calculated from the individual resistances connected in parallel due to the mutual interaction of the earth electrodes.

Radial earth electrodes

Radial earth electrodes in the form of crossed surface earth electrodes are important when relatively low earth resistances

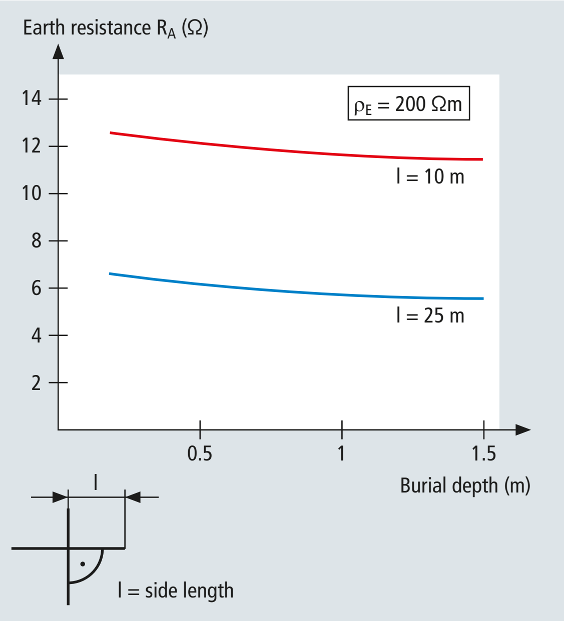


Figure 5.5.11 Earth resistance R_A of crossed surface earth electrodes (90 °) as a function of the burial depth

should be created in poorly conducting ground at acceptable costs.

The earth resistance R_A of a crossed surface earth electrode whose sides are arranged at an angle of 90 ° to each other is calculated as follows:

$$R_A = \frac{\rho_E}{4\pi \cdot l} \cdot \ln \frac{l}{r} + 1.75$$

R_A	Earth resistance of the crossed surface earth electrode in Ω
ρ_E	Earth resistivity in Ωm
l	Side length in m
d	Half bandwidth in m or diameter of the round wire in m

As a rough approximation, in case of greater arm lengths (l > 10 m), the earth resistance R_A can be determined using the total arm length from the equations in **Table 5.5.1**.

Figure 5.5.11 shows the curve of the earth resistance R_A of crossed surface earth electrodes as a function of the burial depth; **Figure 5.5.12** shows the curve of the earth potential. In case of radial earth electrodes, the angle between the individual arms should be greater than 60 °.

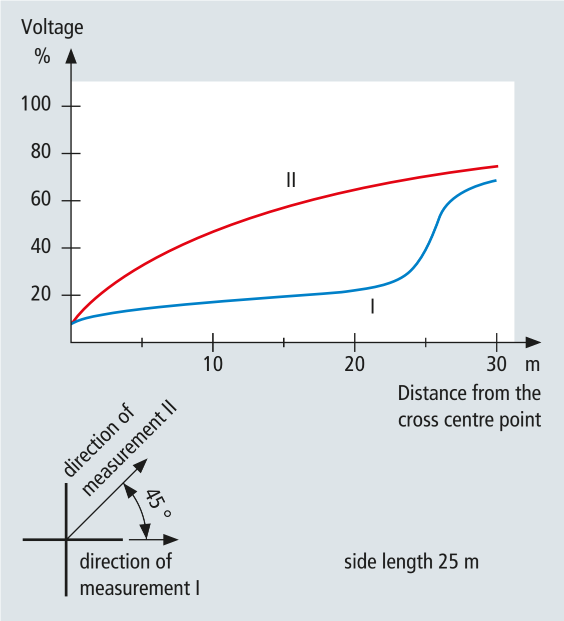


Figure 5.5.12 Earth potential U_E between the supply line of the earth electrode and the earth surface of crossed surface earth electrodes (90 °) as a function of the distance from the cross centre point (burial depth of 0.5 m)

According to **Figure 5.5.12**, the earth resistance of a meshed earth electrode is calculated as follows:

$$R_A = \frac{\rho_E}{2 \cdot d}$$

where d is the diameter of the analogous circle which has the same area as the meshed earth electrode. It is determined as follows:

For rectangular or polygonal dimensions of the meshed earth electrode:

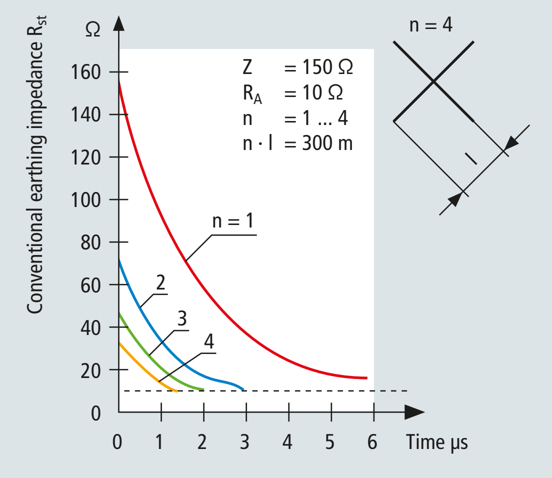
$$d = \sqrt{\frac{4 \cdot A}{\pi}}$$

A	Area of the meshed earth electrode in m^2

For square dimensions (edge length b):

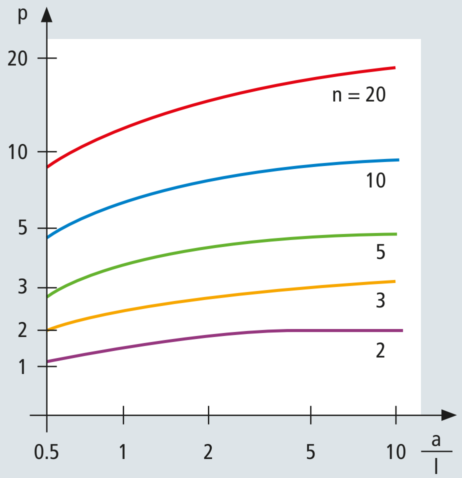
$$d = 1.1 \cdot b$$

Figure 5.5.13 shows the curve of the conventional earth impedance of single-arm and multiple-arm surface earth electrodes in case of square-wave impulse voltages.



Z	Characteristic impedance of the earthing conductor
R_A	Earth resistance
n	Number of earth electrodes connected in parallel
l	Average earth electrode length

Figure 5.5.13 Conventional earthing impedance R_{st} of single-arm or multiple-arm surface earth electrodes of equal length



p	Reduction factor
n	Number of earth electrodes connected in parallel
a	Average earth electrode distance
l	Average earth electrode length

Figure 5.5.14 Reduction factor p for calculating the total earth resistance R_A of earth rods connected in parallel

As can be seen from this diagram, it is more favourable to install a radial earth electrode than a single arm for the same length.

Foundation earth electrodes

The earth resistance of a metal conductor in a concrete foundation can be calculated as an approximation using the formula for hemispherical earth electrodes:

$$R_A = \frac{\rho_E}{\pi \cdot d}$$

where d is the diameter of the analogous hemisphere having the same volume as the foundation:

$$d = 1.57 \cdot \sqrt[3]{V}$$

V Volume of the foundation in m^3

When calculating the earth resistance, it must be observed that the foundation earth electrode is only effective if the concrete body contacts the surrounding ground over a large area. Water-repellent, insulating shielding significantly increases the earth resistance or insulates the conductor in the foundation (see 5.5.2).

Earth rods connected in parallel

To keep interactions within acceptable limits, the distances between the single earth electrodes for earth rods connected in parallel should not be less than the drive-in depth.

If the single earth electrodes are roughly arranged in a circle and have approximately the same length, the earth resistance can be calculated as follows:

$$R_A = \frac{R_{A'}}{p}$$

where $R_{A'}$ is the average earth resistance of the single earth electrodes. The reduction factor p as a function of the length of the earth electrodes, the distance between the single earth electrodes and the number of earth electrodes can be taken from **Figure 5.5.14**.

Combination of strip earth electrodes and earth rods

If earth rods provide a sufficient earth resistance, for example in case of deep water carrying layers in sandy soil, the earth rod should be installed as close as possible to the object to be protected. If a long supply line is required, it is advisable to install a multiple radial earth electrode in parallel to the line to reduce the resistance as the current rises.

As an approximation, the earth resistance of a strip earth electrode with earth rod can be calculated as if the strip earth electrode was extended by the drive-in depth of the earth rod.

$$R_A \approx \frac{\rho_E}{l_{strip\,earth\,electrode} + l_{earth\,rod}}$$

Ring earth electrode

In case of circular ring earth electrodes with large diameters (d > 30 m), the earth resistance is calculated as an approximation using the formula for the strip earth electrode (where the circumference π · d is used for the length of the earth electrode):

$$R_A = \frac{\rho_E}{\pi^2 \cdot d} \cdot \ln \frac{\pi \cdot d}{r}$$

r Radius or the round wire or quarter width of the strip earth electrode in m

For non-circular ring earth electrodes, the earth resistance is calculated by using the diameter d of an analogous circle with the same area:

$$R_A = \frac{2 \cdot \rho_E}{3 \cdot d}$$

$$d = \sqrt{\frac{A \cdot 4}{\pi}}$$

A Area encircled by the ring earth electrode in m^2

Implementation

According to the IEC standards, each installation to be protected must have its own earth-termination system which must be fully functional without using metal water pipes or earthed conductors of the electrical installation.
The magnitude of the earth resistance R_A plays only a minor role for protecting a building or installation against lightning. More important is that the equipotential bonding is established consistently at ground level and the lightning current is safely distributed in the ground.
The lightning current i raises the object to be protected to the earth potential U_E

$$U_E = i \cdot R_A + \frac{1}{2} \cdot L \cdot \frac{di}{dt}$$

with respect to reference earth.

The potential of the earth´s surface decreases as the distance from the earth electrode increases (**Figure 5.5.1**).

The inductive voltage drop across the earth electrode as the lightning current increases only has to be taken into account for extended earth-termination systems (e.g. in case of long surface earth electrodes in poorly conducting soil with rocky surface). In general, the earth resistance is defined by the ohmic component only.

If isolated conductors are led into the structure, the full earth potential U_E occurs.
In order to avoid the risk of puncture and flashover, such conductors are connected to the earth-termination system via isolating spark gaps or in case of live conductors via surge protective devices (see DEHN surge protection main catalogue) as part of the lightning equipotential bonding.

The magnitude of the earth resistance must be limited to minimise touch and step voltages.

The earth-termination system can be designed as a foundation earth electrode, a ring earth electrode and, in case of buildings with large surface areas, as a meshed earth electrode and, in special cases, also as a single earth electrode.
In Germany, foundation earth electrodes must be designed in accordance with DIN 18014.
Conventional foundation earth electrodes are designed as a closed ring and arranged in the foundations of the external walls of the building or in the foundation slab according to DIN 18014. In case of large structures, foundation earth electrodes should contain cross-connections to prevent that the maximum mesh size of 20 m x 20 m is exceeded.
Foundation earth electrodes must be arranged so that they are enclosed by concrete on all sides.
In the service entrance room, the foundation earth electrode must be connected to the equipotential bonding bar. According to IEC 62305-3 (EN 62305-3), a foundation earth electrode must be provided with terminal lugs to connect the down conductors of the external lightning protection system to the earth- termination system.

Due to the risk of corrosion at the point where a terminal lug leaves the concrete, additional anti-corrosion measures should be taken (PVC sheath or preferably stainless steel e.g. of material No. AISI/ASTM 316 Ti).
The reinforcement of slab or strip foundations can be used as a foundation earth electrode if the required terminal lugs are connected to the reinforcement and the reinforcements are interconnected via the joints in such a way that the can carry currents.

Surface earth electrodes must be buried at a depth of at least 0.5 m in the form a closed ring.

The conventional earthing impedance of earth electrodes depends on the maximum value of the lightning current and of the earth resistivity (see also **Figure 5.5.13**). As an approximation, the effective length of the earth electrode in case of lightning currents is calculated as follows:

Surface earth electrode:

$$l_{eff} = 0.28\sqrt{\hat{\imath} \cdot \rho_E}$$

Earth rod:

$$l_{eff} = 0.2\sqrt{\hat{\imath} \cdot \rho_E}$$

l_{eff}	Effective length of the earth electrode in m
$\hat{\imath}$	Peak value of the lightning current in kA
ρ_E	Earth resistivity in Ωm

The conventional earthing impedance R_{st} can be calculated using the formulas in **Table 5.5.1**, where the effective length of the earth electrode l_{eff} is used for the length l.
Surface earth electrodes are advantageous when the upper soil layers have a lower resistivity than the subsoil.

If the ground is relatively homogeneous (namely if the earth resistivity at the surface of the earth is roughly the same as in deep ground), the construction costs of surface earth electrodes and earth rods with the same earth resistance are roughly the same.

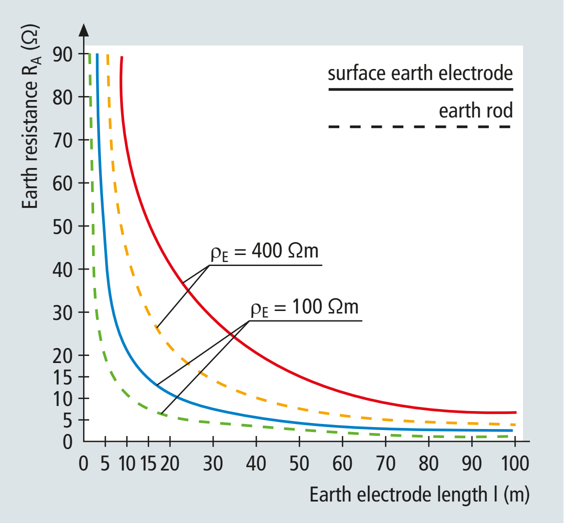


Figure 5.5.15 Earth resistance R_A of surface earth electrodes and earth rods as a function of the earth electrode length l

According to **Figure 5.5.15**, an earth rod must only have approximately half the length of a surface earth electrode.
If the conductivity of the ground is better in deep ground than on the surface, e.g. due to ground water, an earth rod is generally more cost-effective than a surface earth electrode.

The question of whether earth rods or surface earth electrodes are more cost-effective in individual cases can frequently only be answered by measuring the earth resistivity as a function of the depth.
Since earth rods are easy to assemble and achieve excellent constant earth resistances without requiring excavation work and damaging the ground, these earth electrodes are also suitable for improving existing earth-termination systems.

5.5.1 Earth-termination systems in accordance with IEC 62305-3 (EN 62305-3)

The earth-termination system is the continuation of the air-termination systems and down conductors to discharge the lightning current to the earth. Other functions of the earth-termination system are to establish equipotential bonding between the down conductors and to control the potential in the vicinity of the building walls.
It must be observed that a common earth-termination system is to be preferred for the different electrical systems (lightning protection systems, low-voltage systems and telecommunications systems). This earth-termination system must be connected to the equipotential bonding system via the main earthing busbar (MEB).
Since the IEC 62305-3 (EN 62305-3) standard requires consistent lightning equipotential bonding, no particular value is specified for the earth resistance. In general, a low earth resistance (≤ 10 Ω, measured with a low frequency) is recommended.
The standard distinguishes two types of earth electrode arrangements, **type A** and **type B**.
Both type A and B earth electrode arrangements have a minimum earth electrode length l_1 of the earthing conductors according to the class of LPS (**Figure 5.5.1.1**)
The exact soil resistivity can only be determined by on-site measurements using the "WENNER method" (four-conductor measuring method).

Type A earth electrodes

Type A earth electrode arrangements describe individually arranged vertical earth electrodes (earth rods) or horizontal ra-

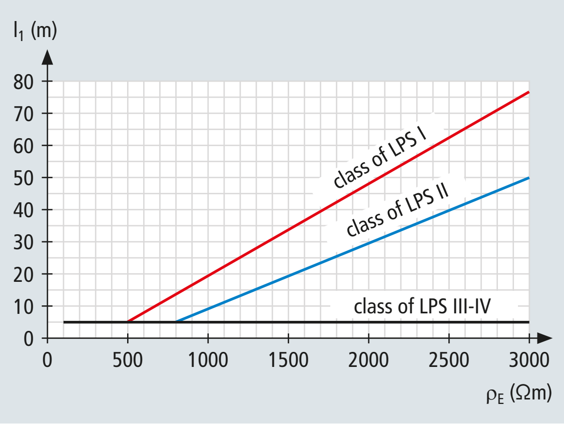


Figure 5.5.1.1 Minimum lengths of earth electrodes

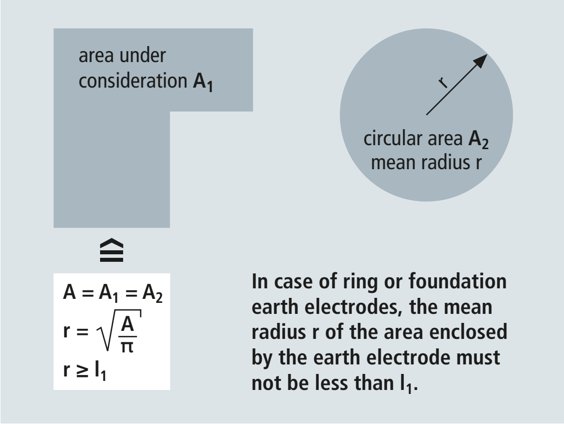


Figure 5.5.1.2 Type B earth electrode – Determination of the mean radius – Sample calculation

dial earth electrodes (surface earth electrodes), which must be connected to a down conductor.

A type A earth electrode arrangement require at least two earth electrodes. A single earth electrode is sufficient for individually positioned air-termination rods or masts.

A minimum earth electrode length of 5 m is required for class of LPS III and IV. For class of LPS I and II the length of the earth electrode is defined as a function of the soil resistivity. **Figure 5.5.1.1** shows the minimum earth electrode length l_1. The minimum length of each earth electrode is:

l_1 x 0.5	For vertical or inclined earth electrodes
l_1	For radial earth electrodes

The values determined apply to each single earth electrode.

If different earth electrodes (vertical and horizontal) are combined, the equivalent total length should be taken into account.

The minimum earth electrode length can be disregarded if an earth resistance of less than 10 Ω is achieved.

In general, earth rods are vertically driven deeply into natural soil which typically starts below foundations. Earth electrode lengths of 9 m have proven to be advantageous. Earth rods have the advantage that they reach soil layers in greater depths whose resistivity is generally lower than in the areas close to the surface.

It is recommended that the first metre of a vertical earth electrode is considered ineffective under frost conditions.

Type A earth electrodes do not meet the requirements with regard to equipotential bonding between the down conductors and potential control. Single earth electrodes of type A must be interconnected to ensure that the current is evenly split. This is important for calculating the separation distance s. Type A earth electrodes can be interconnected below or on the surface of the earth. When retrofitting existing installations, the connecting cable of the single earth electrodes can also be implemented in the structure.

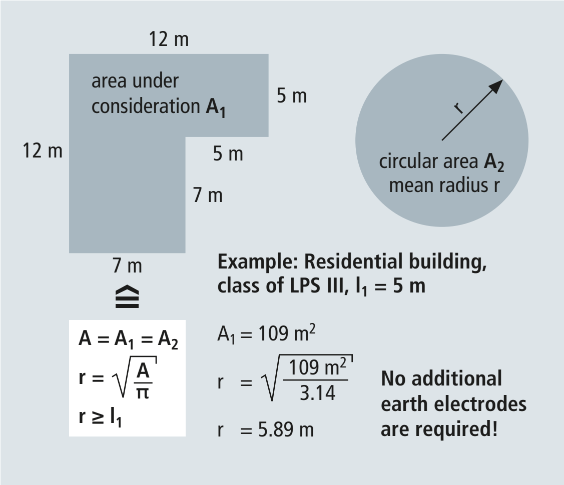


Figure 5.5.1.3 Type B earth electrode – Determination of the mean radius – Sample calculation

Type B earth electrodes

Type B earth electrodes are ring earth electrodes encircling the object to be protected or foundation earth electrodes. In Germany, the requirements for earth-termination systems of new buildings are described in DIN 18014.

If it is not possible to encircle the structure by means of a closed ring, the ring must be complemented by means of conductors inside the structure. Pipework or other permanently conductive metal components can also be used for this purpose. The earth electrode must be in contact with the soil for at least 80 % of its total length to ensure that a type B earth electrode can be used as a base for calculating the separation distance. The minimum lengths of type B earth electrodes depend on the class of LPS. In case of classes of LPS I and II, the minimum earth electrode length also depends on the soil resistivity (**Figure 5.5.1.1**).

The mean radius r of the area encircled by a type B earth electrode must be not less than the specified minimum length l_1.

To determine the mean radius r, the area under consideration is transferred into an equivalent circular area and the radius is determined as shown in **Figures 5.5.1.2 and 5.5.1.3**.

Sample calculation:

If the required value of l_1 is greater than the value of r corresponding to the structure, further radial or vertical earth electrodes (or inclined earth electrodes) must be added whose relevant lengths l_r (radial / horizontal) and l_v (vertical) result from the following equations:

$$l_r = l_1 - r$$

$$l_v = \frac{l_1 - r}{2}$$

The number of additional earth electrodes must not be less than the number of down conductors, but at least two. These additional earth electrodes should be connected to the ring earth electrode so as to be spaced equally around the perimeter.

If additional earth electrodes are to be connected to the foundation earth electrode, the earth electrode material and the connection to the foundation earth electrode must be observed. Stainless steel, e.g. material No. AISI/ASTM 316 Ti, should be preferably used (see chapter 5.5.2, **Figure 5.5.2.1**).

The following systems may place additional requirements on the earth-termination system:

- Electrical systems – Disconnection requirements of the relevant system configuration (TN, TT, IT systems) in accordance with IEC 60364-4-41 (HD 60364-4-41)
- Equipotential bonding in accordance with IEC60364-5-54 (HD 60364-5-54)
- Electronic systems – Data information systems
- Antenna earthing in accordance with DIN VDE 0855 (German standard)
- Electromagnetic compatibility (EMC)
- Transformer station in or near the structure in accordance with EN 50522

5.5.2 Earth-termination systems, foundation earth electrodes and foundation earth electrodes for special structural measures

Foundation earth electrodes – Type B earth electrodes

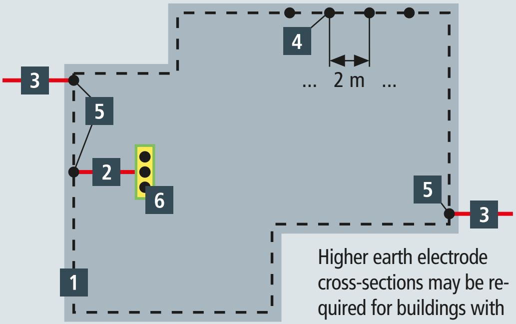
DIN 18014 (German standard) specifies the requirements for foundation earth electrodes of new buildings.

Many national and international standards prefer foundation earth electrodes because, when properly installed, they are embedded in concrete on all sides and are thus corrosion-resistant. The hygroscopic characteristics of concrete typically ensure a sufficiently low earth resistance.

The foundation earth electrode must be installed as a closed ring in the strip foundation or floor slab (**Figure 5.5.2.1**) and thus primarily serves the purpose of functional equipotential bonding. The division into meshes ≤ 20 m x 20 m and the connectors required to the outside to connect the down conductors of the external lightning protection system and to the inside for equipotential bonding must be considered (**Figure 5.5.2.2**). According to DIN 18014, the installation of the foundation earth electrode is an electrical measure and must there-

Foundation earth electrode 1
- Round wire (Ø 10 mm) or strip (30 mm x 3.5 mm), St/tZn
- Concrete cover of at least 5 m
- Closed ring
- Connection to the reinforcement at intervals of 2 m by means of a clamp 4

Terminal lug 2 to **main earthing busbar** 6 and **terminal lugs** 3 for the external lightning protection system with SV clamp 5 at least 1.5 m long, easily identifiable
- Round wire, StSt, e.g. mat. No. AISI/ASTM 316 Ti (V4A), 10 mm
- Strip, StSt, e.g. mat. No. AISI/ASTM 316 Ti (V4A), 30 x 3.5 mm
- Round wire, StZn, Ø 10 mm, with plastic sheath
- Fixed earthing terminal



Higher earth electrode cross-sections may be required for buildings with transformer stations.

Figure 5.5.2.1 Foundation earth electrode with terminal lug

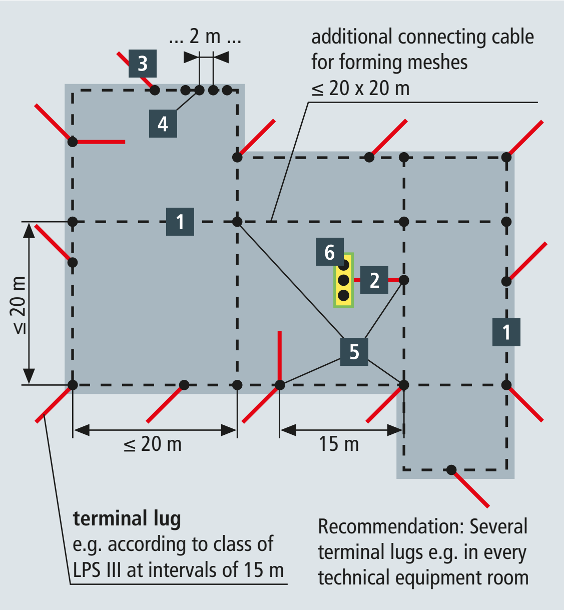


Figure 5.5.2.2 Mesh of a foundation earth electrode

Figure 5.5.2.3 Foundation earth electrode

Figure 5.5.2.4 Foundation earth electrode in use

Figure 5.5.2.5 Fixed earthing terminal

fore be carried out or supervised by a **certified lightning protection specialist** or **electrician**.

The question of how to install the foundation earth electrode depends on the measure required to ensure that the foundation earth electrode is embedded in concrete on all sides.

Installation in non-reinforced concrete

Spacers must be used in non-reinforced foundations such as strip foundations of residential buildings (**Figure 5.5.2.3**). Only by using these spacers at intervals of approximately 2 m it is ensured that the foundation earth electrode is "raised" and embedded in concrete (at least 5 cm) on all sides to protect the foundation earth electrode (St/tZn) against corrosion.

Installation in reinforced concrete

In case of closed reinforced foundations, the foundation earth electrode is installed on the lowest reinforcement layer. When installed properly, a foundation earth electrode made of round or strip steel (galvanised) is covered by concrete by at least 5 cm on all sides and is thus corrosion-resistant. The hygroscopic characteristics of concrete typically ensure a sufficiently low earth resistance.

When using steel mats, reinforcement cages or reinforcing bars in foundations, the foundation earth electrode should be connected to these natural iron components at intervals of 2 m by means of clamping or welding to improve the function of the foundation earth electrode.

Figure 5.5.2.6 Meshed foundation earth electrode

The modern methods of laying concrete in reinforced concrete foundations and then vibrating/compacting it ensure that the concrete also "flows" under the earth electrode enclosing it on all sides if the flat strip is installed horizontally, thus ensuring corrosion resistance. Consequently, vertical installation of the flat strip is not required when mechanically compacting concrete. **Figure 5.5.2.4** shows an example of the horizontal installation of a flat strip as a foundation earth electrode. The intersections of the foundation earth electrode must be connected in such a way that they are capable of carrying currents. It is sufficient to use galvanised steel for foundation earth electrodes.

Terminal lugs to the outside into the ground must be protected against corrosion at the point where they leave the structure. Suitable materials are, for example, plastic sheathed steel wire (owing to the break risk of the plastic sheath at low temperatures, special care must be taken during the installation), high-alloy stainless steel, e.g. material No. AISI/ASTM 316 Ti, or fixed earthing terminals (**Figure 5.5.2.5**).

When installing the foundation earth electrode, the mesh size must not exceed 20 x 20 m. This mesh size does not depend on the class of LPS of the external lightning protection system (**Figure 5.5.2.6**).

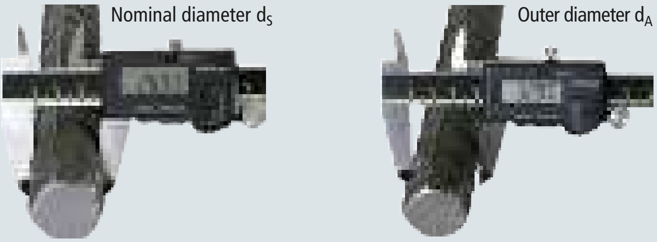
Nowadays, various types of foundations with different designs and sealing versions are used.
Heat insulation regulations have also influenced the design of strip foundations and foundation slabs.
If foundation earth electrodes are installed in new structures based on DIN 18014, the sealing/insulation affects their installation and arrangement.

Connecting clamps for reinforcements

Foundation earth electrodes must be connected to the reinforcement of the foundation slab at intervals of 2 m. To do so, there are various possibilities.
Clamping turned out to be the most cost-effective solution since this connection can be made easily and quickly on site. Moreover, according to the latest lightning protection standards, reinforcing steel, for example, can be used as a natural component of the down-conductor system. Since the components of the foundation earth electrode must be connected in such a way that they are permanently conductive and mechanically stable, these connections are efficiently made by means of screws according to IEC 62561-1 (EN 62561-1) (Lightning protection system components Part 1: Requirements for connection components). More detailed information on this topic can be found in chapter 5.8.

Figure 5.5.2.7 gives an overview of the nominal and outer diameters as well as the cross-sections of reinforcing steel.
The outer diameter of reinforcing steel is decisive for selecting the connection components/clamps.

The outer diameter
including the ribs is about
$d_A = 1.15 \times d_S$



Nominal diameter d_s (mm)	6	8	10	12	14	16	20	25	28	32	40
Outer diameter including the ribs d_A (mm)	6.9	9.2	11.5	13.8	16.1	18.4	23	29	32	37	46
Nominal cross-section (mm^2)	28.3	50.3	78.5	113.1	154	201	314	491	616	804	1257

Figure 5.5.2.7 Diameters of reinforcing steels

Expansion joints

Foundation earth electrodes cannot be passed across expansion joints. At these points, they can be led out near walls and connected by means of fixed earthing terminals and bridging braids in case of e.g. concrete walls (**Figure 5.5.2.8**).

However, in case of foundation slabs with large dimensions, the meshes of the foundation earth electrode must be led through these expansion joints (sections or joints) without leading them out of the wall. Special expansion straps, which create cavities in the concrete by means of a styrofoam block and an integrated flexible connection, can be used in this case.
The expansion strap is embedded in the foundation slab in such a way that the styrofoam block is situated in one section and the other end is routed loosely in the next section (**Figure 5.5.2.9**).

Membranes in case of foundation slabs

Membranes made of polyethylene with a thickness of about 0.3 mm are often laid on the blinding layer as a separation layer (**Figure 5.5.2.10**).
These membranes only slightly overlap and are not water-repellent.
They typically only have little impact on the earth resistance and can thus be neglected. For this reason, foundation earth electrodes can be installed in the concrete of the foundation slab.

Dimpled membranes

Dimpled membranes are used to replace the blinding layer for foundation slabs and often enclose the entire basement (**Figure 5.5.2.11**).
These dimpled membranes are made of special high-density polyethylene with a thickness of approximately 0.6 mm (dimple height of approximately 8 mm) (**Figure 5.5.2.12**). The individual membranes have a width of about 2 to 4 m, overlap (about 20 to 25 cm) and keep water away. The foundation earth electrode therefore cannot be effectively installed in the foundation slab.
For this reason, a ring earth electrode made of stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti, with an adequate mesh size is buried outside the foundation below the dimpled membranes.

Foundations with an increased earth contact resistance

"White tank" made of waterproof concrete

Waterproof concrete has a high resistance to water penetration. In Germany, closed tanks made of waterproof concrete are informally also referred to as "white tanks".

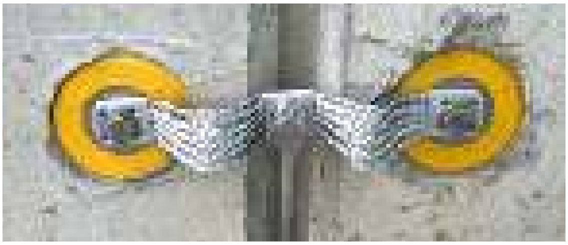


Figure 5.5.2.8 Bridging braid with fixed earthing terminals

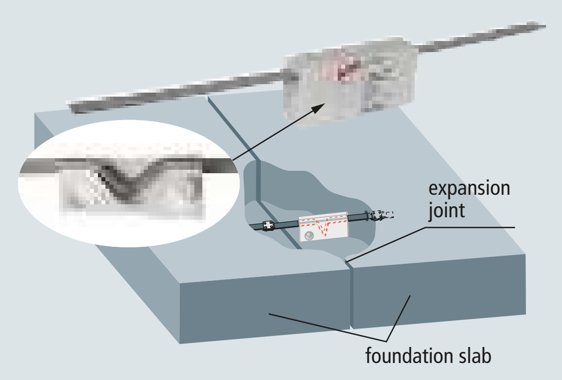


Figure 5.5.2.9 Bridging a foundation earth electrode by means of an expansion strap

Figure 5.5.2.10 Membrane of foundation slabs

Concrete buildings with a high resistance to water penetration are built without additional extensive external sealing and prevent the ingress of water solely due to the concrete and structural measures such as joint sealing and crack width limitation. Particular care is required when erecting these waterproof buildings since all building components such as joint sealings, entries for water, gas, electricity and telephone lines (in the form of multi-line building entries), sewer pipes, other

Figure 5.5.2.11 Use of dimpled membranes

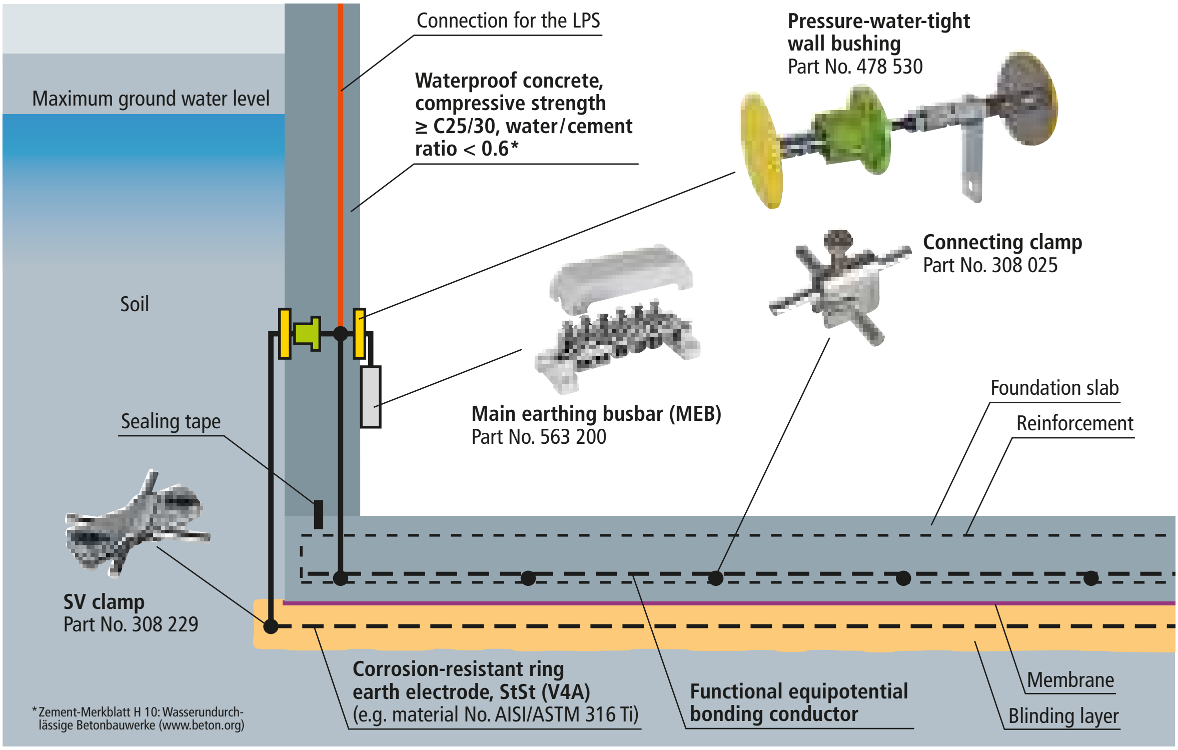
Figure 5.5.2.12 Dimpled membrane

cables or lines, connection components for the foundation earth electrode or equipotential bonding must be permanently waterproof or pressure-water-proof. The installer is responsible for the watertightness of the building.

The term waterproof concrete is not defined in the latest concrete production standards. In practice, concrete with a concrete quality of e.g. C20/25 is used (compressive strength cylinder/cube in N/mm^2).

The watertightness of concrete mixes depends on the cement content. 1 m^3 of waterproof concrete has a cement content of at least 320 kg cement (low-heat cement). A low degree of concrete shrinkage, the recommended minimum concrete compressive strength C25/30 and the water/cement ratio, which must be below 0.6, are equally important.

Compared to previous years, moisture no longer penetrates some centimetres into the "white tank". Modern concretes with a high resistance to water penetration only absorb 1.5 cm of water. Since the foundation earth electrode must be covered by a concrete layer of at least 5 cm (corrosion), the concrete



* Zement-Merkblatt H 10: Wasserundurchlässige Betonbauwerke (www.beton.org)

Figure 5.5.2.13 Arrangement of the foundation earth electrode in case of a "white tank" according to the German DIN 18014 standard can be considered to be an electrical insulator downstream of the water penetration area. Thus, the foundation earth electrode is no longer in contact with the soil.

For this reason, a ring earth electrode with a mesh size ≤ 20 m x 20 m must be installed in the blinding layer or soil below the foundation slab of buildings with "white tank". If a lightning protection system is required, the mesh size is reduced to ≤ 10 m x 10 m. This reduced mesh size is supposed to prevent possible puncture between the functional equipotential bonding conductor / reinforcement and the sealing (concrete) to the ring earth electrode installed underneath the concrete in case of a lightning strike.

In addition, a functional equipotential bonding conductor with a mesh size ≤ 20 m x 20 m must be installed in the foundation slab according to the German DIN 18014 standard. The procedure is identical to that in case of a foundation earth electrode.

The ring earth electrode must be connected to the concrete-embedded functional equipotential bonding conductor at intervals of 20 m (perimeter of the building) or, if a lightning protection system is installed, to each down conductor of the lightning protection system to act as a combined equipotential bonding system according to IEC 60364-4-44 (HD 60364-4-44). These connections can be made above the ground water level or below the ground water level by means of pressure-water-tight bushings.

Figures 5.5.2.13 and 5.5.2.14 show the arrangement of a ring earth electrode and a functional equipotential bonding conductor in a "white tank".

Waterproof wall bushings

The electrical connection to the ring earth electrode must be waterproof. The requirements, which are for example placed on "white tanks", were also considered when developing the waterproof wall bushing. During the product development process, special emphasis was placed on incorporating component requirements as realistically as possible. The specimens were embedded in concrete (**Figure 5.5.2.15**) and then subjected to a pressure water test. Since installation situations up to a depth of 10 m are common practice in the building industry (e.g. underground car parks), this installation situation was transferred to the specimens by subjecting them to a water pressure of 1 bar after the concrete had cured (**Figure 5.5.2.16**). In a long-time test over 65 hours, the watertightness of the specimens was tested.

Capillary action is a problem for wall bushings. This means that liquids (e.g. water) disperse differently in narrow gaps or ducts in the concrete and are thus virtually drawn up or soaked into

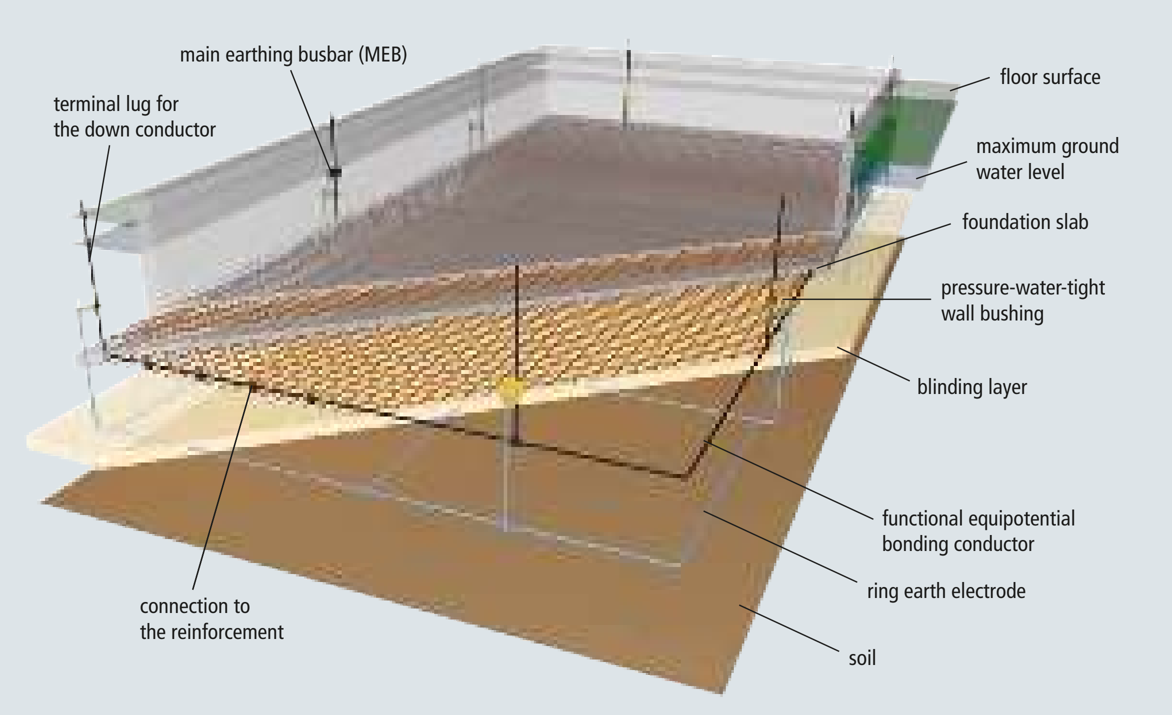


Figure 5.5.2.14 Three-dimensional representation of the ring earth electrode, functional equipotential bonding conductor and connections via pressure-water-tight wall bushings

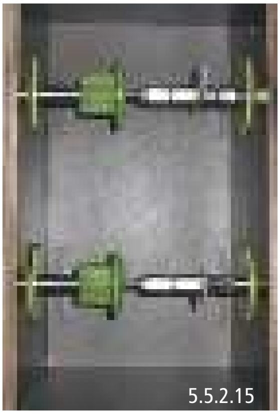


Figure 5.5.2.15 Wall bushing installed in the formwork
Figure 5.5.2.16 Test setup (sectional view) with connection for the pressure water test

Figure 5.5.2.17 Waterproof wall bushing

Figure 5.5.2.18 Bituminous sheetings used as sealing material

the building. These narrow gaps or ducts can occur during the curing process and the resulting shrinkage of concrete. Therefore, professional and proper installation of the wall bushing into the formwork is essential. This is described in detail in the relevant installation instructions. Waterproof wall bushings for "white tanks", e.g. Part No. 478 550 (**Figure 5.5.2.17**):

- Version for installation into the formwork with water barrier and M10/12 double thread on both ends is connected e.g. to a ring earth electrode or equipotential bonding bar.
- Adjustable depending on the wall thickness by means of M10 thread and lock nut. The thread of the bushing can be shortened, if required.
- Tested with compressed air of 5 bars according to IEC 62561-5 (EN 62561-5)

"Black tank"

The term "black tank" refers to the black multi-layer bituminous coating applied to the building in the soil to seal the building. The building structure is covered with a bitumen/tar mass over which typically up to three layers of bituminous sheetings are applied (**Figure 5.5.2.18**). Nowadays, a polymer-modified bituminous coating is also used.

Due to the high insulation values of the materials used, it cannot be ensured that a foundation earth electrode is in contact with the soil. Here again, a ring earth electrode in conjunction with a functional equipotential bonding conductor is required (same procedure as for "white tanks").

Wherever practical, the external ring earth electrode should be led into the building above the building sealing, in other words above the highest ground water level, to ensure that the tank is waterproof in the long term (**Figure 5.5.2.19**). Pressure-water-tight penetration of the concrete is only possible by means of special components.

Perimeter insulation

Nowadays, various types of foundations with different designs and sealing versions are used.

Heat insulation regulations have also influenced the design of strip foundations and foundation slabs. If foundation earth electrodes are installed in new structures based on the German DIN 18014 standard, the sealing/insulation has an effect on their installation and arrangement. Perimeter refers to the wall and floor area of a building that is in contact with the soil. Perimeter insulation is the heat insulation fitted around the building. The perimeter insulation situated outside on the sealing layer encloses the building structure without forming heat

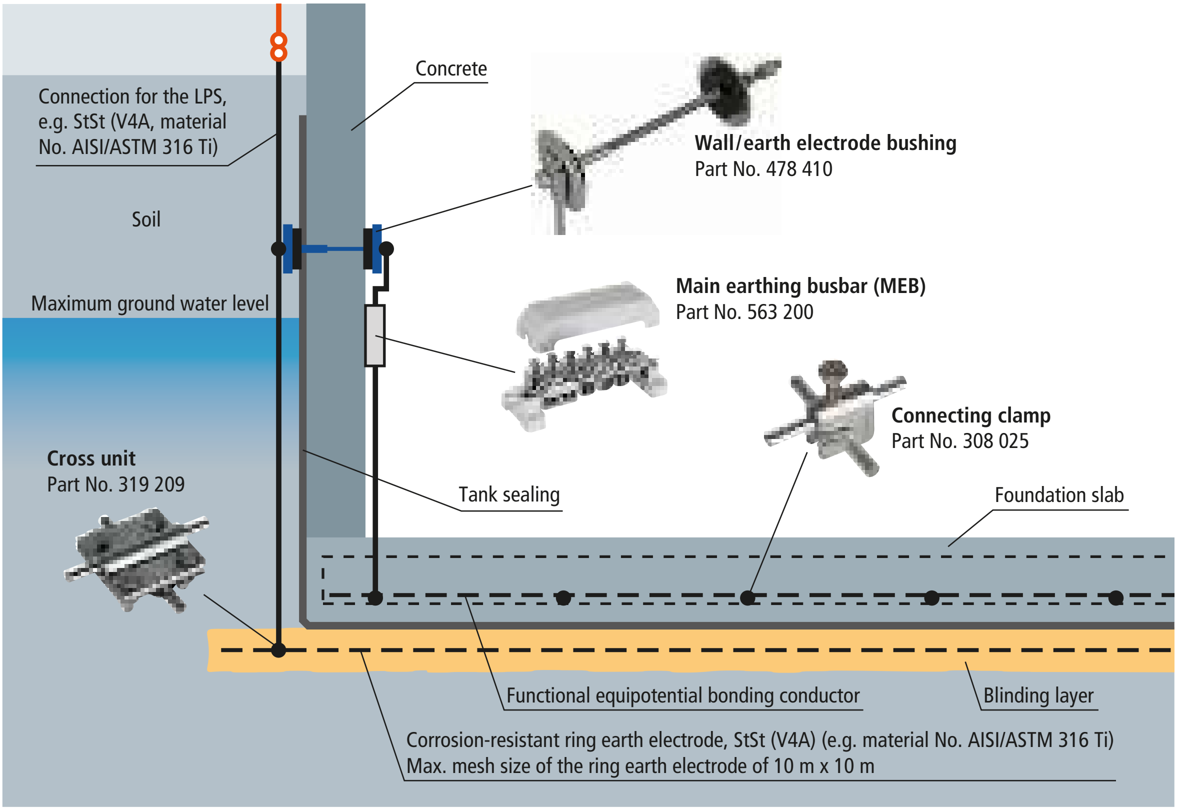


Figure 5.5.2.19 Arrangement of the earth electrode in case of a “black tank” according to the German DIN 18014 standard

Figure 5.5.2.20 Ring earth electrode in case of perimeter insulation; source: Company Mauermann

Figure 5.5.2.21 Detailed view of a ring earth electrode; source: Company Mauermann

bridges and additionally protects the sealing from mechanical damage (**Figures 5.5.2.20 and 5.5.2.21**).

The resistivity of the perimeter insulation boards is a decisive factor when considering the effects of the perimeter insulation on the earth resistance of foundation earth electrodes which are conventionally installed in the foundation slab. A resistivity of $5.4 \cdot 10^{12}$ Ωm is specified for e.g. polyurethane foam with a density of 30 kg/m^3. The resistivity of concrete, in contrast, is

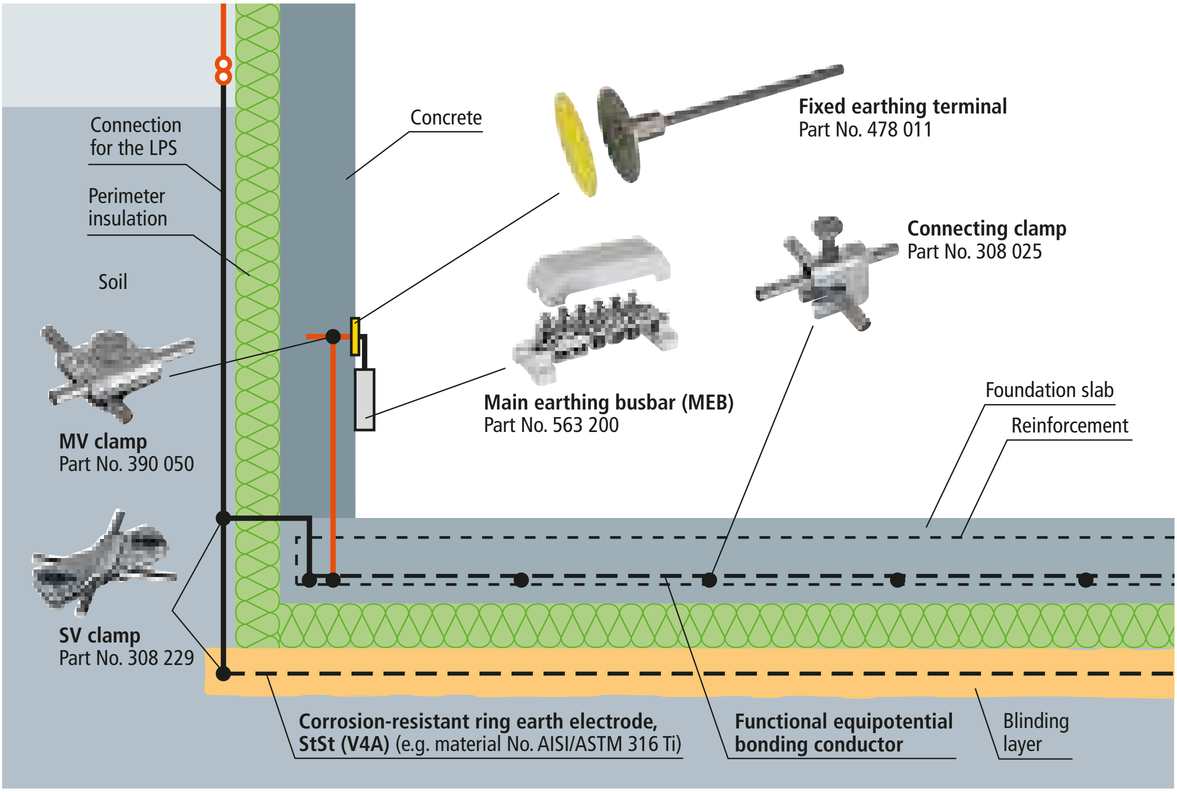


Figure 5.5.2.22 Arrangement of the foundation earth electrode in case of a closed floor slab (fully insulated) acc. to the German DIN 18014 standard

between 150 Ωm and 500 Ωm. This means that, in case of full perimeter insulation, a foundation earth electrode conventionally arranged in the foundation has virtually no effect. Consequently, the perimeter insulation acts as an electrical insulator.

If the foundation slab and the outer walls are fully insulated (full perimeter insulation), a ring earth electrode with an adequate mesh size must be installed below the foundation slab in the blinding layer or soil. This earth electrode must be made of corrosion-resistant stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti (**Figure 5.5.2.22**). As with "white tanks", a functional equipotential bonding conductor is required in this case.

Capillary-breaking, poorly conducting floor layers e.g. made of recycling material

Nowadays, recycling materials such as foam glass gravel or other capillary-breaking materials are used as an alternative to full perimeter insulation (**Figure 5.5.2.23**). These materials are a cost-effective alternative to common polyurethane foam sheets made of crude oil and serve as blinding layer (subgrade) at the same time.

This type of perimeter insulation is commonly used below the floor slab and laterally at the basement wall. Apart from its heat-insulating properties, foam glass gravel also has the advantage that it is draining, capillary-breaking, load-bearing and, compared to gravel, easy to transport. Before filling the

Figure 5.5.2.23 Perimeter insulation: Foam glass granulate is filled in; source: TECHNOpor Handels GmbH

foam glass gravel in the excavation pit, the excavation pit is covered with e.g. geotextiles.

To be able to install a standard-compliant earth-termination system for this type of perimeter insulation, the ring earth electrode must be installed in contact with the soil below the foam glass gravel and geotextiles. Thus, compared to conventional methods, the earth electrode is installed at an earlier stage. The responsible company must be aware of the fact that the installation of the earth electrode must be incorporated at an early design stage, namely directly after the excavation work. Stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti, must be used for the round or flat conductor as well as for the required clamps and connectors which are directly installed in the soil. Also in this case, the functional equipotential bonding conductor must be installed in the foundation (see "White tank").

Pad foundations / point foundations

Pad foundations, also referred to as point foundations, are often used for industrial buildings. These pad foundations serve as a foundation, e.g. for steel supports or concrete beams of halls. The foundation slab is not closed. Since these structures also require a functioning earth-termination system, earthing measures are required for these pad foundations.

Foundation earth electrodes made of round or flat steel (galvanised) must have a length of at least 2.5 m in the pad foundations and must be covered by a concrete layer of at least 5 cm (**Figure 5.5.2.24**).

These "individual earth-termination systems" must be interconnected to prevent potential differences in the earth-termination system. This connection should be made on the lowest floor, preferably in contact with the soil. Both the connecting lines and the connection components of the pad foundation must be made of corrosion-resistant stainless steel (V4A).
If these pad foundations are made of e.g. concrete with a high resistance to water penetration (waterproof concrete), a ring earth electrode made of stainless steel (V4A) with a mesh size ≤ 20 m x 20 m must be installed in the soil.

Non-reinforced strip foundations

Spacers must be used in non-reinforced foundations such as strip foundations of residential buildings. Only by using these spacers at intervals of approximately 2 m, it is ensured that the foundation earth electrode is "raised" and covered by a concrete layer of at least 5 cm on all sides (**Figures 5.5.2.25 and 5.5.2.26**).
Wedge connectors must not be used when compacting (vibrating) this concrete mechanically. The foundation earth electrode must be directly positioned on the subgrade and must be made of stainless steel (V4A) if it is not possible to use a spacer due to the high-density subgrade (wet mix aggregate with rocks, etc.).

Reinforced strip foundations

In case of reinforced strip foundations, the foundation earth electrode is embedded in concrete as a closed ring. The reinforcement is also integrated and connected in such a way that it is permanently conductive. Due to the risk of corrosion, it must be observed that the foundation earth electrode is covered by a concrete layer of 5 cm. The connection components / terminal lugs must be made of stainless steel (V4A).

Steel fibre concrete

Steel fibre concrete is a material which is produced by adding steel fibres to the fresh concrete. In comparison to concrete without fibres, steel fibre concrete may be subjected to tensile force (tensile strength) within certain limits so that the commonly used concrete steel reinforcement can be completely replaced in many cases. Steel fibre concrete foundations are made on site (cast or pumped).

Figure 5.5.2.24 Foundation earth electrode for pad foundations with terminal lug; source: Wettingfeld, Krefeld

Figure 5.5.2.25 Spacer with cross unit

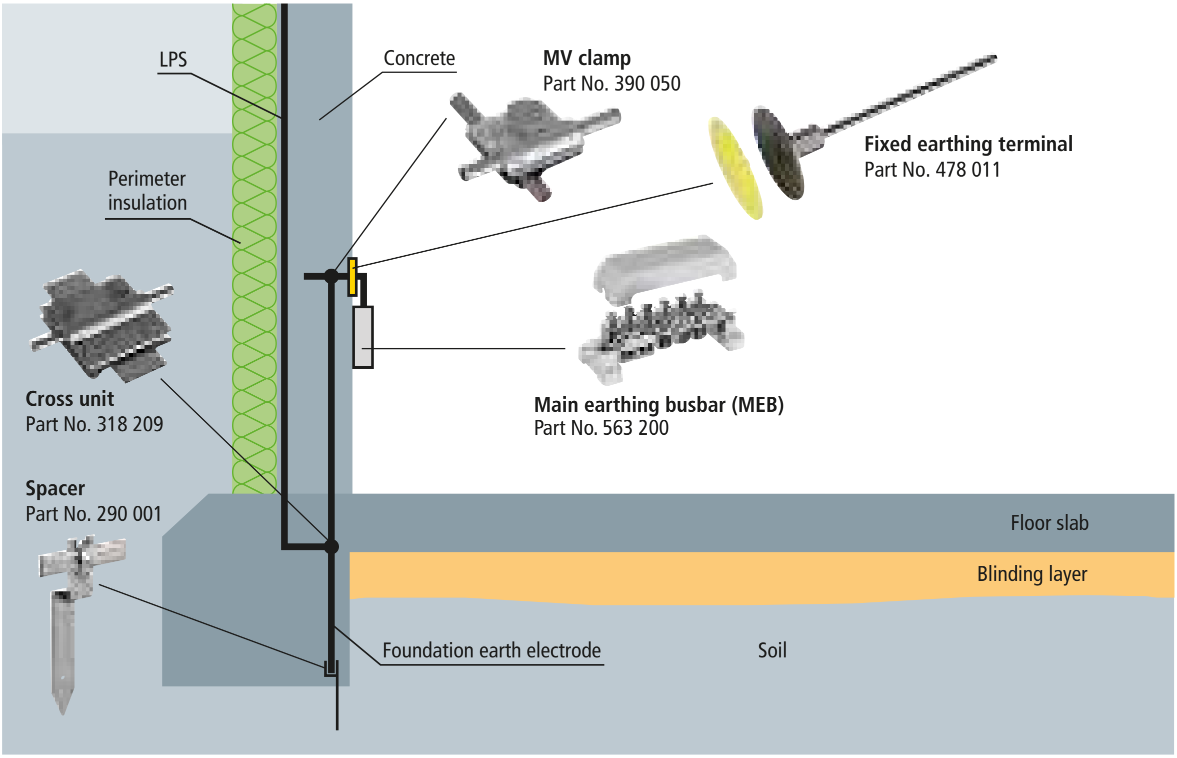


Figure 5.5.2.26 Arrangement of the foundation earth electrode in case of a strip foundation (insulated basement wall) according to the German DIN 18014 standard

In Germany, steel fibre concrete is mainly used for industrial and residential buildings. The steel fibres typically have a length of 50 to 60 mm and a diameter of 0.75 to 1.00 mm. Straight steel fibres with hooked ends or crimped steel fibres are most commonly used (**Figure 5.5.2.27**). The required content of steel fibres depends on the load on the floor slab and the efficiency of the steel fibres used. A static calculation must be made to select the required type and quantity of steel fibres. Since steel fibres do not significantly influence the electrical conductivity of concrete, an earth electrode with a mesh size ≤ 20 m x 20 m must be installed as earthing measure for pure steel fibre concrete slabs. The earthing conductor can be installed in the concrete and must be covered by a concrete layer of 5 cm on all sides for corrosion protection reasons if it consists of galvanised material. This is impractical on site in most cases. It is therefore advisable to install a corrosion-resistant ring earth electrode made of stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti, below the later foundation slabs. The relevant terminal lugs must be considered.

Figure 5.5.2.27 Fresh concrete with steel fibres

5.5.3 Ring earth electrodes – Type B earth electrodes

The earth-termination system of existing structures can be design in the form of a ring earth electrode (**Figure 5.5.3.1**). This earth electrode must be installed as a closed ring around the building or, if this is not possible, a connection must be made inside the structure to close the ring. 80 % of the conductors of

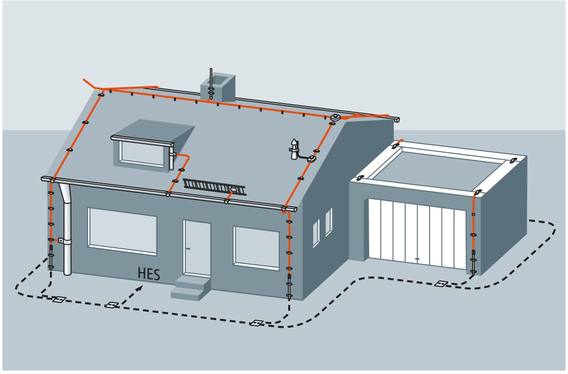


Figure 5.5.3.1 Ring earth electrode around a residential building

the earth electrode must be installed in such a way that they are in contact with the soil. If this is not possible, it has to be checked if additional type A earth electrodes are required.

The requirements on the minimum earth electrode length must be taken into account depending on the class of LPS (see chapter 5.5.1). When installing the ring earth electrode, it must be also observed that it is buried at a depth > 0.5 m and 1 m away from the building. If the earth electrode is driven into the soil as described before, it reduces the step voltage and thus controls the potential around the building.

This ring earth electrode should be installed in natural soil. If it is installed in backfill or soil filled with construction waste, the earth resistance is reduced.

When choosing the earth electrode material with regard to corrosion, local conditions must be taken into consideration. It is advisable to use stainless steel. This earth electrode material does neither corrode nor subsequently require time-consuming and expensive reconstruction measures for the earth-termination system such as removal of paving stones, tar surfaces or even steps for installing a new earthing material.

In addition, the terminal lugs must be particularly protected against corrosion.

5.5.4 Earth rods – Type A earth electrodes

The sectional DEHN earth rods are made of special steel and are hot-dip galvanised or consist of high-alloy stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti. These earth rods are characterised by their self-closing coupling joint, which allows the earth rods to be connected without increasing their diameter.

Each rod has a borehole at its lower end, while the other end of the rod has a corresponding pin (**Figure 5.5.4.1**). This construction has the advantage that this connection is mechanically highly stable, electrically safe and capable of carrying lightning currents during the drive-in process.

- With an earth electrode of type S, the soft metal in the borehole deforms during the drive-in process, creating an excellent electrical and mechanical connection.
- With an earth electrode of type Z, the high coupling quality is achieved by means of a multiply knurled pin.
- With an earth electrode of type AZ, the high coupling quality is achieved by means of an offset multiply knurled pin.

Different striking tools are used to drive the earth rods into the ground. When selecting these tools, it must be observed that the earth rod is driven into the ground with approximately 1200 strokes/min. A significantly higher number of strokes is not advisable, since the striking energy is often not sufficient to drive the earth rod deep enough into the ground. In case of striking tools whose striking frequency is too low as is the case with pneumatic tools, the striking power is much too high and the number of strokes is too low. The weight of the striking tool should not exceed 20 kg.

The penetration depth of earth rods depends on various geological conditions. In light grounds, which can be found for example in coastal areas or wetlands, penetration depths between 30 m to 40 m are possible. Where extremely hard grounds are encountered, for example in natural sandy ground, penetration depths of more than 12 m are frequently impractical. If conventional earth rods are used, the soil is not drilled out during the drive-in process, but pushed away by the earth rod. This compresses the soil around the earth electrode and ensures good electrical contact with the surroundings. The larger the outer diameter of the earth rod, the more soil is pushed away. For heavy grounds, for example, an earth rod with an outer diameter of 25 mm is optimal with regard to the maximum drive-in depth and the soil pushed away by the earth electrode.

To drive earth rods into greater depths (penetration depths > 6 m), it is recommended to use a hammer frame (Part No.

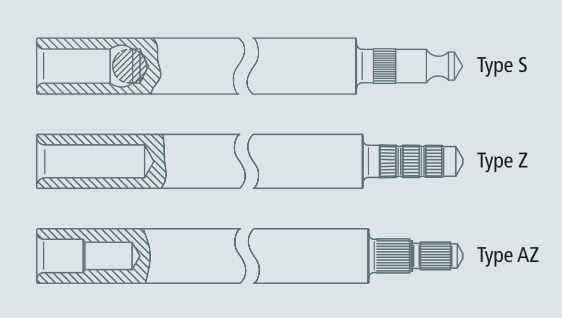


Figure 5.5.4.1 Couplings of DEHN earth rods

600 003) (**Figure 5.5.4.2**). When using this hammer frame with a striking tool, the striking energy is constantly applied to the striking surface of the earth rod via the hammer insert. This is not ensured if no hammer frame is used and the striking tool is operated by hand. Therefore, it is not advisable to drive earth rods more than 6 m into medium or heavy grounds without using a hammer frame.

DEHN earth rods have the following benefits:

- Special coupling: no increase in diameter so that the earth rod is in direct contact with the soil across its full length
- Self-closing coupling when driving the rods into the soil
- Easy to drive in by means of a vibration hammer or manual beetle
- Constant resistance values are achieved since the earth rods penetrate through soil layers which are unaffected by seasonal changes in moisture and temperature
- High corrosion resistance as a result of hot-dip galvanising (thickness of the zinc coating: 70 µm)
- Earth rods made of galvanised steel and stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti, are available
- The coupling joints of galvanised earth rods are also hot-dip galvanised
- Easy to store and transport since the individual rods are 1.5 or 1 m long. The smaller individual rod length of 1 m is particularly designed for subsequent installation e.g. into buildings (working height including vibration hammer).

Figure 5.5.4.2 Driving an earth rod into the ground by means of a hammer frame and a vibration hammer

5.5.5 Earth electrodes in rocky ground

In rocky or stony ground, surface earth electrodes such as ring or radial earth electrodes are often the only way to create an earth-termination system. When installing the earth electrodes, the strip or round material is laid on the stony or rocky ground. The earth electrode should be covered with gravel, wet mix aggregate or the like and should be made of stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti. The clamping points should be installed with care and should be protected against corrosion. They should consist of a similar corrosion-proof material as the earth electrode.

5.5.6 Meshed earth-termination systems

An earth-termination system can fulfil a variety of functions.

The purpose of protective earthing is to safely connect electrical installations and equipment to the earth potential and to protect human life and property in the event of an electrical fault.

Lightning protection earthing ensures that the current from the down conductors is safely discharged to the ground.

The function of functional earthing is to ensure safe and faultless operation of electrical and electronic systems.

The earth-termination system of a structure must be used for all earthing tasks, in other words the earth-termination system fulfils all earthing tasks. If this is not the case, potential differences can occur between the installations earthed on different earth-termination systems.

In practice, "clean earth" used to be separated from lightning protection and protective earth for functionally earthing electronic equipment. This is extremely unfavourable and can even be dangerous. In the event of lightning effects, extremely high potential differences up to some 100 kV occur in the earth-termination system. This can lead to the destruction of electronic equipment and life hazard. Therefore, IEC 62305-3 (EN 62305-3) and IEC 62305-4 (EN 62305-4) require consistent equipotential bonding within a structure.

Electronic equipment within a structure can be earthed radially, centrally or by meshes. A meshed earth-termination system should be preferably used. This depends both on the electromagnetic environment and on the characteristics of the

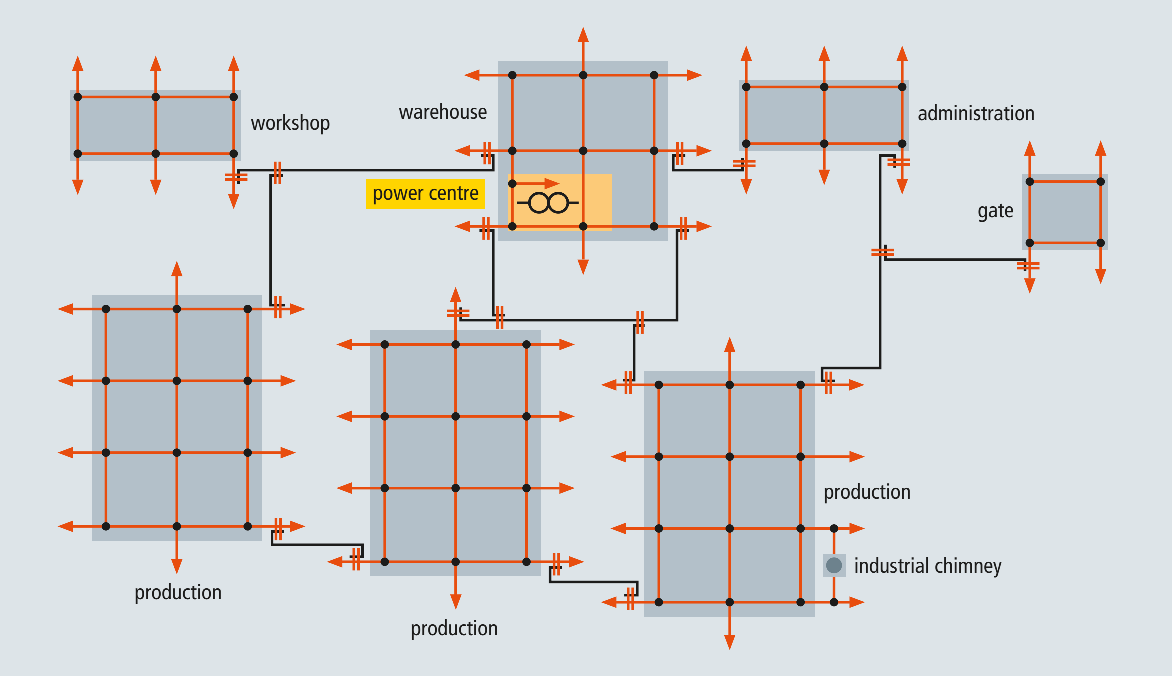


Figure 5.5.6.1 Intermeshed earth-termination system of an industrial plant

electronic equipment. If a large structure comprises more than one building and these buildings are connected by electrical and electronic connecting cables, the (total) earth resistance can be reduced by combining the individual earth-termination systems (**Figure 5.5.6.1**). In addition, the potential differences between the buildings are also considerably reduced. This significantly reduces the voltage load on the electrical and electronic connecting cables. The individual earth-termination systems of the buildings should be interconnected to form a meshed network. This meshed earthing network should be designed such that it contacts the earth-termination systems at the point where the vertical down conductors are connected. The smaller the mesh size of the earthing network, the lower is the potential differences between the buildings in the event of a lightning strike. This depends on the total area of the structure. Mesh sizes of 20 m x 20 m up to 40 m x 40 m have proven to be cost-effective. If, for example, industrial chimneys (preferred points of strike) are installed, the connection components around the relevant part of the installation should be closer, and, if possible, arranged radially with circular cross-connections (potential control). Corrosion resistance and compatibility of materials must be observed when choosing the material for the conductors of the meshed earthing network.

5.5.7 Corrosion of earth electrodes

5.5.7.1 Earth-termination systems with a special focus on corrosion

Metals in direct contact with the soil or water (electrolytes) can corrode due to stray currents, corrosive soils and cell formation. It is not possible to protect earth electrodes from corrosion by completely enclosing them, i.e. by separating the metals from the soil since all common sheaths used until now have a high electrical resistance and therefore eliminate the effect of the earth electrodes.

Earth electrodes made of the same material are prone to corrosion due to corrosive soils and the formation of concentration cells. The risk of corrosion depends on the material and the type and composition of the soil.

Corrosion damage due to cell formation is on the rise. This cell formation between different types of metals with very different metal/electrolyte potentials has been known for years. However, it is often not known that the reinforcements of concrete foundations can also become the cathode of a cell and hence cause corrosion to other buried installations.

Due to changing construction methods – larger reinforced concrete structures and smaller free metal areas in the ground – the surface ratio of the anode/cathode is becoming more and more unfavourable and the risk of corrosion for non-precious metals inevitably increases.

An electrical isolation of parts of an installation acting as anodes to prevent this cell formation is only possible in exceptional cases. Today the aim is to interconnect all earth electrodes also with other metal installations in contact with the soil to establish equipotential bonding and thus ensure maximum safety against excessive touch voltages in the event of a fault and lightning effects.

In high-voltage installations, high-voltage protective earth electrodes are increasingly connected to low-voltage operational earth electrodes in accordance with IEC 60364 (EN 60364). IEC 60364-4-41 (HD 60364-4-41) / IEC 60364-5-54 (HD 60364-5-54) requires to integrate pipework and other installations in the protection measures against electric shock. Thus, the only way of preventing or at least reducing the risk of corrosion for earth electrodes and other installations connected to them is to choose suitable earth electrode materials. In Germany, the national DIN VDE 0151 standard "Material and minimum dimensions of earth electrodes with respect to corrosion" is available since June 1986. Apart from decades of experience in the field of earthing technology, the results of extensive preliminary examinations have also been included in this standard. The fundamental processes leading to corrosion are explained below. Practical anti-corrosion measures especially for lightning protection earth electrodes can be derived from this and from the material prepared by the VDE task force on "Earth electrode materials".

Terms used in connection with corrosion protection and anti-corrosion measurements

Corrosion

is the reaction of a metal material with its environment which impairs the characteristics of the metal material and / or its environment. In most cases, the reaction is electrochemical.

Electrochemical corrosion

is corrosion during which electrochemical processes occur. They only take place in the presence of an electrolyte.

Electrolyte

is an ion-conducting corrodent (e.g. soil, water, molten salt).

Electrode

is an electron-conducting material in an electrolyte. The electrode and electrolyte form a half-cell.

Anode

electrode from which direct current passes into the electrolyte.

Cathode

electrode which absorbs direct current from the electrolyte.

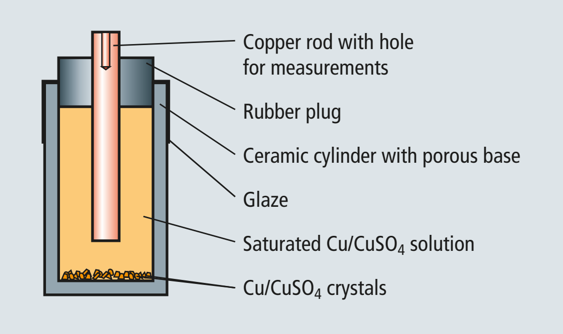


Figure 5.5.7.1.1 Application example of a non-polarisable measuring electrode (copper / copper sulphate electrode) for tapping a potential within the electrolyte (cross-sectional view)

Reference electrode

is a measuring electrode for determining the potential of a metal in the electrolyte.

Copper sulphate electrode

is an almost non-polarised reference electrode consisting of copper in a saturated copper sulphate solution.

The copper sulphate electrode is the most common reference electrode for measuring the potential of buried metal objects (**Figure 5.5.7.1.1**).

Corrosion cell

is a galvanic cell with locally different partial current densities for dissolving the metal. Anodes and cathodes of the corrosion cell can be formed:

- **on the material**
  due to different metals (contact corrosion) or different structural constituents (selective or intercrystalline corrosion).
- **on the electrolyte**
  due to different concentrations of certain substances with stimulating or inhibitory characteristics for dissolving the metal.

Potentials

- **Reference potential**
  potential of a reference electrode with respect to the standard hydrogen electrode.
- **Electrical potential**
  is the electrical potential of a metal or an electron-conducting solid in an electrolyte.

5.5.7.2 Formation of galvanic cells, corrosion

Corrosion processes can be clearly described with the help of a galvanic cell. If, for example, a metal rod is immersed into an electrolyte, positively charged ions pass into the electrolyte and conversely, positive ions are absorbed from the electrolyte by the metal band. This is called "solution pressure" of the metal and "osmotic pressure" of the solution. Depending on the magnitude of these two pressures, either the metal ions from the rod pass into the solution (the rod becomes negative compared to the solution) or the ions of the electrolyte deposit on the rod (the rod becomes positive compared to the electrolyte). Voltage is thus applied between two metal rods in the same electrolyte.

In practice, the potentials of the metals in the ground are measured with the help of a copper sulphate electrode which consists of a copper rod immersed into a saturated copper sulphate solution (**Figure 5.5.7.1.1**) (the reference potential of this reference electrode remains constant).

In the following, it will be described how two rods made of different metals are immersed into the same electrolyte. A voltage of a certain magnitude is now created on each rod in the electrolyte. A voltmeter can be used to measure the voltage between the rods (electrodes); this is the difference between the potentials of the individual electrodes compared to the electrolyte.

How does it come that current flows in the electrolyte and that material is transported, that is corrosion occurs?

If, as shown here, the copper and the iron electrode are connected via an ammeter outside the electrolyte, for example, the following (**Figure 5.5.7.2.1**) is observed: In the outer circuit, the current i flows from + to –, namely from the "more precious" copper electrode according to **Table 5.5.7.2.1** to the iron electrode.

In the electrolyte, in contrast, the current i must therefore flow from the "more negative" iron electrode to the copper electrode to close the circuit. In general, this means that the more negative pole passes positive ions to the electrolyte and hence becomes the anode of the galvanic cell, in other words it is dissolved. The metal is dissolved at those points where the current enters the electrolyte. A corrosion current can also arise due to the concentration cell (**Figure 5.5.7.2.2**). In this case, two electrodes made of the same metal immerse into different electrolytes. The electrode in electrolyte II with the higher concentration of metal ions becomes electrically more positive than the other.

This process is also referred to as polarisation. Connecting the two electrodes enables the current i to flow and the electrode which is electrochemically more negative dissolves.

Such a concentration cell can be formed, for example, by two iron electrodes, one of which is fixed in iron-reinforced concrete while the other lies in the ground (**Figure 5.5.7.2.3**).

Connecting these electrodes, the iron in the concrete becomes the cathode of the concentration cell and the iron in the ground becomes the anode. The latter is therefore destroyed by ion emission.

For electrochemical corrosion it is generally the case that the larger the ions and the lower their charge, the greater the transport of metal associated with the current flow i (this means that i is proportional to the atomic mass of the metal).

In practice, the calculations are carried out with currents flowing over a certain period of time, e.g. one year. **Table 5.5.7.2.1** specifies values which define the effect of the corrosion current (current density) in terms of the quantity of metal dissolved. Corrosion current measurements thus make it possible to calculate in advance how many grammes of a metal will be eroded over a specific period.

Of more practical interest, however, is the prediction if, and over which period of time, corrosion will cause holes or recesses in earth electrodes, steel containers, pipes etc. Thus, it is important whether the current attack will be diffuse or punctiform.

As far as the corrosive attack is concerned, it is not solely the magnitude of the corrosion current which is decisive, but also, in particular, its density, namely the current per unit of area of the discharge area.

It is often not possible to directly determine this current density. In such cases, potential measurements are carried out from which the extent of the available "polarisation" can be read off. The polarisation behaviour of electrodes is discussed only briefly here.

Let us consider the case of a galvanised steel strip situated in the ground and connected to the (black) steel reinforcement of a concrete foundation (**Figure 5.5.7.2.4**). According to our measurements, the following potential differences occur here with respect to the copper sulphate electrode:

- Steel (black) in concrete: –200 mV to –400 mV
- Steel, galvanised, in sand: –800 mV to –900 mV
- Steel, galvanised, as good as new: about –1000 mV

Thus, there is a potential difference of 600 mV between these two metals. If they are now connected above ground, a current i flows in the outer circuit from concrete steel to the steel in the sand, and in the ground from the steel in the sand to the steel in the reinforcement.

The magnitude of the current i is now a function of the voltage difference, the conductance of the ground and the polarisation of the two metals.

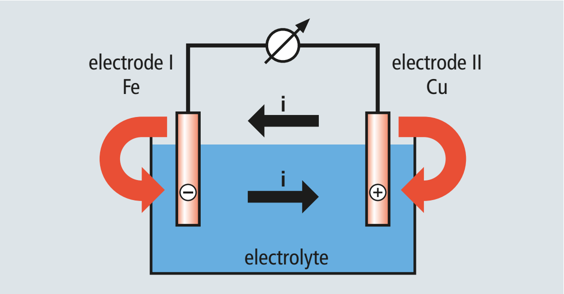


Figure 5.5.7.2.1 Galvanic cell: Iron / copper

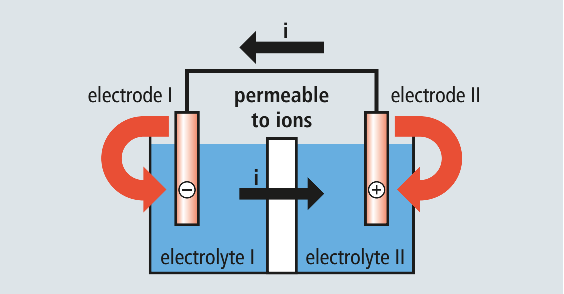


Figure 5.5.7.2.2 Concentration cell

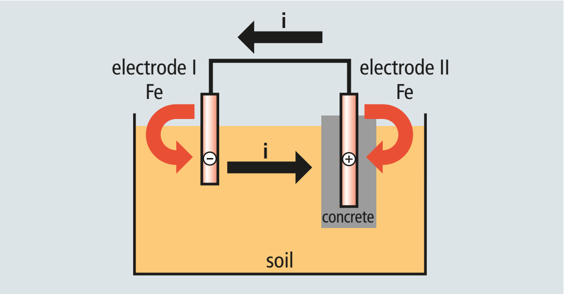


Figure 5.5.7.2.3 Concentration cell: Iron in the soil / iron in concrete

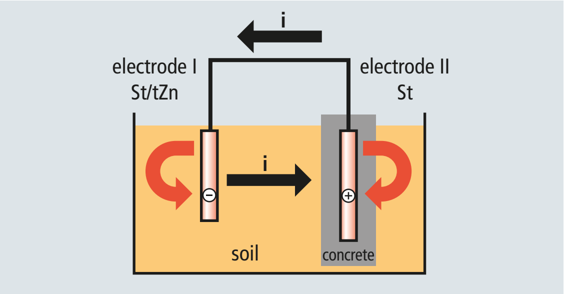


Figure 5.5.7.2.4 Concentration cell: Galvanised steel in the soil / steel (black) in concrete

	Designation	Symbol	Copper	Lead	Tin	Iron	Zinc
1	Free corrosion potential in the soil [1] [V]	$U_{M\text{-}Cu/CuSO4}$	0 to –0.1	–0.5 to –0.6	–0.4 to –0.6 [2]	–0.5 to –0.8 [3]	–0.9 to –1.1 [5]
2	Cathodic protection potential in the soil [1] [V]	$U_{M\text{-}Cu/CuSO4}$	–0.2	–0.65	–0.65 [2]	–0.85 [4])	-1.2 [5]
3	Electrochemical equivalent [kg/(A · year)]	$K = \frac{\Delta m}{I\ t}$	10.4	33.9	19.4	9.1	10.7
4	Linear corrosion rate at J = 1 mA/dm^2 [mm/year]	$W_{lin} = \frac{\Delta s}{t}$	0.12	0.3	0.27	0.12	0.15

[1] Measured against a saturated copper / copper sulphate electrode (Cu/CuSo$_4$).

[2] The potential of tin-coated copper depends on the thickness of the tin coating and, in case of common tin coatings up to some μm, is between the values of tin and copper in the soil.

[3] These values also apply to low-alloy steel. The potential of steel in concrete (reinforcing bar of foundations) heavily depends on external influences. Measured against a saturated copper / copper sulphate electrode, it is generally between –0.1 and –0.4 V. In case of a metal conducting connection with large-scale underground installations made of metal with more negative potentials, it is cathodically polarised and reaches values up to approximately –0.5 V.

[4] In anaerobic soils, the protection potential should be –0.95 V.

[5] Hot-dip galvanised steel with a zinc layer according to the above table has a closed external pure zinc layer. The potential of hot-dip galvanised steel in the soil is therefore almost equal to the value of zinc in the soil. If the zinc layer is removed, the potential gets more positive and can reach the value of steel in case it is completely removed. The potential of hot-dip galvanised steel in concrete has approximately the same initial values. In the course of time, the potential can get more positive. However, values more positive than approx. –0.75 V have not been found yet. Heavily hot-dip galvanised copper with a zinc layer of at least 70 μm also has a closed external pure zinc layer. The potential of hot-dip galvanised copper in the soil is therefore almost equal to the value of zinc in the soil. In case of a thinner zinc layer or removal of the zinc layer, the potential gets more positive. Limit values are still unsecure.

Table 5.5.7.2.1 Potential values and corrosion rates of common metal materials (according to Table 2 of the German VDE 0151 standard)

Generally, it is found that the current i in the ground generates changes in the material.

But a change to the material also means that the voltage of the individual metals changes with respect to the ground. This potential drift caused by the corrosion current i is called polarisation. The strength of the polarisation is directly proportional to the current density. Polarisation phenomena now occur at the negative and positive electrode. However, the current densities at both electrodes are mostly different.

To illustrate this, the following example is considered:

A well-insulated steel gas pipe in the ground is connected to copper earth electrodes.

If the insulated pipe has only a few small defects, there is a high current density at these points resulting in quick corrosion of the steel. In contrast, the current density is low in case of a much larger area of the copper earth electrodes via which the current enters. Thus, the polarisation is greater in case of the more negative insulated steel pipe than in case of the positive copper earth electrodes. The potential of the steel pipe is shifted to more positive values. Thus, the potential difference between the electrodes also decreases. The magnitude of the corrosion current therefore also depends on the polarisation characteristics of the electrodes.

The strength of the polarisation can be estimated by measuring the electrode potentials in case of a disconnected circuit which avoids the voltage drop in the electrolyte. Recording instruments are usually used for such measurements since there is frequently a rapid depolarisation immediately after the corrosion current is interrupted.

If a high polarisation is now measured at the anode (the more negative electrode), i.e. if there is an obvious shift to more positive potentials, there is a high risk that the anode will corrode.

Let us now return to the corrosion cell steel (black) in concrete / steel, galvanised in sand (**Figure 5.5.7.2.4**). With respect to a distant copper sulphate electrode, it is possible to measure a potential of the interconnected cell between –200 mV and –800 mV depending on the ratio between the anode and cathode and the polarisability of the electrodes.

If, for example, the area of the reinforced concrete foundation is very large compared to the surface of the galvanised steel wire, a high anodic current density occurs at the latter so that it is polarised to almost the potential of the reinforcing steel and destroyed in a relatively short time.

Consequently, a high positive polarisation always indicates an increased risk of corrosion.

In practice, it is of course important to know the limit above which a positive potential shift denotes an imminent risk of corrosion. Unfortunately, it is not possible to give an exact value for this which applies in every case since the effects of the soil composition alone are too high. It is, however, possible to define potential shift areas for natural soils.

A polarisation below +20 mV is generally not hazardous. Potential shifts exceeding +100 mV are definitely hazardous. Between 20 and 100 mV there will always be cases where the polarisation causes considerable corrosion effects.

To sum up: The presence of metal and electrolytic anodes and cathodes connected so as to be conductive is always a prerequisite for the formation of corrosion cells (galvanic cells).

Anodes and cathodes consist of:

- **Materials**
  - Different metals or different surface quality of a metal (contact corrosion)
  - Different structural constituents (selective or intercrystalline corrosion)
- **Electrolytes**
  - Different concentration (e.g. salt content, ventilation)

In corrosion cells, the anodic areas always have a more negative metal / electrolyte potential than the cathodic areas.

The metal / electrolyte potentials are measured using a saturated copper sulphate electrode mounted in the immediate vicinity of the metal in or on the ground. If there is a conductive metal connection between the anode and cathode, the potential difference causes a direct current in the electrolyte which passes from the anode into the electrolyte by dissolving metal before entering the cathode again.

The "area rule" is often used to estimate the average anodic current density J_A:

$$J_A = \frac{U_C - U_A}{\varphi_C} \cdot \frac{A_C}{A_A} \quad \text{in A/m}^2$$

J_A	Average anodic current density
U_A, U_C	Anode or cathode potentials in V
φ_C	Polarisation resistivity of the cathode in Ωm^2
A_A, A_C	Anode or cathode surfaces in m^2

The polarisation resistance is the quotient of the polarisation voltage and the total current of a mixed electrode (an electrode where more than one electrode reaction takes place).

In practice, it is possible to determine the driving cell voltage $U_C - U_A$ and the areas A_C and A_A as an approximation in order to estimate the corrosion rate, however, the values of φ_A (polarisation resistivity of the anode) and φ_C are not available with sufficient accuracy. They depend on the electrode materials, the electrolytes and the anodic and cathodic current densities.

Previous examination results allow the conclusion that φ_A is much smaller than φ_C.

The following applies for φ_C:

Steel in the ground	approx.	1 Ωm^2
Copper in the ground	approx.	5 Ωm^2
Steel in concrete	approx.	30 Ωm^2

From the area rule, however, it can be clearly seen that high corrosion effects occur both on enclosed steel pipes and tanks with small defects connected to copper earth electrodes and earthing conductors made of galvanised steel connected to extended copper earth-termination systems or extremely large reinforced concrete foundations.

The risk of corrosion for earth electrodes can be avoided or reduced by choosing suitable materials. To achieve a sufficient service life, the minimum material dimensions must be maintained (**Table 5.5.8.1**).

5.5.7.3 Selection of earth electrode materials

Commonly used earth electrode materials and their minimum dimensions are listed in **Table 5.5.8.1**.

Hot-dip galvanised steel

Hot-dip galvanised steel can also be embedded in concrete. Foundation earth electrodes, earthing and equipotential bonding conductors made of galvanised steel in concrete may be connected with reinforcing bars.

Steel with copper sheath

In case of copper-sheathed steel, the comments for bare copper apply to the sheath material. Damage to the copper sheath, however, presents a high risk of corrosion for the steel core. Therefore, a completely closed copper layer must always be applied.

Bare copper

Bare copper is very resistant due to its position in the electrochemical series. Moreover, when connected to earth electrodes or other installations in the ground made of more "non-precious" materials (e.g. steel), bare copper additionally provides cathodic protection, however, at the expense of the more "non-precious" metals.

Stainless steel

Certain high-alloy stainless steels according to EN 10088-1 are inert and corrosion-resistant in the ground. The free corrosion potential of high-alloy stainless steels in normally aerated soils is mostly close to the value of copper. Since the surface of stainless steel earth electrode materials passivate within a few weeks, they are neutral to other (more precious and non-precious) materials. Stainless steels should consist of at least 16 % chromium, 5 % nickel and 2 % molybdenum. Extensive measurements have shown that only high-alloy stainless steels with material No. AISI/ASTM 316 Ti / AISI/ASTM 316 L, for example, are sufficiently corrosion-resistant in the ground. Stainless steels without molybdenum are not suited for use as earth electrode material and are not permitted by the standard.

Other materials

Other materials can be used if they are particularly corrosion-resistant in certain environments or are at least equivalent to the materials listed in **Table 5.5.8.1**.

5.5.7.4 Combination of earth electrodes made of different materials

The cell current density resulting from the conductive combination of two different buried metals leads to the corrosion of the metal acting as anode (**Table 5.5.7.4.1**). This cell current density basically depends on the ratio between the size of the cathodic area A_C and the size of the anodic area A_A.

The German "Corrosion behaviour of earth electrode materials" research project has found that, when selecting earth electrode materials particularly regarding the combination of different materials, a higher degree of corrosion only has to be expected in case of the following area ratio:

$$\frac{A_C}{A_A} > 100$$

Generally, it can be assumed that the material with the more positive potential will become the cathode. The anode of a cor-

Material with a small area	Material with a large area			
	Galvanised steel	Steel	Steel in concrete	Copper
Galvanised steel	+	+ zinc removal	–	–
Steel	+	+	–	–
Steel in concrete	+	+	+	+
Steel with copper sheath	+	+	+	+
Copper / StSt	+	+	+	+
+ combinable				– not combinable

Table 5.5.7.4.1 Material combinations of earth-termination systems for different area ratios ($A_C > 100 \times A_A$)

rosion cell actually present can be recognised by the fact that it has the more negative potential when the conductive metal connection is opened. When combined with buried steel installations, the earth electrode materials bare copper, tin-plated copper and high-alloy stainless steel always behave as cathodes in (covering) soils.

Steel reinforcement of concrete foundations

The steel reinforcement of concrete foundations can have a very positive potential (similar to copper). Earth electrodes and earthing conductors directly connected to the reinforcement of large reinforced concrete foundations should therefore be made of stainless steel or copper.

This particularly also applies to short connecting cables in the immediate vicinity of the foundations or fixed earthing terminals.

Installation of isolating spark gaps

As already explained, it is possible to interrupt the conductive connection between buried installations with very different potentials by integrating isolating spark gaps. It is then normally no longer possible that corrosion currents flow. In case of a surge, the isolating spark gap trips and interconnects the installations for the duration of the surge. However, isolating spark gaps must not be installed for protective and operational earth electrodes since these earth electrodes must always be connected to the installations.

Material	Configuration	Minimum dimensions		
		Earth rod Ø [mm]	Earthing conductor [mm^2]	Earth plate [mm]
Copper, tin-plated copper	Stranded		50	
	Solid round	15	50	
	Solid tape		50	
	Pipe	20		
	Solid plate			500 x 500
	Lattice plate[c]			600 x 600
Hot-dip galvanised steel	Solid round	14	78	
	Pipe	25		
	Solid tape		90	
	Solid plate			500 x 500
	Lattice plate[c]			600 x 600
	Profile	[d]		
Bare steel[b]	Stranded		70	
	Solid round		78	
	Solid tape		75	
Copper-coated steel	Solid round	14	50	
	Solid tape		90	
Stainless steel	Solid round	15	78	
	Solid tape		100	

[a] Mechanical and electrical characteristics as well as corrosion resistance properties must meet the requirements of the IEC 62561 series.

[b] Must be embedded in concrete for a minimum depth of 50 mm.

[c] Lattice plates should be constructed with a minimum total conductor length of 4.8 m.

[d] Different profiles are permitted with a cross-section of 290 mm^2 and a minimum thickness of 3 mm.

[e] In case of a type B foundation earth electrode, the earth electrode shall be correctly connected at least every 5 m with the reinforcing steel.

Note: According to the German DIN 18014 standard, the earth electrode must be connected to the reinforcement at intervals ≤ 2 m.

Table 5.5.8.1 Material, configuration and minimum dimensions of earth electrodes[a] [e] according to Table 7 of IEC 62305-3 (EN 62305-3)

5.5.7.5 Other anti-corrosion measures

Connecting cables / terminal lugs between foundation earth electrodes and down conductors

Galvanised steel connecting cables between foundation earth electrodes and down conductors should be laid in concrete or masonry until they are above the surface of the earth.

If the connecting cables are led through the ground, terminal lugs with e.g. NYY cable, 1 x 16 mm^2 Cu, stainless steel (V4A), or fixed earthing terminals must be used.

Earthing conductors installed in the masonry can also be led upwards without corrosion protection.

Earth entries made of galvanised steel

Earth entries made of galvanised steel must be protected against corrosion over a distance of at least 0.3 m above and below the surface of the earth.

Generally, bituminous coatings are not sufficient. A moisture-proof sheath, e.g. butyl rubber strips, heat-shrinkable sleeves or preferably stainless steel, provides protection.

Buried connection points

Cut surfaces and connection points in the ground must be designed so as to ensure that they have an equivalent corrosion resistance as the corrosion protection layer of the earth electrode material. Connection points in the ground must therefore be equipped with a suitable coating, e.g. wrapped with an anticorrosive tape.

Corrosive waste

When filling ditches and pits where earth electrodes are installed, pieces of slag and coal must not directly contact the earth electrode material. The same applies to construction waste.

5.5.8 Materials and minimum dimensions of earth electrodes

Table 5.5.8.1 illustrates the minimum cross-sections, configuration and materials of earth electrodes.

5.6 Electrical isolation of the external lightning protection system – Separation distance

There is a risk of uncontrolled flashover between parts of the external lightning protection system and metal and electrical installations in the building if the distance between the air-termination system or down conductor and metal and electrical installations in the structure requiring protection is not sufficient.

Metal installations such as water, air-conditioning and electric lines form induction loops in the building where impulse voltages are induced due to the quickly changing magnetic lightning field. It must be prevented that these impulse voltages cause uncontrolled flashover which can also result in fire. Flashover on electric lines, for example, can cause enormous damage to the installation and the connected loads. **Figure 5.6.1** illustrates the principle of the separation distance.

In practice, it is often difficult to use the formula for calculating the separation distance:

$$s = k_i \frac{k_c}{k_m} \cdot l \quad [m]$$

where

k_i	depends on the class of LPS selected (induction factor)
k_c	depends on the geometric arrangement (partitioning coefficient)
k_m	depends on the material used in the point of proximity (material factor) and

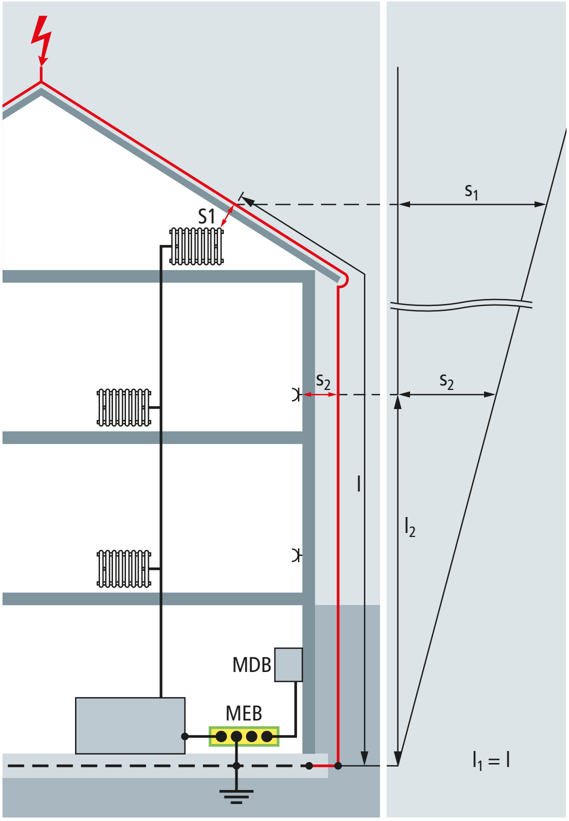


Figure 5.6.1 Principle of the separation distance

l [m] is the length along the air-termination system or down conductor from the point where the separation distance is to be determined to the next equipotential bonding or earthing point.

Coefficient k_i

The coefficient k_i (induction factor) of the relevant class of LPS stands for the risk posed by the current steepness. It depends on the class of LPS and is specified in Table 10 of the IEC 62305-3 (EN 62305-3) standard (**Table 5.6.1**).

Material factor k_m

The material factor k_m takes into consideration the insulation properties of the surroundings. The electrical insulation properties of air are assumed to be a factor 1. All other solid materials used in the building industry (brickwork, wood, etc.) insulate only half as well as air. This must also be taken into account for a roof-mounted air-termination rod. As shown in **Figure 5.6.2**, solid material ($k_m = 0.5$) is situated between the base of the air-termination rod and the roof-mounted structure and an air clearance ($k_m = 1$) is situated between the top edge of the roof-mounted structure and the air-termination rod.

Since no other material factors than $k_m = 0.5$ and 1 are specified in the standard, deviating values must be verified in tests or calculations. A factor 0.7 is specified for glass-fibre reinforced plastic (GRP) which is used in the DEHN products for isolated air-termination systems (DEHNiso spacer, DEHNiso Combi). This factor can be inserted in the calculation in the same way as the other material factors.

Class of LPS	k_i
I	0.08
II	0.06
III and IV	0.04

Table 5.6.1 Induction factor k_i

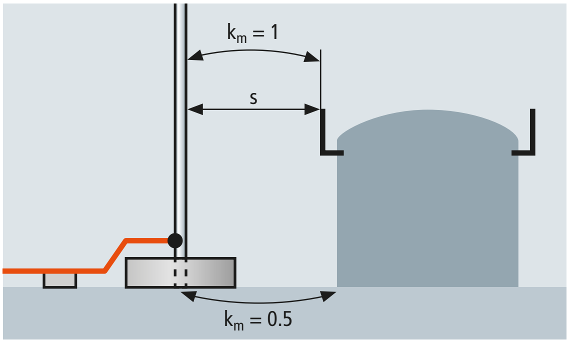


Figure 5.6.2 Material factors for an air-termination rod on a flat roof

According to Supplement 1 of the German DIN EN 62305-3 standard, the factor k_m can be calculated for multi-layered brickwork. This factor k_m consists of the material thicknesses and the insulation properties of the materials (**Figure 5.6.3**). The following formula is used to calculate the factor k_m:

$$k_{m\,total} = \frac{(l_1 \cdot k_{m1} + l_2 \cdot k_{m2} \ldots + lx \cdot k_{mx})}{l_g}$$

where

$k_{m\ total}$	is the total material factor
$l_1, l_2 \ldots l_x$	stands for the material thicknesses
l_g	is the total material thickness
$k_m\ 1, 2 \ldots k_{mx}$	defines the insulation property of the relevant material

For a wall construction as shown in **Figure 5.6.3**, the material factor $k_{m\ total}$ is calculated as follows:

$$k_{m\,total} = \frac{(0.35\,m \cdot 0.5 + 0.08\,m \cdot 1 + 0.12\,m \cdot 0.5)}{0.55\,m}$$

$k_{m\ total} = 0.573$

However, in case of multi-layered brickwork connection elements are commonly used between the different materials

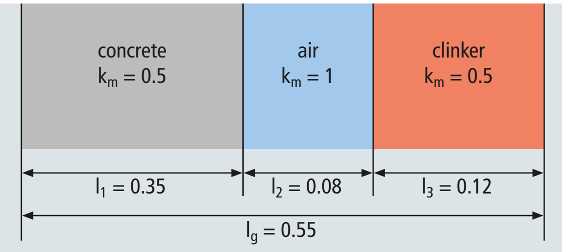


Figure 5.6.3 k_m in case of different materials with air clearance

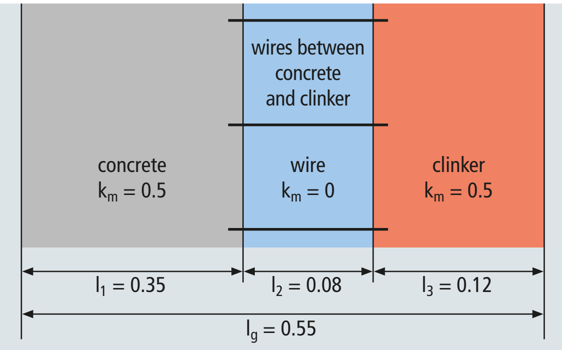


Figure 5.6.4 k_m in case of different materials without air clearance

(e.g. concrete, clinker, thermal insulation composite system) (**Figure 5.6.4**). Thus, it cannot be assumed that there is an air clearance between the two materials. The total material factor for this constellation is accordingly lower:

$$k_{m\,total} = \frac{(0.35\,m \cdot 0.5 + 0.08\,m \cdot 0 + 0.12\,m \cdot 0.5)}{0.55\,m}$$

$k_{m\ total} = 0.427$

In general, it is advisable to assume the worst case and to use a material factor $k_m = 0.5$.

Length l

The length l (**Figure 5.6.4**) is the actual length along the air-termination system or down conductor from the point at which the separation distance is to be determined to the next lightning equipotential bonding level (zero potential level) or the earth-termination system.

Each building with a lightning equipotential bonding system has an equipotential surface of the foundation earth electrode or earth electrode near the surface of the earth. This surface is the reference plane for determining the length l.

If a lightning equipotential bonding level is to be created in case of high buildings, lightning equipotential bonding must be established for all electrical and electronic lines and all metal installations in case of a height of e.g. 20 m. In this case, **type I surge protective devices** must be used to establish lightning equipotential bonding at this height.

In case of high buildings, the equipotential surface of the foundation earth electrode/earth electrode must also be used as a reference point for determining the length l. High buildings make it more difficult to maintain the required separation distances.

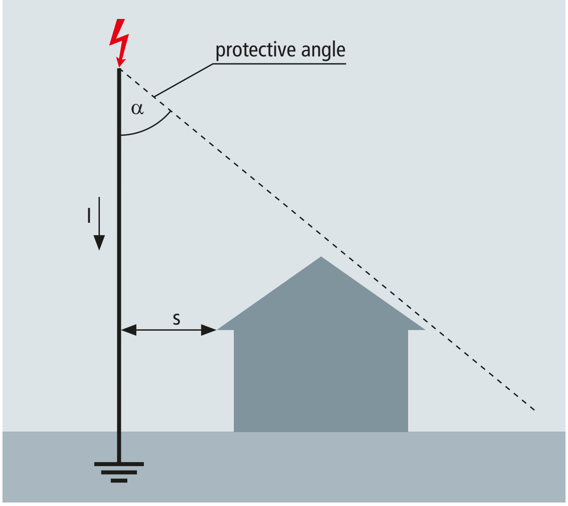


Figure 5.6.5 Air-termination mast with $k_c = 1$

Partitioning coefficient k_c

The factor k_c considers the current distribution in the down-conductor system of the external lightning protection system. Different calculation formulas for k_c are specified in the standard. To be able to achieve separation distances for high buildings which are feasible in practice, it is recommended to install ring conductors. This intermeshing balances the current flow, thus reducing the required separation distance.

The potential difference between the installations of the building and the down conductors is equal to zero near the surface of the earth and grows in relation with the height. This potential gradient area can be imagined as a cone standing on its tip (**Figure 5.6.1**). Thus, the separation distance to be maintained is greatest at the tip of the building or on the roof surface and becomes less towards the earth-termination system. This means that the distance from the down conductors may have to be calculated several times with a different length l.

The calculation of the partitioning coefficient k_c often proves to be difficult due to the different structures.

Partitioning coefficient k_c, single air-termination rod

If a single air-termination mast is installed, for example, next to the building, the total lightning current flows through this air-termination and down conductor. The factor k_c is therefore equal to 1 and the lightning current cannot split here. Therefore, it is often difficult to maintain the separation distance. In **Figure 5.6.5**, this can be achieved if the air-termination mast (e.g. telescopic lightning protection mast) is installed further away from the building.

Partitioning coefficient k_c, simplified approach

To be able to easily and quickly assess k_c, the value can be assumed depending on the number of down conductors as shown in **Table 5.6.2**. The simplified approach can only be used if the largest horizontal expansion of the structure (length or width) is not four times higher than the height.

The values of k_c apply to type B earth electrodes. These values can also be used for type A earth electrodes if the earth resist-

Number of down conductors n	k_c
1 (only in case of an isolated lightning protection system)	1
2	0.66
3 and more	0.44

Table 5.6.2 Partitioning coefficient k_c, simplified approach

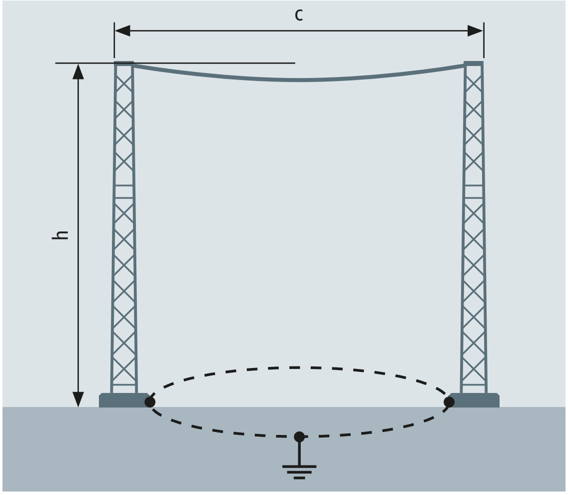


Figure 5.6.6 Determination of k_c in case of two masts with spanned cable and a type B earth electrode

ances of the adjoining earth electrodes (earth rods) do not differ by more than a factor of 2. If, however, the earth resistances of individual earth electrodes differ more than a factor of 2, $k_c = 1$ should be assumed.

Partitioning coefficient k_c, two air-termination rods / interconnected down conductors

If two air-termination rods or masts are spanned, the lightning current can split between two current paths (**Figure 5.6.6**). However, the current is not split 50 % to 50 % due to the different lengths (impedances) since lightning does not always strike exactly the centre of the arrangement (same impedances), but can also strike any point along the air-termination system. The following formula for calculating the factor k_c takes this worst case into account:

$$k_c = \frac{h + c}{2h + c}$$

where

h is the length of the down conductor

c is the distance between the air-termination rods or air-termination masts

A type B earth-termination system is assumed in this calculation. If single earth electrodes of type A are installed, they must be interconnected.

The following example shows the calculation of coefficient k_c in case of a gable roof with two down conductors (**Figure 5.6.7**). A type B earth-termination system (ring or foundation earth electrode) is installed:

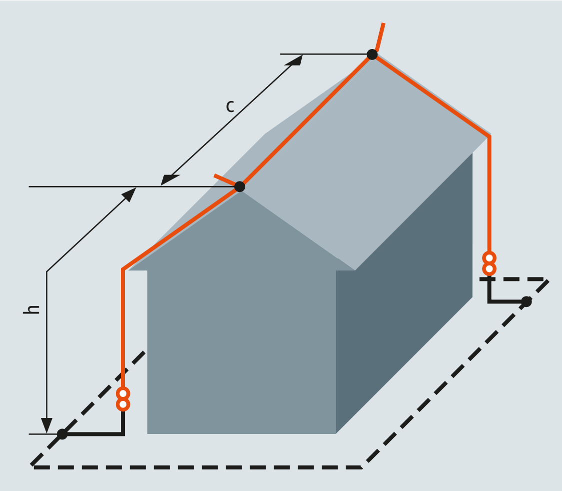


Figure 5.6.7 Determination of k_c in case of a gable roof with two down conductors

$$k_c = \frac{9 + 12}{2 \cdot 9 + 12} = 0.7$$

Partitioning coefficient k_c and separation distance s in case of a gable or flat roof with ≥ 4 down conductors

The arrangement of the down conductors shown in **Figure 5.6.7** should no longer be used even on a single-family house. The partitioning coefficient k_c is significantly improved by using two further down conductors, namely a total of four down conductors (**Figure 5.6.8**). The following formula is used for calculation:

$$k_c = \frac{1}{2n} + 0.1 + 0.2 \sqrt[3]{\frac{c}{h}}$$

where

h is the length of the down conductor up to the gutter of the building as most unfavourable point for the injection of lightning currents

c is the distance between the down conductors

n is the total number of down conductors

$$k_c = \frac{1}{2 \cdot 4} + 0.1 + 0.2 \sqrt[3]{\frac{12}{4}}$$

Result: **$k_c \approx 0.51$**

The equation is an approximation for spatial structures and for n ≥ 4. The values of h and c are assumed to be up to 20 m at a distance of 3 m. If internal down conductors are installed, they should be considered in the number n.

In case of flat-roofed structures, the partitioning coefficient k_c is calculated as follows. A type B earth electrode arrangement is a precondition in this case (**Figure 5.6.9**):

$$k_c = \frac{1}{2n} + 0.1 + 0.2\sqrt[3]{\frac{c}{h}}$$

where

h is the distance or height between ring conductors

c is the distance between a down conductor and the next down conductor

n is the total number of down conductors

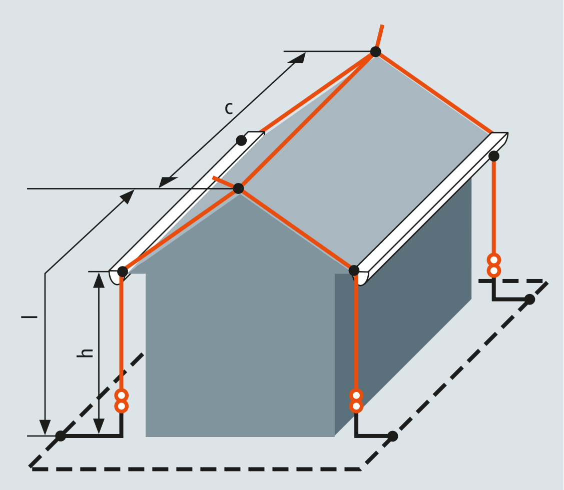


Figure 5.6.8 Gable roof with four down conductors

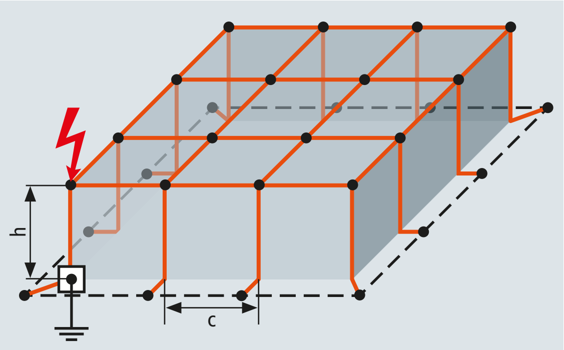


Figure 5.6.9 Values of coefficient k_c in case of a meshed network of air-termination conductors and a type B earthing arrangement

The distances of the down conductors are based on the class of LPS (Table 6 of IEC 62305-3 (EN 62305-3)). A deviation of +/– 20 % is acceptable. Thus, the distance c defines the largest distance between the symmetrically arranged down conductors.

Detailed approach for determining the separation distance s

In addition to the possibilities described above for determining the partitioning coefficient k_c and the separation distance s, a more detailed calculation method can be used. In case of buildings with a meshed lightning protection system, the current is split evenly due to the high number of current paths formed by conductors on the flat roof and down conductors. This has a positive effect on the separation distance. If a roof-mounted structure as shown in **Figure 5.6.10** is installed on a building, the detailed calculation method allows to calculate

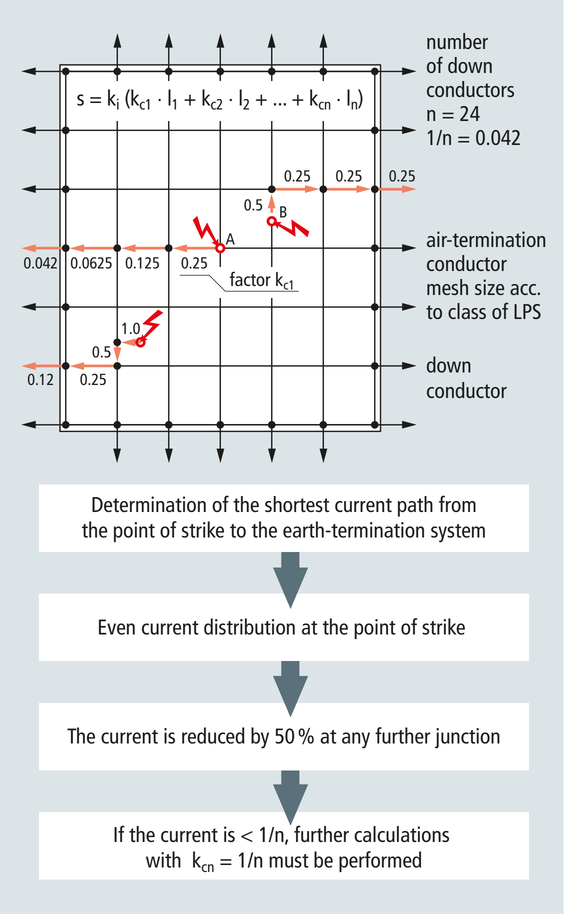


Figure 5.6.10 Values of coefficient k_c in case of a system consisting of several down conductors according Figure C.5 of IEC 62305-3 (EN 62305-3)

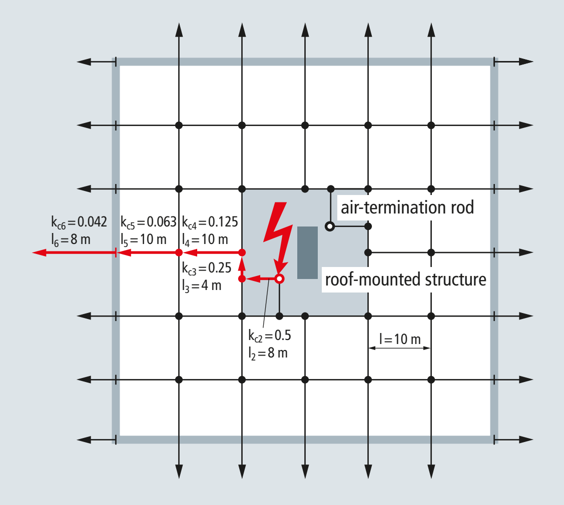


Figure 5.6.11 Current distribution in case of several conductors

the separation distance s as exactly as possible. The following general calculation formula is used:

$$s = \frac{k_i}{k_m}\left(k_{c1} \cdot l_1 + k_{c2} \cdot l_2 + \ldots + k_{cn} \cdot l_n\right)$$

where

k_{c1}, k_{cn}	is the partitioning coefficient according to the number of current paths
l_1, l_n	is the conductor length up to the next node

The values of k_c depend on the number of current paths. Consequently, the following applies:

- $k_c = 1$ from the point of proximity to the first node.

Between the first node and the next node, k_{c2} depends on the number of conductors:

- $k_c = 0.5$ in case of two conductors
- $k_c = 0.33$ in case of three conductors
- $k_c = 0.25$ in case of four conductors

In every further node, the previous value of k_c is halved. The minimum value of k_c should not be less than "1/number of down conductors".

Example: To illustrate this, the separation distance s is described for a flat roof with a roof-mounted structure.
An air-conditioning system was installed on the roof of a building (**Figures 5.6.11 and 5.6.12**) with class of LPS II.

Data of the building:

- Class of LPS II
- Induction factor k_i: 0.06
- Length: 60 m
- Width: 60 m
- Height: 7 m
- Number of down conductors: 24
- Minimum value of k_c (1/number of down conductors) $k_{cmin} = 0.042$
- Earth-termination system, type B foundation earth electrode: –1.0 m

The air-conditioning system is supposed to be located in the protected volume (LPZ 0_B) thanks to two diagonally arranged air-termination rods. The separation distance is supposed to

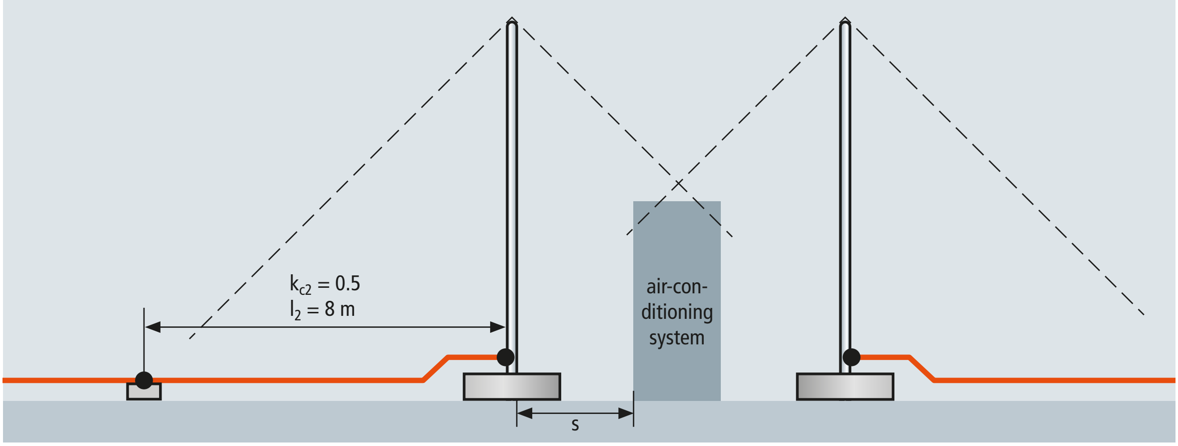


Figure 5.6.12 Example: Roof-mounted structure; system with several down conductors

be determined at the base of the air-termination rod. Current paths with different conductor lengths are formed due to the finely meshed conductor routing on the roof surface. Moreover, the lightning current is split as follows according to the nodes:

- 1. Base of the air-termination rod (two conductors)
  k_{c1} = 0.5 with a conductor length l_1 of 8.0 m
- 2. Node 1 (two conductors)
  k_{c2} = 0.25 with a conductor length l_2 of 4.0 m
- 3. Node 2 (two conductors)
  k_{c3} = 0.125 with a conductor length l_3 of 10.0 m
- 4. Node 3 (three conductors)
  k_{c4} = 0.063 with a conductor length l_4 of 10.0 m
- 5. Node 4 (three conductors)
  k_{c5} = 0.042 with a conductor length l_5 of 8.0 m

The separation distance is calculated as follows:

$$s = \frac{k_i(k_{c1}\cdot l_1 + k_{c2}\cdot l_2 + ... + k_{cn}\cdot l_n)}{k_m}$$

$$s = \frac{0.06\,(0.5\cdot 8m + 0.25\cdot 4m + 0.125\cdot 10m + 0.063\cdot 10m + 0.042\cdot 8m)}{0.5}$$

s = 0.87 in case of solid material

A separation distance of 0.87 m (solid material) must be maintained at the base of the air-conditioning system.

Determination of the zero potential level

To calculate the separation distance, it is important to determine the zero potential level. The zero potential level of buildings is located at the same height as the foundation or ring earth electrode. Thus, the definition of the zero potential level is decisive for the separation distance s.

Buildings with a wall and ceiling reinforcement, which is interconnected in such a way that it is capable of carrying lightning currents, can be used as a down-conductor system. Thus, no separation distances must be maintained due to the constant potential. However, the roof surfaces are typically covered with insulations and roof membranes on which meshed air-termination systems are installed. These meshed air-termination systems are connected to the reinforcement in the vicinity of the roof parapet. In case of a lightning strike, separation distances must be maintained from the meshes and the conductors. Therefore, it is recommended to install insulated conductors which allow to maintain the separation distances.
In case of buildings with an interconnected steel frame construction and a metal roof, it can be assumed that the zero potential level is equal to the height of the building. No separation distances must be maintained.

In general, the requirements of the IEC 62305-3 (EN 62305-3) standard must be observed. The DEHN Distance Tool of the DEHNsupport software allows to easily calculate the separation distance based on nodal analysis as described in 3.3.2.1.

5.7 Step and touch voltage

IEC 62305-3 (EN 62305-3) points out that, in special cases, touch or step voltage outside a building in the vicinity of the down conductors can present a life hazard even though the lightning protection system was designed according to the latest standards.
Special cases are, for example, the entrance areas or covered areas of highly frequented structures such as theatres, cinemas, shopping centres or nursery schools where bare down conductors and earth electrodes are present in the immediate vicinity.
Measures against impermissibly high step and touch voltages may also be required for structures which are particularly exposed (prone to lightning strikes) and freely accessible to the general public.
These measures (e.g. potential control) are primarily taken for churches, observation towers, shelters, floodlight pylons in sports grounds and bridges.
The number of people can vary from place to place (e.g. in the entrance area of shopping centres or in the staircase of observation towers). Therefore, measures to reduce step and touch voltage are only required in areas which are particularly at risk.

Possible measures are potential control, standing surface insulation or additional measures which will be described below. The individual measures can also be combined with each other.

Definition of touch voltage

Touch voltage is a voltage acting on a person between its standing surface on earth and when touching the down conductor. The current path leads from the hand via the body to the feet (**Figure 5.7.1**).

For structures with a steel frame or reinforced concrete construction, there is no risk of impermissibly high touch voltages provided that the reinforcement is safely interconnected or the down conductors are laid in concrete.
Moreover, the touch voltage can be disregarded in case of metal façades if they are integrated in the equipotential bonding system and/or used as natural components of the down conductor.

If reinforced concrete with a safe connection between the reinforcement and the foundation earth electrode is installed under the surface of the earth in the areas outside the structure which are at risk, this measure already improves the curve of the potential gradient area and acts as potential control. Therefore, step voltage can be neglected.

The following measures reduce the risk that persons are injured or even killed when touching the down conductor:

- The down conductor is covered with insulating material (at least 3 mm cross-linked polyethylene with an impulse withstand voltage of 100 kV (1.2/50 µs)).
- The position of the down conductors can be changed so that they are not located e.g. in the entrance area of the structure.
- The probability of persons accumulating can be reduced by notes or prohibition signs. Barriers are also a possibility.
- The contact resistance of the floor layer within a radius of 3 m around the down conductors is not less than 100 kΩ.
  Note: A 5 cm thick layer of insulating material, for example asphalt (or a 15 cm thick gravel layer), typically reduces the risk to an acceptable level (IEC 62305-3 (EN 62305-3), chapter 8.1).
- Compression of the meshed network of the earth-termination system by means of potential control.

Note: A downpipe, even if it is not defined as a down conductor, can present a risk for persons touching it. In this a case, the metal pipe must be replaced by a PVC pipe (height of 3 m).

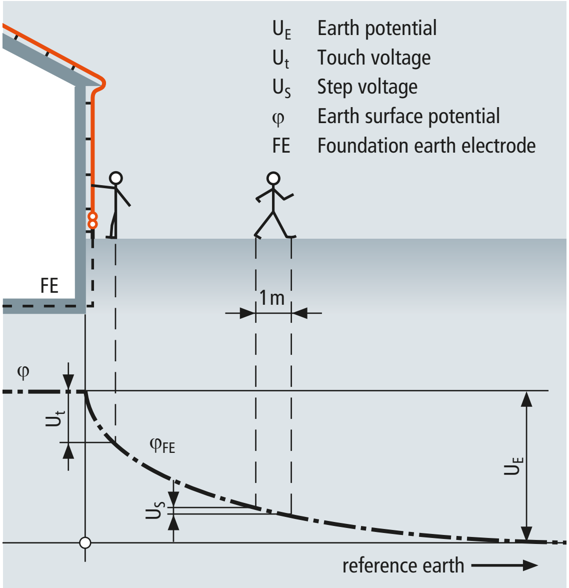


Figure 5.7.1 Step and touch voltage

Definition of step voltage

Step voltage is a part of the earth potential which can be bridged by a person taking a step of 1 m. The current path runs via the human body from one foot to the other (**Figure 5.7.1**). The step voltage depends on the shape of the potential gradient area. As shown in the figure, the step voltage decreases as the distance from the building increases. The risk to persons is therefore reduced the further they are from the structure.

The following measures can be taken to reduce step voltage:

- Persons can be prevented from accessing the areas which are at risk (e.g. by barriers or fences)
- Reducing the mesh size of the earthing network – Potential control
- The contact resistance of the floor layer within an interval of 3 m around the down conductors is not less than 100 kΩ (IEC 62305-3 (EN 62305-3), chapter 8.2).

If a large number of persons frequently stays in an area which is at risk near the structure requiring protection, potential control should be provided to protect them.

Potential control is sufficient if the resistance gradient on the surface of the earth in the area requiring protection does not exceed 1 Ω/m.

To achieve this, an existing foundation earth electrode should be supplemented by a ring earth electrode installed at a distance of 1 m and at a depth of 0.5 m. If the structure already has an earth-termination system in form of a ring earth electrode, this is already "the first ring" of the potential control. Additional ring earth electrodes should be installed at a distance of 3 m from the first and the subsequent ring earth electrodes. The depth of the ring earth electrode should be increased (in steps of 0.5 m) the further it is from the building (see **Table 5.7.1**).

If potential control is implemented for a structure, it must be installed as follows (**Figures 5.7.2 and 5.7.3**):

- The down conductors must be connected to all the rings of the potential control.
- However, the individual rings must be connected at least twice (**Figure 5.7.4**).

	Distance from the building	Depth
First ring	1 m	0.5 m
Second ring	4 m	1.0 m
Third ring	7 m	1.5 m
Fourth ring	10 m	2.0 m

Table 5.7.1 Ring distances and potential control depths

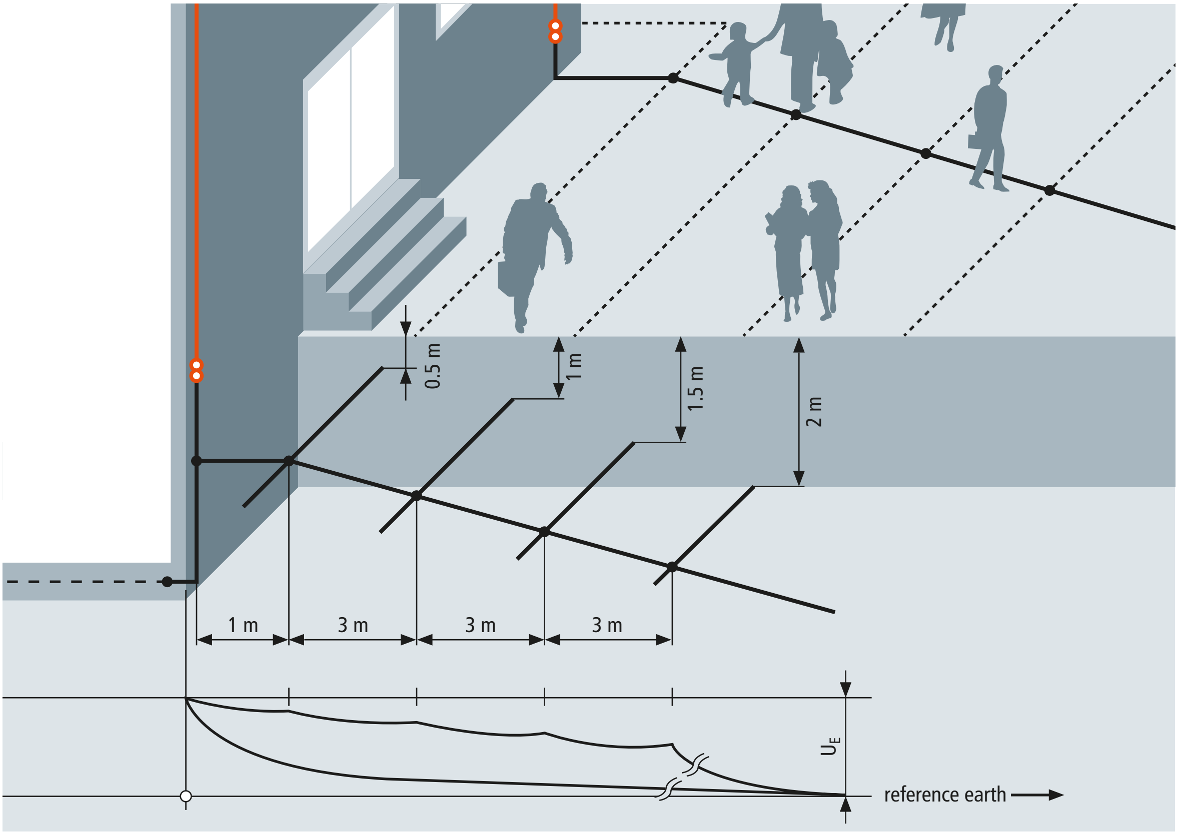


Figure 5.7.2 Potential control – Basic principle and curve of the potential gradient area

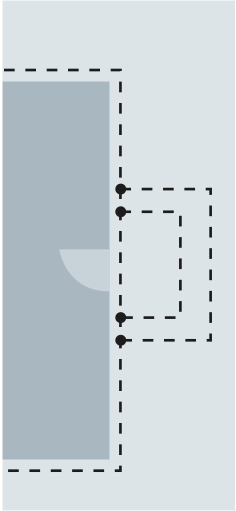


Figure 5.7.3 Possible potential control in the entrance area of a structure

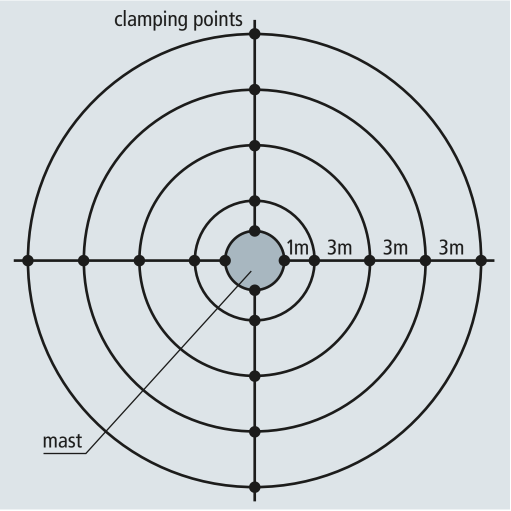


Figure 5.7.4 Potential control for a floodlight or mobile phone mast

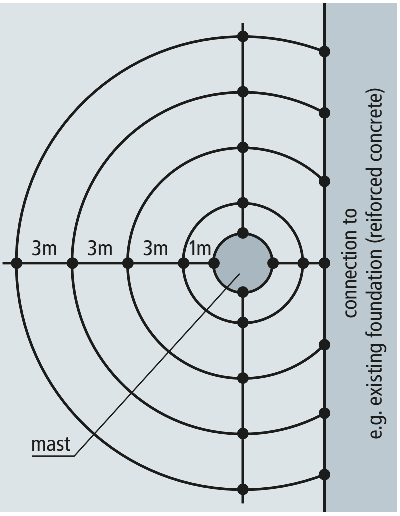


Figure 5.7.5 Connection control at the ring/ foundation earth electrode

If ring earth electrodes (control earth electrodes) cannot be installed as a circle, their ends must be connected to the other ends of the ring earth electrodes. There should be at least two connections within the individual rings (**Figure 5.7.5**).

When choosing the materials for the ring earth electrodes, possible corrosion must be observed (chapter 5.5.7).

Stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti, has proven to be a good choice when the cell formation between the foundation and ring earth electrode is taken into account. Ring earth electrodes can be designed as round wires (Ø 10 mm) or flat strips (30 mm x 3.5 mm).

5.7.1 Coping with touch voltage at the down conductors of a lightning protection system

The area at risk of touch and step voltages for persons outside a building is located within a distance of 3 m around the building and at a height of 3 m. The height of this area is equal to the height of the maximum reachable height of a person raising a hand and an additional separation distance s (**Figure 5.7.1.1**).

Special requirements apply to protection measures in e.g. entrance areas or covered areas of highly frequented structures such as theatres, cinemas, shopping centres and nursery schools for which no insulated down conductors and lightning protection earth electrodes are in close proximity.
In case of extremely exposed structures (structures prone to lightning strikes) which are accessible to the general public (e.g. shelters), measures against impermissibly high touch voltages may also be required. In addition, the risk to persons is included in a risk analysis for a structure according to IEC 62305-2 (EN 62305-2) in the form of the parameter L1 (injury or death of persons).

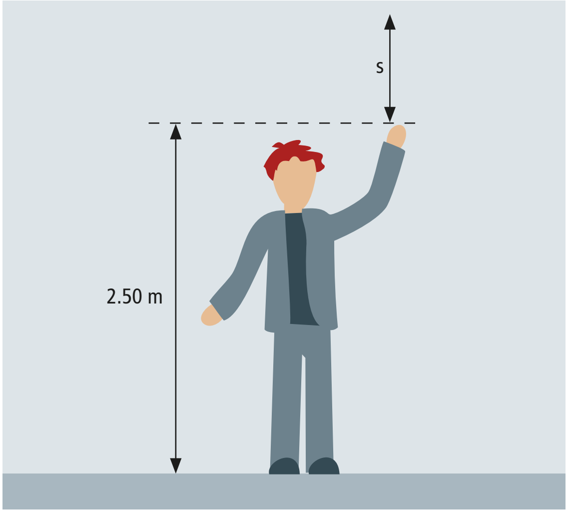


Figure 5.7.1.1 Area to be protected for a person

The following measures reduce the risk of touch voltage:

- The down conductor is covered with insulating material (at least 3 mm cross-linked polyethylene with an impulse withstand voltage of 100 kV (1.2/50 µs)).
- The position of the down conductors is changed (e.g. no down conductors in the entrance area of the structure).
- The resistivity of the surface layer of the earth within up to 3 m around the down conductor is at least 100 kΩ (IEC 62305-3 (EN 62305-3)).
- The probability of persons accumulating can be reduced by notes or prohibition signs. Barriers are also a possibility.

Protection measures against touch voltage are not always sufficient to ensure effective personal protection. For example, it is not sufficient to cover an exposed down conductor with a high-voltage-resistant insulation if protection measures against creeping flashover at the surface of the insulation are not taken at the same time. This is particularly important if environmental influences such as rain (moisture) must be considered.
As is the case with bare down conductors, a high voltage builds up in the event of a lightning strike if insulated down conductors are used. However, the insulation protects persons from this voltage. Since it can be assumed that the human body is extremely conductive compared to the insulating material, the insulation layer is loaded with almost the total touch voltage. If the insulation does not withstand this voltage, a part of the lightning current can travel through the human body to earth as is the case with bare down conductors. To ensure that persons are reliably protected against touch voltage, it is therefore

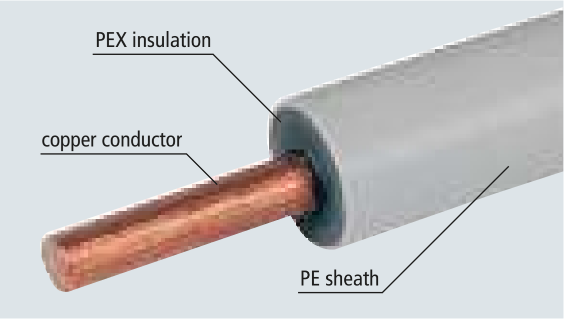


Figure 5.7.1.2 Design of a CUI Conductor

mandatory to prevent puncture of the insulation and creeping flashover along the insulating clearance.
A harmonised system solution such as the CUI Conductor prevents puncture and creeping flashover and thus ensures protection against touch voltage.

Design of CUI Conductors

CUI Conductors consist of an inner copper conductor with a cross-section of 50 mm^2 and is coated with an insulation layer of impulse-voltage-proof cross-linked polyethylene (PEX) with a thickness of about 6 mm (**Figure 5.7.1.2**).

To protect the insulated conductor from external influences, it is additionally covered with a thin polyethylene (PE) layer. The insulated down conductor is installed in the entire area which is at risk, in other words 3 m of the CUI Conductor are vertically installed above the surface of the earth. The upper end of the conductor is connected to the down conductor coming from the air-termination system, the lower end to the earth-termination system.
In addition to the puncture strength of the insulation, the risk of creeping flashover between the connection point to the bare down conductor and the hand of the person touching it must also be considered. Pollution layers such as rain make this problem of creeping discharge even worse. It could be proven in tests that under wet conditions flashover can occur on an insulated down conductor along a distance of more than 1 m if no additional measures are taken. If the insulated down conductor is provided with an adequate shield, a sufficiently dry area is created on the CUI Conductor which prevents creeping flashover along the surface of the insulation. Impulse withstand voltage tests under wet conditions according to IEC 60060-1 (EN 60060-1) have shown that the CUI Conductor is both resistant to puncture and creeping flashover in case of impulse voltages up to 100 kV (1.2/50 µs). During these wet tests, a defined quantity of water with a specific conductivity is sprayed onto the conductor at an angle of about 45 ° (**Figure 5.7.1.3**).

Figure 5.7.1.3 Withstand voltage test under wet conditions

CUI Conductors are prewired with an element which can be connected to the down conductor (test joint) and can be shortened on site where appropriate to connect the CUI Conductor to the earth-termination system. The product is available with a length of 3.5 m and 5 m and the required plastic or metal conductor holders (**Figure 5.7.1.4**).
The special CUI Conductor copes with touch voltages at down conductors through simple measures and is easy to install, thus considerably reducing the risk to persons in areas which are particularly at risk.

Inductive coupling in case of an extremely high current steepness

The effects of the magnetic field of the arrangement on the immediate vicinity of the down conductor must also be considered to protect persons from touch voltage. In large installation loops, for example, voltages of several 100 kV can occur in close proximity to the down conductor, resulting in serious economic consequences. In conjunction with the down conductor and the conductive soil, the human body, which conducts electricity, also forms a loop with a mutual induction M in which high voltages U_i can be induced (**Figures 5.7.1.5a and 5.7.1.5b**). The combination of the down conductor and the human body acts like a transformer.
This induced voltage is applied to the insulation since the human body and the soil can be assumed to be conductive. If the voltage load becomes too high, puncture or flashover occurs on the insulation. The induced voltage pushes a current through this loop whose magnitude depends on the resistances and the self-inductance of the loop and can be life-threatening for the relevant person. Therefore, the insulation must withstand this voltage load.

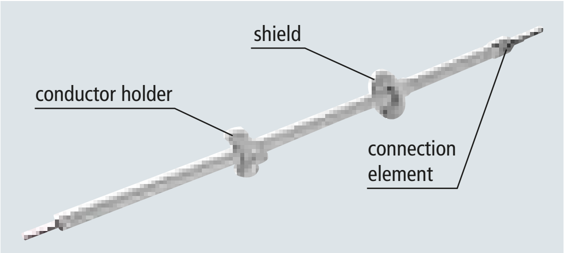


Figure 5.7.1.4 CUI Conductor

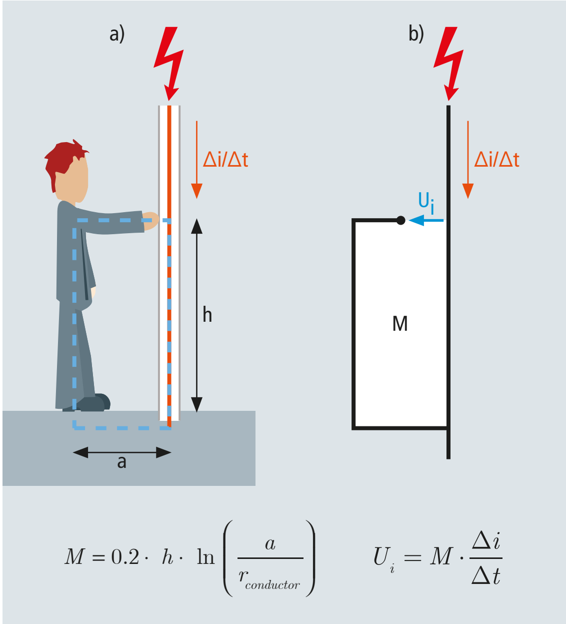


Figure 5.7.1.5 a) Loop formed by a down conductor and a person
b) Mutual inductance M and induced voltage U_i

The normative requirement of 100 kV at 1.2/50 µs includes the high, but extremely short voltage impulses which are only present during the current rise (0.25 µs in case of a negative subsequent stroke). The loop and thus the mutual inductance increase in relation with the burial depth of the insulated down conductors. Consequently, the induced voltage and the load on the insulation are increased accordingly. This must be observed when considering inductive coupling.

5.7.2 Optimisation of lightning protection earthing considering step voltage aspects

The arrangements of ring earth electrodes as described in 5.7.1 are not always feasible since they involve substantial structural and financial effort and for space reasons cannot always be implemented in, for example, densely built-up residential areas. In the following, the optimisation possibilities using today's modern simulation tools and their use for real arrangements will be described.

Due to fundamental research and a comprehensive analysis of literature, a tool is now available, which allows a 3D simulation of widespread earth-termination systems and also considers the effect of soil ionisation. This is a considerable improvement compared to the previous simplified analytic approaches. Moreover, the reaction of the human body to the step / body voltage can be included in the simulation. However, simulations with unloaded step voltages lead to excessive and supposedly unacceptable voltage values.

To be able to assess the simulation results, a step voltage value is available, which is secured by extensive literature research. A prerequisite for the optimisation of earth-termination systems with regard to step voltage aspects is to define a permissible step / body voltage which does not cause health damage.

Step voltage limit values

Literature provides information on technical a.c. voltages as well as hand-to-hand and hand-to-foot current paths. Step voltage control in case of short-term impulses and a foot-to-foot current path are not considered. Based on the time parameters of a first stroke of a 10/350 µs impulse form, possible limit values can be derived from IEC/TS 60479-1: "Effects of current on human beings and livestock – Part 1: General aspects" and IEC/TS 60479-2: "Effects of current on human beings and livestock – Part 2: Special aspects", volume 44 of the German VDE series "Neuhaus, H.: Blitzschutzanlagen – Erläuterungen zur DIN 57185/VDE 0185" [Lightning protection systems – Explanations on DIN 57185/VDE 0185] and the so-called "electrocution equation" from C. F. Dalziel and W. R. Lee "Reevaluation of Lethal Electric Currents. IEEE Transactions on Industry Applications". To affirm this information and to make it comprehensible, the flow fields in the human body in case of a step voltage were simulated on a PC by means of an FEM software and the so-called Hugo model. This Hugo model is a 3D simulation of the human body including all organs with a spatial resolution of max. 1 mm x 1 mm x 1 mm and is based

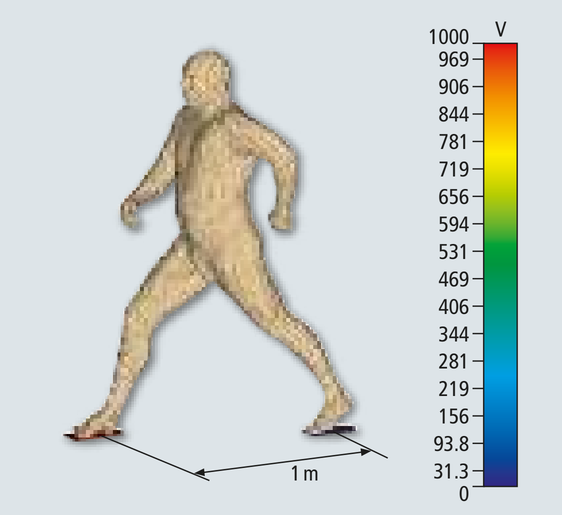


Figure 5.7.2.1 HUGO model with feet in step position acting as contact points (source: TU Darmstadt)

Source	U_k
IEC 60479-1 and IEC 60479-2	25 kV
Neuhaus	15 kV
Dalziel	32 kV
Electric shock simulation (HUGO)	26.6 kV

Table 5.7.2.1 Step / body voltage limit values according to different sources

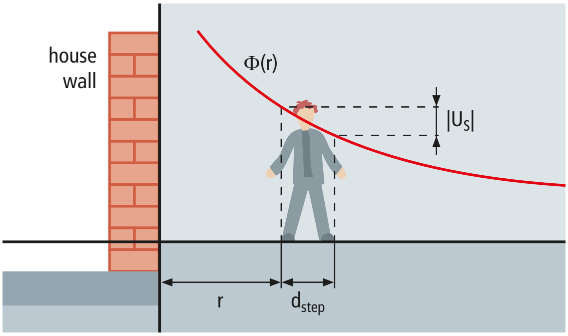


Figure 5.7.2.2 Reference system for information on the step voltage

on the "Visible Human Project" of the National Library of Medicine in Bethesda / USA. It can also be used to simulate electrical fields in the human body.

Simulation of step voltages

A step voltage of 1 kV is applied to the Hugo model with feet in step position (step size of 1 m) (**Figure 5.7.2.1**). In case of this arrangement, the maximum current density in the heart is about 1.2 A/m^2 and the total current flowing through the heart is 7.5 kA. In case of a 10/350 µs impulse, the maximum heart current must not exceed 200 mA. This results in a maximum value of the step / body voltage of 26.6 kV. These calculated limit values of the step / body voltage are summarised in **Table 5.7.2.1** according different sources.

After evaluating all theoretical considerations and the relevant backgrounds of the limit values, the IEC limit value of 25 kV was used for the simulations. Different configurations were simulated to be able to test and vary earth-termination systems at low costs.

Reference model

To minimise the influence of side effects, the calculation for all earth-termination systems is performed in a hemisphere with a radius of 100 m. The surface of the sphere is defined as ground (zero potential). The slice plane of the sphere is equivalent to the surface of the earth if it is defined as electrical insulation.

Calculations are performed in the stationary flow field. The lightning current amplitude is assumed to be 100 kA.

The soil was simulated by means of two different models:

- Model 1: The electrical properties of the soil are independent from other electrical parameters ("linear"). Unless specified otherwise, an electrical conductivity of 0.001 S/m is selected which corresponds to a resistivity of 1000 Ωm. This represents a soil with a relatively poor electrical conductivity.
- Model 2: Soil that changes its electrical conductivity depending on the electric field strength ("non-linear"). This model was selected to simulate the effect of soil ionisation. To achieve this, a conductivity characteristic is defined which has an electrical conductivity of 0.001 S/m for an electric field strength of less than 300 kV/m and an electrical conductivity of 0.01 S/m for an electric field strength of more than 500 kV/m and approximately linearly increases between these values.

To be able to compare different earth-termination systems, a reference model was defined:

- Small building with a floor space of 10 m × 10 m and a basement depth of 2 m
- This building is assumed to be ideally insulating

To perform the simulation, the lightning current is injected into a terminal lug of the earth-termination system. From there it spreads through the earth-termination system and the soil to the ground area. The arising electric potential is determined at the soil surface and the value of the step voltage $|U_S|$ is calculated for a step width $d_{step} = 1$ m. This is done along a straight line on the soil surface ranging from the one of the house walls to the edge of the calculation area. The location r is equal to the distance from the house wall (**Figure 5.7.2.2**).

Simulations at the reference model

Simulations are performed at the reference model with an increasing number of ring earth electrodes that are installed in line with common practice at a distance of 1 m, 4 m, 7 m and 10 m from the house walls and at a depth of 0.5 m, 1 m, 1.5 m and 2 m (**Figure 5.7.2.3**).

When comparing the results, several aspects are particularly striking: It can be seen that the step voltages are considerably reduced compared to a linear soil if soil ionisation is considered. While a maximum step voltage of approximately 325 kV can be observed on an individual ring earth electrode when considering soil ionisation, a voltage of approximately 750 kV occurs on a single earth electrode in case of linear soil. However, the more rings are used, the smaller is the difference. In case of two ring earth electrodes, for example, only approximately 220 kV respectively 225 kV occur.

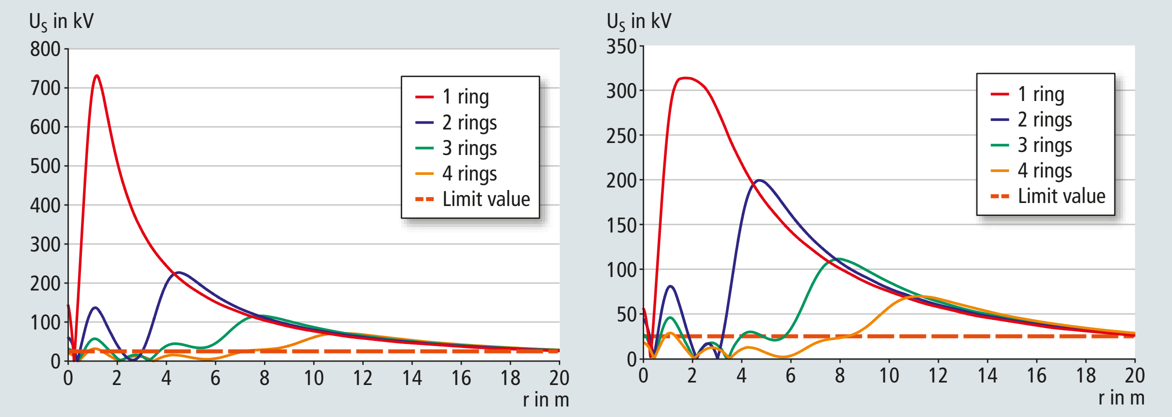


Figure 5.7.2.3 Comparison of the step voltages in the reference model when using several ring earth electrodes: Soil ionisation is not considered (left), soil ionisation is considered (right)

As expected, the relevant step voltages are considerably reduced if further rings are added. However, it must be observed that the step voltages are particularly reduced within the earth-termination system. Step voltages typically rise at the edge of the earth-termination system where the flow field controlled by the ring earth electrodes enters the uncontrolled electrical fields in the soil.

In this context, it is also remarkable that the step voltages arising outside the earth-termination system have a similar characteristic curve and are virtually independent of the number of rings installed in the earth-termination system. This can be clearly seen in **Figure 5.7.2.3** for r > 11 m. It is equally remarkable that, even in case of a very complex arrangement of four rings and under consideration of soil ionisation, the step voltages determined still significantly exceed the limit value of 25 kV.

Reaction of the human body

Since in some cases the arising step voltages are considerably higher than the assumed limit value, the question arises as to whether the current state of the art and common practice provide adequate protection from excessive step voltages. Bearing in mind that, in particular in case of a poorly conducting soil, the human body represents a significantly lower electric resistance than the soil, the human body reacts to the arising step voltage. This is comparable to the load on a voltage source with an extremely high internal resistance (**Figure 5.7.2.4**).

In "Blitzschutzanlagen – Erläuterungen zur DIN 57185/VDE 0185" [Lightning protection systems – More detailed information on DIN 57185/VDE 0185], H. Neuhaus introduces a similar concept in the form of earth resistances of the feet, which present some kind of contact resistance between the

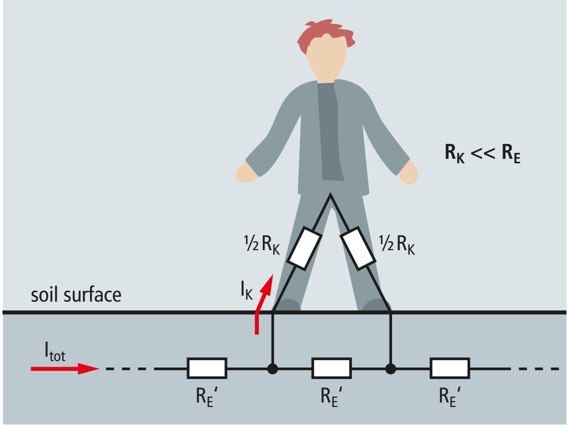


Figure 5.7.2.4 Person loading the step voltage on the soil surface

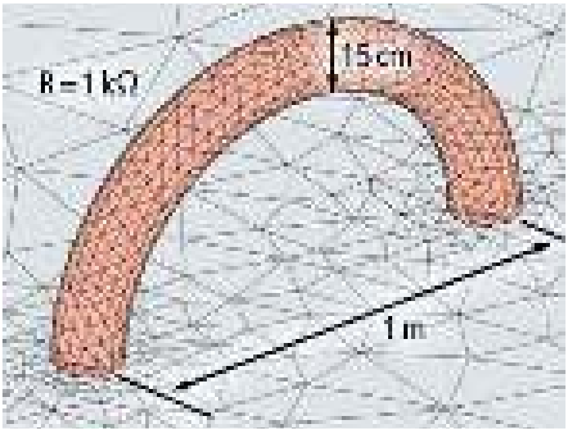


Figure 5.7.2.5 Highly simplified model of a human body to test its reaction to step voltage (marked in red)

soil and the feet. However, these resistances are not to be mistaken for other resistances such as shoe soles. According to Neuhaus, these earth resistances act in series with the internal resistance of the human body, form a voltage divider and reduce the step/body voltage actually applied to a person compared to the pure step voltage on the soil.

To be able to verify this reaction also in the simulation, a highly simplified object in the form of an arc was developed, the two bases of which correspond to the area of a foot assumed by Neuhaus (D = 0.15 m). The electrical conductivity is selected so that the resistance of the arc is 1 kΩ. Extensive research has shown that this value is the most critical case to be assumed with regard to the resulting electric shock. The arc is positioned on the soil surface above an earth-termination system with four rings and the step voltage resulting from the reaction of the object to this step voltage is calculated (**Figure 5.7.2.5**).

Figure 5.7.2.6 shows the arising step voltages $U_{S,with}$ with reaction of the human body, the step voltages $U_{S,without}$ without reaction of the human body as well as the quotient obtained from both values for soil models without ionising effect and an electrical conductivity of $\sigma = 0.001$ S/m.

Table 5.7.2.2 compares the results of further simulations with the factors analytically assessed by Neuhaus.

Figure 5.7.2.6 shows that the factor $U_{S,without} / U_{S,with}$ is approximately constant over the entire calculation period at a given soil conductivity. If the soil conductivity varies, the factor $U_{S,without} / U_{S,with}$ also changes (**Table 5.7.2.2**). The factors determined in the simulation are in good agreement with the factors analytically assessed by Neuhaus. For these reasons, the factors described before can be used to directly convert the simulation results of step voltages into the arising step/body voltages without performing time-consuming individual simulations with a replacement body for each earth electrode configuration to be simulated. **Figure 5.7.2.7** shows the

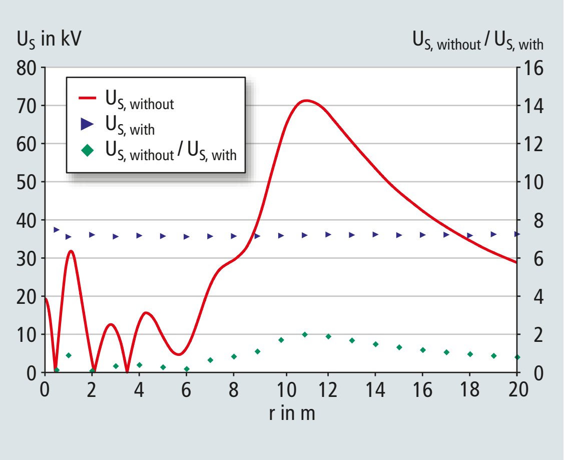


Figure 5.7.2.6 Reaction of a human body to the arising step voltage

ρ in Ωm	**σ in S/m**	**$U_{S,\ without} / U_{S,\ with}$**	**Factor acc. to Neuhaus**
100	0.01	1.64	1.66
200	0.005	2.3	2.3
500	0,002	4.1	4.3
1000	0.001	7.2	7.6
–	0.001 ... 0.01 (non-linear)	7	–

Table 5.7.2.2 Simulation results with and without consideration of the reaction of the human body to the step voltage

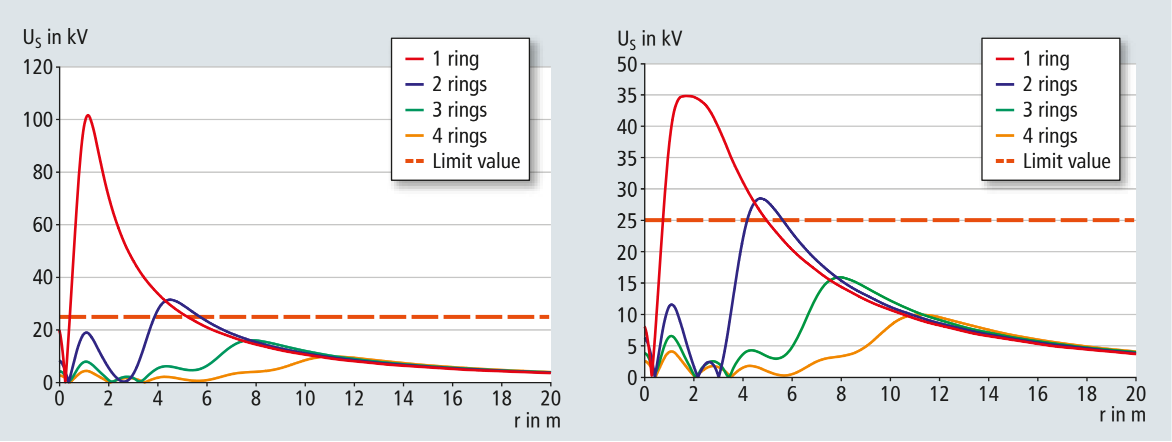


Figure 5.7.2.7 Comparison of step voltages in the reference model of several ring earth electrodes considering the correction factor for the reaction of a human body: Soil ionisation is not considered (left), soil ionisation is considered (right)

converted step voltage values for different earth electrode configurations. This shows that in case of an earth-termination system with three or four ring earth electrodes, the permissible step voltages inside and outside the system are complied with. It can be seen that common earth electrode configurations do not exceed the permissible step voltages based on the assumptions described before. In general, it should be observed that significantly higher step voltages occur at the edge of every earth-termination system than within the earth electrode region.

Further examinations are supposed to show up possibilities to optimise the design and installation of earth-termination systems. Moreover, it must be clarified whether stationary calculations correctly reflect the actual conditions and which additional effects occur in case of transient calculations.

5.8 Manufacturer's test of lightning protection components

Prior to a manufacturer's test, metal lightning protection components such as clamps, conductors, air-termination rods or earth electrodes, which are exposed to all weather conditions, must be subjected to artificial ageing / conditioning to prove their suitability for this field of application.

Natural weathering and corrosion

According to IEC 60068-2-52 (EN 60068-2-52) and ISO 6988 (EN ISO 6988), artificial ageing and testing of metal components is done in two steps.

Step 1: Salt mist treatment

This test is used for components or devices which are designed to withstand a saline atmosphere. The test equipment (**Figure 5.8.1**) consists of a salt mist chamber where the specimens are tested for more than three days using severity 2. Severity 2 includes three spraying periods of 2 hours each with a 5 % sodium chloride solution (NaCl) at a temperature between 15 °C and 35 °C followed by a storage period under humid conditions between 20 and 22 hours at a relative humidity of 93 % and a temperature of 40 °C.

Step 2: Humid sulphurous atmosphere treatment

This test is a method to assess the resistance of materials or objects to condensed humidity containing sulphur dioxide. The test equipment (**Figure 5.8.2**) consists of a test chamber where the specimens are treated in seven test cycles.

Each cycle, which has a duration of 24 hours, consists of a heating period of 8 hours at a temperature of 40 ± 3 °C in a humid saturated atmosphere which is followed by a rest period of 16 hours. After that, the humid sulphurous atmosphere is replaced.

Both components for outdoor use and components buried in the ground must be subjected to ageing / conditioning. However, additional requirements and measures must be considered for components buried in the ground. In general, no aluminium clamps or conductors should be installed in the ground. If stainless steel clamps or conductors are installed in the ground, only high-alloy stainless steel may be used, e.g. StSt (V4A). In accordance with the German DIN VDE 0151 standard, StSt (V2A) is not permissible. Components for indoor use such as equipotential bonding bars do not have to be subjected to ageing / conditioning. The same applies to components which are embedded in concrete. These components are therefore often made of non-galvanised (black) steel.

Figure 5.8.1 Test in a salt mist chamber

Figure 5.8.2 Test in a Kesternich chamber

Air-termination systems and rods

Air-termination rods with a length of 1 m (e.g. installed in a concrete base in case of flat-roofed buildings) up to 25 m (e.g. in case of biogas plants) are typically used as air-termination system.

IEC 62561-2 (EN 62561-2) specifies the material combinations of air-termination systems and down conductors with one another and with structural parts, minimum cross-sections and permissible materials including their electrical and mechanical properties. In case of air-termination rods with larger heights, the bending resistance of the air-termination rod and the stability of complete systems (air-termination rod in a tripod) must be verified in a static calculation. The required cross-sections and materials are then selected based on this calculation. The requirements / parameters of the relevant wind zone form the basis for this calculation.

Testing of connection components

Connection components, often simply referred to as clamps, are used for lightning protection systems to connect conductors (down conductors, air-termination conductors, earth entries) with one another or to an installation. Depending on the type of clamp and clamp material, many different clamp combinations are possible. These depend on the type of conductor routing and the relevant material combinations. Type of conductor routing means whether the clamp connects the conductor or conductors in a cross or parallel arrangement. A lightning current load causes electrodynamic and thermal forces which act on the clamp and must be withstood by the clamp. The resulting forces are heavily dependant on the type of conductor routing and the clamp connection. **Table 5.8.1** shows materials which can be combined without causing contact corrosion. The combination of different materials with one another and their different mechanical strengths and thermal properties have different effects on the connection components when lightning current flows through them. This particularly becomes evident in case of connection components made of stainless steel (V4A) where high temperatures occur due to the low conductivity as soon as lightning currents flow through them. Therefore, a lightning current test in compliance

	Steel	Aluminium	Copper	StSt (V4A)	Titanium	Tin
Steel (StZn)	yes	yes	**no**	yes	yes	yes
Aluminium	yes	yes	**no**	yes	yes	yes
Copper	**no**	**no**	yes	yes	**no**	yes
StSt (V4A)	yes	yes	yes	yes	yes	yes
Titanium	yes	yes	**no**	yes	yes	yes
Tin	yes	yes	yes	yes	yes	yes

Table 5.8.1 Possible material combinations of air-termination systems and down conductors with one another and with structural parts

Figure 5.8.3 New and artificially aged components

with IEC 62561-1 (EN 62561-1) must be carried out for all clamps.
The test procedure is described below based on the example of a MV clamp. At first, it must be determined how many combinations are to be tested. The MV clamp used is made of stainless steel (V4A) and hence can be combined with steel, aluminium, stainless steel (V4A) and copper conductors. Moreover, it can be connected in cross and parallel arrangement which also has to be tested. This means that there are eight possible test combinations for the MV clamp used (**Figures 5.8.3 and 5.8.4**).
In accordance with IEC 62561-1 (EN 62561-1), each of these test combinations must be tested with three suitable specimens / test set-ups. This means that 24 specimens of this single MV clamp must be tested to cover the complete range. Every single specimen is mounted with the adequate tightening torque in compliance with normative requirements and is subjected to artificial ageing consisting of a salt mist and humid sulphurous atmosphere treatment as described above. For the subsequent electrical test, the specimens are fixed on an insulated plate (**Figure 5.8.5**).

Each specimen is subjected to three 50 kA (normal duty) and 100 kA (heavy duty) lightning current impulses of 10/350 μs wave form. After this lightning current load, the specimens must not show signs of damage. The contact resistance (measured above the clamp) must not exceed 1 mΩ in case of aluminium, copper or steel clamps and 2.5 mΩ in case of stainless steel clamps. Moreover, the required loosening torque must still be ensured. A manufacturer's test report is prepared for every test combination which is available on request from the manufacturer or a less detailed report can be downloaded from the internet (e.g. www.dehn-international.com ➡ Product data).
For installers of lightning protection systems this means that the connection components must be selected for the duty (H or N) to be expected at the place of installation. Consequently, a clamp for duty H (100 kA) must be used for e.g. an air-termination rod (full lightning current) and a clamp for duty N (50 kA) must be used e.g. in a mesh or at an earth entry (lightning current is already split).

Requirements on conductors

IEC 62561-2 (EN 62561-2) also places specific requirements on conductors (air-termination and down conductors or e.g. ring earth electrodes) for example:

- Mechanical properties (minimum tensile strength and minimum elongation),
- Electrical properties (maximum resistivity) and
- Corrosion protection properties (artificial ageing as described before).

Figure 5.8.4 Test combinations for MV clamps (parallel and cross arrangement)

Figure 5.8.5 Specimen (MV clamp) fixed on an insulating plate for a test in an impulse current laboratory

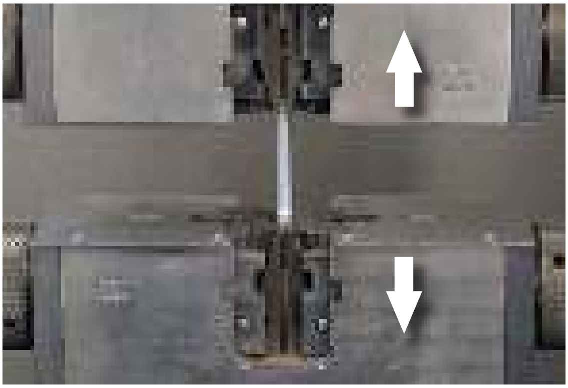


Figure 5.8.6 Tensile test of conductors

Figure 5.8.6 shows the test set-up for testing the tensile strength of round conductors (e.g. aluminium). The coating quality as well as the minimum thickness and adhesion to the base material are important and must be tested particularly if coated materials such as galvanised steel (St/tZn) are used. Moreover, the conductor materials must be easy to process during the installation of lightning protection systems. Wires or strips, for example, are supposed to be easily straightened by means of a wire straightener (guide pulleys) or by means of twisting. These normative requirements are relevant product features which must be documented. This information can be found in the manufacturer's product data sheets.

Earth electrodes and earth rods

IEC 62561-2 (EN 62561-2) describes the requirements earth electrodes have to fulfil. These requirements include the material, configuration, minimum dimensions as well as mechanical and electrical properties. The coupling joints linking the individual rods are weak points of earth rods. For this reason, IEC 62561-2 (EN 62561-2) requires that additional mechanical and electrical tests be performed to test the quality of these coupling joints. The test setup contains a test holder and a steel plate (impact area). A specimen consisting of two joined rod parts with a length of 500 mm each is inserted into this test holder. Three specimens are required for every type of earth electrode. The top end of the specimen is impacted with a vibration hammer for a duration of two minutes. The stroke rate of the hammer must be 2000 ± 1000 min^{-1} and the single stroke impact energy must be 50 ± 10 [Nm].

If the coupling joints have passed this test without visible defects, they are subjected to artificial ageing consisting of a salt mist and humid sulphurous atmosphere treatment. After that, each coupling joint is loaded with three 50 kA and 100 kA lightning current impulses of 10/350 µs wave form. The contact resistance of stainless steel earth rods (measured above the coupling) must not exceed 2.5 mΩ in case of stainless steel earth rods.

To test whether the coupling joint is still firmly connected after being subjected to this lightning current load, the coupling force is tested by means of a tensile testing machine.

Lightning protection components made of GRP

Nowadays roof-mounted structures such as domelights, antennas, air-conditioning systems, advertising signs, sirens, etc. are often located on the roofs of large office and industrial buildings. These roof-mounted structures are typically electrically operated or have a conductive connection into the building. According to the latest lightning protection technology, these roof-mounted structures are protected against direct lightning strikes by means of isolated air-termination systems. This prevents partial lightning currents from entering the building.

Isolated air-termination systems

Isolated air-termination systems can be installed in a concrete base or tripod (without additional mechanical fixing). If air-termination rods are between 2.5 m and 3.0 m high, they must be installed in a concrete base and mechanically fixed at the object to be protected using spacers made of insulating material (insulating clearance made of GRP – glass-fibre reinforced plastic) due to the wind load.

If no additional measures are taken, high impulse voltages will cause flashover at the surfaces of the insulating materials. This effect is known as creeping flashover. If the creeping discharge inception voltage is exceeded, a surface discharge occurs which can easily flash over a distance of several metres to earthed parts. This undesired flashover to metal installations at or in the object to be protected can be prevented if the necessary separation distance calculated in accordance with IEC 62305-3 (EN 62305-3) is maintained. In general, the separation distance s is calculated as follows:

$$s = \frac{k_i \cdot k_C}{k_m} \cdot l$$

s	Separation distance
k_i	Factor depending on the lightning protection level selected
k_c	Factor depending on the current distribution
k_m	Factor depending on the material of the electrical insulation
l	Length along the air-termination or down conductor from the point where the separation distance s is to be determined to the nearest equipotential bonding point or earthing point.

It can be seen that the separation distance depends on the length of the down conductor, the lightning protection level selected, the distribution of the lightning current to the different down conductors and the insulating material in the insulating clearance. The factor k_m must also be considered in addition to the factors k_i, k_c and the length l. The values of k_m have been sufficiently determined and proven for solid materials and air.

DEHNiso spacers and DEHNiso Combi supporting tubes have been sufficiently tested with impulse voltage and are specified with a factor k_m of 0.7 which is used to calculate the separation distance s. Thus, the factor k_m of 0.7 can be taken into account when calculating the necessary separation distance for the relevant object (air or solid material in conformity with the standard). The separation distance calculated must be smaller or equal to the insulating clearance of the product used to prevent flashover as shown in **Figure 5.8.7** which would impair the function of the entire lightning protection system.

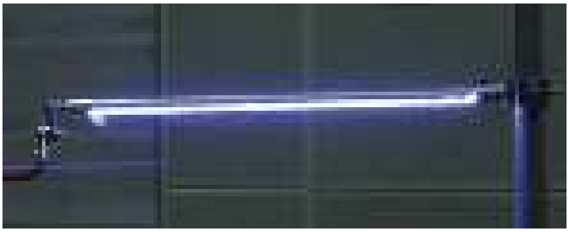


Figure 5.8.7 Flashover along the DEHNiso spacer made of GRP

If the separation distance is calculated correctly and the required components are properly selected and mounted on site, an effective isolated lightning protection system can be implemented for the structure.
Components tested in conformity with the standard must be used to be able to install a functional lightning protection system. Installers of lightning protection systems must select the components according to the requirements at the place of installation and install them correctly. In addition to the mechanical requirements, the electrical criteria according to the latest lightning protection technology must be considered and observed. This also applies to GRP components used for lightning protection systems.
In addition to the standards described before, international component standards e.g. for test joints or conductor holders have already been published.

5.9 Dimensioning of earth-termination systems for transformer stations

Earth-termination systems are vital for a functioning power supply. The main tasks of a properly functioning earth-termination are to form high-voltage protection and low-voltage ground, ensure protection measures and voltage limitation to permissible maximum values even in case of a fault, form the basis for all equipotential bonding and lightning protection measures and ensure the protection of persons and material assets. Irrespective of this, experience and discussion about earth-termination systems took a back seat. Properly functioning earth-termination systems are often taken as given without any question. Therefore, the most important physical and normative backgrounds and possible technical solutions will be described in this chapter.

Normative references

The requirements of high-voltage and low-voltage systems typically go hand in hand in a transformer station. The following standards apply:

- IEC 61936-1 (EN 61936-1): Power installations exceeding 1 kV a.c.
- EN 50522: Earthing of power installations exceeding 1 kV a.c.
- IEC 62271-202 (EN 62271-202): High-voltage / low-voltage prefabricated substation
- IEC 60364-4-41 (HD 60364-4-41): Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock
- IEC 60364-5-54 (HD 60364-5-54): Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors
- IEC 62305-3 (EN 62305-3): Protection against lightning: Physical damage to structures and life hazard
- DIN 18014: Foundation earth electrode – General planning criteria (German standard)
- DIN VDE 0151: Material and minimum dimensions of earth electrodes with respect to corrosion (German standard)

Important terms and definitions

Earth electrodes are defined as non-insulated conductors in contact with earth. A locally restricted system of conductively interconnected earth electrodes is termed earth-termination system. This earth-termination system is connected to the part of an installation to be earthed via the earthing conductor and the main earthing busbar. The earth resistance R_E (remote earth) can be determined depending on the earth resistivity ρ.
Earthing of a dead part is called protective earthing, while earthing of a point of the operating circuit such as the neutral of a transformer is called operational earthing. If currents flow into the earth-termination system in the event of a fault, the earth potential can be calculated as follows:

$$U_E = I_E \cdot Z_E$$

U_E	earth potential rise
I_E	current to earth
Z_E	impedance to earth

Depending on the distance, the earth surface potential φ arises between the earth-termination system and remote earth. A person approaching the fault location is exposed to step voltage and a person touching the faulty part of the installation is exposed to touch voltage U_T. To reduce possible step voltage, potential control measures can be taken. All conductive parts inside the electrical installation are integrated in the equipotential bonding system.
The term transferred potential means that potentials can be transferred into areas with a different or no potential rise by means a conductor (e.g. cable shield, PEN conductor) connected to the earth-termination system. Global earth-termination

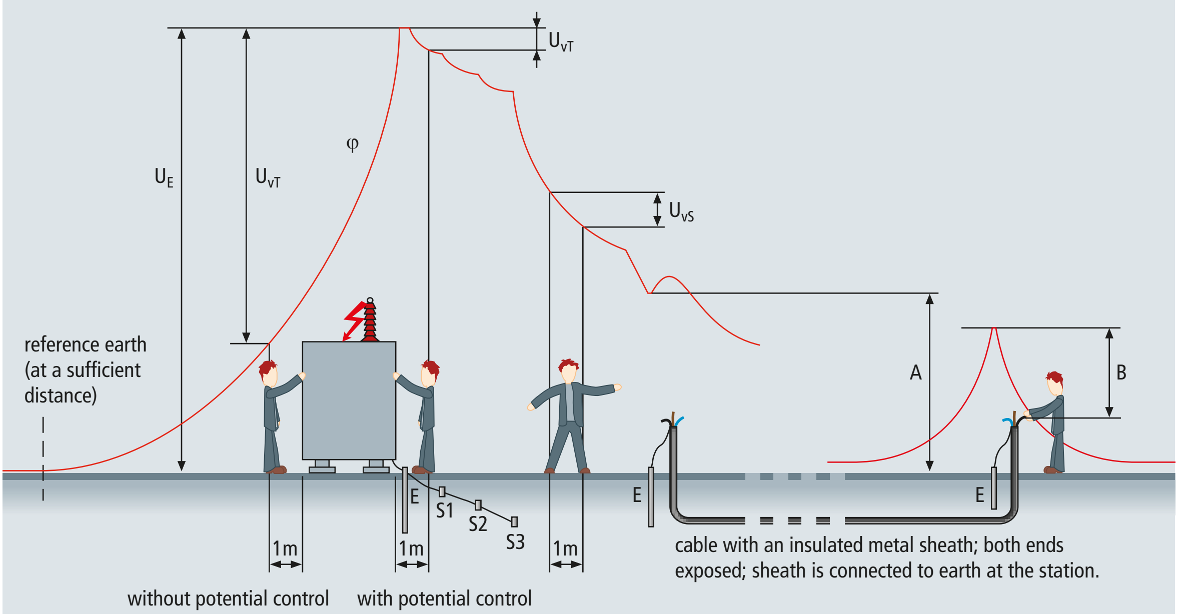
systems are defined as an enclosed area where all earth-termination systems in this area act like a large common meshed earth electrode. A global earth-termination system (industrial plants, residential areas) can typically be assumed if more than ten meshed earth-termination systems are installed in the enclosed area. In case of a fault, a wide-ranging quasi equipotential surface is formed where by definition no dangerous touch voltages occur any more (**Figure 5.9.1**). U_{TP} = 80 V is defined as maximum permissible sustained touch voltage in high-voltage systems in case of a fault (disconnection time > 10 s). The maximum permissible touch voltage in low-voltage systems is 50 V a.c. These values must be ensured in all cases.

System configurations and the associated currents to earth

Medium-voltage systems can be operated as systems with isolated neutral, systems with low-impedance neutral earthing, solidly earthed neutral systems or inductively earthed neutral systems (compensated systems). In case of an earth fault, the latter allows to limit the capacitive current flowing at the fault location to the residual earth fault current I_{RES} by means of a compensation coil (suppression coil with inductance $L = 1/3\ \omega\ C_E$) and is thus widely used. Only this residual current (typically up to max. 10 % of the uncompensated earth fault current) stresses the earth-termination system in case of a fault. The residual current is further reduced by connecting the local earth-termination system to other earth-termination systems (e.g. by means of the connecting effect of the cable shield of the medium-voltage cables). To this end, a reduction factor r is defined. If a system has a prospective capacitive earth fault current of 150 A, a maximum residual earth fault current of about 15 A, which would stress the local earth-termination system, is assumed in case of a compensated system. If the local earth-termination system is connected to other earth-termination systems, this current would be further reduced. The earth potential rise would be:

$$U_E = I_E \cdot Z_E$$

I_E	current to earth
I_C	capacitive earth fault current
I_L	rated current of the arc suppression coil
I_{RES}	residual earth fault current
I''_{kEE}	double earth fault current
I'_{k1}	line-to-earth short-circuit



E	Earth electrode	U_E	Earth potential rise (ERP)	A	Prospective touch voltage resulting from transferred potential in case of single-side cable sheath earthing
S1, S2, S3	Potential grading electrodes (e.g. ring earth electrodes) connected to the earth electrode E	U_{vS}	Prospective step voltage	B	Prospective touch voltage resulting from transferred potential in case of a cable sheath earthed on both sides
		U_{vT}	Prospective touch voltage		
		φ	Earth surface potential		

Figure 5.9.1 Definitions according to EN 50511, Figure 1

I_N nominal current

r reduction factor (e.g. for cable shields)

Dimensioning of earth-termination systems with respect to the earth potential rise

When planning earthing measures for a medium-voltage system, the possible earth potential rise U_E must be determined. If $U_E < 2 \times U_{TP}$, the earth potential rise is correctly rated. If $U_E < 4 \times U_{TP}$, compensating measures (e.g. potential control) must be implemented. In special cases, additional measures must be taken; the exact procedure is described in Figure 5 of the EN 50522 standard. By definition, there is no impermissibly high voltage rise if the relevant installation is part of a global earth-termination system. TN and TT systems are commonly used as low-voltage distribution systems, therefore other system configurations are not considered here. Particularly in TN systems, a voltage may be transferred into the customer installation in case of a fault. The voltage rise at the PEN conductor must not exceed 50 V in TN systems and 250 V in TT systems. In this context, IEC 60364-4-41 (HD 60364-4-41) refers to the so-called voltage balance. This is ensured if

$$\frac{R_B}{R_E} \leq \frac{U_B}{(U_0 - U_B)}$$

where

R_B is the total resistance of all operational earth electrodes

R_E is the earth contact resistance at a possible fault location

U_0 is the nominal voltage to earth of 230 V and

U_B is the agreed maximum touch voltage of 50 V

Thus, the following must apply: $R_B / R_E \leq 0.27$. If an accidental contact resistance of 10 Ω (typical empirical value) is assumed at the fault location, R_B must be ≤ 2.7 Ω. Therefore, in practice a maximum limit of $R_B = 2$ Ω is often used for system operation. This total earth resistance of the station earth must be documented before commissioning and must be tested at regular intervals.

Dimensioning of earth-termination systems with respect to the current carrying capability

To dimension the current carrying capability of earthing conductors and earth electrodes, different worst case scenarios must be examined. In medium-voltage systems, a double earth fault would be the most critical case. A first earth fault (for example at a transformer) may cause a second earth fault in another phase (for example in the medium-voltage system, faulty cable sealing end). In this case, a double earth fault current I''_{kEE}, which is defined as follows according to Table 1 of the EN 50522 standard, will flow via the earthing conductors (**Table 5.9.1**):

$$I''_{kEE} \sim 0.85 \cdot I''_k$$

I''_k = three-pole initial symmetrical short-circuit current

In a 20 kV installation with an initial symmetrical short-circuit current I''_k of 16 kA and a disconnection time of 1 second, the double earth fault current would be 13.6 kA. The current car-

Type of high-voltage system	Relevant for the thermal stress		Relevant for the earth potential rise and touch voltages
	Earth electrode	Earthing conductor	
Systems with isolated neutral			
	I''_{kEE}	I''_{kEE}	$I_E = r \cdot I_C$
Systems with resonant earthing (includes short-time earthing for fault detection)			
Stations without arc suppression coils	I''_{kEE}	I''_{kEE}	$I_E = r \cdot I_{RES}$
Stations with arc suppression coils	I''_{kEE}	I''_{kEE} a)	$I_E = r \cdot \sqrt{I_L^2 + I_{RES}^2}$
Systems with low-impedance neutral earthing (Includes short-time earthing for tripping)			
Stations without neutral earthing	I''_{k1}	I''_{k1}	$I_E = r \cdot I''_{k1}$
Stations with neutral earthing	I''_{k1}	I''_{k1}	$I_E = r \cdot (I''_{k1} - I_N)$ b)

a) The earthing conductors of the arc suppression coils have to be sized according to the maximum coil current.

b) It has to be checked if external faults may be decisive.

Table 5.9.1 Decisive currents for measuring earth-termination systems according to Table 1 of EN 50522

Time [s]	St/tZn [A/mm²]	Copper [A/mm²]	StSt (V4A) [A/mm²]
0.3	129	355	70
0.5	100	275	55
1	70	195	37
3	41	112	21
5	31	87	17

Table 5.9.2 Short-circuit current density G (max. temperature of 200 °C)

rying capability of the earthing conductors and the earthing busbars in the station building must be rated according to this value. In this context, current splitting can be considered in case of a ring arrangement (a factor of 0.65 is used in practice). According to **Table 9.5.1**, the earth electrode must have the same rating as the earthing conductor (except for installations with arc suppression coil (transformer substations)). The fault current frequently splits in the earth-termination system, therefore it is permissible to dimension every earth electrode and earthing conductor for a part of the fault current. The design must always be based on the actual system data. **Table 5.9.2** shows the current carrying capability of different cross-sections and materials. The cross-section of a conductor can be determined from the material and the disconnection time. The EN 50522 standard specifies the maximum short-circuit current density G (A/mm^2) for different materials (**Figure 5.9.1**).

In case of a compensated system, for example, the earth-termination system itself (namely the part in direct contact with earth) is loaded with a considerably lower current, namely only with the residual earth fault current

$$I_E = r \cdot I_{RES}$$

reduced by the factor r (**Table 5.9.1**). This current does not exceed some 10 A and can permanently flow without problems if common earthing material cross-sections are used. In the low-voltage installation, a single-pole earth fault between the transformer and the low-voltage main circuit breaker would be a possible critical fault. In case of an earth fault of a transformer's low-voltage winding (e.g. via the earthed transformer tank), a single-pole short-circuit current I''_{k1} will flow to the main earthing busbar. From there, the fault circuit is closed via the connected protective conductor of the low-voltage distribution board and the PEN conductor to the neutral of the transformer. In this case, the circuit breaker of the transformer or the associated switch-disconnector / fuse combination would disconnect the installation on the high-voltage side. The earthing / protective conductor in the installation room is rated according to section 543.1.2 of the IEC 60364-5-54 (HD 60364-5-54) standard. The cross-section must be calculated as follows:

$$S = \frac{I}{k} \cdot \sqrt{t}$$

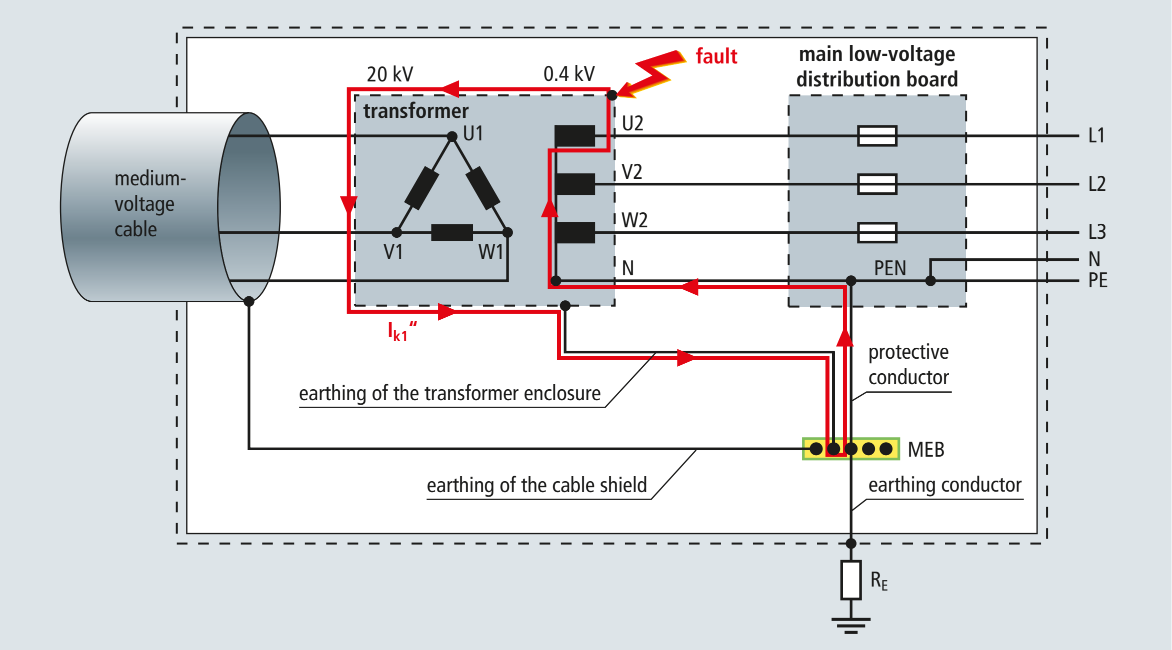


Figure 5.9.2 Single-pole fault in a transformer station with integrated main low-voltage distribution board

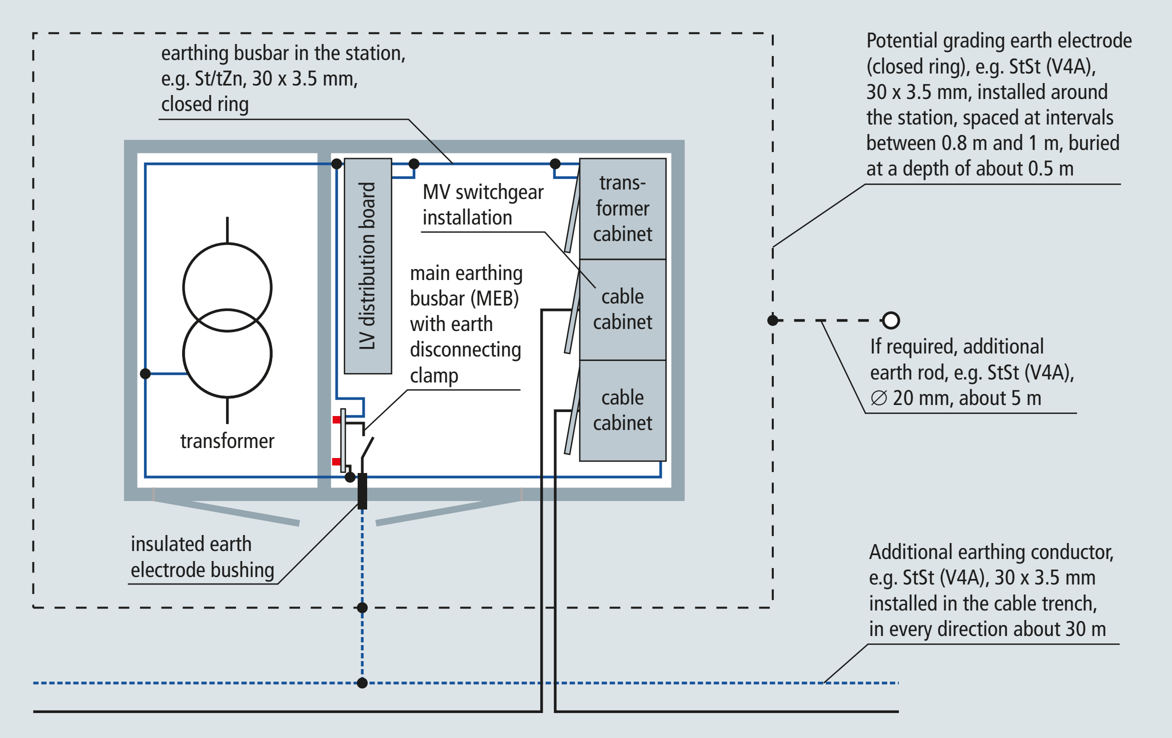


Figure 5.9.3 Schematic diagram of the earth-termination system at a transformer station (source: Niemand / Kunz; "Erdungsanlagen", page 109; VDE-Verlag)

where according to Table A 54.2 of the standard the material factor k (insulated, thermoplastic) is 143 in case of a copper line, I is the short-circuit current and t the duration of current flow (**Figure 5.9.2**). It is extremely difficult to calculate the actual flow of fault current since it depends on the nominal power of the transformer S_N, the driving voltage, the short-circuit voltage u_k and the relevant loop impedance (which can only be determined by measurements). Fast analysis is only possible to a limited extent by considering the initial symmetrical short-circuit current I''_k (~three-pole short-circuit as a defined state) which can be calculated by the nominal power of the transformer, the nominal voltage and the short-circuit voltage according to the following equation:

$$I''_k = \frac{S_N}{(\sqrt{3} \cdot U_N \cdot u_k)}$$

In case of a 630 kVA transformer with u_k = 4 % and U_N = 400 V, the initial symmetrical short-circuit current I''_k would be e.g. 22.7 kA. In our example with a 20 kV installation, the transformer would have to be protected by means of HH fuses with a nominal current from 31.5 to 50 A on the high-voltage side. According to the transformation ratio n of 50, the short-circuit current would be transformed to the high-voltage side with about 450 A and trip the HH fuses according to the fuse characteristic curve at a nominal current of 31.5 A in about 25 ms (on all poles). According to the equation

$$S = \frac{I}{k} \cdot \sqrt{t}$$

the copper protective conductors / protective bonding conductors in the station would have a minimum cross-section S_{min} = 25 mm². In practice, this value is rounded up to 50 mm². It must be observed that in case of larger transformers and consequently higher currents in conjunction with the relevant disconnection times the cross-sections for the protective and earthing conductor can be considerably higher. The earth-termination system itself (namely the part in direct contact with earth) is not stressed in case of this fault. On the low-voltage side, currents only flow through the earth-termination system in case of an earth fault outside the station. The current

$$I_E = \frac{U}{(R_E + R_B)}$$

Figure 5.9.4 Connection of an earth rod to the ring earth electrode of the station

which flows back to the neutral of the transformer via the earth-termination system of the station, occurs at the fault location. In case of a line-to-earth voltage of 230 V, a resistance R_E of some ohms and an earth resistance of the station R_B of about 2 Ω, this current is uncritical. The current will not exceed some 10 A so that overload is not to be expected if the maximum earth resistance is observed.

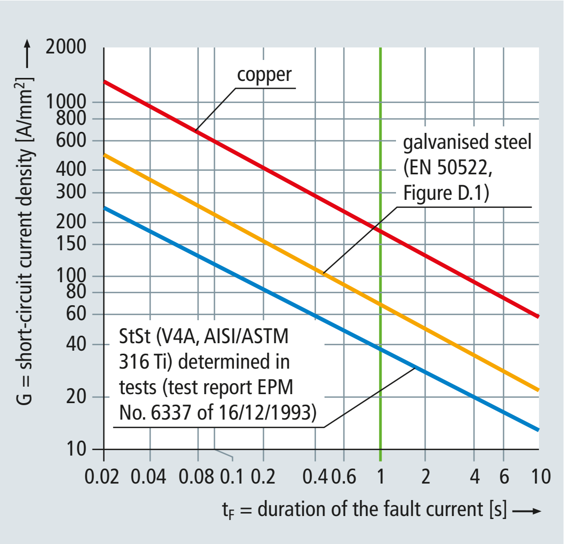


Figure 5.9.5 Current carrying capability of earth electrode materials

Practical implementation of earth-termination systems for transformer stations

The earth-termination system of a transformer station (**Figure 5.9.3**) must be designed according to IEC 61936-1 (EN 61936-1) and EN 50522 considering the local system data from the distribution network operator. An earth-termination system typically consists of several horizontal, vertical or inclined earth electrodes which are buried or driven into the soil. In Germany, the use of chemicals to improve the earth resistance is not common and is not recommended. Surface earth electrodes should be typically buried at a depth of 0.5 m to 1 m below ground level. This provides sufficient mechanical and frost protection. Earth rods are typically buried below the surface of the earth (**Figure 5.9.4**). Vertical or inclined earth rods are particularly advantageous since the earth resistivity decreases in relation with the depth. Typical values of the earth resistivity depending on the type of ground can be found in **Figure 5.5.4** of section 5.5. In general, a ring earth electrode (potential grading earth electrode) is installed at a depth of about 0.5 m at a distance of about 1 m around the station building. The earth resistance is often improved by driving an earth rod (typical length of about 6 m) into the ground. In addition, a strip earth electrode of some 10 m is frequently routed along the cable routes in the cable trench. In practice, a common earth-termination system should be preferred on the high-voltage and low-voltage side. In this context, the requirements concerning touch voltage and voltage rise specified in Table 2 of the IEC 61936-1 (EN 61936-1) standard must be observed in low-voltage systems. Therefore, isolated earth-termination systems may be required in special cases, particularly in overhead line systems or in case of dead-end feeders. In such cases, case-by-case examination is required. This outdoor earth-termination system enters the station in an isolated way to prevent contact with the building reinforcement, which would negatively affect a measurement result. The outdoor earth-termination system is connected to the main earthing busbar by means of a disconnecting clamp. If the disconnecting clamp is closed, the total earth resistance can be measured. If the disconnecting clamp is open, the earthing conditions of the relevant installation can be measured. As already described before, the total earth resistance of the station R_B of about 2 Ω is sufficient. Distribution network operators often refer to this value in the German Technical Connection Conditions. Therefore, it is often helpful to roughly determine the total earth resistance before installing the earth-termination system. **Table 5.5.1** of chapter 5.5 includes formulas for roughly determining the total earth resistance of different buried earth electrodes. When selecting the materials for earth electrodes, not only their current carrying capability (**Figure 5.9.5**), but also the corrosion behaviour must be considered, which will be described below.

Selection of earth electrode materials considering the corrosion behaviour

If adequate materials are chosen, corrosion hazards for earth electrodes can be reduced or even prevented. To ensure a sufficient service life, the minimum material dimensions must

Figure 5.9.6 Corrosion of a galvanised earth rod after 7 years

Figure 5.9.7 Corrosion of a galvanised earth rod (below) and a stainless steel earth electrode (above) after 2.5 years

be observed. The exact values are specified in Table 3 of the German DIN VDE 0151 standard.

Bare copper

Due to its position in the electrolytic series, bare copper is extremely resistant. In addition, it is cathodically protected when connected to earth electrodes or other buried systems made of more non-precious materials (e.g. steel), however, at the cost of the more non-precious materials.

Hot-dip galvanised steel

When using galvanised material for buried earth electrodes, the corrosion behaviour must be especially observed. In case of transformer stations, galvanised steel is typically embedded in concrete (in the foundation slab of the building). This earth electrode embedded in concrete is connected to the ring earth electrode. This direct connection forms a concentration cell. The steel embedded in concrete has a higher potential (like copper) and thus the more non-precious metal (galvanised steel in the ground) corrodes like a battery in the ground. The area ratio of the two earth-termination systems is decisive for this electrochemical corrosion. This is described in detail in chapter 5.5.7.

Stainless steel

When using high-alloy stainless steel, the before mentioned effect can be virtually excluded. According to EN 10088-3, high-alloy stainless steel is passive and corrosion-resistant in the ground. In the majority of cases, the free corrosion potential of high-alloy stainless steel in conventionally ventilated grounds is similar to that of copper. Since stainless steel earth electrode materials passivate at the surface within a few weeks, they show a neutral behaviour with regard to other (more precious or non-precious) materials. Stainless steel should consist of at least 16 % chromium, 5 % nickel and 2 % molybdenum. Extensive measurements have shown that only high-alloy stainless steel (V4A), e.g. AISI/ASTM 316 Ti, is sufficiently protected against corrosion in the ground.

Nowadays numerous power supply systems are operated for 50 years or even longer, that is frequently far longer than the service life of earth-termination systems made of conventional materials. Therefore, the earth-termination system must be dimensioned for this operating time. It is advisable to use stainless steel (V4A). **Figure 5.9.6** clearly shows localised corrosion of an earth rod after only seven years.

Figure 5.9.7 shows that high-alloy stainless steel does not corrode in the ground.

Reliable and correctly dimensioned earth-termination systems are vital for a functioning power supply to ensure personal and operational safety. However, their correct operation is often taken as given without any question. In case of earth-termination systems for transformer stations, the technical requirements of the high-voltage and low-voltage systems must be considered in context. A global earth-termination system provides considerable advantages with regard to the hazard potential of a possible earth potential rise U_E. According to the standard, dangerous touch voltages will typically not occur in this case. To ensure that personal protection requirements are met in the system parts connected to the earth-termination system even under fault conditions, a total earth resistance R_B of the individual earth-termination systems of less than 2 Ω has proven its worth in practice. The minimum cross-sections of the earthing conductor and the earthing busbars of the installation must be observed with regard to the current carrying capability in case of possible faults in the station. In case of a fault, the stress on the earth-termination system is reduced depending on the neutral point treatment (e.g. compensated system). In practice, the principles of the before mentioned standards and important notes by local distribution network operators must be observed. When designing and dimensioning the earth-termination system, it often makes sense to assess the total earth resistance in advance to define all necessary measures before installing the installation. It is vital to pick a corrosion-resistant material for the earth electrode of the earth-termination system. The examples described before as well as experience over the last decades with many systems clearly show that only high-alloy stainless steel (V4A, AISI/ASTM 316 Ti) is corrosion-resistant in the ground. Therefore, only high-alloy stainless steel should be used for the earth-termination system to ensure long-term safe operation of a transformer station.

Internal lightning protection

6.1 Equipotential bonding for metal installations

Equipotential bonding according to IEC 60364-4-41 (HD 60364-4-41) and IEC 60364-5-54 (HD 60364-5-54)

Equipotential bonding is required for all electrical consumer's installations installed. Equipotential bonding according to the IEC 60364 series removes potential differences, in other words it prevents hazardous touch voltages, for example, between the protective conductor of the low-voltage consumer's installation and metal water, gas and heating pipes.

According to IEC 60364-4-41 (HD 60364-4-41), equipotential bonding consists of **protective equipotential bonding** and **supplementary protective equipotential bonding**.

Every building must be equipped with a protective equipotential bonding system in accordance with the standards stated above (**Figure 6.1.1**).

Supplementary protective equipotential bonding is intended for those cases where the conditions for disconnection of supply cannot be met or for special areas which conform to the IEC 60364 series Part 7.

Protective equipotential bonding

The following extraneous conductive parts must be **directly** integrated in the protective equipotential bonding system:

- Protective bonding conductor in accordance with IEC 60364-4-41 (HD 60364-4-41) (in the future: earthing conductor)

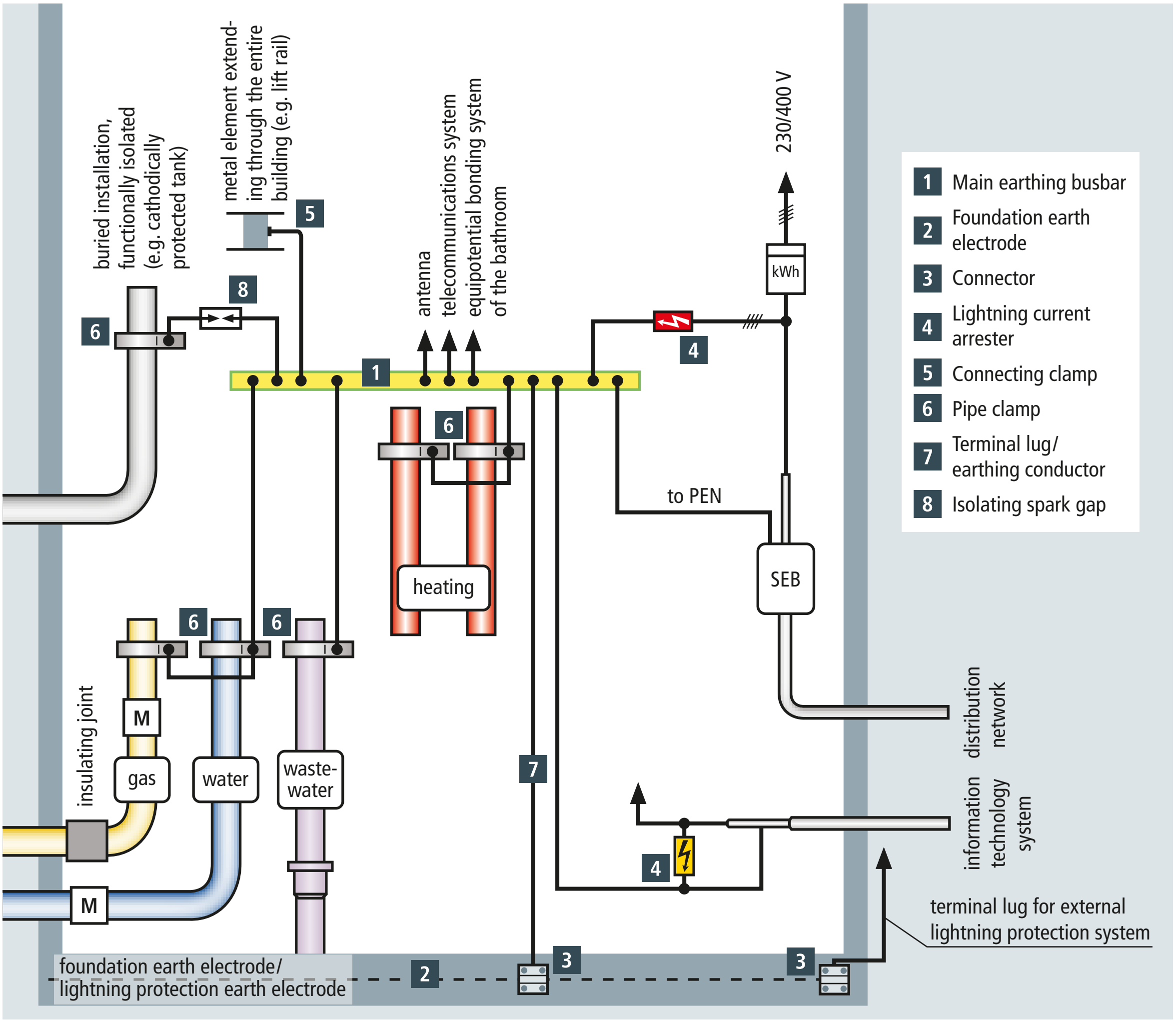


Figure 6.1.1 Principle of lightning equipotential bonding consisting of lightning and protective equipotential bonding

- Foundation earth electrode or lightning protection earth electrode
- Central heating system
- Metal water supply pipe
- Conductive parts of the building structure (e.g. lift rails, steel frame, ventilation / air conditioning ducts)
- Metal drain pipe
- Internal gas pipe
- Earthing conductor for antennas (German DIN VDE 0855-300 standard)
- Earthing conductor for telecommunication systems (German DIN VDE 0800-2 standard)
- Protective conductor of the electrical installation in accordance with the IEC 60364 series (PEN conductor in case of TN systems and PE conductor in case of TT systems or IT systems)
- Metal shields of electrical and electronic conductors
- Metal sheaths of power cables up to 1000 V
- Earth-termination systems of power installations exceeding 1 kV according to IEC 61936-1 (EN 61936-1), EN 50522 if no impermissibly high earthing voltage can be produced

Normative definition of an extraneous conductive part according to IEC 60050-826 (HD 60050-826): A conductive part not forming part of the electrical installation and liable to introduce a potential generally the earth potential.

Note: Extraneous conductive parts also include conductive floors and walls if an electric potential including the earth potential can be introduced via them.

The following installation parts must be integrated **indirectly** in the protective equipotential bonding system via isolating spark gaps:

- Installations with cathodic corrosion protection and stray current protection measures in accordance with EN 50162
- Earth-termination systems of power installations exceeding 1 kV in accordance with IEC 61936-1 (EN 61936-1), EN 50522 if impermissibly high earthing voltages can be produced (in rare cases)
- Traction system earth in case of a.c. and d.c. railways in accordance with EN 50122-1 (tracks of Deutsche Bahn (German Railways) may only be connected with prior written approval)
- Signal earth for laboratories if it is separated from the protective conductors

Figure 6.1.1 shows the connections and the relevant components of the protective and lightning equipotential bonding system.

Earth-termination system for equipotential bonding

Since the electrical low-voltage consumer's installation requires certain earth resistances (disconnection conditions of the protection elements) and the foundation earth electrode provides good earth resistances when installed cost-effectively, the foundation earth electrode complements the equipotential bonding in an optimum and effective way. In Germany, the design of foundation earth electrodes is governed by DIN 18014, which, for example, requires terminal lugs for the equipotential bonding bar. More detailed information and designs of foundation earth electrodes can be found in chapter 5.5.

If a foundation earth electrode is used as lightning protection earth electrode, additional requirements may have to be considered. These requirements can also be found in chapter 5.5.

Protective bonding conductors according to IEC 60364-5-54 (HD 60364-5-54)

Equipotential bonding conductors should, as long as they fulfil a protective function, be labelled as protective conductors, namely green / yellow.

Equipotential bonding conductors do not carry operating currents and can therefore be either bare or insulated.

The minimum cross-section of protective bonding conductors for connection to the main earthing busbar is:

- 6 mm^2 (copper) or
- 16 mm^2 (aluminium) or
- 50 mm^2 (steel)

The minimum cross-section for earthing conductors of antennas (according to IEC 60728-11 (EN 60728-11)), is 16 mm^2 (copper), 25 mm^2 (aluminium) or 50 mm^2 (steel).

Equipotential bonding bars

Equipotential bonding bars are a central component of the equipotential bonding system and must clamp all connecting cables and cross-sections which occur in practice so that they have high contact stability; they must be able to carry currents safely and have sufficient corrosion resistance.

The German DIN VDE 0618-1 standard describes requirements on equipotential bonding bars for protective equipotential bonding. It defines the following connection possibilities as a minimum:

- 1 x flat conductor (4 x 30 mm) or round conductor (Ø 10 mm)
- 1 x 50 mm^2
- 6 x 6 mm^2 to 25 mm^2
- 1 x 2.5 mm^2 to 6 mm^2

Figure 6.1.2 K12 equipotential bonding bar, Part No. 563 200

Figure 6.1.3 R15 equipotential bonding bar, Part No. 563 010

Figure 6.1.4 Earthing pipe clamp, Part No. 407 114

K12 and R15 meet these requirements on an equipotential bonding bar (**Figures 6.1.2 and 6.1.3**).

This standard also includes requirements for testing the lightning current carrying capability of clamping points with cross-sections greater than 16 mm^2. The standard refers to the test for lightning protection components described in in IEC 62561-1 (EN 62561-1).
If the requirements of the previously mentioned standard are met, this component can also be used for lightning equipotential bonding in accordance with IEC 62305-1 to 4 (EN 62305-1 to 4).

Equipotential bonding connections

Equipotential bonding connections must provide good and permanent contact.

Integrating pipes in the equipotential bonding system

In order to integrate pipes in the equipotential bonding system, earthing pipe clamps which correspond to the diameters of the pipes are used (**Figure 6.1.4**).

Stainless steel earthing pipe clamps with tensioning straps, which can be universally adapted to the diameter of the pipe, offer enormous installation benefits (**Figure 6.1.5**).
These earthing pipe clamps can be used to clamp pipes made of different materials (e.g. steel, copper and stainless steel) and also allow through-wiring.
Figure 6.1.6 shows the equipotential bonding system of heating pipes with through-wiring.

Testing and monitoring the equipotential bonding system

Before the electrical consumer's installation is commissioned, the connections must be tested to ensure their proper condition and effectiveness.
Low-impedance continuity to the various installation parts and to the equipotential bonding system is recommended. A value of < 1 Ω is considered to be sufficient for the equipotential bonding connections. In a continuity test according to IEC 60364-6 (HD 60364-6), test equipment with a test current of 200 mA as per IEC 61557-4 (EN 61557-4) must be used.

Supplementary protective equipotential bonding

If the disconnection conditions of the relevant system configuration cannot be met for an installation or a part thereof, a local supplementary protective equipotential bonding is required. The reason behind this is to interconnect all simultaneously accessible parts as well as the stationary equipment and to connect extraneous conductive parts to keep any touch voltage which may occur as low as possible.

Figure 6.1.5 Earthing pipe clamp, Part No. 540 910

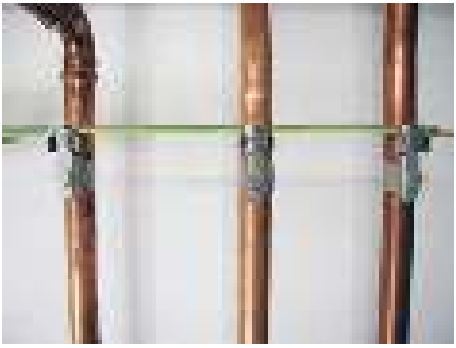


Figure 6.1.6 Through-wired equipotential bonding bar

Moreover, supplementary protective equipotential bonding must be used for installations or installation parts of IT systems with insulation monitoring.

Supplementary protective equipotential bonding is also required if the environmental conditions in special installations or parts thereof present a particular risk.

The IEC 60364 series Part 7 draws attention to supplementary protective equipotential bonding for special operating areas, rooms and installations.

These are, for example,

- IEC 60364-7-701 (HD 60364-7-701) Locations containing a bath or shower (no longer generally required)
- IEC 60364-7-702 (HD IEC 60364-7-702) Basins of swimming pools and other water basins
- IEC 60364-7-705 (HD 60364-7-705) Agricultural and horticultural premises

Minimum cross-sections for the supplementary protective bonding copper conductor of 2.5 mm^2 (in case of protected installation) and 4 mm^2 (in case of unprotected installation) are required.

The difference to the protective equipotential bonding consists in the fact that the cross-sections of the conductors can be chosen to be smaller and this supplementary protective equipotential bonding can be limited to a particular location.

6.1.1 Minimum cross-section for equipotential bonding conductors according to IEC 62305-3 (EN 62305-3)

The cross-sections of conductors used for lightning protection purposes must be dimensioned for high stress since these conductors must be capable of carrying lightning currents. Therefore, they must have larger cross-sections.

Irrespective of the class of LPS, the minimum cross-sections according to **Table 6.1.1.1** must be used for connecting equipotential bonding bars with one another and to the earth-termination system.

The minimum cross-sections of equipotential bonding conductors, which allow to connect internal metal installations to the equipotential bonding bar, can be smaller since only low partial lightning currents flow through these conductors (**Table 6.1.1.2**).

Note: If standards provide different information on the minimum cross-sections of conductors, the cross-sections stated in IEC 62305-3 (EN 62305-3) must be used for lightning protection purposes.

6.2 Equipotential bonding for power supply systems

Equipotential bonding for low-voltage consumer's installations as part of the internal lightning protection represents an extension of the protective equipotential bonding (previously: main equipotential bonding) according to IEC 60364-4-41 (HD 60364-4-41) (**Figure 6.1.1**).

In addition to all conductive systems, the feeder cables of the low-voltage consumer's installation are also integrated in the equipotential bonding system. A special feature of this equipotential bonding system is the fact that connection to the equipotential bonding system is only possible via adequate surge protective devices. The requirements made on such surge protective devices are described in more detail in section 7 and Annexes C and D of the IEC 62305-4 (EN 62305-4) standard.

Analogous to the equipotential bonding for metal installations (see chapter 6.1), equipotential bonding for the feeder cables of the low-voltage consumer's installation should also be established directly at the entry point into the object. The requirements governing the installation of the surge protective devices upstream of the meter of the low-voltage consumer's installation (main power supply system) are described in the guideline published by the German VDN (Association of German Network Operators) "Surge Protective Devices Type 1 – Guideline for the use of surge protective devices (SPDs) Type 1 in main power supply systems" (see chapter 7.5.2 and 8.1) (**Figures 6.2.1 and 6.2.2**).

Class of LPS	Material	Cross-section
I to IV	Copper	16 mm^2
	Aluminium	25 mm^2
	Steel	50 mm^2

Table 6.1.1.1 Minimum dimensions of conductors connecting different equipotential bonding bars with one another or with the earth-termination system (according to IEC 62305-3 (EN62305-3), Table 8)

Class of LPS	Material	Cross-section
I to IV	Copper	6 mm^2
	Aluminium	10 mm^2
	Steel	16 mm^2

Table 6.1.1.2 Minimum dimensions of conductors connecting internal metal installations to the equipotential bonding bar (according to IEC 62305-3 (EN62305-3), Table 9)

Figure 6.2.1 DEHNbloc M for installation in conformity with the lightning protection zone concept at the boundaries from 0_A – 1

Figure 6.2.2 DEHNventil combined arrester for installation in conformity with the lightning protection zone concept at the boundaries from 0_A – 2

6.3 Equipotential bonding for information technology systems

Lightning equipotential bonding requires that all metal conductive parts such as cable cores and shields at the entrance point into the building be integrated in the equipotential bonding system so as to cause as little impedance as possible. Examples of such parts include antenna lines (**Figure 6.3.1**), telecommunication lines with metal conductors and also optical fibre installations with metal elements. The lines are connected with the help of lightning current carrying elements (arresters and shield terminals). An adequate place of installation is the point where the cabling extending beyond the building transfers to cabling inside the building. Both the arresters and the shield terminals must be chosen according to the lightning current parameters to be expected.

In order to minimise induction loops within buildings, the following additional steps are recommended:

- Cables and metal pipes should enter the building at the same location
- Power and data lines should be laid spatially close, but shielded
- Unnecessarily long cables should be prevented by laying lines directly

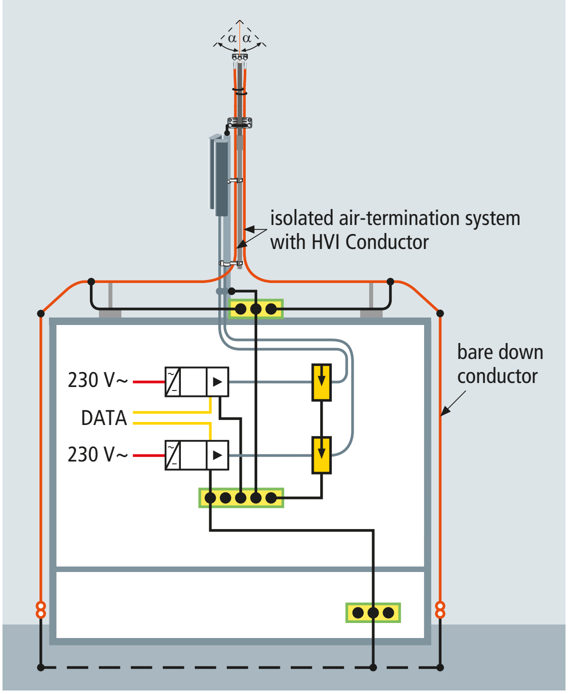


Figure 6.3.1 Lightning equipotential bonding with an isolated air-termination system and a HVI Conductor for professional antenna installations according to IEC 62305-3 (EN 62305-3)

Antenna systems

For reasons concerning radio communication, antenna systems are generally mounted in an exposed location. Therefore, they are more affected by lightning currents and surges, especially in the event of a direct lightning strike. In Germany they must be integrated in the equipotential bonding system according to DIN VDE 0855-300 (German standard) and must reduce the risk of being affected by means of their design (cable structure, connectors and fittings) or suitable additional measures. Antenna elements that are connected to an antenna feeder and cannot be connected directly to the equipotential bonding system for functional reasons should be protected by lightning current carrying arresters.

Expressed simply, it can be assumed that 50 % of the direct lightning current flows away via the shields of all antenna lines. If an antenna system is dimensioned for lightning currents up to 100 kA (10/350 μs) (lightning protection level (LPL) III), the lightning current splits so that 50 kA flow through the earthing conductor and 50 kA via the shields of all antenna cables. Antenna systems which are not capable of carrying lightning currents must therefore be equipped with air-termination systems in whose protected volume the antennas are located. When choosing a suitable cable, the relevant partial lightning current ratio must be determined for each antenna line sharing the down conductor. The required dielectric strength of the cable can be determined from the transfer impedance, the length of the antenna line and the amplitude of the lightning current.

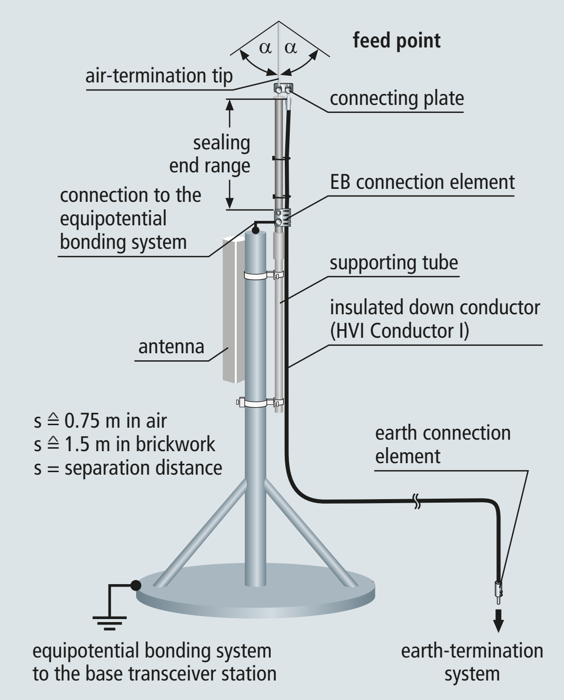


Figure 6.3.2 Isolated installation of a lightning protection system and a mobile phone antenna

According to the latest IEC 62305-3 (EN 62305-3) lightning protection standard, antenna systems on buildings can be protected by means of

- Air-termination rods
- Elevated wires
- Or spanned cables.

In each case, the separation distance **s** must be maintained.

The electrical isolation of the lightning protection system from conductive parts of the building structure (metal structural parts, reinforcement etc.) and the isolation of the lightning protection system from electrical lines in the building prevent partial lightning currents from entering control and supply lines and thus prevent that sensitive electrical and electronic devices are affected or destroyed (**Figures 6.3.1 and 6.3.2**).

Optical fibre installations

Optical fibre installations with metal elements can normally be divided into the following types:

- Cables with metal-free core, but with metal sheath (e.g. metal vapour barrier) or metal supporting elements
- Cables with metal elements in the core and with metal sheath or metal supporting elements
- Cables with metal elements in the core, but without metal sheath.

For all types of cable with metal elements, the minimum peak value of the lightning current, which adversely affects the transmission characteristics of the optical fibre cables, must be determined. Cables which are capable of carrying lightning currents must be chosen and the metal elements must be connected to the equipotential bonding bar either directly or via an SPD.

- Metal sheath: Connection by means of shield terminals e.g. shield terminal at the entrance point into the building
- Metal core: Connection by means of an earthing clamp e.g. protective conductor terminal near the splice box
- Prevention of equalising currents: Indirect connection via a spark gap e.g. DEHNgap CS, BLITZDUCTOR XT with indirect shield earthing (**Figure 6.3.3**)

Telecommunication lines

Telecommunication lines with metal conductors typically consist of cables with balanced or coaxial stranding elements of the following types:

Figure 6.3.3 EMC spring terminals for the protected and unprotected side of a BLITZDUCTOR XT for permanent low-impedance shield contact with a shielded signal line; with snap-on insulating cap for indirect shield earthing, cable ties and insulating strips.

- Cables without additional metal elements
- Cables with metal sheath (e.g. metal vapour barrier) and / or metal supporting elements
- Cables with metal sheath and additional lightning protection reinforcement

The splitting of the partial lightning current between information technology lines can be determined using the procedures in Annex E of the IEC 62305-1 (EN 62305-1) standard. The individual cables must be integrated in the equipotential bonding system as follows:

a) Unshielded cables must be connected by SPDs which are capable of carrying partial lightning currents. Partial lightning current of the cable divided by the number of single cores = partial lightning current per core.

b) If the cable shield is capable of carrying lightning currents, the lightning current flows via the shield. However, capacitive / inductive interferences can reach the cores and make it necessary to use surge arresters. Requirements:

   - The shield at both cable ends must be connected to the main equipotential bonding system in such a way that it can carry lightning currents (**Figure 6.3.4**).
   - The lightning protection zone concept must be used in both buildings where the cable ends and the active cores must be connected in the same lightning protection zone (typically LPZ 1).
   - If an unshielded cable is laid in a metal pipe, it must be treated as if it were a cable with a lightning current carrying cable shield.

c) If the cable shield is not capable of carrying lightning currents, then:

   - If the shield is connected at both ends, the procedure is the same as for a signal core in an unshielded cable. Partial lightning current of the cable divided by the number of single cores + 1 shield = partial lightning current per core
   - If the shield is not connected at both ends, it must be treated as if it were not there: Partial lightning current of the cable divided by the number of single cores = partial lightning current per core

If it is not possible to determine the exact core load, it is advisable to use the threat parameters given in IEC 61643-22 (CLS/TS 61643-22). Consequently, the maximum lightning current load per cable core for a telecommunications line is a category D1 impulse of 2.5 kA (10/350 μs).

Of course not only the SPDs used (**Figure 6.3.5**) must be capable of withstanding the expected lightning current load, but also the discharge path to the equipotential bonding system. This can be illustrated based on the example of a multi-core telecommunications line:

Figure 6.3.4 Lightning current carrying shield connection system (SAK)

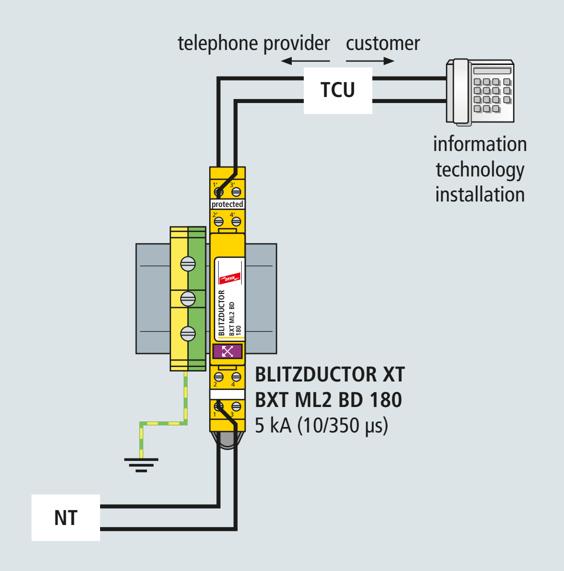


Figure 6.3.5 Lightning equipotential bonding for the connection of a telecommunications device by means of BLITZDUCTOR XT (use permitted by Deutsche Telekom)

- A telecommunications cable with 100 pairs coming from LPZ 0_A is connected in an LSA building distributor and should be protected by arresters.

Figure 6.3.6 Lightning current carrying DEHN equipotential bonding enclosures (DPG LSA) for LSA-2/10 technology

- The lightning current load on the cable was assumed to be 30 kA (10/350 µs).
- The resulting symmetrical splitting of the lightning current to the single cores is 30 kA / 200 cores = 150 A / core.

This means no special requirements are placed on the discharge capacity of the protection elements to be used. After flowing through the discharge elements, the partial currents of all cores add up to 30 kA again and stress, for example, terminal enclosures, earthing clamps or lightning equipotential bonding conductors in the discharge path. Lightning-current-tested enclosure systems can be used to prevent destruction in the discharge path (**Figure 6.3.6**).

7

Protection of electrical and electronic systems against LEMP

7.1 Lightning protection zone concept

Electrical and electronic systems, which are sensitive to high-energy temporary overvoltage resulting from the lightning discharge, are rapidly becoming common in practically all areas of residential and functional buildings in the form of building management, telecommunications, control and security systems. The owner/operator places very high demands on the permanent availability and reliability of such systems.

The protection of electrical and electronic systems in structures against surges resulting from the lightning electromagnetic pulse (LEMP) is based on the principle of lightning protection zones (LPZ). According to this principle, the structure to be protected must be divided into inner lightning protection zones according to the risk level posed by the LEMP (**Figure 7.1.1**). This allows to adapt areas with different LEMP risk levels to the immunity level of the electronic system. With this flexible concept, suitable LPZs can be defined according to the number, type and sensitivity of the electronic devices/systems ranging from small local zones to large integral zones which can encompass the whole building. Depending on the lightning threat, inner and outer lightning protection zones are defined in the IEC 62305-4 (EN 62305-4) standard.

Outer zones:

LPZ 0 Zone where the threat is due to the unattenuated lightning electromagnetic field and where the internal systems may be subjected to the full or partial lightning current.

LPZ 0 is subdivided into:

LPZ 0_A Zone where the threat is due to direct lightning strikes and the full lightning electromagnetic field. The internal systems may be subjected to the full lightning current.

LPZ 0_B Zone protected against direct lightning strikes but where the threat is due to the full lightning electromagnetic field. The internal systems may be subjected to partial lightning currents.

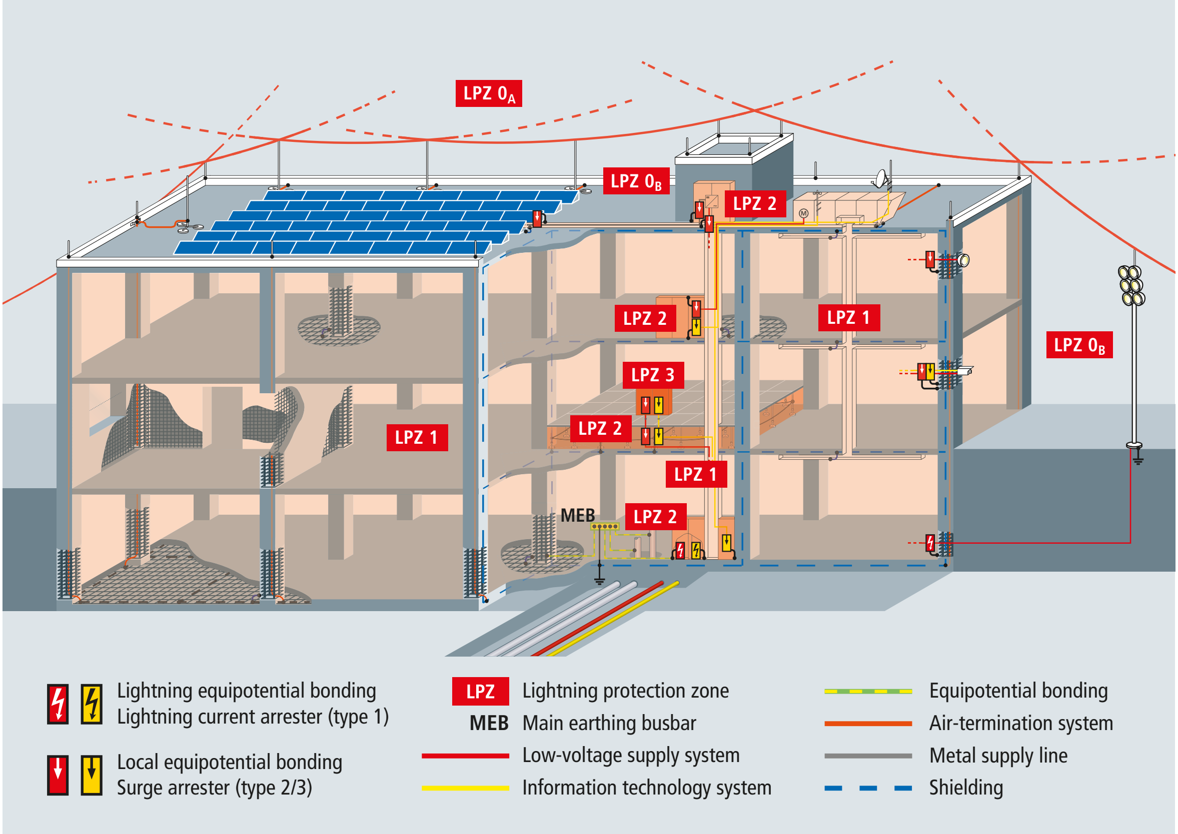


Figure 7.1.1 Overall view of the lightning protection zone concept according to IEC 62305-4 (EN 62305-4)

Inner zones (protected against direct lightning strikes):

LPZ 1 Zone where the impulse currents are limited by current distribution and isolating interfaces and / or by SPDs at the zone boundaries. Spatial shielding may attenuate the lightning electromagnetic field.

LPZ 2...n Zone where the impulse currents are limited by current distribution and isolating interfaces and / or by additional SPDs at the zone boundaries. Additional spatial shielding may be used to further attenuate the lightning electromagnetic field.

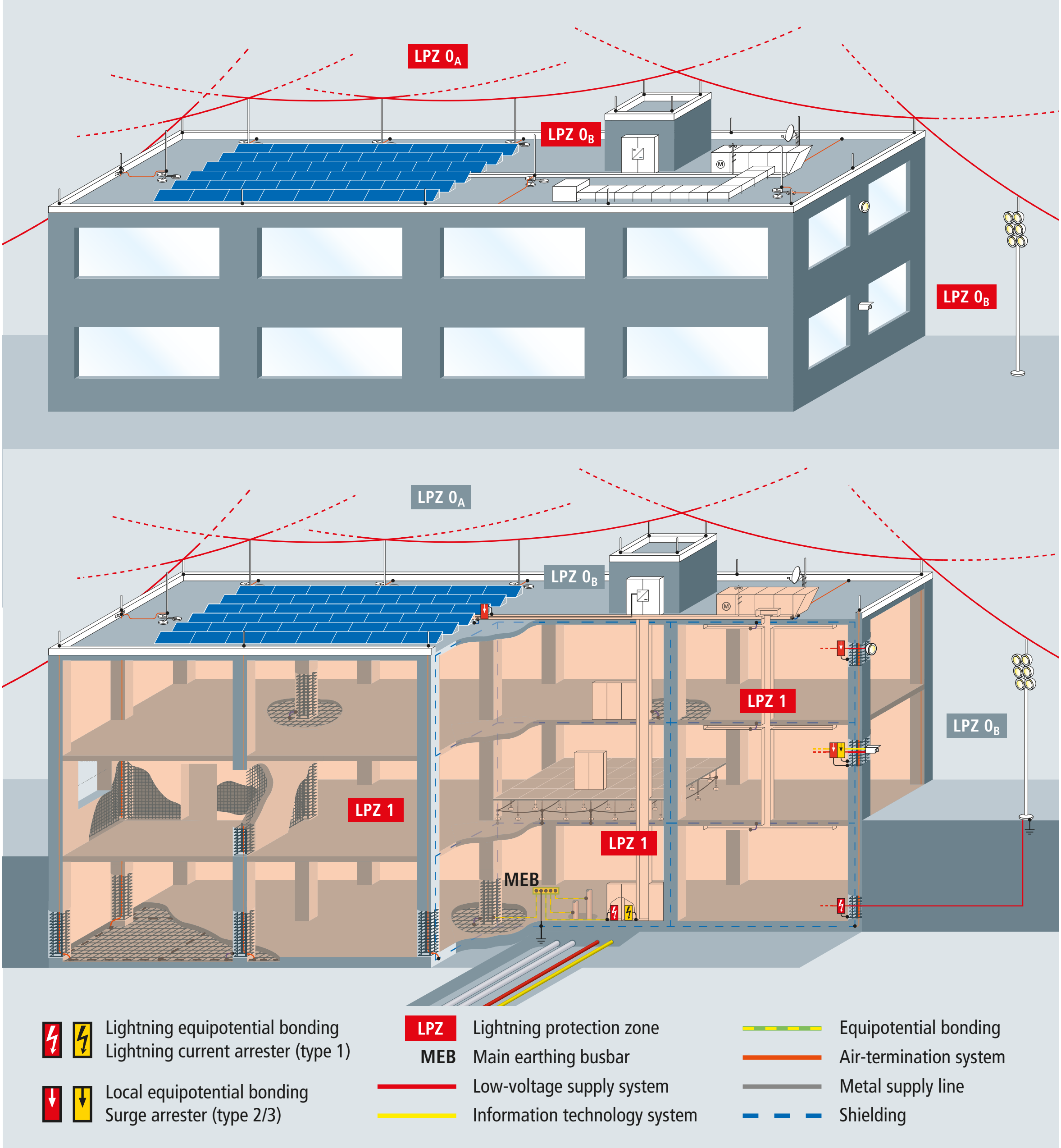


Figure 7.1.2a Lightning protection zone concept according to IEC 62305-4 (EN 62305-4)

The requirements for the inner zones must be defined according to the dielectric strength of the electrical and electronic systems to be protected.

Equipotential bonding must be established at the boundary of each inner zone for all incoming metal parts and supply lines either directly or by means of suitable SPDs. The zone boundary is formed by the shielding measures. The implementation of the lightning protection zone concept is an important prerequisite for safe and undisturbed operation.

To ensure the required availability of the installation, a lot of information (e.g. on the use of the building, earth-termination system, electrical installation, computer system) must be col-

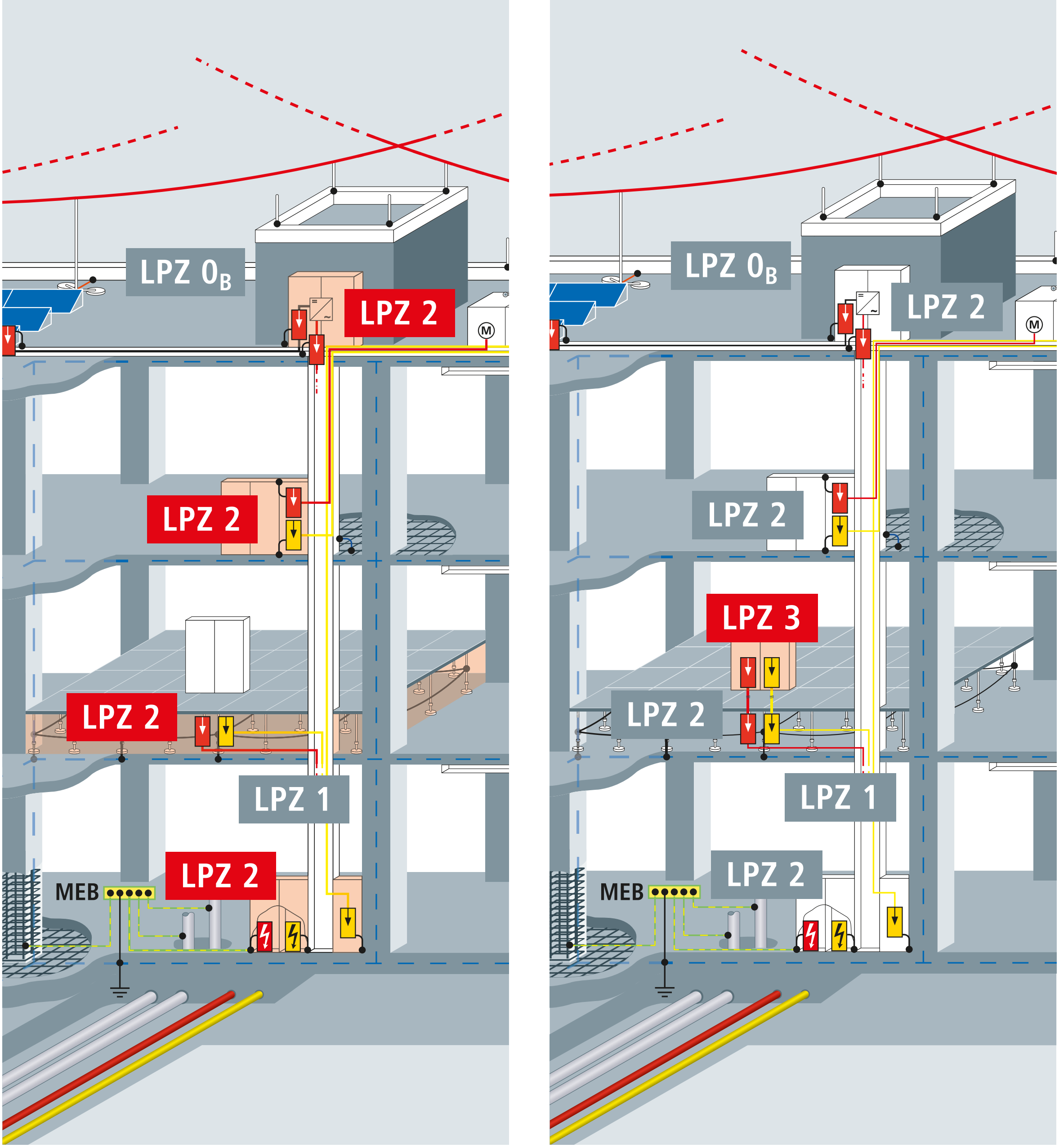


Figure 7.1.2b Lightning protection zone concept according to IEC 62305-4 (EN 62305-4)

lected and centrally evaluated for a comprehensive overall protection system.

Figures 7.1.2a and b show examples of how to implement the measures described for the lightning protection zone concept.

7.2 SPM management

For new structures, optimum protection of electronic systems with a minimum of expenses can only be achieved if the electronic systems are designed together with the building and before its construction. In this way, building components such as the reinforcement, metal girders and metal buttresses can be integrated in the LEMP protection management.

The costs of LEMP protection measures for existing structures are usually higher than those for new structures. If, however, the LPZs are chosen appropriately and existing installations are used or upgraded, costs can be reduced.
If a risk analysis in accordance with IEC 62305-2 (EN 62305-2) shows that LEMP protection measures are required, this can only be achieved if:

- The measures are planned by a lightning protection specialist having sound knowledge of EMC,
- There is close coordination between the building and LEMP experts (e.g. civil and electrical engineers) and
- The management plan according to **Table 7.2.1** (subclause 9.2 of IEC 62305-4 (EN 62305-4)) is observed.

A final risk analysis must prove that the residual risk is less than the tolerable risk.

Step	Aim	Action to be taken by (if relevant)
Initial risk analysis [a]	Assessing the necessity of an LEMP protection measures system. If necessary, an appropriate LEMP Protection Measures System (LPMS) must be chosen based on a risk assessment.	• Lightning protection specialist [b] • Owner
Final risk analysis [a]	The cost/benefit ratio of the protection measures chosen should be optimised again by a risk assessment. The following must be determined: • Lightning protection level (LPL) and lightning parameters • LPZs and their boundaries	• Lightning protection specialist [b] • Owner
Design of the LEMP Protection Measures System (LPMS)	Definition of the LPMS: • Spatial shielding measures • Equipotential bonding networks • Earth-termination systems • Conductor routing and shielding • Shielding of incoming supply lines • SPD system	• Lightning protection specialist [b] • Owner • Architect • Designer of internal systems • Designer of relevant installations
Design of the LPMS	• General drawings and descriptions • Preparation of tender lists • Detailed drawings and schedules for installation	• Engineering office or equivalent
Installation and inspection of the LPMS	• Quality of the installation • Documentation • Possible revision of the detailed drawings	• Lightning protection specialist [b] • Installer of the LPMS • Engineering office • Supervisor
Acceptance of the LPMS	Inspection and documentation of the system	• Independent lightning protection expert [b] • Supervisor
Periodic inspections	Ensuring an appropriate LPMS	• Lightning protection specialist [b] • Supervisor

[a] see IEC 62305-2 (EN 62305-2)
[b] with a broad knowledge of EMC and knowledge of installation practices

Table 7.2.1 SPM management plan for new buildings and for comprehensive changes to the construction or use of buildings according to IEC 62305-4 (EN 62305-4)

7.3 Calculation of the magnetic shield attenuation of building / room shields

Lightning currents and the associated electromagnetic field represent the primary source of interference for devices and installations requiring protection in an object. **Figure 7.3.1** shows the principle of how grid structures work. The calculation bases, which are described in the IEC 62305-4 (EN 62305-4) standard, are based on assumptions and assessments. The complex distribution of the magnetic field inside grid-like shields is determined in a first approximation. The formulas for determining the magnetic field are based on numerical calculations of the magnetic field. The calculation takes into account the magnetic field coupling of each rod in the grid-like shield with all other rods including the simulated lightning channel.

To consider whether the effect of the electromagnetic field of the first stroke or of the subsequent stroke is more critical for the electrical installation to be protected, the calculations must be performed with the maximum value of the current of the first positive stroke ($i_{f/max}$) and of the first negative stroke ($i_{fn/max}$) and with the maximum value of the current of the subsequent strokes ($i_{s/max}$) according to the lightning protection level (LPL) given in Table 3 of the IEC 62305-1 (EN 62305-1) standard.

The shielding effect of grid-like shields in the event of direct lightning strikes can be calculated using the formula shown in **Figures 7.3.2a and b**. This consideration is based on the fact that the lightning current can be injected at any point of the roof.

When calculating the safety distances, the following must be considered in addition to the information provided in the latest IEC 62305-4 (EN 62305-4) standard:

Internal electronic systems may only be installed within a safety volume with a safety distance from the shield of the LPZ. The

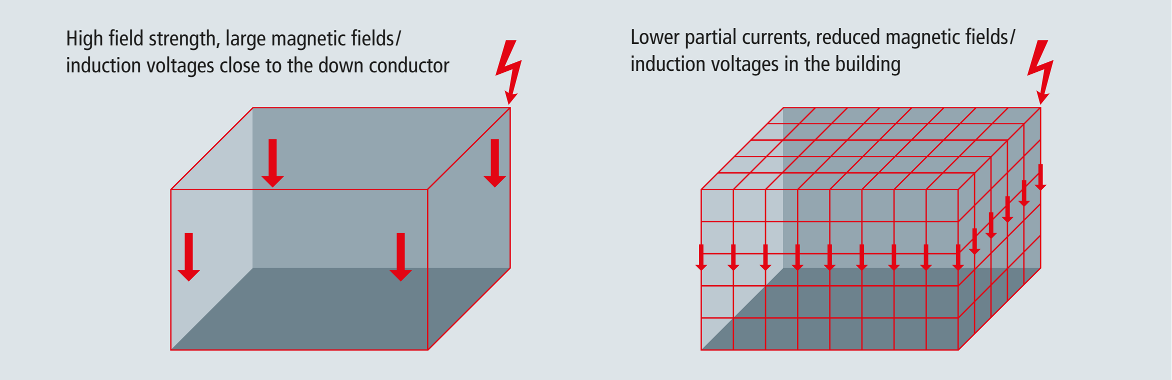
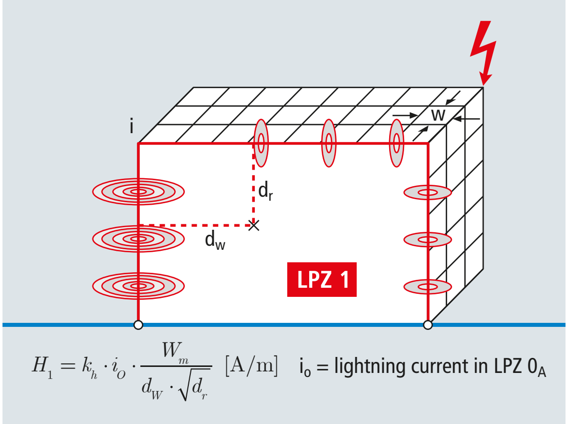


Figure 7.3.1 Reduction of the magnetic field by means of grid-like shields



$$H_1 = k_h \cdot i_O \cdot \frac{W_m}{d_W \cdot \sqrt{d_r}} \quad [\mathrm{A/m}]$$

i_o = lightning current in LPZ 0_A

Figure 7.3.2a Magnetic field in case of a direct lightning strike in LPZ 1 (LEMP), IEC 62305-4 (EN 62305-4)

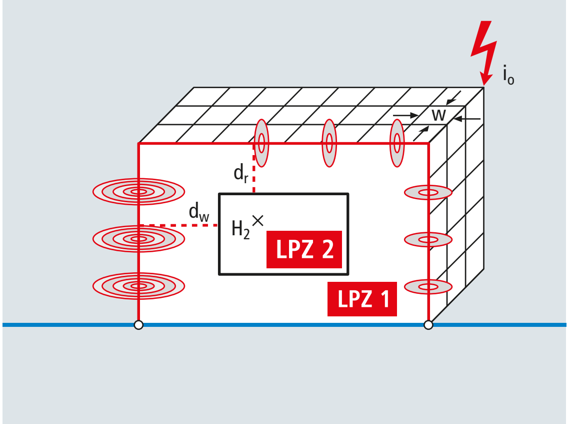


Figure 7.3.2b Magnetic field strength in case of a direct lightning strike in LPZ 2

previous definitions of these safety distances $d_{s/1}$ and $d_{s/2}$ were often incorrectly assigned to LPZ 1 and LPZ 2.

$d_{s/1}$ Safety distance in case of a spatial shield of LPZ 1 if lightning current flows into this spatial shield (The spatial shield of LPZ 1 produces a magnetic field. In this case, no shielding factor can be assigned:

- Only in case of a direct lightning strike (S1) to the shield of LPZ 1.)

$d_{s/2}$ Safety distance in case of spatial shields if no lightning current flows into these spatial shields (the shielding factor defines the attenuation of H_n to H_{n+1}):

- Applies to all spatial shields of LPZ 1 or higher in case of nearby lightning strikes (S2)

or

- Applies to all internal spatial shields of LPZ 2 or higher in case of direct lightning strikes (S1) or nearby lightning strikes.

Therefore, Germany suggested editorial changes for the future revision of the EN 62305-4 lightning protection standard. The following new designations should be used in the future:

- $d_{s/1}$ becomes d_{DF} in case of direct lightning strikes to the shield of LPZ 1;
- $d_{s/2}$ becomes d_{SF} when using the shielding factor SF.

Consequently, the formulas for calculating the safety distances must be adapted accordingly.

Calculation of the magnetic field strength in case of a direct lightning strike

The magnetic field strength H_1 at a certain point in LPZ 1 is calculated as follows:

$$H_1 = \frac{k_h \cdot I_0 \cdot w_m}{\left(d_w \cdot \sqrt{d_r}\right)} \quad \text{in A/m}$$

where

d_r	is the shortest distance between the point considered and the roof of the shielded LPZ 1 in m;
d_w	is the shortest distance between the point considered and the wall of the shielded LPZ 1 in m;
I_0	is the lightning current in LPZ 0_A in A;
k_h	is the configuration factor, typically $k_h = 0.01$ in $1/\sqrt{m}$;
w_m	is the mesh size of the grid-like shield of LPZ 1 in m.

The result of this formula is the maximum value of the magnetic field in LPZ 1 (observe notes 1 and 2):

- Caused by the first positive stroke:

$$H_{1/f/\max} = \frac{k_h \cdot I_{f/\max} \cdot w_m}{\left(d_w \cdot \sqrt{d_r}\right)} \quad \text{in A/m}$$

- Caused by the first negative stroke:

$$H_{1/fn/\max} = \frac{k_h \cdot I_{fn/\max} \cdot w_m}{\left(d_w \cdot \sqrt{d_r}\right)} \quad \text{in A/m}$$

- Caused by the subsequent strokes:

$$H_{1/s/\max} = \frac{k_h \cdot I_{s/\max} \cdot w_m}{\left(d_w \cdot \sqrt{d_r}\right)} \quad \text{in A/m}$$

where

$I_{f/max}$	is the maximum value of the first positive stroke current in accordance with the LPL in A;
$I_{fn/max}$	is the maximum value of the first negative stroke current in accordance with the LPL in A;
$I_{s/max}$	is the maximum value of the subsequent stroke currents in accordance with the LPL in A.

Note: The magnetic field is reduced by a factor of 2 if a meshed equipotential bonding network in accordance with 5.2 of the IEC 62305-4 (EN 62305-4) standard is installed.

These values of the magnetic field are only valid in the safety volume V_s inside the grid-like shield with a safety distance $d_{s/1}$ from the shield (**Figure 7.3.3**):

$$d_{s/1} = \frac{w_m \cdot SF}{10} \quad \text{for SF} \geq 10 \text{ in m}$$

$$d_{s/1} = w_m \quad \text{for SF} < 10 \text{ in m}$$

where

SF	is the shielding factor in dB determined using the equations in **Table 7.3.1**;
w_m	is the mesh size of the grid-like shield in m.

Note: Experimental results of the magnetic field inside a grid-like shield around LPZ 1 show that the magnetic field strength close to the shield is less than that resulting from the equations above.

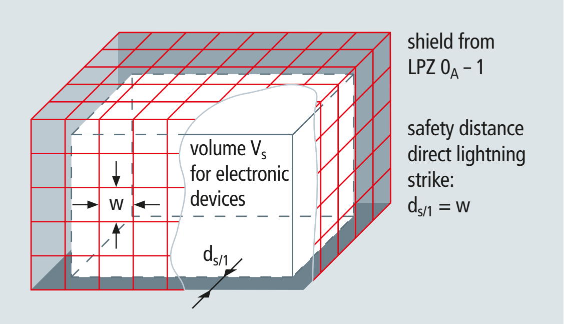


Figure 7.3.3 Volume for electronic devices in LPZ 1

Determination of the magnetic field in case of a nearby lightning strike

The incident magnetic field H_0 is calculated as follows:

$$H_0 = \frac{I_0}{\left(2 \cdot \pi \cdot s_a\right)} \quad \text{in A/m}$$

where

I_0	is the lightning current in LPZ 0_A in A;
s_a	is the distance between the point of strike and the centre of the shielded volume in m.

From this follows for the maximum value of the magnetic field in LPZ 0:

Material	Shielding factor SF (dB)	
	25 kHz (first stroke)	1 MHz (subsequent stroke)
Copper or aluminium	$20 \cdot \log (8.5/w_m)$	$20 \cdot \log (8.5/w_m)$
Steel	$20 \cdot \log \frac{(8.5 / w_m)}{\sqrt{1 + 18 \cdot 10^{-6} / r_c^2}}$	$20 \cdot \log (8.5/w_m)$
w_m = mesh size [m] ($w_m \leq 5$ m); r_c = rod radius [m]; $\mu_r \approx 200$ (permeability)		

Example: Steel grid

w_m (m)	r (m)	dB at 25 kHz	dB at 1 Mhz
0.012	0.0010	44	57
0.100	0.0060	37	39
0.200	0.0090	32	33
0.400	0.0125	26	27

Table 7.3.1 Magnetic attenuation of grids in case of a nearby lightning strike according to IEC 62305-4 (EN 62305-4)

- ➡ Caused by the first positive stroke:

$$H_{0/f/\max} = \frac{I_{f/\max}}{\left(2 \cdot \pi \cdot s_a\right)} \quad \text{in A/m}$$

- ➡ Caused by the first negative stroke:

$$H_{0/fn/\max} = \frac{I_{fn/\max}}{\left(2 \cdot \pi \cdot s_a\right)} \quad \text{in A/m}$$

- ➡ Caused by the subsequent strokes:

$$H_{0/s/\max} = \frac{I_{s/\max}}{\left(2 \cdot \pi \cdot s_a\right)} \quad \text{in A/m}$$

where

$I_{f/max}$	is the maximum value of the first positive stroke current in accordance with the LPL in A;
$I_{fn/max}$	is the maximum value of the first negative stroke current in accordance with the LPL in A;
$I_{s/max}$	is the maximum value of the subsequent stroke currents in accordance with the LPL in A.

The reduction of H_0 to H_1 inside LPZ 1 can be derived using the SF values given in **Table 7.3.1**:

$$H_{1/\max} = \frac{H_{0/\max}}{10^{SF/20}} \quad \text{in A/m}$$

where

SF	is the shielding factor determined using the equations in **Table 7.3.1** in dB;
H_0	is the magnetic field in LPZ 0 in A/m.

From this follows for the maximum value of the magnetic field in LPZ 1:

- ➡ Caused by the first positive stroke:

$$H_{1/f/\max} = \frac{H_{0/f/\max}}{10^{SF/20}} \quad \text{in A/m}$$

- ➡ Caused by the first negative stroke:

$$H_{1/fn/\max} = \frac{H_{0/fn/\max}}{10^{SF/20}} \quad \text{in A/m}$$

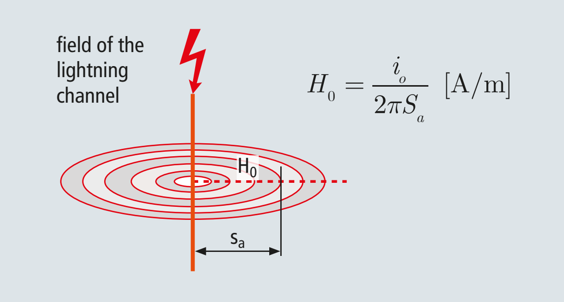


Figure 7.3.4 Magnetic field in case of a nearby lightning strike (LEMP), IEC 62305-4 (EN 62305-4)

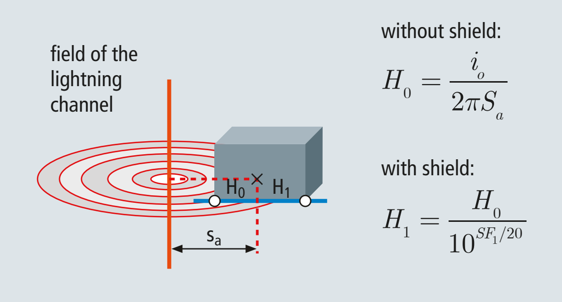


Figure 7.3.5 Magnetic field in case of a nearby lightning strike (LEMP), IEC 62305-4 (EN 62305-4)

➡ Caused by the subsequent strokes:

$$H_{1/s/\max} = \frac{H_{0/s/\max}}{10^{SF/20}} \quad \text{in A/m}$$

These magnetic field values are only valid for a safety volume V_s inside the grid-like shield with a safety distance $d_{s/2}$ from the shield (**Figure 7.3.3**).

$$d_{s/2} = w_m^{SF/20} \quad \text{for SF} \geq 10 \text{ in m}$$

$$d_{s/2} = w_m \quad \text{for SF} < 10 \text{ in m}$$

where

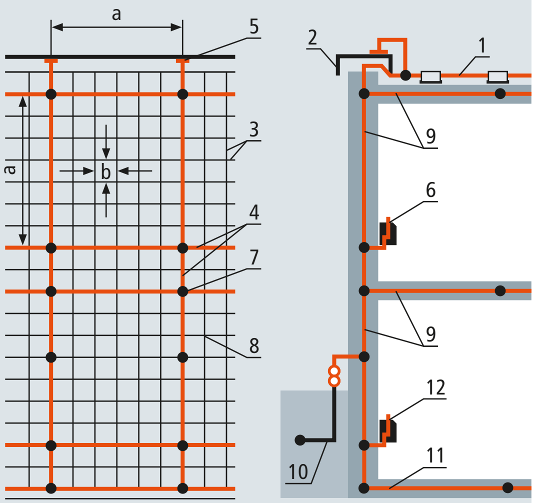
SF is the shielding factor determined using the equations in **Table 7.3.1** in dB;

w_m is the mesh size of the grid-like shield in m.

For more detailed information on the calculation of the magnetic field strength inside grid-like shields in case of nearby lightning strikes, see A.4.3 of the IEC 62305-4 (EN 62305-4) standard.

The values calculated for the magnetic field are valid for the safety volume V_s inside grid-like shields, which are defined by the safety distance $d_{s/\dots}$ (**Figure 7.3.3**).
This safety volume takes into account the maximum values of the magnetic field strength directly at the grid structure which are insufficiently considered in the approximation formula. Information technology devices may only be installed in this volume V_s.

The calculation basis for the shielding effect of grid-like shields in case of nearby lightning strikes is described in **Figures 7.3.4 and 7.3.5**.
Figure 7.3.4 shows the formation of an electromagnetic field in the form of a plane wave whose reduction of the field



1 Conductor of the air-termination system
2 Metal capping of the roof parapet
3 Steel reinforcing rods
4 Meshed grid superimposed on the reinforcement
5 Connection to the grid
6 Connection for internal equipotential bonding bar
7 Connection by welding or clamping
8 Any connection
9 Steel reinforcement in concrete (with superimposed meshed grid)
10 Ring earth electrode (if any)
11 Foundation earth electrode
a Typical distance of 5 m in the superimposed meshed grid
b Typical distance of 1 m for connecting this grid to the reinforcement
(typical dimensions: a ≤ 5 m, b ≤ 1 m)

Figure 7.3.6 Use of the reinforcing rods of a structure for shielding and equipotential bonding

Figure 7.3.7a Galvanised reinforcement mats for shielding the building

Figure 7.3.7b Use of galvanised reinforcement mats for shielding, e.g. in case of planted roofs

strength is indirectly proportional to the distance s_a. The magnitude of the magnetic field inside a volume to be protected e.g. LPZ 1 (**Figure 7.3.5**) can be described by the shielding quality.

Implementation of the magnetic shield attenuation of building / room shields

Extended metal components such as metal roofs and façades, steel reinforcements in concrete, expanded metals in walls, grids, metal supporting structures and pipe systems existing in the building are particularly important when shielding against magnetic fields and thus for the installation of lightning protection zones. A meshed interconnection creates an effective electromagnetic shield.

Figure 7.3.6 shows the principle of how a steel reinforcement can be developed into an electromagnetic cage (hole shield). In practice, however, it is not possible to weld or stick together every junction in large structures. The usual practice is to install a meshed system of conductors into the reinforcement, said system typically having a size of a ≤ 5 m. This meshed network is connected in an electrically safe way at the cross points, e.g. by means of clamps. The reinforcement is "electrically hitched" onto the meshed network at a typical distance of b ≤ 1 m. This is done on site, for example by means of tie connections.

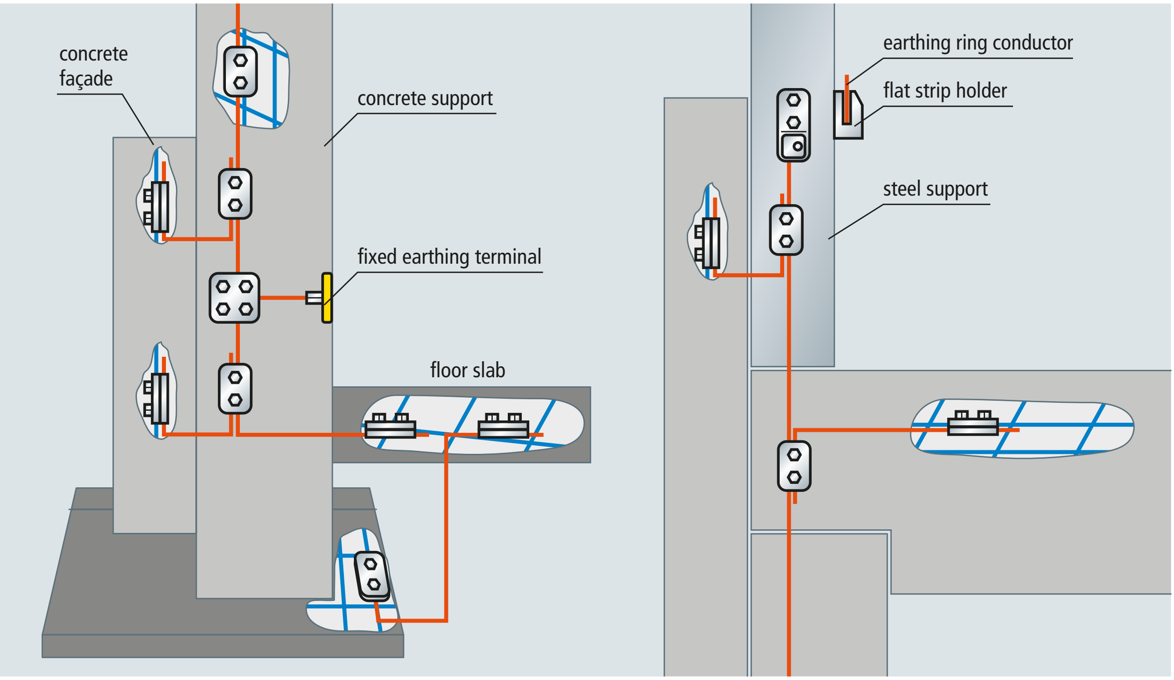


Figure 7.3.8 Shielding of a building

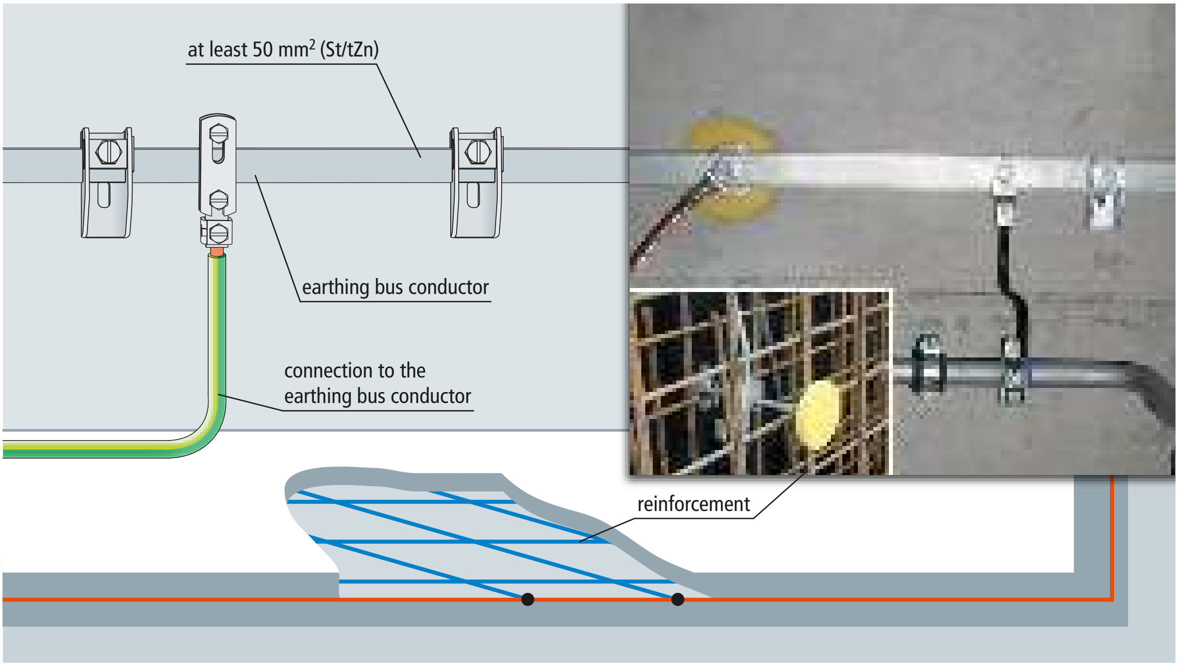


Figure 7.3.9 Earthing bus conductor / ring equipotential bonding

Reinforcement mats in concrete are suitable for shielding purposes. When upgrading existing installations, such reinforcement mats are also laid at a later date. For this type of design, the reinforcement mats must be galvanised to protect them from corrosion. These galvanised reinforcement mats are, for example, laid on roofs so that they overlap or are applied either externally or internally to the exterior wall to provide shielding for the building.

Figures 7.3.7a and b show the subsequent installation of galvanised reinforcement mats on the roof of a building.

To bridge expansion joints, connect the reinforcement of precast concrete components and for connection to the external earth-termination system or the internal equipotential bonding system, the building must already be equipped with a sufficient number of fixed earthing terminals.

Figure 7.3.8 shows such an installation, which must be taken into consideration for designing the preliminary building works.

The magnetic field inside the structure is reduced over a wide frequency range by means of reduction loops, which arise as a result of the meshed equipotential bonding network. Typical mesh sizes are a ≤ 5 m.

The interconnection of all metal components both inside and on the structures results in a three-dimensional meshed equipotential bonding network. **Figure 7.3.9** shows a meshed equipotential bonding network with appropriate connections.

If an equipotential bonding network is installed in the lightning protection zones, the magnetic field calculated according to the formulas given above is typically further reduced by a factor of 2 (corresponds to 6 dB).

7.3.1 Cable shielding

Cable shields are used to reduce the effect of the interference on the active cores and the interference emitted from the active cores to neighbouring systems. From a lightning and surge protection point of view, attention must be paid to the following applications of shielded lines:

No shield earthing

Some installation systems recommend a shielded cable, but, at the same time, forbid shield earthing (e.g. KNX). If there is no shielding connection, the shield is not effective against interferences and must therefore be thought of as being not there (**Figure 7.3.1.1**).

Double-ended shield earthing

A cable shield must be continuously connected along the whole of its length for good conducting performance and earthed at least at both ends. Only a shield used at both ends can reduce inductive and capacitive coupling (**Figure 7.3.1.2**).

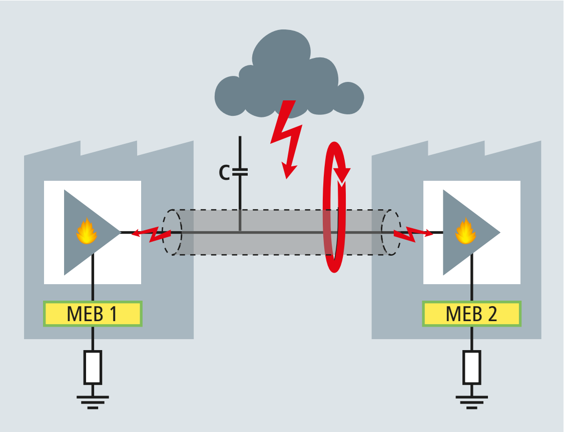


Figure 7.3.1.1 No shield connection – No shielding from capacitive / inductive coupling

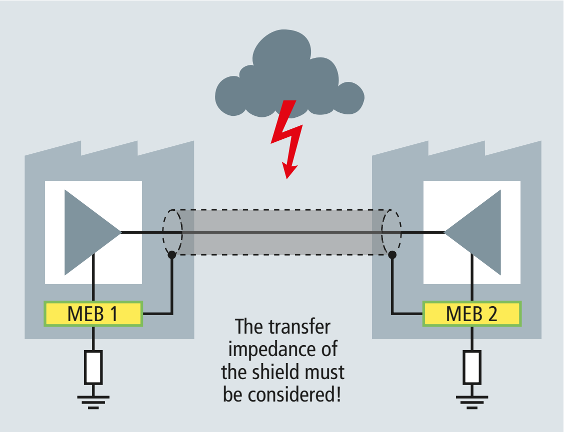


Figure 7.3.1.2 Shield connection at both ends – Shielding from capacitive / inductive coupling

Cable shields entering a building must have a certain minimum cross-section to avoid the risk of dangerous sparking. If this is not the case, the shields are not capable of carrying lightning currents.

The minimum cross-section of a cable shield (S_{cmin}) laid insulated to earth or air depends on its shield resistivity (ρ_c) (**Table 7.3.1.1**), the lightning current flowing (I_f), the impulse withstand voltage of the system (U_w) and the cable length (L_c):

$$S_{cmin} = \frac{I_f \cdot \rho_c \cdot L_c \cdot 10^6}{U_w} \, [mm^2]$$

I_f can be calculated in accordance with IEC 62305-1 (EN 62305-1). Since the shield connection system is typically tested with lightning currents up to 10 kA (10/350 µs), this value, as a first approximation, can be used as maximum value. U_w can be interpreted in many different ways. If the cable shield is removed at the entrance point into the building far away from the internal system, the impulse withstand voltage strength of the cable is decisive. If, however, the cable shield is not interrupted up to the terminal device, the dielectric strength of the terminal device must be observed (**Table 7.3.1.2**).

The difference can be seen in the following two examples:

- Telecommunication cable shield up to the entrance point into the building, Al, stressed with 10 kA, length of 100 m, dielectric strength of 5 kV.
  - $S_{cmin} \approx 6$ mm^2
  - It must also be observed that the shield connection to the MEB must be capable of carrying lightning currents.
- Bus cable shield up to the terminal device, Cu, stressed with 5 kA, length of 100 m, dielectric strength of 0.5 kV
  - $S_{cmin} \approx 17$ mm^2
  - Such cable shields for bus cables, however, are not feasible in practice. Therefore, the cable described is not capable of carrying lightning currents.

Indirect single-ended shield earthing

For operational reasons, cable shields are sometimes earthed at only one end. While this provides a certain attenuation from capacitive interference fields, it does not provide any protection against the electromagnetic induction arising with lightning strikes. The reason for single-ended shield earthing is the fear of low-frequency equalising currents. In extended installations, a bus cable, for example, can often stretch many hundreds of

Shield material	ρ_c in Ωm
Copper	$17.241 \cdot 10^{-9}$
Aluminium	$28.264 \cdot 10^{-9}$
Lead	$214 \cdot 10^{-9}$
Steel	$138 \cdot 10^{-9}$

Table 7.3.1.1 Shield resistivity ρ_c for different materials

Examples	Dielectric strength
Low-voltage cable	15 kV
Telecommunication cable	5 kV
Subscriber side	1.5 kV
Measuring and control system	0.5 – 1 kV

Table 7.3.1.2 Dielectric strength

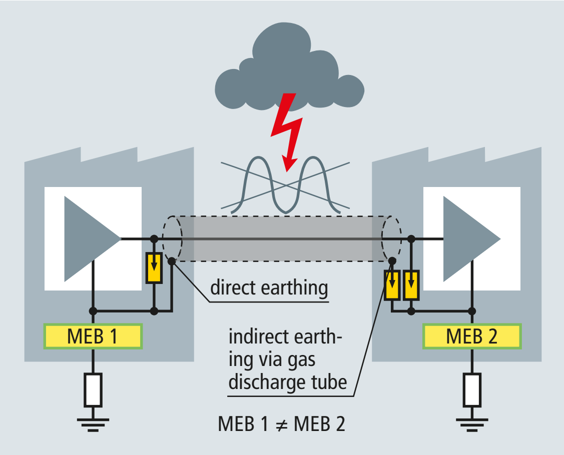


Figure 7.3.1.3 Shield connection at both ends – Solution: Direct and indirect shield earthing

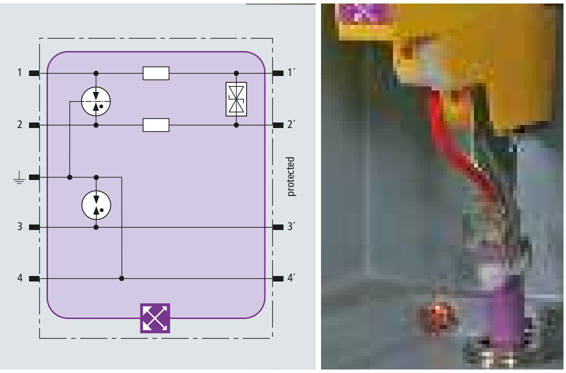


Figure 7.3.1.4 BLITZDUCTOR XT with SAK BXT LR shield terminal with direct or indirect shield earthing

metres between buildings. Especially with older installations, it can happen that one part of the earth-termination systems is no longer in operation or that no meshed equipotential bonding network is installed. In such cases, interferences can occur as a result of multiple shield earthing. Potential differences of the different earth-termination systems of the building can allow low-frequency equalising currents (n x 50 Hz) and the transients superimposed thereon to flow. At the same time, currents measuring up to a few amperes are possible which, in extreme cases, can cause cable fires. In addition, crosstalk can cause signal interference if the signal frequency is in a similar frequency range to the interference signal.

The aim is to implement the EMC requirements and prevent equalising currents. This can be achieved by combining direct single-ended and indirect shield earthing. All shields are directly connected with the local equipotential bonding system at a central point such as the control room. At the far ends of the cable, the shields are indirectly connected to the earth potential via isolating spark gaps. Since the resistance of a spark gap is around 10 GΩ, equalising currents are prevented during surge-free operation. If EMC interference such as lightning strikes occurs, the spark gap ignites and discharges the interference impulse without destruction. This reduces the residual impulse on the active cable cores and the terminal devices are subject to even less stress. The two-pole BLITZDUCTOR XT arrester allows direct or indirect shield earthing. A gas discharge tube, which eliminates interference impulses via the cable shield, can be installed at one side between the cable shield and the equipotential bonding system for indirect shield earthing (**Figure 7.3.1.3**). Thanks to the combination of a lightning current carrying SAK BXT LR shield terminal and BLITZDUCTOR XT, the coding at the terminal connection allows to change between direct and indirect shield earthing (**Figure 7.3.1.4**).

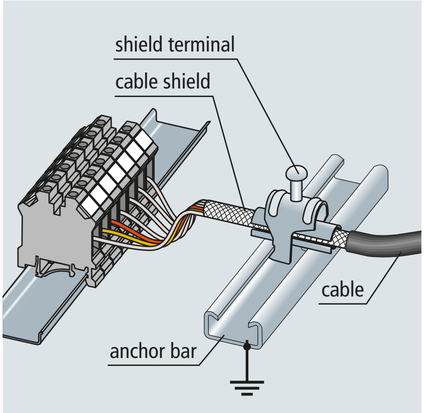


Figure 7.3.1.5 Shield connection

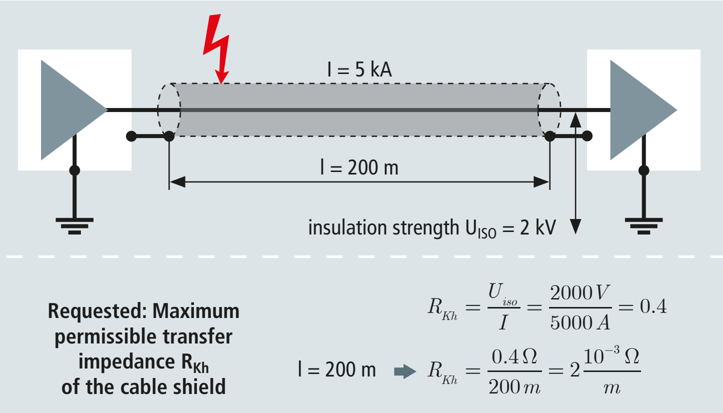


Figure 7.3.1.6 Shield connection at both ends – Shielding from capacitive / inductive coupling

Low-impedance shield earthing

Cable shields can conduct impulse currents of up to several kA. During the discharge, the impulse currents flow through the shield and the shield terminal to earth. The impedance of the cable shield and the shield terminal create voltage differences between the shield potential and earth. In such a case, voltages of up to some kV can develop and destroy the insulation of conductors or connected devices. Coarse-meshed shields and twisting of the cable shield (pig tail) for connection in a terminal block are particularly critical. The quality of the cable shield used affects the number of shield earthings required. Under certain circumstances, earthing is required every 10 metres in order to achieve a sufficient shielding effect. Suitable large-area contact terminals with slipping spring elements are recommended for shield connection. This is important to compensate the yield of the plastic insulation of the conductors (**Figure 7.3.1.5**).

Maximum length of shielded cables

Cable shields have a so-called transfer impedance, which roughly corresponds to the d.c. resistance specified by the cable manufacturer. An interference impulse flowing through the resistance creates a voltage drop on the cable shield. The permissible transfer impedance for the cable shield can be determined depending on the dielectric strength of the terminal device and the cable as well as the cable length. It is crucial that the voltage drop is lower than the insulation strength of the system (**Figure 7.3.1.6**). If this is not the case, arresters must be used.

Extension of LPZs with the help of shielded cables

According to IEC 62305-4 (EN 62305-4), no arresters have to be installed if a shielded cable is used between two identical LPZs. This applies to interferences to be expected from the surroundings of the shielded cable (e.g. electromagnetic fields) and for meshed equipotential bonding conforming to the standard. However, it must be observed that hazards can still arise depending on the installation conditions and arresters may be required. Typical potential hazards are: the supply of terminal devices from different main low-voltage distribution boards, TN-C systems, high transfer impedances of the cable shields or insufficient earthing of the shield. Caution must be exercised in case of cables with poorly covered shields, which are often used for economic reasons. This leads to residual interferences on the signal cores. Such interferences can be controlled by using a high-quality shielded cable or surge protective devices.

7.4 Equipotential bonding network

The main function of the equipotential bonding network is to prevent hazardous potential differences between all devices / installations in the inner LPZs and to reduce the magnetic field of the lightning strike. The low-inductance equipotential bonding network required is achieved by multiply interconnecting all metal components by means of equipotential bonding conductors inside the LPZ of the structure. This creates a three-dimensional meshed network (**Figure 7.4.1**). Typical components of the network are:

- All metal installations (e.g. pipes, boilers)
- Reinforcements in the concrete (in floors, walls and ceilings)
- Gratings (e.g. intermediate floors)
- Cable ducts

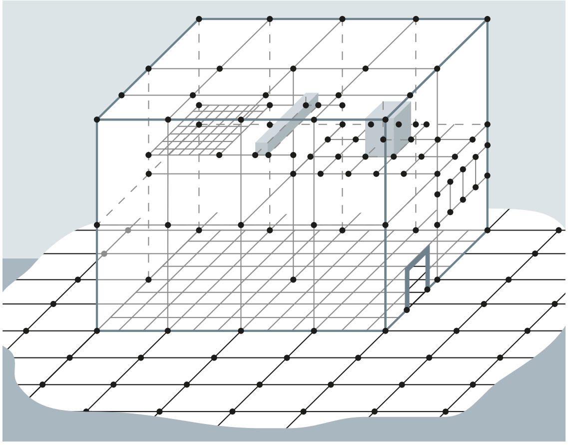


Figure 7.4.1 Equipotential bonding network in a structure

Figure 7.4.2 Ring equipotential bonding bar in a computer room

- Ventilation ducts
- Lift rails
- Metal floors
- Supply lines

A grid structure of the equipotential bonding network of around 5 m x 5 m would be ideal. This typically reduces the electromagnetic lightning field inside an LPZ by a factor of 2 (corresponding to 6 dB).

Enclosures and racks of electronic devices and systems should be integrated in the equipotential bonding network by means of short connections. To this end, a sufficient number of equipotential bonding bars and/or ring equipotential bonding bars (**Figure 7.4.2**) must be provided in the structure. These bars must be connected to the equipotential bonding network (**Figure 7.4.3**).

Protective conductors (PE) and cable shields of the data lines of electronic devices and systems must be integrated in the equipotential bonding network according to the instructions of the system manufacturer. Meshed or star configuration is possible (**Figure 7.4.4**).

Note: The equipotential bonding network according to IEC 62305-4 (EN 62305-4) described above, which reduces dangerous potential differences in the inner LPZs, also integrates the meshed equipotential bonding system according to IEC 60364-4-44 (HD 60364-4-444) in the structure. SPDs at the zone boundaries are connected to this equipotential bonding structure along the shortest possible route.

Figure 7.4.3 Connection of the ring equipotential bonding bar to the equipotential bonding network via a fixed earthing terminal

When using a star configuration S, all metal components of the electronic system must be adequately insulated against the equipotential bonding network. A star configuration is therefore mostly limited to applications in small, locally confined systems. In such cases, all lines must enter the structure or a room within the structure at a single point. The star configuration S may be connected to the equipotential bonding network at a single earthing reference point (ERP) only. This results in the configuration S_S.

When using the meshed configuration M, the metal components of the electronic system do not have to be insulated against the equipotential bonding network. All metal compo-

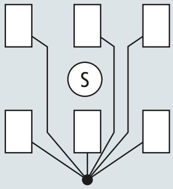
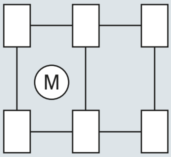
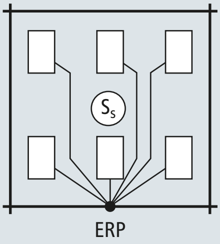
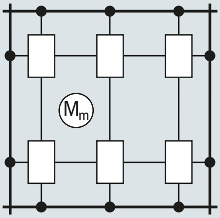
	Star configuration S	Meshed configuration M	Key for Figure 7.4.4 and 7.4.5
Basic configuration			━ Equipotential bonding network — Equipotential bonding conductor ▭ Equipment ● Connection point to the equipotential bonding network ERP Earthing reference point S_s Star configuration integrated by star point M_m Meshed configuration integrated by mesh M_s Meshed configuration integrated by star point
Integration in the equipotential bonding network			

Figure 7.4.4 Integration of electronic systems in the equipotential bonding network according to IEC 62305-4 (EN 62305-4)

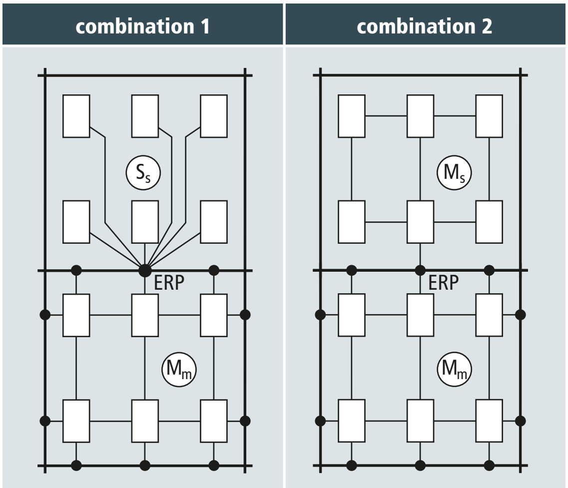


Figure 7.4.5 Combination of the integration methods according to Figure 7.4.4: Integration in the equipotential bonding network according to IEC 62305-4 (EN 62305-4)

nents should be integrated in the equipotential bonding network at as many equipotential bonding points as possible. The resulting configuration M_m is used for extended and open systems with many lines between the individual devices. A further advantage of this configuration is the fact that the lines of the system can enter a structure or room at different points.

Star and meshed configurations can also be combined in complex electronic systems (**Figure 7.4.5**) in order to profit from the advantages of both configurations.

7.5 Equipotential bonding at the boundary of LPZ 0_A and LPZ 1

7.5.1 Equipotential bonding for metal installations

Measures must be taken at the boundary between the EMC lightning protection zones to reduce the radiated electromagnetic field and all metal and electrical lines / systems passing through the boundary must be integrated in the equipotential bonding system without exception. This requirement on the equipotential bonding basically corresponds to that on the protective equipotential bonding in accordance with IEC 60364-4-41 (HD 60364-4-41), IEC 60364-5-54 (HD 60364-5-54) and IEC 60364-5-54 (HD 60364-5-54).

In addition to protective equipotential bonding, lightning equipotential bonding must be implemented for electrical and electronic lines (see also chapter 7.5.2) at this zone boundary. This equipotential bonding must be implemented as close as possible to the points where the lines and metal installations enter the structure. The lines should be kept as short as possible (low impedance).

The minimum cross-sections listed in **Table 7.5.1** for connecting the equipotential bonding bar to the earth-termination system, interconnecting the different equipotential bonding bars and connecting the metal installations to the equipotential bonding bar must be taken into account for equipotential bonding.

The following metal installations must be incorporated into the equipotential bonding system:

- Metal cable ducts
- Shielded cables and lines
- Building reinforcement
- Metal water supply pipes
- Metal conduits for lines
- Other metal pipe systems or conductive parts (e.g. compressed air)

A corrosion-free earth connection can be easily established by fixed earthing terminals. In this process, the reinforcement can be connected to the equipotential bonding system at the same time. **Figure 7.5.1.1** shows the connection of the equipoten-

Material	Cross-section
Cu	16 mm^2
Al	25 mm^2
Fe	50 mm^2

Table 7.5.1 Minimum cross-sections according to IEC 62305-3 (EN 62305-3), Table 8

Figure 7.5.1.1 Connection of the EBB to the fixed earthing terminal

tial bonding bar to the fixed earthing terminal and the connection of pipes to the equipotential bonding system.
The integration of cable shields in the equipotential bonding system is described in chapter 7.3.

7.5.2 Equipotential bonding for power supply systems

As is the case with metal installations, all electrical power and data lines entering the building (transition from LPZ 0_A to LPZ 1) must be integrated in the equipotential bonding system. While the equipotential bonding for data lines is described in section 7.5.3, the equipotential bonding for electrical power lines will be described in the this section. The boundaries for the equipotential bonding system at the transition from LPZ 0_A to LPZ 1 are defined with the help of the specific design of the object requiring protection. For installations supplied by low-voltage systems, the boundary LPZ 0_A / LPZ 1 is mostly assumed to be the boundary of the building (**Figure 7.5.2.1**).

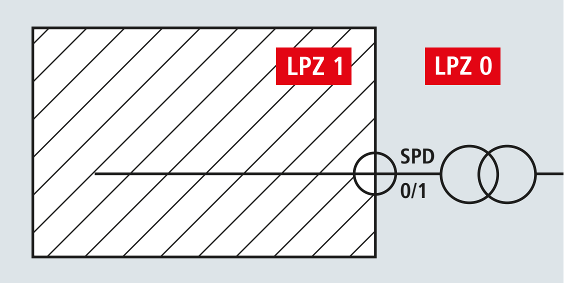


Figure 7.5.2.1 Transformer outside the structure

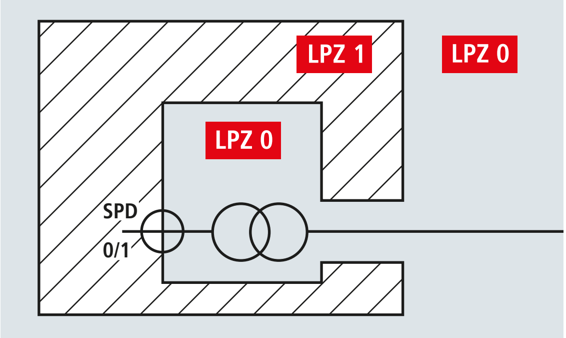
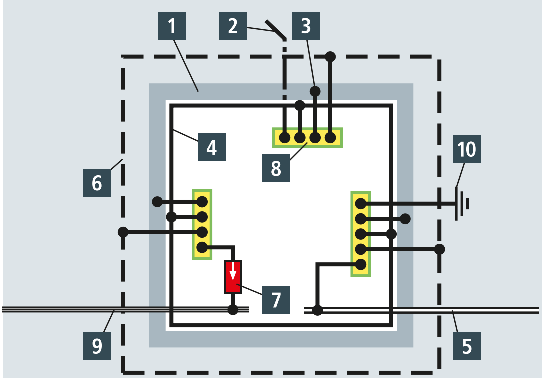


Figure 7.5.2.2 Transformer inside the structure (LPZ 0 integrated in LPZ 1)



1	Reinforcement of the outer walls and the foundation
2	Other earth electrodes, e.g. intermeshing to neighbouring buildings
3	Connection to the reinforcement
4	Internal (potential) ring conductor
5	Connection to external conductive parts, e.g. water pipe
6	Type B earth electrode, ring earth electrode
7	Surge protective device (SPD)
8	Equipotential bonding bar
9	Electrical power or information technology line
10	Connection to additional earth electrodes, type A earth electrodes

Figure 7.5.2.3 Example of an equipotential bonding system in a structure with several entries for the external conductive parts and with an inner ring conductor connecting the equipotential bonding bars

Lightning protection level (previously: class of LPS)	**Lightning impulse current carrying capability**		
	In TN systems	In TN systems (L–N)	In TT systems (N–PE)
I	≥ 100 kA/m	≥ 100 kA/m	≥ 100 kA
II	≥ 75 kA/m	≥ 75 kA/m	≥ 75 kA
III / IV	≥ 50 kA/m	≥ 50 kA/m	≥ 50 kA
m: number of conductors, e.g. m = 5 in case of L1, L2, L3, N and PE			

Table 7.5.2.1 Required lightning impulse current carrying capability of type 1 surge protective devices depending on the lightning protection level and the type of low-voltage consumer's installation (see also German VDN guideline "Surge Protective Devices Type 1 – Guideline for the use of surge protective devices (SPDs) Type 1 in main power supply systems" and IEC 60364-5-53 (HD 60364-5-534))

For objects which are directly supplied by the medium-voltage system, LPZ 0_A is extended up to the secondary side of the transformer. Lightning equipotential bonding is implemented on the 230/400 V side of the transformer (**Figure 7.5.2.2**).

To avoid damage to the transformer, it is recommended to additionally use surge protective devices on the high-voltage side of the transformer.

Additional shielding measures for the incoming medium-voltage line prevent partial lightning currents in LPZ 0 from flowing into parts of the installation / systems in LPZ 1.

To prevent equalising currents between the various equipotential bonding points in an electrical installation, it is recommended to implement lightning equipotential bonding of all incoming metal lines and electrical power and data lines

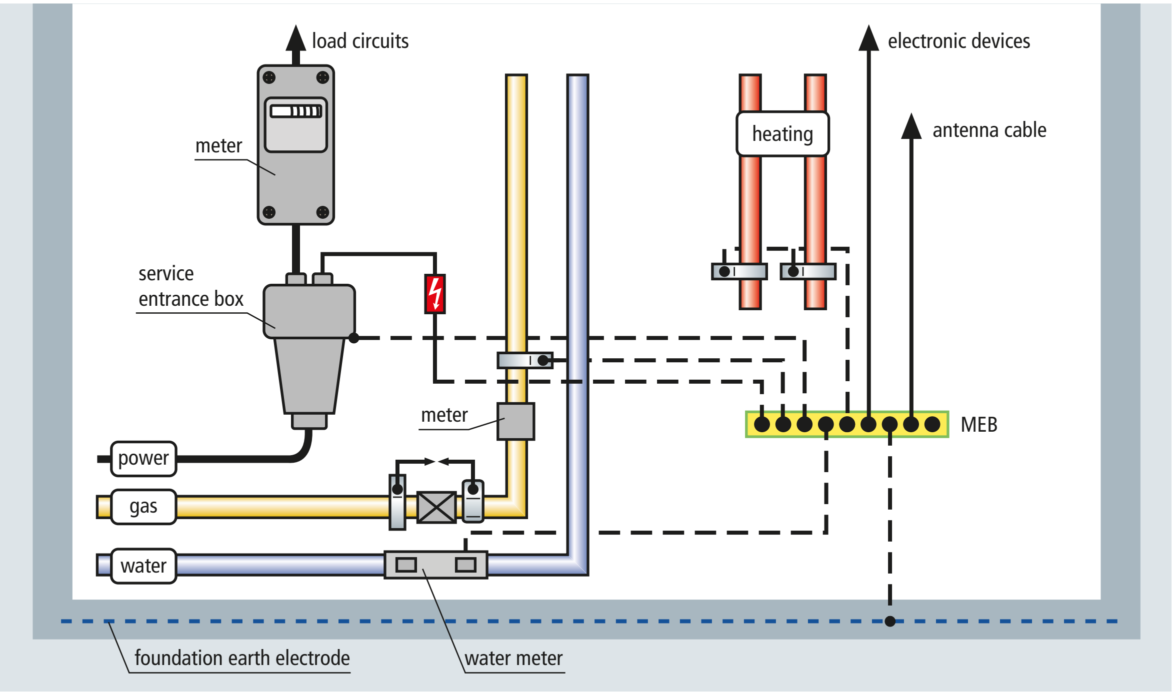


Figure 7.5.2.4 Internal lightning protection with a common entry point for all supply lines

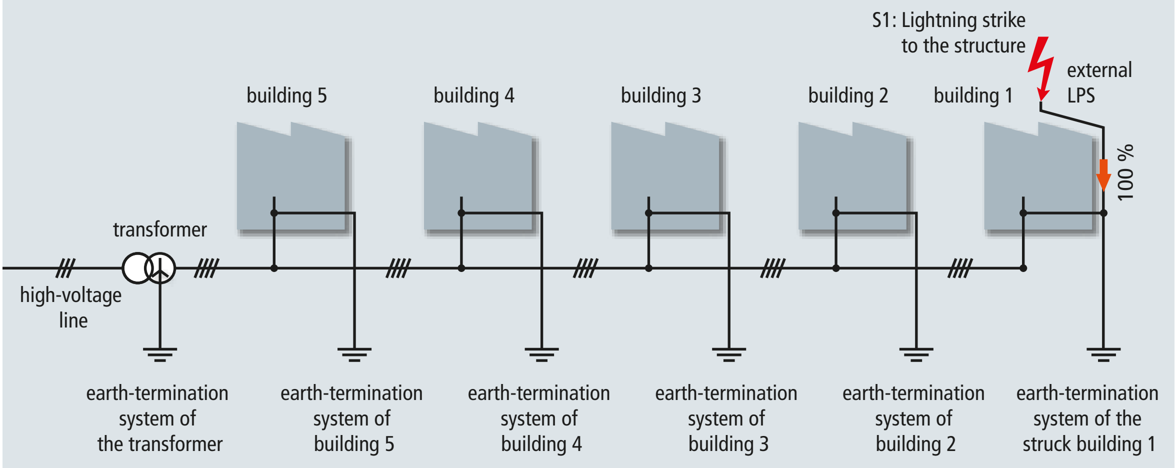


Figure 7.5.2.5 Model of the lightning current distribution in case of several parallel load systems – String topology

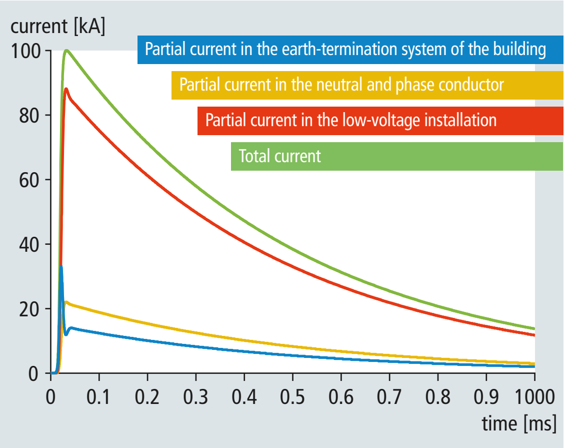


Figure 7.5.2.6 Model of the lightning current distribution in case of several parallel load systems – String topology

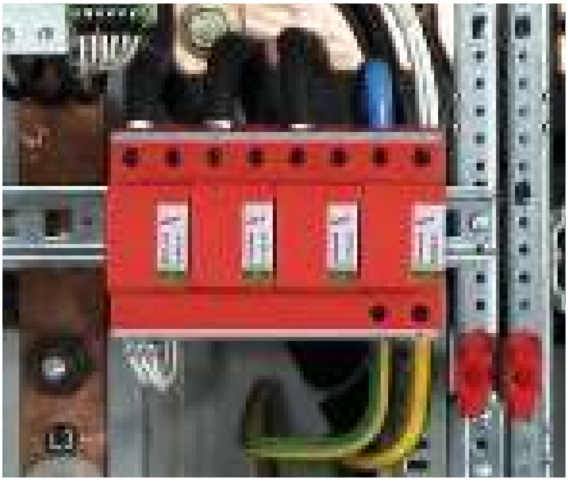


Figure 7.5.2.7 DEHNventil combined arrester

centrally at one point. If this is not possible due to local conditions, it is recommended to use a ring equipotential bonding bar (**Figures 7.5.2.3 and 7.5.2.4**).

The discharge capacity of the lightning current arrester used (type 1 SPD) must correspond to the stress at the place of installation based on the lightning protection level defined for the object. The lightning protection level appropriate for the relevant structure must be chosen based on a risk assessment. If no risk assessment is available or if it is not possible to provide detailed information on the lightning current distribution at the transition from LPZ 0_A to LPZ 1, it is advisable to use the class of LPS with the highest requirements (lightning protection level I) as a basis. The resulting lightning current stress on the individual discharge paths is shown in **Table 7.5.2.1**. In this context, it is assumed that the total current (e.g. 150 kA in case of LPL II) is evenly distributed between the earth-termination system of the relevant building and the number of conductors (m) of the type 1 SPDs used in the low-voltage system. Therefore, the minimum lightning current carrying capability of a type 1 SPD is 75 kA/m in case of e.g. LPL II.

Supplement 1 of the German DIN EN 62305-4 standard additionally describes the lightning current distribution depending on the different installation conditions. In case of several parallel load systems, for example, the stress on the building hit by lightning is increased. **Figure 7.5.2.5** shows that the resulting earth resistance of the low-voltage system (consisting of several adjoining buildings and the transformer) is low compared to the single earth resistance of the building hit by lightning. **Figure 7.5.2.6** shows that the current is not evenly distributed between the low-voltage installation and earth-termination system. The type 1 SPDs in the low-voltage system must discharge a considerably larger amount of current in the relevant building compared to the earth-termination system.

Figure 7.5.2.8 Lightning equipotential bonding for power supply and information technology systems situated centrally at one point

However, Supplement 1 of the German DIN EN 62305-4 standard confirms that adequately dimensioned type 1 SPDs (tested with 10/350 μs wave form) also reliably protect the low-voltage installation from direct lightning strikes in case of different applications and lightning threat scenarios.

Figure 7.5.2.9 Lightning current arrester at the transition from LPZ 0_A to LPZ 1

When installing lightning current arresters at the transition from LPZ 0_A to LPZ 1, it must also be observed that the recommended place of installation at the service entrance box can frequently only be implemented in agreement with the utility (new: distribution network operators). The requirements on lightning current arresters in main power supply systems are laid down in the guideline by the VDN (Association of German Network Operators) 2004-08: "Überspannungs-Schutzeinrichtungen Typ 1. Richtlinie für den Einsatz von Überspannungs-Schutzeinrichtungen (ÜSE) Typ 1 in Hauptstromversorgungssystemen" [Surge Protective Devices Type 1 – Guideline for the use of surge protective devices (SPDs) Type 1 in main power supply systems] and IEC 60364-5-53 (HD 60364-5-534) (**Figures 7.5.2.7 to 7.5.2.9**).

7.5.3 Equipotential bonding for information technology systems

LPZ 0_A – LPZ 1

Lightning equipotential bonding from LPZ 0_A to LPZ 1 must be implemented for all metal systems entering a building. Information technology lines must be protected by lightning current arresters with an adequate discharge capacity as close as possible to their entry point into the structure. A general discharge capacity up to 2.5 kA (10/350 μs) per core of information technology lines is required for the transition from LPZ 0_A to LPZ 1. However, this general approach is not used when rating the discharge capacity for installations with multiple information technology lines. After calculating the partial lightning current to be expected for an information technology cable (see IEC 62305-1 (EN 62305-1)), the lightning current must be divided by the number of single cores in the cable in order to determine the impulse current per core. The partial lightning current stress per core is lower in case of multi-core cables than in case of cables with some few single cores. For further information please see chapter 6.3.

Therefore, only surge protective devices for which a discharge current (10/350 μs) is specified may be used (**Figure 7.5.3.1**).

If equipotential bonding is established for lines at the transition from LPZ 0_B to LPZ 1, surge protective devices with an impulse current discharge capacity up to 20 kA (8/20 μs) are sufficient since no galvanically coupled partial lightning currents will flow though them.

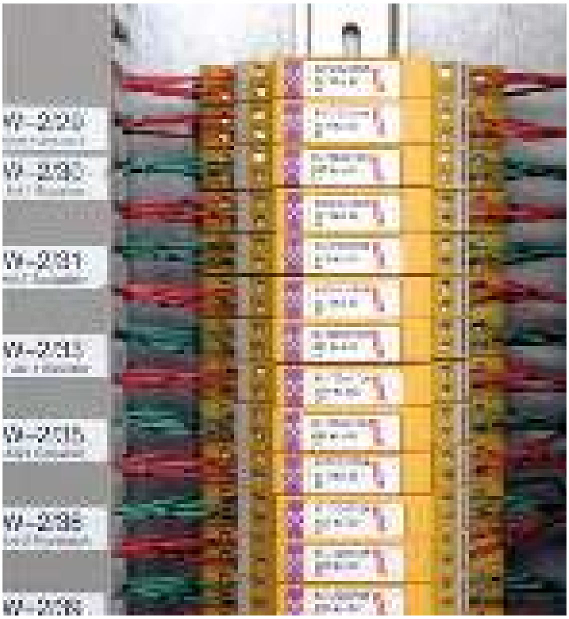


Figure 7.5.3.1 Use of BLITZDUCTOR XT combined arresters

7.6 Equipotential bonding at the boundary of LPZ 0_A and LPZ 2

7.6.1 Equipotential bonding for metal installations

See chapter 7.5.1.

7.6.2 Equipotential bonding for power supply systems

LPZ 0_A – LPZ 2

Due to the design of the structure, it can often not be avoided to implement an LPZ transition from LPZ 0_A to LPZ 2 at a boundary, especially in case of compact installations (**Figure 7.6.2.1**).

The implementation of such an LPZ transition places high demands on the surge protective devices used and their surroundings. Besides the parameters as described in 7.5.2, a protection level must be achieved which ensures safe operation of equipment and systems of LPZ 2. A low voltage protection level and high limitation of the interference energy transmitted by the arrester form the basis for safe energy coordination with surge protective devices in LPZ 2 or with surge-limiting components in the input circuits of the equipment to be protected. With a voltage protection level ≤ 1.5 kV, the spark-gap-based combined arresters of the DEHNventil

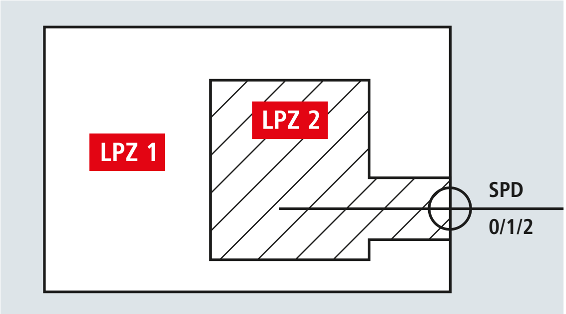


Figure 7.6.2.1 Only one SPD (LPZ 0/1/2) required (LPZ 2 integrated in LPZ 1)

Figure 7.6.2.2 DEHNventil M TT 255

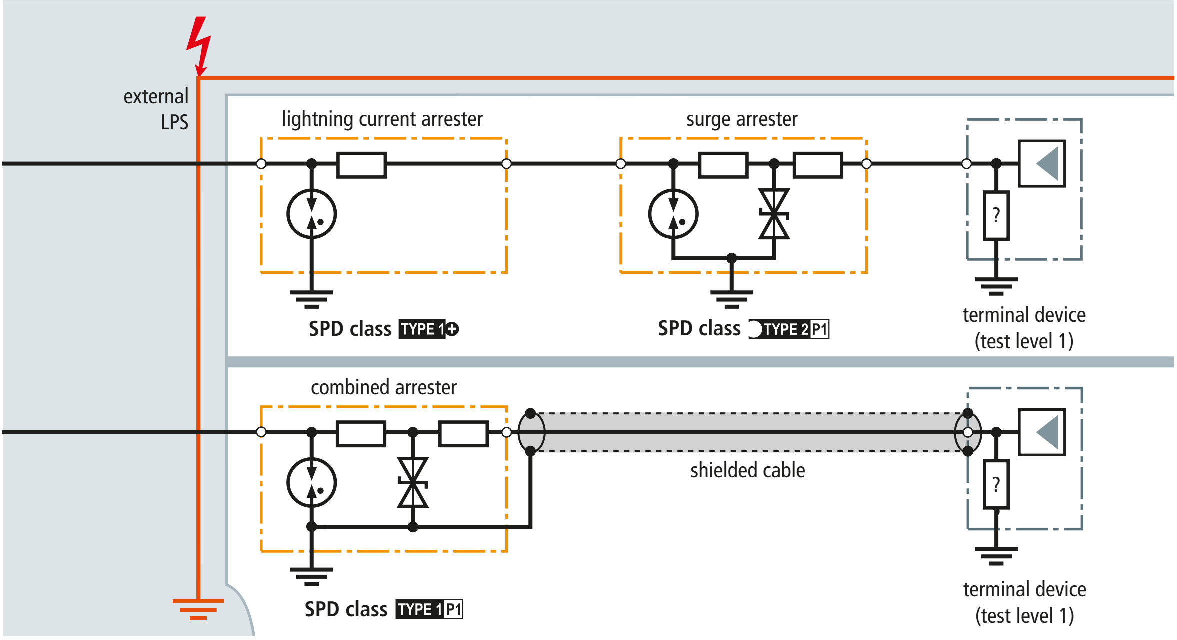


Figure 7.6.3.1 Combination guide for Yellow/Line SPD classes (see also Figure 7.8.2.2)

and DEHNvenCI family are ideally suited for such applications and provide optimal protection of terminal devices even for sensitive equipment with a rated impulse withstand voltage of 1.5 kV (overvoltage category I according to IEC 60364-5-53 (HD 60364-5-534)). Consequently, they allow the user to combine lightning equipotential bonding and coordinated protection of terminal devices, namely energy coordination of a type 1, type 2 and type 3 arrester within the first 5 m, in a single device (**Figure 7.6.2.2**).

Since, for the LPZ transition from LPZ 0 to LPZ 2, it is inevitable that both lightning protection zones are adjacent to each other, a high degree of shielding at the zone boundaries is absolutely imperative. In principle, it is recommended to keep the area of the adjoining lightning protection zones LPZ 0 and LPZ 2 as small as possible. If the structure permits it, LPZ 2 should be equipped with an additional zone shield which is installed separately from the lightning current carrying zone shield at the zone boundary LPZ 0 as can be seen in **Figure 7.6.2.1** so that LPZ 1 covers a large part of the installation. The attenuation of the electromagnetic field in LPZ 2 implemented by this measure eliminates the need for consistent shielding of all lines and systems in LPZ 2.

7.6.3 Equipotential bonding for information technology systems

LPZ 0_A – LPZ 2

A lightning current arrester from LPZ 0 to LPZ 1 discharges a large part of the interference energy, thus protecting the installation in the building from damage. However, it is frequently the case that the level of residual interference is still too high to protect the terminal devices. In a further step, additional surge protective devices are installed at the LPZ transition from LPZ 1 to LPZ 2 to limit the interference to a residual voltage level which is adjusted to the dielectric strength of the terminal device (**Figure 7.8.2.1**).

If equipotential bonding is implemented from LPZ 0 to LPZ 2, the place of installation must be chosen and the partial lightning current of the single cores and shields must be determined as described in chapter 6.3.

However, the requirements on an SPD to be installed at the LPZ transition and the requirements on the wiring downstream this transition change. A combined arrester which is energy-coordinated with the terminal device must be used (**Figure 7.6.3.1**). Combined arresters have an extremely high discharge capacity and a low residual interference level to protect the terminal devices. Furthermore, it must be observed that the outgoing line from the protective device to the terminal device is shielded and that both ends of the cable shield are integrated in the equipotential bonding system to prevent that interference is injected.

The use of combined arresters is recommended, if

- ➡ The terminal devices are close to the point where the cables enter the building
- ➡ Low-impedance equipotential bonding can be established between the protective device and the terminal device
- ➡ The line from the protective device to the terminal device is continuously shielded and earthed at both ends
- ➡ A particularly cost-effective solution is required

The use of lightning current arresters and surge arresters is recommended, if

- ➡ There are long cable distances between the protective device and the terminal device and the injection of interference is to be expected
- ➡ The SPDs for power supply and information technology systems are earthed via different equipotential bonding bars
- ➡ Unshielded lines are used
- ➡ High interference can occur in LPZ 1

7.7 Equipotential bonding at the boundary of LPZ 1 and LPZ 2 and higher

7.7.1 Equipotential bonding for metal installations

This equipotential bonding system must be installed as close as possible to the point where the lines and metal installations enter the zone (zone transition).

Likewise, all systems and conductive parts must be connected as described in chapter 7.5.1.

The conductors should be routed along the shortest possible route (low impedance).

Ring equipotential bonding in these zones allows low-impedance connection of the systems to the equipotential bonding system.

Figure 7.7.1.1 illustrates the preparation for connecting a cable trough to the ring equipotential bonding system at the zone transition.

The following metal installations must be integrated in the equipotential bonding system:

- ➡ Metal cable ducts
- ➡ Shielded cables and lines
- ➡ Building reinforcement

Figure 7.7.1.1 Ring equipotential bonding and fixed earthing terminal for the connection of metal installations

- Metal water supply pipes
- Metal conduits for lines
- Other metal pipe systems or conductive parts (e.g. compressed air)

The same cross-sections as described in chapter 6.2 must be used for the connecting cables of the equipotential bonding bar leading to the earth-termination systems and other equipotential bonding bars.

Reduced cross-sections can be used for these zone transitions to connect the metal installations to the equipotential bonding system (**Table 7.7.1.1**).

Material	Cross-section
Cu	6 mm^2
Al	10 mm^2
Fe	16 mm^2

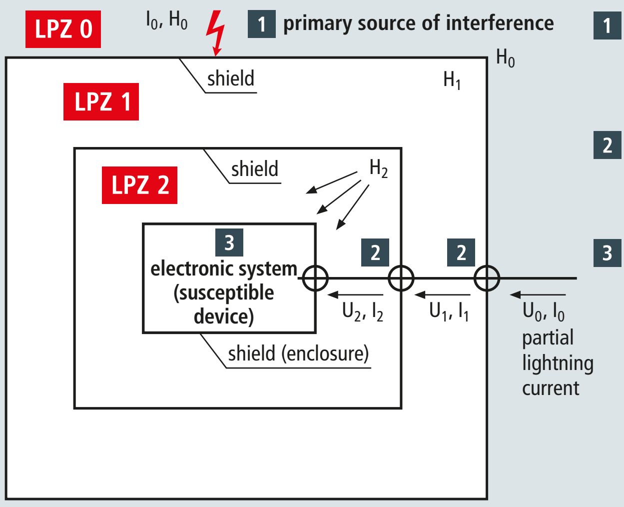
Table 7.7.1.1 Minimum cross-sections for internal equipotential bonding connections

7.7.2 Equipotential bonding for power supply systems

LPZ 1 – LPZ 2 and higher

Surge limitation and field attenuation is also achieved for the transitions from LPZ 1 to LPZ 2 and higher by systematically integrating the electrical power supply and data lines in the equipotential bonding system at each LPZ transition in parallel to all metal systems (**Figure 7.7.2.1**). Shielding the rooms and devices attenuates the electromagnetic effect.

The function of the surge protective devices used at the transitions from LPZ 1 to LPZ 2 or higher is to further minimise the residual values of upstream surge protective devices. They must reduce induced surges affecting the lines installed in the LPZ and surges generated in the LPZ itself. The discharge capacity of the SPDs which must be used can be derived from Table E.2 of the IEC 62305-1 (EN 62305-1) standard. Type 2 SPDs should therefore be capable of discharging at least 5 kA (8/20 µs) per phase without destruction. Depending on the location where the protection measures are taken, they can be either assigned to a device (device protection) (**Figure**



1 Primary source of interference defined according to the lightning protection level chosen by means of:
IEC 62305-1 (EN 62305-1):
I_0 and H_0: 10/350 µs, 1/200 µs and 0.25/100 µs impulse

2 Power supply installation with an immunity defined by IEC 60604-1: Overvoltage categories I to IV; telecommunication installation with an immunity defined by the ITU-T recommendations K.20:2008, K.21:2003 and K.45:2003.

3 Electronic system (susceptible device) defined by the immunity to conducted (U, I) and radiated (H) lightning effects:

IEC 61000-4-5:	U: 1.2/50 µs impulse, I: 8/20 µs impulse
IEC 61000-4-9:	H: 8/20 µs impulse, (attenuated wave 25 kHz), $T_p = 10$ µs
IEC 61000-4-10:	H: 0.2/5 µs impulse, (attenuated wave 1 MHz), $T_p = 0.25$ µs

Figure 7.7.2.1 Lightning protection system with spatial shielding and coordinated surge protection according to Figure A.1 of IEC 62305-4 (EN 62305-4)

Figure 7.7.2.2 DEHNflex M surge protective device for final circuits

Figure 7.7.2.3 Multipole DEHNguard M TT surge arrester

Figure 7.7.3.1 Protection of industrial electronic equipment (e.g. a PLC) by BLITZDUCTOR XT and SPS Protector

7.7.2.2) or form the infrastructural basis for the proper operation of a device or system (**Figure 7.7.2.3**). Thus, different types of surge protective devices can be used at the LPZ transitions from LPZ 1 to LPZ 2 and higher.

7.7.3 Equipotential bonding for information technology systems

LPZ 1 – LPZ 2 and higher

Further measures must be taken at the LPZ transitions in buildings to reduce the interference level (**Figure 7.7.3.1**). Since terminal devices are typically installed in LPZ 2 or higher, the protection measures must ensure that the residual interference level is below values the terminal devices can cope with. This can be achieved by:

- Installation of surge protective devices in the vicinity of terminal devices
- Integration of the cable shields in the equipotential bonding system
- Connection of the low-impedance equipotential bonding system of the SPD for information technology systems with the terminal device and SPD for power supply systems
- Energy coordination of the upstream SPD with the SPD and terminal device
- Distance of at least 130 mm between the telecommunication lines and gas discharge lamps
- Distribution board and data distributor should be located in different cabinets
- Low-voltage and telecommunication lines must cross at an angle of 90 °
- Cable crossing along the shortest possible route

7.8 Coordination of the protection measures at different LPZ boundaries

7.8.1 Power supply systems

While surge protection in a device (or directly upstream of it) fulfils the function of protecting the device, the surge protective devices in the surrounding installation have two functions. On the one hand, they protect the installation, and, on the other hand, they form the protective link between the threat parameters of the complete system and the immunity of the equipment and systems requiring protection. The threat parameters of the system and the immunity of the device to be protected are thus dimensioning factors for the protective cascade to be installed. To ensure that this protective cascade, beginning with the lightning current arrester and ending with the protection for terminal devices, works properly, it must be ensured that the individual surge protective devices are selectively effective, in other words each protection stage only takes on the amount of interference energy for which it is designed. The coordination between the protection stages is explained in more detail in Annex J of IEC 61643-12 (CLC/TS 61643-12). In order to achieve the described selectivity as the surge protective device operates, the parameters of the individual arrester stages must be coordinated in such a way that if one protection stage is faced with the threat of an energy overload, the upstream more powerful arrester "responds" and thus discharges the interference energy. When implementing the coordination, it must be observed that the impulse wave form with the longest impulse duration must be assumed to be a threat for the entire arrester chain. The energy-coordinated Red/Line product family was developed to prevent the risks in case of incorrect coordination and the resulting overload of protection stages with a lower energy. These surge protective devices which are coordinated both with one another and with the device to be protected provide maximum safety. Available as lightning current, surge and combined arresters, they can be ideally adapted to the requirements of the relevant LPZ transitions (**Figures 7.8.1.1 to 7.8.1.3**).

Especially in case of type 1 arresters or combined arresters special attenion must be paid to the arrester technology used.

Type 1 arresters must be capable of protecting the electrical installation from lightning currents of 10/350 μs wave form. The extremely long time to half value of 350 μs is characteristic of this impulse current. In the following, the different behaviour of spark gaps and varistors in case of this load will be compared.

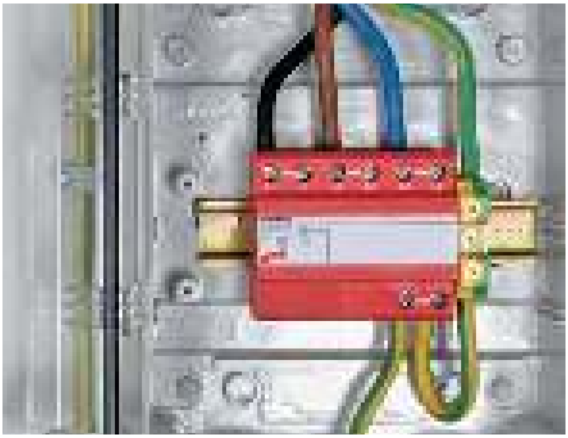


Figure 7.8.1.1 Three-pole DEHNbloc lightning current arrester

Figure 7.8.1.2 Multipole DEHNguard M TT surge arrester

Figure 7.8.1.3 Modular DEHNventil M TNS combined arrester

Spark gap

- After an extremely short period of time, the voltage drops to the so-called arc voltage which in case of a modern follow current limiting spark gap is typically in the range of the supply voltage.
- The voltage-switching characteristic of the spark gap acts like a wave breaker function. The lightning impulse current wave is "switched", thus considerably reducing the impulse duration. This reduction of the impulse duration reduces the remaining voltage-time area, which is decisive for the load on the downstream protection stages and terminal devices, to extremely low values.

Varistor

- A varistor limits the voltage for a longer time to a level which is typically significantly higher than the arc voltage of a spark gap and the nominal voltage of the supply system.
- Therefore, the voltage-time area of a varistor is considerably larger than that of a spark gap. This high voltage is applied over the entire impulse duration. Therefore, a considerably higher load is placed on the downstream devices and installations in case of a varistor than in case of a spark gap, resulting in destruction or a reduced service life of these devices.

To verify these theoretical considerations, coordination tests according to Annex J of IEC 61643-12 (CLC/TS 61643-12) have been performed by means of conventional spark-gap-based and varistor-based type 1 arresters which, according to the manufacturer, are suited for protecting terminal devices (combined arresters). In this process, coordination with a reference varistor of type S20K275 was tested, which is a typical protective circuit in a terminal device in case of a supply voltage of 230 V.

The let-through energy which is transmitted by a type 1 SPD and reaches the terminal devices (reference varistor) is a coordination criterion. This let-through energy was measured for different amplitude values of the 10/350 µs impulse current up to the maximum value specified by the manufacturer (12.5 kA). Starting at 0 kA, the amplitude values are increased in small steps to avoid blind spots in case of voltage-switching SPDs. Blind spots are low amplitude values of the 10/350 µs impulse current which do not yet trip voltage-switching SPDs and thus stress the reference varistor with the maximum energy.

Spark-gap-based type 1 SPDs

The diagram in **Figure 7.8.1.4** shows the let-through energy curve as a function of the 10/350 µs impulse current for this configuration.

The following can be derived form this diagram:

- The maximum permissible energy input of 150 J for the S20K275 varistor is not exceeded for any of the impulse currents applied.
- Even in case of a distance of 0 m between the surge protective device and the reference varistor (direct coordination), a sufficient "energy reserve" ΔW is provided in addition to the maximum permissible energy in the reference varistor.
- In case of additional cable lengths (e.g. 2 m) between the surge protective device and the reference varistor, the "energy reserve" ΔW can even be considerably increased.

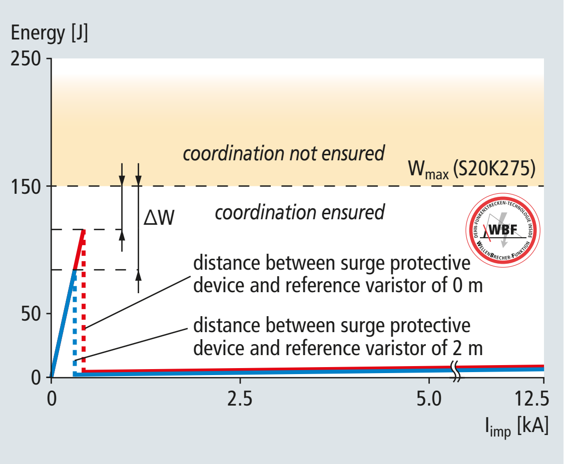


Figure 7.8.1.4 Let-through energy curve at the reference varistor with an upstream spark-gap-based type 1 SPD

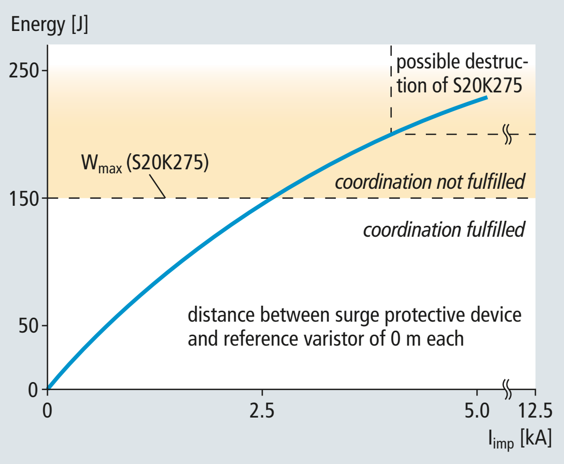


Figure 7.8.1.5 Let-through energy curve at the reference varistor with an upstream varistor-based type 1 SPD

Coordination with the reference varistor is fully ensured over the entire duration of the 10/350 µs impulse current under consideration (information provided by the manufacturer: I_{imp} = 12.5 kV).

Varistor-based type 1 SPDs

Varistor-based type 1 SPDs are devices for which the manufacturer specifies a maximum continuous operating voltage U_C of 280 V. This value is typically used in 230/400 V low-voltage systems.
The diagram in **Figure 7.8.1.5** shows the let-through energy curve at the reference varistor for this type of device.
The following can be derived form this diagram:

- It can be seen that the downstream reference varistor is energetically overloaded from about 2.5 kA (10/350 µs) and may be destroyed from about 4 kA (10/350 µs).
- In case of devices with a higher rated voltage (e.g. U_e = 335 V), energy overload and destruction may occur at even lower impulse current values due to the more unfavourable impulse current distribution between the SPD and the reference varistor.
- In comparison to the maximum specified impulse current of 12.5 kA, already extremely low impulse currents energetically overload the downstream protection stages or terminal devices. In practice, these components would be pre-damaged or even destroyed.

The scenario of an additional cable length (2 m) between the surge protective device and the reference varistor is not described since there is almost no deviation from the values shown due to the technology used.

The results described above clearly show that, without detailed knowledge of the internal structure, a functioning energy coordination with downstream surge protective devices (type 2 and / or type 3) and terminal devices can only be achieved by means of spark-gap-based combined arresters (type 1 SPDs). The voltage-switching characteristic of the spark gap mitigates the incoming energy of the 10/350 µs lightning current to a sufficiently low level due to the wave breaker function. The spark gap takes on almost the entire energy and the energy load on the downstream protection stages is only minimal.
This is not the case if a varistor-based type 1 SPD is used. The ABB bulletin 19 by the German Committee for Lightning Protection and Lightning Research (ABB) at the VDE specifies that general coordination is virtually excluded if voltage-limiting components (varistor) are used as type 1 SPD because the energy is not "switched", but only limited. Since in case of doubt it can always be assumed that in a 230/400 V low-voltage system the protection stages and terminal devices are rated with 275 V, the energy load on them is considerably higher, which may damage or destroy components or devices in the electrical installation even in case of low lightning currents.

7.8.2 Information technology systems

When implementing measures to protect buildings against interference from the effects of nearby, distant and direct lightning strikes, it is recommended to use a multi-stage SPD concept. This reduces the high-energy interference (partial lightning current) in stages since an initial upstream energy absorbing stage prevents the main portion of the interference from reaching the downstream system (wave breaker). The downstream stages reduce the interference to system-compatible values. Depending on the installation conditions, several protection stages can also be integrated in a single surge protective device using a combined protective circuit (combined arrester). The relevant boundaries where the surge protective devices are installed in the form of a cascade are, for example, the zone boundaries (LPZ) of a lightning protection zone concept according to IEC 62305-4 (EN 62305-4).

Surge protective devices must be cascaded considering the coordination criteria.
Various methods are available to determine the coordination conditions according to IEC 61643-22 (CLC/TS 61643-22), some of which require special knowledge about the structure of the surge protective devices. A "black box" method is the so-called "let-through energy method", which is based on

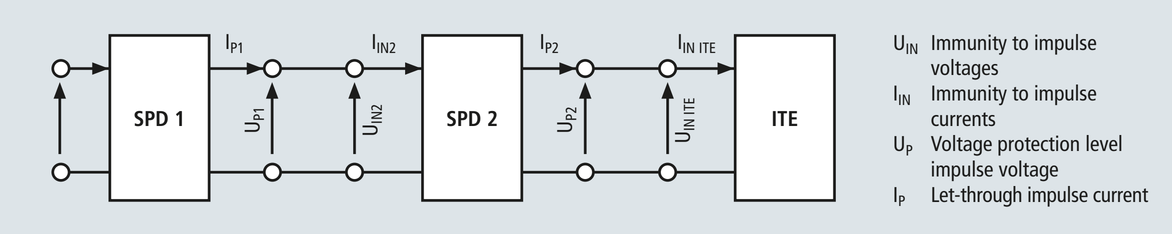


Figure 7.8.2.1 Coordination according to the let-through method of two surge protective devices and one terminal device, cascade (according to IEC 61643-22 (CLC/TS 61643-22))

Characteristic	Symbol	Description
Discharge capacity of an arrester (according to the categories of IEC 61643-21 (EN 61643-21))	TYPE 1	D1 impulse (10/350 μs), lightning impulse current ≥ 2.5 kA / core or ≥ 5 kA / total • Exceeds the discharge capacity of TYPE 2 – TYPE 4
	TYPE 2	C2 impulse (8/20 μs), increased impulse load ≥ 2.5 kA / core or ≥ 5 kA / total • Exceeds the discharge capacity of TYPE 3 – TYPE 4
	TYPE 3	C1 impulse (8/20 μs), impulse load ≥ 0.25 kA / core or ≥ 0.5 kA / total • Exceeds the discharge capacity of TYPE 4
	TYPE 4	Load < TYPE 3
Protective effect of an arrester (limitation below the test levels acc. to IEC 61000-4-5 (EN 61000-4-5))	P1	Test level required for the terminal device: 1 or higher
	P2	Test level required for the terminal device: 2 or higher
	P3	Test level required for the terminal device: 3 or higher
	P4	Test level required for the terminal device: 4
Energy coordination (with another Yellow/Line arrester)	⊕	Arrester has a decoupling impedance and is suitable for coordination with an arrester marked with ⊐
	⊐	Arrester suitable for coordination with an arrester with decoupling impedance ⊕

Table 7.8.2.1 SPD class symbols

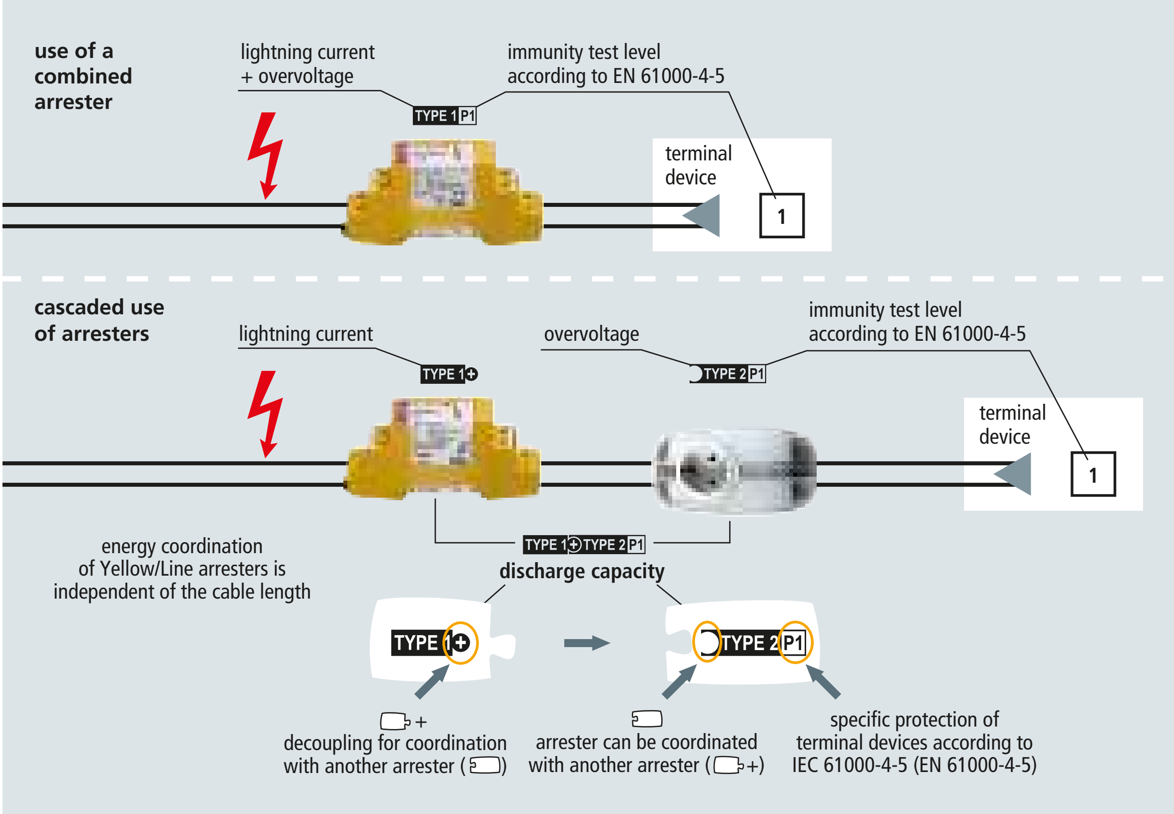


Figure 7.8.2.2 Examples of the energy-coordinated use of arresters according to the Yellow/Line SPD class and structure of the Yellow/Line SPD class symbol

standard impulse parameters and thus can be understood from both a mathematical and a practical point of view.
The cascade according to **Figure 7.8.2.1** is considered to be coordinated if the residual values I_p in case of a short-circuited output and U_p in case of an open-circuit output are smaller than the relevant input values I_{IN} / U_{IN}.
However, these methods are difficult to implement for the user since they are very time-consuming. In order to save time and work, the standard also allows to use the information provided by the manufacturer for coordination.

A discharge capacity of 10/350 μs wave form is typically specified for lightning current arresters installed at LPZ 0/1 or higher. For surge arresters, in contrast, only a 8/20 μs wave form is specified. This is due to the fact that surge arresters are mainly developed for inductively and capacitively coupled interference. If, however, a line extending beyond the building is connected to a cascade comprising lightning current and surge arresters, the following can be concluded from the coordination conditions:

- The most sensitive element (surge arrester) operates first
- The surge arrester must also be capable of carrying a part of the partial lightning current of 10/350 μs wave form, albeit a low one
- Before the surge arrester is overloaded, the lightning current arrester must trip and take over the main portion of the discharge energy

The surge protective devices of the Yellow/Line family are consistently and safely coordinated with one another and with the terminal devices. To this end, they are marked with the relevant SPD class symbol (**Tables 7.8.2.1 and 7.8.2.2, Figure 7.8.2.2**).

7.9 Inspection and maintenance of the LEMP protection measures system

The fundamentals and prerequisites governing the inspection and maintenance of the LEMP protection measures system are the same as those governing the inspection and maintenance of lightning protection systems as previously described in chapter 3.4.
The inspections carried out during the construction phase are particularly important for the inspection of the LEMP protection measures system since many components of the LEMP protection measures system are no longer accessible when the construction work has been completed. The necessary measures (e.g. connection of the reinforcement) must be documented with photos and included in the test report.

Inspections should be carried out:

- During the installation of the LEMP protection measures system
- After the installation of the LEMP protection measures system

Conductor routing	Arrester solution	Exemplary assignment of SPD classes to LPZ transitions		
		To LPZ 1	To LPZ 2	To LPZ 3
From LPZ 0_A	Combined arresters	TYPE 1 P1		
	Cascaded arresters	TYPE 1 ⊕	◗TYPE 2 P1	
		TYPE 1 ◖	⊕TYPE 3 P1	
From LPZ 0_B	Combined arresters	TYPE 1 P1		
	Surge arresters	TYPE 2 P1 or ◗TYPE 2 P1		
	Cascaded arresters	TYPE 2 ◖	⊕TYPE 3	
From LPZ 1	Combined arresters	–	TYPE 1 P1	
	Surge arresters	–	TYPE 2 P1 or ◗TYPE 2 P1	
From LPZ 2	Combined arresters	–	TYPE 1 P1	
	Surge arresters	–	–	TYPE 2 P1
		–	–	TYPE 3 P1
		–	–	TYPE 4 P1

Table 7.8.2.2 Assignment of the SPD classes to the LPZ transitions

- Periodically
- After each modification to components which are relevant for the LEMP protection measures system
- After a lightning strike to the structure, if necessary

After completion of the inspection, all defects found must be rectified with immediate effect. The technical documentation must be updated, if necessary.

In Germany, a comprehensive inspection of the LEMP protection measures system should be carried out at least every two to four years as part of the inspection of the electrical installation.

8

Selection, installation and assembly of surge protective devices (SPDs)

8.1 Power supply systems (as part of the lightning protection zone concept according to IEC 62305-4 (EN 62305-4))

The installation of a lightning and surge protection system for electrical installations represents the latest state of the art and is an indispensable infrastructural condition for the trouble-free operation of complex electrical and electronic systems without consequential damage. The requirements on SPDs which are necessary for the installation of such a lightning and surge protection system as part of the lightning protection zone concept according to IEC 62305-4 (EN 62305-4) for power supply systems are defined in IEC 60364-5-53 (HD 60364-5-534).

SPDs used as part of the fixed building installation are classified into type 1, 2 and 3 surge protective devices according to the requirements and stress on the places of installation and are tested to IEC 61643-11 (EN 61643-11).

The highest requirements with respect to the discharge capacity are placed on type 1 SPDs. These are used as part of the lightning and surge protection system at the boundary from LPZ 0_A to LPZ 1 and higher as shown in **Figure 8.1.1**. These surge protective devices must be capable of repeatedly carrying lightning currents of 10/350 µs wave form without destructing the equipment. These type 1 SPDs are called lightning current arresters. Their function is to prevent destructive partial lightning currents from entering the electrical installation of a building.

To protect against surges, type 2 SPDs with a discharge capacity of about some 10 kA (8/20 µs) are used at the transition from LPZ 0_B to LPZ 1 and higher or LPZ 1 to LPZ 2 and higher.

The last link in the lightning and surge protection system for power supply systems is the protection of terminal devices (transition from LPZ 2 to LPZ 3 and higher). The main function of a type 3 surge protective device installed at this point is to protect against overvoltages arising between the conductors of an electrical system, in particular switching overvoltages.
A summary of the different functions, arrangements and requirements on arresters is given in **Table 8.1.1**.

8.1.1 Characteristics of SPDs

Maximum continuous operating voltage U_c
The maximum continuous operating voltage (previously: rated voltage) is the root mean square (rms) value of the maximum

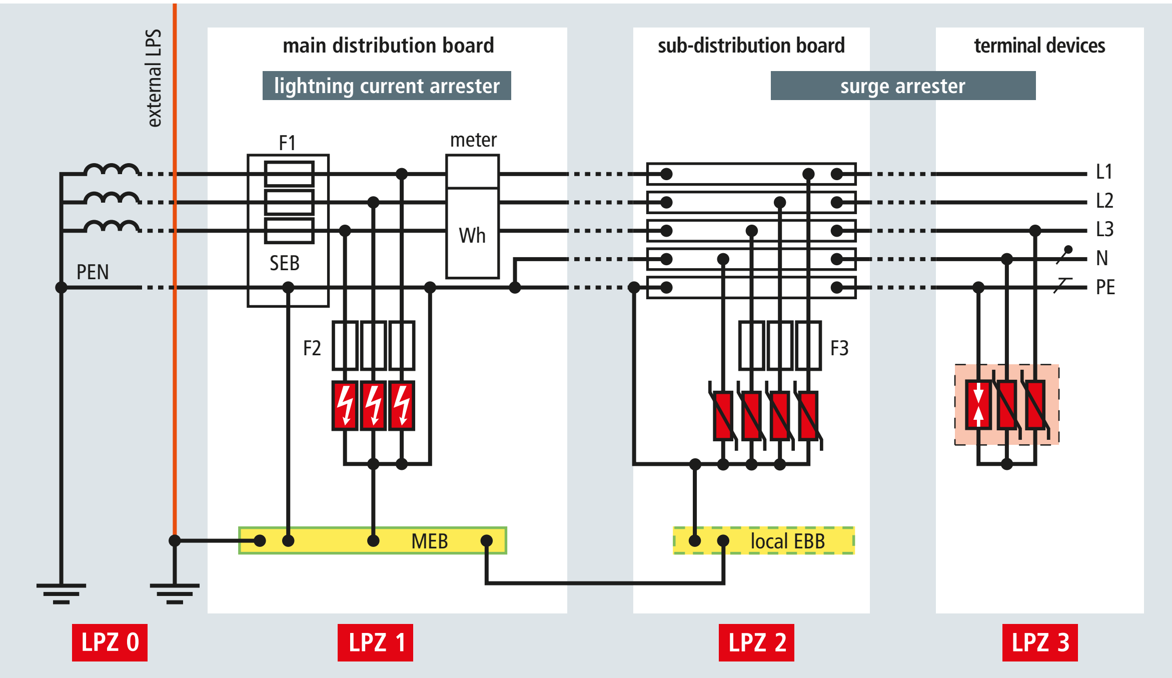


Figure 8.1.1 Use of arresters in power supply systems (schematic diagram)

Standard Type / designation	EN 61643-11:2012	IEC 61643-11:2011
Lightning current arrester / combined arrester	Type 1 SPD	Class I SPD
Surge arrester for distribution boards, sub-distribution boards, fixed installations	Type 2 SPD	Class II SPD
Surge arrester for socket outlets / terminal devices	Type 3 SPD	Class III SPD

Table 8.1.1 Classification of surge protective devices according to IEC and EN

voltage which may be applied to the correspondingly labelled terminals of the surge protective device during operation. It is the maximum voltage applied to the arrester in the defined non-conductive state which ensures that this state is restored after the operation and discharge process.
The value U_c depends on the nominal voltage of the system to be protected and the requirements of the installation standard (IEC 60364-5-53 (HD 60364-5-534)). Taking into account a 10 % voltage tolerance for TN and TT systems, the maximum continuous operating voltage U_c for 230/400 V systems is 253 V.

Lightning impulse current I_{imp}

This is a standardised impulse current curve with a 10/350 μs wave form. Its parameters (peak value, charge, specific energy) simulate the stress caused by natural lightning currents. Lightning impulse currents (10/350 μs) apply to type 1 SPDs. They must be able to discharge such lightning impulse currents several times without destructing the equipment.

Nominal discharge current I_n

The nominal discharge current I_n is the peak value of the current flowing through the surge protective device (SPD). It has an 8/20 μs impulse current wave form and is rated for classifying the test of type 2 SPDs.

Voltage protection level U_p

The voltage protection level of an SPD denotes the maximum instantaneous value of the voltage on the terminals of an SPD while at the same time characterising their capacity to limit surges to a residual level.

Depending on the type of SPD, the voltage protection level is determined by means of the following individual tests:

- Impulse sparkover voltage 1.2/50 μs (100 %)
- Residual voltage U_{res} at nominal discharge current (in accordance with IEC 61643-11 (EN 61643-11))

The surge protective device appropriate to the place of installation is chosen in accordance with the overvoltage categories described in IEC 60664-1 (EN 60664-1). It must be observed that the required minimum value of 2.5 kV for a 230/400 V three-phase system only applies to equipment of the fixed electrical installation. Equipment in the final circuits supplied by this installation requires a voltage protection level which is much lower than 2.5 kV.
IEC 60364-5-53 (HD 60364-5-534) also requires a minimum voltage protection level of 1.5 kV for a 230/400 V low-voltage consumers' installation – for consumers according to overvoltage category I. This minimum voltage protection level can be achieved by means of a coordinated system of type 1 and type 2 SPDs or by using a type 1 combined arrester.

Short-circuit withstand capability I_{SCCR}

This is the value of the prospective power-frequency short-circuit current which the surge protective device can safely handle in case it is provided with an upstream backup fuse (backup protection).

Follow current extinguishing capability I_{fi} (at U_c)

The follow current extinguishing capability is the unaffected (prospective) rms value of the mains follow current which can be automatically extinguished by the surge protective device when U_c is applied.
According to IEC 62305-3 (EN 62305-3) and IEC 60364-5-53 (HD 60364-5-534), the follow current extinguishing capability of the SPDs should be equal to the maximum prospective short-circuit current at the place of installation of the SPDs. In case of distribution boards in industrial plants with too high short-circuit currents, an adequate backup fuse which interrupts the mains follow current by means of the protective device must be chosen for the protective device.
According to IEC 60364-5-53 (HD 60364-5-534) and IEC 61643-11 (EN 61643-11), the SPDs which are connected between the neutral and PE conductor and where a power-frequency follow current may occur after they have operated (e.g. spark gaps) have a follow current extinguishing capability $I_{fi} \geq 100\ A_{rms}$.

Follow current limitation (in case of spark-gap-based type 1 SPDs)

Follow current limitation is the capability of a spark-gap-based SPD to limit any mains follow currents which arise to such a degree that the current actually flowing is noticeably smaller than the possible short-circuit current at the place of installation.

A high degree of follow current limitation prevents upstream protection elements (e.g. fuses) from tripping due to a too high mains follow current.

The follow current limitation is an important parameter for the availability of the electrical installation, particularly for spark-gap-based SPDs with a low voltage protection level. This is also described in the German VDN guideline 2004-08: "Überspannungs-Schutzeinrichtungen Typ 1. Richtlinie für den Einsatz von Überspannungs-Schutzeinrichtungen (ÜSE) Typ 1 (bisher Anforderungsklasse B) in Hauptstromversorgungssystemen." [Surge Protective Devices Type 1 – Guideline for the use of surge protective devices (SPDs) Type 1 in main power supply systems].

Modern follow current limiting spark gaps even ensure selectivity with respect to low-rated fuses in the range from 20 to 35 AgK/gG.

Coordination

In order to ensure that the various SPDs function selectively, energy coordination of the individual SPDs is absolutely essential. The basic principle of energy coordination is characterised by the fact that each protection stage must only discharge the amount of interference energy which the SPD is designed for. If higher interference energies occur, the protection stage upstream of the SPD, e.g. type 1 SPD, must discharge the impulse current and relieve the downstream protective devices. Such coordination must take into account all possible interference such as switching overvoltages, partial lightning currents, etc. Coordination must be proven by the manufacturer according to IEC 62305-4 (EN 62305-4), IEC 60364-5-53 (HD 60364-5-534) and the German VDN guideline.

When using devices from different manufacturers, proper coordination cannot be assumed without making specific calculations or performing a laboratory test as outlined in the German bulletin 19 published by the ABB (Committee for Lightning Protection and Lightning Research of the VDE). The devices of the Red/Line family are harmonised and tested with reference to their energy coordination.

TOV

TOV (**T**emporary **O**ver**V**oltage) is the term used to describe temporary power-frequency surges which can arise as a result of faults in medium and low-voltage systems. In case of TN systems as well as the L-N path in TT systems, a rated time of 5 seconds produces $U_{TOV} = 1.45 \times U_0$, where U_0 represents the nominal a.c. voltage of the phase conductors to earth. In case of 230/400 V systems, a TOV $U_{TOV} = 1.32 \times U_{REF} = 1.32 \times 255$ V = 336.6 V must be taken into consideration for the SPDs between L and N for 5 s. The SPD needs to withstand this TOV.

In addition to this also a TOV test with $\sqrt{3} \times U_{REF} = \sqrt{3} \times 255$ V = 441,7 V for 120 min must be applied between L and N to simulate a loss of neutral. A safe failure mode is acceptable for this test.

If TOVs arise as a result of earth faults in the high-voltage system, a rated time of 200 ms produces $U_{TOV} = 1200$ V for the N-PE path in TT systems.

IEC 60364-5-53 (HD 60364-5-534) requires that SPDs installed in low-voltage consumer's installations have a TOV withstand capability. The devices of the Red/Line family must be rated for TOVs according to IEC 61643-11 (EN 61643-11) and meet the requirements of IEC 60364-5-53 (HD 60364-5-534).

8.1.2 Use of SPDs in various systems

Personal protection measures always take priority over surge protection measures. Since both measures are directly linked to the type of system and thus to the use of surge protective devices (SPDs), TN, TT and IT systems and the many ways in which SPDs can be used in these systems will be described in the following. Electric currents flowing through the human body can have serious consequences. Therefore, protection measures which prevent hazardous electric shock are required in every electrical installation. Parts which are energised during normal operation must be insulated, covered, sheathed or arranged to prevent that they are touched if this could result in hazardous electric shock. This protection measure is termed "protection against electric shock under normal conditions". Moreover, a hazard caused by electric shock must be prevented if the voltage is transferred to the metal enclosure (body of a piece of electrical equipment) due to a fault, e.g. a faulty insulation. This protection against hazards which, in the event of a fault, may result from touching bodies or extraneous conductive parts is termed "protection against electric shock under fault conditions".

The limit for the permanently permissible touch voltage U_L typically is 50 V for a.c. voltages and 120 V for d.c. voltages.

In circuits containing socket outlets and in circuits containing class I mobile equipment, which is continuously handheld during operation, higher touch voltages, which can arise in the event of a fault, must be automatically disconnected within 0.4 s. In all other circuits, higher touch voltages must be automatically disconnected within 5 s. These times apply to TN systems. In case of other system configurations, the disconnection times may differ.

IEC 60364-4-41 (HD 60364-4-41) describes protection measures against indirect contact with protective conductors. These protection measures include automatic disconnection or an alarm in the event of a fault. When implementing measures for "protection against electric shock under fault conditions", the protective device must be assigned according to the system configuration.

According to IEC 60364-4-41 (HD 60364-4-41), a low-voltage distribution system in its entirety, from the power source to the last piece of equipment, is typically characterised by:

- ➡ Earthing conditions of the power source (e.g. low-voltage side of the distribution transformer) and
- ➡ Earthing conditions of the bodies of the equipment in electrical consumer´s installations

Thus, there are three basic types of distribution systems: **TN** system, **TT** system and **IT** system.

The letters have the following meaning:

The **first letter** describes the earthing conditions of the supplying power source:

T	Direct earthing of one point of the power source (generally the neutral point of the transformer winding)
I	Insulation of all live parts from earth or connection of one point of the power source to earth via an impedance

The **second letter** describes the earthing conditions of the bodies of the equipment of the electrical installation:

T	Body of the equipment is directly earthed regardless of whether one point of the power supply is earthed
N	Body of the electrical equipment is directly connected to the operational earth electrode (earthing of the power source)

Further letters describe the arrangement of the neutral and protective conductor:

S	Neutral and protective conductor are laid separately from each other
C	Neutral and protective conductor are combined (in one conductor)

Thus, there are three possible TN systems: **TN-S** system, **TN-C** system and **TN-C-S** system.

The protective devices which can be installed in the various systems are:

- ➡ Overcurrent protective device
- ➡ Residual current protective device
- ➡ Insulation monitoring device
- ➡ Fault-voltage-operated protective device (in special cases)

This results in the following assignments:

TN system

- ➡ Overcurrent protective device
- ➡ Residual current protective device

TT system

- ➡ Overcurrent protective device
- ➡ Residual current protective device
- ➡ Fault-voltage-operated protective device (in special cases)

IT system

- ➡ Overcurrent protective device
- ➡ Residual current protective device
- ➡ Insulation monitoring device

These personal protection measures have top priority when installing power supply systems. All other protection measures such as lightning and surge protection for electrical systems and installations are secondary to the protection measures against indirect contact with protective conductors under consideration of the system configuration and the protective device and must not make these measures ineffective. In this context, an SPD fault, even it is most unlikely, must also be taken into account. This is particularly important because the surge protective devices are always used between the live conductors and the protective conductor.

Therefore, the use of SPDs in different system configurations will be described in the following sections. These circuit concepts are taken from IEC 60364-5-53 (HD 60364-5-534).

In these sample solutions, the lightning current arresters are shown in the vicinity of the service entrance box, i.e. upstream of the meter. IEC 60364-5-53 (HD 60364-5-534) defines that lightning current arresters must be installed "close to the origin of the installation".
In Germany, the use of lightning current arresters upstream of the meter is governed by the VDN (Association of German Network Operators) guideline 2004-08: "Überspannungs-Schutzeinrichtungen Typ 1. Richtlinie für den Einsatz von Überspannungs- Schutzeinrichtungen (ÜSE) Typ 1 (bisher

Anforderungsklasse B) in Hauptstromversorgungssystemen." [Surge Protective Devices Type 1 – Guideline for the use of surge protective devices (SPDs) Type 1 in main power supply systems].

This guideline published by the VDN defines basic requirements which, depending on the distribution network operator, can lead to different technical designs.

The technical design (system configuration) preferred in the supply area must be requested from the responsible distribution network operator.

8.1.3 Use of SPDs in TN systems

In TN systems, overcurrent and residual current protective devices can be used for "protection against electric shock under fault conditions". For the installation of SPDs, this means that these surge protective devices may only be arranged downstream of the protective devices for "protection against electric shock under fault conditions" to ensure personal protection in the event of a faulty SPD.

If a type 1 or 2 SPD is installed downstream of a residual current protective device, it has to be expected that the residual current protective device (RCD) interprets this process as residual current due to the impulse current discharged to PE and that it interrupts the circuit. Moreover, if a type 1 SPD is stressed with partial lightning currents, it must be assumed that the high dynamics of the lightning current will cause mechanical damage to the residual current protective device (**Figure 8.1.3.1**). This would make the protection measure "protection against electric shock under fault conditions" ineffective which must be avoided. Therefore, both a type 1 lightning current arrester and a type 2 SPD should be used upstream of the residual current protective device. Consequently, overcurrent protective devices only ensure "protection against electric shock under fault conditions" if type 1 and type 2 SPDs are used. SPDs may therefore only be installed if a fuse is used as overcurrent protective device. Whether an additional separate backup fuse must be provided in the arrester path depends on the size of the next upstream supply fuse and the maximum permissible backup fuse for the SPD. The maximum continuous operating voltages shown in **Figures 8.1.3.2 and 8.1.3.3a and b** apply to type 1, type 2 and type 3 SPDs used in TN systems.

Figure 8.1.3.1 RCD destroyed by lightning impulse currents

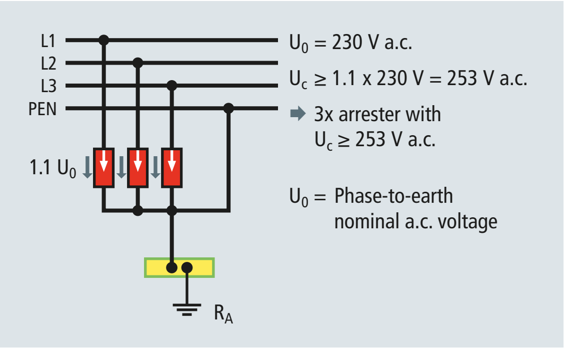


Figure 8.1.3.2 "3–0" circuit in a TN-C system

Figure 8.1.3.4 illustrates an example of lightning current and surge arresters in a TN-C-S system. It can be seen that type 3 SPDs are used downstream of the residual current protective device (RCD).

In this context, it must be noted that type 3 SPDs are primarily used for differential mode protection due to the frequency of switching overvoltages in the final circuits. These overvoltages typically occur between L and N. Surge limitation between L and N means that no impulse current is discharged to PE. Thus, the RCD cannot interpret this process as residual current. Moreover, type 3 SPDs are designed for a nominal discharge capacity of 1.5 kA. These values are sufficient if upstream protection stages of the type 1 and type 2 SPDs discharge high-energy impulses. When using an impulse-current-proof RCD, these impulse currents do not

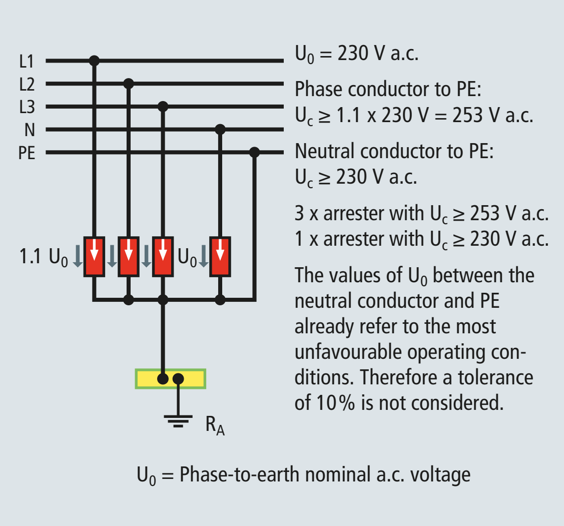


Figure 8.1.3.3a "4–0" circuit in a TN-S system

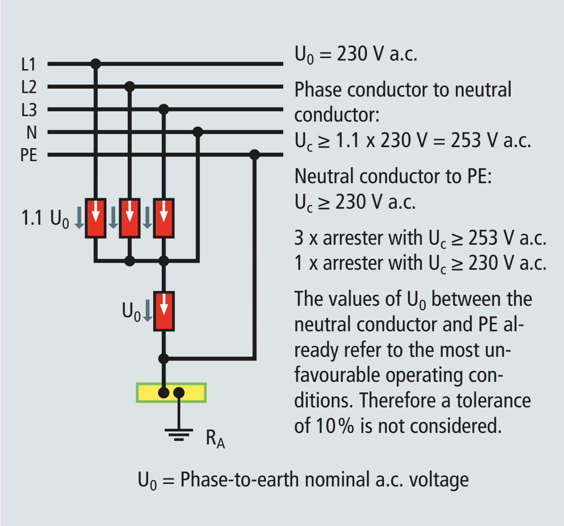


Figure 8.1.3.3b "3+1" circuit in a TN-S system

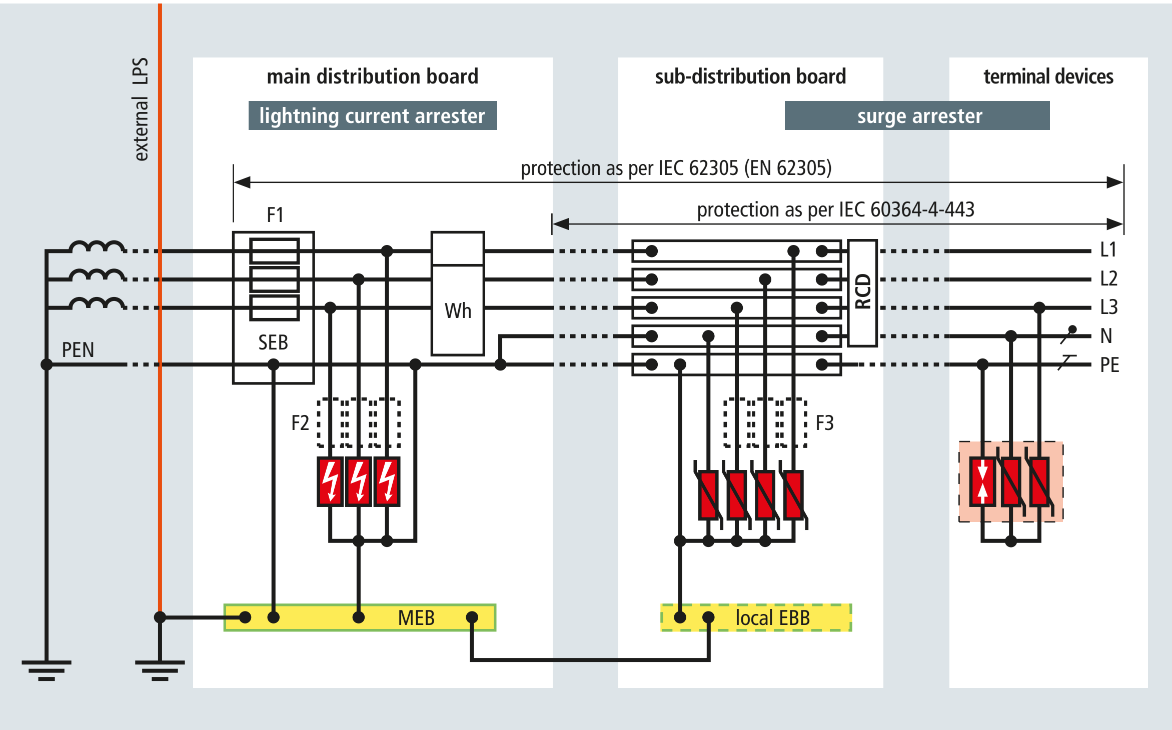


Figure 8.1.3.4 SPDs used in a TN-C-S system

trip the RCD or cause mechanical damage. **Figures 8.1.3.5 to 8.1.3.11** illustrate the use of SPDs as part of the lightning protection zone concept and the resulting lightning and surge protection measures for TN systems.

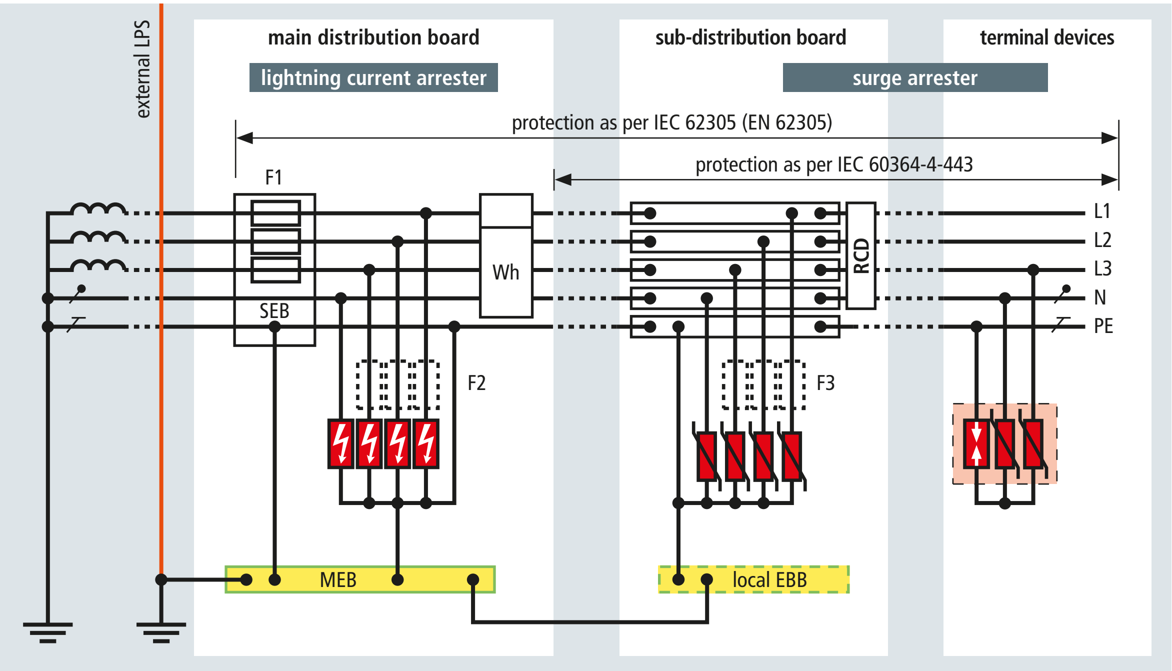
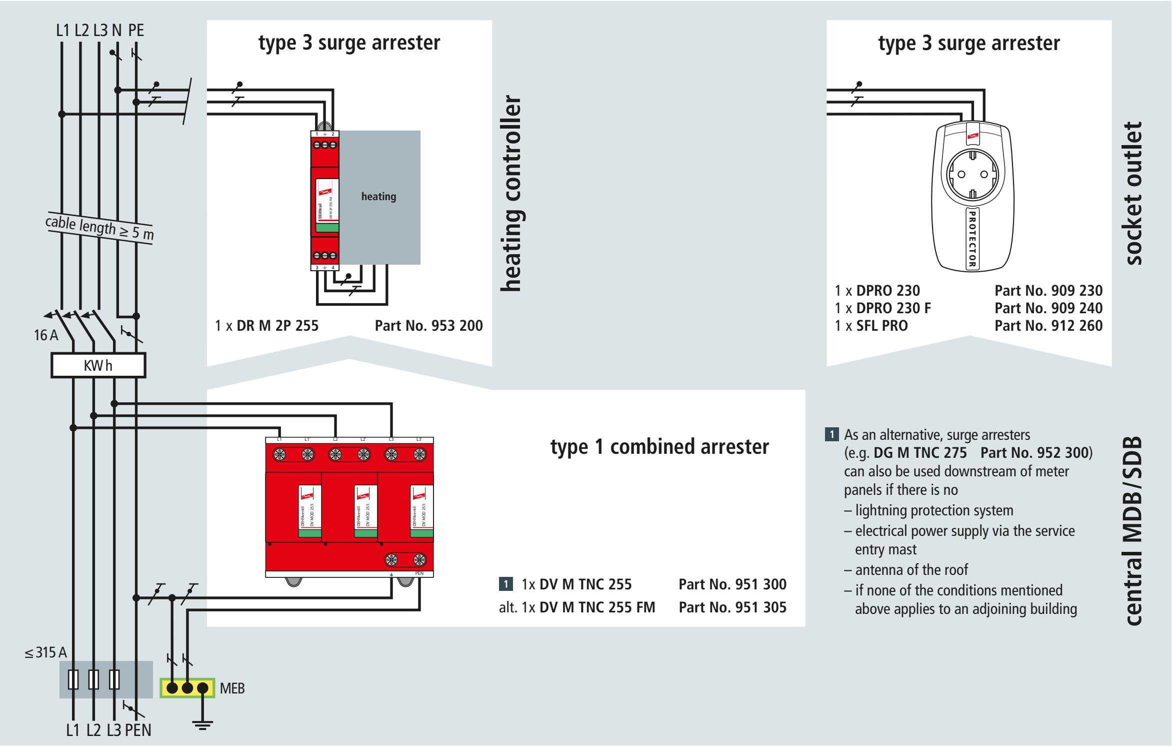


Figure 8.1.3.5 SPDs used in a TN-S system



1 x **DR M 2P 255** **Part No. 953 200**

1 x **DPRO 230** **Part No. 909 230**
1 x **DPRO 230 F** **Part No. 909 240**
1 x **SFL PRO** **Part No. 912 260**

1 1x **DV M TNC 255** **Part No. 951 300**
alt. 1x **DV M TNC 255 FM** **Part No. 951 305**

1 As an alternative, surge arresters (e.g. **DG M TNC 275 Part No. 952 300**) can also be used downstream of meter panels if there is no
– lightning protection system
– electrical power supply via the service entry mast
– antenna of the roof
– if none of the conditions mentioned above applies to an adjoining building

Figure 8.1.3.6 SPDs used in a TN system – Single-family house

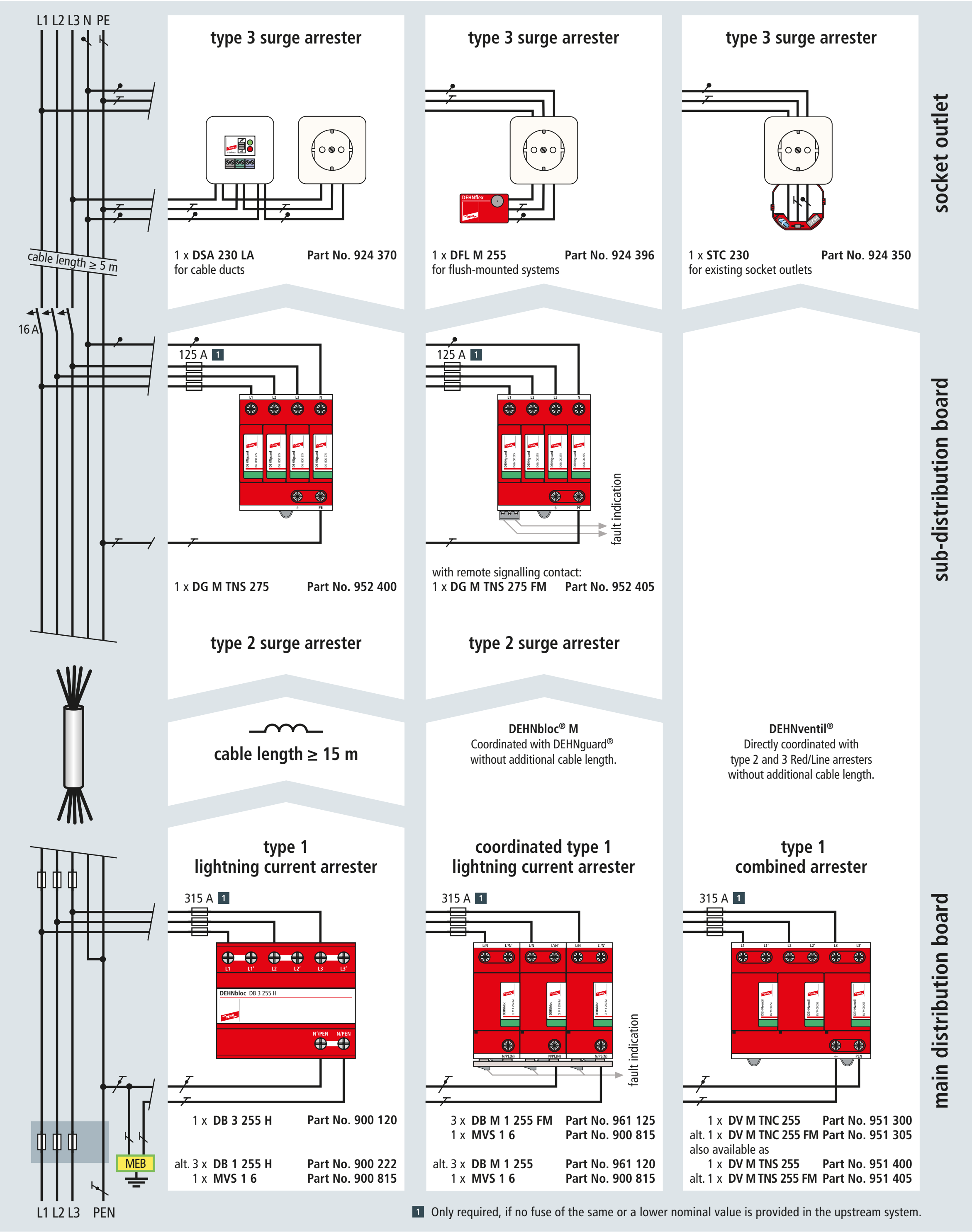
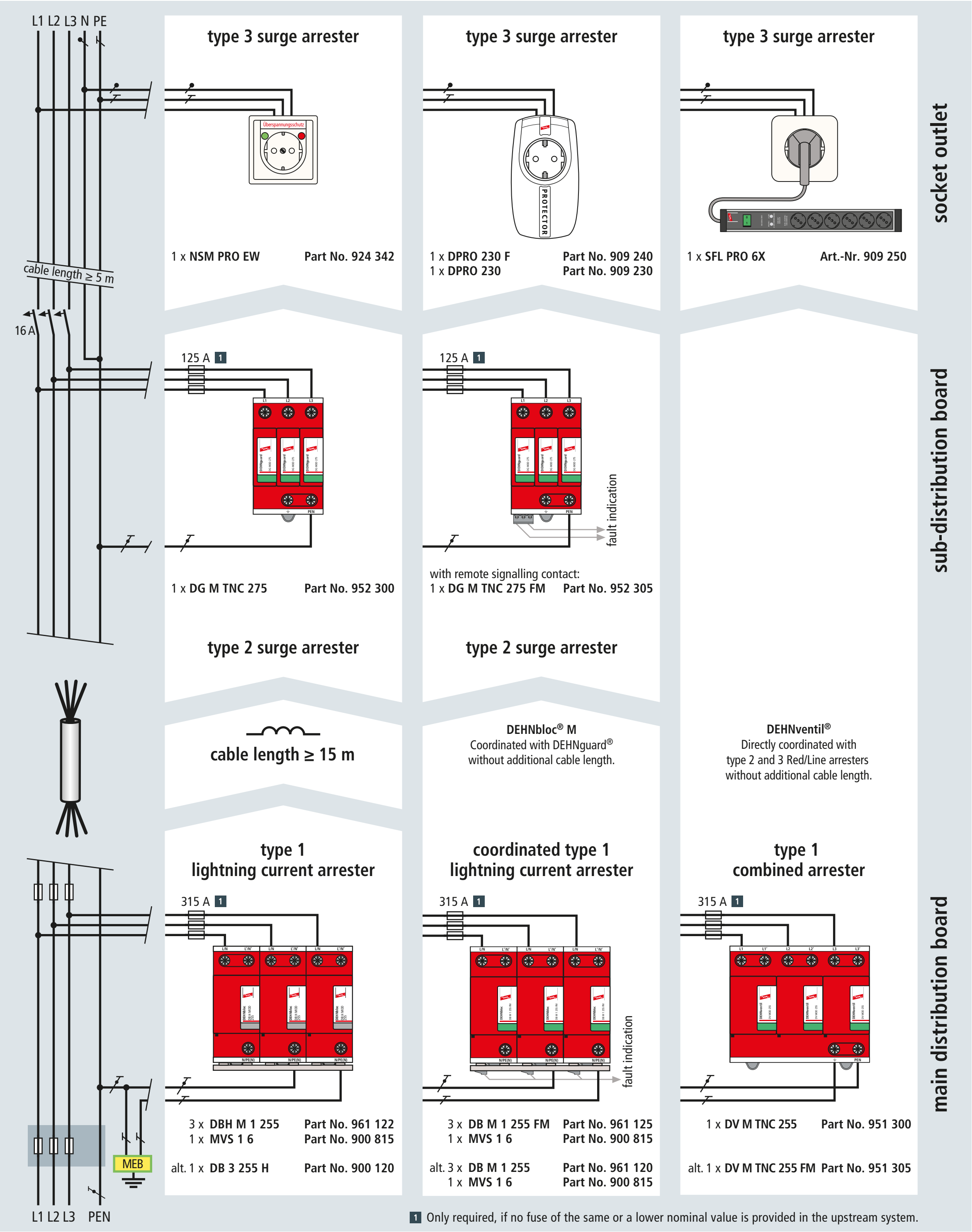
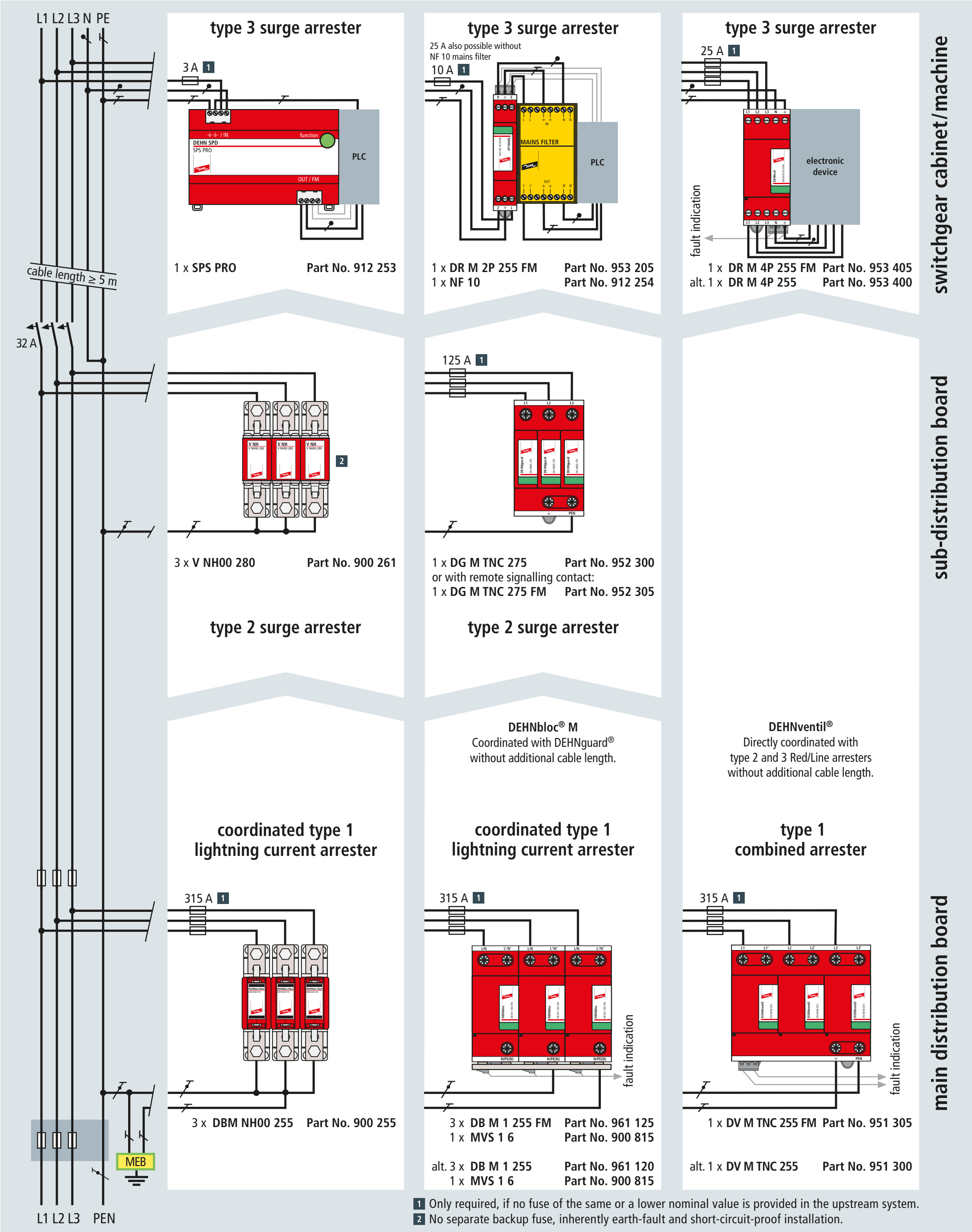


Figure 8.1.3.7 SPDs used in a TN system – Office building with separation of the PEN conductor in the main distribution board



1 Only required, if no fuse of the same or a lower nominal value is provided in the upstream system.

Figure 8.1.3.8 SPDs used in a TN system – Office building with separation of the PEN conductor in the sub-distribution board



1 Only required, if no fuse of the same or a lower nominal value is provided in the upstream system.

2 No separate backup fuse, inherently earth-fault and short-circuit-proof installation.

Figure 8.1.3.9 SPDs used in a TN system – Industrial building with separation of the PEN conductor in the sub-distribution board

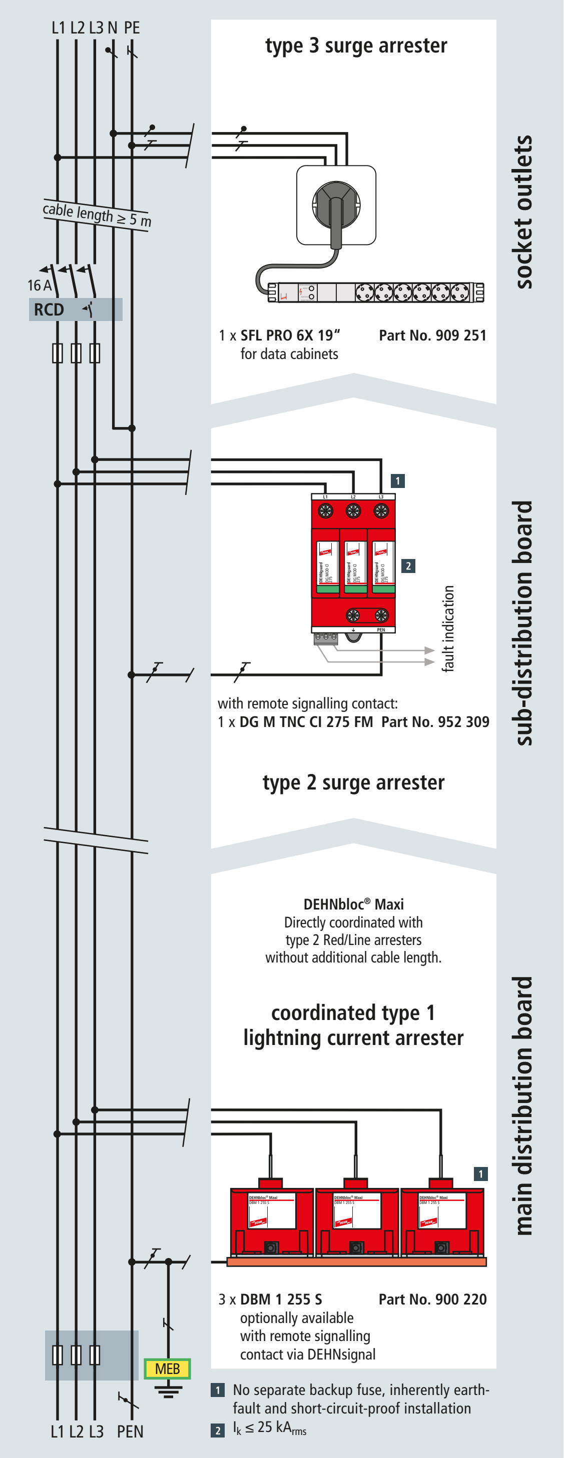


Figure 8.1.3.10 SPDs used in a TN system – Arrester with integrated backup fuse in an industrial building

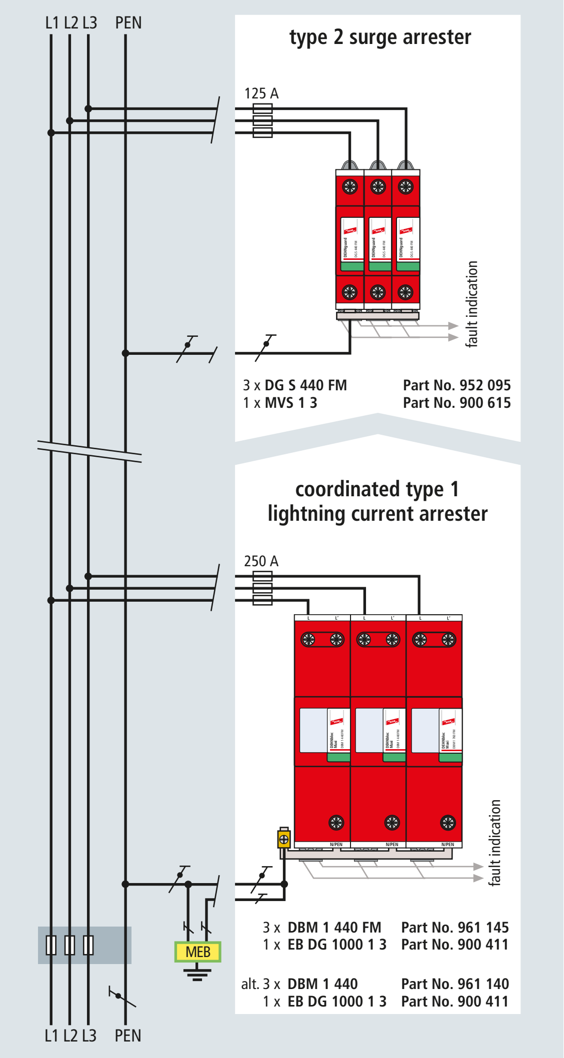


Figure 8.1.3.11 SPDs used in a TN system – 400/690 V industrial building

8.1.4 Use of SPDs in TT systems

In TT systems, overcurrent protective devices, residual current protective devices (RCDs) and, in special cases, fault-voltage-operated protective devices can be used for "protection against electric shock under fault conditions". For the installation of lightning current and surge arresters in TT systems, this means that they may only be arranged downstream of the protective devices described above to ensure "protection against electric shock under fault conditions" in the event of a faulty SPD. If type 1 or type 2 SPDs are installed downstream of an RCD, it has to be expected that the RCD interprets this discharge process as residual current due to the impulse current discharged to PE and the RCD interrupts the circuit as already described in section 8.1.3. If type 1 SPDs are used, it must also be assumed that the dynamics of the discharged partial lightning current causes mechanical damage to the RCD when the type 1 SPDs operate as is the case with TN systems. This would damage the protective device for "protection against electric shock under fault conditions" and make the protection measure ineffective. Such a state, which can result in life hazard, must be avoided. Therefore, in TT systems type 1 and type 2 SPDs must always be installed upstream of the residual current protective device and must be arranged in such a way that the conditions for the use of overcurrent protective devices for "protection against electric shock under fault conditions" are met.

In the event of a fault, namely an SPD fault, short-circuit currents must flow to initiate an automatic disconnection of the overcurrent protective devices within 5 s. If the arresters in the TT system were arranged as shown in **Figures 8.1.3.4 and 8.1.3.5** for a TN system, only earth fault currents would occur in the event of a fault instead of short-circuit currents. In certain cases, however, these earth fault currents do not trip an upstream overcurrent protective device within the required time.

Therefore, type 1 and type 2 SPDs are arranged between L and N in TT systems. This arrangement is supposed to ensure that, in the event of a faulty protective device in the TT system, a short-circuit current is formed and trips the next upstream overcurrent protective device. Since, however,

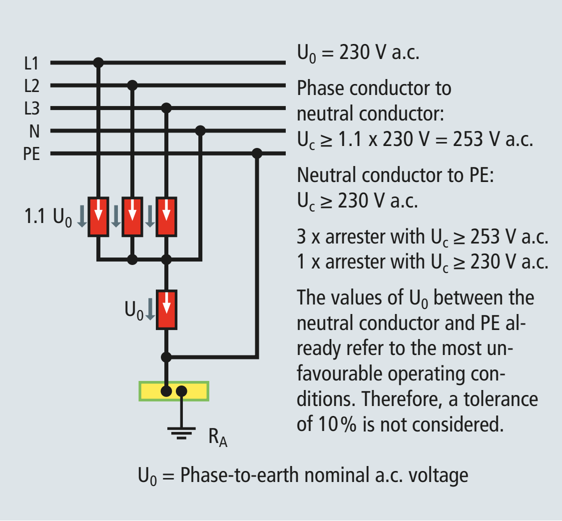


Figure 8.1.4.1 TT system (230/400 V); "3+1" circuit

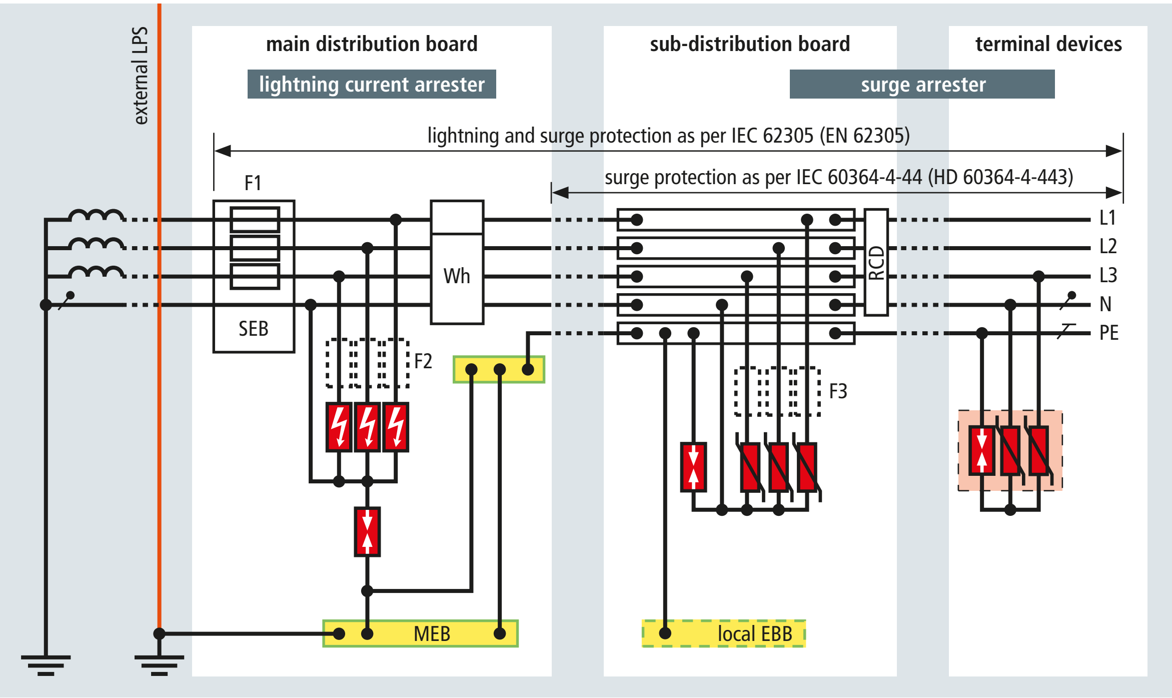


Figure 8.1.4.2 SPDs used in a TT system

lightning currents always flow to earth, namely PE, an additional discharge path must be provided between N and PE. These so-called “N-PE arresters” must meet special requirements since in this case the sum of the partial discharge currents from L1, L2, L3 and N must be conducted and they must be capable of extinguishing follow currents of 100 A_{rms} due to a possible shifting of the neutral point.
Moreover, an N-PE arrester must fulfil increased TOV requirements. According to IEC 60364-5-53 (HD 60364-5-534), a withstand capability of 1200 V for 200 ms must be proven.
The maximum continuous operating voltages shown in **Figure 8.1.4.1** must be observed when using SPDs in TT systems between L and N.

The lightning current carrying capability of the type 1 SPDs is rated to conform to lightning protection levels I, II, III/IV as per IEC 62305-1 (EN 62305-1).
The following values must be complied with to ensure the lightning current carrying capability of SPDs between N and PE:

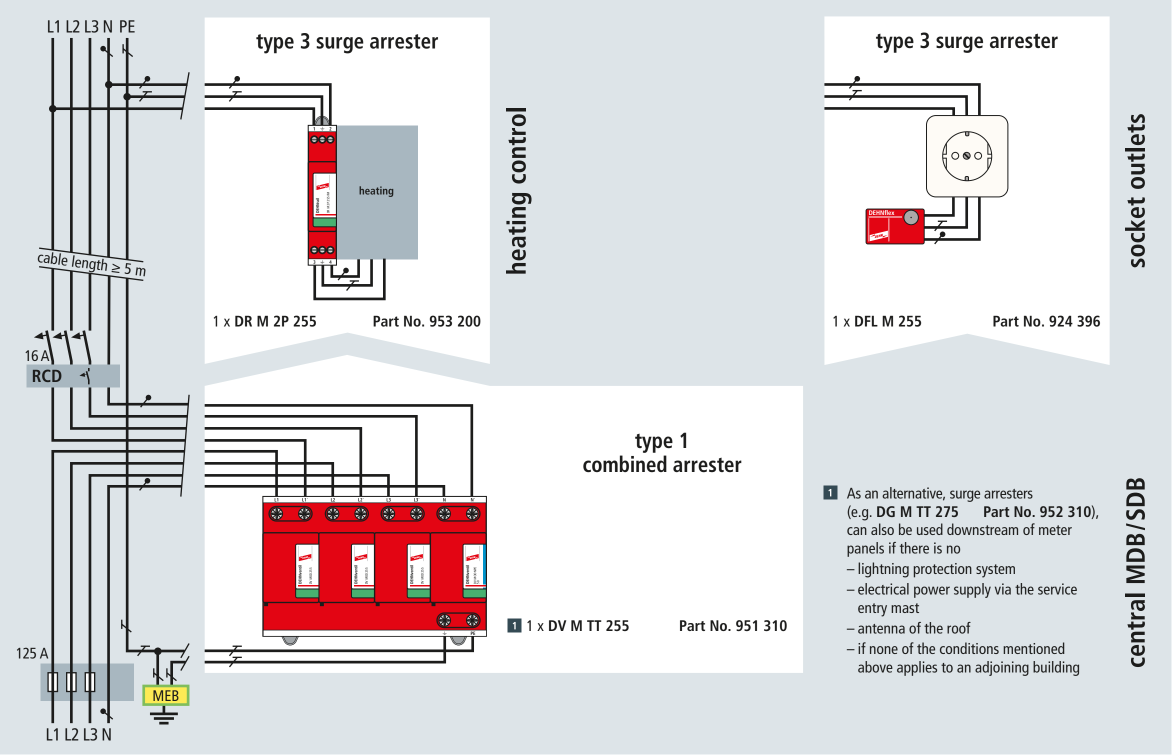
Lightning protection level:

I $I_{imp} \geq 100$ kA (10/350 µs)
II $I_{imp} \geq 75$ kA (10/350 µs)
III/IV $I_{imp} \geq 50$ kA (10/350 µs)

The type 2 SPDs are also connected between L and N and between N and PE. Type 2 SPDs between N and PE must have a discharge capacity of at least $I_n \geq 20$ kA (8/20 µs) for three-phase systems and $I_n \geq 10$ kA (8/20 µs) for a.c. systems.
Since coordination is always based on the worst-case conditions (10/350 µs wave form), type 2 N-PE arresters of the Red/Line series have a value of 12 kA (10/350 µs).
Figures 8.1.4.2 to 8.1.4.5 show examples of how to connect SPDs in TT systems. As is the case with TN systems, type 3 surge protective devices are installed downstream of the RCD. Generally, the impulse current discharged by this SPD is so low that the RCD does not identify this process as residual current. Nevertheless, an impulse-current-proof RCD should also be used in this case.

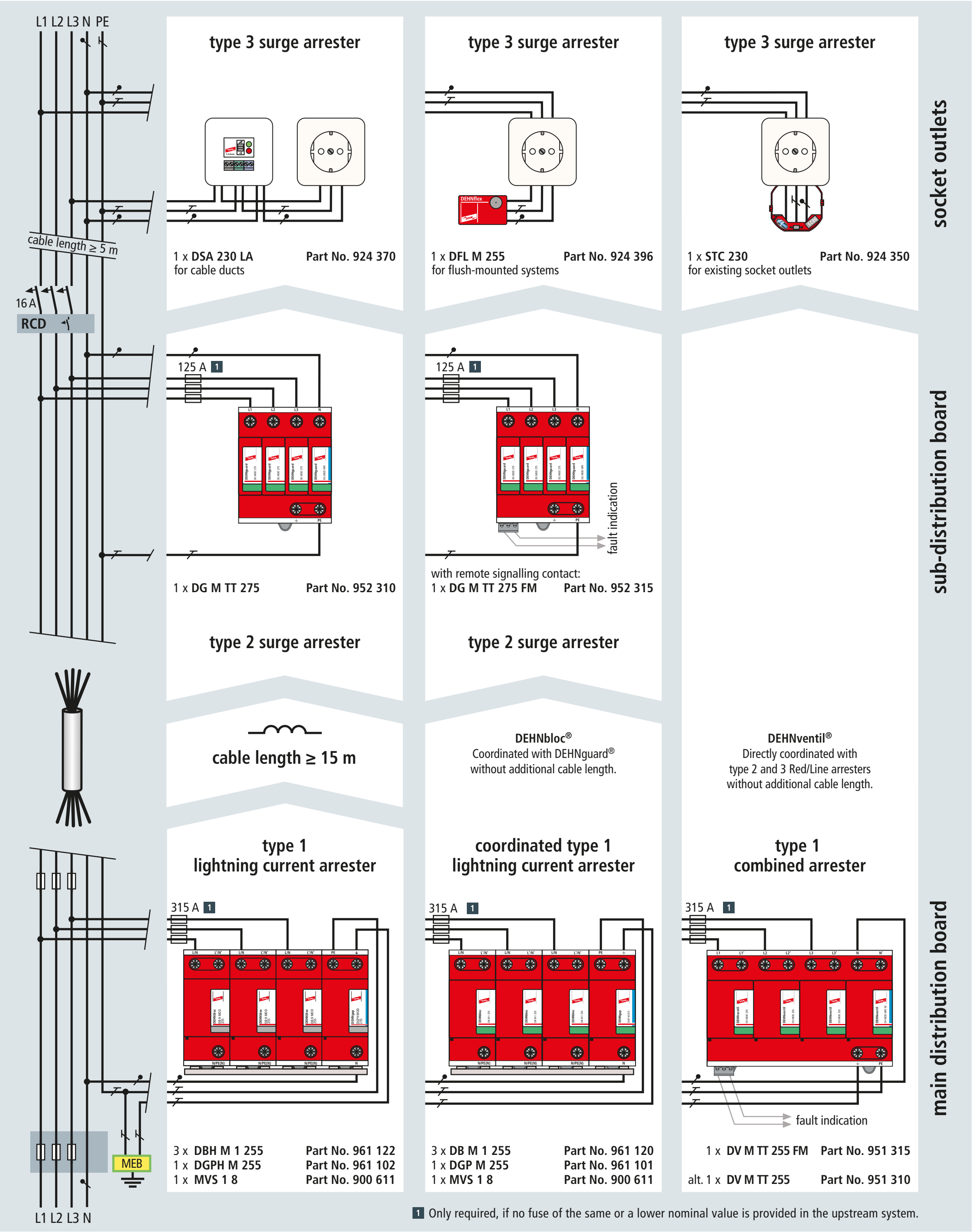
8.1.5 Use of SPDs in IT systems

In IT systems, overcurrent protective devices, residual current protective devices (RCDs) and insulation monitoring



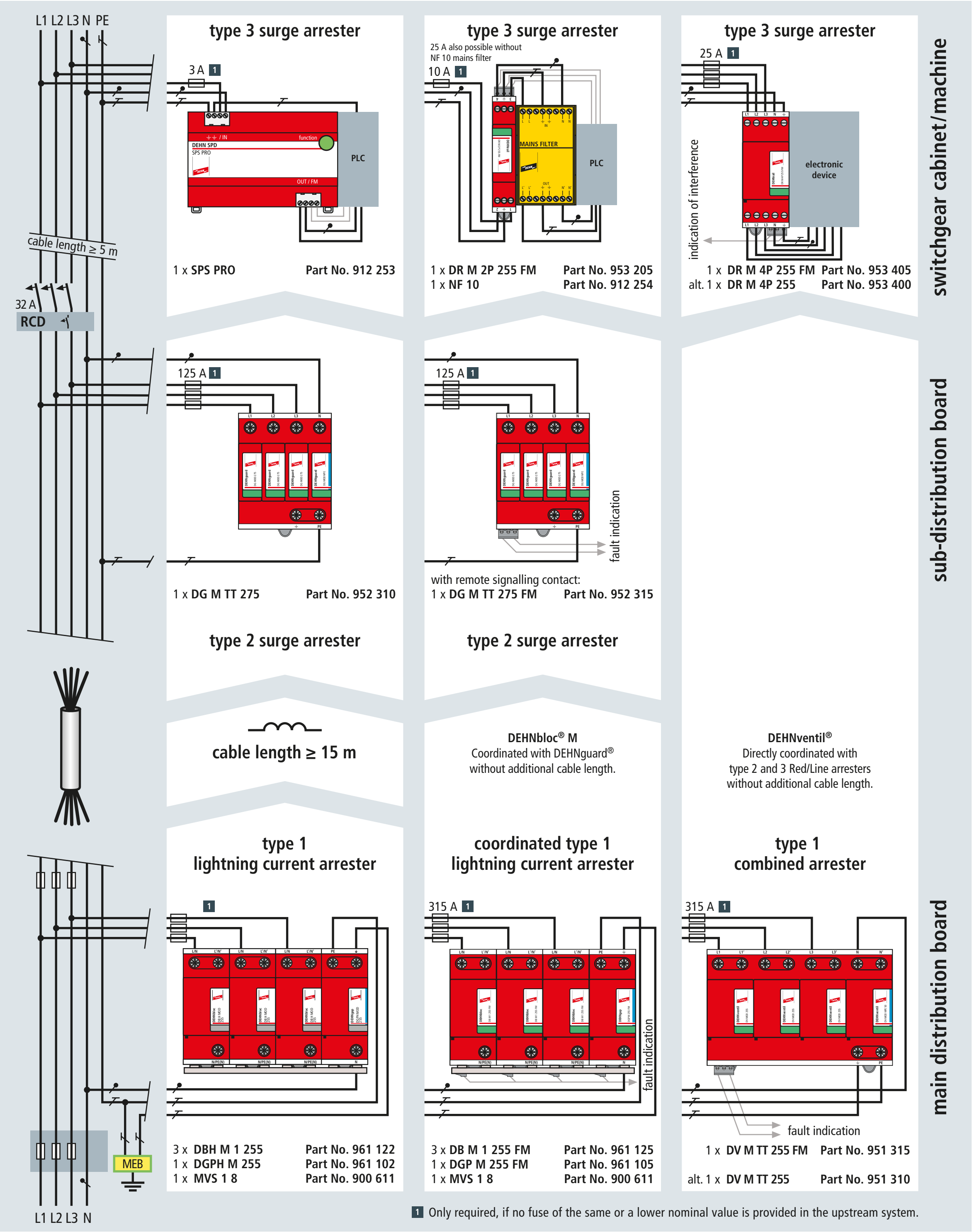
1 As an alternative, surge arresters (e.g. **DG M TT 275** **Part No. 952 310**), can also be used downstream of meter panels if there is no
- lightning protection system
- electrical power supply via the service entry mast
- antenna of the roof
- if none of the conditions mentioned above applies to an adjoining building

Figure 8.1.4.3 SPDs used in a TT system – Single-family house



1 Only required, if no fuse of the same or a lower nominal value is provided in the upstream system.

Figure 8.1.4.4 SPDs used in a TT system – Office building



1 Only required, if no fuse of the same or a lower nominal value is provided in the upstream system.

Figure 8.1.4.5 SPDs used in a TT system – Industrial building

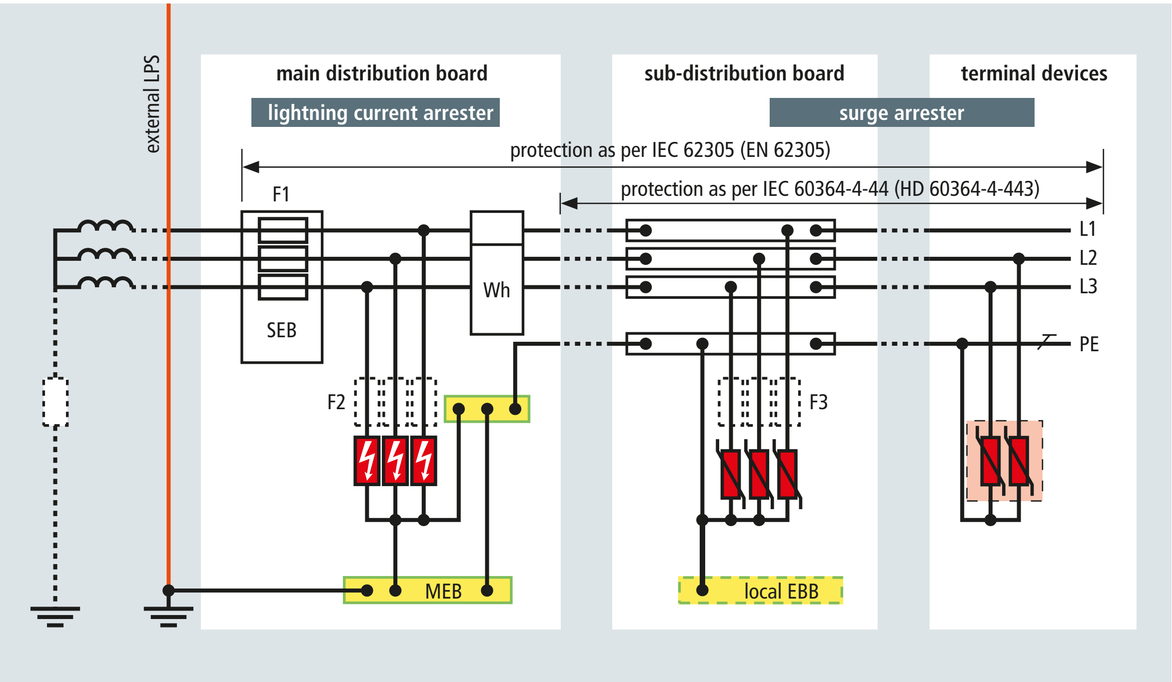


Figure 8.1.5.1 SPDs used in a IT system

devices can be used for "protection against electric shock under fault conditions". While in TN or TT systems, "protection against electric shock under fault conditions" is ensured by the relevant disconnection conditions of the overcurrent protective devices or RCDs in the event of the first fault, the first fault in an IT system only creates an alarm. Excessive touch voltage cannot occur since the first fault in an IT system simply creates an earth connection of the system. The operating state of the IT system changes to that of a TN or TT system. Therefore, an IT system can be further operated without risk after the first fault so that work or production processes (e.g. in the chemical industry) can still be completed. In case of the first fault, the protective conductor reaches the potential of the faulty phase conductor, which, however, does not present a risk since all bodies and exposed metal parts reach this potential via the protective conductor and thus no hazardous potential differences can be bridged. However, it must be observed that when the first fault occurs in the IT system, the voltage of the intact conductors to earth corresponds to the voltage between the phase conductors. Consequently, in the event of the first fault of an SPD there is a voltage of 400 V in a 230/400 V IT system. This possible operating state must be taken into account when choosing the SPDs with respect to their maximum continuous operating voltage.

A distinction is made between IT systems with incorporated neutral conductor and IT systems without incorporated neutral conductor (**Figure 8.1.5.1**). In case of IT systems without incorporated neutral conductor, the SPDs are installed between each phase conductor and the PE conductor in a so-called "3–0" circuit. For IT systems with incorporated neutral conductors, both a "4–0" and a "3+1" circuit can be used. In case of a "3+1" circuit, it must be observed that an SPD with a follow current extinguishing capability appropriate to the system conditions must be installed in the N-PE path.
The maximum continuous operating voltages shown in **Figures 8.1.5.1a to c** must be used for type 1, type 2 and type 3 SPDs in IT systems with and without incorporated neutral conductors.

A second fault in an IT system must trip a protective device. The information on TN and TT systems provided in section 8.1 and 8.2 also applies to the use of SPDs in IT systems in conjunction with a protective device for "protection against electric shock under fault conditions". Consequently, in IT systems

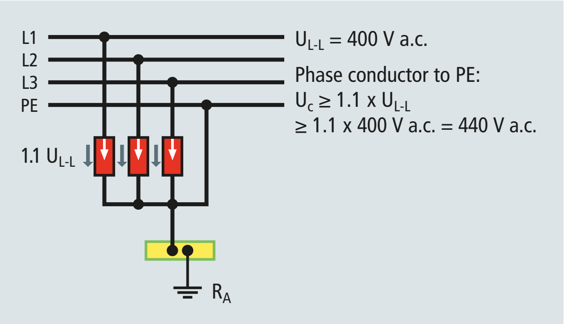


Figure 8.1.5.2a IT system without incorporated neutral conductor; "3-0" circuit

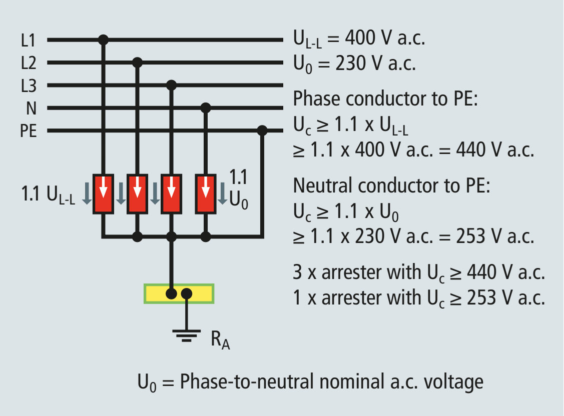


Figure 8.1.5.2b IT system with incorporated neutral conductor; "4-0" circuit

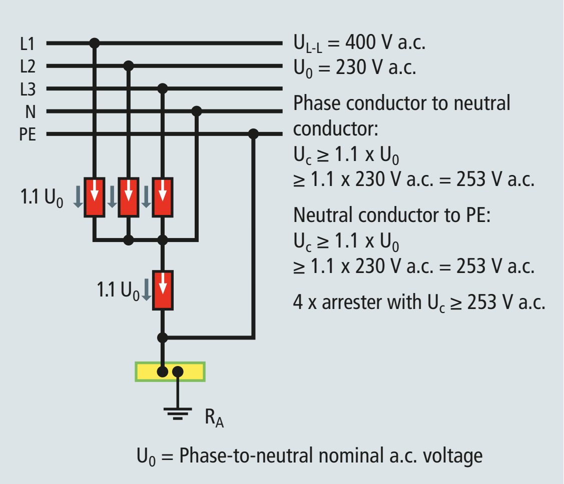


Figure 8.1.5.2c IT system with incorporated neutral conductor; "3+1" circuit

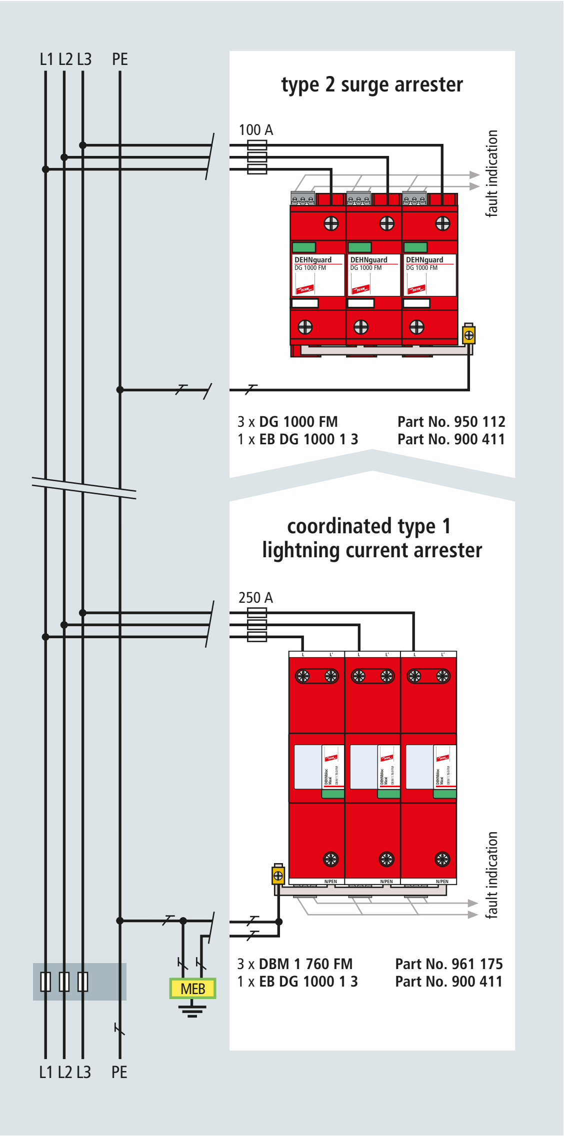


Figure 8.1.5.3 SPDs used in a 690 V IT system – Without incorporated neutral conductor

it is also advisable to install type 1 and type SPDs upstream of the RCD.

Figure 8.1.5.3 shows the use of SPDs in an IT system without incorporated neutral conductor. An example of how to connect the SPDs in IT systems with incorporated neutral conductor is shown in **Figure 8.1.5.4**.

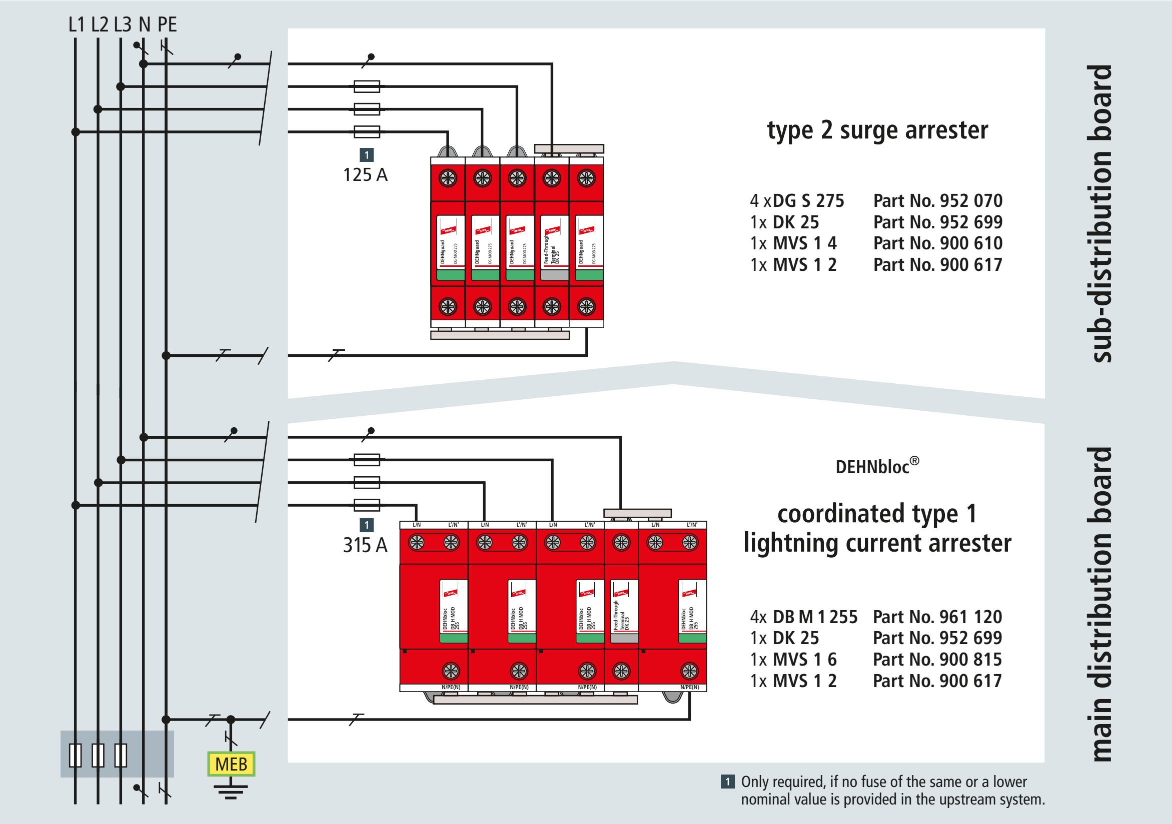


Figure 8.1.5.4 SPDs used in a 230/400 V IT system – With incorporated neutral conductor (3+1 circuit)

8.1.6 Determination of the correct connecting cable lengths for SPDs

The determination of the correct connecting cable lengths for surge protective devices is an integral part of the IEC 60364-5-53 (HD 60364-5-534) standard.

The aspects described below are also frequent reasons for complaints by experts, members of technical inspectorates, etc. who inspect the installation.

Series connection in accordance with IEC 60364-5-53 (HD 60364-5-534)

The impulse voltage level which is actually applied to the installations to be protected is crucial for protecting installations, equipment and loads. An optimum protective effect is achieved if the impulse voltage level at the installation to be protected is equal to the voltage protection level of the surge protective device.

Therefore, IEC 60364-5-53 (HD 60364-5-534) suggests to connect surge protective devices in series as shown in **Figure 8.1.6.1**. To this end, no separate cable branches are used for connecting the surge protective devices.

Parallel connection in accordance with IEC 60364-5-53 (HD 60364-5-534)

The optimal series connection cannot be used for all system conditions.

The nominal currents, which are conducted via the double terminals on the surge protective device in case of series connection, are limited by the thermal withstand capability of the double terminals. For this reason, the manufacturer of the surge protective device prescribes a certain maximum permissible value for the backup fuse which means that series connection can sometimes not be used for systems with higher nominal operating currents.

Meanwhile, so-called two-conductor or pin-shaped terminals are available which allow to better solve this problem. Thus, cables can be kept short, even if the nominal operating

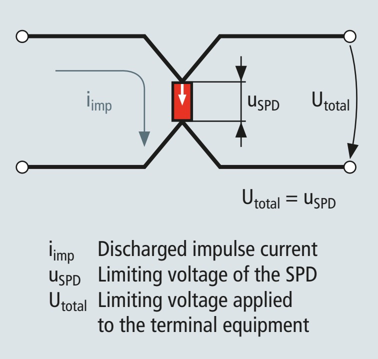


Figure 8.1.6.1 Surge protective devices connected in series

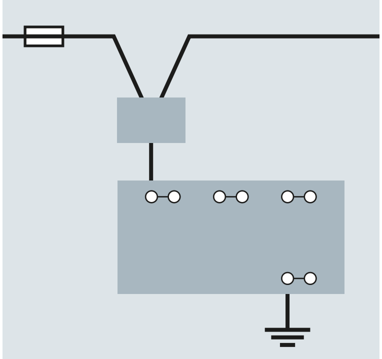


Figure 8.1.6.2 Principle of the two-conductor terminal (single-pole unit)

Figure 8.1.6.3 STAK 2X16 and STAK 25 pin-shaped terminals

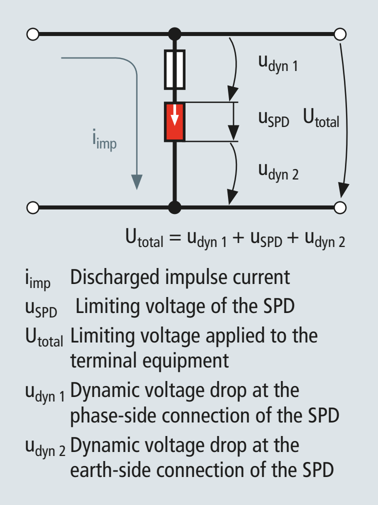
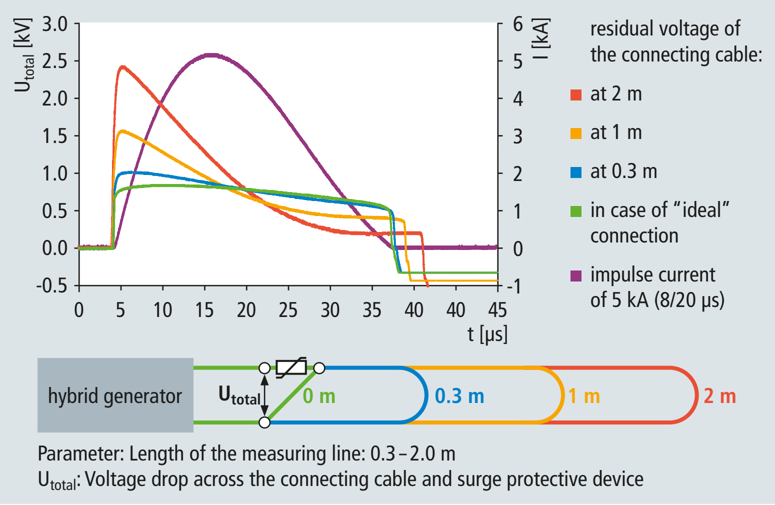


Figure 8.1.6.4a Connection of surge protective devices in the cable branch



Parameter: Length of the measuring line: 0.3 – 2.0 m
U_{total}: Voltage drop across the connecting cable and surge protective device

Figure 8.1.6.4b Limiting voltage of DEHNguard 275 in case of different connecting cable lengths

current is increased. However, when using the two-conductor terminals, the value of the backup fuse specified by the manufacturer for the particular application must always be observed (**Figures 8.1.6.2 and 8.1.6.3**).

If series connection is definitely no option, surge protective devices must be integrated in a separate cable branch of the circuit. If the nominal value of the next upstream fuse in the installation exceeds the nominal current of the maximum permissible backup fuse of the surge protective device, the cable branch must be equipped with a backup fuse for the surge protective device (**Figure 8.1.6.4a and b**) or SPDs with integrated backup fuse must be used (**Figures 8.1.6.5 and 8.1.6.6**).

When the surge protective device in the cable branch operates, the discharge current flows through further elements (conductors, fuses), causing additional dynamic voltage drops across these impedances.

In this case, the ohmic component is negligible compared to the inductive component.

Considering the relation

$$u_{dyn} = i \cdot R + \left(\frac{di}{dt}\right) L \approx \left(\frac{di}{dt}\right) L$$

Figure 8.1.6.5 DEHNbloc Maxi S: Coordinated lightning current arrester with integrated backup fuse for busbars

Figure 8.1.6.6 DEHNguard modular CI: Type 2 surge arrester with integrated backup fuse

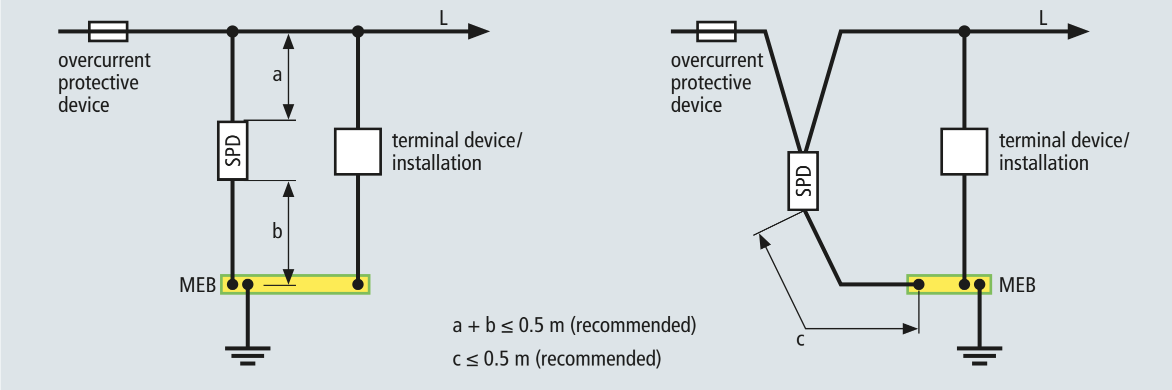


Figure 8.1.6.7 Recommended maximum cable lengths of surge protective devices in the cable branch (IEC 60364-5-53 (HD 60364-5-534))

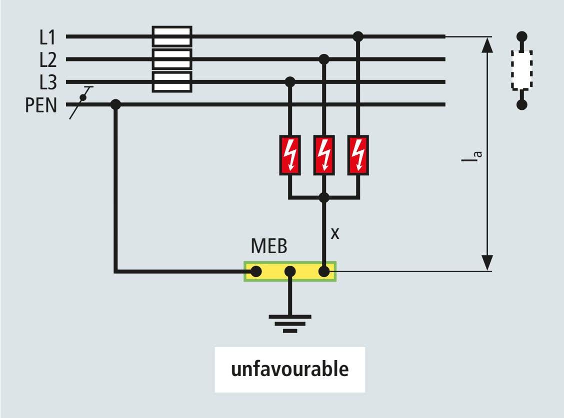


Figure 8.1.6.8a Unfavourable cable routing from the consumer's point of view

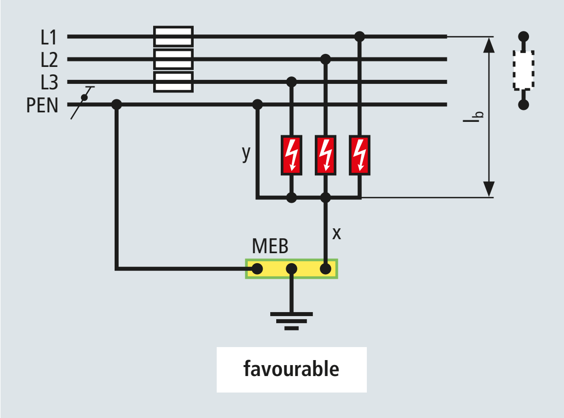


Figure 8.1.6.8b Favourable cable routing from the consumer's point of view

and the rate of current change (di/dt) for transient processes of some 10 kA/µs, the dynamic voltage drop U_{dyn} mainly depends on the inductive component.

In order to keep this dynamic voltage drop low, the electrician carrying out the work must keep the inductance of the connecting cable and thus its length as low as possible. Therefore, IEC 60364-5-53 (HD 60364-5-534) recommends that the total cable length of surge protective devices in cable branches should not exceed 0.5 m (**Figure 8.1.6.7**). According to IEC 60364-5-53 (HD 60364-5-534), it is mandatory to maintain a maximum cable length of 1 m. **Figure 8.1.6.4b** shows the effects of different connecting cables on the resulting voltage protection level of an arrangement.

Design of the earth-side connecting cable

This requirement, which seems to be difficult to implement, will be explained based on the example shown in **Figures 8.1.6.8a and b**. These show the protective equipotential bonding (previously: main equipotential bonding) of a low-voltage consumer's installation in accordance with IEC 60364-4-41 (HD 60364-4-41) and IEC 60364-5-54 (HD 60364-5-54). In this case, equipotential bonding becomes lightning equipotential bonding due to the use of type 1 surge protective devices.

In **Figure 8.1.6.8a**, both measures are installed separately. In this case, the PEN conductor is connected to the equipotential bonding bar and the surge protective devices are connected to earth via a separate equipotential bonding conductor.

Thus, the effective cable length (l_a) for the surge protective devices is the distance between the place of installation of the surge protective devices (e.g. service entrance box, main distribution board) and the equipotential bonding bar. In the majority of cases, such a connection configuration does not effectively protect the installation. However, the effective cable length of the surge protective devices ($l_b < 0.5$ m) can be reduced without great effort (**Figure 8.1.6.8b**).

This is achieved by using a "bypass" conductor (y) between the earth-side output of the arresters and the PEN conductor. The connection between the earth-side output of the arresters and the equipotential bonding bar (x) remains as it was.

According to the German VDN (Association of German Network Operators) guideline 2004-08: "Überspannungsschutzeinrichtungen Typ 1. Richtlinie für den Einsatz von Überspannungs – Schutzeinrichtungen (ÜSE) Typ 1 (bisher Anforderungsklasse B) in Hauptstromversorgungssystemen." [Surge Protective Devices Type 1 – Guideline for the use of surge protective devices (SPDs) Type 1 in main power supply systems], the bypass conductor (y) does not have to be used if the surge protective device is installed in close proximity (≤ 0.5 m) to the service entrance box and thus also in close proximity to the equipotential bonding system.

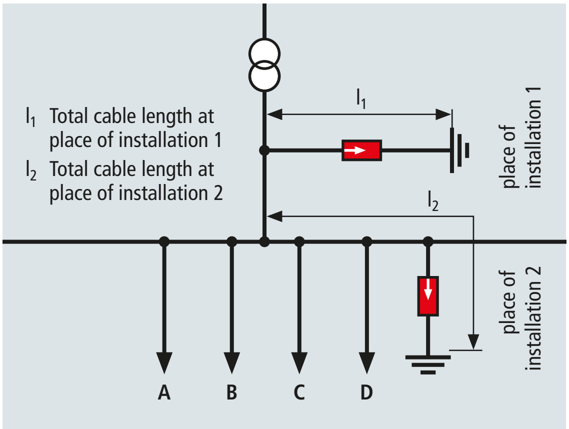


Figure 8.1.6.9 Arrangement of surge protective devices in an installation and the resulting effective cable length

Consequently, the distance between the service entrance box or main distribution board and the equipotential bonding bar is not important when installing the connection y. The solution to this problem only referred to the design of the earth-side connecting cable of the surge protective devices.

Design of the phase-side connecting cable

The length of the phase-side connecting cables must also be taken into consideration. This is explained based on the following example:

In a large-scale switchgear installation, surge protection must be provided for the busbar system and the circuits connected to it (A to D) including their loads (**Figure 8.1.6.9**).

To use surge protective devices in this case, places of installation 1 and 2 are assumed. Place of installation 1 is located directly at the infeed of the busbar system. This ensures that all loads are equally protected against surges. The effective cable length of the surge protective device at place of installation 1 is l_1 for all loads. If space is restricted, surge protective devices are sometimes installed along the busbar system. In extreme cases, place of installation 2 can be chosen for the arrangement shown in **Figure 8.1.6.9**. For circuits A and B, the effective cable length is l_2. Busbar systems have a lower inductance compared to cables and conductors (approx. 1/4) and thus a lower inductive voltage drop. However, the length of the busbars must not be disregarded.

The design of the connecting cables considerably influences the effectiveness of surge protective devices and must there-

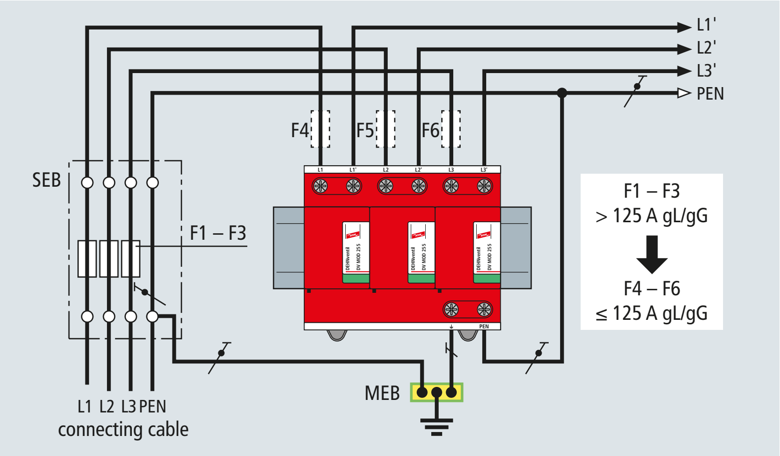


Figure 8.1.6.10 Series connection

Figure 8.1.6.11 Series connection of the DEHNventil M TNC combined arrester by means of a busbar

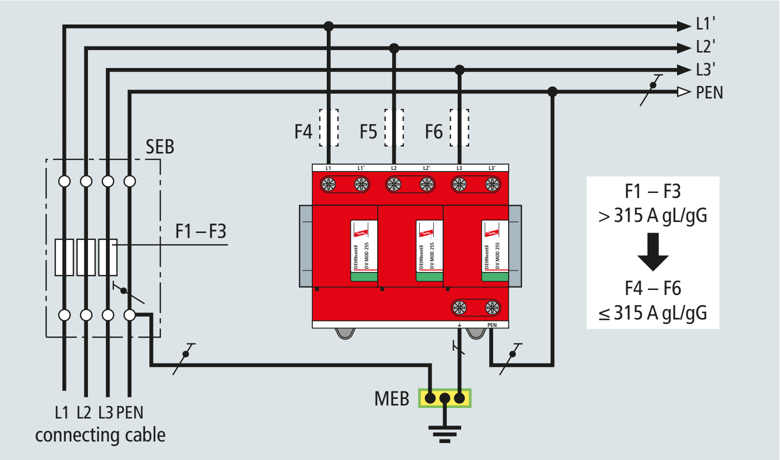


Figure 8.1.6.12 Parallel connection

fore be taken into consideration at the design stage of the installation! The contents of the IEC 60364-5-53 (HD 60364-5-534) standard described above were an important basis for developing the DEHNventil combined arrester which combines the requirements for lightning current and surge arresters according to IEC 62305 Part 1-4 (EN 62305 Part 1-4) in a single device.

This allows series connection directly via the device. **Figure 8.1.6.10** shows such a series connection in the form of a detailed wiring diagram.

In **Figure 8.1.6.11** it can be seen how advantageous it is to implement series connection with the help of a busbar.

Due to the thermal loading capacity of the double terminals used, series connection (also referred to as through-wiring) is possible up to 125 A.

In case of currents in the installation > 125 A, the surge protective devices are connected in the branch (parallel connection). In this context, the maximum cable lengths according to IEC 60364-5-53 (HD 60364-5-534) must be observed. Parallel connection can be implemented as shown in **Figure 8.1.6.12**.

It should be ensured that the earth-side connecting cable still profits from the double terminal for earth connection. As shown in **Figure 8.1.6.12**, an effective cable length l < 0.5 m can often be achieved without great effort by routing the terminal part "PE(N)" of the earth-side double terminal to the PEN conductor.

When installing surge protective devices in distribution boards, it must be generally observed that conductors carrying impulse currents and those not carrying impulse currents are routed as far as possible from each other. In any case, parallel routing of both conductors must be avoided (**Figure 8.1.6.13**).

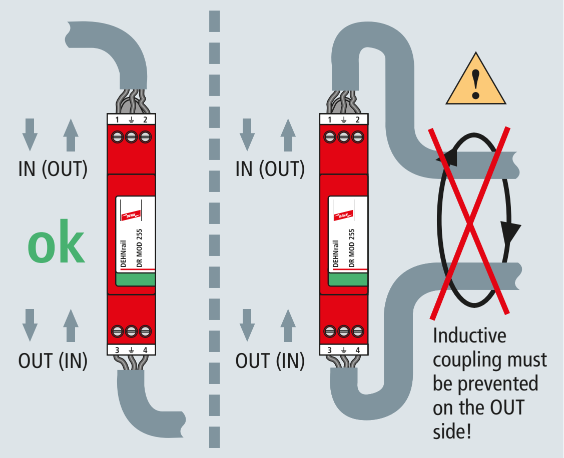


Figure 8.1.6.13 Cable routing

8.1.7 Rating of the cross-sectional areas and backup protection for surge protective devices

Connecting cables of arresters can be subjected to impulse currents, operating currents and short-circuit currents. The individual stress depends on various factors:

- Type of protective circuit: One-port (**Figure 8.1.7.1**) / two-port (**Figure 8.1.7.2**)
- Type of arrester: Lightning current arrester, combined arrester, surge arrester
- Performance of the arrester in case of follow currents: Follow current extinction / follow current limitation

If surge protective devices are installed as shown in **Figure 8.1.7.1**, the S2 and S3 connecting cables must only be rated according to the short-circuit protection criteria as outlined in IEC 60364-4-43 (HD 60364-4-43) and the impulse current carrying capability. The maximum permissible overcurrent protective device, which can be used as backup protection for the arrester in this application, is specified in the data sheet of the surge protective device.

When installing the devices, it must be ensured that the actually flowing short-circuit current trips the backup protection. The rating of the cross-sectional area of the conductor is calculated according to the following equation:

$$k^2 \cdot S^2 \geq I^2 \cdot t$$

t Permissible disconnection time in the event of a short-circuit in s

S Cross-sectional area of the conductor in mm^2

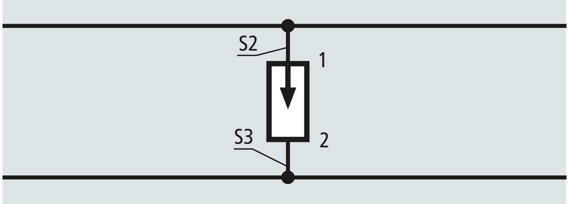


Figure 8.1.7.1 One-port SPD

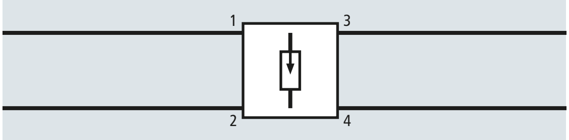


Figure 8.1.7.2 Two-port SPD

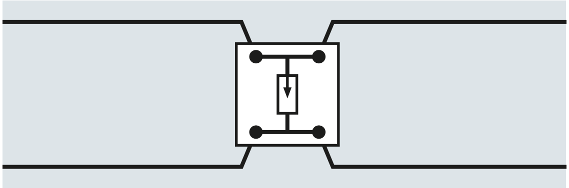


Figure 8.1.7.3 Through-wired one-port SPD

Conductor material	Insulation material		
	PVC	EPR / XLPE	Rubber
Cu	115	143	141
Al	76	94	93

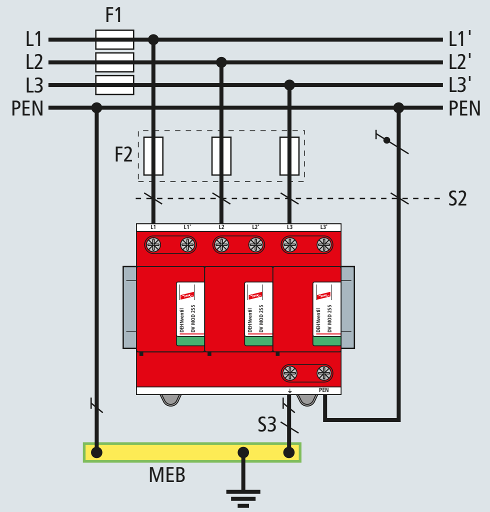
Table 8.1.7.1 Material coefficient k for copper and aluminium conductors with different insulating materials (as per IEC 60364-4-43)

I Current in case of a direct short-circuit in A

k Material coefficient in A · s/mm^2 according to **Table 8.1.7.1**

Furthermore, it must be observed that the information about the maximum permissible overcurrent protective devices in the data sheet of the surge protective device is only valid up to the value stated for the short-circuit withstand capability of the protective device. If the short-circuit current at the place of installation is greater than the value stated for the short-circuit withstand capability of the protective device, a backup fuse must be chosen which is smaller than the maximum backup fuse in the data sheet of the arrester by a ratio of 1:1.6.

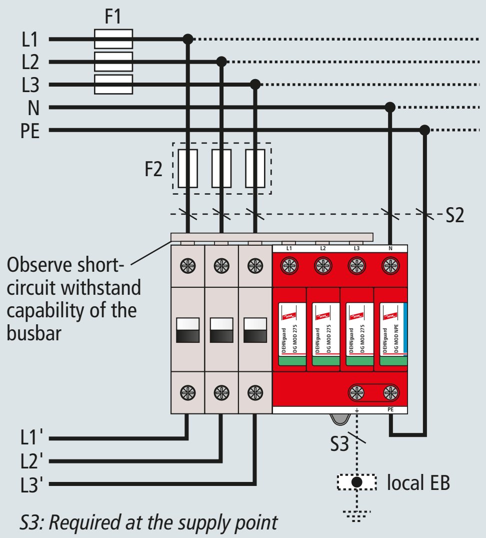
For surge protective devices installed as shown in **Figure 8.1.7.2**, the maximum operating current must not exceed the



DEHNventil DV M TNC 255	
F1	F1 > 315 A gL/gG ↓ F2 ≤ 315 A gL/gG
F2	F1 ≤ 315 A gL/gG ↓ ~~F2~~

Fuse F1 A gL/gG	**S2**/mm^2	**S3**/mm^2	**Fuse F2** A gL/gG
25	10	16	---
35	10	16	---
40	10	16	---
50	10	16	---
63	10	16	---
80	10	16	---
100	16	16	---
125	16	16	---
160	25	25	---
200	35	35	---
250	35	35	---
315	50	50	---
> 315	50	50	≤ 315

Figure 8.1.7.4 Example: DEHNventil M TNC 255



S3: Required at the supply point

DEHNguard M TNC 275 **DEHNguard** M TNS 275 **DEHNguard** M TT 275	
F1	F1 > 125 A gL/gG ↓ F2 ≤ 125 A gL/gG
F2	F1 ≤ 125 A gL/gG ↓ ~~F2~~

Fuse F1 A gL/gG	**S2**/mm^2	**S3**/mm^2	**Fuse F2** A gL/gG
35	4	6	---
40	4	6	---
50	6	6	---
63	10	10	---
80	10	10	---
100	16	16	---
125	16	16	---
>125	16	16	125

Figure 8.1.7.5 Example: DEHNguard M TNC/TNS/TT

nominal load current specified for the protective device. The maximum current for through-wiring applies to protective devices which can be connected in series (**Figure 8.1.7.3**).

Figure 8.1.7.4 shows examples of cross-sectional areas and backup protection for lightning current arresters and type 1 combined arresters, **Figure 8.1.7.5** for type 2 surge protective devices and **Figure 8.1.7.6** for type 3 surge protective devices.

When dimensioning the backup fuses for surge protective devices, the impulse current behaviour must be taken into consideration. There is a noticeable difference in the way fuses disconnect short-circuit currents compared to the way they disconnect impulse currents, particularly lightning impulse currents of 10/350 μs wave form.

The behaviour of fuses was determined as a function of the rated current and the impulse current (**Figure 8.1.7.7 and Table 8.1.7.2**).

Field 1: No melting

The energy injected into the fuse by the lightning impulse current is too low to melt the fuse.

Field 2: Melting

The energy of the lightning impulse current is sufficient to melt the fuse and interrupt the current path by means of the fuse (**Figure 8.1.7.8**).

It is characteristic of the performance of the fuse that the lightning impulse current still flows unaffected by the performance of the fuse since it is injected. The fuse trips only after the lightning impulse current has decayed. Thus, the fuses are not selective with respect to the disconnection of lightning impulse currents. Therefore, it must be ensured that the maximum permissible backup fuse according to the data sheet and/or installation instructions of the protective device is always used due to the impulse current behaviour.

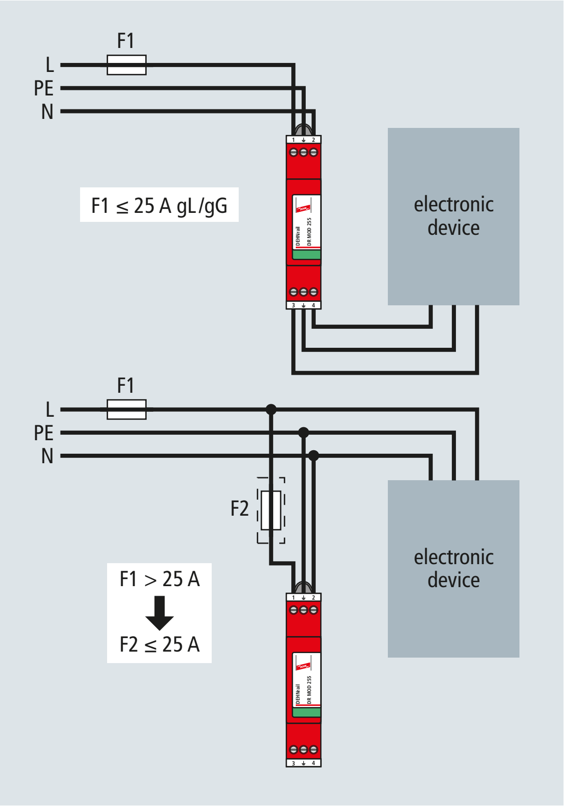


Figure 8.1.7.6 Example: DEHNrail

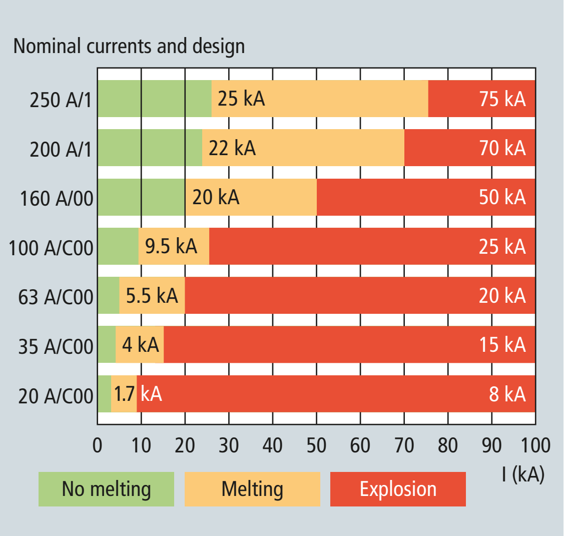


Figure 8.1.7.7 Performance of NH fuses when subjected to impulse currents (10/350 μs)

Nominal values of the NH fuse		Tripping value calculated in case of impulse currents (8/20 μs) kA
I_n A	I^2t_{min} A^2s	
35	3 030	14.7
63	9 000	25.4
100	21 200	38.9
125	36 000	50.7
160	64 000	67.6
200	104 000	86.2
250	185 000	115.0

Table 8.1.7.2 Impulse current carrying capability of NH fuses when subjected to impulse currents (8/20 μs)

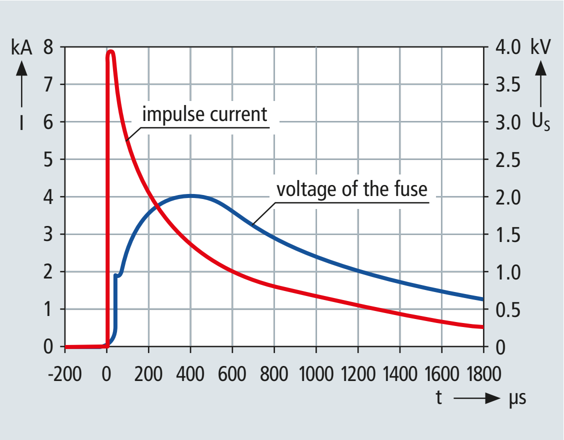


Figure 8.1.7.8 Current and voltage of a melting 25 A NH fuse when subjected to impulse currents (10/350 μs)

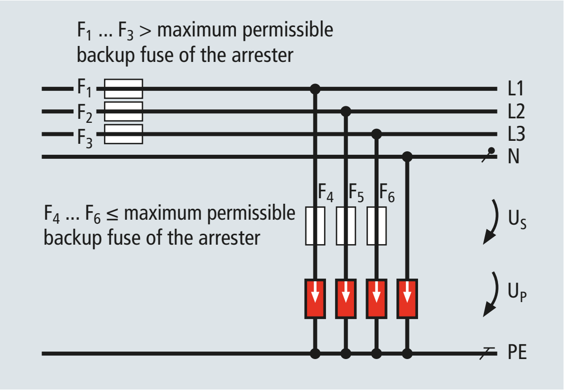


Figure 8.1.7.9 Use of a separate backup fuse for surge protective devices

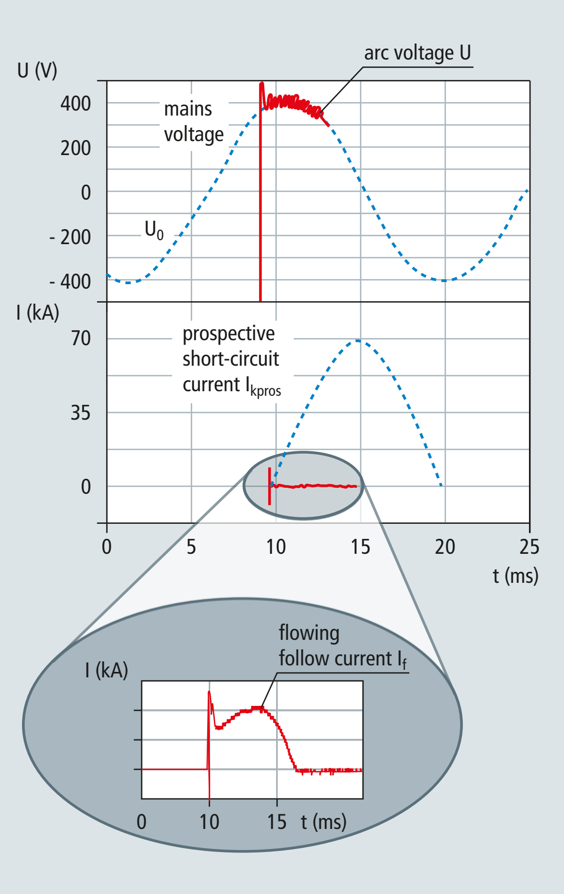


Figure 8.1.7.10 Reduction of the follow current by means of the patented RADAX Flow principle

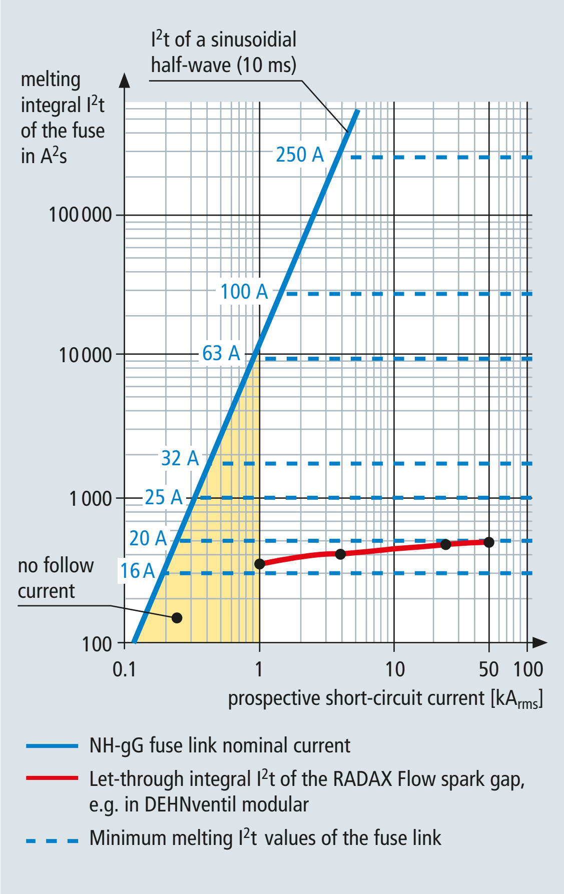


Figure 8.1.7.11 Follow current disconnection selectivity of DEHNventil M with respect to NH fuse links with different rated currents

In **Figure 8.1.7.8** it can also be seen that, during the melting process, a voltage drop U_S builds up across the fuse which can sometimes significantly exceed 1 kV. For applications as illustrated in **Figure 8.1.7.9**, the resulting voltage protection level $U_S + U_P$ can be significantly higher than the voltage protection level U_P of the surge protective device used due to the melting of the fuse.

Field 3: Explosion

If the energy of the lightning impulse current is so high that it significantly exceeds the melting integral of the fuse, the fuse strip can vaporise explosively. This often leads to the bursting of the fuse enclosure. Apart from the mechanical effects, it must be observed that the lightning impulse current continues to flow via the bursting fuse in the form of an electric arc. The lightning impulse current thus cannot be interrupted and the required impulse current carrying capability of the arrester used cannot be reduced.

Selectivity with respect to the protection of the installation

When using spark-gap based surge protective devices, it must be considered that mains follow currents are limited to such an extent that overcurrent protective devices such as cable protection fuses and / or arrester backup fuses cannot trip. This is called follow current limitation or follow current suppression. Only technologies such as the RADAX Flow technology allow the development of arresters and arrester combinations which, even in case of installations with high short-circuit currents, are able to reduce and extinguish the prospective short-circuit current to such an extent that upstream fuses with low rated currents do not trip (**Figure 8.1.7.10**).

Figure 8.1.8.1 DEHNguard M TNC CI 275 FM – Type 2 arrester with integrated backup fuse

Figure 8.1.8.2 Inner structure of the DEHNguard M/S … CI (front and rear view)

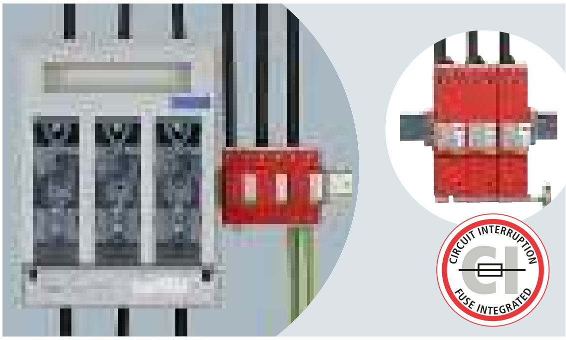


Figure 8.1.8.3 Considerably reduced space requirements – Comparison of the installation space of a conventional type 1 arrester with that of DEHNvenCI

The availability of installations required by the IEC 61439-1 (EN 60439-1) standard, even if surge protective devices operate, can be ensured by means of the "follow current suppression" described before. Particularly for surge protective devices with a low sparkover voltage which are supposed to ensure lightning equipotential bonding and surge protection in the installation, the performance of the follow current limitation is more important than ever for the availability of the electrical installation. In **Figure 8.1.7.11** it can be seen that even in case of a prospective short-circuit current of 50 kA$_{rms}$, the let-through integral of the RADAX Flow spark gap is below the minimum threshold value of a NH-gG fuse link with a rated current of 20 A.

8.1.8 Surge arrester with integrated backup fuse

When choosing backup fuses for surge protective devices, two dimensioning criteria must be observed:

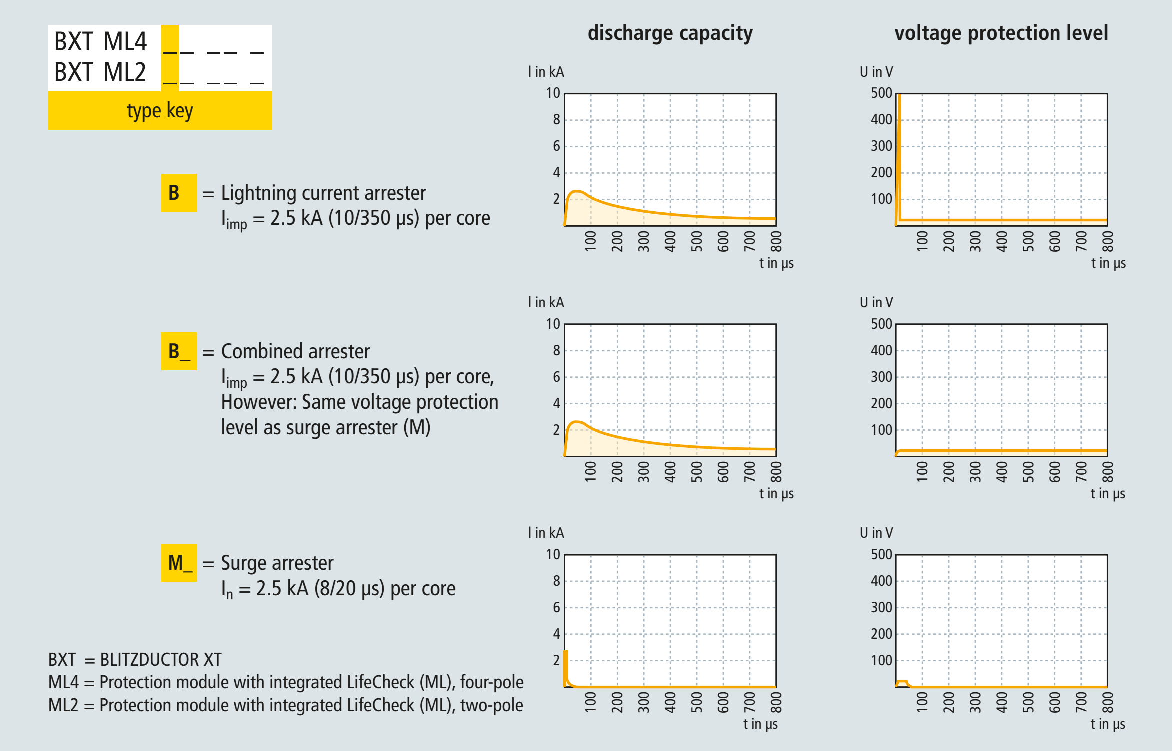
- Maximum value of the backup fuse specified by the manufacturer
- Impulse current carrying capability of the backup fuse

This can be effectively and easily implemented by using surge protective devices with integrated backup fuse.

DEHN offers different type 1 and type 2 arresters where the backup fuse is already integrated in the surge protective device such as DEHNvenCI and DEHNguard M/S … CI (**Figures 8.1.8.1 to 5.1.8.3**). These DIN rail mounted arresters offer various benefits for the user:

- No need for an additional backup fuse since the backup fuse is integrated in the arrester
- Considerably reduced space requirements (**Figure 8.1.8.3**)
- Significantly less installation effort
- Monitoring of the integrated arrester backup fuse by means of an operating state / fault indication and remote signalling contact
- Easy implementation of short connecting cable lengths according to IEC 60364-5-53 (HD 60364-5-534)
- Available for all systems configurations (TNC, TNS, TT, single-pole systems)

Arresters with integrated backup fuse offer many advantages such as minimum space requirements and ease of installation.



B = Lightning current arrester
I_{imp} = 2.5 kA (10/350 µs) per core

B_ = Combined arrester
I_{imp} = 2.5 kA (10/350 µs) per core,
However: Same voltage protection level as surge arrester (M)

M_ = Surge arrester
I_n = 2.5 kA (8/20 µs) per core

BXT = BLITZDUCTOR XT
ML4 = Protection module with integrated LifeCheck (ML), four-pole
ML2 = Protection module with integrated LifeCheck (ML), two-pole

Figure 8.2.1 SPD classification

Moreover, no detailed knowledge of dimensioning criteria for arrester backup fuses is required since the backup fuse is already integrated in and perfectly adapted to the arrester.

8.2 Information technology systems

The main function of arresters is to protect downstream terminal devices. They also reduce the risk of cable damage.
The selection of arresters depends, among other things, on the following criteria:

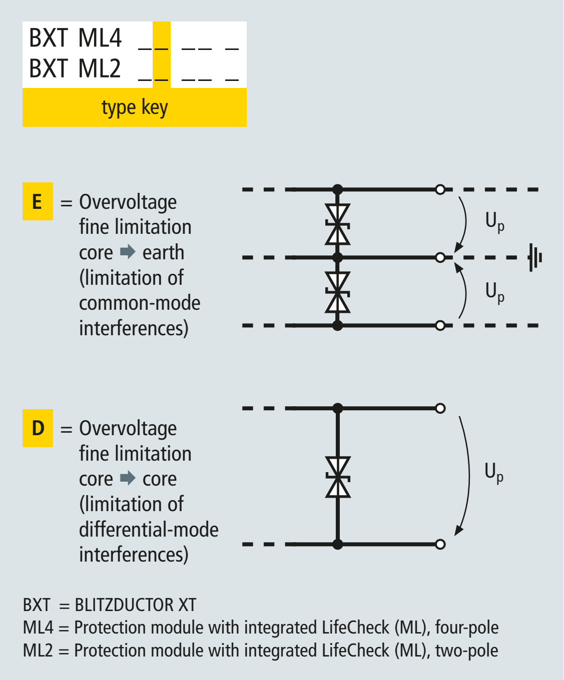
- Lightning protection zones of the place of installation, if any
- Energies to be discharged
- Arrangement of the protective devices
- Immunity of the terminal devices
- Differential-mode and / or common-mode protection
- System requirements, e.g. transmission parameters
- Compliance with product or application-specific standards, if required
- Adaption to environmental / installation conditions

Protective devices for antenna cables are classified according to their suitability for coaxial, balanced or waveguide cable systems, depending on the physical design of the antenna cable.
In case of coaxial and waveguide cable systems, the phase conductor can be connected directly to the equipotential bonding system. Earthing sleeves specifically adapted to the relevant cable can be used for this purpose.

Procedure for selecting and installing arresters based on the example of BLITZDUCTOR XT

Opposite to the selection of surge protective devices for power supply systems (see chapter 8.1) where uniform conditions can be expected with respect to the voltage and frequency in 230/400 V systems, the types of signal to be transmitted in automation and measuring and control systems differ with respect to their

- Voltage (e.g. 0 – 10 V)
- Current (e.g. 0 – 20 mA, 4 – 20 mA)
- Type of signal transmission (balanced, unbalanced)
- Frequency (DC, LF, HF)

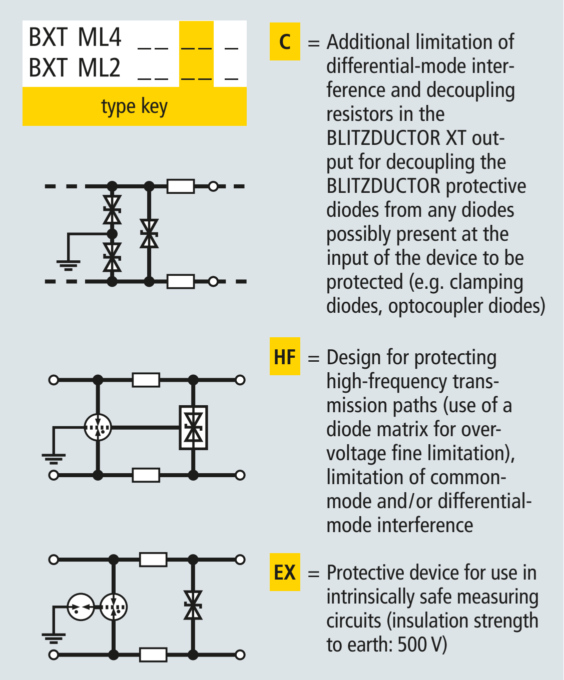


E = Overvoltage fine limitation core ➡ earth (limitation of common-mode interferences)

D = Overvoltage fine limitation core ➡ core (limitation of differential-mode interferences)

BXT = BLITZDUCTOR XT
ML4 = Protection module with integrated LifeCheck (ML), four-pole
ML2 = Protection module with integrated LifeCheck (ML), two-pole

Figure 8.2.2 Limiting performance

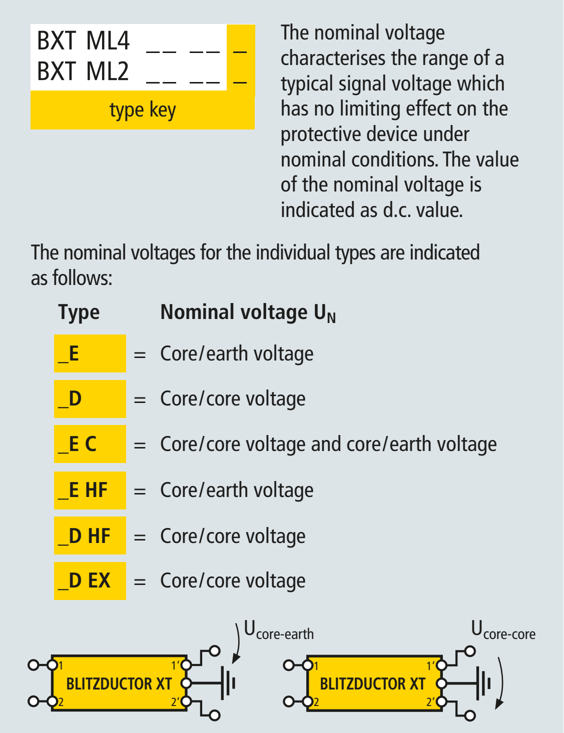


C = Additional limitation of differential-mode interference and decoupling resistors in the BLITZDUCTOR XT output for decoupling the BLITZDUCTOR protective diodes from any diodes possibly present at the input of the device to be protected (e.g. clamping diodes, optocoupler diodes)

HF = Design for protecting high-frequency transmission paths (use of a diode matrix for overvoltage fine limitation), limitation of common-mode and/or differential-mode interference

EX = Protective device for use in intrinsically safe measuring circuits (insulation strength to earth: 500 V)

Figure 8.2.3 Special applications



The nominal voltage characterises the range of a typical signal voltage which has no limiting effect on the protective device under nominal conditions. The value of the nominal voltage is indicated as d.c. value.

The nominal voltages for the individual types are indicated as follows:

Type		Nominal voltage U_N
_E	=	Core/earth voltage
_D	=	Core/core voltage
_E C	=	Core/core voltage and core/earth voltage
_E HF	=	Core/earth voltage
_D HF	=	Core/core voltage
_D EX	=	Core/core voltage

Figure 8.2.4 Nominal voltage and reference

➡ Type of signal (analogue, digital)

Each of these electrical parameters for the useful signal to be transmitted can contain the actual information to be transferred.

Therefore, the useful signal must not be impermissibly influenced by lightning current and surge arresters in measuring and control systems. In this context, several points must be taken into account when selecting protective devices for measuring and control systems. In the following, these points are described for our universal BLITZDUCTOR XT surge protective devices and are illustrated based on sample applications (**Figures 8.2.1 to 8.2.4 and Table 8.2.1**).

Type designation of protection modules

C	Additional limitation of differential-mode interference and decoupling resistors in the BLITZDUCTOR XT output for decoupling the BLITZDUCTOR protective diodes from any diodes possibly present at the input circuit of the device to be protected (e.g. clamping diodes, optocoupler diodes)
HF	Design for protecting high-frequency transmission paths (use of a diode matrix for overvoltage fine limi-

ML4 B	180	ML2 B	180
ML4 BE	5 12 24 36 48 60 180	ML2 BE S	5 12 24 36 48
ML4 BD	5 12 24 48 60 180	ML2 BD S	5 12 24 48 180
ML4 BC	5 24		
ML4 BE C	12 24		
ML4 BE HF	5	ML2 BE HFS	5
ML4 BD HF	5 24	ML2 BD HFS	5
ML4 MY	110 250	ML2 MY	110 250
		ML2 BD DL S	15
ML4 BD EX	24	ML2 BD S EX	24
ML4 BC EX	24		
		ML2 BD HF EX	6

Table 8.2.1 Type designation of BXT protection modules

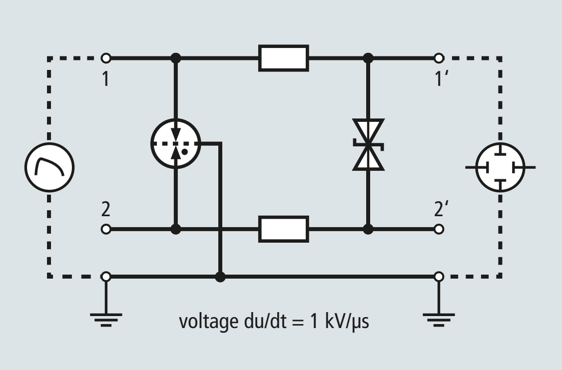


Figure 8.2.5 Test setup for determining the limiting voltage at a rate of voltage rise du/dt = 1 kV/µs

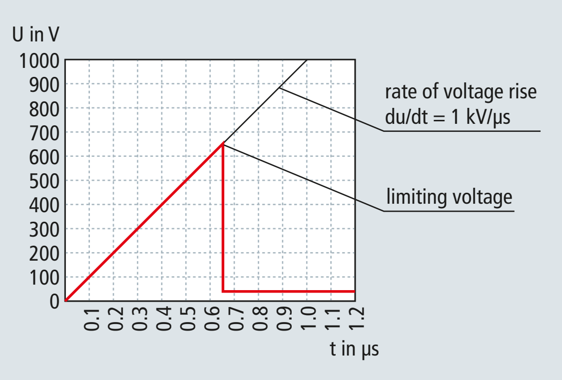


Figure 8.2.6 Sparkover performance of a gas discharge tube at du/dt = 1 kV/µs

tation), limitation of common-mode and differential-mode interference

EX Protective device for use in intrinsically safe measuring circuits with ATEX, IECEx and FISCO approval (insulation strength to earth of 500 V a.c.)

Technical data

Voltage protection level U_p

The voltage protection level is a parameter that characterises the performance of a surge protective device which limits the voltage across its terminals. The specified voltage protection level must be higher than the maximum value of the limiting voltages measured.

The limiting voltage measured is the maximum voltage measured at the terminals of the surge protective device when exposed to impulse currents and / or impulse voltages of a certain wave form and amplitude.

Limiting voltage in case of a steepness of the test voltage wave form of 1 kV/µs

This test is carried out to determine the sparkover performance of gas discharge tubes (GDT). These protection elements have a “switching characteristic”. The functional principle of a GTD can be compared to that of a switch whose resistance can “automatically“ switch from values > 10 GΩ (in a non-ignited state) to values < 0.1 Ω (in an ignited state) when a certain voltage value is exceeded so that the surge applied is almost short-circuited. The voltage value, at which the GDT trips, depends on the rate of rise of the incoming voltage wave (du/dt).

The following generally applies: The higher du/dt, the higher is the sparkover voltage of the gas discharge tube. To compare the sparkover values of the different gas discharge tubes, a voltage with a rate of rise of 1 kV/µs is applied to the electrodes of the gas discharge tube to determine the dynamic sparkover voltage (**Figures 8.2.5 and 8.2.6**).

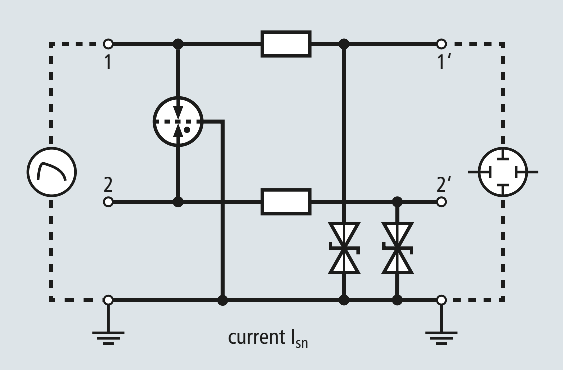


Figure 8.2.7 Test setup for determining the limiting voltage in case of nominal discharge currents

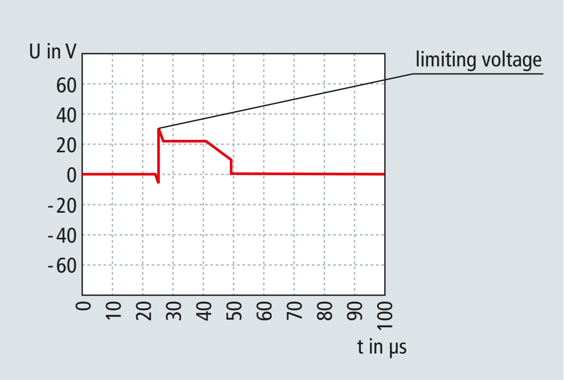


Figure 8.2.8 Limiting voltage in case of nominal discharge currents

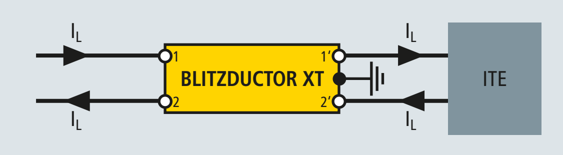


Figure 8.2.9 Nominal current of BLITZDUCTOR XT

Type	I_L at 45 °C	Type	I_L at 45 °C
B	1.2 A		
BE	0.75 A / 1 A	BD	0.75 A / 1 A
BC	0.75 A / 1 A	BE C	0.1 A
BE HF	1 A	BD HF	1 A
MY	3 A	BD DL S	0.4 A
		BD EX	0.5 A
		BD HF EX	4.8 A

Table 8.2.2 Maximum nominal currents of the BXT protection modules

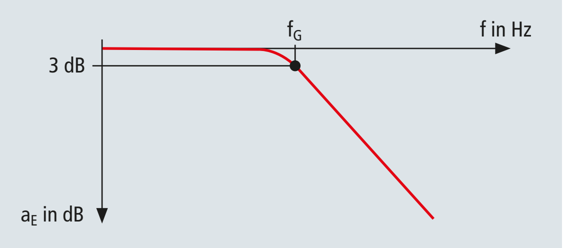


Figure 8.2.10 Typical frequency response of a BLITZDUCTOR XT

Limiting voltage in case of nominal discharge currents

This test is carried out to determine the limiting behaviour of protection elements with constant limiting characteristics (**Figures 8.2.7 and 8.2.8**).

Nominal current I_L

The nominal current of BLITZDUCTOR XT characterises the permissible operating current of the measuring circuit to be protected. The nominal current of BLITZDUCTOR XT is determined by the current carrying capability and the insertion loss of the impedances used for decoupling between the gas discharge tubes and fine protection elements as well as by the follow current extinguishing capability of the gas discharge tubes. The nominal current is stated as d.c. value (**Figure 8.2.9**).
Examples of the maximum nominal currents of the individual BLITZDUCTOR XT protection modules are listed in **Table 8.2.2**.

Cut-off frequency f_G

The cut-off frequency describes the frequency-dependent behaviour of an arrester. The cut-off frequency is the frequency which causes an insertion loss (a_E) of 3 dB under certain test conditions (see IEC 61643-21 (EN 61643-21)) (**Figure 8.2.10**). Unless specified otherwise, the specified frequency refers to a 50 ohm system.

Selection criteria (SC)

1. Which discharge capacity is required?

The discharge capacity of BLITZDUCTOR XT depends on the protective task the arrester must fulfil. To facilitate selection, the following cases a to d are explained.

Case a

In this case, the terminal device to be protected is located in a building with an external lightning protection system or the roof of the building is equipped with metal roof-mounted structures which are prone to lightning strikes (e.g. antenna masts, air-conditioning systems). The measuring and control or telecommunications cable connecting the terminal device (**Figure 8.2.11**) to a measuring transducer in the field is mounted outside the building. Since the building is fitted with an external lightning protection system, a type 1 lightning current arrester must be installed. Lightning current arresters or combined arresters (type 1) of the BLITZDUCTOR XT family can be used for this purpose.

Case b

Case b is similar to case a, however, the building in which the terminal device to be protected is located has no external lightning protection system: In this case, it is not to be expected that direct lightning currents occur. A lightning current carrying type 1 arrester only has to be installed if the measuring and control cable can be influenced by lightning strikes to adjacent buildings, namely if the cable carries partial lightning currents. If this can be excluded, type 2 surge protective devices are used (**Figure 8.2.12**).

Case c

In case c, no measuring and control / telecommunications cable is installed outside the building. Although the building is fitted with an external lightning protection system, direct lightning currents cannot be injected into this part of the telecommuni-

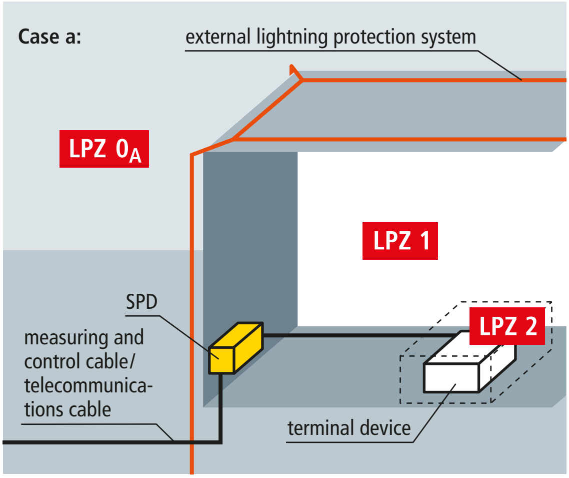


Figure 8.2.11 Building with external lightning protection system and cables installed outside the building according to the lightning protection zone concept

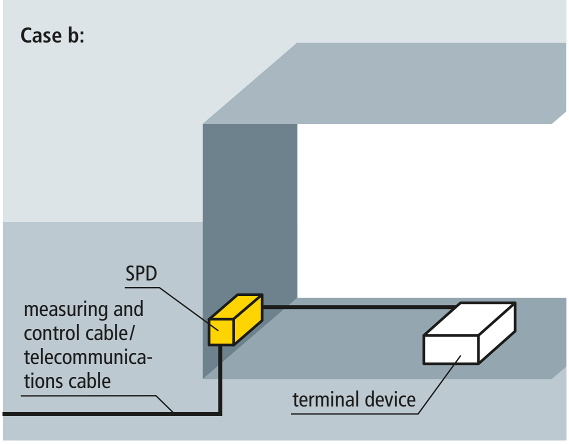


Figure 8.2.12 Building without external lightning protection system and cables installed outside the building

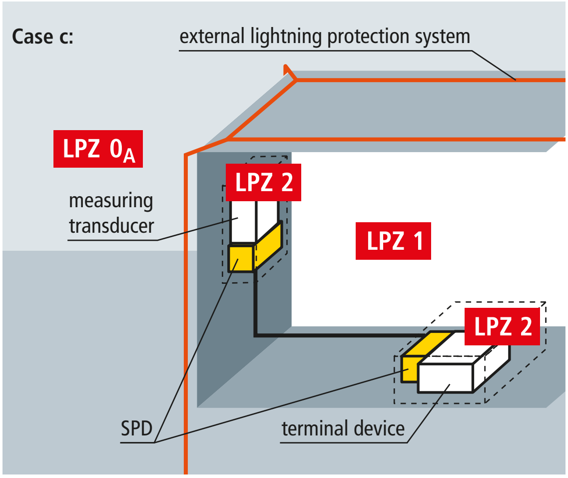


Figure 8.2.13 Building with external lightning protection system and cables installed inside the building according to the lightning protection zone concept

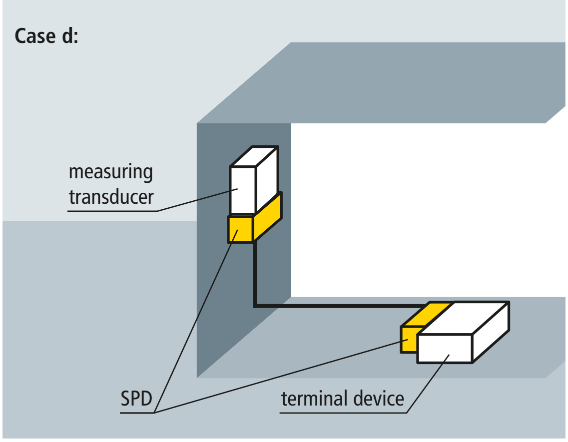


Figure 8.2.14 Building without external lightning protection system and cables installed inside the building

cations system. Therefore, surge arresters are installed in this case. BLITZDUCTOR XT combined arresters for protecting terminal devices can also be used (**Figure 8.2.13**).

Case d

The difference between case d and case c is that the relevant building has no external lightning protection system and no measuring and control / telecommunications cables are installed outside the building. Therefore, only surge arresters must be installed to protect the devices. As in cases b and c, combined arresters of the BLITZDUCTOR XT family can be used (**Figure 8.2.14**).

2. Which interference phenomena have to be prevented?

Interference is basically classified into **common-mode** and **differential-mode interference**. **Common-mode interference** always occurs **between the signal line and earth**, whereas **differential-mode interference** only occurs **between two signal lines**. Most of the interference occurring in signal circuits is common-mode interference. Therefore, protective devices with overvoltage fine limitation between the signal core and earth should be selected (**type …E**). Some input stages of devices such as isolating transformers do not require overvoltage fine limitation between the signal core and earth. In this case, only gas discharge tubes provide protection against common-mode interference. Due to their different tripping characteristics, tripped gas discharge tubes may develop differential-mode interference into common-mode interference. Therefore, a fine protection element is integrated between the signal cores in this case (**type ...D**).

3. Are there special requirements for adopting the protective circuit to the input circuit of the device to be protected?

In some cases, it is necessary to protect the device inputs against common-mode and differential-mode interference. The input stages of such electronic devices requiring protection are normally fitted with their own protective circuit or contain optocoupler inputs to isolate the potential of of the signal circuit and internal circuit of the automation device. This requires additional measures to decouple BLITZDUCTOR XT from the input circuit of the device to be protected. For this purpose, additional decoupling elements between the fine protection elements and output terminals of BLITZDUCTOR XT are used.

4. How high is the signal frequency / data transmission rate which must be transmitted?

The protective circuit of BLITZDUCTOR XT has low-pass characteristics. The cut-off frequency indicates the frequency value above which the amplitude of the signal to be transmitted is attenuated (above 3 dB). In order to keep the reaction of BLITZDUCTOR XT to the transmission system within permissible limits, the signal frequency of the signal circuit must be below the cut-off frequency for BLITZDUCTOR XT. The cut-off frequency is indicated for sine-shaped signals. However, sine-shaped signals are not very common in data transmission. In this context, it must be observed that the maximum data transmission rate of BLITZDUCTOR XT is higher than the transmission speed of the signal circuit. When transmitting pulse-shaped signals for which the rising or decreasing edge of the pulse is evaluated, it must be considered that this edge switches from "Low" to "High" or from "High" to "Low" within a certain period of time. This time interval is important for the identification of an edge and for crossing "restricted areas". Therefore, this signal requires a frequency bandwidth which is significantly wider than the fundamental wave of this oscillation. Thus, the cut-off frequency for the protective device must be correspondingly set high. As a general rule, the cut-off frequency must not be less than five times the fundamental wave.

5. How high is the operating current of the system to be protected?

Due to the electrical properties of the components used in the protective circuit of BLITZDUCTOR XT, the operating current which can be transmitted via the protective device is limited. For the application, this means that the operating current of a signalling system may be less than or equal to the nominal current of the protective device. In this context, possible short-circuit currents must be considered and limited by adequate measures (e.g. backup fuses) in the circuit of the installation.

6. What is the maximum operating voltage which can occur in the system to be protected?

The maximum operating voltage which occurs in the signal circuit must be less than or equal to the maximum continuous operating voltage U_C of BLITZDUCTOR XT so that the protective device has no limiting effect under normal operating conditions.

The maximum operating voltage occurring in a signal circuit is typically the nominal voltage of the transmission system when tolerances are taken into account. If current loops (e.g. 0 – 20 mA) are used, the open-circuit voltage of the system can always be employed as maximum operating voltage.

7. Which reference has the maximum operating voltage?

Different signal circuits require different types of signal transmission (balanced / unbalanced). On one hand, the operating voltage of the system can be provided as core / core voltage and on the other hand as core / earth voltage. This must be considered when choosing the protective devices. Due to the different circuits of the fine protection elements in the

BLITZDUCTOR XT protection module, different nominal voltages are given. These are shown in **Figure 8.2.4 and Table 8.2.1**.

8. Does the switching of the decoupling impedances of BLITZDUCTOR XT to the signal circuit have any effects on the signal transmission?

Decoupling impedances are integrated to coordinate the protection elements in BLITZDUCTOR XT. They are located directly in the signal circuit and may therefore have an effect on it. Particularly in case of current loops (0–20 mA, 4–20 mA), the maximum load on the signal circuit can be exceeded as soon as BLITZDUCTOR XT operates if the signal circuit is already being operated at its maximum load. This must be taken into consideration before installation!

9. Which protective effect is required?

In principle, it is possible to dimension the voltage protection level for a surge protective device in such a way that it is below the destruction limit of an automation/telecommunications equipment. However, the problem with this type of dimensioning consists in the fact that the destruction limit for a terminal device is often not known. It is therefore necessary to use other comparison criteria in this case. As part of the test for electromagnetic compatibility (EMC), electrical and electronic equipment must have a certain immunity to pulse-shaped conducted interference. The requirements for these tests and the test setups are described in IEC 61000-4-5 (EN 61000-4-5). Different test levels are defined with respect to the immunity to pulse-shaped interference for the various devices used under varying electromagnetic environmental conditions. These test levels range from 1 to 4, whereas test level 1 has the lowest immunity requirements on the devices to be protected and test level 4 ensures the highest immunity requirements of a device. For the protective effect of a surge protective device, this means that the "let-through energy" related to the voltage protection level must be so low that it is below the specified immunity level of the device to be protected. Therefore, Yellow/Line products were subdivided into SPD classes (**Table 7.8.2.1**) to facilitate coordinated installation of the arresters for protecting automation devices. The surge immunity test for these devices was taken as a basis for determining the SPD class symbols. If, for example, an automation device is tested with test level 1, the surge protective device may only have a "let-through energy" corresponding to this interference level. In practice, this means that automation devices tested with test level 4 can only discharge surges without damaging the equipment if the output of the surge protective device has a voltage protection level according to test level 1, 2, 3, or 4. This makes it very easy for the user to choose suitable surge protective devices.

10. Shall a one-stage or two-stage protection be used in the installation?

Depending on the infrastructure of the building and the protection requirements resulting from the lightning protection zone concept, it may be necessary to install lightning current and surge arresters so that they are spatially separated or alternately at one point of the installation by means of a combined arrester. In the first case, a BLITZDUCTOR XT with a protection module of type BXT ML … B is installed as lightning current arrester and an upstream arrester as surge arrester. If lightning and surge protection measures are required at the same point of the installation, a BLITZDUCTOR XT of type BE… or BD… can be used.

Note: The following solution examples show the selection of surge protective devices of the BLITZDUCTOR XT family with the help of the 10 selection criteria (SC). The result of every single selection step is shown in the "intermediate result" column. The "final result" column shows the effect of the relevant intermediate result on the total result.

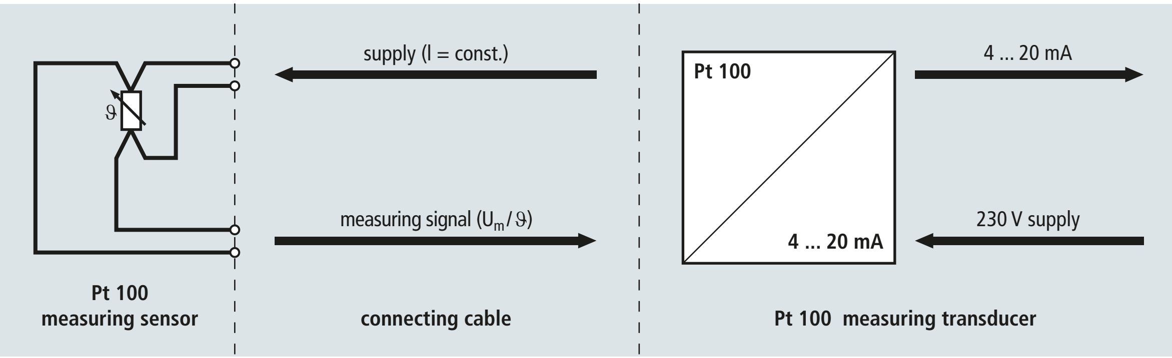


Figure 8.2.15 Block diagram for the temperature measurement

SC	Case description	Intermediate result	Final result
1	The measuring sensor is situated at a process frame in a production facility and the measuring transducer in a control room inside the production building which is not equipped with an external lightning protection system. The measuring lines are routed inside the building. This example corresponds to **case d (Figure 8.2.14)**.	BLITZDUCTOR XT BXT ML4 B...	BLITZDUCTOR XT BXT ML4 B...
2	The surge threat to the Pt 100 measuring sensors and Pt 100 measuring transducer arises between signal core and earth. This requires **fine limitation of common-mode interference**.	BLITZDUCTOR XT BXT ML4 BE	BLITZDUCTOR XT BXT ML4 BE
3	There are no special requirements to adjust the protective circuit to the input circuit of the devices to be protected (Pt 100, Pt 100 measuring transducer).	No impact	BLITZDUCTOR XT BXT ML4 BE
4	The temperature measuring equipment to be protected is a system supplied with direct current. The temperature-dependent measuring voltage is also a d.c. voltage. Thus, no signal frequencies have to be considered.	No impact	BLITZDUCTOR XT BXT ML4 BE
5	The physical measuring principle of Pt 100 limits the operating current of the supply circuit to 1 mA. The operating current of the measuring signal is in the µA range due to the extremely high-impedance measurement tap.	I_L of type BE = at least 0.75 kA 1 mA < 0.75 A ➡ ok µA < 0.75 A ➡ ok	BLITZDUCTOR XT BXT ML4 BE
6	The maximum operating voltage in this system results from the following consideration: According to IEC 60751, Pt 100 measuring resistors are designed for a maximum temperature up to 850 °C. The respective resistance is 390 Ω. Considering the load-independent measuring current of 1 mA, a measuring voltage of **approx. 390 mV** occurs.	BLITZDUCTOR XT BXT ML4 ... 5V	BLITZDUCTOR XT BXT ML4 BE 5
7	The operating voltage of the system arises from **core to core**.	BXT ML4 BE 5 has a nominal voltage of 5 V d.c. core ➡ earth, thus 10 V d.c. core ➡ core, possible ➡ No impact on the measuring signal	BLITZDUCTOR XT BXT ML4 BE 5
8	When using the four-conductor circuit for measuring the temperature with Pt 100, the influence of the cable resistance and its temperature-related fluctuations on the measuring result is completely eliminated. This also applies to the increase of the cable resistance by means of the decoupling impedances of BLITZDUCTOR XT.	No impact	BLITZDUCTOR XT BXT ML4 BE 5
9	The Pt 100 measuring transducer has an immunity to conducted interference according to test level 2 as per IEC 61000-4-5 (EN 61000-4-5). The "let-through energy" related to the voltage protection level of the surge protective device must not exceed test level 2 of IEC 61000-4-5 (EN 61000-4-5).	BLITZDUCTOR XT BXT ML4 BE 5 TYPE 1 P1 "Let-through energy" according to test level 1; "let-through energy" of the protective device is lower than the immunity of the terminal device ➡ TYPE 1 P1 is ok	BLITZDUCTOR XT BXT ML4 BE 5
10	One-stage surge protection is required	BLITZDUCTOR XT BXT ML4 BE 5 ➡ combined arrester	BLITZDUCTOR XT BXT ML4 BE 5
Result of the selection:			**BLITZDUCTOR XT** **BXT ML4 BE 5**

Table 8.2.3 Selection criteria for electrical temperature measuring equipment

Surge protection for electrical temperature measuring equipment

The electrical temperature measurement of media in technological processes is used in all industrial sectors. The fields of application can be very different: They range from food processing and chemical reactions to air-conditioning systems for buildings and building services management systems. A common characteristic of these processes is that the location of measured value acquisition is a long way from where the data is displayed or processed. Due to these long connecting cables, surges, which are not only caused by atmospheric discharges, can be injected. Therefore, a possible surge protection concept for measuring the temperature with a standard resistance thermometer of type Pt 100 will be described in the following. The building where the measuring equipment is located has no external lightning protection system.

The temperature is measured indirectly by measuring the electrical resistance. The Pt 100 sensor has a resistance of 100 Ω at 0 °C. Depending on the temperature, this value varies by about 0.4 Ω/K. The temperature is measured by injecting a constant measuring current which causes a voltage drop across the resistance thermometer proportional to the temperature. In order to prevent self-heating of the resistance thermometer resulting from the measuring current, this current is limited to 1 mA. There is therefore a voltage drop of 100 mV across Pt 100 at 0 °C. This measuring voltage must now be transmitted to the location where the data is displayed or evaluated (**Figure 8.2.15**). The four-conductor configuration has been chosen as one example of the various possible ways to connect a Pt 100 measuring sensor to a measuring transducer. This represents the optimum connection system for resistance thermometers and completely eliminates the influence of the line resistances and their temperature-dependent fluctuations on the measurement result. The Pt 100 sensor is supplied with an injected current. The change in the line resistances is compensated by the automatic variation of the supply voltage. If the line resistance does not change, the measured voltage U_m remains constant. Consequently, this measuring voltage is only changed by changing of the measuring resistance as a function of the temperature and is measured at high-impedance by the measuring transformer on the measuring transducer. Line compensation is therefore not necessary for this configuration.

Note: To easily fit the temperature measuring system with surge protective devices, the same types of surge protective devices are installed for the power supply and measuring lines. In practice, it has proven feasible that the pairs for supply and measurement are assigned to one protective device each (**Table 8.2.3**).

Surge protection is also required for the 230 V power supply of the Pt 100 measuring transducer as well as for the 4 ... 20 mA current loop coming from the measuring transducer, but is not shown here for reasons of clarity.

8.2.1 Measuring and control systems

Due to the large distance between the measuring sensor and the evaluation unit in measuring and control systems, surges may be injected. The resulting destruction of components and the failure of complete control units can significantly interfere with process technology procedures. The extent of surge damage caused by a lightning strike often only becomes apparent weeks later since more and more electronic components which no longer operate safely have to be replaced. Such kind of damage can have serious consequences for the operator who uses a so-called field bus system if all intelligent field bus components in one segment fail at the same time.

This can be prevented by installing lightning current and surge arresters (SPDs) which have to be chosen according to the interface.

Typical interfaces and the system-specific surge protective devices can be found in our Surge Protection Catalogue or at www.dehn-international.com.

Electrical isolation by means of optocouplers

Optoelectronic components (**Figure 8.2.1.1**) which typically produce a dielectric strength between the input and output of some 100 V to 10 kV are frequently installed to transmit signals in process plants in order to electrically isolate the field side from the process side. Thus, their function is similar to that of transmitters and can primarily be installed to block low common-mode interference. However, they do not provide sufficient protection against common-mode and differential-

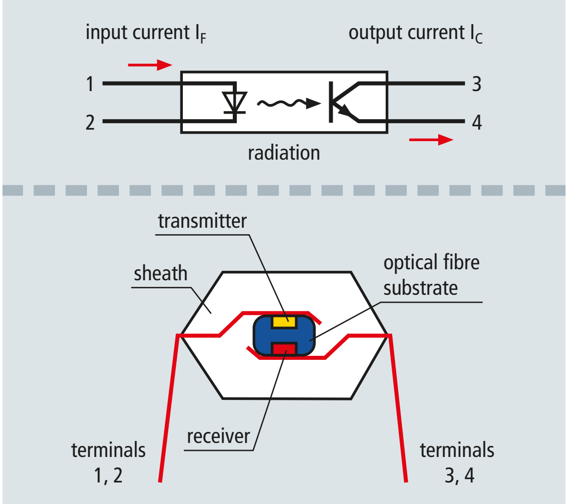


Figure 8.2.1.1 Optocoupler – Schematic diagram

mode interference in case of a lightning strike (> 10 kV) above their transmitter / receiver impulse withstand voltage.

Many designers and operators of such installations by mistake assume that this also ensures lightning and surge protection. At this point, it is expressly pointed out that this voltage merely provides the insulation strength between the input and output (common-mode interference). This means that, when installed in transmission systems, not only the limitation of common-mode interference, but also sufficient limitation of differential-mode interference must be ensured. Furthermore, the integration of additional decoupling resistors at the output of the SPD ensures energy coordination with the optocoupler diode.

Thus, in this case, SPDs which limit common-mode and differential-mode interference, e.g. BLITZDUCTOR XT of type BXT ML BE C 24, must be installed.

More detailed information on the application-specific selection of surge protective devices for measuring and control systems can be found in chapter 9.

8.2.2 Building management systems

The increasing cost pressure forces the owners and operators of buildings both in the public and in the private sector to look for cost saving potentials in building management. Technical building management can help to sustainably reduce costs. This is a comprehensive instrument to make technical equipment in buildings continuously available, to keep it operational and to adapt it to changing organisational requirements, thus facilitating optimum management which increases the profitability of a property.

Building automation (BA) has grown out of measuring and control systems on the one hand, and centralised instrumentation and control on the other hand. The function of building automation is to automate all technical processes in the building. Therefore, the complete installation comprising room automation, the M-bus measuring system and the heating, ventilation, air-conditioning and alarm system are networked via powerful computers on the management level (**Figure 8.2.2.1**) where data is archived. Long-term storage of data allows to evaluate the energy consumption and the adjustment of the installations in the building.

The actual control devices are located at the automation level. DDC (Direct Digital Control) stations are increasingly being installed. They implement the complete control and switching functions by means of a software. All operating modes, control parameters, desired values, switching times, alarm limits and the corresponding software are filed at the automation level.

Field devices such as actuators and sensors are located at the lowest level, the field level. They represent the interface between the electrical control and the process. Actuators transform an electrical signal into another physical quantity (motors, valves, etc.), while sensors transform a physical quantity into an electrical signal (temperature sensor, limit switch, etc.).

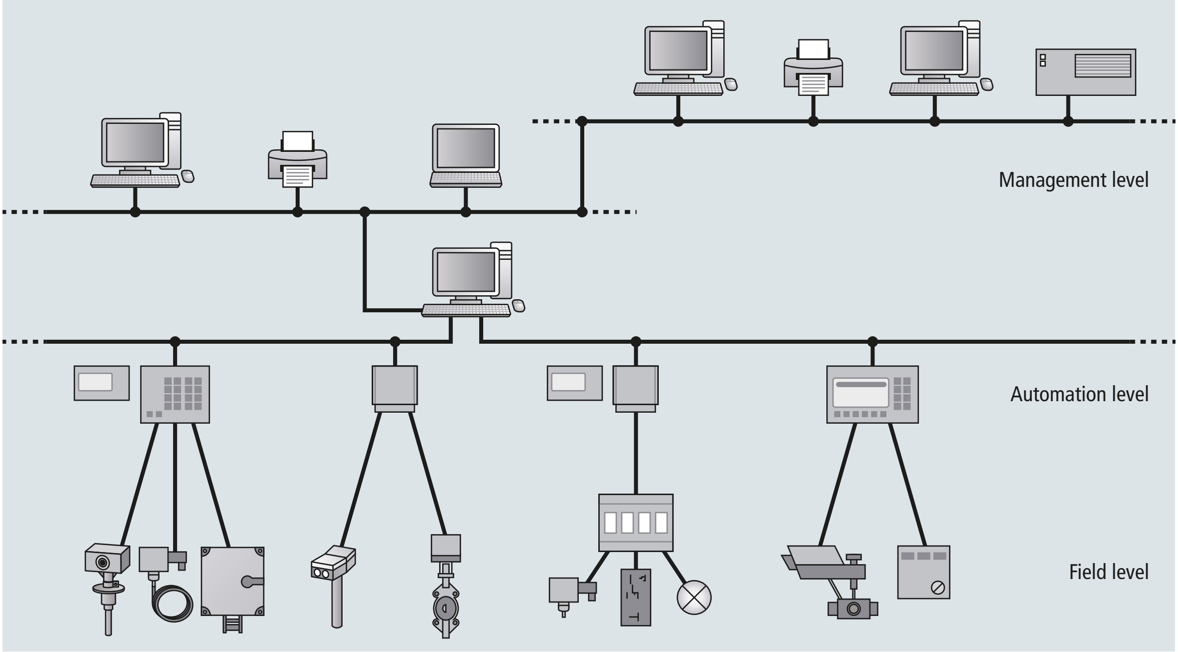


Figure 8.2.2.1 Levels of building automation

It is precisely the widely distributed network of DDC stations and the associated integration into building control systems which offer a large target for interference caused by lightning currents and surges. If this causes failure of the entire lighting, air-conditioning or heating control system, this failure does not only cause primary costs for the equipment, but also entails high costs for the consequences of this system failure. It can significantly increase the energy costs since peak loads can no longer be analysed and optimised due to the fault in the control electronics. If production processes are integrated in the BA, damage to the BA can lead to production downtimes and thus to high economic loss. To ensure permanent availability, protection measures are required which depend on the risk to be controlled.

8.2.3 Generic cabling systems (computer networks, telecommunication systems)

The European standard EN 50173 "Information technology – Generic cabling systems" defines a universal cabling system which can be used at locations with one or more buildings. It deals with cabling systems consisting of balanced copper cables and optical fibre cables. This universal cabling system supports a wide range of services including voice, data, text and images.

It provides:

- An application-independent and universal cabling system and an open market for (active and passive) cabling components
- Users with a flexible cabling topology that allows to easily make changes in a cost-effective way
- Building installers with a guideline which allows to install the cabling before specific requirements are known (namely at the design stage irrespective of which platform is installed later)
- The industry and standardisation committees for network applications with a cabling system, which supports current products and forms a basis for future product development.

The universal cabling system comprises the following functional elements:

- Campus distributors (CD)
- Campus backbone cables
- Building distributors (BD)
- Building backbone cables
- Floor distributors (FD)
- Horizontal cables
- Consolidation point (optional) (CP)
- Telecommunications outlet (TO)

Groups of these functional elements are interconnected to form cabling subsystems.

Generic cabling systems contain three subsystems: The campus backbone, building backbone and horizontal cabling system. These cabling subsystems are interconnected to form a generic cabling structure as shown in **Figure 8.2.3.1**. The relevant distributors allow any network topology such as bus, star, tree and ring.

The campus backbone cabling subsystem extends from the campus distributor to the building distributors which are typically located in separate buildings. If present, it includes the campus backbone cables, their terminations (both at the campus distributor and building distributors) and the cross-connects in the campus distributor.

A building backbone cabling subsystem extends from building distributor(s) to the floor distributor(s). It includes the building backbone cables, their mechanical terminations (both at the building distributor and floor distributors) and the cross-connects in the building distributor.

The horizontal cabling subsystem extends from the floor distributor to the telecommunications outlet(s) connected to it. It includes the horizontal cables, their mechanical terminations at the floor distributor, the cross-connects in the floor distributor and the telecommunications outlets.

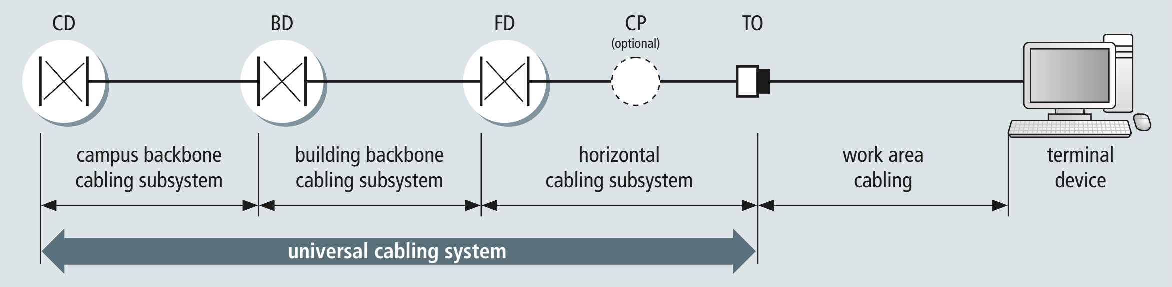


Figure 8.2.3.1 Generic cabling structure

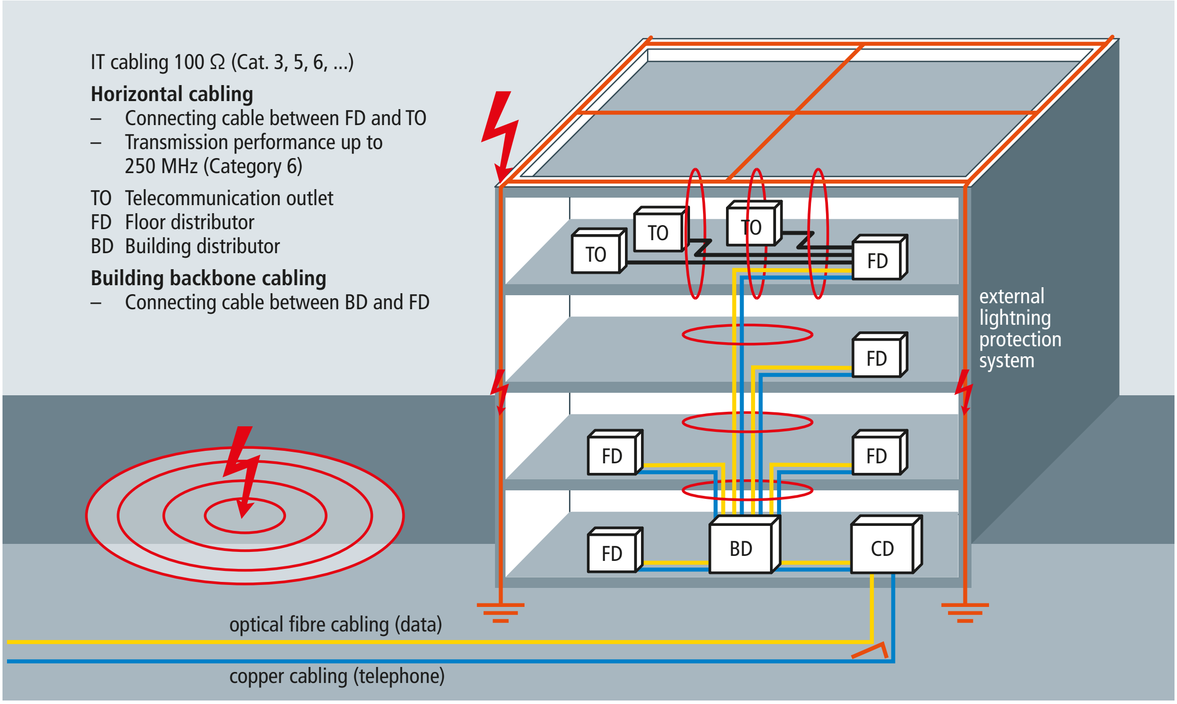


Figure 8.2.3.2 Lightning interference on the IT cabling

Optical fibre cables are typically used as data connection between the campus and building distributor. This means that no surge arresters (SPDs) are required for the field side. If, however, the optical fibre cables have a metal rodent protection, it must be integrated in the lightning protection system. The active optical fibre components for distributing the optical fibre cables, however, are supplied with 230 V on the power side. In this case, SPDs for power supply systems can be used.

Nowadays, the building backbone cabling (between the building distributor and the floor distributor) almost exclusively consists of optical fibre cables for the transmission of data. However, balanced copper cables (also referred to as master cables) are still used for voice transmission (telephone).
With a few exceptions, balanced copper cables are nowadays used for the horizontal cabling (floor distributor and terminal equipment).

For cable lengths of about 500 m (building backbone cables) or about 100 m (horizontal cables), direct lightning strikes to the building (**Figure 8.2.3.2**) can induce high common-mode interference which would overload the insulation strength of a router and / or an ISDN card in the PC. In this case, protection measures must be taken both for the building / floor distributor (hub, switch, router) and the terminal equipment.

The protective devices required for this purpose must be selected according to the network application. Common network applications are:

- ➡ Token ring
- ➡ Ethernet 10 Base-T
- ➡ Fast Ethernet 100 Base-TX
- ➡ Gigabit Ethernet 1000 Base-TX

8.2.4 Intrinsically safe measuring circuits

Special explosion protection measures must be taken in all industrial sectors where gas, vapour, mist or dust form a hazardous explosive atmosphere with air during the processing or transport of flammable substances.

Depending on the probability and duration of the presence of an explosive atmosphere, the areas of an Ex system are divided into zones – also referred to as Ex zones.

Ex zones

Ex zones with areas where hazardous explosive atmospheres arise due to e.g. gases, vapours and mists are divided into Ex zones 0 to 2 and those in which hazardous explosive atmospheres can arise due to dusts are divided into Ex zones 20 to 22.

Depending on the ignitability of the ignitable substances occurring in the relevant field of application, a distinction is made between explosion groups I, IIA, IIB and IIC which have different ignition limit curves. The ignition limit curve, which is a function of the ignition behaviour of the ignitable substance under consideration, indicates the maximum values for the operating voltage and operating current.

Explosion group IIC contains the most easily ignitable substances such as hydrogen and acetylene. When heated, these substances have different ignition temperatures which are classified into temperature classes (T1 ... T6).

To avoid that electrical equipment represents ignition sources in explosive atmospheres, it is designed with different types of protection. One type of protection, which is used in measuring and control systems all over the world, is intrinsic safety Ex(i).

Intrinsic safety type of protection

Intrinsic safety is based on the principle of current and voltage limitation in a circuit. The energy of the circuit or a part of the circuit, which is capable of igniting an explosive atmosphere, is kept so low that neither sparks nor intolerable surface heating of the electrical components can ignite the surrounding explosive atmosphere. Apart from the voltage and current of the electrical equipment, the inductances and capacitances in the complete circuit which act as energy storage systems must be limited to safe maximum values.

To ensure safe operation of a measuring and control circuit, for example, this means that neither the sparks which arise during the operational opening and closing of the circuit (e.g. at a switch contact in an intrinsically safe circuit) nor those arising in the event of a fault (e.g. short-circuit or earth fault) must cause ignition. Moreover, both during normal operation and in the event of a fault, heat ignition as a result of an excessive temperature rise of the equipment and cables in the intrinsically safe circuit must also be excluded.

This basically limits the intrinsic safety type of protection to circuits with relatively low power levels such as the circuits of measuring and control / data systems. Intrinsic safety, which can be achieved by limiting the energy available in the circuit, does not relate to individual devices – as is the case with other types of protection – but to the complete circuit. This provides many advantages over other types of protection.

On the one hand, no expensive special constructions are required for the electrical equipment used in the field, for example flame-proof enclosure or embedding in cast resin, which mainly leads to more cost-effective protection solutions. On the other hand, intrinsic safety is the only type of protection which allows the user to work freely on all live intrinsically safe installations in a potentially explosive atmosphere without adversely affecting explosion protection.

Intrinsic safety is therefore of paramount importance, particularly in measuring and control systems, not least due to the increased use of electronic automation systems. However, intrinsic safety demands more of the designer or installer of an installation than other types of protection. The intrinsic safety of a circuit does not only depend on compliance with the building regulations for the individual pieces of equipment, but also on the correct interconnection of all pieces of equipment in the intrinsically safe circuit and on the correct installation.

Transients in hazardous areas

The intrinsic safety type of protection considers all electrical energy storage systems present in the system, but not surges injected from outside e.g. resulting from atmospheric discharges.

Injected surges occur in large-scale industrial installations mainly as a result of nearby and remote lightning strikes. In the event of a direct lightning strike, the voltage drop across the earth-termination system causes a potential rise between some 10 and 100 kV. This potential rise acts as a potential difference on all pieces of equipment connected to distant equipment via cables. These potential differences are considerably higher than the insulation strength of the equipment and can easily cause sparkover. In case of remote lightning strikes, mainly the injected surges in conductors have an effect and as differential-mode interference (differential voltage between the cores) they can destroy the inputs of electronic equipment.

Classification of electrical equipment into protection levels ia, ib or ic

An important aspect of the intrinsic safety type of protection as far as explosion protection is concerned is the reliability with respect to the maintenance of the voltage and current limits, even in the event of certain faults. There are three different protection levels (ia, ib and ic) concerning the reliability and safety of the intrinsically safe electrical equipment.

Protection level ic describes the undisturbed operation without faults. In this case, intrinsic safety must be maintained during operation.

Protection level ib requires that intrinsic safety must be maintained if a fault occurs in the intrinsically safe circuit.

Protection level ia requires that intrinsic safety must be maintained if two independent faults occur.

Figure 8.2.4.1 shows the basic use of SPDs for a measuring and control circuit.

Maximum values of current I_0, voltage U_0, inductance L_0 and capacitance C_0

Safety barriers or measuring transducers with Ex(i) output circuit are used at the interface between the hazardous and

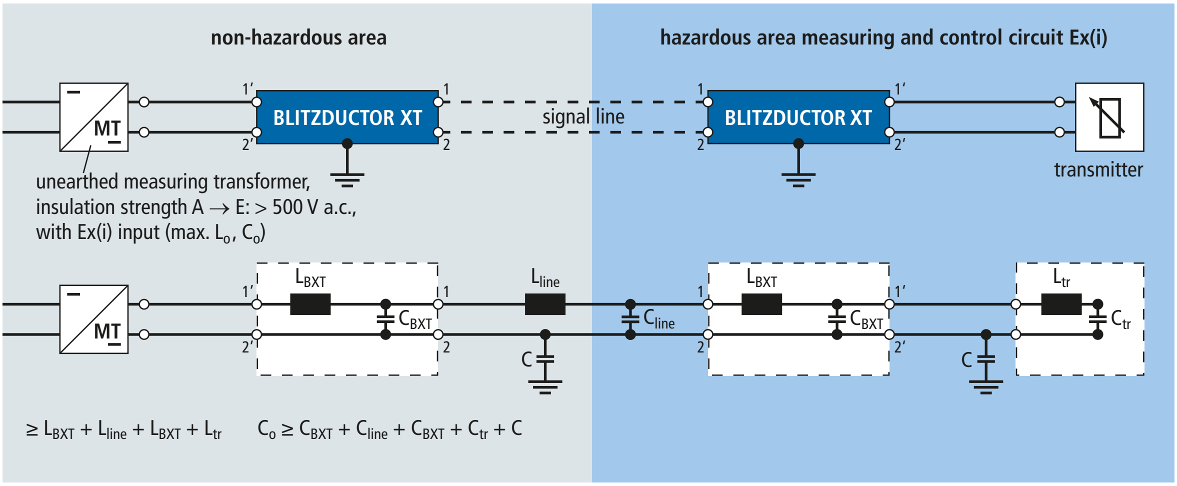


Figure 8.2.4.1 Calculation of L_0 and C_0

non-hazardous area (safe area) to separate these two different areas.
The maximum safety values of a safety barrier or a measuring transducer with Ex(i) output circuit are defined in the test certificates of an authorised test institute:

- Maximum output voltage U_0
- Maximum output current I_0
- Maximum external inductance L_0
- Maximum external capacitance C_0

The designer/installer must test in each individual case, whether these permissible maximum values of connected equipment located in the intrinsically safe circuit (i.e. process field devices, conductors and SPD) are maintained. The corresponding values are printed on the rating plate of the relevant equipment or can be found in the type examination certificate.

Note

When using intrinsically safe SPDs from DEHN, the internal inductances and capacitances of the equipment are negligibly small according to the EC type examination certificate. Zero must be used here to calculate the maximum values of L_0 and C_0.

Classification into explosion groups

Explosive gases, vapours and mists are classified according to the spark energy required to ignite the most explosive mixture with air.
Equipment is classified according to the gases with which it can be used.
Group II is valid for all fields of application, e.g. chemical industry, coal and grain processing, with the exception of underground mining.
Group II C has the highest risk of explosion since this group takes into account a mixture with the lowest ignition energy.
The certification of BLITZDUCTOR for explosion group II C means that it fulfils the highest, i.e. most sensitive requirements for a mixture of hydrogen in air.

Classification into temperature classes

When an explosive atmosphere is ignited as a result of the hot surface of a piece of equipment, a substance-specific minimum temperature is required to cause an explosion. This ignition temperature characterises the ignition behaviour of the gases, vapours or dusts on a hot surface. For economic reasons, gases and vapours are therefore classified into certain temperature classes. Temperature class T6, for example, specifies that the maximum surface temperature of the component must not exceed 85 °C during operation or in the event of a fault and that the ignition temperature of the gases and vapours must be higher than 85 °C.
With its T6 classification, BLITZDUCTOR XT also fulfils the highest requirements in this aspect.
In accordance with the ATEX/IECEx certificate of conformity, the following electrical parameters must also be taken into consideration.

Selection criteria for SPDs – BLITZDUCTOR XT

Based on the example of BLITZDUCTOR XT, BXT ML4 BD EX 24, the specific selection criteria for this component are explained below (**Figures 8.2.4.2**).

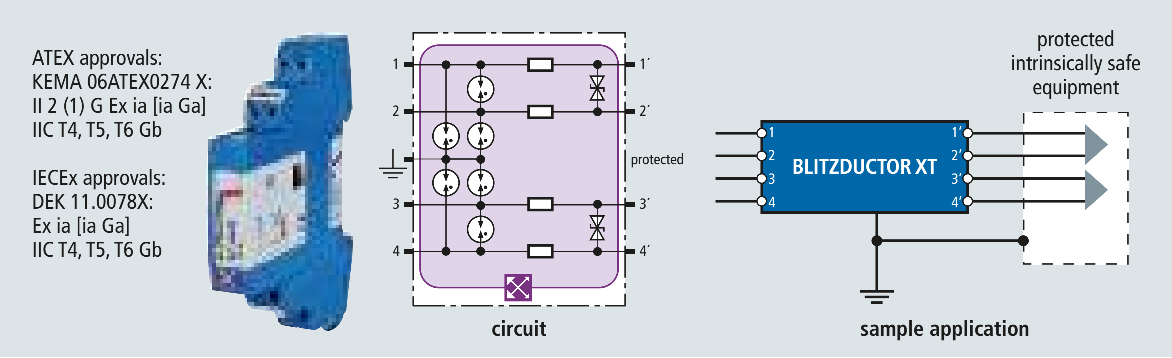


Figure 8.2.4.2 Intrinsically safe BXT ML4 BD EX 24 arrester

This component has an EC type examination certificate issued by KEMA (**KEMA 06ATEX0274 X**).

This classification means:

KEMA	Symbol of the test institute
06	First certification of the device in 2006
ATEX	ATEX generation
0274	Consecutive number of the test institute
X	"X" – Special conditions must be observed to ensure safe use. These can be found in section 17 of the EC type examination certificate.

The surge protective device is classified as follows:
II 2(1) G Ex ia [ia Ga] IIC T4…T6 Gb

This classification means:

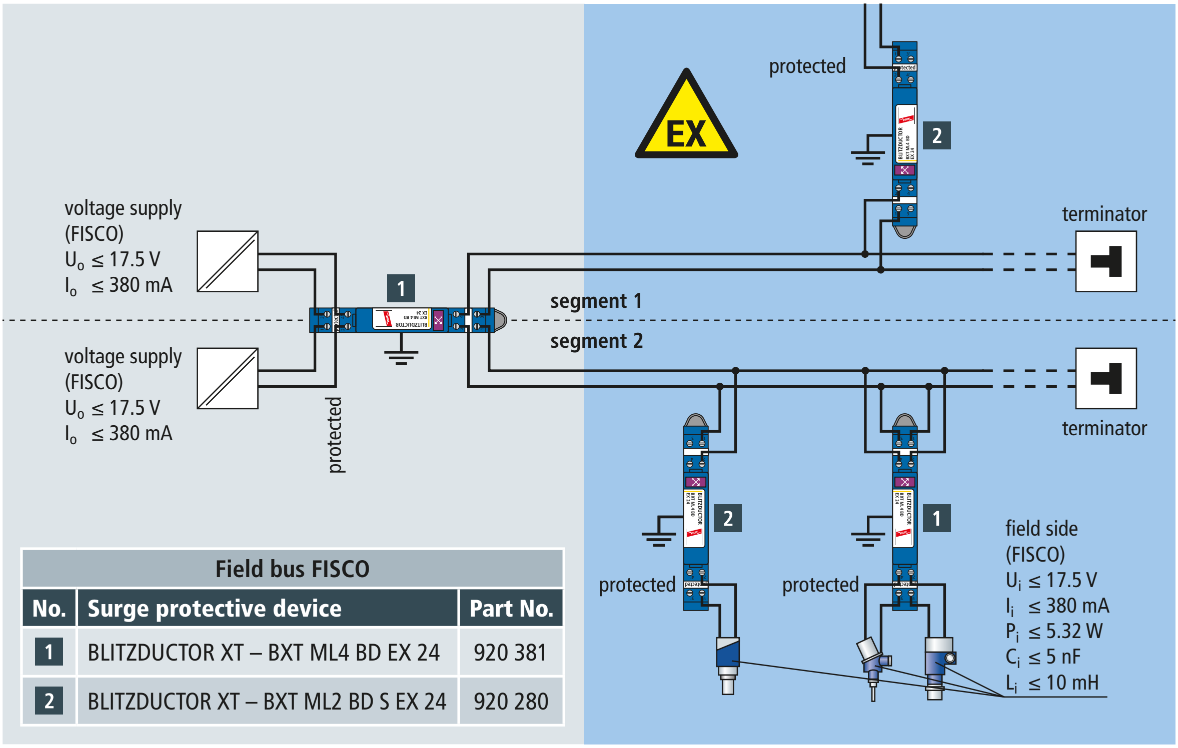
II	Equipment group – The SPD may be used in all fields with the exception of mining.
2(1) G	Equipment category – The SPD may be installed in Ex zone 1 and also in installation circuits with conductors coming from zone 0 (to protect terminal devices in zone 0). Atmosphere: G = gas; D = dust.
Ex	The test institute certifies that this electrical equipment complies with the harmonised European standards IEC 60079-0 (EN 60079-0): General provisions and IEC 60079-11:2011 (EN 60079-11:2012): Intrinsic safety "i".
ia	Type of protection – The SPD can even handle a combination of two arbitrary faults in an intrinsically safe circuit without causing ignition itself.
[ia Ga]	Type of protection ia and EPL Ga – Device with a "very high" level of protection for explosive gas atmospheres which is not a source of ignition during normal operation and in case of expected or rare faults/malfunctions. The device is thus suited for protecting signals from Ex zone 0. The equipment itself must not be installed in Ex zone 0 (see Gb).
IIC	Explosion group – The SPD fulfils the requirements of explosion group IIC and may also be used with ignitable gases such as hydrogen or acetylene.
T4	Between −40 °C and +80 °C
T5	Between −40 °C and +75 °C
T6	Between −40 °C and +60 °C
Gb	EPL Gb - Device with a "high" level of protection for explosive gas atmospheres which is not a source of ignition during normal operation or in case of predicted faults/malfunctions.

Other important electrical data:

- Maximum external inductance (L_0) and maximum external capacitance (C_0):
  The special selection of components in BLITZDUCTOR XT means that the values of the internal inductance and capacitance of the various individual components are negligibly small ($L_i = 0$; $C_i = 0$).
- Maximum input current (I_i):
  The maximum current which may be supplied via the connection components without eliminating intrinsic safety is 500 mA.
- Maximum input voltage (U_i):
  The maximum voltage which may be applied to BLITZDUCTOR XT without eliminating intrinsic safety is 30 V.

Unearthed Ex(i) circuits

The insulation between an intrinsically safe circuit and the frame of the electrical equipment or other parts which can be earthed must typically be able to withstand the root mean square value of an a.c. test voltage which is twice as high as



Field bus FISCO

No.	Surge protective device	Part No.
1	BLITZDUCTOR XT – BXT ML4 BD EX 24	920 381
2	BLITZDUCTOR XT – BXT ML2 BD S EX 24	920 280

Figure 8.2.4.3 SPDs in intrinsically safe bus systems – Insulation strength > 500 V a.c.

the voltage of the intrinsically safe circuit or 500 V, whichever value is higher. Equipment with an insulation strength < 500 V a.c. is considered to be earthed.
Intrinsically safe equipment (e.g. cables, measuring transducers, sensors) generally has an insulating strength > 500 V a.c. (**Figure 8.2.4.3**).

Intrinsically safe circuits must be earthed if this is required for safety reasons. They may be earthed if this is required for functional reasons. This earthing must be carried out at only one point by connecting them with the equipotential bonding system. If the d.c. sparkover voltage to earth of the SPD is < 500 V d.c., the intrinsically safe circuit is considered to be earthed.
If the d.c. sparkover voltage of the SPD is > 500 V d.c., the intrinsically safe circuit is not considered to be earthed. BLITZDUCTOR XT (BXT ML4 BD EX 24 or BXT ML2 BD S EX 24) meets this requirement.
In order to coordinate the dielectric strength of the devices to be protected (measuring transducer and sensor) with the voltage protection level of the SPD, it must be ensured that the insulation strength of the devices to be protected is considerably higher than the requirements for an a.c. test voltage of 500 V a.c.

To prevent that the voltage drop of the interference current to be discharged in the earth connection deteriorates the voltage protection level, consistent equipotential bonding must be established between the device to be protected and the SPD.

Earthing / Equipotential bonding

Consistent equipotential bonding and intermeshing of the earth-termination system in the hazardous area of the installation must be ensured. The cross-section of the earthing conductor between the SPD and the equipotential bonding system must be at least 4 mm^2 (copper). When using several SPDs, a cross-section of 16 mm^2 (copper) is recommended.

Installation of BLITZDUCTOR XT in Ex(i) circuits

The normative requirements for Ex(i) circuits with regard to explosion protection and electromagnetic compatibility (EMC) correspond to different points of view, a situation which occasionally causes consternation among designers and installers.
The most important selection criteria for intrinsic safety and EMC / surge protection in installations are listed in chapter 9.32 to identify the interaction of the requirement profile in each case.

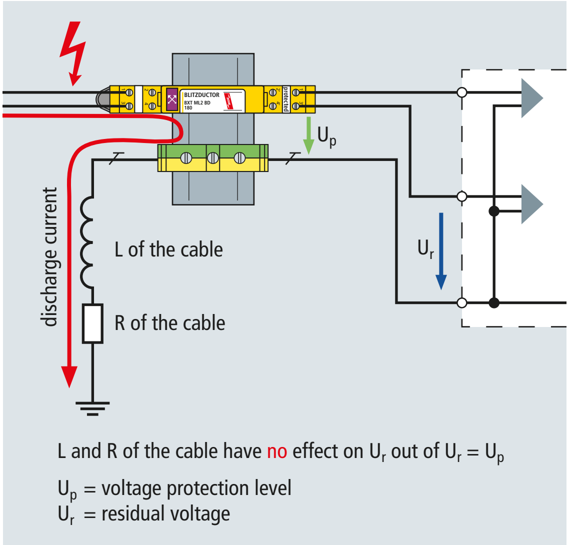


Figure 8.2.5.1 Correct installation

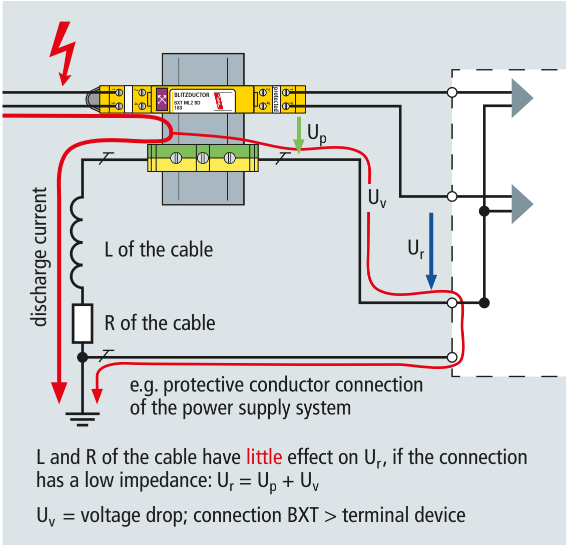


Figure 8.2.5.2 Most common installation

8.2.5 Aspects to be observed for the installation of SPDs

The protective effect of an SPD for a device to be protected is provided if a source of interference is reduced to a value below the interference or destruction limit and above the maximum continuous operating voltage of a device to be protected. Generally, the protective effect of an arrester is given by the manufacturer in form of the voltage protection level U_p (see IEC 61643-21 (EN 61643-21)). The effectiveness of a surge protective device, however, depends on additional parameters which are defined by the installation. During the discharge process, the current flow through the installation (e.g. L and R of the equipotential bonding conductor) can cause a voltage drop $U_L + U_R$ which must be added to U_p and results in the residual voltage at the terminal device U_r:

$$U_r = U_p + U_L + U_R$$

Optimal surge protection is ensured under the following conditions:

- The maximum continuous operating voltage U_c of the SPD should be slightly above the open-circuit voltage of the system.
- The voltage protection level U_p of the SPD should be as low as possible since additional voltage drops through the installation have a lower effect.
- The equipotential bonding should be designed so as to cause as little impedance as possible.
- Installation of the SPD as close as possible to the terminal device since this has a positive effect on the residual voltage.

Installation examples

Example 1: Correct installation (Figure 8.2.5.1)

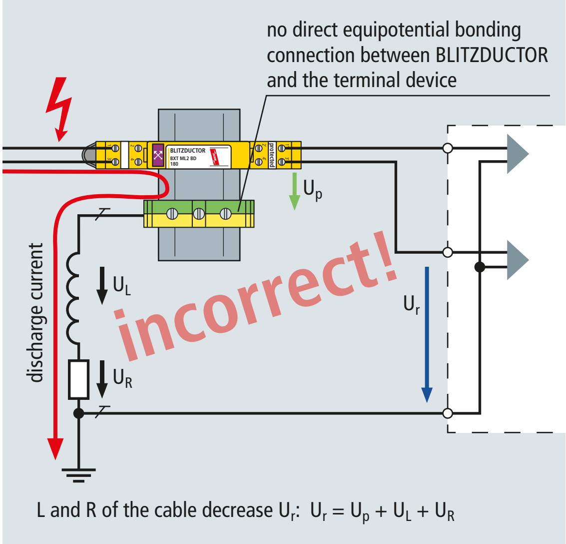
The terminal device is only directly earthed via the earth connection point of the arrester. This means that the voltage protection level U_p of the SPD is actually available at the input of the terminal device in the form of the residual voltage U_r. This type of installation is the most favourable method for protecting the terminal device.

$$U_r = U_p$$

$U_L + U_R$ have no effect.

Example 2: Most common installation (Figure 8.2.5.2)

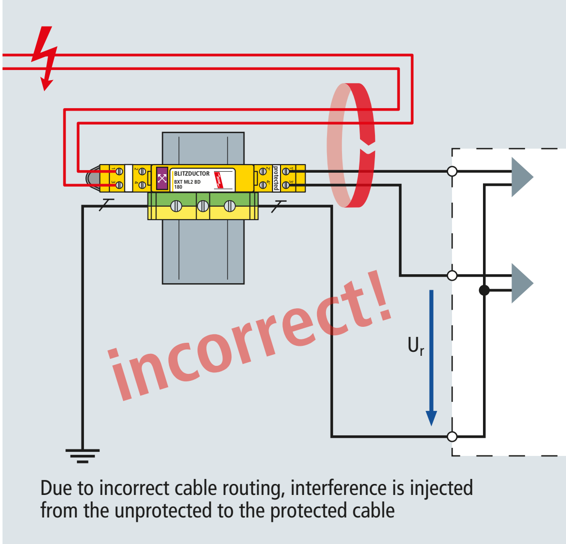
The terminal device is directly earthed via the earth connection point of the arrester and also via the protective conductor connected. This means that a part of the discharge current, depending on the impedance ratio, flows via the connection to the terminal device. To prevent that the interference is injected from the connecting equipotential bonding conductor to the protected cores and to keep the residual voltage low, this equi-



no direct equipotential bonding connection between BLITZDUCTOR and the terminal device

L and R of the cable decrease U_r: $U_r = U_p + U_L + U_R$

Figure 8.2.5.3 Incorrectly established equipotential bonding



Due to incorrect cable routing, interference is injected from the unprotected to the protected cable

Figure 8.2.5.4 Incorrect conductor routing

potential bonding conductor must be installed separately, if possible, and/or designed to have extremely low impedance (e.g. metal mounting plate). This type of installation is the common installation practice for class I terminal devices.

$$U_r = U_p + U_v$$

Example 3: Incorrectly established equipotential bonding (Figure 8.2.5.3)

The terminal device is only directly earthed via the protective conductor terminal, for example. There is no low-impedance equipotential bonding to the protective device. The path of the equipotential bonding conductor from the protective device to the protective conductor terminal of the terminal device (e.g. equipotential bonding bar) considerably influences the residual voltage. Depending on the cable length, voltage drops up to some kV can occur which add up to U_p and can lead to the destruction of the terminal device due to a high residual voltage level at the device input.

Example 4: Incorrect conductor routing (Figure 8.2.5.4)

Even if equipotential bonding is carried out correctly, incorrect conductor routing can interfere with the protective effect or even damage the terminal device. If strict spatial separation or shielding of an unprotected cable upstream of the SPD and a protected cable downstream of the SPD is not observed, the electromagnetic interference field can cause injection of interference impulses on the protected cable side.

Shielding

Cable shielding is described in section 7.3.1.

Installation recommendations

The use of metal shields or cable ducts reduces the interaction between the pair and the environment. For shielded cables, the following must be observed:

- Shield earthing at one end reduces the radiation of electric fields
- Shield earthing at both ends reduces the radiation of electromagnetic fields
- Conventional shields do not provide sufficient protection against low-frequency magnetic fields

Recommendations

Shields should run continuously between information technology installations, have a low transfer impedance and be conducted around the complete circumference, if possible. The shield must completely enclose the cables, as far as practicable. Interruptions in the shield as well as high-impedance earth connections and “pig tails” should be avoided.

The extent to which low-voltage lines can influence telecommunication lines depends on many factors. The recommended values for the spatial distances to low-voltage lines are described in EN 50174-2. For a cable length less than 35 m, typically no separation distance has to be maintained. In all other cases, **Table 8.2.5.1** gives the separations which apply.

		Cable ducts used for information technology or power supply cabling systems		
Separation classification (from Table 3)	Separation without electromagnetic barriers	Open metallic cable duct a)	Perforated metallic cable duct b) c)	Solid metallic cable duct d)
d	10 mm	8 mm	5 mm	0 mm
c	50 mm	38 mm	25 mm	0 mm
b	100 mm	75 mm	50 mm	0 mm
a	300 mm	225 mm	150 mm	0 mm

a) Shield performance (0 MHz to 100 MHz) equivalent to welded mesh steel basket of mesh size 50 mm × 100 mm (excluding ladders). This shield performance is also achieved with a steel tray (cable unit without cover) of less than 1.0 mm wall thickness and / or more than 20 % equally distributed perforated area.

b) Shield performance (0 MHz to 100 MHz) equivalent to a steel tray (cable unit without cover) of at least 1.0 mm wall thickness and no more than 20 % equally distributed perforated area. This shield performance is also achieved with shielded power cables that do not meet the performance defined in footnote d).

c) The upper surface of the installed cables must be at least 10 mm below the top of the barrier.

d) Shield performance (0 MHz to 100 MHz) equivalent to a steel conduit of 1.5 mm wall thickness. The separation specified is in addition to that provided by any divider / barrier.

Table 8.2.5.1 Separation of telecommunications and low-voltage lines according to EN 50174-2, Table 4: "Minimum separation s"

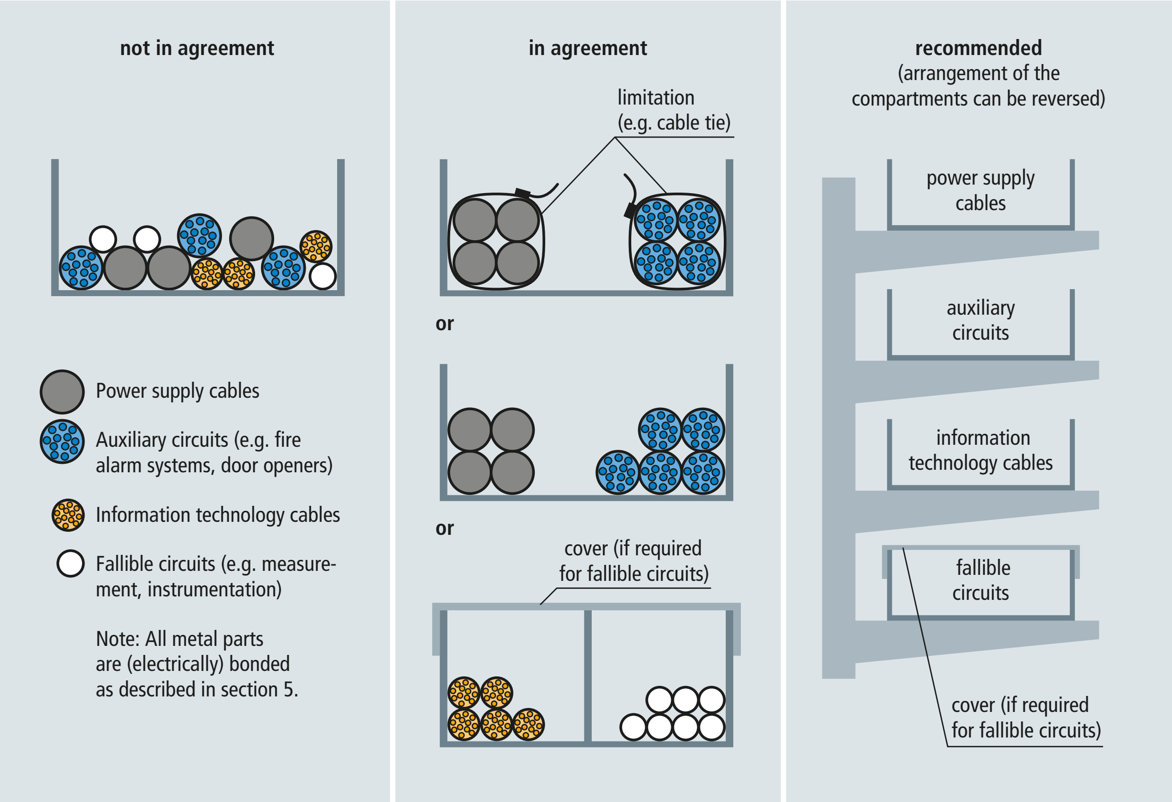


Figure 8.2.5.5 Separation of cables in cable duct systems

It is recommended to install telecommunication lines in metal ducts which are electrically connected and completely enclosed. The metal cable duct systems should be connected with low impedance to earth as frequently as possible, at least at the beginning and at the end (**Figure 8.2.5.5**).

8.2.6 Protection and availability of installations thanks to maintenance strategies

As with all electrical and electronic devices, the electronic components of surge protective devices for information technology systems are subject to ageing. **Figure 8.2.6.1** shows the "bath tub curve".

Therefore, the aim of a maintenance strategy for SPDs should be the timely identification of SPDs which could fail in the near future.

The main aim of lightning and surge protection measures is also to increase the availability of installations by timely maintenance and repair work. At the same time, the maintenance and repair costs should be reduced.

Corrective maintenance (failure-oriented)

The arrester protects the installation circuit until it exceeds its overload limit and fails completely. Only then, corrective measures are taken to restore the signal availability. Three important arrester features are important:

- Fail-safe: The data signal is interrupted after the arrester has failed – The installation circuit or the system failed. The fail-safe feature ensures that the installation is still protected against interference caused by partial lightning currents or surges.
- Pluggable arrester consisting of a protection module and a base part: The two-part design of the arrester comprising a base part and a protection module allows easy module replacement without wiring effort.
- Make-before-break contact in the base part: If the arrester is overloaded, system availability is easily and quickly restored by removing the protection module from the base part. Even if a signal line is active, the module can be quickly replaced without affecting the signal circuit. If the protection module is removed, the base part can only be used as a maintenance-free feed-through terminal. Only if the module is plugged in, the signal circuit, which is not interrupted when replacing the protection module, is protected.

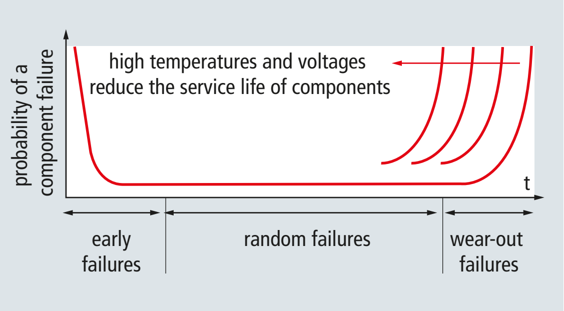


Figure 8.2.6.1 Ageing of electronic components – "Bath tub curve"

Figure 8.2.6.2 LifeCheck arrester testing by means of DRC LC M1+

BLITZDUCTOR XT, which interrupts the signal flow in case of failure, comprises a base part and protection module and features a make-before-break contact in the base part, ensures safe protection, easy maintenance and thus increased availability of installations and systems.

Preventive maintenance

Supplement 3 of the German DIN EN 62305-3 standard (Table 1) describes maintenance tests and intervals for a lightning protection system. It is difficult to visually inspect SPDs for information technology systems since the status of the arrester is typically not visible. Therefore, the protection modules are equipped with a LifeCheck monitoring system which detects thermal or electrical stress on all arrester components. If LifeCheck is activated by a pre-damaged arrester, this can be detected within the maintenance intervals by means of an arrester test device (DRC LC M1+ or M3+) (**Figure 8.2.6.2**). To prevent possible downtime due to subsequent surges, the pre-damaged protection module should be replaced as soon as possible.

Benefits of this type of SPD test:

- Extremely easy and within a matter of seconds
- Protection module does not have to be removed

Figure 8.2.6.3 Monitoring of surge protective devices by means of the DRC MCM XT condition monitoring unit

- Detection of thermal and electrical pre-damage of all arrester elements

The availability of installations and systems can be further increased by reducing the maintenance intervals. However, the cost-effectiveness of the maintenance measure must be observed.

Condition monitoring

Condition monitoring is used in industries where maximum availability of systems and installations must be ensured and cost-effectiveness of maintenance measures is of paramount importance. LifeCheck-equipped arresters (e.g. BLITZDUCTOR XT) are combined to form a monitoring group by means of a stationary monitoring device and are permanently monitored (**Figure 8.2.6.3**). If the status of the monitoring group changes, i.e. there are one or more pre-damaged arresters, this change is immediately indicated via the floating remote signalling contacts integrated in the monitoring device or via the RS-485 interface. Imminent failure can be detected immediately due to the timely preventive replacement of pre-damaged protection modules, thus preventing downtime.

This type of SPD monitoring has the following benefits:

- Permanent condition monitoring of SPDs during operation
- Remote signalling option via RS-485 interface and remote signalling contacts
- Gateway allows connection to a higher-level control system or another bus system

Surge protection for frequency converters

A frequency converter typically consists of a rectifier, d.c. link, inverter and control electronics (**Figure 9.1.1**).

At the inverter input, a single-phase a.c. voltage or three-phase line-to-line a.c. voltage is converted into a pulsating d.c. voltage and is fed into the d.c. link which also serves as an energy storage system (buffer).

Capacitors in the d.c. link and earthed L-C sections in the mains filter can cause problems with upstream residual current protective devices (RCDs). These problems are often incorrectly associated with surge arresters. They are, however, caused by short-time fault currents of the frequency converter which are sufficiently high to trip sensitive RCDs. This can be prevented by using a surge-proof RCD circuit breaker which is available with a discharge capacity of 3 kA (8/20 µs) and higher for a tripping current $I_{\Delta n}$ = 30 mA.

The inverter provides a pulsed output voltage via the control electronics. The higher the pulse frequency of the control electronics for pulse width modulation, the more similar is the output voltage to a sinusoidal curve. However, with each pulse a voltage peak occurs that is superimposed on the fundamental wave. This voltage peak reaches values of more than 1200 V (depending on the frequency converter). The better the simulation of the sinusoidal curve, the better the run and control performance of the motor. This, however, means that voltage peaks occur more frequently at the output of the frequency converter.

In order to pick the correct surge arrester for your frequency converter, the maximum continuous operating voltage U_c must be taken into account which specifies the maximum permissible operating voltage a surge protective device may be connected to. Owing to the voltage peaks that occur during the operation of frequency converters, arresters with a high U_c value must be used to avoid "artificial ageing" due to the heating of the surge arrester under "normal" operation conditions and the associated voltage peaks.

Heating of surge arresters can lead to a shorter service life and a disconnection of the surge arrester from the installation it is supposed to protect.

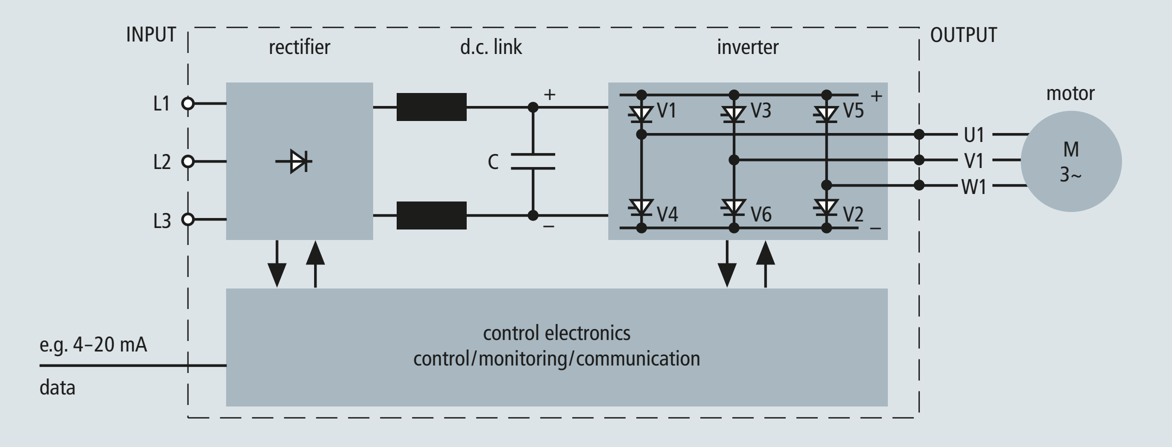


Figure 9.1.1 Basic principle of a frequency converter

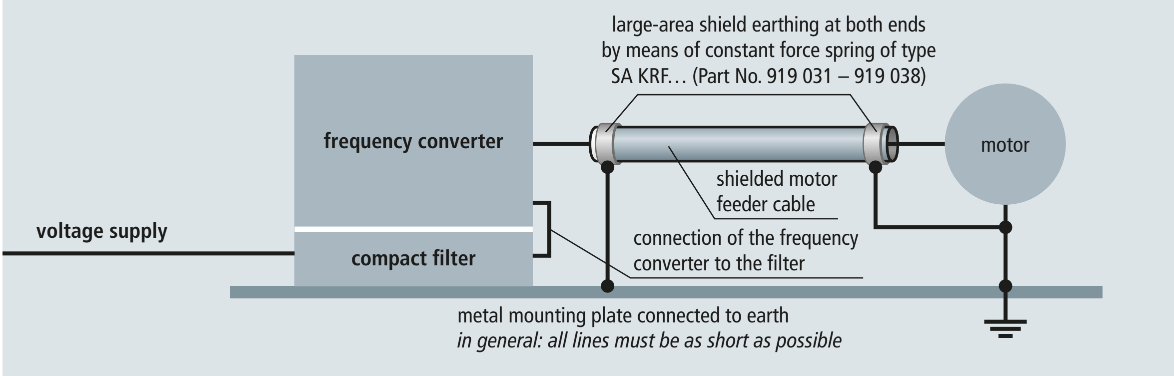
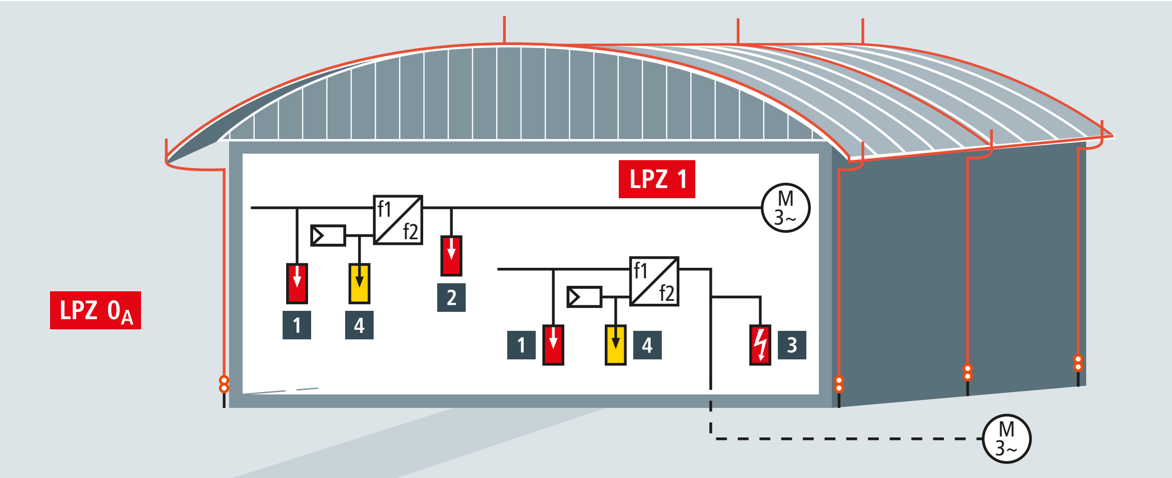


Figure 9.1.2 EMC-compatible shield connection of the motor feeder cable



No.	Surge protective device		Part No.
1	DEHNguard modular	DG M TNS 275 (TN-S system)	952 400
	DEHNguard modular	DG M TT 275 (TT system)	952 310
2	DEHNguard S	DG S WE 600 (3 items)	952 077
3	DEHNbloc Maxi + DEHNguard S	DBM 1 760 FM (3 items) DG S WE 600 (3 items)	961 175 + 952 077
4	BLITZDUCTOR XT + BLITZDUCTOR XT base part	BXT ML2 BE S 24 (e.g. 4 – 20 mA) BXT BAS	920 224 + 920 300

Figure 9.1.3 Frequency converter with drives in LPZ 0_A and LPZ 1

The high pulse frequency at the output of the frequency converter causes field-based interference. To avoid that other systems are interfered with, the motor feeder cable must be shielded. The shield of the motor feeder cable must be earthed on both ends, namely at the frequency converter and at the motor. To this end, large-area contact with the shield must be provided, preferably by constant force springs (**Figure 9.1.2**), to fulfil EMC requirements. Intermeshed earth-termination systems, namely the connection of the earth-termination system of the frequency converter to that of the drive motor, reduce potential differences between the different parts of the installation, thus preventing equalising currents from flowing through the shield.

When integrating a frequency converter in the building automation, all evaluation and communication interfaces must be protected by surge protective devices to prevent surge-related system failure. **Figure 9.1.3** shows an example of the controller interface 4 – 20 mA.

Lightning and surge protection for outdoor lighting systems

Outdoor lighting systems can be installed at the outside walls of a building and in open terrain. In both cases, it must be checked whether the outdoor lighting systems are located in lightning protection zone LPZ 0_A or LPZ 0_B. Outdoor lighting systems in LPZ 0_A are subjected to direct lightning strikes, impulse currents up to the full lightning current and the full lightning field. In LPZ 0_B they are protected against direct lightning strikes, however, they are subjected to impulse currents up to partial lightning currents and the full lightning field.

Lamp poles in LPZ 0_A have to be connected to one another in the soil and to the earth electrodes of the buildings by means of suitable earthing conductors. It is advisable to use Table 7 of IEC 62305-3 (EN 62305-3) when selecting the materials and cross-sections to be used. **Table 9.2.1** shows an excerpt of the before mentioned table for practical use. The relevant material must always be selected with regard to its corrosion resistance.
It must be checked in each individual case whether measures to reduce the probability of electric shock hazard resulting from touch and/or step voltage must be taken.

To reduce touch voltages, the IEC 62305-3 (EN 62305-3) standard requires, for example, an asphalt layer with a thickness of at least 5 cm in a radius of 3 m around the lamp pole (**Figure 9.2.1**).

To reduce step voltages, the IEC 62305-3 (EN 62305-3) standard requires, for example, potential control. To this end, four rings are buried around the lamp pole at distances of 1.0 m; 4.0 m; 7.0 m and 10.0 at depths of 0.5 m; 1.0 m; 1.5 m and 2.0 m. These rings are interconnected by means of four connecting cables at right angles to each other and are connected to the lamp pole (**Figure 9.2.2**).

Material	Configuration	Earthing conductor
Copper	Stranded/ round/tape	50 mm^2
Steel	Round, galvanised Tape, galvanised	78 mm^2 90 mm^2
Stainless steel (V4A)	Round Tape	78 mm^2 100 mm^2

Table 9.2.1 Minimum dimensions of earthing conductors for interconnecting lamp poles in LPZ 0_A and connecting lamp poles to the earth-termination systems of the buildings

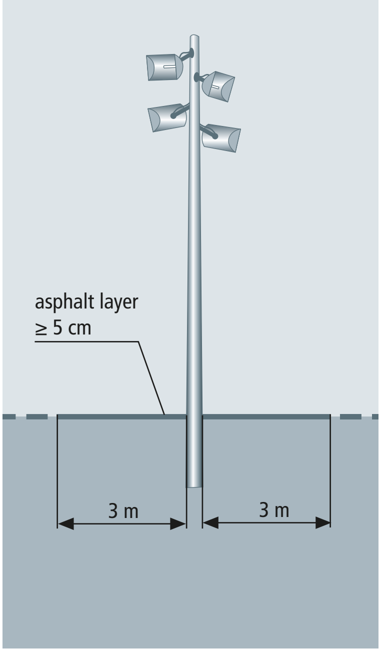


Figure 9.2.1 Standing surface insulation to reduce the risk of touch voltage in case of a lightning strike to a lamp pole

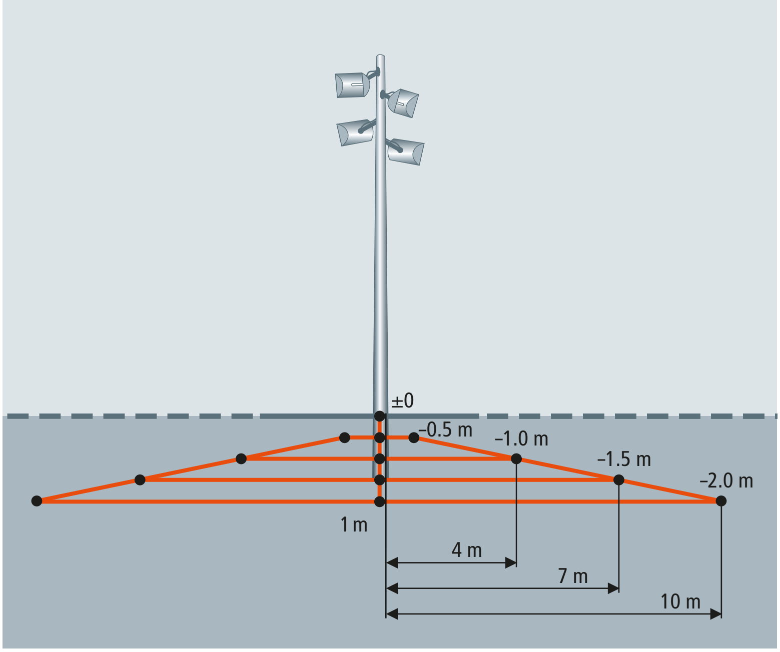
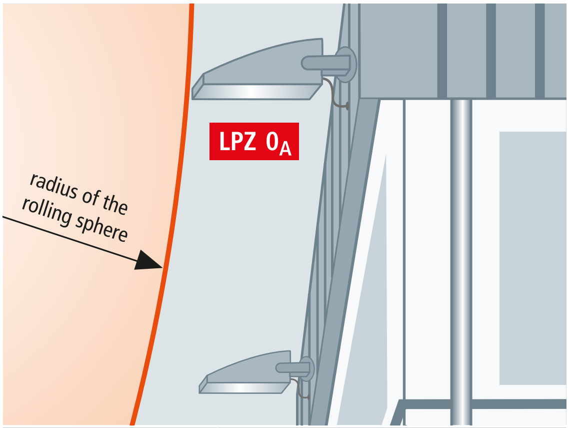


Figure 9.2.2 Potential control to reduce step voltage in case of a lightning strike to a lamp pole

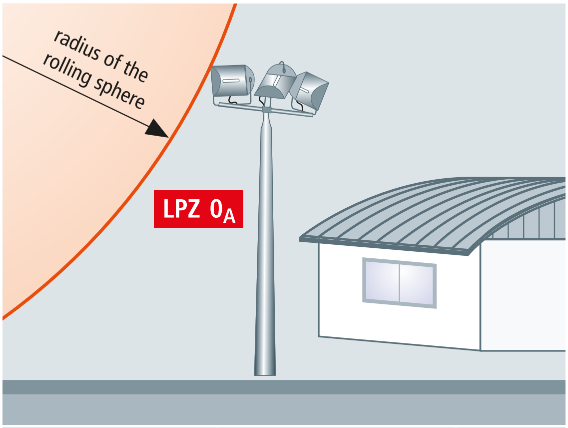


Application	Type	Part No.
Lightning current arresters		
TN system	DB M 1 255 (2x)	961 120
TT system	DB M 1 255 DGP M 1 255	961 120 961 101
Combined arresters		
TN system	DSH TN 255	941 200
TT system	DSH TT 2P 255	941 110

Figure 9.2.3 Outdoor lighting system in the form of a 230 V wall lamp in lightning protection zone 0_A with lightning equipotential bonding at the entrance point into the building

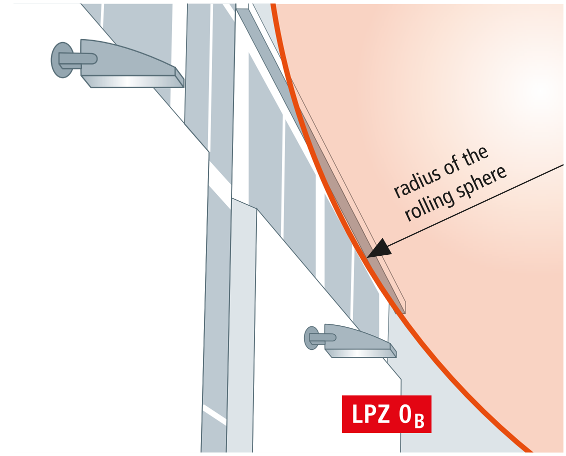
The recommended arrester types must be installed at the transition from LPZ 0_A to 1 or from LPZ 0_B to 1.
Type 1 lightning current arresters must be provided at the entrance point into the building for all outdoor lighting systems in LPZ 0_A. To determine this lightning protection zone, the relevant rolling sphere is "rolled over" the outdoor lighting system from all possible directions. If the rolling sphere touches the outdoor lighting system, it is located in LPZ 0_A (**Figures 9.2.3 and 9.2.4**).

Before installing type 1 lightning current arresters, it has to be checked whether an energy-coordinated type 2 surge arrester is already installed in the distribution board which houses the circuits of the outdoor lighting system. If this is not the case, we recommend to install combined arresters at the transition of the lightning protection zones.
Type 2 surge arresters must also be installed at the entrance point into the building for all outdoor lighting systems in LPZ 0_B (**Figure 9.2.5**).



Application	Type	Part No.
Lightning current arresters		
TN-S system	DB M 1 255 (4x)	961 120
TT system	DB M 1 255 (3x) DGP M 1 255	961 120 961 101
Combined arresters		
TN-S system	DSH TNS 255	941 400
TT system	DSH TT 255	941 310

Figure 9.2.4 Outdoor lighting system in the form of a 3x 230/400 V lamp pole in lightning protection zone 0_A with lightning equipotential bonding at the entrance point into the building



Application	Type	Part No.
TN system	DG M TN 275	952 200
TT system	DG M TT 2P 275	952 110

Figure 9.2.5 Outdoor lighting system in the form of a 230 V wall lamp in lightning protection zone 0_B

Lightning and surge protection for biogas plants

In modern biogas plants, biodegradable organic substrates such as manure, dung, grass, straw, green waste, residues of the sugar, wine and beer production, leftovers and grease are fermented in an air-tight container (fermenter). In this oxygen-free atmosphere, bacteria produce biogas from the fermentable, organic biomass components. This biogas is used to generate heat and electricity.

Figure 9.3.1 shows the basic principle of a biogas plant. Biogas plants frequently consist of feed-in systems for solids and / or liquid substrates, one or more heated fermenters, a storage tank, a post-fermenter, if any, a gas tank and a gas treatment unit, if any. The gas engine with heat exchanger and a generator connected to it is referred to as combined heat and power station (CHP). Depending on the energy content of biogas, a combined heat and power station generates electricity with an efficiency of about 30 % and heat with an efficiency of about 60 %. While the electricity is fed into the public power grid, some of the heat is used for heating the fermenter and the waste heat is used, for example, for heating residential and agricultural buildings.

Necessity of a lightning protection system

Different hazards and risks for persons, the environment and system technology can occur during the generation, storage and energy recovery of biogas. To be able to take adequate precautions and protection measures, potential risk sources which may cause failure or a dangerous event are considered in a risk analysis according to the German Federal Immission Control Act (BImSchG) / Ordinance on Industrial Safety and Health (BetrSichV).

The German Safety Regulations for Agricultural Biogas Plants published by the German Agricultural Professional Association as well as the German BGR 104 specify that measures which prevent the ignition of dangerous explosive atmospheres must be taken in potentially explosive atmospheres to avoid ignition sources.

According to sub-clause 5.3.1 of the EN 1127-1 standard, there are thirteen different ignition sources. In sub-clause 5.3.8 of the EN 1127-1 standard and in the German BGR 104, lightning is defined as a possible ignition source: "If lightning strikes in an explosive atmosphere, ignition will always occur. Moreover, there is also a possibility of ignition due to the high temperature reached by lightning conductors. Large currents flow from where the lightning strikes and these currents can produce sparks in the vicinity of the point of impact. Even in the absence of lightning strikes, thunderstorms can cause high induced voltages in equipment, protective systems and components".

A risk analysis according to the calculation method specified in IEC 62305-2 (EN 62305-2) must be performed to define the

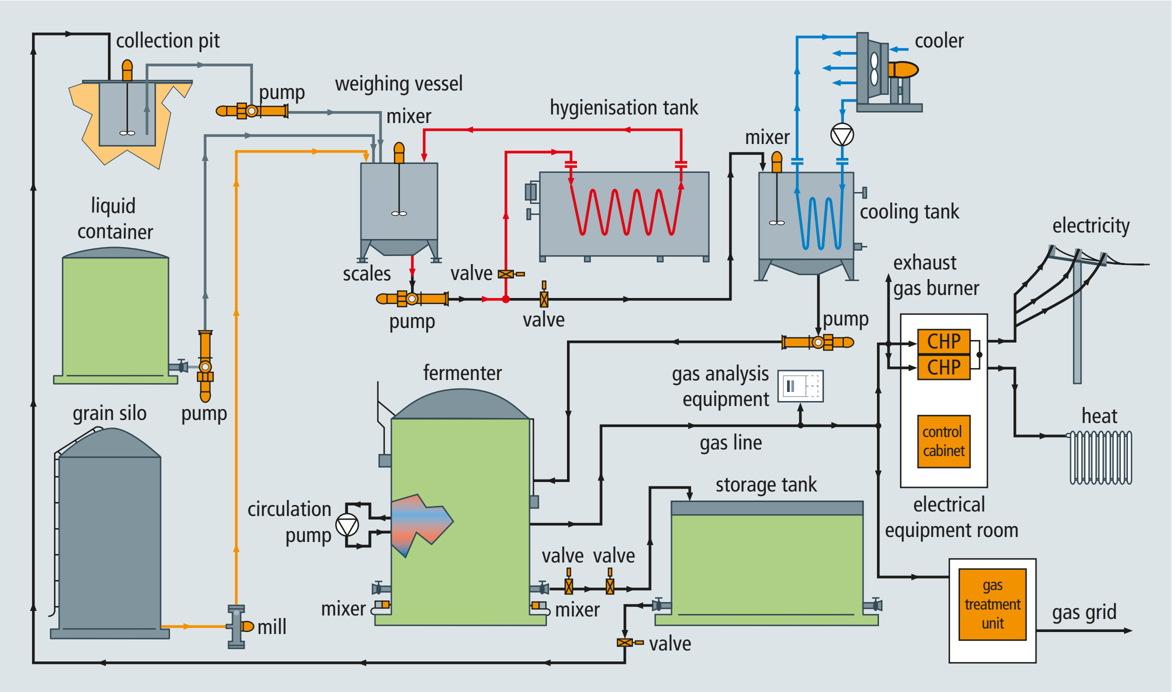


Figure 9.3.1 System overview of a biogas plant

relevant protection measures. The purpose of this risk analysis is to determine the risk resulting from direct and indirect lightning strikes for a structure including the persons and equipment therein. If the risk is higher than the tolerable risk, lightning protection measures must be taken to minimise the risk resulting from a lightning strike so that it is no longer higher than the tolerable risk.

Supplement 2 of the German DIN EN 62305-3 (VDE 0185-305-3) standard includes additional information on special buildings including requirements on lightning protection systems for biogas plants. According to this supplement, biogas plants should be protected by isolated air-termination and down-conductor systems if it cannot be excluded that risks resulting from ignitable sparks occur at contact and connecting points.

External lightning protection

The fermenter, which is available in different designs, is the core of every biogas plant. Therefore, the required lightning protection system must always be adapted to the structural conditions of the fermenter. There are different solutions for the same protection goals. As mentioned in Supplement 2 of the German DIN EN 62305-3 (VDE 0185-305-3) standard, a lightning protection system with class of LPS II meets the general requirements for systems with a risk of explosion and thus those for biogas plants.

A lightning protection system consists of an external and internal lightning protection system.

The function of an external lightning protection system is to intercept all lightning strikes including side flashes to the structure, to conduct the lightning current from the point of strike to the ground and to disperse it in the ground without causing damage to the structure to be protected resulting from thermal, mechanical or electrical effects.

Fermenters with foil roof

Fermenters with foil roof are frequently used for biogas plants. If lightning strikes the foil roof of the fermenter, it will be damaged and melting and spraying effects at the point of strike can cause fire and explosion. Lightning protection measures must be taken in such a way that direct lightning strikes to the foil roof of the fermenter are prevented (**Figure 9.3.2**).

The German Safety Regulations for Agricultural Biogas Plants define that e.g. Ex zone 2 is located in a radius of 3 m around the foil roof of the fermenter. In Ex zone 2 potentially explosive atmospheres only occur occasionally or for a short period of time. This means that a potentially explosive atmosphere is only to be expected in case of rare and unpredictable events (failure and maintenance work). Therefore, air-termination systems may be positioned in Ex zone 2 according to IEC 62305-3 (EN 62305-3).

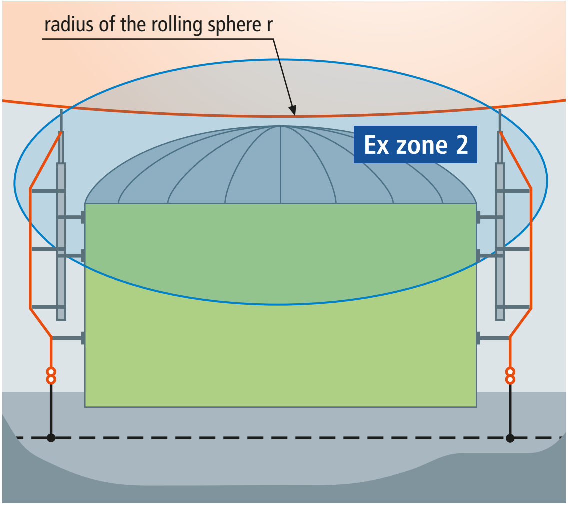


Figure 9.3.2 DEHNiso Combi system used to protect a fermenter with foil roof

Type	Part No.
DEHNiso Combi set, one-piece, total length of 5700 mm	105 455
Consisting of:	
1 StSt air-termination tip, 1000 mm long	105 071
1 GRP/Al supporting tube, 4700 mm long	105 301
3 wall mounting brackets made of StSt (V2A)	105 340
2 GRP/Al spacers, 1030 mm long	106 331

Table 9.3.1 DEHNiso Combi set

The rolling sphere method is used to determine the height and number of air-termination systems. The sag of the rolling sphere, which can be determined according to IEC 62305-3 (EN 62305-3), is decisive for dimensioning the air-termination system. In case of class of LPS II for systems with a risk of explosion, the rolling sphere radius is 30 m (**Figure 9.3.2**).

Depending on the gas volume, the inner membranes in the gas storage tank of the fermenter contact the metal inner wall of the fermenter. An insulated down conductor is used to avoid uncontrolled flashover from the down conductor to the metal wall of the fermenter. The lightning protection system is electrically isolated from conductive parts of the fermenter since the down conductor is routed separately by means of spacers made GRP (glass-fibre reinforced plastic). The length of the spacers depends on the separation distance determined according to IEC 62305-3 (EN 62305-3).

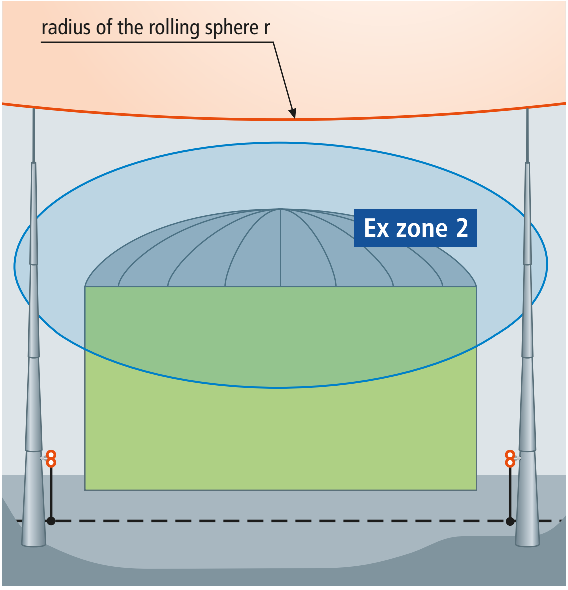


Figure 9.3.3 Protection of a fermenter with a foil roof by means of telescopic lightning protection masts

The DEHNiso Combi set according to **Table 9.3.1** is used for the application illustrated in **Figure 9.3.2**.

Another possibility to avoid direct lightning strikes to fermenters with foil roof is to use steel telescopic lightning protection masts (**Figure 9.3.3**). These masts are installed in natural soil or in the ground foundation. Free heights above ground level up to 25 m or in case of customised versions even higher can be achieved. The standard lengths of the steel telescopic lightning protection masts are supplied in partial lengths of 3.5 m, offering enormous transportation benefits. More detailed information on the use of steel telescopic lightning protection masts can be found in installation instructions No. 1729.

A third possibility to protect fermenters with foil roof from direct lightning strikes is to use a HVI Conductor. HVI Conductors are high-voltage-resistant, insulated conductors with a special outer sheath. In the field of lightning protection, they are typically used as insulated down conductors for keeping the separation distance according to IEC 62305-3 (EN 62305-3). To this end, the separation distance must be calculated according to IEC 62305-3 (EN 62305-3). Then it must be checked whether this calculated separation distance can be achieved by means of the equivalent separation distance of the HVI Conductor. There are two possible solutions:

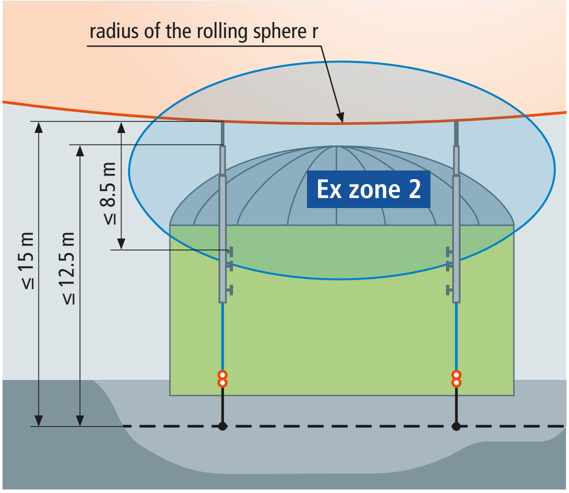


Figure 9.3.4 Protection of a fermenter by means of air-termination masts, isolated by means of a HVI Conductor (Part No. 819 720)

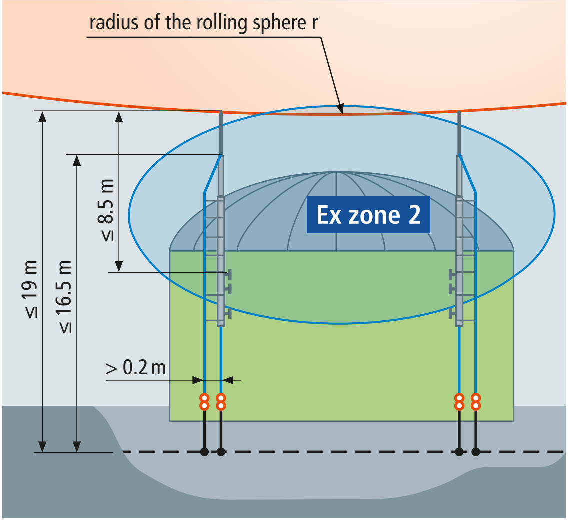


Figure 9.3.5 Protection of a fermenter by means of air-termination masts, isolated by means of two HVI Conductors (Part No. 819 750)

- ➡ **Solution 1**: Air-termination masts with **one** HVI Conductor (**Figure 9.3.4**). The maximum total length of the air-termination system from the equipotential bonding level (earth-termination system) to the air-termination tip is 15 m (in case of class of LPS II). The maximum free length above the top edge of the fermenter must not exceed 8.5 m (for mechanical reasons).
- ➡ **Solution 2**: Air-termination masts with **two** HVI Conductors (**Figure 9.3.5**). The maximum total length of the air-

Figure 9.3.6 Fermenter made of bolted metal sheets

Figure 9.3.7 Protection of a fermenter made of metal sheets by means of an isolated air-termination system (source: Büro für Technik, Hösbach)

termination system from the equipotential bonding level (earth-termination system) to the air-termination tip is 19 m (in case of class of LPS II). The maximum free length above the top edge of the fermenter is also 8.5 m.

Note: The two HVI Conductors must be installed in parallel at intervals of more than 20 cm.

More detailed information on HVI Conductors and the relevant installation instructions can be found at www.dehn-international.com.

Design service

Isolated air-termination systems are complex and comprehensive systems. DEHN will be pleased to assist you in designing isolated air-termination systems based on HVI Conductors, the DEHNiso Combi system or steel telescopic lightning protection masts. This design service is available for a fee and comprises:

- Drawings of the lightning protection system (general layout drawings)
- Detailed drawings for the isolated air-termination system (in some cases in the form of exploded views)
- Comprehensive parts list of the components required for the isolated air-termination system
- Quotation based on this parts list.

If you are interested in our design service, please contact your local sales representative or our head office in Neumarkt, Germany at www.dehn-international. com.

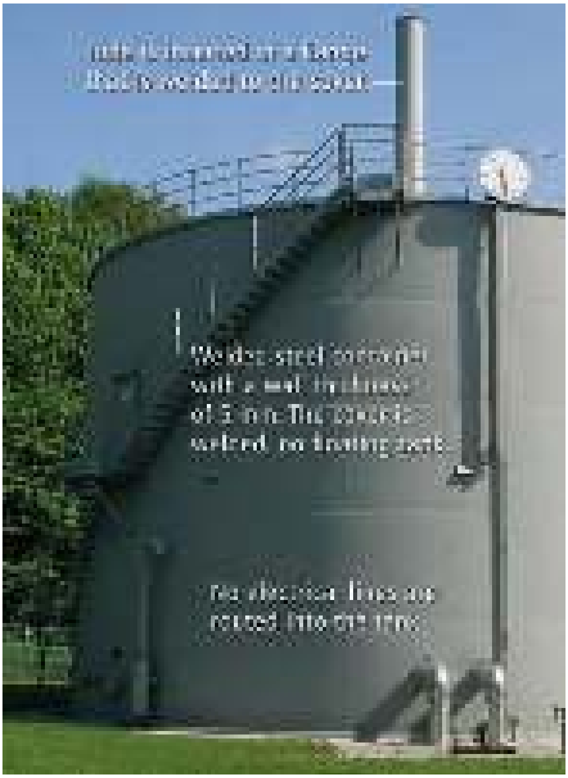


Figure 9.3.8 Welded steel container (source: Eisenbau Heilbronn GmbH)

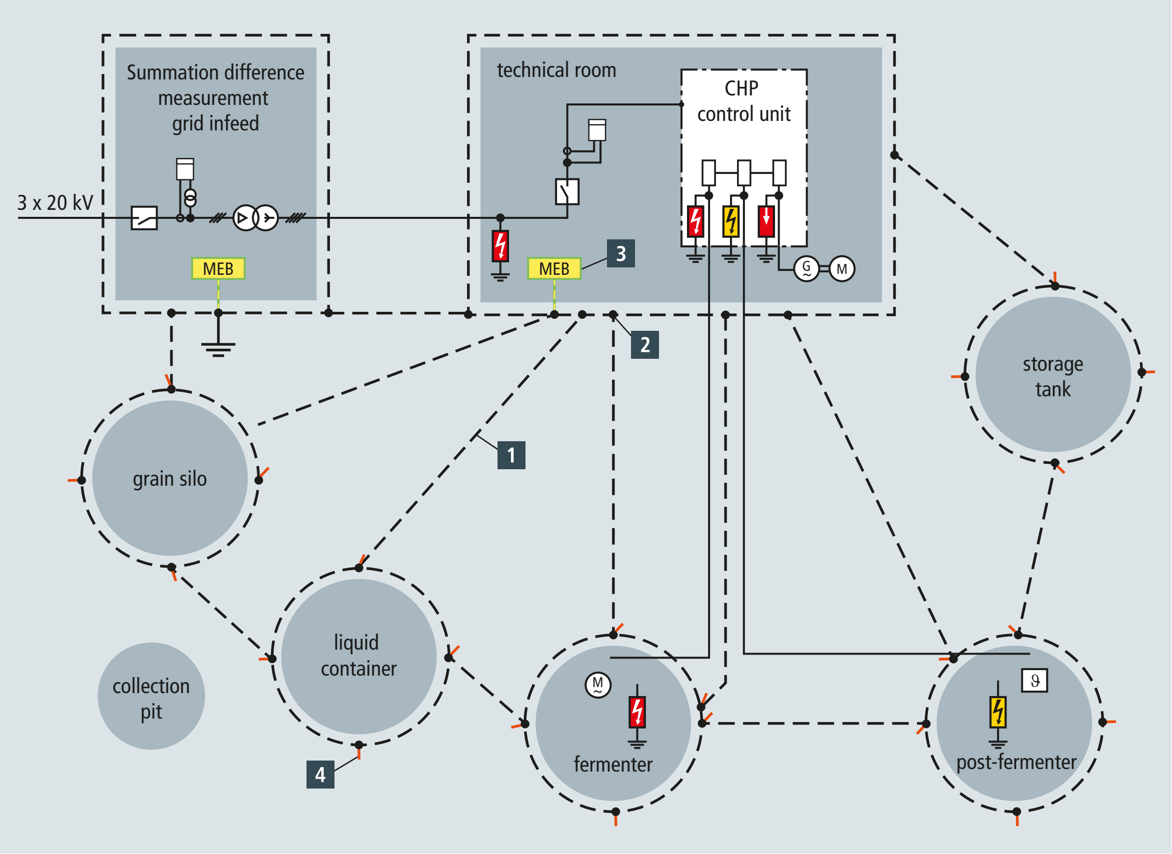
Fermenters made of metal sheets

Fermenters made of metal sheets typically have a thickness between 0.7 mm and 1.2 mm. The individual metal sheets are screwed together (**Figure 9.3.6**).

If metal sheets are to be used as natural air-termination system, the metal sheets must have the relevant thickness listed in Table 3 of IEC 62305-3 (EN 62305-3). If the thickness of the metal sheets does not comply with Table 3 of IEC 62305-3 (EN 62305-3), a lightning strike may cause melting or impermissible heating at the point of strike resulting in a risk of fire and explosion. In this case, these fermenters must be protected by additional air-termination systems to avoid melting at the point of strike. For this purpose, an isolated lightning protection system is installed. The rolling sphere method is used to determine the arrangement of the air-termination system. The down conductor is routed along the metal sheets by means of spacers according to the calculated separation distance (**Figure 9.3.7**).

Steel container

Figure 9.3.8 shows a biogas tank enclosed by fully welded steel sheets. According to Table 3 of IEC 62305-3



	Protection for the earth-termination system	Part No.		Protection for the earth-termination system	Part No.
1	Strip made of stainless steel (V4A), 30 mm x 3.5 mm, or round wire made of stainless steel (V4A), Ø 10 mm	860 335 860 010	3	Equipotential bonding bar made of stainless steel (V4A) or earthing busbar	472 209 472 139
2	Cross unit made of stainless steel (V4A) or SV clamp made of stainless steel (V4A) Note: Anti-corrosive band	319 209 308 229 556 125	4	Terminal lug in the form of a flat strip made of stainless steel (V4A) or terminal lug in the form of a round wire made of stainless steel (V4A)	860 215 860 115

Figure 9.3.9 Intermeshed earth-termination system for a biogas plant

(EN 62305-3), a minimum wall thickness of the enclosure of 4 mm is required for steel. The lightning protection system must meet the requirement according to Annex D of IEC 62305-3 (EN 62305-3) "Additional information for LPS in the case of structures with a risk of explosion". If the Ex zones of exhaust openings are located in the protected volume of lightning current carrying metal parts of the enclosure, no additional air-termination systems are required. If this is not the case, additional air-termination systems must be installed to protect the exhaust openings from direct lightning strikes.

Earthing concept

To avoid high potential differences between the individual earth-termination systems, they are interconnected to an overall earth-termination system (**Figure 9.3.9**). This is achieved by intermeshing the individual earth-termination systems of the buildings and systems. Mesh sizes from 20 m x 20 m to 40 m x 40 m have proven to be economically and technically feasible. By intermeshing all earth-termination systems, potential differences between the parts of the installation are considerably reduced. Moreover, the voltage stress on the electrical connecting cables between the buildings in case of lightning effects is reduced.

Feeding electricity into the grid

The biogas produced is typically used in gas or pilot injection engines to generate electricity and heat. In this context, such engines are referred to as combined heat and power plants (CHP). These CHPs are located in a separate operations building. The electrical equipment, switchgear cabinets and control cabinets are housed in the same room or in a separate room of this operations building. The electricity generated by the CHPs is fed into the public grid (**Figure 9.3.10**).

Lightning equipotential bonding, which must be established for all conductive systems entering the building, is an integral part of a lightning protection system. Lightning equipotential bonding requires that all metal systems be incorporated in the equipotential bonding so as to cause as little impedance as possible and that all live systems are indirectly integrated in the equipotential bonding via type 1 surge protective devices. Lightning equipotential bonding should be established as close as possible to the entrance point into the structure to prevent partial lightning currents from entering the building. The incoming 230/400 a.c. lines of the main low-voltage distribution board of the consumer installation (**Figure 9.3.10**) are protected by type 1 surge protective devices (SPDs). DEHNbloc, for example, is a type 1 surge protective device with RADAX Flow spark gaps for power supply systems. This lightning current arrester has a discharge capacity up to 50 kA (10/350 μs) per pole. The patented RADAX Flow principle limits and extinguishes short-circuit currents (follow currents) up to 100 kA_{rms}. Undesired supply disruption resulting from tripping main fuses is thus prevented. Type 2 DEHNguard M TNS 275 FM surge arresters are installed in the downstream sub-distribution boards.

A modular multipole DEHNventil combined arrester with high follow current limitation is installed in the distribution board of the CHP (**Figure 9.3.10**). This prewired spark-gap-based combined arrester comprises a base part and plug-in protection modules. DEHNventil ensures maximum availability of the installation, disconnection selectivity with respect to 20 A gL/gG fuses as well as limitation and extinction of mains follow currents up to short-circuit currents of 100 kA_{rms}.

If DEHNventil is installed close to the loads (≤ 5 m), protection of terminal equipment is also ensured.

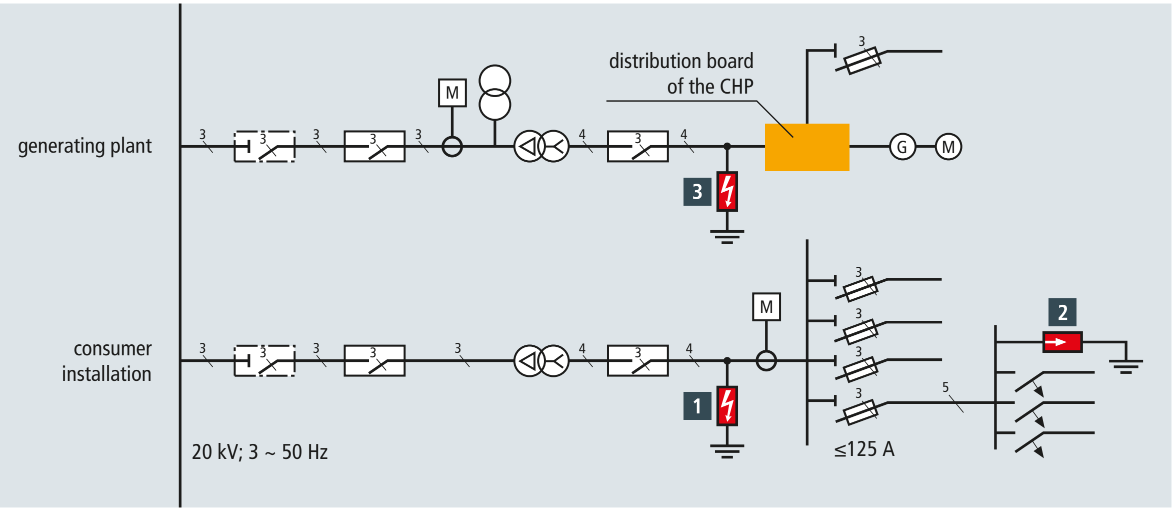
Remote monitoring

The remote monitoring system ensures that the performance data of the biogas plant are permanently available. The installation-specific measured values can be directly read off the acquisition unit. This unit features interfaces such as Ethernet or RS 485 which are connected to a PC and / or modems for remote enquiry and maintenance. Remote monitoring, for example via modem, allows service staff to log on to existing systems and to provide immediate support to the operator in case of failure. The modem is connected to the network termination unit (NTBA) of a basic ISDN connection. It must also be ensured that the measured data are forwarded by means of the telecommunication network via ISDN modem to provide permanent monitoring and to optimise the installation's performance. For this purpose, the U_{k0} interface upstream of the NTBA which is connected to the ISDN modem is protected by a BLITZDUCTOR XT combined arrester (**Figure 9.3.11**). It is advisable to use a DEHNprotector surge arrester to protect the power and data side of telecommunications terminal equipment and telephone systems with RJ connection. **Figure 9.3.11** shows an example of how to protect a CCTV camera by means of these arresters. A shielded UKGF BNC surge arrester is provided for the coaxial cable (video transmission system). More detailed information on the protection of CCTV systems can be found in chapter 9.7 "Surge protection for CCTV systems".

Process control

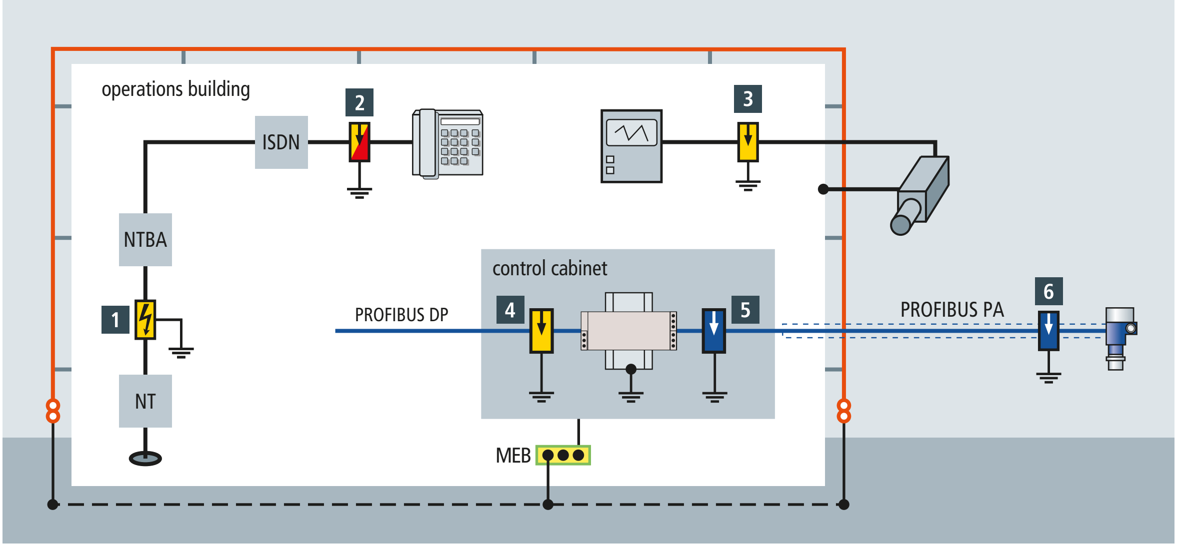
The control unit is a key element of a biogas plant. Its function is to centrally actuate all pumps and mixers, record process data such as the gas volume and gas quality, monitor the temperature, acquire all input materials as well as visualise and document all data.

If the process control fails as a result of surges, processes for biogas production are interfered with and interrupted. Since these processes are extremely complex, unscheduled downtime can lead to further problems so that the standstill period may be extended to several weeks.



No.		Surge protective device	Part No.	Notes
Feed-in system / main distribution board				
1	TN-C system	3 x DEHNbloc DB M 1 255 FM	961 125	Single-pole spark-gap-based lightning current arrester with high follow current limitation and remote signalling contact
	TN-S system	4 x DEHNbloc DB M 1 255 FM	961 125	
	TT system	3 x DEHNbloc DB M 1 255 FM + 1 x DEHNgap DGP M 255 FM	961 125 + 961 105	
Alternative				
1	TN-C system	3 x DEHNbloc Maxi DBM 1 255 S	900 220	Coordinated lightning current arrester with integrated arrester backup fuse for industrial busbar systems
	TN-S system	4 x DEHNbloc Maxi DBM 1 255 S	900 220	
	TT system	3 x DEHNbloc Maxi DBM 1 255 S + 1 x DEHNgap Maxi DGPM 1 255 S	900 220 + 900 050	
Alternative				
1	TN-C system	3 x DEHNvenCI DVCI 1 255 FM	961 205	Combined arrester with integrated arrester backup fuse and a voltage protection level ≤ 1.5 kV for terminal equipment
	TN-S system	4 x DEHNvenCI DVCI 1 255 FM	961 205	
	TT system	3 x DEHNvenCI DVCI 1 255 FM 1 x DEHNgap DGP M 255 FM	961 205 961 105	
Sub-distribution board				
2	TN-C system	DEHNguard DG M TNC 275 FM	952 305	Multipole surge arrester with Thermo Dynamic Control and remote signalling contact
	TN-S system	DEHNguard DG M TNS 275 FM	952 405	
	TT system	DEHNguard DG M TT 275 FM	952 315	
Generating plant				
3	TN-C system	DEHNventil DV M TNC 255 FM	951 305	Modular combined arrester with high follow current limitation and a voltage protection level ≤ 1.5 kV
	TN-S system	DEHNventil DV M TNS 255 FM	951 405	
	TT system	DEHNventil DV M TT 255 FM	951 315	

Figure 9.3.10 Excerpt from the block diagram of a biogas plant



No.	Protection for…	Surge protective device	Part No.
Telecommunication / data technology			
1	Fixed line network	BLITZDUCTOR BXT ML2 BD 180 + BXT BAS base part	920 247 + 920 300
2	ISDN devices	DEHNprotector DPRO 23 ISDN	909 320
3	Coaxial cable (video transmission system)	UGKF BNC	929 010
Measuring and control equipment			
4	PROFIBUS DP	BLITZDUCTOR BXT ML4 BD HF 5 + BXT BAS base part	920 371 + 920 300
	Analogue signals (non-hazardous area)	BLITZDUCTOR BXT ML4 BE 24 + BXT BAS base part	920 324 + 920 300
5	PROFIBUS PA Ex (i)	BLITZDUCTOR BXT ML2 BD S EX 24 + BXT BAS EX base part	920 280 + 920 301
	Temperature measurement PT 100, PT 1000, Ni 1000 (non-hazardous area)	BLITZDUCTOR BXT ML4 BC 24 + BXT BAS base part	920 354 + 920 300
Field devices			
6	4–20 mA, PROFIBUS PA, Fieldbus Foundation, Ex (i)	DPI MD EX 24 M 2	929 960
	4–20 mA, PROFIBUS PA, Fieldbus Foundation, non-hazardous area	DPI MD 24 M 2S	929 941

Figure 9.3.11 Surge protection for the installations of information technology systems

The control unit is installed in the control cabinet. In addition to digital inputs and outputs, e.g. PT 100 signals, 4–20 mA signals or the like are evaluated here. To ensure undisturbed and permanent transmission of the measured data to the control unit in the control cabinet at any time, the control and signal lines extending beyond the buildings, for example that of frequency converters and actuators, must be protected by installing BLITZDUCTOR XT lightning current arresters (category D1) as close as possible to the entrance point into the building (**Figure 9.3.12**). A contactless and fast arrester testing system (LifeCheck) is integrated in these surge protective devices. Surge protective devices for information technology systems

Figure 9.3.12 Combined arrester modules with LifeCheck

Figure 9.3.13 DEHNpipe surge arrester for outdoor use is screwed onto two-conductor field devices

are chosen according to the maximum continuous operating voltage, the nominal current, the type of signal (DC, LF, HF) and the type of signal transmission (balanced, unbalanced).

Figure 9.3.11 shows examples of surge protective devices for signal and control lines.

It is recommended to install a DEHNpipe surge arrester to protect two-wire field devices such as pressure or level sensors, valves, pressure transmitters or flow meters (**Figure 9.3.13**). This arrester ensures energy-coordinated surge protection for outdoor field devices and takes up little space.

Retrofitting sewage plants with lightning and surge protection measures

A more efficient use of drinking water is growing in significance, especially against a backdrop of increasingly scarce drinking water resources. Therefore, sewage plants are a key element of the drinking water cycle. The necessary high efficiency of sewage plants (**Figure 9.4.1**) requires that the operating procedure be optimised and the operating costs be reduced at the same time. For this purpose, high investments were made in electronic measuring equipment and distributed electronic control and automation systems over the last years. However, these new electronic systems only provide a low resistance to transients compared to conventional technology. The structural conditions of the widespread outdoor wastewater treatment systems with measuring equipment and control units extending over large areas additionally increase the risk of interference caused by lightning discharges or surges. Thus, it is most likely that the complete process control system or parts thereof fail if no protection measures are taken. The consequences of such a failure can be serious ranging from costs for re-establishing the availability of the sewage plant to the unknown costs for eliminating ground water contamination. Consequently, external and internal lightning protection measures must be taken to efficiently eliminate this threat and to increase the availability of the systems.

Assessment of the risk for the operations building

The example described in the following was calculated based on the IEC 62305-2 (EN 62305-2) standard. We expressively point out that the procedure shown is only an example. This solution is not binding in any way and can be substituted by other equivalent solutions. In the following, only the essential characteristics of the example will be shown. At first, a questionnaire with important questions on the structure and its use was discussed and filled in together with the operator. This procedure allows to prepare a lightning protection concept that is comprehensible for all parties involved. The concept includes the minimum requirements which, however, can be technically improved at any time.

Plant description

The complete process control system of the sewage plant is centrally located in the operations building. In case of a lightning strike, substantial partial lightning currents and surges are injected into the switch rooms via the extended cables leading to measuring stations and substations. In the past, this caused destruction and failure of the plant over and over again. The same applies to the power supply and telephone line. The operations building itself must be protected against damage resulting from fire (caused by a direct lightning strike) and the electrical and electronic systems (control and automation system, telecontrol system) from the effects of the lightning electromagnetic pulse (LEMP).

Additional conditions:

- Protection measures against lightning effects have already been taken (external lightning protection system accord-

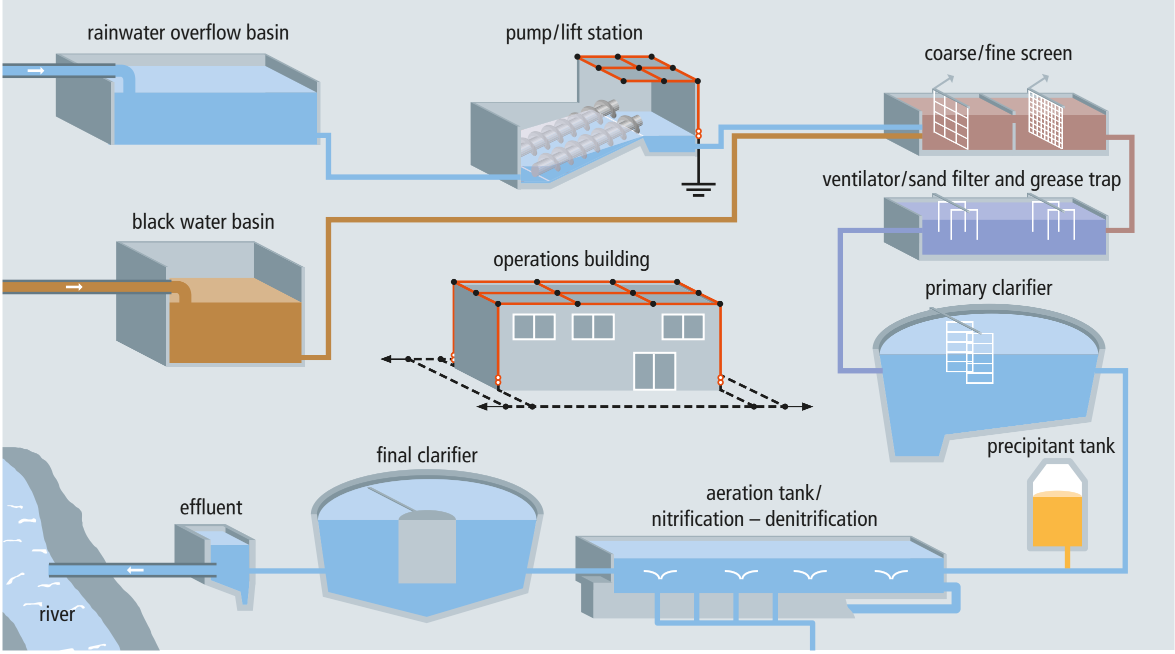
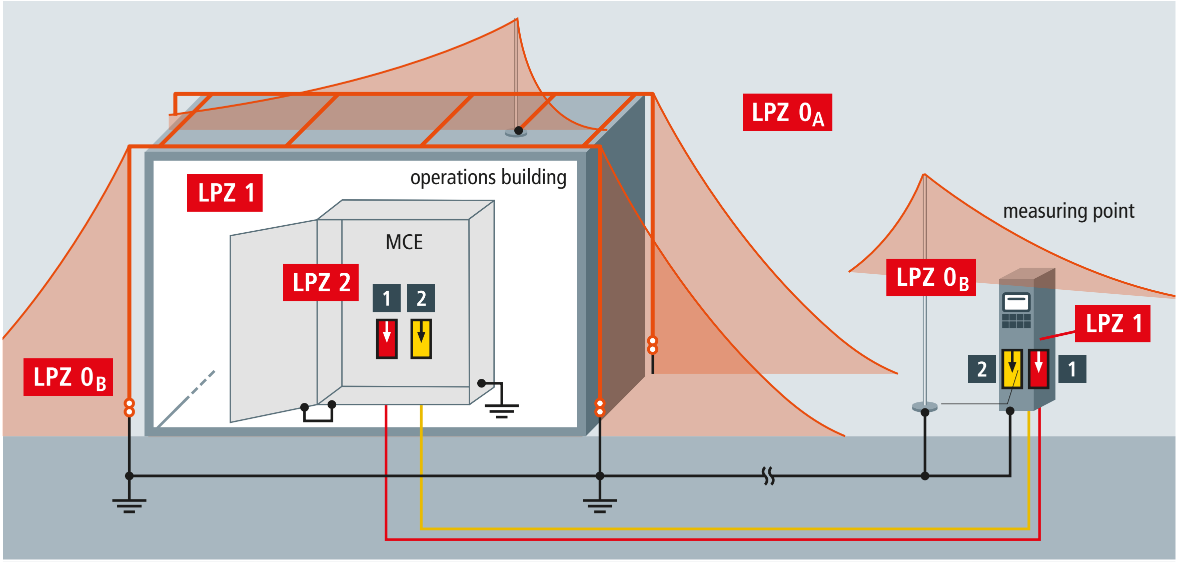


Figure 9.4.1 Schematic diagram of a sewage plant



	Protection for…		Type	Part No.
1	Power supply system	TN system	DEHNguard DG M TN 275 DEHNguard DG M TN 275 FM	952 200 952 205
		TT system	DEHNguard DG M TT 2P 275 or DEHNguard DG M TT 2P 275 FM	952 110 952 115
2	Oxygen measurement device	e.g. 4 to 20 mA	BLITZDUCTOR BXT ML4 BE S 24 + BXT BAS base part or BLITZDUCTOR BXT ML2 BE 24 + BXT BAS base part	920 224 + 920 300 920 324 + 920 300

Figure 9.4.2 Division of the operations building into lightning protection zones; example: selection of surge protective devices for the oxygen measurement device

ing to the previous IEC 62305-1 (EN 62305-1) standard, VGA 280/4 surge protective devices (SPDs) installed at the entrance point of the 230/400 V power supply line into the building, VM 280 SPDs of requirement class C installed in the switchgear cabinets of the measuring and control equipment).

- The following types of loss are relevant: L2: Loss of service to the public (water supply and wastewater disposal) and L4: Loss of economic value (structures and their contents). Type of damage L1: Loss of human life was excluded since the plant will be fully automated at a later date.

An assessment of the actual state shows that the calculated risk R for the types of damage L2 and L4 is still considerably higher than the tolerable risk R_T.

Possible protection measures are taken to ensure $R < R_T$ for both types of damage:

- Installation of a lightning protection system with class of LPS III according to IEC 62305-3 (EN 62305-3) (this complies with the recommendations in the German VdS publication 2010).
- Installation of type 1 SPDs according to IEC 61643-11 (EN 61643-11) (power supply) and SPDs of category D1 according to IEC 61643-21 (EN 61643-21) for the information technology lines (measuring and control lines as well as telecommunication lines) at the zone transitions from LPZ 0_A to 1.
- Type 2 SPDs according to IEC 61643-11 (EN 61643-11) (power supply) and surge protective devices of category C2 according to IEC 61643-21 (EN 61643-21) for the information technology lines (measuring and control lines as well as telecommunication lines) at the zone transitions from LPZ 0_B to 1 and 1 to 2.

Lightning protection zone concept

To ensure maximum technical and economic protection, the operations building is subdivided into lightning protection zones (LPZs). Subsequently, a risk analysis is carried out for each LPZ and the relevant types of damage. The mutual dependences of the LPZs are then examined and the required

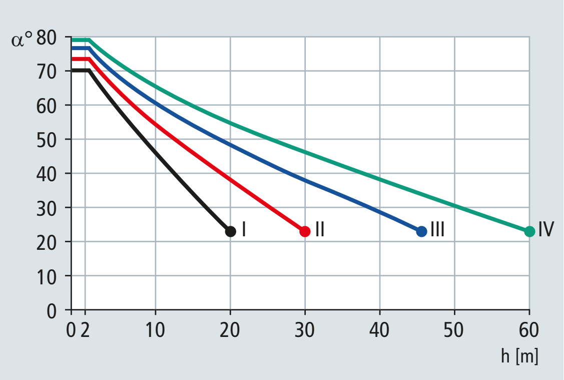


Figure 9.4.3 Protective angle method according to IEC 62305-3 (EN 62305-3)

protection measures are defined to reach the necessary protection goal in all lightning protection zones. The following areas were subdivided into lightning protection zone 1 (LPZ 1) and lightning protection zone 2 (LPZ 2):

- Evaluation unit in the control room (LPZ 2)
- Oxygen measurement device in the aeration tank (LPZ 1)
- Interior of the control room (LPZ 1)

According to the lightning protection zone concept described in IEC 62305-4 (EN 62305-4), all lines at the boundaries of lightning protection zones must be protected by suitable surge protection measures.

Figure 9.4.2 exemplarily shows suitable surge protection measures for the oxygen measurement device in the aeration tank. The field cables are located in LPZ 0_B throughout their entire course. Therefore, type 2 SPDs can be used for protecting the oxygen measurement device and the control systems since (partial) lightning currents are not to be expected in LPZ 0_B.

Lightning protection system

The existing lightning protection system of the operations building was tested according to the requirements of class of LPS III. The indirect connection of the roof-mounted structures (air-conditioning systems) via isolating spark gaps was removed. Air-termination rods with the required separation distances and protective angles were used to protect the sewage plant from a direct lightning strike (**Figure 9.4.3**). Consequently, in case of a direct lightning strike to the control room, partial lightning currents can no longer flow into the structure and cause damage. Due to the dimensions of the control room (15 m x 12 m), the number of down conductors (4) did not have to be changed. The local earth-termination system of the operations building was tested at all measuring points and the values were documented. Retrofitting was not required.

Lightning equipotential bonding for all conductive systems entering the sewage plant

In principle, all conductive systems entering the sewage plant must be integrated in the lightning equipotential bonding (**Figure 9.4.4**). This is achieved by directly connecting all metal systems and indirectly connecting all live systems via surge protective devices. Type 1 SPDs (power supply systems) and category D1 SPDs (information technology systems) must have a discharge capacity of 10/350 µs test waveform. Lightning equipotential bonding should be established as close as possible to the entrance point into the structure to prevent lightning currents from entering the building.

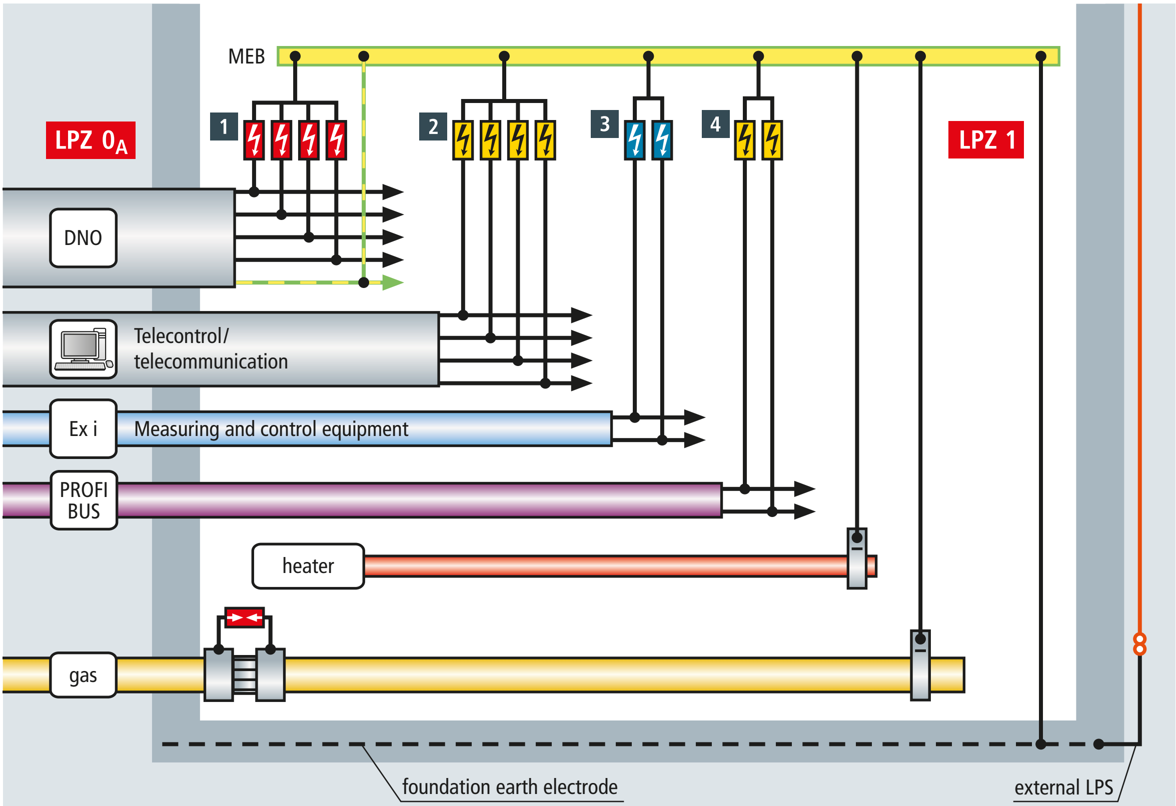
Equipotential bonding

Consistent equipotential bonding according to IEC 60364-4-41 (HD 60364-4-41), IEC 60364-5-54 (HD 60364-5-54) and IEC 62305-3 (EN 62305-3) is established in the entire operations building. The existing equipotential bonding system is tested to avoid potential differences between different extraneous conductive parts. Supporting and structural parts of the building, pipes, containers, etc. are integrated in the equipotential bonding system so that voltage differences do not have to be expected, even in case of failure. If surge protective devices are used, the cross-section of the copper earthing conductor for equipotential bonding must be at least 16 mm^2 in case of SPDs for power supply systems and at least 6 mm^2 in case of SPDs for information technology systems (e.g. BLITZDUCTOR) or the cross section specified in the installation instructions must be used. Moreover, in areas with potentially explosive atmospheres the connections of the equipotential bonding conductors e.g. at equipotential bonding bars must be secured against self-loosening (e.g. by means of spring washers).

Surge protection for the low-voltage power supply system

In the described application, the VGA 280/4 surge protective device installed at the entrance point into the building is replaced by a DEHNventil M TNS 255 FM type 1 combined arrester (**Figure 9.4.5**) since the "old" SPD no longer fulfils the requirements for lightning protection systems according to IEC 62305-3 (EN 62305-3). The VM 280 type 2 SPDs were tested by means of a PM 10 arrester test unit. Since the test values were still within the tolerances, the SPDs did not have to be removed. If further SPDs are installed for protecting terminal equipment, they must be coordinated with each other and with the terminal equipment to be protected. The relevant installation instructions must be observed.

In other respects, the use of surge protective devices in the low-voltage consumer's installation does not differ from other



No. in Fig.	Protection for	Surge protective device *floating remote signalling contact	Part No.
Power supply systems			
1	TN-C system	DEHNventil DV M TNC 255 DEHNventil DV M TNC 255 FM* DEHNventil DV ZP TNC 255	951 300 951 305 900 390
	TN-S/TT system	DEHNventil DV M TT 255 DEHNventil DV M TT 255 FM* DEHNventil DV ZP TT 255	951 310 951 315 900 391
Information technology systems			
2	Telecontrol, telecommunication	BLITZDUCTOR BXT ML2 BD 180 or BLITZDUCTOR BXT ML4 BD 180 + BXT BAS base part	920 247 920 347 + 920 300
Measuring and control equipment			
3	Intrinsically safe measuring circuits + systems	BLITZDUCTOR BXT ML2 BD S EX 24 or BLITZDUCTOR BXT ML4 BD EX 24 + BXT BAS base part	920 280 920 381 + 920 301
Bus systems			
4	e.g. Profibus DP	BLITZDUCTOR BXT ML2 BD HFS 5 + BXT BAS base part	920 271 + 920 300

Figure 9.4.4 Lightning equipotential bonding according to DIN EN 62305-3 (VDE 0185-305-3), Supplement 1

Figure 9.4.5 DEHNventil installed in a switchgear cabinet for protecting the power supply systems

Figure 9.4.6 DEHNconnect terminal blocks with integrated surge protection for protecting the complete measuring and control equipment

applications (for more detailed information, please also see brochure DS 649 E "Red/Line Selection Guide").

Surge protection for information technology systems

The entrance point into the building serves as a transfer point between all information technology lines and the sewage plant. At this point, lightning current carrying SPDs (category D1), e.g. of type DRL 10 B 180 FSD, are installed. The lines are directly routed from this transfer point to the switchgear cabinets and are connected there. According to the risk analysis, the incoming lines for the 20 mA signals and the telecontrol system must be protected by adequate arresters from the DEHNconnect or BLITZDUCTOR series. These SPDs can be installed in conformity with the lightning protection zone concept (category C2) and are compatible with the system (**Figures 9.4.6 and 9.4.7**).

This ensures a consistent surge protection concept for the information technology lines.

Additional applications for protecting sewage plants can be found in brochure DS 107 E which can be downloaded at www.dehn-international.com.

Figure 9.4.7 DEHNconnect surge protection devices; lines entering from the double floor

Safety requirements for cable networks, remote signals, sound signals and interactive services

Nowadays conventional satellite and terrestrial antennas are almost exclusively installed on the roofs of buildings. Therefore, the IEC 60728-11 (EN 60728-1) standard calls for earthing measures in addition to equipotential bonding and lightning equipotential bonding of the cable network (cable shields). This standard typically applies to stationary systems and devices. Mobile systems (e.g. caravans), which are also covered by the standard, are not dealt with here.

Moreover, this practical solution does not describe earthing measures for antenna systems installed at locations with a low risk of lightning strikes and equipotential bonding in case of let-go threshold currents ≤ 3.5 mA, which are both not required.

In general, antennas installed in conformity with this standard do not increase the probability of a lightning strike and earthed antenna standpipes are no substitute for a lightning protection system.

Earth-termination system

An earth-termination system may consist of one foundation earth electrode, two horizontal earth electrodes (earth strips) with a length of 2.5 m and an angle > 60° each, one vertical earth electrode (earth rod) with a length of 2.5 m or two vertical earth electrodes with a length of 1.5 m each spaced at intervals of 3 m (**Figure 9.5.1**). It must be observed that earth-termination systems must be connected to the main earthing busbar (MEB). The earth electrode must have a minimum cross-section of 50 mm^2 (copper) or 90 mm^2 (galvanised or stainless steel) (typical: flat strip 30 x 35 mm; cross-section of 105 mm^2).

Equipotential bonding

To ensure that persons and property are protected, the cable network must be integrated in the protective equipotential bonding of the building. If cables are installed in such a way

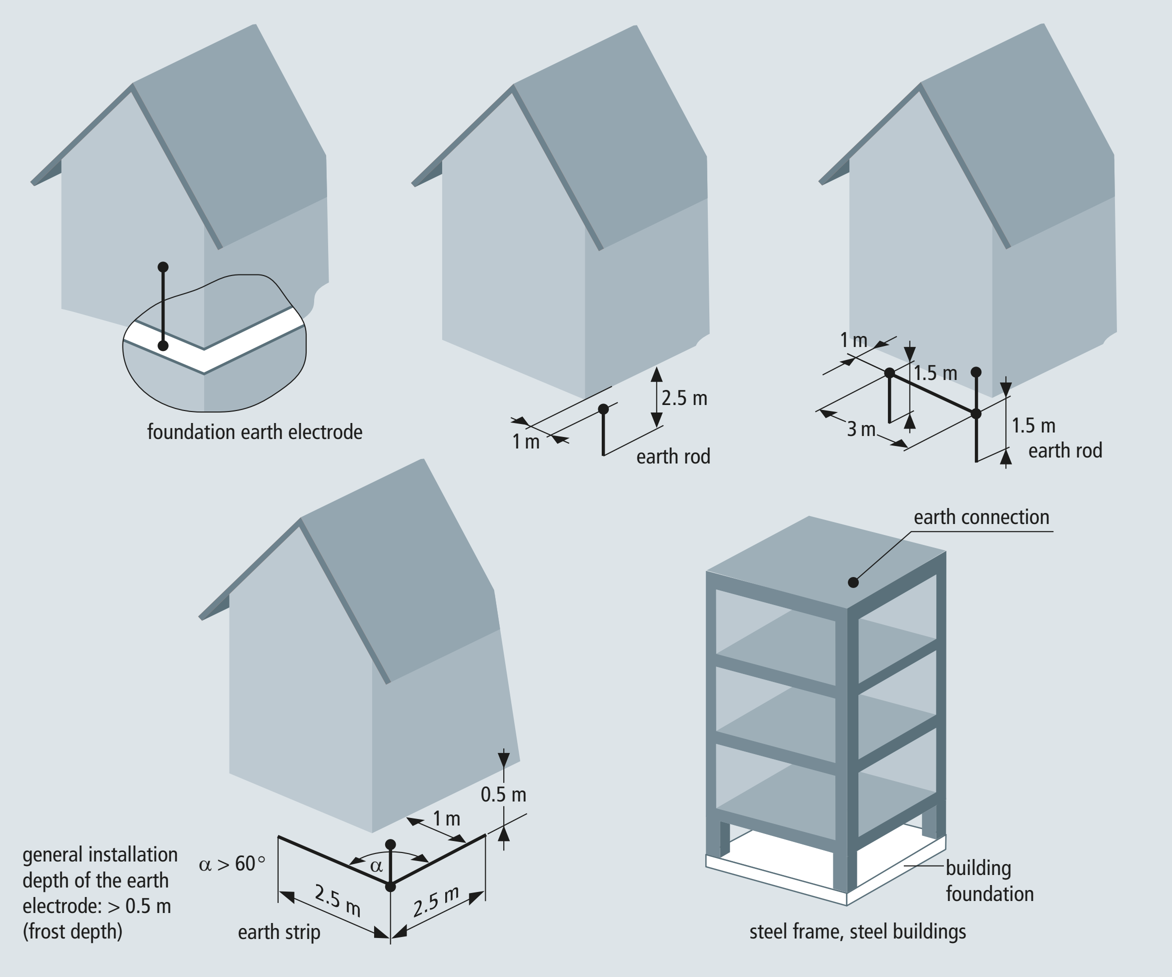


Figure 9.5.1 Permitted earth electrodes

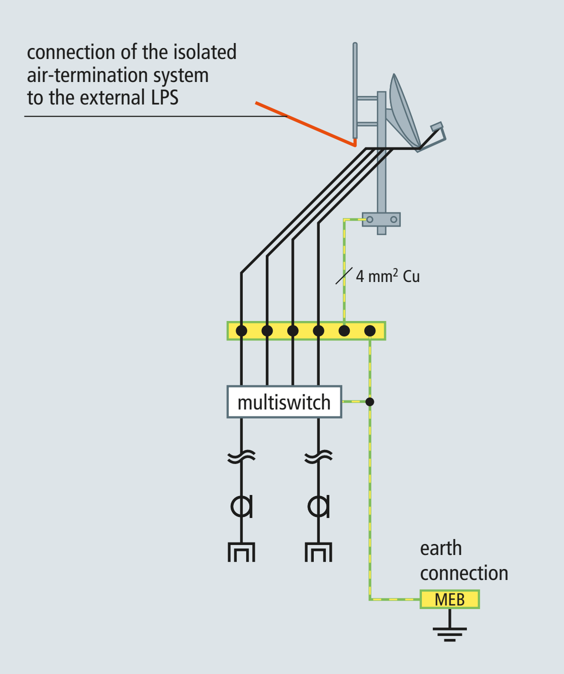


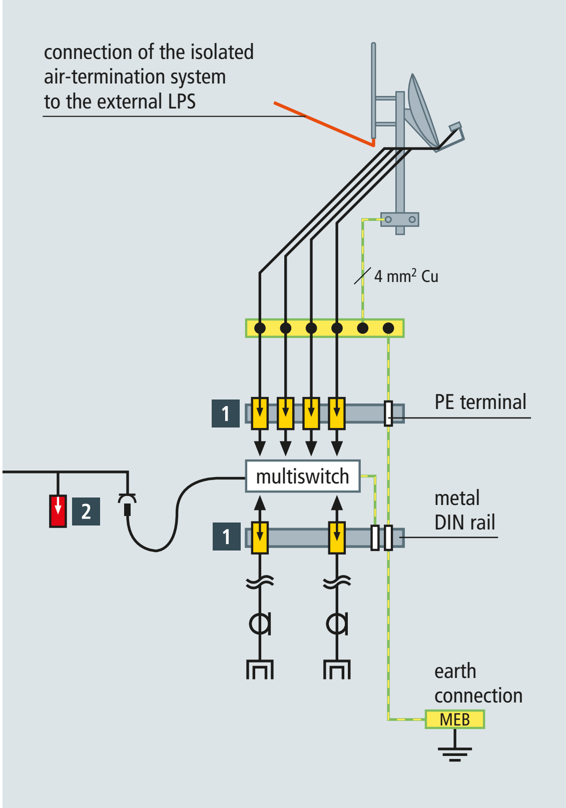
Figure 9.5.2 Protective equipotential bonding of the cable network and the devices

that they are / are not mechanically protected, the minimum cross-section is at least 2.5 mm² / 4 mm² (copper). This measure is required due to the discharge currents on the mains side which are injected from the devices to the cable network. For this reason, all cables entering a building (**Figure 9.5.2**) must be connected to the protective equipotential bonding (exception: galvanic isolation of the inner and outer conductor). If active and passive devices (e.g. amplifiers, splitters) are removed, the cable shields connected to them must be interconnected before removing the devices and the inner conductors must be insulated.

Special attention must be paid to mains-powered devices of protection class I connected to the cable network. If no integrated TN-S system is installed, the system unbalance and the accumulation of the third harmonic can lead to shield currents which can cause malfunction and fire.

Internal lightning protection system

An internal lightning protection system protects the content of a building, in particular the electrical systems and electronic devices. The main function of an internal lightning protection system is to establish lightning equipotential bonding via the 4 mm² copper conductor and the installation of surge protective devices between the inner and outer conductor to avoid sparking.



No.	Surge protective device	Part No.
1	DEHNgate DGA FF TV	909 703
2	DEHNflex DFL M 255	924 396

Figure 9.5.3 Antenna system with equipotential bonding at the lowest point of the installation and surge protective devices

Surge protection

The protection goal of the surge protective devices at the head-end described in the standard also applies to equivalent installations (**Figure 9.5.3**).

Surge protective devices for a detached house, which are also described in the standard, provide protection from inductive coupling and can also be used for connections in multi-family houses according to the note in the standard.

Antennas in buildings or underneath the roof

Antenna systems in a building and antenna systems which are located at least 2 m underneath the roof and do not protrude more than 1.5 m from the wall (**Figure 9.5.4**) do not have to be earthed via an earthing conductor. However, equipotential bonding must be established as described before.

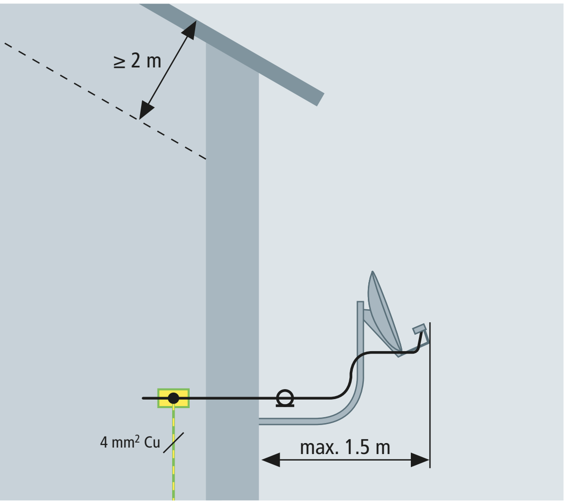


Figure 9.5.4 Arrangement of antennas which do not have to be earthed

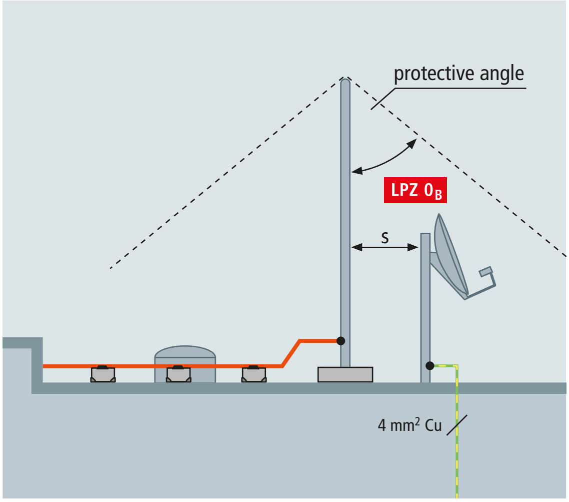


Figure 9.5.5 Antenna system located in the protected volume of an existing air-termination system

Building with lightning protection system

The following considerations have been made in conformity with the protection goal of the IEC 62305-3 (EN 62305-3) lightning protection standard and the so-called "best solution(s)" of the antenna standard.

If buildings are equipped with a lightning protection system, the antenna system must be positioned in the protected volume of an existing air-termination system (**Figure 9.5.5**) or protected by an air-termination rod isolated by a DEHNiso spacer (**Figure 9.5.6**) or by a DEHNcon-H solution (**Figure 9.5.7**). In addition to establishing equipotential bonding as described before, in all these cases, the lowest point of the cable shields must be connected to the main earthing busbar via copper equipotential bonding conductors with a minimum cross-section of 4 mm² to reduce the risk of induction loops (**Figure 9.5.3**).

Building without lightning protection system

Earthing measures for antennas do not ensure preventive lightning protection for buildings or any other structures.

If buildings are not equipped with a lightning protection system, the antenna mast must be earthed. The earthing conduc-

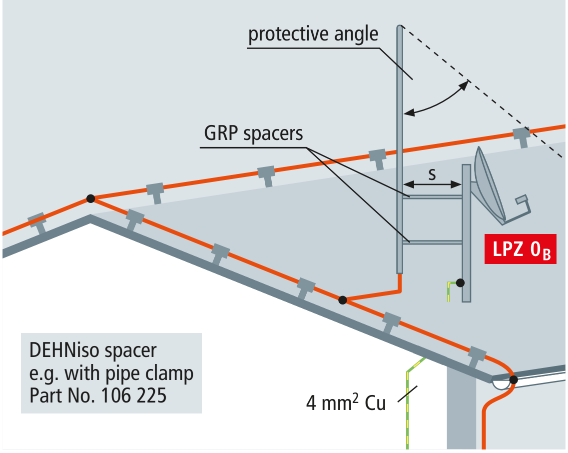


Figure 9.5.6 Antenna system with an air-termination rod isolated by DEHNiso spacers (insulating clearance made of glass-fibre reinforced plastic (GRP))

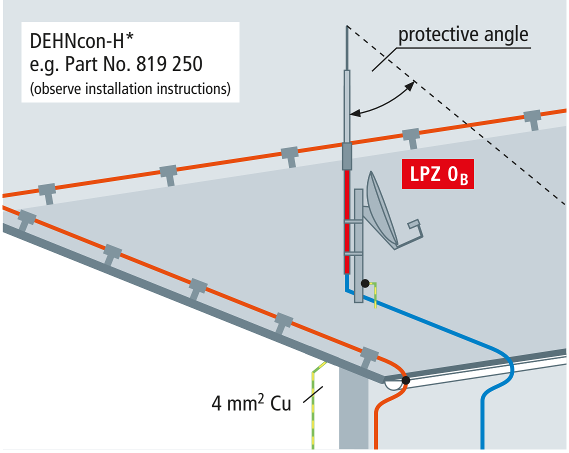
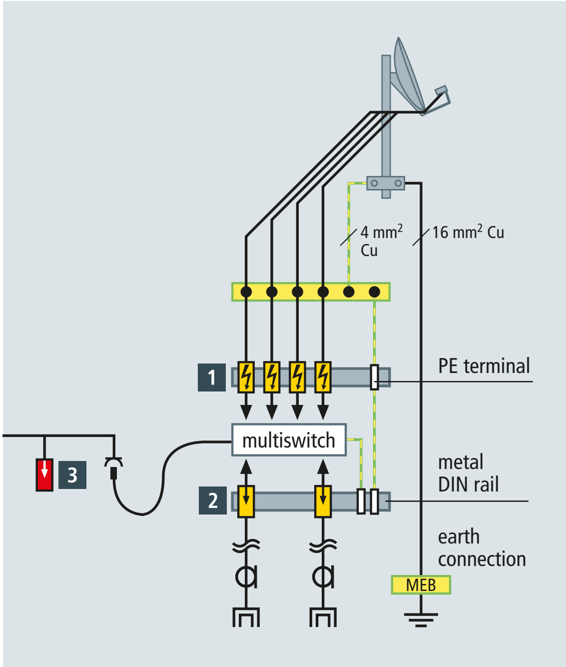
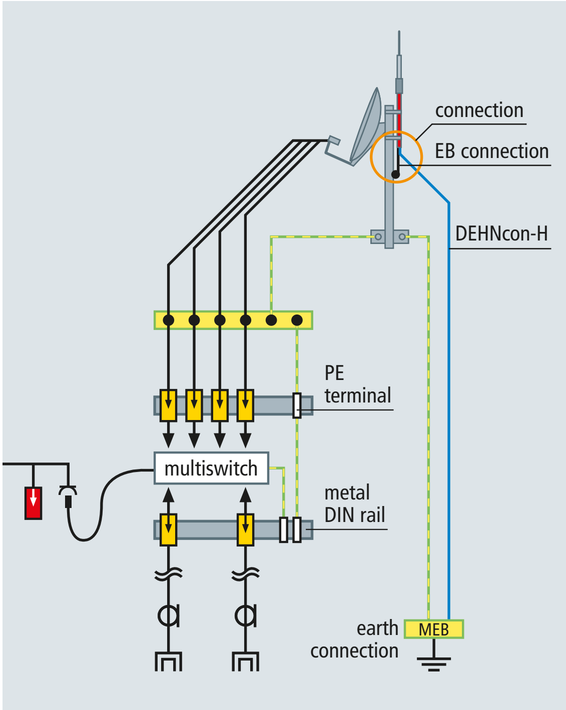


Figure 9.5.7 Antenna system with high-voltage-resistant, insulated down conductor DEHNcon-H



No.	Surge protective device	Part No.
1	DEHNgate DGA GFF TV	909 705
2	DEHNgate DGA FF TV	909 703
3	DEHNflex DFL M 255	924 396

Figure 9.5.8 Antenna system with surge protective devices



No.	Surge protective device	Part No.
1	DEHNgate DGA FF TV	909 703
2	DEHNflex DFL M 255	924 396

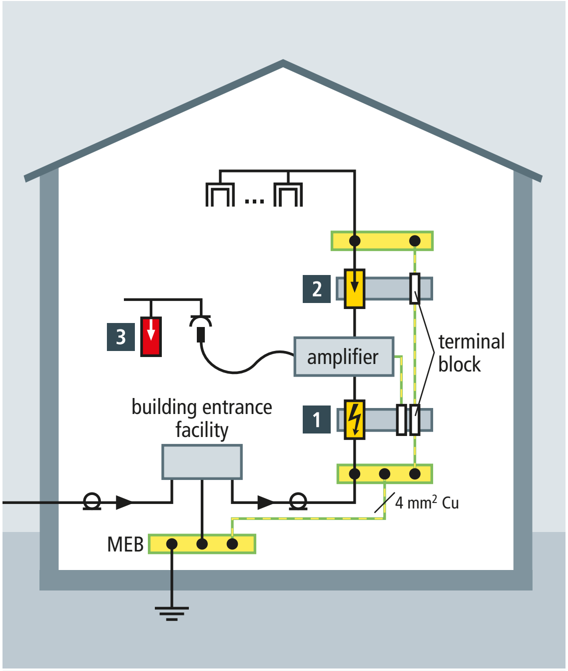
Figure 9.5.9 Antenna system with high-voltage-resistant down conductor DEHNcon-H and surge protective devices

tor must be installed vertically in a straight line and must have a cross-section of at least 16 mm² (copper), 25 mm² (insulated aluminium) or 50 mm² (steel) (**Figure 9.5.8**). The connections of the equipotential bonding conductor, for example to pipe clamps and equipotential bonding bars, must be dimensioned for lightning currents and tested to IEC 62561-1 (EN 62561-1). The equipotential bonding conductor must be installed as far as possible from conductors and earthed systems since in case of a lighting strike the same physical interactions occur that must be observed for keeping the separation distance in an external lightning protection system. In addition, natural components of the building / installation may be used as earthing conductor if they are permitted, electrically conductive and have the same dimensions as standard earthing conductors. Also in this case, equipotential bonding must be established as described before, however, without connecting the lowest point of the cable shields to the main earthing busbar (**Figure 9.5.8**).

The DEHNcon-H solution where the high-voltage-resistant, insulated down conductor is routed to the earth-termination system provides more effective protection from the effects of a lightning strike than earthing the antenna mast. The connection at the mast is made via the existing protective bonding conductor (**Figure 9.5.9**).

Building with broadband cable connection

If a broadband cable enters the building, lightning strikes are to be expected. Therefore, only lightning current carrying surge protective devices such as DEHNgate GFF TV are used (**Figure 9.5.10**).



No.	Surge protective device	Part No.
1	DEHNgate DGA GFF TV	909 705
2	DEHNgate DGA FF TV	909 703
3	DEHNflex DFL M 255	924 396

Figure 9.5.10 Broadband cable connection with surge protective devices

Surge protection for agricultural buildings

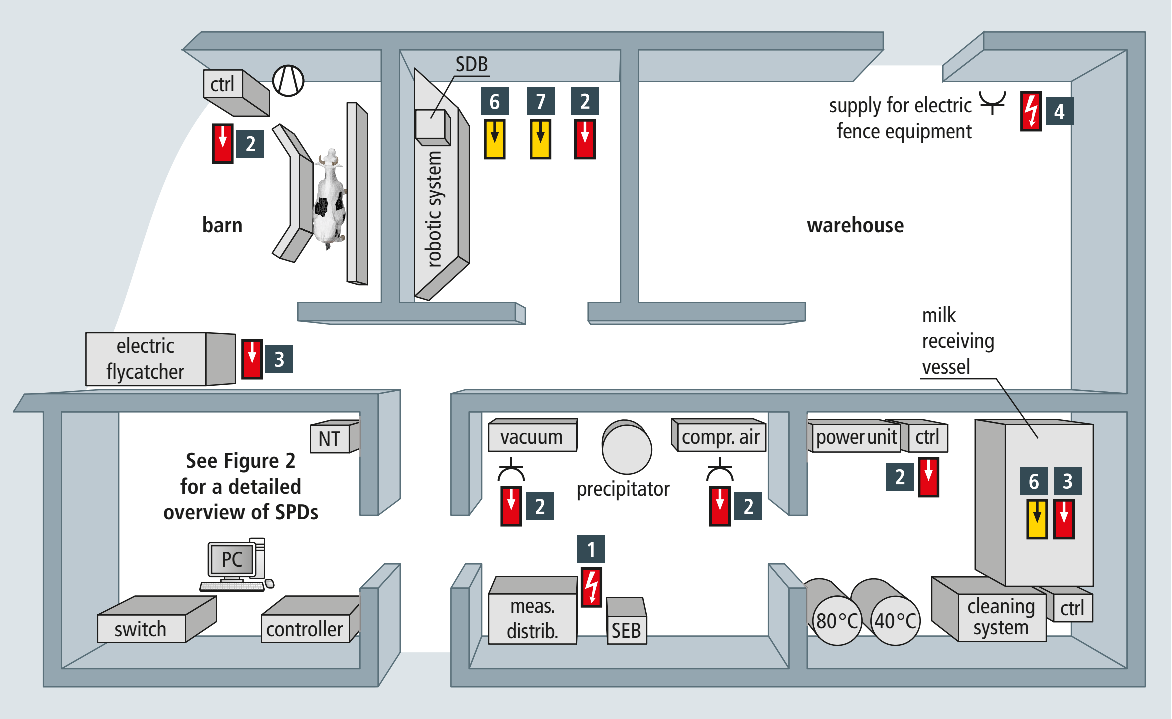


Figure 9.6.1 Surge protective devices for an agricultural building

No. in Fig. 9.6.1 and 2	Surge protective device			Part No.
1	DEHNventil DEHNventil *alternative:* DEHNshield DEHNshield	DV ZP TNC 255 DV ZP TT 255 DSH TNC 255 DSH TT 255	Installed on the busbar upstream of the measuring device	900 390 900 391 941 300 941 310
2	DEHNrail	DR M 4P 255	3/N/PE ≤ 25 A	953 400
3	DEHNrail DEHNflex	DR M 2P 255 DFL A 255	1/N/PE ≤ 25 A 1/N/PE ≤ 16 A	953 200 924 389
4	DEHNshield	DSH TT 2P 255		941 110
5	SFL Protector	SFL PRO 6X	Multiple socket outlet	909 250
6	BLITZDUCTOR + base part	BSP M2 BE HF 5 BXT BAS	CAN bus or ALCOM bus	926 270 920 300
7	DEHNpatch	DPA M CLE RJ45B 48	LAN	929 121
8	BLITZDUCTOR + base part *alternative:* DEHNbox	BXT ML2 BD 180 BXT BAS DBX TC 180	Telephone U_{K0}	920 247 920 300 922 210

Table 9.6.1 Example of surge protective devices for an agricultural building with robotic milking system (technical data of the manufacturer must be observed)

Complex electrical and information technology systems shape the image of modern agriculture. These systems are used to optimise and, if possible, automate time-consuming processes to increase the revenue.

For dairy animal breeding, this means

- That the fully automated milking system/feeding station identifies the transponder of the cow and controls the milking process or the food volume;
- That fresh milk is analysed for the presence of blood/infections and is discarded or transferred to the milk receiving vessel;
- That the milk from the milking system is cooled in the milk receiving vessel and the waste heat of the compressor is passed through a heat exchanger to heat the water in an industrial water boiler (reduced costs by heating industrial water);
- That the cleaning system rinses the milk hoses;
- That the vacuum system provides a vacuum to extract milk from the cow;
- That compressed air is produced to actuate the entrance gates of the robotic milking system, position the feeding trough/droppings box and supply the forced cow traffic system;
- That electric flycatchers minimise fly populations and thus disease transmission;
- That ventilators improve the climate in the barn and thus animal health/milk quality.

Figure 9.6.1 shows an example of an agricultural building with robotic milking system. The individual systems are controlled via several data lines (**Figure 9.6.2**). The operator can access the entire building via modem.

In subsection 705.443 of the IEC 60364-7-705 (HD 60364-7-705) standard it is recommended that lightning and surge protection measures be taken if electronic equipment is installed. **Table 9.6.1** shows suitable surge protective devices for the sample building (**Figures 9.6.1 and 9.6.2**).

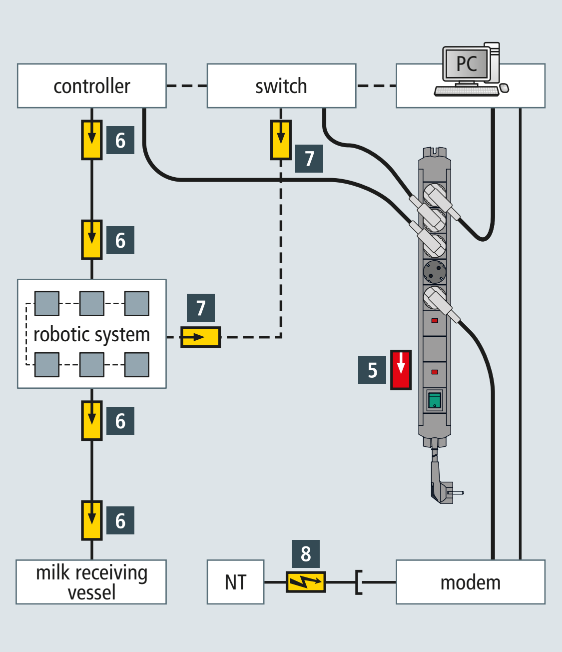


Figure 9.6.2 Surge protective devices for bus systems and the telephone

Protective equipotential bonding according to IEC 60364-5-54 (HD 60364-5-54) as well as supplementary protective equipotential bonding for agricultural and horticultural premises according to IEC 60364-7-705 (HD 60364-7-705) is important to protect agricultural buildings against surges. These standards describe how to integrate extraneous conductive parts in the floor of the standing, lying and milking area (also recommended for slatted floors made of concrete).

Surge protection for CCTV systems

CCTV systems are used in all sectors for access control and facility supervision. In the following, surge protection measures will be described which meet the high availability requirements of CCTV systems.
A CCTV system consists of at least one camera, one monitor and one suitable video transmission path. Remotely controlled camera stations are typically equipped with a pan/tilt head which allows the operator to individually adjust the position and the perspective of the station.
In the simplest case, the transmission line between the junction box and the monitor is a coaxial or a balanced two-wire cable. Coaxial cables are used for unbalanced transmission, in other words the video signal is transmitted through the core of the coaxial cable (inner conductor). The shield (earth) is the reference point for signal transmission. Balanced transmission (baluns) where the coaxial signal is converted to a two-wire signal is used for two-wire cables.
The voltage supply cable is often routed separately. In case of IP cameras, however, a single cable is used for the transmission of the video signal and for voltage supply. An RS 485 bus controls the panning and tilting of the camera.

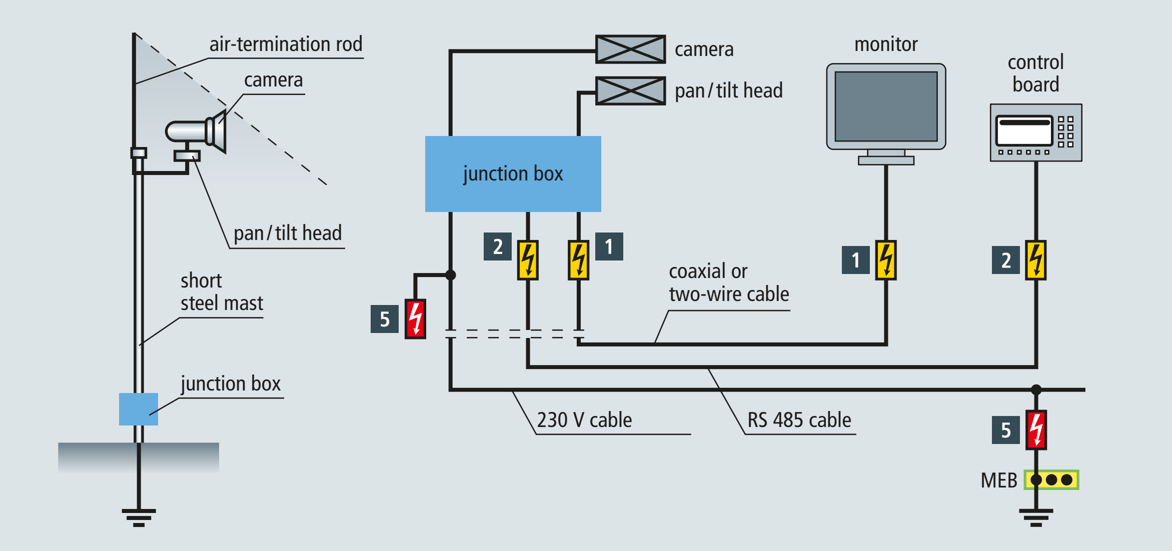


Figure 9.7.1 Camera connected to a building with external lightning protection system and lightning current carrying surge protective devices on both ends

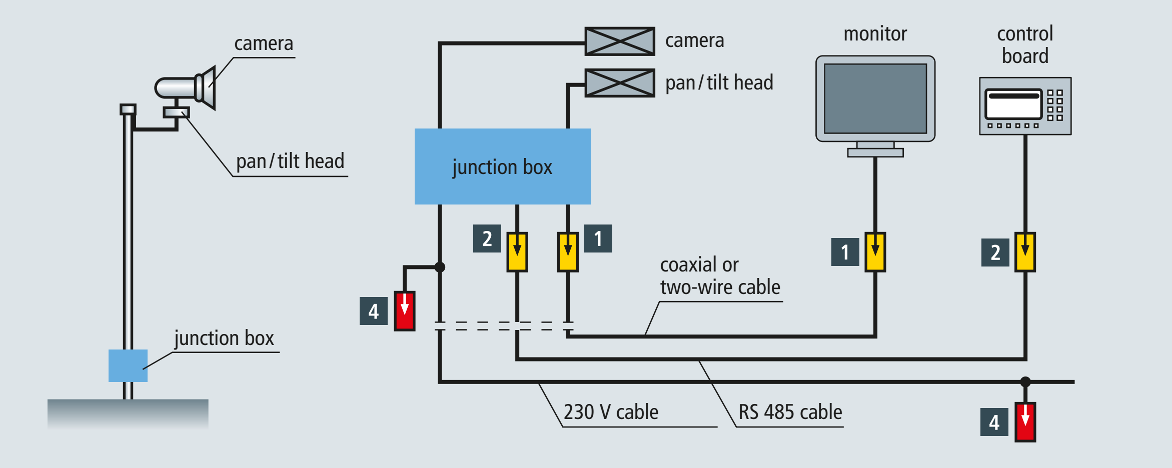


Figure 9.7.2 Camera connected to a building without external lightning protection system with surge protective devices on both ends

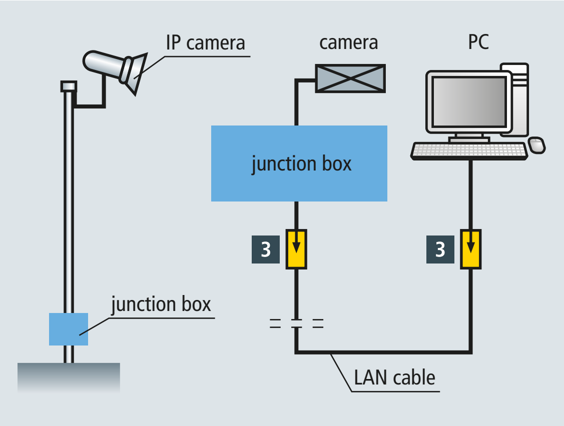


Figure 9.7.3 IP camera with surge protective devices on both ends

Building with external lightning protection system

Figure 9.7.1 shows a CCTV camera installed at a mast. A direct lightning strike to the camera can be prevented if an air-termination rod is installed at the mast. The connecting cable between the junction box and the camera is typically installed in the metal mast. If this is not possible, the camera cable must be routed in a metal tube and conductively connected to the mast. In this case, surge protective devices do not have to be installed in the junction box if the cable length does not exceed some metres.

Lightning equipotential bonding must be established at the entrance point into the building for all cables mentioned above which are routed from the junction box at the mast to a building with external lightning protection system (**Table 9.7.1**).

If cameras are mounted on the outer façade of a building, it should be ensured that the camera is located in the protected volume or is protected from direct lightning strikes by an air-termination system.

Building without external lightning protection system

If buildings are not equipped with an external lightning protection system, the risk resulting from a direct or nearby lightning strike to the building is assumed to be low and is thus acceptable. In this case, the installation of surge arresters provides sufficient protection (**Table 9.7.1**).

Figure 9.7.2 shows a multi-line CCTV system and **Figure 9.7.3** a digital IC camera system.

No.	Protection for…	Surge protective device	Part No.
Surge protective devices for information technology systems			
1	Two-wire cable (video transmission)	BLITZDUCTOR XT / BLITZDUCTOR SP + BXT BAS	920 271 / 926 271 920 300
	Coaxial cable (video transmission system)	UGKF BNC or DGA BNC VCID	929 010 909 711
2	RS 485 cable (camera controller)	BLITZDUCTOR XT / BLITZDUCTOR SP + BXT BAS	920 271 / 926 271 920 300
3	LAN cable (IP camera)	DPA M CLE RJ45B 48 DPA M CAT6 RJ45H 48	929 121 929 110
Surge protective devices for power supply systems – Surge arresters			
4	a.c. TN system a.c. TT system	DEHNguard DG M TN 275 DEHNguard DG M TT 2P 275	952 200 952 110
Surge protective devices for power supply systems – Combined arresters			
5	a.c. TN system a.c. TT system	DEHNshield DSH TN 255 DEHNshield DSH TT 255	941 200 941 110

Table 9.7.1 Surge protective devices shown in Figures 9.7.1 to 9.7.3

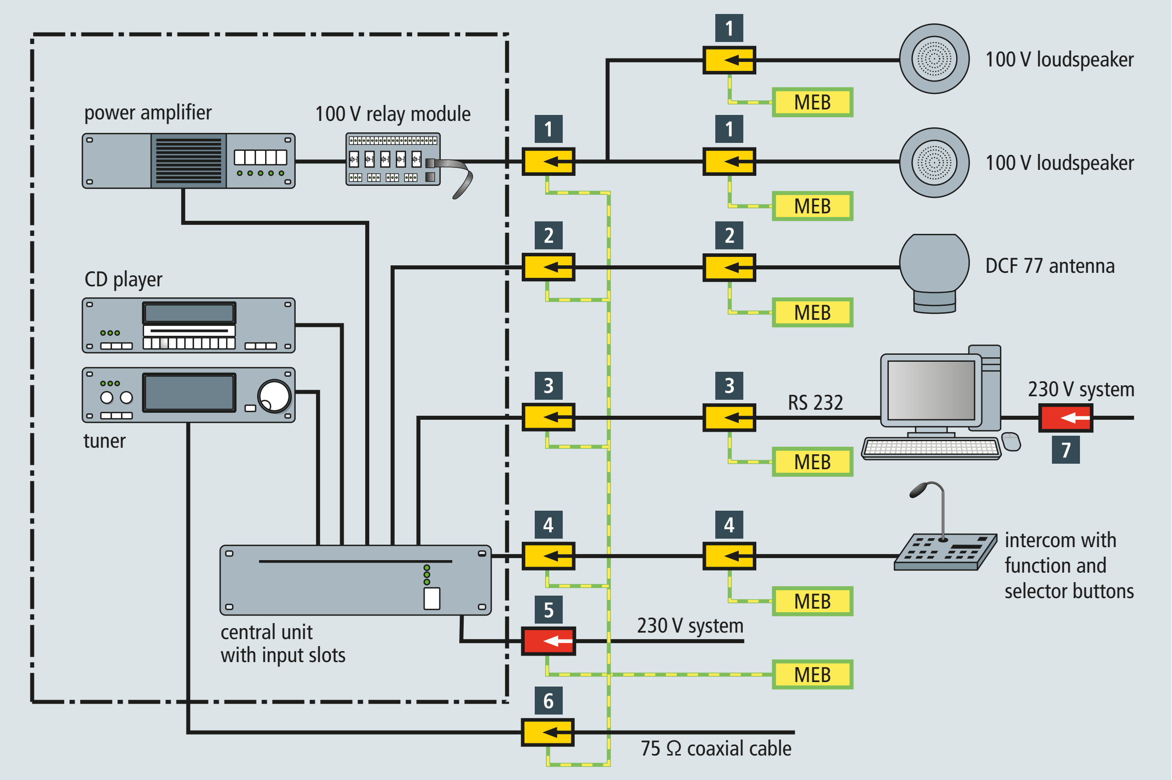
Surge protection for public address systems

Public address systems are used for voice, music and alarm transmission. To this end, the useful signal is modulated onto a carrier voltage (50 V, 70 V, 100 V) and reaches the loudspeaker via a transmitter. This transmitter transforms the low impedance of the loudspeaker to a higher value, thus reducing the current. Therefore, telecommunication lines with a diameter of 0.6 mm or 0.8 mm can be used.

There are different kinds of loudspeakers. Flush and wall loudspeakers typically have a rated power between 6 and 30 W, column loudspeakers between 20 W and 100 W and horn loudspeakers between 10 W and 60 W. Modular amplifiers have a rated power between 100 W and 600 W (in some cases even higher).

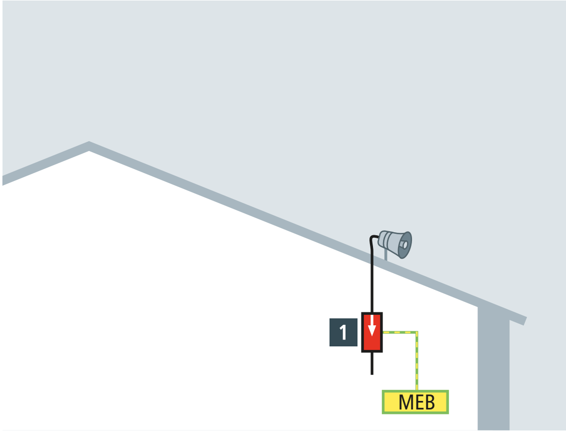
Loudspeakers with different power ratings can be jointly used in a line or group. The minimum power of the amplifier is the sum of the individual loudspeaker power ratings in the public address system. When determining the minimum power of the amplifier, the sum of the loudspeaker power ratings is not decisive, but instead the sum of the selected power ratings at the transmitters.

Subsection 7.2.1 of the EN 50174-2 standard describes the protection from lightning strikes and induced surges and compares the risk of damage with the risk which is accepted by the operator. If this risk assessment reveals that surge protection measures are required, surge protective devices must be installed for the relevant installations and systems in need of protection.



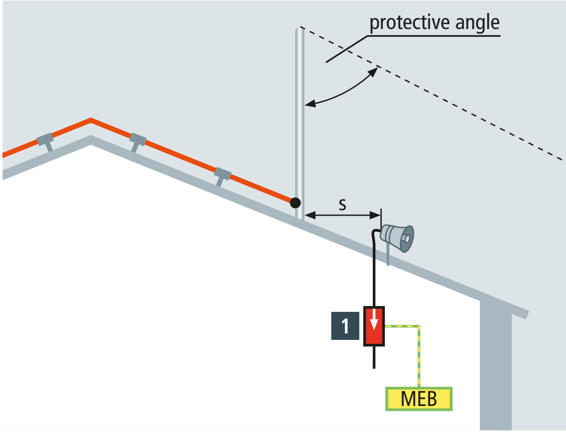
No.	Surge protective device	Part No.
1	DR M 2P 150 (current > 1 A–25 A) or BXT ML4 BE 180 (current < 1 A) + BXT BAS	953 204 920 327 920 300
2	DGA G BNC	929 042
3	FS 9E HS 12	924 019
4	BXT ML2 BD HFS 5 + BXT BAS	920 271 920 300
5	DR M 2 P 255	953 200
6	DGA FF TV	909 703
7	DPRO 230	909 230

Figure 9.8.1 Modular public address system with surge protective devices



No.	Surge protective device	Part No.
1	DR M 2P 150 (current > 1 A–25 A) or BXT ML4 BE 180 (current < 1 A) + BXT BAS	953 204 920 327 920 300

Figure 9.8.2 Horn loudspeaker installed on a structure without external lightning protection system



No.	Surge protective device	Part No.
1	DR M 2P 150 (current > 1 A–25 A) or BXT ML4 BE 180 (current < 1 A) + BXT BAS	953 204 920 327 920 300

Figure 9.8.3 Horn loudspeaker located in the protected volume of an air-termination system on a structure with external lightning protection system

In the following, further applicable regulations will not be specified (e.g. German Sample Directive on Fireproofing Requirements for Line Systems (MLAR), building regulations, regulations concerning electroacoustic emergency warning systems, regulations concerning burglar and fire alarm systems).

Large-scale public address systems feature a modular 19” design (**Figure 9.8.1**) and are frequently located in close proximity to a permanently manned workstation. In such cases, the relevant length of the connecting cable to the PC or intercom decides whether the surge arresters shown (4 + 5) must be installed. If this length exceeds 5 m, surge protective devices are required.

To be able to dimension the surge arresters for the loudspeaker lines (1 + 2), the maximum current I in the relevant branch must be determined by means of the ratio I = P/U where P is the power of the amplifier or loudspeaker (group) and U is the carrier voltage.

All earth connections of the surge arresters in the vicinity of the public address system must be connected to a nearby common potential point.

If exterior loudspeakers are located on the roof of a building, they can be damaged by indirect lightning effects (inductive / capacitive coupling) in case of systems with external lightning protection system (**Figure 9.8.3**) and without external lightning protection system (**Figure 9.8.2**). If the system is equipped with an external lightning protection system (**Figure 9.8.3**), the exterior loudspeaker is reliably protected from direct lightning strikes since it is located in the protected volume of an air-termination system.

Surge protection for emergency alarm systems

The function of emergency alarm systems (fire or burglar alarm systems) is to actively produce an alarm in the event of danger and remain passive when there is no danger. Malfunction of these systems (no alarm is produced if there is danger or alarm is produced if there is no danger) is undesired and expensive and is responsible for several hundred millions of euros in losses annually. Moreover, false alarms have the following consequences:

- If false alarms frequently occur, the operator can no longer rely on the system and questions the significance of such a system and the associated investment.
- Security personnel start ignoring the alarm messages.
- Neighbours are disturbed by acoustic alarms.
- Emergency staff (e.g. fire brigade) is unnecessarily called out.
- Triggering of fire extinguishing systems cause interruption of operations.

All these factors cause unnecessary costs and can be prevented if possible causes of false alarms are recognised at an early design stage and are eliminated by taking suitable preventive measures. For this purpose, the German Insurance Association (GDV) published the VdS 2833 guideline, which describes lightning and surge protection for emergency alarm systems.

Coordinated lightning and surge protection prevents false alarms or the destruction by atmospheric discharges or switching overvoltages and increases the availability of the systems. When installing emergency alarm systems which are not required by the building law, the VdS guideline should be used for designing and installing these emergency alarm systems and for defining individual measures between the installer and operator.

Many of today’s emergency alarm systems have an increased surge immunity according to IEC 61000-4-5 (EN 61000-4-5) on the primary lines, secondary lines and mains voltage cables. Nevertheless, only external and internal lightning protection

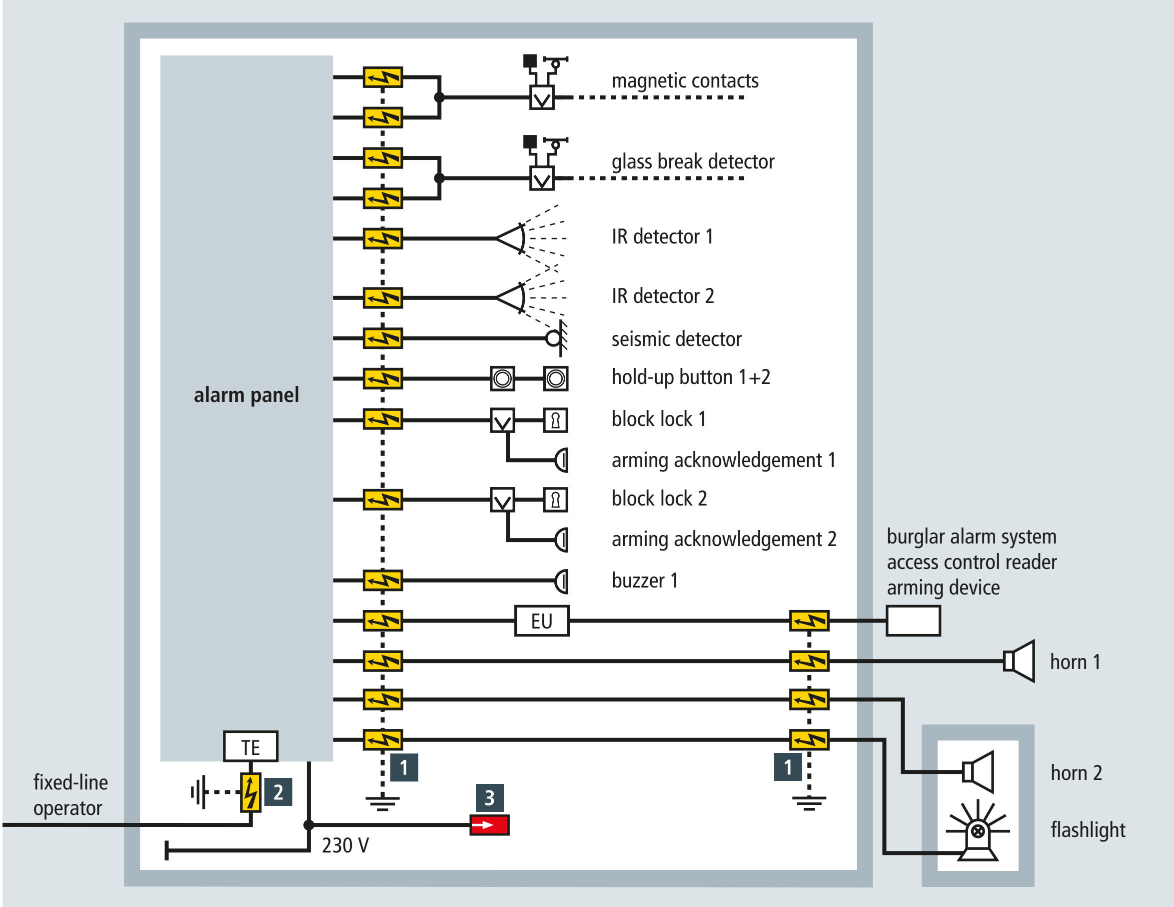


Figure 9.9.1 Lightning and surge protection for a burglar alarm system with pulse polling technology

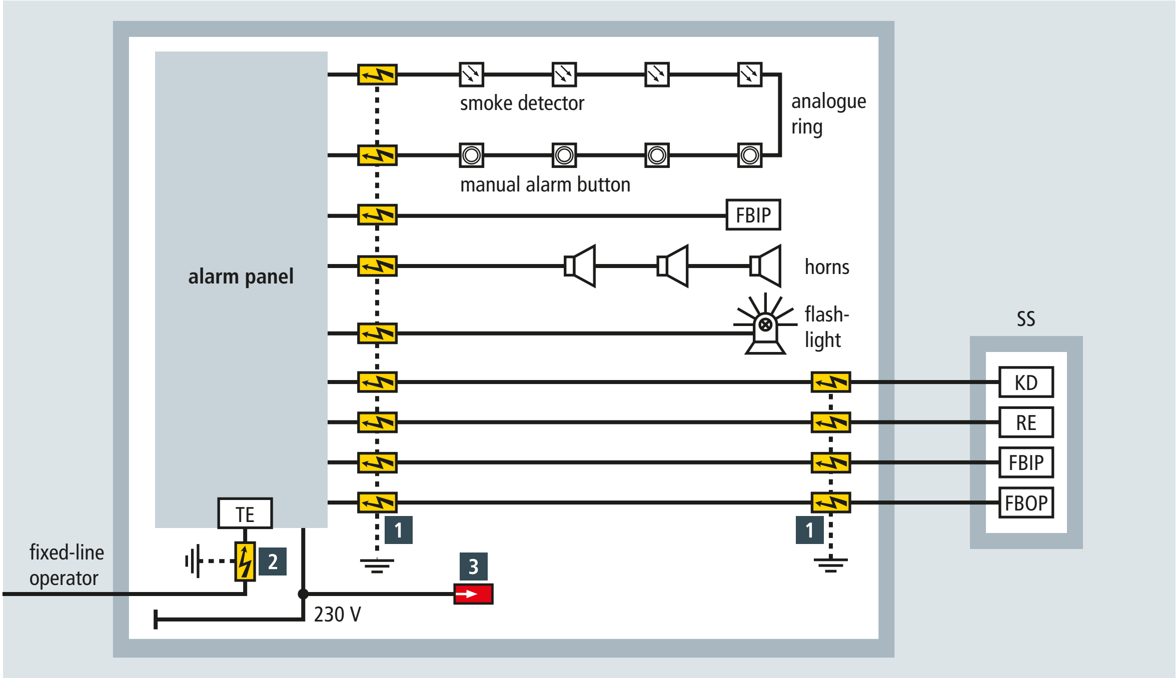


Figure 9.9.2 Lightning and surge protection for a fire alarm system with analogue ring technology

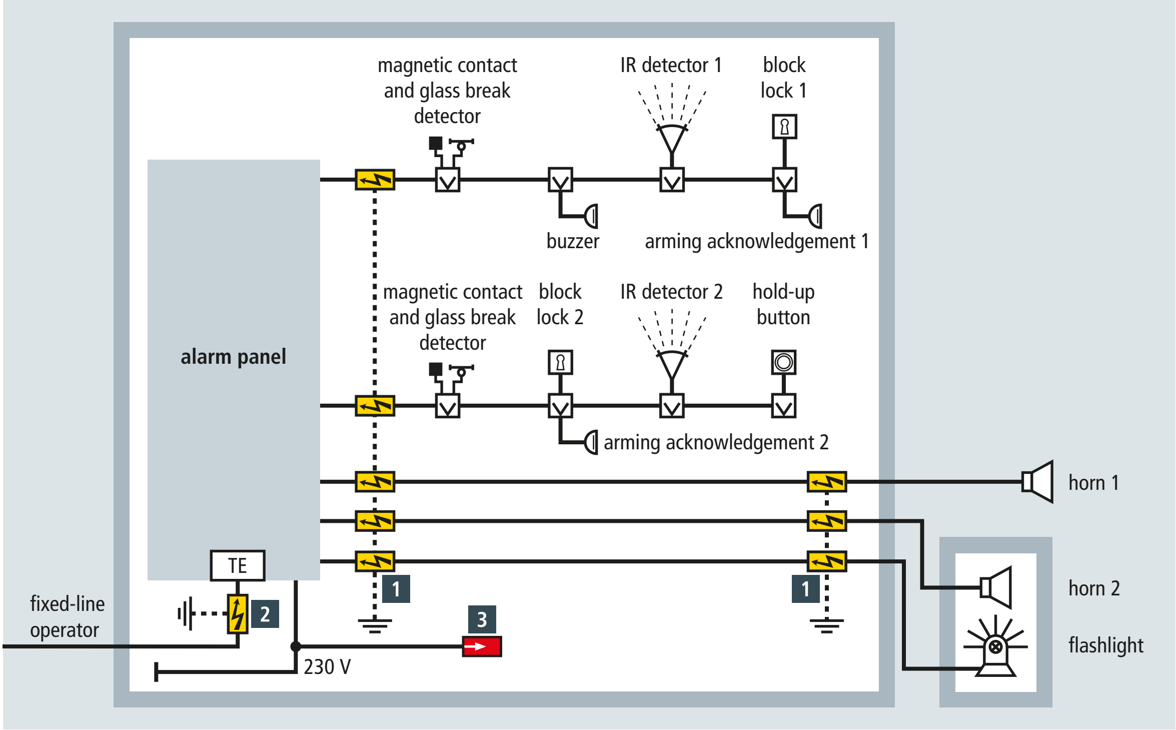


Figure 9.9.3 Lightning and surge protection for a burglar alarm system with d.c. circuit technology

No.	Protection for...	Surge protective device	Part No.
Combined arresters for information technology systems at the boundaries from LPZ 0_A (0_B) ⬌ LPZ 1 or area 0/A (0/B) ⬌ area 1			
1	Alarm line groups, external alarms (24 V) (in this case max. 0.75 A)	BXT ML2 BE S 24 (2 cores + earth drain wire) BXT ML4 BE 24 (4 cores) + BXT BAS + SAK BXT LR (for earth drain wire)	920 224 920 324 920 300 920 395
2	Exchange line U_{K0} of the fixed-line operator	BXT ML2 BD 180 + BXT BAS	920 247 920 300
Surge arresters for power supply systems at the boundaries from LPZ 0_B ⬌ LPZ 1 or area 0/B ⬌ area 1			
3	a.c.TN-S system a.c. TT system	DG M TN 275 DG M TT 2P 275	952 200 952 110

Table 9.9.1 Combined arresters and surge arresters in Figures 9.9.1 to 9.9.3

measures provide comprehensive protection against damage resulting from lightning strikes and surges (**Figures 9.9.1 to 9.9.3**).

Monitoring principles

Different monitoring principles are used for emergency alarm systems:

- **Pulse polling technology**
  Information from the detector which has triggered the alarm is digitally transmitted. This allows to identify the detector and its exact location (**Figure 9.9.1**).
- **Analogue ring**
  The addressable detectors define each detector in a ring. Line interruptions or short-circuits do not compromise the function (**Figure 9.9.2**).
- **d.c. circuit technology**
  According to the closed-circuit principle, every alarm line is permanently monitored. If a detector in a line is triggered, the line is interrupted and an alarm is produced in the alarm panel. However, only the alarm line, but not the individual detector can be identified (**Figure 9.9.3**).

Irrespective of the monitoring principle used, all cables extending between the different areas of the emergency alarm system must be integrated in the lightning and surge protection concept of the overall system.

Recommended protection

BLITZDUCTOR XT of type BXT ML2 BE … must be installed to protect two-wire alarm lines (approval from the manufacturer required, please contact DEHN + SÖHNE GmbH + Co.KG.) and allows to connect the earth drain wire by means of an EMC spring terminal. For cables with more than two wires, a four-wire version of type BXT ML4 BE … is available. Surge protective devices are selected according to the voltage of the alarm lines, which is typically between 12 and 48 V (**Table 9.9.1**). The low internal resistance of BLITZDUCTOR arresters is also a clear advantage since the maximum resistances of the alarm lines must not be exceeded.
For the outputs of the alarm panels (acoustic and visual alarm) it must be ensured that the nominal current of the surge protective devices is not exceeded.

A telephone dialler is typically used if the alarm panel is connected to the exchange line of a fixed-line operator e.g. Deutsche Telekom. BLITZDUCTOR XT of type BXT ML2 BD 180 is ideally suited for this purpose. The power supply system can be protected by means of DEHNguard modular surge protective devices (**Table 9.9.1**).
Emergency alarm systems, which must be approved by the German Insurance Association (VdS approval), must comply with VDS 2095 (fire alarm systems), VDS 2311 (burglar alarm systems) and VDS 2833 (surge protective devices for emergency alarm systems).

The Executive Board or Executive Director of a company is responsible for the health and safety of all employees. In the legal sense, a system operator is an ordinary person who is not able to assess whether risks may arise from a technical solution. Therefore, electricians, who provide technical solutions, must make sure in every single case whether their solutions meet the actual requirements.

Surge protection for KNX systems

Electrical installations in buildings with complex operator control units, displays and control devices are frequently equipped with an installation bus system. The EIB (European Installation Bus), which was developed at the beginning of the 1990s, is a widely used installation bus system. Today this installation bus system is still the core of a KNX system which is the world's first open standard described in the European EN 50090 standard.

An advantage of the KNX standard is the interoperability between different devices in all industries independent of the manufacturer. Thus, the values of a wind and rain sensor or a temperature and sun sensor can be processed in different building systems. Lighting systems can be switched on or off as needed depending on the light level and different lighting scenarios can be programmed. Consumption values can be recorded and used for load management. These are only some of the many applications where KNX systems can be used. In addition to these advantages, the installation time and the costs of such systems can be considerably reduced.

The smallest installation unit in the bus topology is a line. It consists of max. 64 bus devices (ETS 3 starters). If more than 64 bus devices are required, up to 15 lines can branch off from each main line via a line coupler. The area line connects a maximum of 15 area couplers to each other (**Figure 9.10.1**).

The KNX bus is supplied with a safety extra-low voltage (SELV) of max. 29 V. The cable length within a line segment and the length of the bus cable between two bus devices are limited. In case of a maximum length of 1000 m per line segment, the KNX systems may be destroyed by coupling despite of their high dielectric strength.

Moreover, it must be observed that no induction loops are formed when installing the cables. Therefore, the bus and low-voltage cables leading to the bus devices must be installed close to each other (**Figure 9.10.2**).

Loops are also formed if a metal construction or pipe is connected to the main earthing busbar (**Figure 9.10.3**). Also in this case, it is advisable to install the cables as close as possible to the construction or pipe.

Structure with external lightning protection system

The standard calls for lightning equipotential bonding, therefore all cables at the zone transition from LPZ 0_A to 1 must be protected by lightning current arresters. Since the electromagnetic field inside a structure with external lightning protection system is higher in case of a direct lightning strike than in case of a remote lightning strike, a structure with external lightning protection system must be equipped with surge arresters (**Figure 9.10.4**).

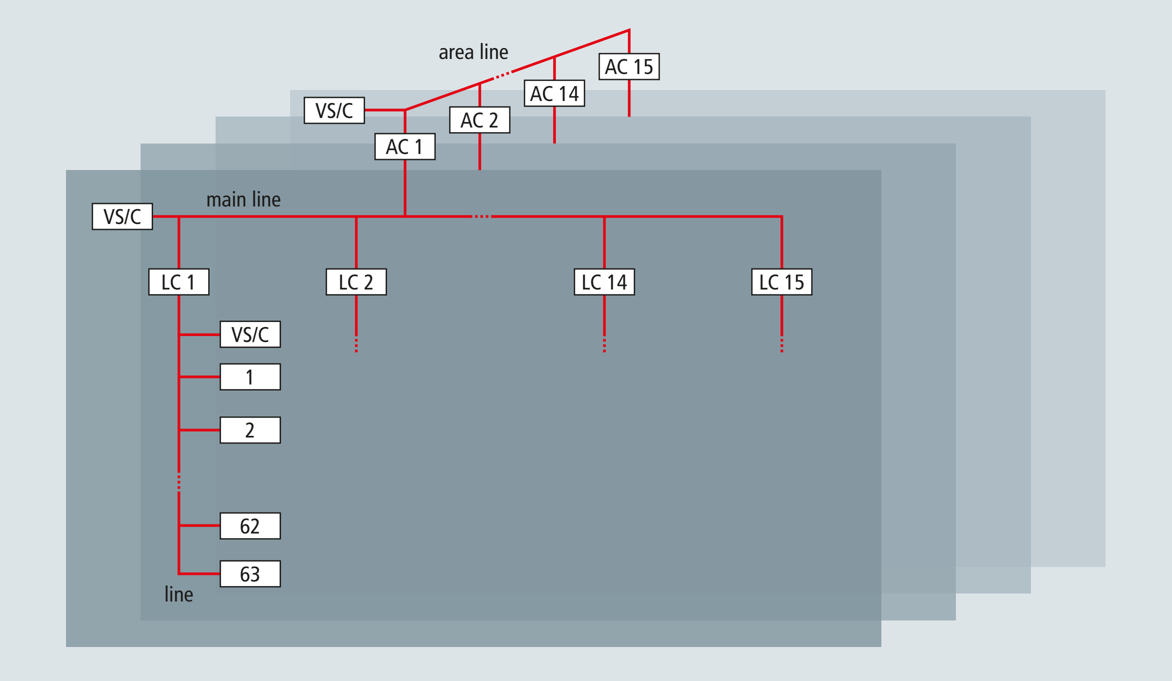


Figure 9.10.1 KNX bus topology with maximum number of bus devices per line, maximum number of lines per main line and maximum number of main lines per area line

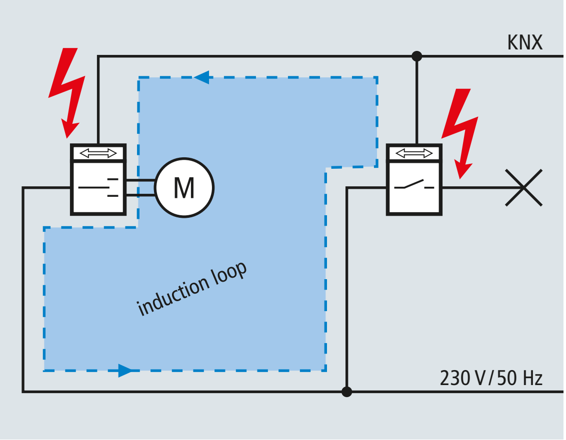


Figure 9.10.2 Induction loop formed by two KNX bus devices supplied with low voltage

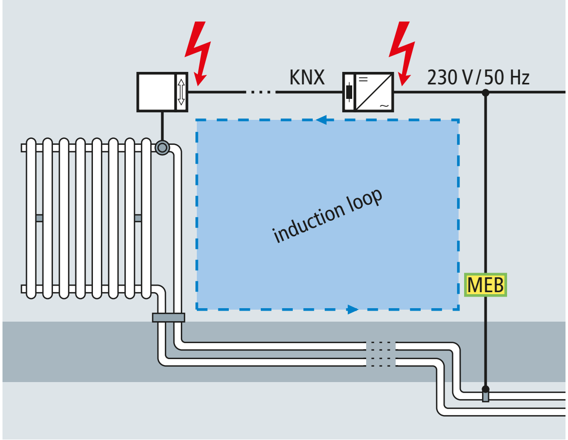
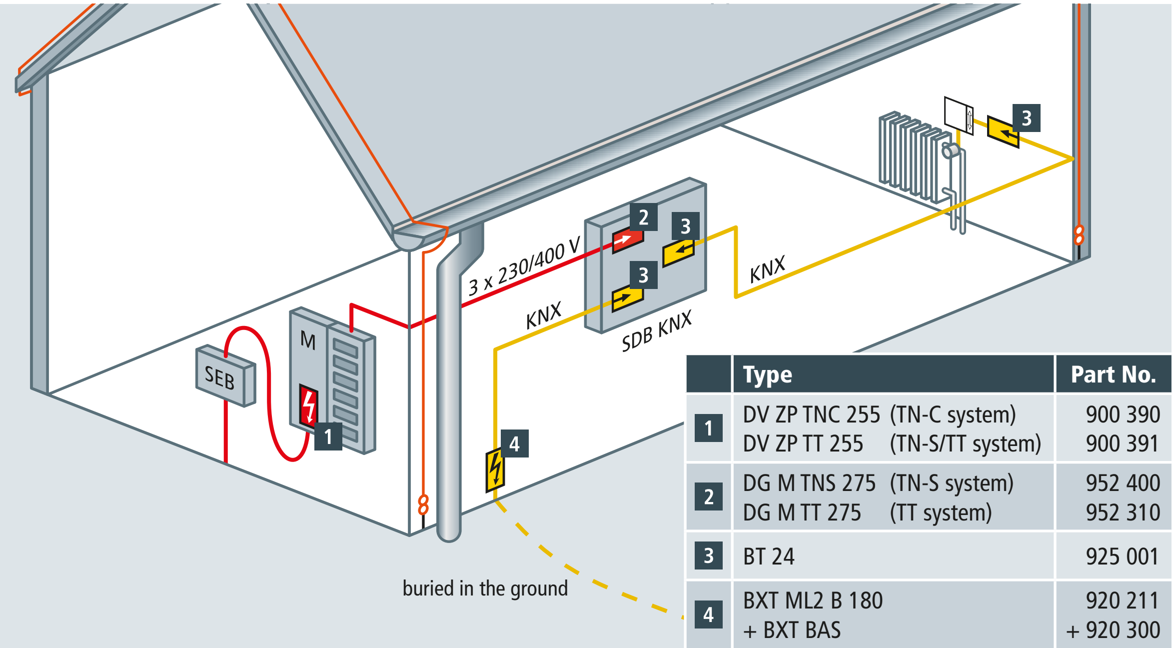


Figure 9.10.3 Induction loop formed by one KNX bus device installed at a metal construction or pipe



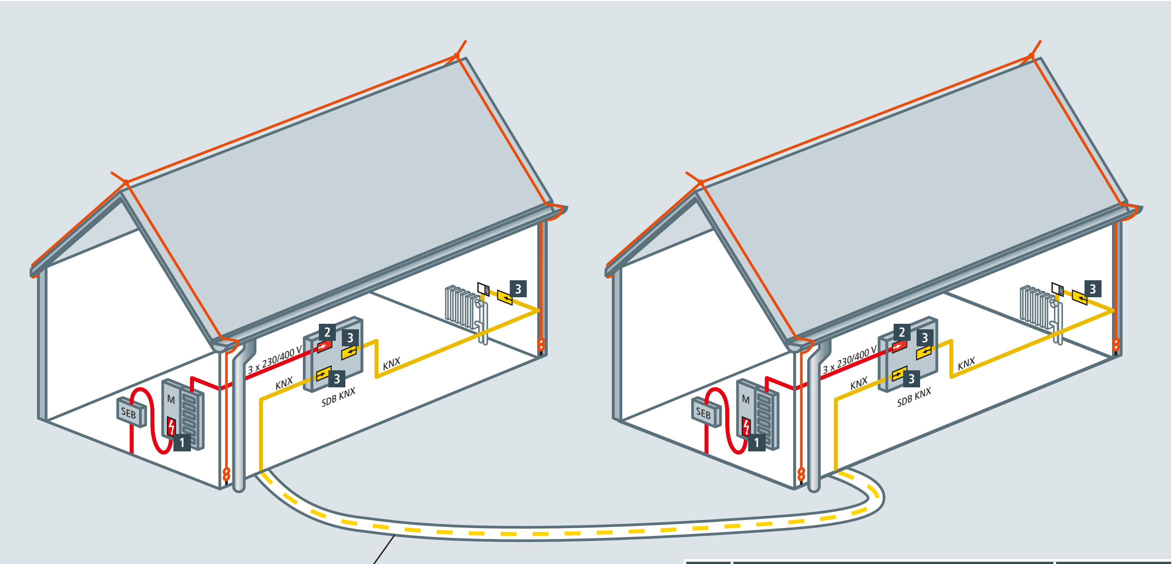
	Type	Part No.
1	DV ZP TNC 255 (TN-C system) DV ZP TT 255 (TN-S/TT system)	900 390 900 391
2	DG M TNS 275 (TN-S system) DG M TT 275 (TT system)	952 400 952 310
3	BT 24	925 001
4	BXT ML2 B 180 + BXT BAS	920 211 + 920 300

Figure 9.10.4 Lightning equipotential bonding at the entrance point of the KNX bus cable into the building and surge protective devices installed at the distribution board of the KNX system and at the actuator of the heater

If the bus cable is routed between different buildings in a lightning current carrying and shielded duct/metal pipe that is earthed on both ends, lightning equipotential bonding does not have to be established for the KNX cable extending beyond the buildings and it is sufficient to install surge arresters (**Figure 9.10.5**).

Structure without external lightning protection system

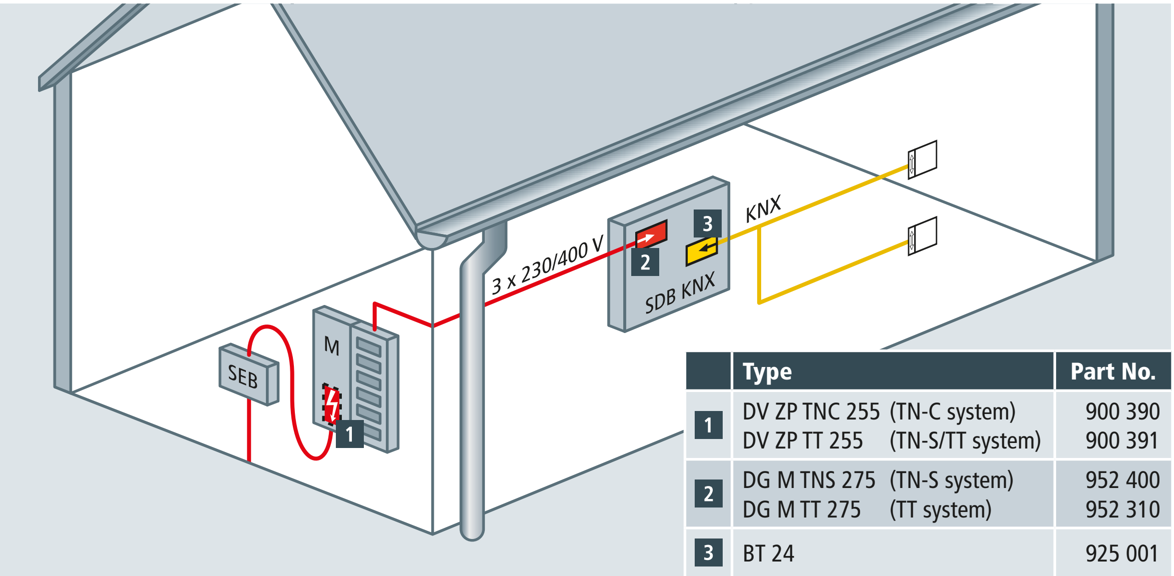
If there is a risk of nearby lightning strikes, it is advisable to install lightning current carrying combined arresters at the entrance point into the building to protect the incoming power cable (**Figure 9.10.6**).



shielded duct or metal pipe connected
to the main earthing terminal on both ends

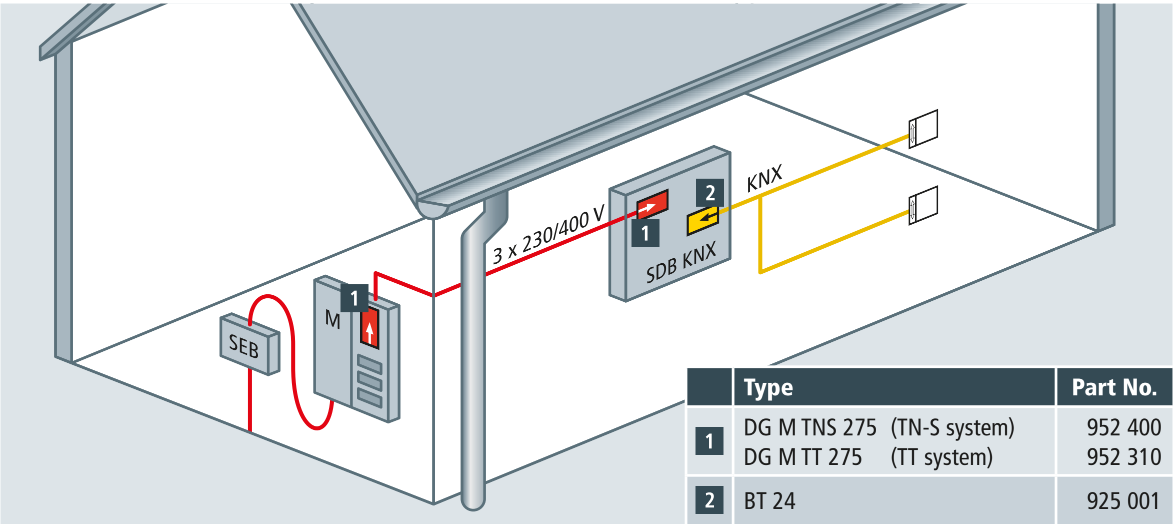
	Type	Part No.
1	DV ZP TNC 255 (TN-C system) DV ZP TT 255 (TN-S/TT system)	900 390 900 391
2	DG M TNS 275 (TN-S system) DG M TT 275 (TT system)	952 400 952 310
3	BT 24	925 001

Figure 9.10.5 Lightning equipotential bonding is not required for the KNX cable due to zone expansion



	Type	Part No.
1	DV ZP TNC 255 (TN-C system) DV ZP TT 255 (TN-S/TT system)	900 390 900 391
2	DG M TNS 275 (TN-S system) DG M TT 275 (TT system)	952 400 952 310
3	BT 24	925 001

Figure 9.10.6 Lightning current arresters installed in the main power supply system and surge arresters installed at the distribution board of the KNX system



	Type	Part No.
1	DG M TNS 275 (TN-S system) DG M TT 275 (TT system)	952 400 952 310
2	BT 24	925 001

Figure 9.10.7 Surge protective devices installed at the main distribution board and at the distribution board of the KNX system

Independent of the point of strike, surge protective devices always have to be installed at the distribution board of the KNX system (**Figures 9.10.6 and 9.10.7**).

Due to the high dielectric strength of the bus cable, it is unlikely that short bus cables with isolated sensors (e.g. in a socket outlet combination without earthed installation devices) are destroyed. In this case, it is not necessary to install surge arresters directly at the bus devices (**Figures 9.10.6 and 9.10.7**).

Surge protection for Ethernet and Fast Ethernet networks

To date, Ethernet is the most commonly used technology for local area networks. The name "Ether" refers to the first radio networks. Introduced in the 1980s, the 10 MBit Ethernet used coaxial cables. Later Fast Ethernet with 100 MBit/s and Gigabit Ethernet with 1000 MBit/s and 10 GBit/s were introduced. All Ethernet versions are based on the same principles. From the 1990s on, Ethernet became the most widely used LAN (Local Area Network) technology and replaced other LAN standards such as Token Ring and ARCNET. Ethernet consists of different types of 50 Ω coaxial cables or twisted pair cables, glass fibre cables or other media. At present, Ethernet typically has a data rate of 100 MBit/s, however, data rates of 1000 MBit/s are on the rise.

Surges cause malfunction and destruction and thus failure of computer systems. This can significantly affect operations, resulting in long standstill of the installations and systems. Therefore, surge protection concepts are required in addition to the protection of the power supply system and regular data backups to ensure reliable operation of computer systems.

Causes of damage

Failure of computer systems is typically caused by:

- Remote lightning strikes causing conducted transients in power supply, data or telecommunication lines,
- Nearby lightning strikes causing electromagnetic fields that inject transients into power supply, data or telecommunication lines,
- Direct lightning strikes causing impermissibly high potential differences and partial lightning currents in the building installations.

Structured cabling as uniform connection medium

Structured cabling is a uniform connection medium for different services such as analogue telephones, ISDN or different network technologies. Consequently, existing installations can be easily adapted to new tasks without exchanging the cables or connection parts. A structured cabling system provides application-independent and universal cables which are not tailored to a specific network topology, manufacturer or product. The type of cables and the topology ensure that all current and future protocols can be used.

A universal cabling system consists of three different hierarchical levels:

1. The **campus backbone cabling** connects the campus distributor of a building complex to the building distributors of the individual buildings. In case of data networks, 50 µm / 125 µm multimode optical fibre cables (in case of distances > 2 km monomode optical fibre cables) with a maximum length of about 1500 m are mainly used.
2. The **building backbone cabling** connects the building distributors to the floor distributors. Also in this case, 50 µm optical fibre cables and balanced 100 ohm cables with a length of 500 m are mainly used.
3. The **horizontal cabling** (floor distributor) includes all cables of the work stations of a floor and should not exceed 90 m. Copper cables or in some cases 62.5 µm optical fibre cables are typically used to connect the floor distributor to the telecommunication outlet.

The interfaces between these areas form passive distribution panels. Such distribution panels link the campus backbone, building backbone and horizontal cabling of universal cabling systems. They allow to easily start communication services on a work station by simply patching patch cables. Distribution panels for optical fibre cables (campus backbone and building backbone) and twisted pair cables (horizontal cabling) differ according to the number of ports. For example, 24 ports are commonly used for structured cabling systems and 25 ports for telecommunication installations. Cables are typically installed in 19" data cabinets or racks.

Star topologies are used for generic cabling systems. All currently available protocols can be operated by means of star topologies irrespective of whether they form a logical ring or bus system.

Structured cabling systems connect all terminal devices. They allow communication between telephones, networks, safety systems, building automation systems, LAN and WLAN interconnection as well as access to the intranet and internet. Generic cabling systems ensure flexible use of terminal devices. It is assumed that all information such as data, voice, television, automation and control of machines and installations will be transmitted via Ethernet over the next years and Ethernet will thus become a universal transmission concept. Therefore, electromagnetic compatibility (EMC) must be ensured.

EMC concept

Electromagnetic compatibility is defined as the capability of a device – especially of an installation or a system – to properly operate in its electromagnetic environment without causing electromagnetic interference itself which would be inacceptable for devices, installations or systems in this environment.

To ensure continuous and trouble-free operation of data networks, it is therefore imperative to consider EMC at an early stage. This does not only affect the data cables of the network, but also the entire electrotechnical infrastructure of the buildings and building complexes where the entire network should be installed. Consequently, it is important to consider the electromagnetic environmental conditions:

- Are there potential sources of electromagnetic interference such as radio-relay systems, mobile phone base stations, assembly lines or elevators?
- What about the quality of the electrical energy (e.g. harmonics, flickers, voltage drops, excess voltages, transients)?
- What about the risk of a lightning strike (e.g. frequency)?
- Is there possible emission?

To ensure the performance of data networks even in case of the increased requirements to be expected in the future, special attention has to be given to the electromagnetic compatibility of the installation. Therefore, the design of a data network should include an earthing and equipotential bonding concept which provides information on:

- Cable duct and cable routing
- Cable structure
- Active components
- Lightning protection
- Shielding of signal lines
- Equipotential bonding
- Surge protection

The most important measures to ensure EMC and thus undisturbed data transmission are:

- Spatial separation of known sources of electromagnetic interference (e.g. transformer stations, elevator drives) of information technology components
- Use of closed and earthed metal ducts in case of interference caused by strong radio transmitters and, if required, connection of the terminal devices via optical fibre cables only
- Use of separate circuits for terminal devices and use of noise filters and uninterrupted power supply systems, if required
- No parallel installation of power and data lines of terminal devices with power lines of powerful loads (due to the risk of high switching overvoltages when switching on / off the loads) and known sources of interference (e.g. thyristor controllers)
- Use of shielded data cables which must be earthed on both ends (**Figure 9.11.1**). Patch and connecting cables must be integrated in the shielding concept.
- Integration of the reinforcement (intermeshing) in the equipotential bonding system (**Figure 9.11.2**) for metal enclosures and shields (e.g. cable trays, cable ducts)
- Shielded data cables and power lines should use the same riser duct in the building backbone area. Separate riser ducts opposed to one another must be avoided. A distance of 20 cm between these two different types of cables should not be exceeded.
- The power lines for the devices and the relevant data lines must be basically routed via the same cable route. Separating webs should be provided. In the horizontal area, it is advisable to keep a distance of max. 10 cm between these lines.
- If a lightning protection system is installed on the building, the safety distances between the power / data lines and elements of the external lightning protection system (air-termination systems, down conductors) must be kept and power / data lines must not be routed in parallel with

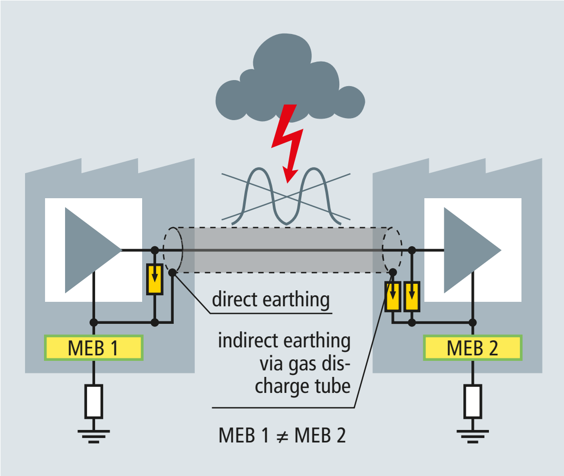


Figure 9.11.1 Shield connection on both ends – Shielding from capacitive / inductive coupling and direct and indirect shield earthing to prevent equalising currents

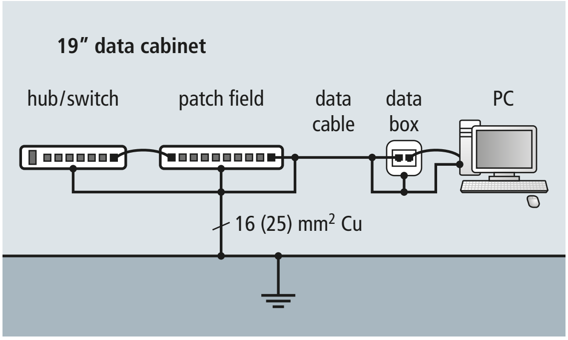


Figure 9.11.2 Equipotential bonding of a shielded cable system

the down conductors of the external lightning protection system.

- Use of optical fibre cables for the information technology cables of different buildings (campus backbone cabling)
- Installation of surge protective devices in power circuits and for the horizontal cabling system to protect them from transients caused by switching operations and lightning discharges (**Figures 9.11.3 and 9.11.4**)
- Power installation in the form of a TN-S system to prevent interference currents on the shields of the data lines
- Establishing main equipotential bonding with the power installation (PEN) at one point in the building (e.g. service entrance room)

To ensure proper EMC protection, it is also important to choose adequate lightning current and surge arresters for information technology systems and to be familiar with their protective effect.

Protective effect of arresters for information technology systems

For testing the electromagnetic compatibility (EMC), electrical and electronic equipment (devices) must have a defined immunity to conducted interference (surges).

Different electromagnetic environmental conditions require that the devices have different immunity levels. The immunity level of a device depends on the test level. To define the different immunity levels of terminal devices, the test levels are subdivided into four different levels from 1 to 4. Test level 1 places the lowest requirement on the immunity of a terminal device. The test level can be usually found in the documentation of the device or can be requested from the manufacturer of the device.

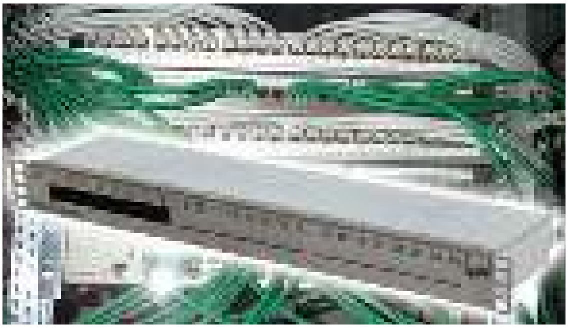


Figure 9.11.3 NET Protector – Universal surge protective device for protecting the data lines of a floor distributor (also suited for class D networks)

Arresters for information technology systems must limit conducted interference to an acceptable level so that the immunity level of the terminal device is not exceeded. For example, an arrester with a lower let-through value than the EMC test values of the terminal device must be selected for a terminal device tested with test level 2: Impulse voltage < 1 kV in combination with an impulse current of some amperes (depending on the type of injection).

Depending on the application and design, the information technology interfaces of terminal devices have different immunity levels. When selecting an adequate surge arrester, not only the system parameters are important, but also the fact whether the arrester is capable of protecting the terminal device. To ensure easy selection, an SPD class sign was developed for the Yellow/Line product family. Together with the documentation of the terminal device, this sign provides exact information on whether an arrester is suitable for the relevant terminal device, namely whether they are energy-coordinated with each other.

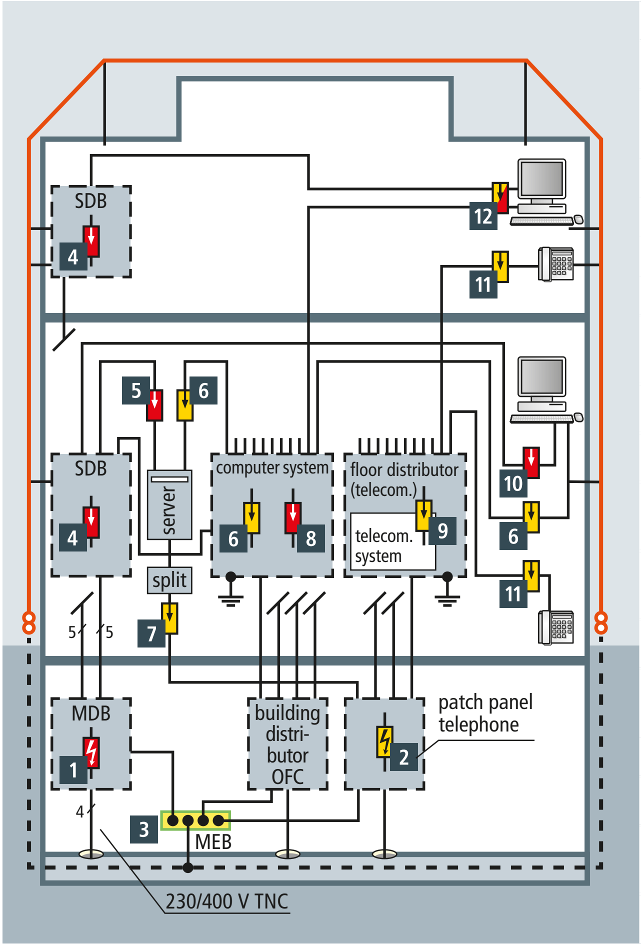
Correctly dimensioned surge arresters reliably protect terminal devices from voltage and energy peaks, thus increasing the availability of the installation.

Modern communication networks are increasingly becoming high-frequency networks and thus more and more susceptible to interference. Therefore, a consistent EMC concept that also includes lightning and surge protection for the buildings and systems is required to ensure smooth network operation (**Figure 9.11.5**).

Selection of surge protective devices

To ensure effective surge protection, the electricians and IT experts must coordinate the measures for the different systems in cooperation with the manufacturer of the device.

Figure 9.11.4 DEHNprotector – Universal surge protective device for protecting the network and data lines of a work station



	SPD	Type	Part No.
1	DEHNventil	DV M TNC 255	951 300
2	Equipotential bonding enclosure	DPG LSA ... P	906 10...
	Disconnection block	TL2 10DA LSA	907 996
	DEHNrapid LSA	DRL 10 B 180 FSD	907 401
	Earthing frame	EF 10 DRL	907 498
	DEHNrapid LSA	DRL PD 180	907 430
3	Equipotential bonding bar	K12	563 200
4	DEHNguard modular	DG M TNS 275	952 400
5	DEHNrail modular	DR M 2P 255	953 200
6	DEHNpatch	DPA M CAT6 RJ45H 48	929 110
7	DEHNlink (up-stream of splitter)	DLI TC 2 I	929 028
8	SFL Protector	SFL PRO 6X 19“	909 251
9	NET Protector for 8 x 2 pairs	NET PRO TC 2 LSA	929 072
	19” enclosure	EG NET PRO 19“	929 034
10	DEHNflex M	DFL M 255	924 396
11	DSM telephone protection module	DSM TC 2 SK	924 272
12	DEHNprotector	DPRO 230 LAN100	909 321

Figure 9.11.5 Administration building with highly available installation parts

Therefore, experts (e.g. engineering consultants) must be called in for large projects.

Surge protection for the M-bus

The function of an M-bus (meter bus) is to transfer meter readings of consumption meters. Data can be centrally read off from all devices connected to an M-bus system, either directly on site or via data transfer in an external control room. This increases e.g. the living quality of tenants and allows to check the energy consumption of an entire building at any time.

The M-bus system is used for consumption cost billing and remote monitoring of

- Community and district heating systems as well as
- Multi-family houses

Centralised and distributed systems can be used to read off data from consumption meters.

If the consumption meters are located in close proximity to the system panel, a simple and cost-effective centralised system architecture is preferred. In this case, every single consumption meter is wired to the system panel in a radial configuration. If a distributed system is used, the data of the consumption meters installed on site are collected in sub-stations and are centrally transmitted to the system panel via the bus line.

As shown in **Figure 9.12.1**, a central master (in the simplest case a PC with a downstream level converter) communicates with the bus devices via a bus line. The installation can be subdivided into M-bus segments using M-bus repeaters. Up to max. 250 slaves such as heat meters, water meters, electricity meters, gas meters, sensors and actuators of any type can be connected per segment. More and more manufacturers integrate the electric M-bus interface including the protocol level in their consumption meters.

The M-bus is a two-wire bus system which is supplied by the bus master. All other bus devices of the M-bus must not be connected to earth during operation. The maximum bus voltage is 42 V.

Lines as well as the connected M-bus devices and protective circuits stress the M-bus segment due to their resistances and

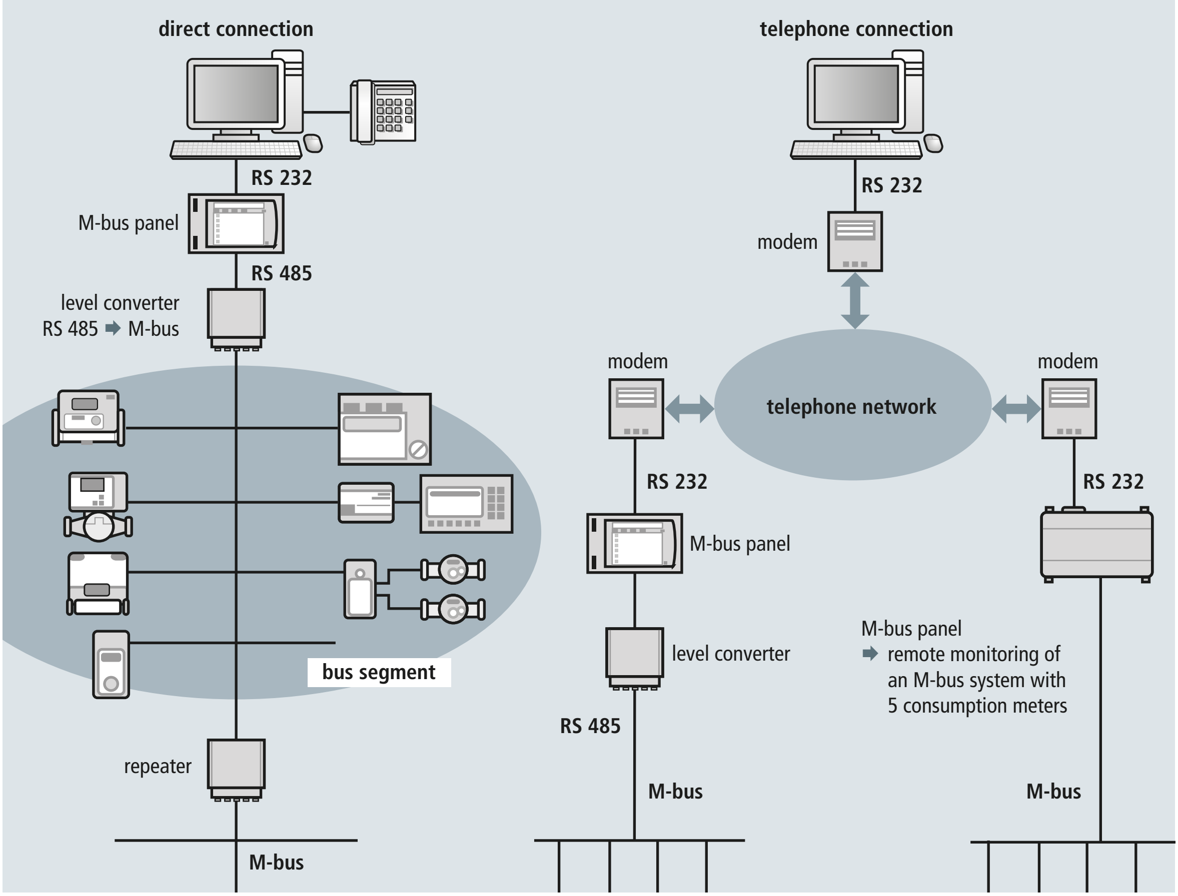


Figure 9.12.1 System example for an M-bus

Line J-Y (ST) Y...x 0.8	Number of bus devices	Current per bus device	Max. voltage drop
0.8 km	60	e.g. 1.5 mA	5.4 V

Table 9.12.1 Maximum voltage drop on the bus line

Baud rate	Max. bus capacitance at a baud rate of 9600	Total capacitance of the bus devices + line
9600	100 nF	60 meters + 0.8 km J-Y (ST) Y ... · 0.8 60 · 1 nF + 0.8 km · 50 nF/km

Table 9.12.2 Maximum baud rate depending on the bus devices (in this case meters) and the line capacitance

Surge protective device		Part No.	Capacitance: core / core	Series impedance per core
BLITZDUCTOR XT	BXT ML2 BD S 48	920 245	0.7 nF	1.0 Ω
BLITZDUCTOR XT	BXT ML2 BE S 24	920 224	0.5 nF	1.8 Ω
BLITZDUCTOR XT	BXT ML2 BE S 5	920 220	2.7 nF	1.0 Ω
DEHNconnect	DCO SD2 MD 48	917 942	0.6 nF	1.8 Ω
DEHNconnect	DCO SD2 ME 24	917 921	0.5 nF	1.8 Ω
DEHNconnect	DCO SD2 E 12	917 987	1.2 nF	–

Table 9.12.3 Capacitances and series impedances of surge protective devices

capacitances and have an impact on the length of the bus line / baud rate.

An M-bus panel has an M-bus standby current of e.g. 375 mA (250 standard loads of 1.5 mA each) which supplies different M-bus devices with different standard loads (e.g. three standard loads are equivalent to 4.5 mA). The cross-section of the copper lines and the sum of the voltage drops in the partial sections up to the relevant bus device define the maximum length of the bus line (**Table 9.12.1**).

Another aspect is the dependence of the maximum transmitted baud rate on the total capacitance in the bus segment. This is shown based on the example of an M-bus panel with a capacitance of 100 nF at a baud rate of 9600:

- Type of line J-Y (ST) Y… x 0.8
- About 75 Ω/km, about 50 nF/km for M-bus devices, e.g. meters, about 1 nF, about 1.5 mA (**Table 9.12.2**).

If surge protective devices are used, their series resistances and core / core capacitances must be observed (**Table 9.12.3**).

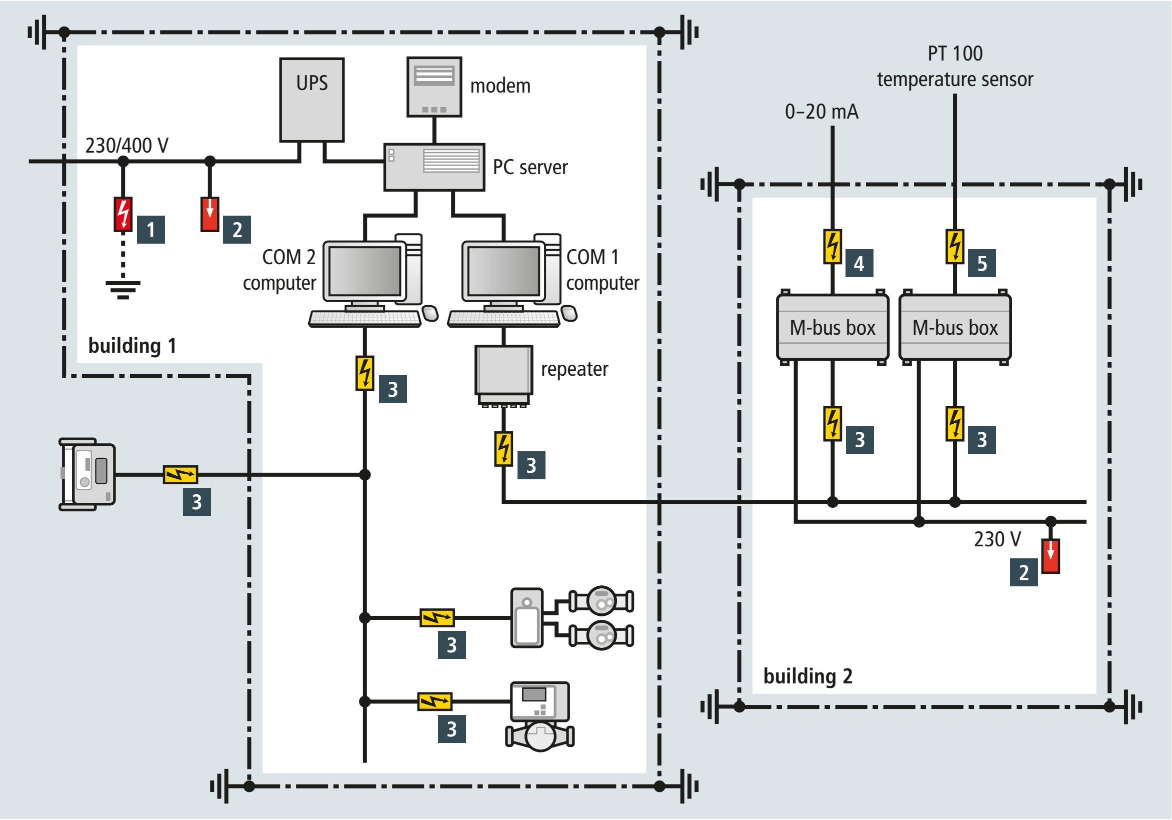
Building with external lightning protection system

If a building is fitted with an external lightning protection system, lightning equipotential bonding is required.

All cores of power supply and information technology cables and lines entering or leaving the building are connected to the lightning equipotential bonding system via lightning current arresters. **Figure 9.12.2** shows an example of how to protect an interconnected M-bus system from lightning currents and surges.

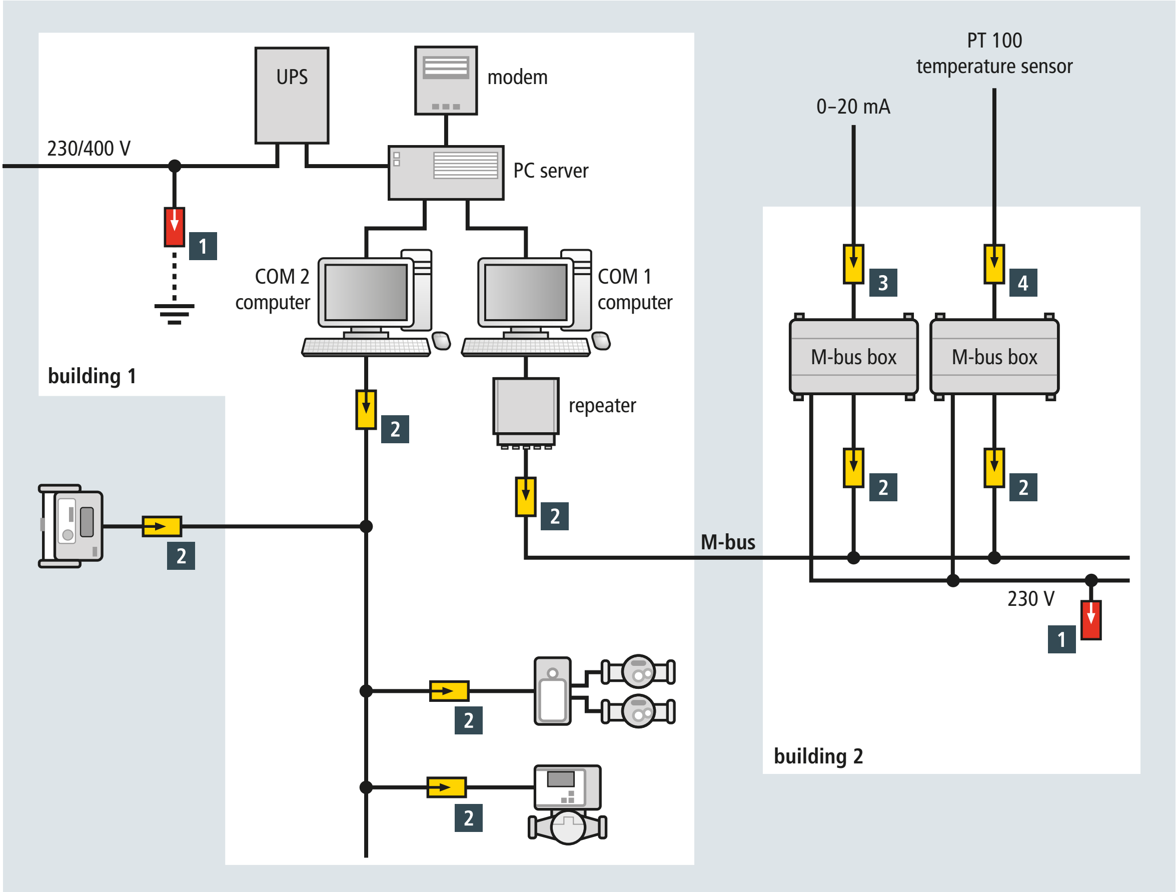
Building without external lightning protection system

If no external lightning protection system is installed, surge protective devices protect the electrical installations and systems. **Figure 9.12.3** shows an example of how to protect an interconnected M-bus system from surges.



No.	Protection for…	Surge protective device	Part No.
Selection of combined arresters according to the system configuration (in the main distribution board next to the entrance point into the building)			
1	Three-phase TN-C system	DEHNventil DV M TNC 255	951 300
	Three-phase TN-S system	DEHNventil DV M TNS 255	951 400
	Three-phase TT system	DEHNventil DV M TT 255	951 310
Surge protective devices for the voltage supply			
2	Three-phase TN-S system	DEHNguard DG M TNS 275	952 400
	Three-phase TT system	DEHNguard DG M TT 275	952 310
	Alternating current TN system	DEHNguard DG M TN 275	952 200
	Alternating current TT system	DEHNguard DG M TT 2P 275	952 110
Surge protective devices for signal interfaces			
3	M-bus	BLITZDUCTOR XT BXT ML2 BD S 48 + BXT BAS base part	920 245 + 920 300
4	0–20 mA	BLITZDUCTOR XT BXT ML2 BE S 24 + BXT BAS base part	920 224 + 920 300
5	PT 100 temperature sensor	BLITZDUCTOR XT BXT ML2 BE S 5 + BXT BAS base part	920 220 + 920 300

Figure 9.12.2 Protection concept for an M-bus system in buildings with external lightning protection system



No.	Protection for…	Surge protective device	Part No.
Surge protective devices for the voltage supply			
1	Three-phase TN-S system Three-phase TT system Alternating current TN system Alternating current TT system	DEHNguard DG M TNS 275 DEHNguard DG M TT 275 DEHNguard DG M TN 275 DEHNguard DG M TT 2P 275	952 400 952 310 952 200 952 110
Surge protective devices for signal interfaces			
2	M-bus	DEHNconnect DCO SD2 MD 48	917 942
3	0–20 mA	DEHNconnect DCO SD2 ME 24	917 921
4	PT 100 temperature sensor	DEHNconnect DCO SD2 E 12	917 987

Figure 9.12.3 Protection concept for an M-bus system in buildings without external lightning protection system

Surge protection for PROFIBUS FMS, DP and PA

PROFIBUS requires high availability since it is used as communication system in process-oriented applications and as instrumentation and control medium between cells and objects. However, PROFIBUS is highly susceptible to surges since high inductive / capacitive coupling may occur due to its large spatial dimensions.

PROFIBUS is a product designation by Siemens for communication products (hardware and software) according to the standardised PROFIBUS standard (ProcessFieldBus). Alternative designations for PROFIBUS FMS and PROFIBUS DP are the Siemens product designations SINEC L2 and SINEC L2-DP. While PROFIBUS FMS is only designed for data transmission rates up to 500 kBit/s, PROFIBUS DP is capable of transmitting data with a transmission rate up to 12 MBits/s. PROFIBUS FMS (SINEC L2) is mainly used to handle large data volumes of the process and group control level. The fast PROFIBUS DP is designed for applications in the decentralised programmable logic controller I/O.

The latest development in the PROFIBUS segment is the intrinsically safe PROFIBUS PA which can also be used in potentially explosive atmospheres of process plants.
A two-wire bus cable is typically used as a transmission medium. The physical properties of the bus system mainly comply with the RS 485 standard.

The bus devices can be connected as follows:

- Connection via 9-pin D-Sub miniature plug (typically 3/8 pin assignment)
- Connection via screw terminals
- Connection via bus terminals

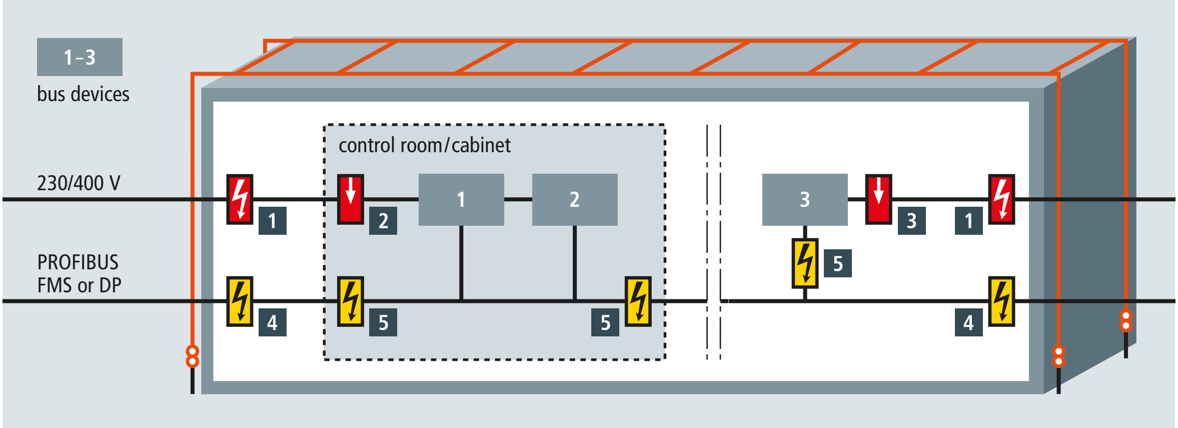


Figure 9.13.1 PROFIBUS FMS or DP extending beyond a building with external lightning protection system

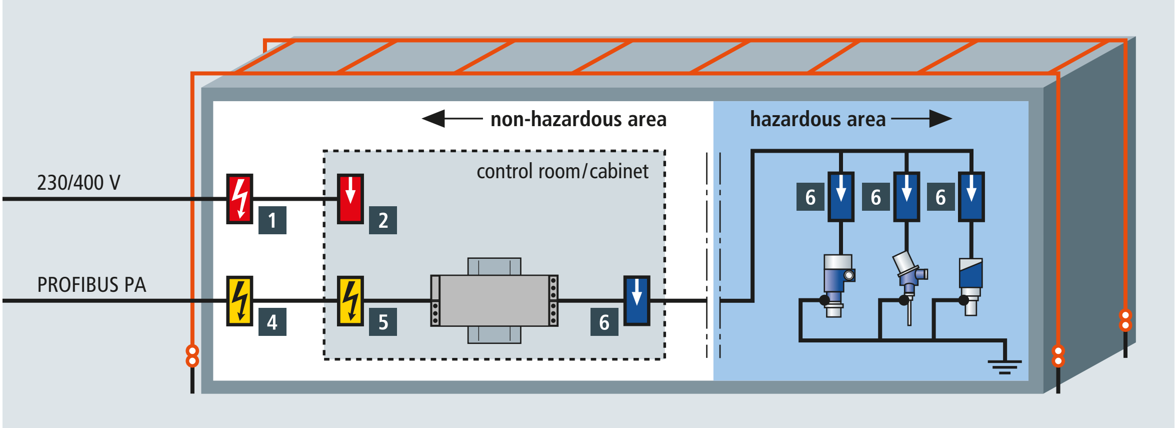


Figure 9.13.2 Intrinsically safe PROFIBUS PA in a building with external lightning protection system

No. in Fig. 9.13.1 and 2	Protection for…	Surge protective device	Part No.
1	Three-phase TN-S system Three-phase TT system	DEHNventil DV M TNS 255 DEHNventil DV M TT 255	951 400 951 310
2	Three-phase TN-S system Three-phase TT system	DEHNguard DG M TNS 275 DEHNguard DG M TT 275	952 400 952 310
3	230 V supply 24 V d.c. supply	DEHNrail DR M 2P 255 DEHNrail DR M 2P 30	953 200 953 201
4	PROFIBUS	BLITZDUCTOR XT BXT ML2 B 180 + BXT BAS base part	920 211 920 300
5	PROFIBUS	BLITZDUCTOR XT BXT ML2 BE HFS 5 + BXT BAS base part	920 270 920 300
6	PROFIBUS in hazardous area	BLITZDUCTOR XT BXT ML4 BD EX 24 + BXT BAS EX base part or DEHNpipe DPI MD EX 24 M 2	920 381 920 301 929 960

Table 9.13.1 Lightning current and surge arresters for intrinsically safe PROFIBUS PA, PROFIBUS FMS and DP

Building with external lightning protection system

If a building is equipped with an external lightning protection system, lightning equipotential bonding is required. To this end, the earth-termination system is connected to pipes, metal installations and earthed parts of the power supply and information technology systems. In addition, all power supply and information technology cables entering and leaving the structure are connected to the earth-termination system via lightning current arresters (**Figures 9.13.1 and 9.13.2**).

In addition to lightning equipotential bonding, surge protection measures must be taken to protect electrical installations and systems.

If lightning equipotential bonding, surge protection and external lightning protection measures are properly implemented, they reduce failure in case of direct lightning strikes to a minimum.

Building without external lightning protection system

If no external lightning protection system is installed, the bus devices must be protected by surge arresters. In this case, lightning current arresters for power supply and information technology lines do not have to be installed (arresters 1 and 4 are not required).

Surge protection for telecommunication connections

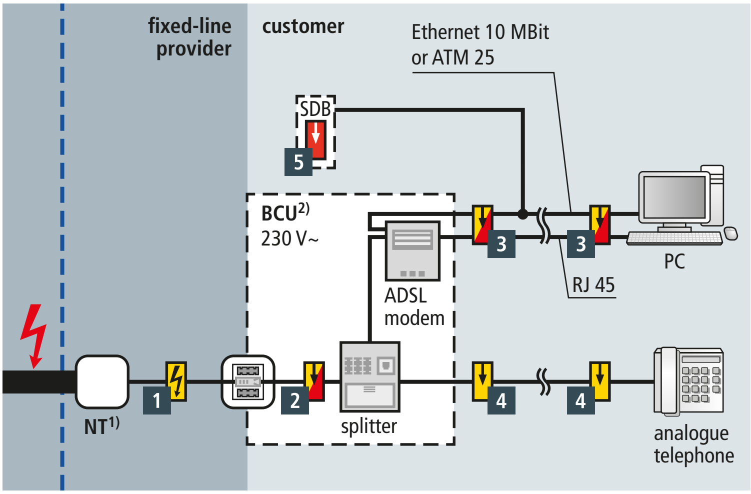
In addition to power supply lines, telecommunication lines are the most important lines. Permanently functioning interfaces to the "outside world" are vital for the highly technical processes in today's industrial plants and offices.

Telecommunication line networks frequently extend over some km². Therefore, it is quite likely that surges are injected into such widespread networks.

The safest solution to protect a structure from the negative consequences of lightning effects is to install a complete lightning protection system consisting of an external and internal lightning protection system.

Risks

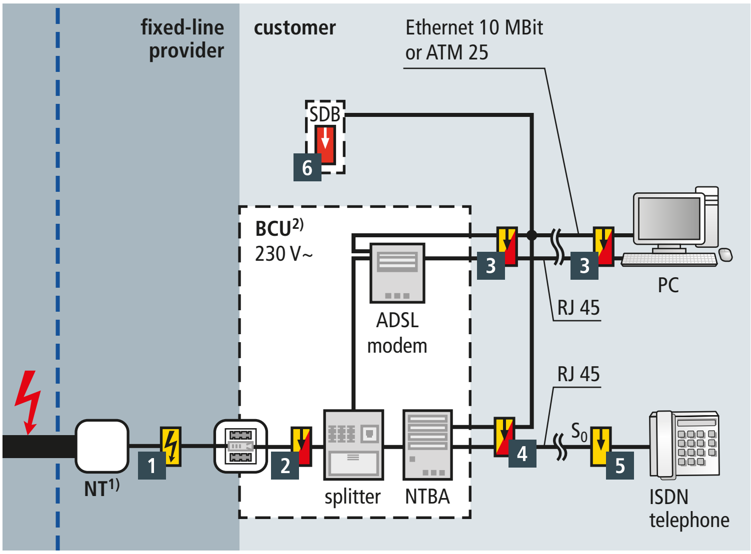
Copper cables with a low shielding effect are used as connecting cables to the local exchange and in a company's internal cabling system. High potential differences can occur between the building installation and the incoming lines since the incoming lines extend beyond several buildings. Potential rise of the cores caused by galvanic and inductive coupling must be expected. If high-power and low-power lines are routed in parallel, switching overvoltages in the power system can also cause failure which interferes with the low-power lines.



	Type	Part No.
1	BXT ML2 BD 180 + BXT BAS	920 247 + 920 300
	DRL 10 B 180 FSD + EF 10 DRL + DRL PD 180	907 401 + 907 498 + 907 430
2	DPRO 230 NT	909 310
3	DPRO 230 LAN100	909 321
4	DLI TC 2 I	929 028
	DSM TC 2 SK	924 272
5	DG M TNS 275	952 400

[1] Network Termination
[2] Broadband Connection Unit

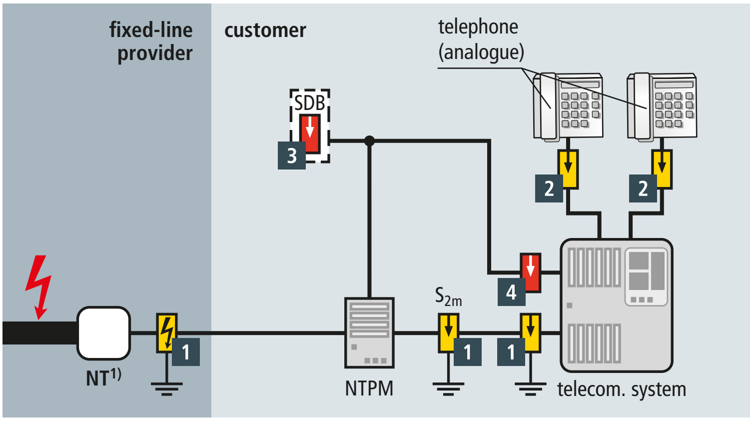
Figure 9.14.1 Lightning and surge protection for an analogue connection with ADSL



	Type	Part No.
1	BXT ML2 BD 180 + BXT BAS	920 247 + 920 300
	DRL 10 B 180 FSD + EF 10 DRL + DRL PD 180	907 401 + 907 498 + 907 430
2	DPRO 230 NT	909 310
3	DPRO 230 LAN100	909 321
4	DPRO 230 ISDN	909 320
5	DLI ISDN I	929 024
	DSM ISDN SK	924 270
6	DG M TNS 275	952 400

[1] Network Termination
[2] Broadband Connection Unit

Figure 9.14.2 Lightning and surge protection for an ISDN connection with ADSL



	Type	Part No.
1	BXT ML4 BD HF 24 + BXT BAS	920 375 + 920 300
	DRL 10 B 180 FSD + EF 10 DRL + DRL HD 24	907 401 + 907 498 + 907 470
2	DLI TC 2 I	929 028
	DSM TC 2 SK	924 272
3	DG M TNS 275	952 400
4	SFL PRO 6X	912 250

[1] Network Termination

Figure 9.14.3 Surge protection for telecommunication systems with “ISDN primary multiplex connection”

Surge protection for the ADSL connection

In addition to a conventional telephone connection, an ADSL connection requires a network or ATM card in the PC (depending on the type of access), a special ADSL modem and a splitter to separate the telephone and data traffic. The telephone connection can be an analogue or ISDN connection.

The splitter divides the analogue voice signal or the digital ISDN signal from the ADSL data taking into account all important system parameters such as impedances, attenuation and level. It thus fulfils the function of a dividing network. The splitter is connected to the telephone socket on the input side. On the output side, it provides the high-frequency signals of the ADSL frequency band to the ADSL modem and controls communication with the NTBA or the analogue terminal device in the low frequency range.

The ADSL modem is connected to the PC via an Ethernet (10 MBit/s), ATM25 or USB interface and requires a 230 V a.c. supply voltage (**Figures 9.14.1 and 9.14.2**).

Surge protection for the ISDN connection

ISDN (Integrated Service Digital Network) offers different services in a common public network. Both voice and data can be transmitted via digital transmission. The transfer interface for the NTBA, which is also supplied with 230 V a.c. on the power supply side, is a network termination unit.

Figure 9.14.2 shows surge protective devices for an ISDN connection.

Surge protection for the primary multiplex connection

The primary multiplex connection (NTPM) features 30 B-channels with 64 kBit/s each, a D-channel and a synchronisation channel with 64 kBit/s and allows data transfer rates up to 2 MBit/s. The NTPM is supplied by the U_{2m} interface. The device interface is referred to as S_{2m}. Large-scale interphone systems or data connections with high data volumes are connected to this interface. **Figure 9.14.3** shows surge protective devices for such a connection. The NTPM is also supplied with 230 V a.c. on the power supply side.

Surge protection for LED mast lights

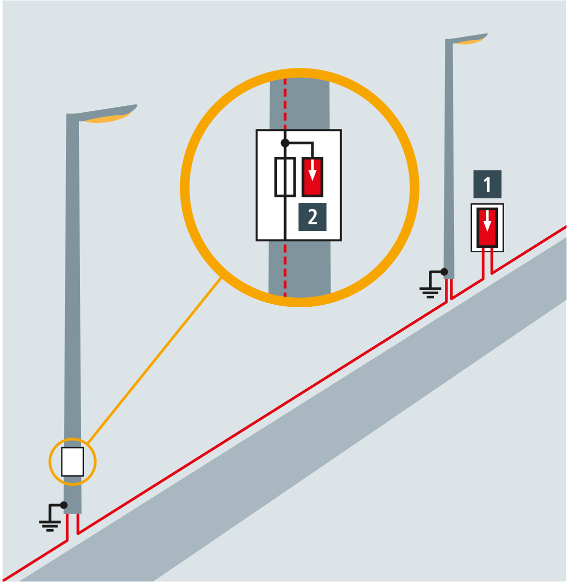
LED mast lights for street, walkway and open space lighting are mounted at light point heights of several metres to ensure a large field of illumination. This, however, is only possible if the luminous flux of the light source is sufficiently high which is no problem for today's highly efficient LEDs. Their long service life, a low temperature sensitivity and individual settings of different scenes make them cost-effective and environmentally-friendly.

LED mast lights stand out due to the following special characteristics:

- High luminous efficacy up to 110 lm/W
- The light distribution can be easily adapted to the relevant illumination task by using different lenses
- Different light colours / colour temperatures
- LEDs have a service life between 50,000 and 100,000 h depending on the operating current
- The temperature-dependent luminous flux of the LEDs varies only slightly and is e.g. 115 % at -30 °C and 95 % at 40 °C
- Individual scenes (e.g. luminous flux, operating times, dusk dependence) can be pre-set via the LED drivers
- In some cases, individual scenes can be set via a 1 – 10 V or DALI interface
- LEDs are ideally suited for safety lighting systems due to their high luminous flux without switch-on delay

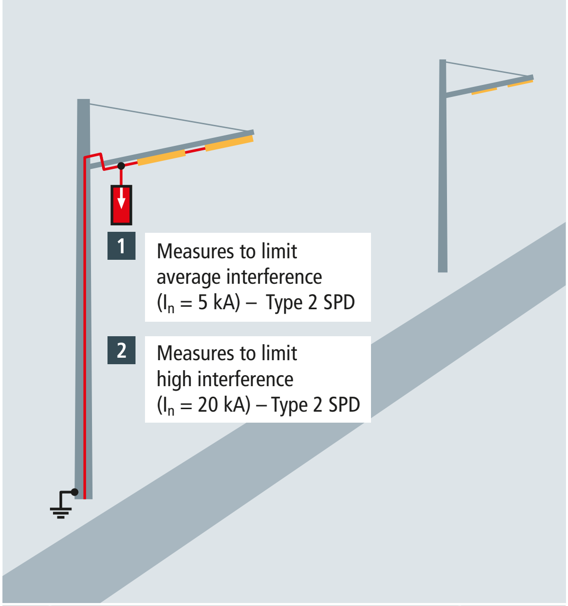
In practice, different LED mast lights are used. All fixture bodies are typically made of metal independent of whether LED mast lights with "double or reinforced insulation" (previously class II) or "automatic disconnection of supply" (previously class I) as per IEC 60364-4-41 (HD 60364-4-41) are used. The metal housing of the LED mast light dissipates the resulting heat loss over a large area.
The mast frequently consists of metal and the supply voltage flows through a buried cable into the mast. A terminal compartment that can be opened using tools is situated in the lower section of small masts. A rubber hose which is relieved of any strain on both ends connects the terminal compartment with the mast light. This terminal compartment houses the terminals and the overcurrent protective device. Large masts are fitted with a supply distributor and, if this distributor feeds the mains and equivalent power supply, it is physically divided according to the relevant normative requirements.
If LED mast lights or PVC masts are used, electrostatic charge must be observed. This, however, will not be described here.

If you compare the surge-related replacement costs of previously used mast lights with high-pressure lamps with the replacement costs of today's LED mast lights, it can be seen that the illuminant, ignition device and inductive control unit of the previously used high-pressure lamps are damaged while the LED drivers, their parameterisation devices and the LEDs of today's LED mast lights entail high costs. Although amortisation is to be expected over a transparent time frame due to the long service life of LED mast lights, the question arises whether the manufacturer accepts the warranty for the overall system (LED drivers and LEDs) since surges negatively affect the system-specific service life. The lighting industry has already responded to this with a higher dielectric strength of the LED drivers and an impulse current withstand capability of 2 kA and a dielectric strength of 4 kV for new LED mast lights, however, the impulse currents and surges occurring in the mains can exceed these values many times over. It has to be particularly observed that the dielectric strengths L to N considerably differ from that of L/N to PE.
A metal mast in conjunction with a metal LED mast light minimises the probability of field-based injection. Consequently, only surges extending over the cable network must be considered. To this end, a surge arrester can be installed in the terminal compartment / distributor of the mast (**Figure 9.15.1**).



	Surge protective device	Part No.
1	DEHNguard DG M TT 275 or DEHNguard DG M TNS 275	952 310 952 400
2	DEHNguard DG M TT 2P 275 or DEHNguard DG M TN 275	952 110 952 200

Figure 9.15.1 Surge arrester installed in the terminal compartment / distributor of the metal mast for protecting the metal LED mast light from conducted surges caused by distant atmospheric events and switching operations



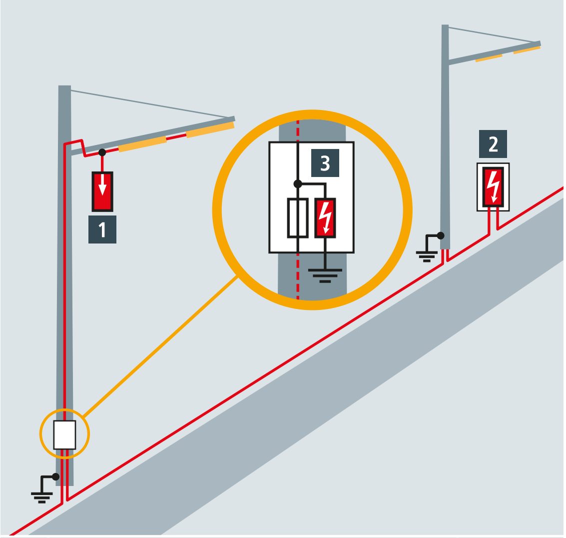
	Surge protective device	Part No.
1	DEHNcord DCOR L 2P 275	900 430
2	DEHNguard DG M TT 2P 275	952 110

Figure 9.15.2 Surge arrester installed next to the LED mast light with the feeder cable of the mast light being installed in open space for protecting the LED mast light from field-based injection or as sole protection from conducted surges caused by distant atmospheric events and switching operations

This has the advantage that the surge arrester can be tested without forklift.

If, however, a metal LED mast light and its metal mast do not form a closed system since the feeder cable of the LED mast light was placed in free space at the mast exit point and several LED mast lights are located on a mast arm, a surge arrester must be installed next to the LED mast light (**Figure 9.15.2**). If the probability of surges is expected to be low, no additional surge protective devices have to be installed. The relevant protection measure used for the LED mast light must be considered when installing a surge arrester in the LED mast light. Surge arresters with basic insulation (insulation of dangerous live parts as basic protection), for example, must not interfere with the "double or reinforced insulation" (previously class II) of the LED mast light according to IEC 60364-4-41 (HD 60364-4-41).

It is advisable to use DEHNcord to limit average interference (I_n = 5 kA). DEHNguard modular DG M TT 2P 275 should be installed to limit high interference (I_n = 20 kA).



	Surge protective device	Part No.
1	DEHNcord DCOR L 2P 275	900 430
2	DEHNshield DSH TT 255 or DEHNshield DSH TNS 255	941 310 941 400
3	DEHNshield DSH TT 2P 255 or DEHNshield DSH TN 255	941 110 941 200

Figure 9.15.3 Combined arrester installed in the terminal compartment / distributor of the metal mast in conjunction with a surge arrester for protecting the LED mast light from nearby atmospheric events and conducted surges caused by switching operations

If lightning strikes the metal mast, the mast shields the cable installed in it and the application-optimised combined arrester located at the base of the mast discharges the lightning current (total current up to 50 kA (10/350 μs)) across the distribution network and protects the LED mast light by means of its low voltage protection level (**Figure 9.15.3**). This always requires a vertical or horizontal earth electrode and an additional surge arrester must be installed on the LED mast light according to **Figure 9.15.2**, depending on the cable routing.

Basically, the described protection of the LED mast light by means of a combined arrester must be used if a risk analysis requires a higher protection goal than a surge arrester can achieve. This is the case with extremely high masts with large-area LED mast lights on the mast arms (e.g. large parking lots, stadiums, etc.) and LED mast lights that are fed by a building with a lightning protection system since the lightning current is discharged via the lightning equipotential bonding system to the LED mast light.

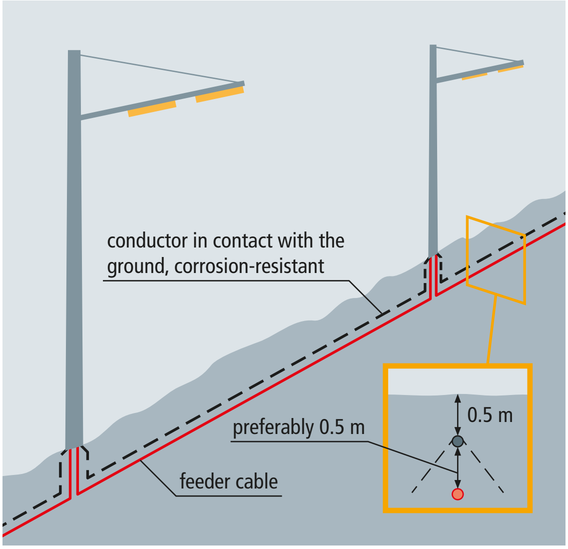


Figure 9.15.4 Earthing conductor for protecting the cable route and earthing the mast

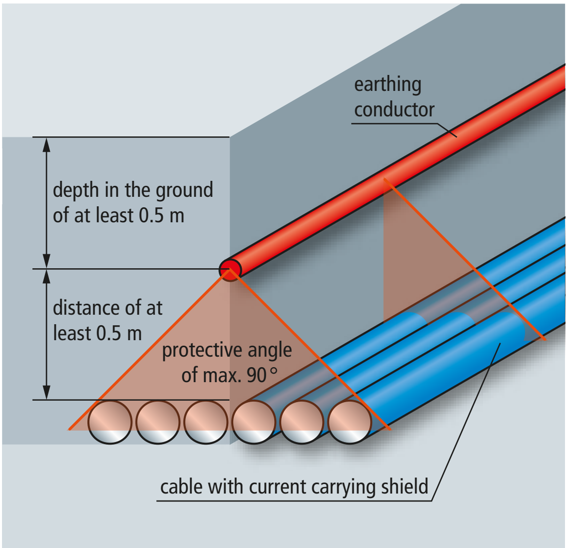


Figure 9.15.5 Protected volume of a cable route

In case of new installations where the masts and cables have not been installed yet, a bare earthing conductor is to be installed above the cable route.

If lightning hits the mast (not the mast light itself) or the ground, the earthing conductor assumes the function of the required earth electrode and linearises the potential drop, thus preventing flashover to the cable (**Figures 9.15.4 and 9.15.5**).

Lightning and surge protection for wind turbines

Due to their exposed location and height, wind turbines are vulnerable to the effects of direct lightning strikes. Several studies have shown that at least 10 direct lightning strikes to wind turbines in the multimegawatt range have to be expected every year. The feed-in compensation must amortise the high investment costs within a few years, meaning that downtime caused by lightning and surge damage and the resulting repair costs must be avoided. For this reason, comprehensive lightning and surge protection measures are required. When planning lightning protection measures, not only cloud-to-earth flashes, but also earth-to-cloud flashes, so-called upward leaders, must be considered for objects at exposed locations with a height of more than 60 m. The high electric charge of these upward leaders must be particularly observed for the protection of the rotor blades and for the design of the lightning current arresters.

Standardisation

The IEC 61400-24 (EN 61400-24) standard, the IEC 62305 (EN 62305) standard series and the guidelines by Germanischer Lloyd (e.g. GL 2010 IV – Part 1: Guideline for the certification of wind turbines) form the basis for the protection concept.

Protection measures

The IEC 61400-24 (EN 61400-24) standard and GL 2010 guidline recommend to protect all sub-components of the lightning protection system of a wind turbine according to lightning protection level (LPL) I unless a risk analysis demonstrates that a lower LPL is sufficient. A risk analysis may also reveal that different sub-components have different LPLs. The IEC 61400-24 (EN 61400-24) standard recommends a comprehensive lightning protection concept.

Lightning protection (LP) for a wind turbine consists of an external lightning protection system (LPS) and surge protection measures (SPMs) for protecting electrical and electronic equipment. In order to plan protection measures, it is advisable to subdivide the wind turbine into lightning protection zones (LPZs).

The lightning protection system of a wind turbine protects two sub-systems which can only be found in wind turbines, namely the rotor blades and the mechanical drive train. The IEC 61400-24 (EN 61400-24) standard describes in detail how to protect these special parts of a wind turbine and how to prove the effectiveness of the lightning protection measures. The standard recommends to verify the lightning current withstand capability of these systems in high-current tests with the first stroke and the long stroke, if possible, in a common discharge.

In the following, it will be described how to implement lightning and surge protection measures for electrical and electronic devices / systems of a wind turbine. The complex problems concerning the protection of the rotor blades and rotably mounted parts / bearings must be examined in detail and depend on the manufacturer and type. The IEC 61400-24 (EN 61400-24) standard provides important information in this respect.

Lightning protection zone concept

The lightning protection zone concept is a structuring measure for creating a defined EMC environment in an object. This defined EMC environment depends on the immunity of the electrical equipment used. The lightning protection zone concept allows to reduce conducted and field-bound interference at the boundaries to defined values. For this reason, the object to be protected is subdivided into protection zones.

The rolling sphere method is used to determine LPZ 0_A, namely the parts of a wind turbine which may be subjected to direct lightning strikes, and LPZ 0_B, namely the parts of a wind turbine which are protected from direct lightning strikes by external air-termination systems or air-termination systems integrated in parts of a wind turbine (for example in the rotor blade). According to the IEC 61400-24 (EN 61400-24) standard, the rolling sphere method must not be used for the rotor blade itself. For this reason, the design of the air-termination system should be tested according to subsection 8.2.3 of the IEC 61400-24 (EN 61400-24) standard. **Figure 9.16.1** shows a typical application of the rolling sphere method, **Figure 9.16.4** the possible division of a wind turbine into different lightning protection zones. In this context, the division of a wind turbine into lightning protection zones depends on the design of the wind turbine. Therefore, the structure of the wind turbine should be observed. However, it is decisive that the lightning parameters which are injected into LPZ 0_A from the outside are reduced by suitable shielding measures and surge protective devices at all zone boundaries so that the electrical and electronic devices and systems inside a wind turbine are not interfered with.

Shielding measures

The nacelle should be designed as a closed metal shield. Thus, a volume with an electromagnetic field that is considerably lower than the field outside the wind turbine is generated in the nacelle. In accordance with IEC 61400-24 (EN 61400-24), a tubular steel tower, which is frequently used for large wind turbines, can be regarded as an almost perfect Faraday cage for electromagnetic shielding. In case of concrete hybrid towers, the function of the galvanic cage must be ensured by reinforcing steel as well as earthing and electrical connection of the individual components. The switchgear and control cabinets in the nacelle and, if any, in the operations building should also be made of metal. The connecting cables should feature an external shield that is capable of carrying lightning currents. Shielded cables are only resistant to EMC interference if the shields are connected to the equipotential bonding system on both ends. The shields must be contacted by means of fully

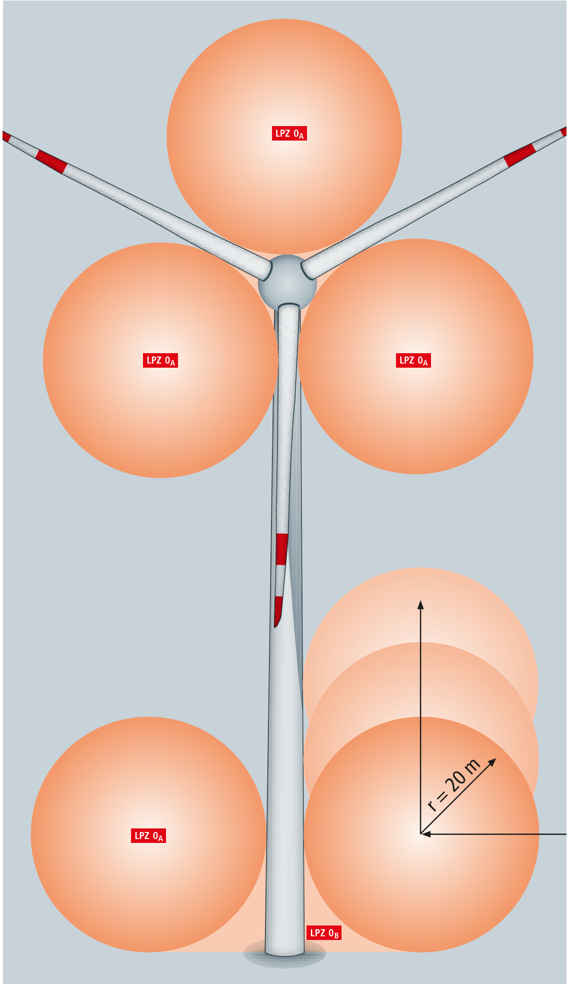


Figure 9.16.1 Rolling sphere method

(360 °) contacting terminals to prevent EMC-incompatible, long connecting cables in the wind turbine.
Magnetic shielding and cable routing should be performed as per section 4 of IEC 62305-4 (EC 62305-4). For this reason, the general guidelines for an EMC-compatible installation practice according to IEC/TR 61000-5-2 should be observed.
Shielding measures include for example:

- Installation of a metal braid on GRP-coated nacelles
- Metal tower
- Metal switchgear cabinet
- Metal control cabinets
- Lightning current carrying, shielded connecting cables (metal cable duct, shielded pipe or the like)
- Cable shielding

External lightning protection measures

These include:

- Air-termination and down-conductor systems in the rotor blades
- Air-termination systems for protecting nacelle superstructures, the nacelle and the hub
- Using the tower as air-termination system and down conductor
- Earth-termination system consisting of a foundation earth electrode and a ring earth electrode

The function of an external lightning protection system (LPS) is to intercept direct lightning strikes including lightning strikes to the tower of a wind turbine and to discharge the lightning current from the point of strike to the ground. An external lightning protection system is also used to distribute the lightning current in the ground without causing thermal or mechanical damage or dangerous sparking which may lead to fire or explosion and endanger persons.
The rolling sphere method can be used to determine potential points of strike for a wind turbine (except for the rotor blades) (**Figure 9.16.1**). For wind turbines, it is recommended to use class of LPS I. Therefore, a rolling sphere with a radius r = 20 m is rolled over the wind turbine to determine the points of strike. Air-termination systems are required where the sphere touches the wind turbine (potential points of strike).
The nacelle construction should be integrated in the lightning protection system to ensure that lightning strikes to the nacelle hit either natural metal parts that are capable of withstanding this stress or an air-termination system designed for this purpose. GRP-coated nacelles or the like should be fitted with an air-termination system and down conductors forming a cage around the nacelle (metal braid). The air-termination system including the bare conductors in this cage should be capable of withstanding lightning strikes according to the relevant lightning protection level. Other conductors in the Faraday cage should be designed in such a way that they withstand the amount of lightning current to which they may be subjected. The IEC 61400-24 (EN 61400-24) standard requires that air-termination systems for protecting measurement equipment etc. mounted outside the nacelle be designed in compliance with the general requirements of IEC 62305-3 (EN 62305-3) and that down conductors be connected to the cage described above.
Natural components made of conductive materials which are permanently installed in/on a wind turbine and remain unchanged (e.g. lightning protection system of the rotor blades, bearings, mainframes, hybrid tower) may be integrated in the LPS. If wind turbines consist of a metal construction, it can be assumed that they fulfil the requirements for an external

lightning protection system of class of LPS I according to IEC 62305 (EN 62305).

This requires that the lightning strike be safely intercepted by the lightning protection system of the rotor blades so that it can be discharged to the earth-termination system via the natural components such as bearings, mainframes, the tower and/or bypass systems (e.g. open spark gaps, carbon brushes).

Air-termination system/down conductor

As can be seen in **Figure 9.16.1**, the

- Rotor blades,
- Nacelle including superstructures (**Figure 9.16.2, Table 9.16.1**),
- Rotor hub and
- Tower of the wind turbine

may be hit by lightning. If they are capable of safely intercepting the maximum lightning impulse current of 200 kA and to discharge it to the earth-termination system, they can be used as natural components of the air-termination system of the wind turbine's external lightning protection system.

A metallic receptor, which represents a defined point of strike for flashes, is frequently attached to the tip of the GRP blade to protect the rotor blades from lightning strikes. A down conductor is routed from the receptor to the blade root. In case of a lightning strike, it can be assumed that lightning hits the blade tip (receptor) and then travels through the down conductor inside the blade via the nacelle and the tower to the earth-termination system.

Earth-termination system

The earth-termination system of a wind turbine must perform several functions such as personal protection, EMC protection and lightning protection.

An effective earth-termination system (**Figure 9.16.3**) is essential to distribute lightning currents and to prevent that the wind turbine is destroyed. Moreover, the earth-termination system must protect persons and animals against electric shock. In case of a lightning strike, the earth-termination system must discharge high lightning currents to the ground and distribute them in the ground without causing dangerous thermal and/or electrodynamic effects.

In general, it is important to install an earth-termination system for a wind turbine which is used to protect the wind turbine against lightning strikes and to earth the power supply system.

Note: Electrical high-voltage regulations such as CENELEC HO 637 S1 or applicable national standards describe how to design an earth-termination system to prevent high touch and step voltages caused by short-circuits in high or medium-voltage systems. With regard to the protection of persons, the IEC 61400-24 (EN 61400-24) standard refers to IEC/TS 60479-1 and IEC 60479-4.

Arrangement of earth electrodes

The IEC 62305-3 (EN 62305-3) standard describes two basic types of earth electrode arrangements for wind turbines:

Type A: According to the informative Annex I of IEC 61400-24 (EN 61400-24), this arrangement must not be used for wind turbines, but for adjoining buildings of wind turbines (for example, buildings containing measurement equipment or office sheds of a wind farm). Type A earth electrode arrangements consist of horizontal or vertical earth electrodes connected to the building by at least two down conductors.

Type B: According to the informative Annex I of IEC 61400-24 (EN 61400-24), type B earth electrodes must be used for wind turbines. They either consist of a buried external ring earth electrode and/or a foundation earth electrode. Ring earth electrodes and metal parts in the foundation must be connected to the tower construction.

In any case, the reinforcement of the tower foundation should be integrated in the earth-termination system of a wind turbine. To ensure an earth-termination system ranging over as large an area as possible, the earth-termination system of the tower base and the operations building should be connected by means of a meshed earth electrode network. Corrosion-resistant ring earth electrodes (made of stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti) with potential control prevent excessive step voltages in case of a lightning strike and must be installed around the tower base to ensure personal protection (**Figure 9.16.3**).

Figure 9.16.2 Example of an air-termination system for the weather station and the aircraft warning light

Foundation earth electrodes

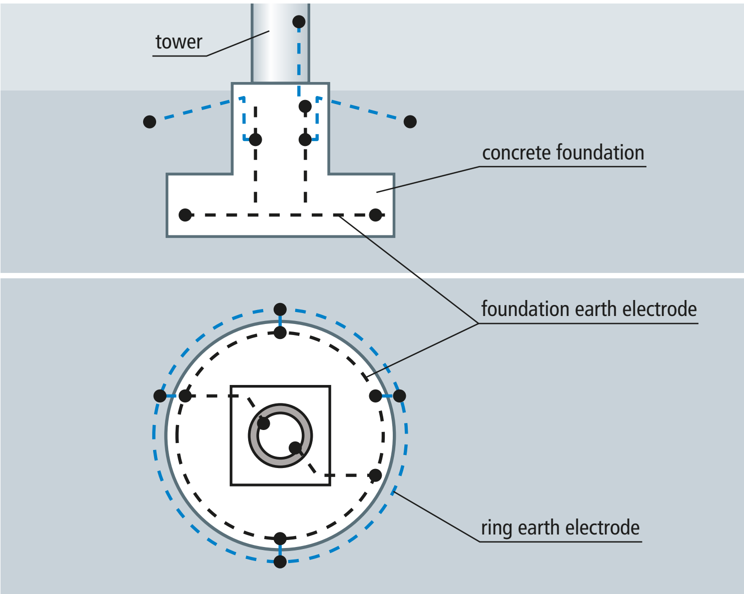
Foundation earth electrodes make technical and economic sense and are required in the German Technical Connection Conditions (TAB) published by German distribution network operators. They are part of the electrical installation and fulfil essential safety functions. For this reason, they must be installed by or under supervision of an electricians.

The metals used for earth electrodes must comply with the materials listed in Table 7 of IEC 62305-3 (EN 62305-3). The corrosion behaviour of metal in the ground must be observed at any time.

Foundation earth electrodes must be made of galvanised or non-galvanised (round or strip) steel. Round steel must have a minimum diameter of 10 mm, while strip steel must have minimum dimensions of 30 mm x 3.5 mm. It must be observed that this material must be covered with a concrete layer of at least 5 cm (corrosion protection). The foundation earth electrode must be connected to the main earthing busbar in the wind turbine. Corrosion-resistant connections must be established via fixed earthing terminals or terminal lugs made of stainless steel (V4A). Moreover, a ring earth electrode made of stainless steel (V4A) must be installed in the ground.

Internal lightning protection measures

- Earthing and equipotential bonding measures
- Spatial shielding and separation distance



Nr.		Art.-Nr.
1	Equipotential bonding bar for industrial use	472 209
2	**Wire, stainless steel (V4A)**	**860 010**
3	**Fixed earthing terminal, stainless steel (V4A)**	**478 011**
4	**Cross unit, stainless steel (V4A)**	**319 209**
5	Strip, 30 mm x 3.5 mm, St/tZn	810 335
6	Pressure U-clamp	308 031
7	MAXI MV clamp, UL467B-approved	308 040

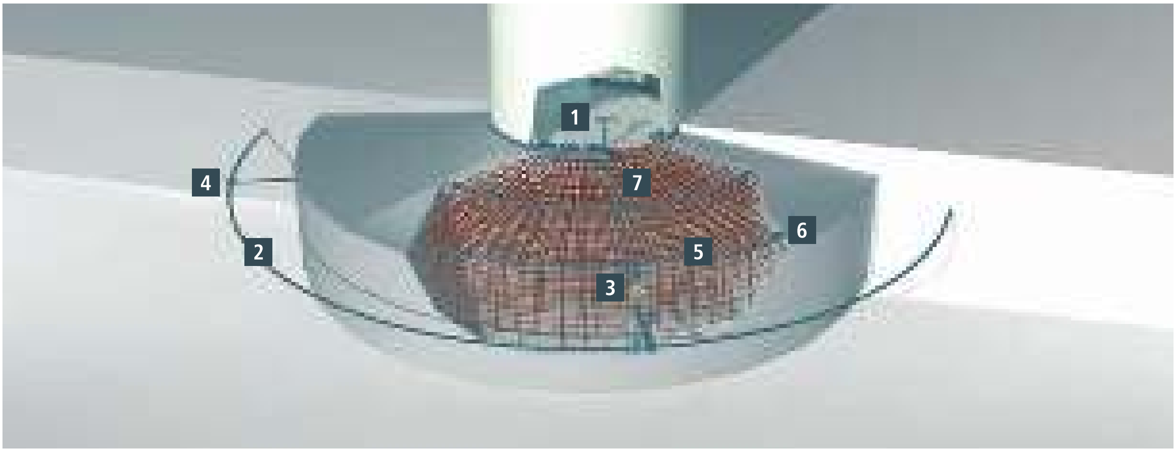


Figure 9.16.3 Earth-termination system of a wind turbine

- Cable routing and cable shielding
- Installation of coordinated surge protective devices

Protection of the lines at the transition from LPZ 0_A to LPZ 1 and higher

To ensure safe operation of electrical and electronic devices, the boundaries of the lightning protection zones (LPZs) must be shielded against field-based interference and must be protected against conducted interference (**Figures 9.16.4 and 9.16.5**). To this end, surge protective devices that are capable of discharging high partial lightning currents without destruction must be installed at the transition from LPZ 0_A to LPZ 1 (also referred to as lightning equipotential bonding). These surge protective devices are referred to as type 1 lightning current arresters and are tested by means of impulse currents of 10/350 µs waveform. At the transition from LPZ 0_B to LPZ 1 and higher only low-energy impulse currents caused by voltages induced on the system or surges generated in the system must be coped with. These surge protective devices are referred to as type 2 surge arresters and are tested by means of impulse currents of 8/20 µs waveform.

According to the lightning protection zone concept, all incoming cables and lines must be integrated in the lightning equipotential bonding system by means of type 1 lightning current arresters at the boundary from LPZ 0_A to LPZ 1 or from LPZ 0_A to LPZ 2. This affects both power supply and communication lines. An additional local equipotential bonding system where all cables and lines entering this boundary are integrated must be established for every further zone boundary within the volume to be protected. Type 2 surge arresters must be installed at the transition from LPZ 0_B to LPZ 1 and from LPZ 1 to LPZ 2, whereas type 3 surge arresters must be provided at the transition from LPZ 2 to LPZ 3. The function of type 2 and type 3 surge arresters is to further reduce the residual interference of the upstream protection stages and to limit the surges induced on the wind turbine or generated in the wind turbine.

Selection of SPDs based on the voltage protection level (U_p) and the immunity of the equipment

To describe the required voltage protection level U_p in an LPZ, the immunity levels of the equipment located in an LPZ must be defined, e.g. for power lines and connections of equipment according to IEC 61000-4-5 (EN 61000-4-5) and IEC 60664-1 (EN 60664-1), for telecommunication lines and connections of equipment according to IEC 61000-4-5 (EN 61000-4-5), ITU-T K.20 and ITU-T K.21 and for other lines and connections of equipment according to the manufacturer's instructions. Manufacturers of electrical and electronic components or devices should be able to provide the required information on the immunity level according to the EMC standards. If this is not the case, the wind turbine manufacturer should perform tests to determine the immunity level. The specific immunity level of components in an LPZ directly defines the voltage protection level required at the LPZ boundaries. The immunity of a system must be proven, where applicable, with all SPDs installed and the equipment they are supposed to protect.

Protection of power supply systems

The transformer of a wind turbine may be housed at different locations (in a separate distribution station, in the tower base, in the tower, in the nacelle). In case of large wind turbines, for example, the unshielded 20 kV cable in the tower base is routed to the medium-voltage switchgear installation consisting of a vacuum circuit breaker, mechanically locked selector switch disconnector, outgoing earthing switch and protective relay. The medium-voltage cables are routed from the medium-voltage switchgear installation in the tower of the wind turbine to the transformer which may be situated in the tower base or in the nacelle (**Figure 9.16.4**). The transformer feeds the control cabinet in the tower base, the switchgear cabinet in the nacelle and the pitch system in the hub by means of a TN-C system (L1, L2, L3, PEN conductor). The switchgear cabinet in the nacelle supplies the electrical equipment in the nacelle with an a.c. voltage of 230/400 V.

According to IEC 60364-4-44, all pieces of electrical equipment installed in a wind turbine must have a specific rated impulse withstand voltage according to the nominal voltage of the wind turbine (see IEC 60664-1 (EN 60664-1): Table 1, insulation coordination). This means that the surge arresters to be installed must have at least the specified voltage protection level according to the nominal voltage of the wind turbine. Surge arresters used to protect the 400/690 V supply must have a minimum voltage protection level $U_p \leq 2.5$ kV, whereas surge arresters used to protect the 230/400 V supply must have a voltage protection level $U_p \leq 1.5$ kV to ensure protection of sensitive electrical / electronic equipment (**Figures 9.16.6 and 9.16.7**).

Surge protective devices shall be capable of discharging lightning currents of 10/350 µs waveform without destruction and shall have a voltage protection level of $U_p \leq 2.5$ kV (**Figure 9.16.8**).

Protection of the transformer infeed

The medium-voltage transformer infeed is protected by DEHNmid medium-voltage arresters which must be adapted to the system configuration and voltage of the medium-voltage system (**Figure 9.16.9**).

230/400 V supply

Type 2 surge arresters, for example DEHNguard M TNC 275 CI FM, should be used to protect the voltage supply of the control cabinet in the tower base, the switchgear cabinet in the na-

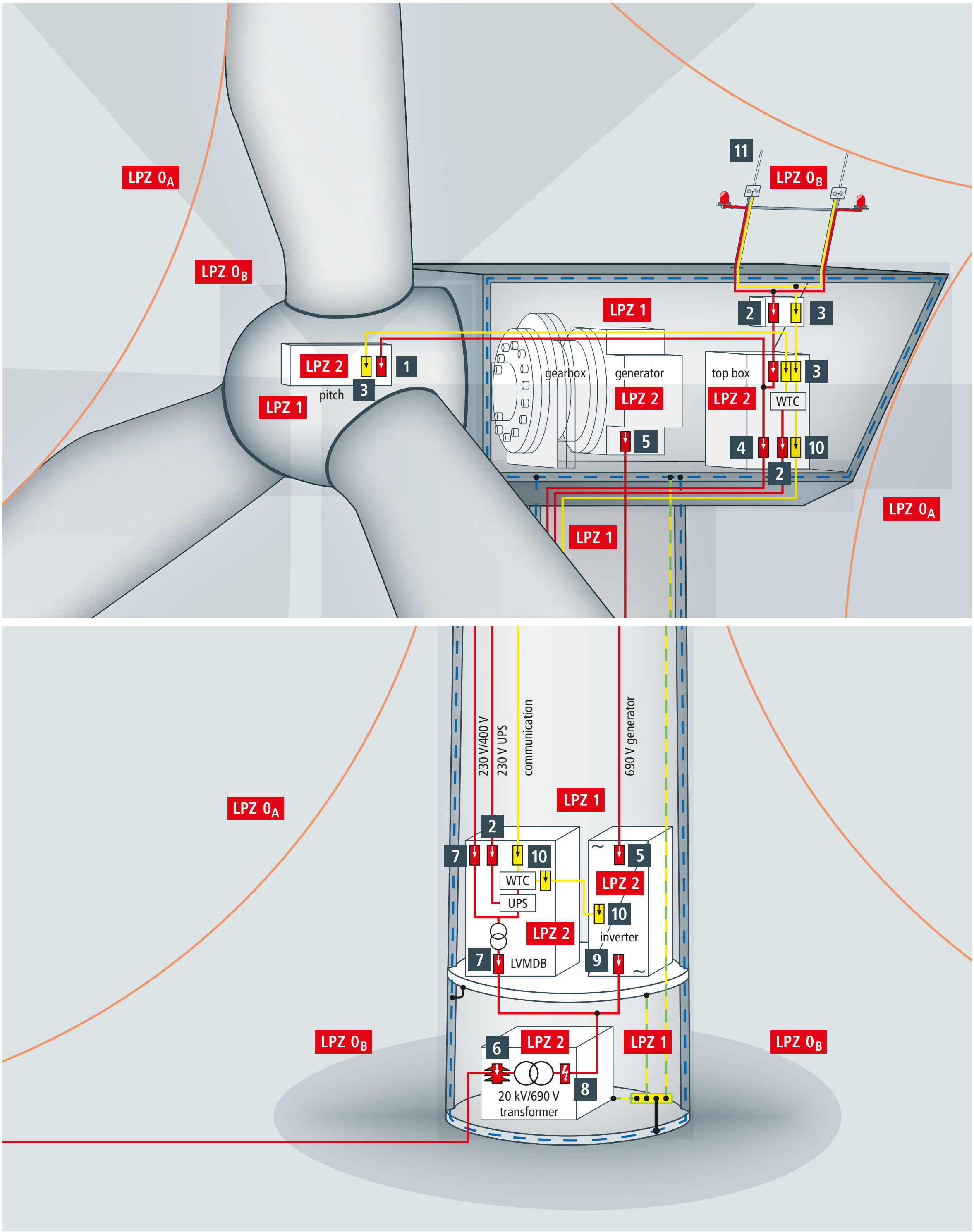


Figure 9.16.4 Lightning and surge protection for a wind turbine

No. in Fig. 4	Area to be protected	Surge protective device	Part No.
1	Voltage supply of the hub Signal lines between the nacelle and the hub	DEHNguard TN 275 FM BLITZDUCTOR XT BE 24 * DENHpatch DPA M CAT6 RJ45S48	952 205 920 324 929 121
2	Protection of the aircraft warning light	DEHNguard M TN 275 FM	952 205
3	Signal lines of the weather station and the control cabinet in the nacelle	BLITZDUCTOR XT ML4 BE 24 * BLITZDUCTOR XT ML2 BE S 24 *	920 324 920 224
4	Control cabinet in the nacelle 230/400 V voltage supply	DEHNguard M TNC 275 FM DEHNguard M TNC CI 275 FM	952 305 952 309
5	Protection of the generator	DEHNguard M WE 600 FM	952 307
6	Protection of the transformer	DEHNmid DMI 9 10 1 DEHNmid DMI 36 10 1	990 003 990 013
7	Voltage supply of the control cabinet in the tower base, 230/400 V TN-C system	DEHNguard M TNC 275 FM DEHNguard M TNC CI 275 FM	952 305 952 309
8	Main incoming supply, 400/690 V TN system	3x DEHNbloc M 1 440 FM	961 145
9	Protection of the inverter	DEHNguard M WE 600 FM	952 307
10	Protection of the signal lines in the control cabinet of the tower base	BLITZDUCTOR XT ML4 BE 24 * BLITZDUCTOR XT ML2 BE S 24 *	920 324 920 224
11	Protection of the nacelle superstructures	Air-termination rods Pipe clamp for air-termination rods	103 449 540 105

Table 9.16.1 Protection of a wind turbine (lightning protection zone concept according to Figure 9.16.4)
* associated base part: BXT BAS, Part No. 920 300

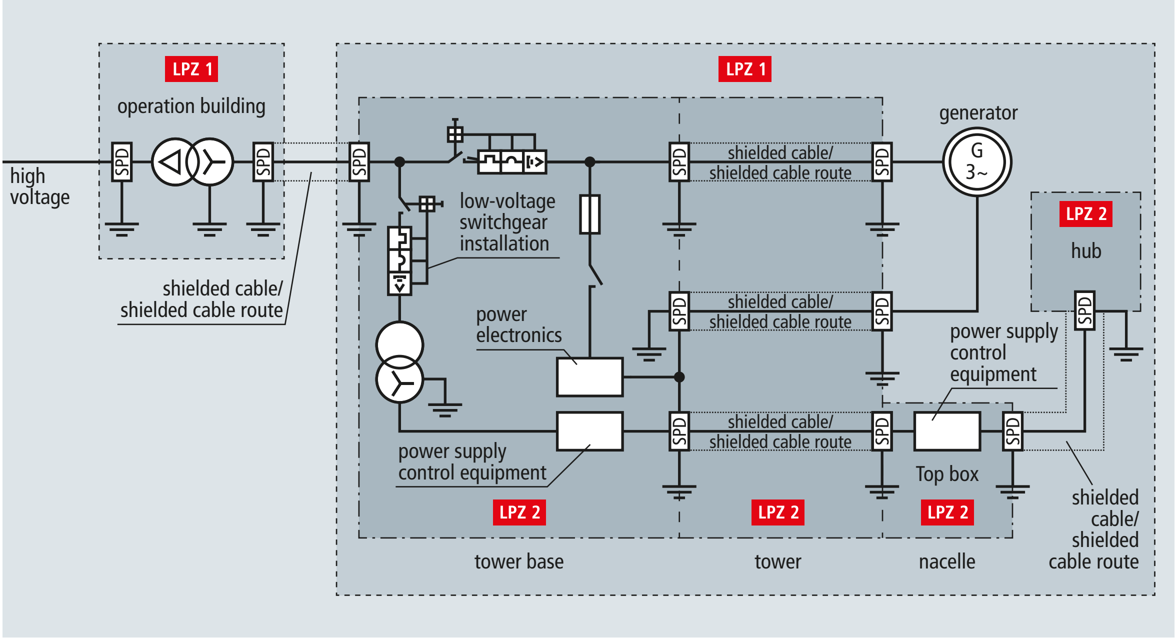


Figure 9.16.5 Example of arresters installed at the zone boundaries of a wind turbine

Figure 9.16.6 Modular type 2 surge arrester for protecting the 230/400 V supply

Figure 9.16.7 Protection of the stator side of the generator

Figure 9.16.8 Coordinated type 1 surge arrester

Figure 9.16.9 DEHNmid medium-voltage arresters installed in a transformer for wind turbines

celle and the pitch system in the hub by means of a 230/400 V TN-C system (**Figure 9.16.6**).

Protection of the aircraft warning light

The aircraft warning light on the sensor mast in LPZ 0_B should be protected by a type 2 surge arrester at the relevant zone transitions (LPZ $0_B \rightarrow 1$, LPZ $1 \rightarrow 2$) (**Table 9.16.1**). Depending on the system, e.g. components of the DEHNguard series (low voltage) and / or BLITZDUCTOR family can be used for extra low voltage / signal lines.

400/690 V system

Coordinated single-pole lightning current arresters with a high follow current limitation for the 400/690 V systems, for example DEHNbloc M 1 440 FM (**Figure 9.16.8**), must be installed to protect the 400/690 V transformer, inverters, mains filters and the measurement equipment. It must be ensured at the frequency converter that the arresters are dimensioned for the maximum voltage peaks, which are higher than in case of pure sinusoidal voltages. In this context, surge arresters with a nominal voltage of 600 V and U_{mov} = 750 V have proven their worth. The DEHNguard DG M WE 600 FM (**Figure 9.16.7**) arresters can be installed at both sides of the converter (grid and machine side) and on the generator. Only if doubly-fed induction generators are used, an arrester combination with an increased electric strength must be used on the rotor side. For this purpose, it is advisable to install a 3 + 1 Neptune circuit with a nominal voltage up to 1000 V. An additional spark-gap-based arrester ensures electrical isolation and prevents premature tripping of the varistors.

Surge arresters for information technology systems

Surge arresters for protecting electronic equipment in telecommunication and signalling networks against the indirect and direct effects of lightning strikes and other transients are described in IEC 61643-21 (EN 61643-21) and are installed at the zone boundaries in conformity with the lightning protection zone concept (**Figure 9.16.4, Table 9.16.1**). Multi-stage arresters must be designed without blind spots, in other words it must be ensured that the different protection stages are coordinated with one another. Otherwise not all protection stages will be activated, thus causing faults in the surge protective device. Glass fibre cables are frequently used for routing information technology lines into a wind turbine and for connecting the control cabinets in the tower base to the nacelle. Shielded copper cables are used to connect the actuators and sensors with the control cabinets. Since interference by an electromagnetic environment is excluded, the glass fibre cables do not have to be protected by surge arresters unless they have a metal sheath which must be integrated in the equipotential bonding system either directly or by means of surge protective devices.

In general, the following shielded signal lines connecting the actuators and sensors with the control cabinets must be protected by surge protective devices:

- Signal lines of the weather station and aircraft warning light on the sensor mast
- Signal lines routed between the nacelle and the pitch system in the hub
- Signal lines for the pitch system
- Signal lines to the inverter
- Signal lines to the fire extinguishing system

Signal lines of the weather station

The signal lines (4 – 20 mA interfaces) between the sensors of the weather station and the switchgear cabinet are routed from LPZ 0_B to LPZ 2 and can be protected by means of BLITZDUCTOR XT ML4 BE 24 or BLITZDUCTOR XT ML2 BE S 24 combined arresters (**Figure 9.16.10**). These space-saving combined arresters with LifeCheck feature protect two or four single cores sharing a common reference potential as well as unbalanced interfaces and allow direct or indirect shield earthing. Shield terminals with a flexible spring element for permanent low-impedance shield contact with the protected and unprotected side of the arrester are used for earthing the shield.

If the wind measurement equipment (anemometer) is fitted with a heating system, BLITZDUCTOR BVT ALD 36 combined arresters may be installed. These DIN rail mounted combined arresters are energy-coordinated with the surge protective devices of unearthed d.c. power supply systems (**Figure 9.16.10**).

Signal lines for the pitch system

An universal DEHNpatch DPA M CLE RJ45B 48 surge arrester can be used if information between the nacelle and the pitch system is exchanged via 100 MB Ethernet data lines. This arrester is designed for Industrial Ethernet and similar applications in structured cabling systems according to class E up to 250 MHz for all data services up to 48 V d.c. and protects four pairs (**Figure 9.16.11**).

Alternatively, a DEHNpatch DPA M CAT6 RJ45S 48 arrester can be used to protect the 100 MB Ethernet data lines. This surge protective device is a prewired standard patch cable with integrated surge arrester.

Figure 9.16.10 Protection of wind measurement equipment (anemometer)

Whether the signal lines for the pitch system must be protected by surge protective devices depends on the sensors used which may have different parameters depending on the manufacturer. If, for example, sensors supplied with 24 V d.c. or lower voltages are used, BLITZDUCTOR BXT ML4 BE 24 surge arresters are ideally suited to protect these signal lines. These arresters can be installed in conformity with the lightning protection zone concept at the boundaries from LPZ 0_A to LPZ 2 and higher. Surge protective devices should be installed on both sides, namely in the pitch system and in the controller.

Condition monitoring

The availability of wind turbines, especially that of offshore wind turbines, increasingly gains importance. Therefore, lightning current and surge arresters must be monitored for signs of pre-damage (condition monitoring).

The specific use of condition monitoring allows to plan service work, thus reducing costs.

BLITZDUCTOR XT arresters for information technology systems with integrated LifeCheck feature are a simple and ideal monitoring system that detects pre-damage at an early stage and allows to replace pre-damaged arresters in the next service interval. LifeCheck permanently monitors the status of the arresters free of potential since the LifeCheck status is read out via contactless RFID technology. Like an early warning system, LifeCheck reliably detects imminent electrical or thermal

Figure 9.16.11 Example of surge protective devices in a pitch system

Figure 9.16.12 Customer-specific testing in the impulse current laboratory

overload of the protection components. A stationary condition monitoring system allows condition-based maintenance of 10 BLITZDUCTOR XT arresters.

Two systems are available:

1. DRC MCM XT (**Figure 9.16.11**) – Compact DIN rail mounted multiple condition monitoring system for condition monitoring:
   - ➡ Condition monitoring of LifeCheck-equipped arresters
   - ➡ Cascaded system permanently monitors up to 150 arresters (600 signal cores)
   - ➡ Minimal wiring
   - ➡ Remote signalling via RS485 or remote signalling contacts (1 break and 1 make contact)
2. DRC SCM XT – Single condition monitoring system ideally suited for small-sized wind turbines with max. ten arresters:
   - ➡ Condition monitoring of LifeCheck-equipped arresters
   - ➡ Monitoring of up to 10 arresters (40 signal cores)
   - ➡ Minimal wiring
   - ➡ Remote signalling via remote signalling contact (1 break contact)

As is the case with the condition monitoring systems of the BLITZDUCTOR XT series, all arrester systems of the DEHNguard or DEHNblock series with the addition "FM" can be optionally monitored via a floating contact. In case of DEHNguard arresters with the addition "LI" (Lifetime Indication), the visual indication indicates three operating states, namely yellow (end of service life), green (fully functional) and red (faulty). If the yellow indicator flag appears, the module has reached about 80 % of its service life. In addition to the visual indication at the module, this signal to replace the arrester is also transmitted to the turbine controller via the remote signalling contact in the next service interval.

Laboratory tests according to IEC-61400-24

IEC 61400-24 (EN 61400-24) describes two basic methods to perform system-level immunity tests for wind turbines:

- ➡ When performing impulse current tests under operating conditions, impulse currents or partial lightning currents are injected into the individual lines of a control system while mains voltage is present. Thus, the equipment to be protected including all SPDs is subjected to an impulse current test.
- ➡ The second test method simulates the electromagnetic effects of the LEMP. To this end, the full lightning current is injected into the structure which discharges the lightning current and the behaviour of the electrical system is analysed by means of simulating the cabling under operating conditions as realistically as possible. The lightning current steepness is a decisive test parameter.

DEHN offers engineering and test services (**Figure 9.16.12**) for wind turbine manufacturers such as:

- ➡ Lightning current tests for bearings and gearboxes of the mechanical drive string
- ➡ High-current tests for the receptors and down conductors of rotor blades

- System-level immunity tests for important control systems such as pitch systems, wind sensors or aircraft warning lights
- Testing of customer-specific connection units

The IEC 61400-24 (EN 61400-24) standard recommends to carry out such system tests for important control systems.

Protection of cell sites (4G / LTE)

Besides voice communication, mobile data communication gained momentum with the commercial introduction of UMTS technology in 2003. Due to this increased demand for data volumes, the global demand for bandwidth also grew. The increased use of smartphones and other mobile devices pushes current conventional network spectrums to their limits.

The high investment costs for new network infrastructures and system technology as well as high maintenance and operating costs for existing cell sites are disadvantages mobile network operators using this modern and innovative technology have to deal with. Consequently, their aim is to efficiently reduce maintenance and operating costs and to provide an ever growing number of mobile phone users with considerably increased availability and reliability of mobile services.

Mobile network operators and system technology manufacturers worldwide increasingly use remote radio head/unit technology for UMTS (3G) and LTE (4G). Remote radio heads/units (RRHs/RRUs) are an enhancement of the third mobile radio generation.

Remote radio head technology is not only used for commercial mobile radio applications, but also for the digital radio systems of security authorities (BOS) such as police departments and rescue services since these systems require high reliability and availability.

Conventional cell sites

Conventional cell sites use coaxial cables, also referred to as waveguide cables. A clear disadvantage of this technology is the high transmission loss (up to 50 %), depending on the cable length and cross-sections of the high-frequency cables. Moreover, the complete radio transmission technology is integrated in the base station/radio base station (RBS). This requires permanent cooling of the technical equipment rooms and leads to an increased energy consumption and increased maintenance costs (**Figure 9.17.1**).

Cell sites with remote radio heads/units

Remote radio heads/units incorporate the high-frequency technology which was originally centrally integrated in the base station. The high-frequency signal is directly generated at the antenna and is then transmitted. Therefore, RRHs/RRUs are installed directly at the antennas, thus reducing loss and increasing the transmission speed. Another benefit is that less air-conditioning systems are required due to the self-cooling of the remote radio heads. Optical fibre cables allow to transmit data between the base station/radio base station and the remote radio heads/units up to 20 km. The use of remote system technology and modern small-sized base stations saves energy costs as well as lease and location-related costs due to the reduced number of technical equipment rooms (**Figure 9.17.1**).

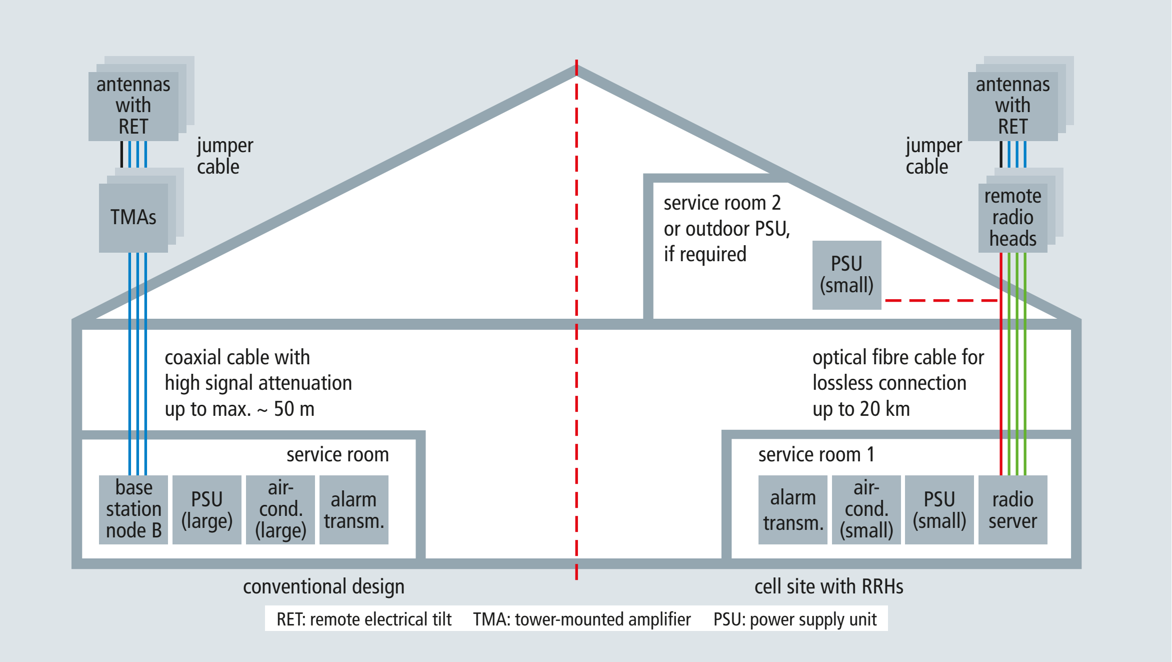


Figure 9.17.1 Comparison: Conventional cell site (left) and cell site with remote radio head technology (right)

External lightning protection

The antennas of the before mentioned systems are often installed on rented roof space. The antenna operator and the building owner usually agree that the placement of antennas must not present an additional risk for the building. For the lightning protection system this means that no partial lightning currents may enter the building in case of a lightning strike to the antenna tower since partial lightning currents inside the building would threaten the electrical and electronic devices (**Figure 9.17.2**).

Figure 9.17.3 shows an antenna tower with an isolated air-termination system.

The air-termination tip must be attached to the antenna tower by means of a supporting tube made of non-conductive material. The height of the air-termination tip depends on the antenna tower, possible electrical equipment of the antenna system and the base station (RBS) and must be selected in such a way that these elements are located in the protected volume of the air-termination system. In case of buildings with several antenna systems, several isolated air-termination systems must be installed.

Radio base stations (RBS) with DEHNvap CSP combined arresters

The power supply unit of the RBS must have a separate feeder cable that is independent from the power supply unit of the building. A separate power sub-distribution board / floor distributor should be provided for cell sites. Every sub-distribution board is equipped with lightning and surge arresters (type 1 combined arresters) as standard. In addition, a type 1 combined arrester is installed downstream of the meter panel, namely downstream of the fuses. To ensure energy coordination, surge protective devices (SPDs) from the same manufacturer should be used at both places of installation. Extensive laboratory tests at DEHN with power supply units from different manufacturers confirm that coordination of combined arresters such as DEHNvap CSP (CSP = Cell Site Protection) with the integrated input circuits of the power supply unit is essential.

DEHNvap CSP 3P 100 FM spark-gap-based combined arresters are used to protect the power supply unit (PSU) of a base station. These type 1 arresters are specifically designed for protecting power supply units in transmitting / receiving systems.

When using combined arresters, "disconnection selectivity" with respect to upstream fuses must be ensured. Only arresters with sufficient follow current extinction and limitation allow to avoid false tripping of system fuses and thus disconnection of the power supply unit.

Remote radio head / unit applications

Cell sites consist of:

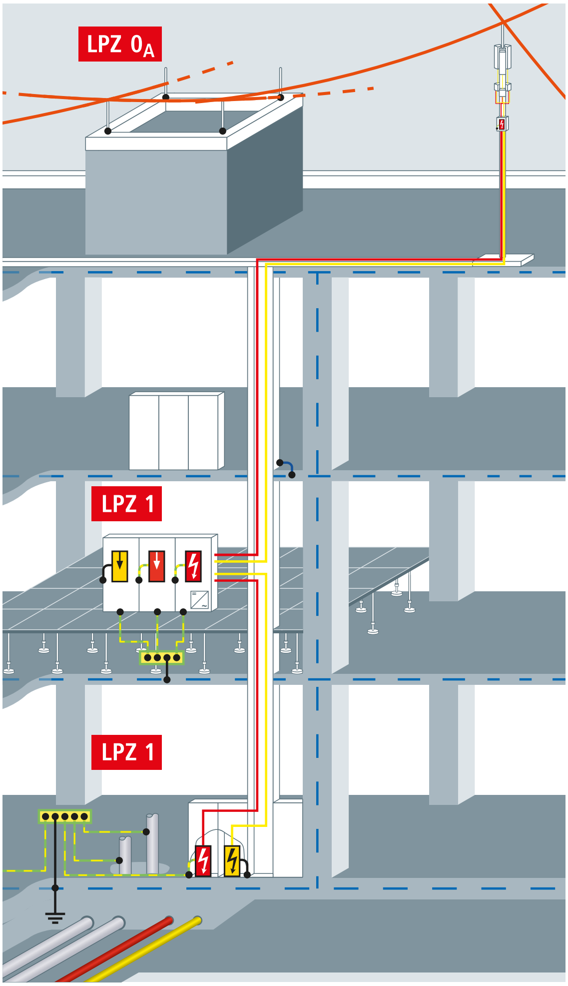


Figure 9.17.2 Basic design of the remote radio head / unit in case of roof-mounted systems

- Base station / radio base station (indoor or outdoor cabinet)
- Baseband unit / radio server
- Remote radio heads / units (RRHs / RRUs)

The remote radio heads / units (active system technology) require a separate 48 V d.c. power supply from the service room. To this end, shielded multi-wire copper cables with a cross-section of 6 to 16 mm^2 are typically used. In the majority of cases, these d.c. cables are installed outside the building up to the roof surface and the RRHs / RRUs or from the base station to the mast. Data communication between RRHs / RRUs and system technology is done via prewired glass fibre cables instead of the previously used cables with corrugated sheath.

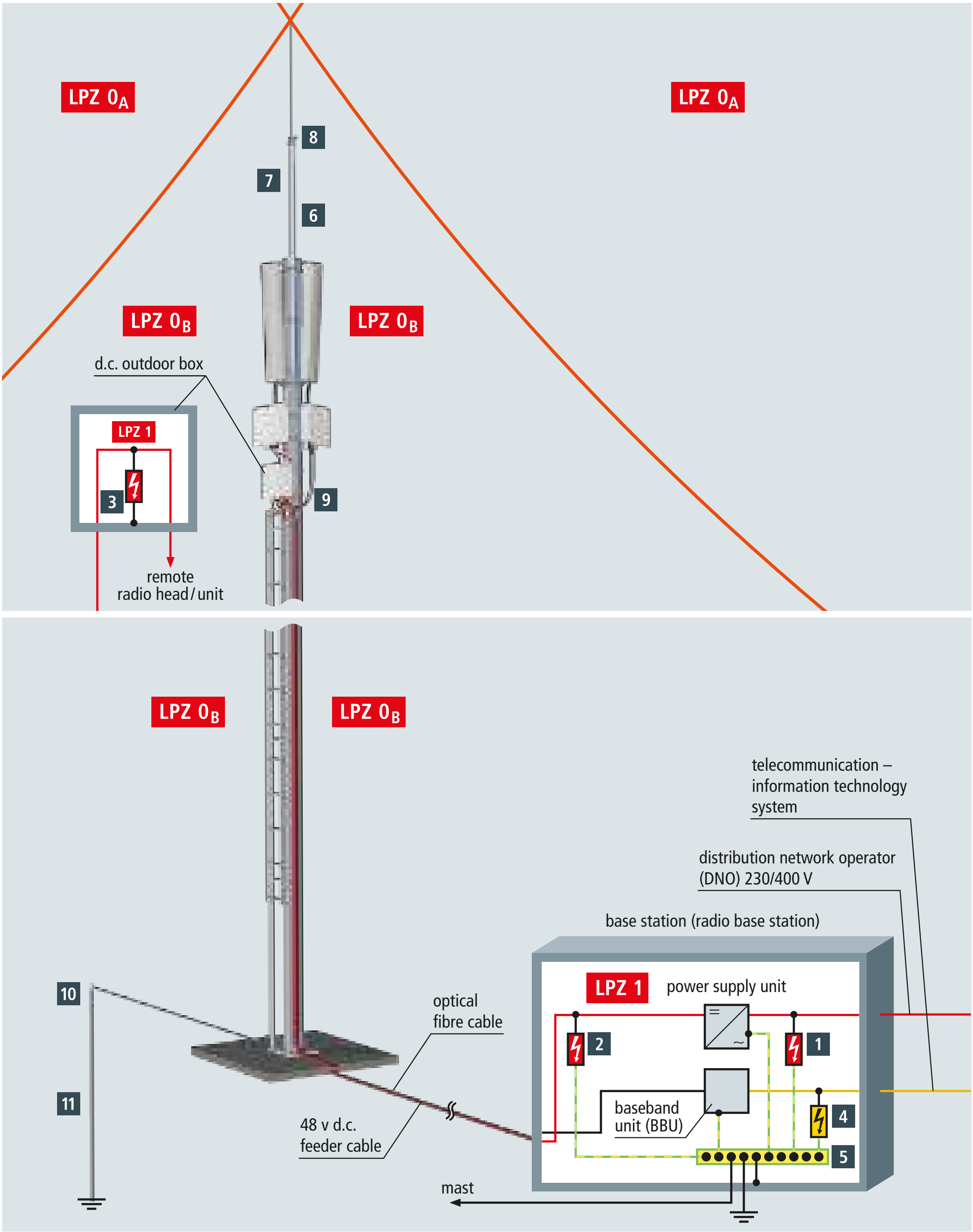


Figure 9.17.3 Remote radio head / unit and radio base station (RBS) in case of ground-mounted masts

No. in 9.17.3	Protection	Type	Part No.
a.c. power supply			
1	Base station (230/400 V a.c.)	DEHNvap CSP 3P 100 FM	900 360
d.c. power supply			
2	Power supply unit (48 V d.c.)	DEHNsecure DSE M 1 60 FM	971 126
3	Remote radio head (48 V d.c.)	DEHNsecure DSE M 2P 60 FM	971 226
Fixed-line connection			
4	Telecommunication lines	BLITZDUCTOR XT BXT ML4 B 180 + BXT BAS base part	920 310 920 300
External lightning protection			
5	Ground-mounted system / roof-mounted system	Equipotential bonding bar, 10 terminals	472 219
6	Ground-mounted system / roof-mounted system	HVI Conductor III	819 025
7	Ground-mounted system / roof-mounted system	GRP/Al supporting tube	105 300
8	Ground-mounted system / roof-mounted system	Terminal plate	301 339
9	Ground-mounted system / roof-mounted system	Pipe clamp for antennas	540 100
10	Ground-mounted system	Stainless steel terminal bracket	620 915
11	Ground-mounted system	Stainless steel earth rod	620 902

Table 9.17.1 Lightning and surge protection for cell sites

In case of both types of installation, the d.c. feeder cables and system technology are exposed to lightning currents in the event of a direct lightning strike.

Thus, lightning current and surge arresters must be capable of safely conducting lightning currents to the earth-termination system. To this end, type 1 lightning current arresters in conformity with EN 61643-11 (class I, IEC 61643-1/-11) are used. Only spark-gap-based type 1 arresters ensure reliable energy coordination with downstream protective circuits integrated in the input of terminal equipment. If spark gaps are used to protect base stations, power supply units and remote radio heads / units, lightning currents are prevented from entering system technology, thus providing maximum protection and ensuring availability of the station even under lightning conditions (**Figures 9.17.2 and 9.17.3**).

Customised solutions for 48 V d.c. remote radio heads / units (type 1 arresters)

D.c. arresters: Modular DEHNsecure 60 … (FM) type 1 lightning current arresters

RRHs / RRUs are centrally supplied with direct current from the service room. The shielded feeder cable must be integrated in the antenna earthing as per IEC 60728-11 (EN 60728-11) and, if a lightning protection system is installed on the building, as per IEC 62305-3 (EN 62305-3).

Type 1 d.c. arresters with a low voltage protection level that are specifically developed for RRH / RRU applications are installed in the d.c. indoor box near the power supply unit in the technical equipment room and in the d.c. outdoor box at the antenna mast. The d.c. box at the mast features a "1+1" circuit, meaning that the positive pole and cable shield are interconnected indirectly via a so-called total spark gap to prevent corrosion and stray currents. In the power supply unit, the positive pole is directly earthed and single-pole type 1 d.c. arresters are typically installed.

Prewired d.c. assembly systems (d.c. box) for indoor and outdoor installations with DEHNsecure DSE M 1 60 FM and DSE 2P 60 FM type 1 d.c. lightning current arresters ensure efficient protection. The voltage protection level U_p of the type 1 lightning current arresters must be lower than the dielectric strength of the system technology.

Benefits of the new d.c. arrester concept are, for example, enough leeway for future extensions of the site in case of nominal load currents up to 2000 A, no mains follow cur-

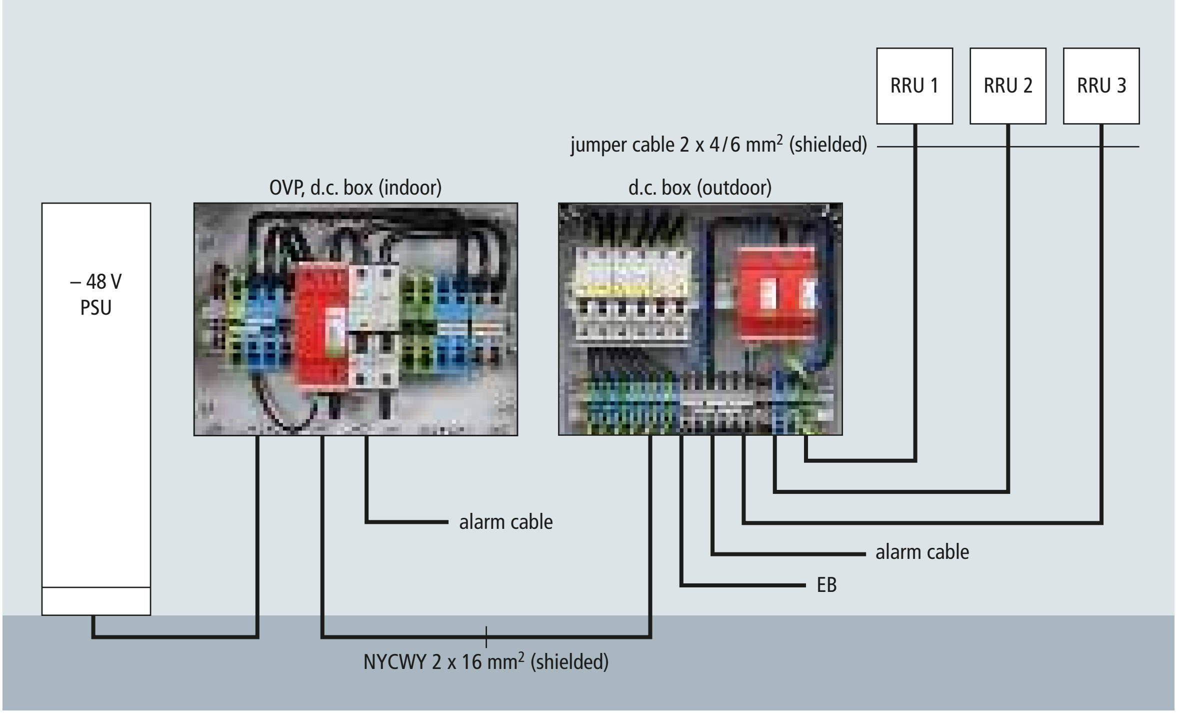


Figure 9.17.4 Basic circuit diagram of remote radio heads (RRHs) in case of physically separated functional equipotential bonding levels with d.c. box (outdoor) and DEHNsecure DSE M 2P 60 FM as well as with OVP box (indoor) and DEHNsecure DSE M 1 60 FM

rents up to max. 60 V d.c., no leakage currents and a high degree of protection for terminal equipment due to the low residual voltage of ≤ 0.4 kV at 5 kA (voltage protection level of 1.5 kV (10/350 μs)).

Figure 9.17.4 shows the protection concept for RRHs / RRUs in case of physically separated functional equipotential bonding levels.

Type 1 combined arresters for RRH / RRU installations

Figure 9.17.5 shows an example of a customised assembly system with a spark-gap-based type 1 arrester according to IEC 61643-1/11 (EN 61643-1/11).

The space-saving DEHNshield arrester with a width of only two modules has a maximum discharge capacity of 12.5 kA per pole (10/350 μs) and a voltage protection level U_p of 1.5 kV and is thus ideally suited for protecting terminal equipment. This assembly system allows to supply up to six RRHs / RRUs with a nominal voltage of 48 V d.c. (max. 60 V and max. 80 A) via glass fibre cables for data communication. Moreover, the design of the d.c. box ensures an extremely low wind load and easy installation on the mast.

Figure 9.17.5 RRH installation protected by a type 1 arrester in a typical installation environment

Figure 9.17.6 Prewired hybrid box for 48 V d.c. outdoor installations with DEHNguard type 2 arrester

Customised solutions for 48 V d.c. remote radio heads / units (type 2 arresters)

Type 2 assembly systems as per IEC 61439-1 (EN 61439-1) / IEC 61439-2 (EN 61439-2) are also used depending on the protection philosophy of mobile network operators and system manufacturers, technical specifications and country-specific conditions. Varistor-based type 2 arresters with an extremely low voltage protection level such as DEHNguard DG S 75 FM protect terminal equipment and are used for RRH / RRU installations with a nominal voltage up to 48 V d.c.

Figure 9.17.6 shows a prewired type 2 assembly system in the form of a hybrid box (d.c. box) for indoor and outdoor installations. The lockable glass-fibre reinforced (GRP) enclosure with an IP 66 degree of protection provides space for up to and including six RRHs / RRUs. All incoming and outgoing lines up to 48 V d.c. are wired on terminal blocks. This provides significant installation benefits for the installer, in particular in case of mast installation and retrofitting. For data communication, the d.c. hybrid box houses up to 12 LC Duplex adapters that accept the prewired glass fibre cable from the technical equipment room. These adapters are connected to the RRHs / RRUs via so-called jumper cables by the most direct path. Easy-to-install accessories such as wall and mast brackets with tensioning strap ensure easy and fast installation.

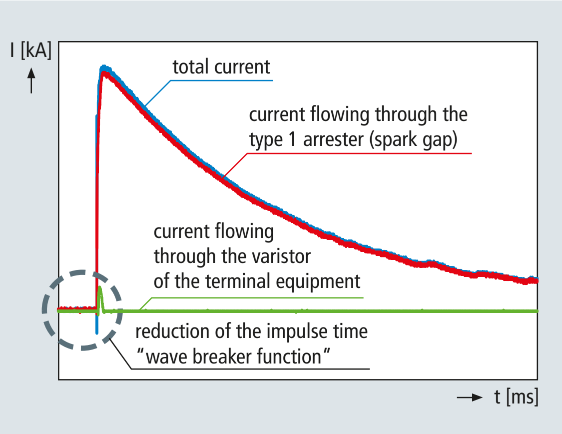


Figure 9.17.7 Spark-gap-based type 1 arrester (typical characteristic curve)

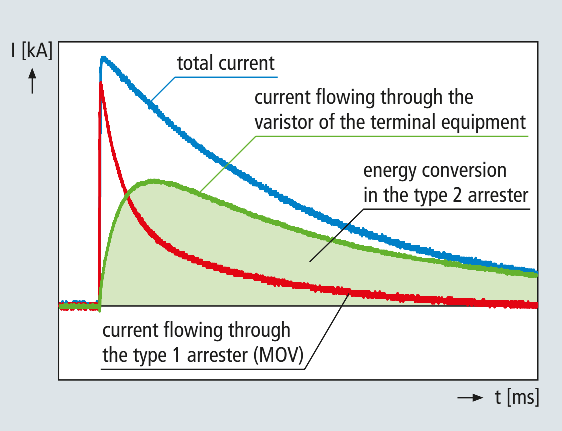


Figure 9.17.8 Varistor-based type 1 arrester (typical characteristic curve)

Comparison of the protective effect of spark-gap-based type 1 arresters with that of varistor-based type 1 arresters

Energy coordination with terminal equipment to be protected is an important advantage of spark gaps used in type 1 arresters (10/350 µs) over MOVs (metal oxide varistors).

A so-called "wave breaker function" is achieved by the fast triggering of the spark gap within a matter of microseconds, meaning that almost no current flows into the terminal equipment to be protected after the spark gap has ignited (**Figure 9.17.7**). Thus, a relatively small amount of energy enters the terminal equipment even in case of extremely high impulse currents. This energy, however, is uncritical for the protective circuit integrated in the input of the terminal equipment.

If MOV-based surge protective devices are used, the current flows into the terminal equipment to be protected over the entire impulse duration. In many cases, the connected a.c./d.c. power supply unit and system technology are damaged and in the worst case completely destroyed (**Figure 9.17.8**).

System tests with mobile radio equipment from different manufacturers clearly show that only spark gaps ensure the required degree of protection in this field of application.

Lightning and surge protection for rooftop photovoltaic systems

At present, about one million PV systems are installed in Germany. Based on the fact that self-generated electricity is generally cheaper and provides a high degree of electrical independence from the grid, PV systems will become an integral part of electrical installations in the future. However, these systems are exposed to all weather conditions and must withstand them over decades.

The cables of PV systems frequently enter the building and extend over long distances until they reach the grid connection point.

Lightning discharges cause field-based and conducted electrical interference. This effect increases in relation with increasing cable lengths or conductor loops. Surges do not only damage the PV modules, inverters and their monitoring electronics, but also devices in the building installation. More importantly, production facilities of industrial buildings may also easily be damaged and production may come to a halt.

If surges are injected into systems that are far from the power grid, which are also referred to as stand-alone PV systems, the operation of equipment powered by solar electricity (e.g. medical equipment, water supply) may be disrupted.

Necessity of a rooftop lightning protection system

The energy released by a lightning discharge is one of the most frequent causes of fire. Therefore, personal and fire protection is of paramount importance in case of a direct lightning strike to the building.

At the design stage of a PV system, it is evident whether a lightning protection system is installed on a building. Some countries' building regulations require that public buildings (e.g. places of public assembly, schools and hospitals) be equipped with a lightning protection system. In case of industrial or private buildings it depends on their location, type of construction and utilisation whether a lightning protection system must be installed. To this end, it must be determined whether lightning strikes are to be expected or could have severe consequences. Structures in need of protection must be provided with permanently effective lightning protection systems.

According to the state of scientific and technical knowledge, the installation of PV modules does not increase the risk of a lightning strike. Therefore, the request for lightning protection measures cannot be derived directly from the mere existence of a PV system. However, substantial lightning interference may be injected into the building through these systems. Therefore, it is necessary to determine the risk resulting from a lightning strike as per IEC 62305-2 (EN 62305-2) and to take the results from this risk analysis into account when installing the PV system. For this purpose, DEHN offers the DEHNsupport Toolbox software which allows to determine the risk. A risk analysis performed by means of this software provides a result which is understood by all parties involved. The software compares the risk with the technical expenditure and provides economically optimised protection measures.

Section 4.5 (Risk Management) of Supplement 5 of the German DIN EN 62305-3 standard describes that a lightning protection system designed for class of LPS III (LPL III) meets the usual requirements for PV systems. In addition, adequate lightning protection measures are listed in the German VdS 2010 guideline (Risk-oriented lightning and surge protection) published by the German Insurance Association. This guideline also requires that LPL III and thus a lightning protection system according to class of LPS III be installed for rooftop PV systems (> 10 kW$_p$) and that surge protection measures be taken.

As a general rule, rooftop photovoltaic systems must not interfere with the existing lightning protection measures.

Necessity of surge protection for PV systems

In case of a lightning discharge, surges are induced on electrical conductors. Surge protective devices (SPDs) which must be installed upstream of the devices to be protected on the a.c., d.c. and data side have proven very effective in protecting electrical systems from these destructive voltage peaks. Section 9.1 of the CENELEC CLC/TS 50539-12 standard (Selection and application principles – SPDs connected to photovoltaic installations) calls for the installation of surge protective devices unless a risk analysis demonstrates that SPDs are not required. According to the IEC 60364-4-44 (HD 60364-4-44) standard, surge protective devices must also be installed for buildings without external lightning protection system such as commercial and industrial buildings, e.g. agricultural facilities. Supplement 5 of the German DIN EN 62305-3 standard provides a detailed description of the types of SPDs and their place of installation.

Cable routing of PV systems

Cables must be routed in such a way that large conductor loops are avoided. This must be observed when combining the d.c. circuits to form a string and when interconnecting several strings. Moreover, data or sensor lines must not be routed over several strings and form large conductor loops with the string lines. This must also be observed when connecting the inverter to the grid connection. For this reason, the power (d.c. and a.c.) and data lines (e.g. radiation sensor, yield monitoring) must be routed together with the equipotential bonding conductors along their entire route.

Earthing of PV systems

PV modules are typically fixed on metal mounting systems. The live PV components on the d.c. side feature double or reinforced insulation (comparable to the previous protective

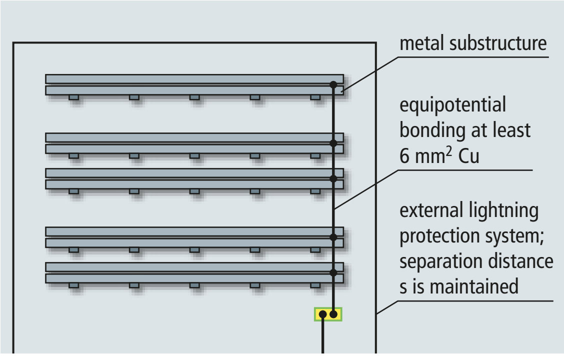


Figure 9.18.1 Functional earthing of the mounting systems if no external lightning protection system is installed or the separation distance is maintained (DIN EN 62305-3, Supplement 5)

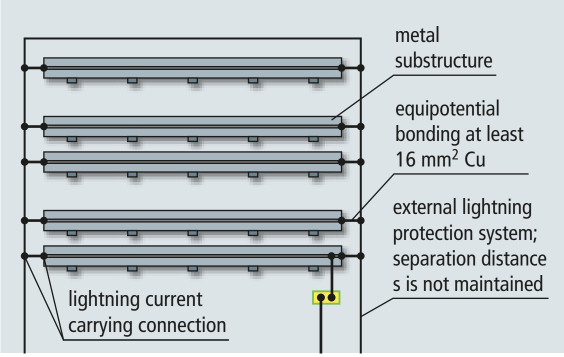


Figure 9.18.2 Lightning equipotential bonding for the mounting systems if the separation distance is not maintained

Figure 9.18.3 UNI earthing clamp: A stainless steel intermediate element prevents contact corrosion, thus establishing reliable long-term connections between different conductor materials

insulation) as required in the IEC 60364-4-41 standard. The combination of numerous technologies on the module and inverter side (e.g. with or without galvanic isolation) results in different earthing requirements. Moreover, the insulation monitoring system integrated in the inverters is only permanently effective if the mounting system is connected to earth. Information on the practical implementation is provided in Supplement 5 of the German DIN EN 62305-3 standard. The metal substructure is functionally earthed if the PV system is located in the protected volume of the air-termination systems and the separation distance is maintained. Section 7 of Supplement 5 requires copper conductors with a cross-section of at least 6 mm^2 or equivalent for functional earthing (**Figure 9.18.1**). The mounting rails also have to be permanently interconnected by means of conductors of this cross-section. If the mounting system is directly connected to the external lightning protection system due to the fact that the separation distance s cannot be maintained, these conductors become part of the lightning equipotential bonding system. Consequently, these elements must be capable of carrying lightning currents. The minimum requirement for a lightning protection system designed for class of LPS III is a copper conductor with a cross-section of 16 mm^2 or equivalent. Also in this case, the mounting rails must be permanently interconnected by means of conductors of this cross-section (**Figure 9.18.2**). The functional earthing / lightning equipotential bonding conductor should be routed in parallel and as close as possible to the d.c. and a.c. cables / lines.

UNI earthing clamps (**Figure 9.18.3**) can be fixed on all common mounting systems. They connect, for example, copper conductors with a cross-section of 6 or 16 mm^2 and bare round wires with a diameter from 8 to 10 mm to the mounting system in such a way that they can carry lightning currents. The integrated stainless steel (V4A) contact plate ensures corrosion protection for the aluminium mounting systems.

Separation distance s as per IEC 62305-3 (EN 62305-3)

A certain separation distance s must be maintained between a lightning protection system and a PV system. It defines the distance required to avoid uncontrolled flashover to adjacent metal parts resulting from a lightning strike to the external lightning protection system. In the worst case, such an uncontrolled flashover can set a building on fire. In this case, damage to the PV system becomes irrelevant. Details on the calculation of the separation distance s can be found in chapter 5.6 and can be easily and quickly calculated by means of the DEHN Distance Tool software (chapter 3.3.2).

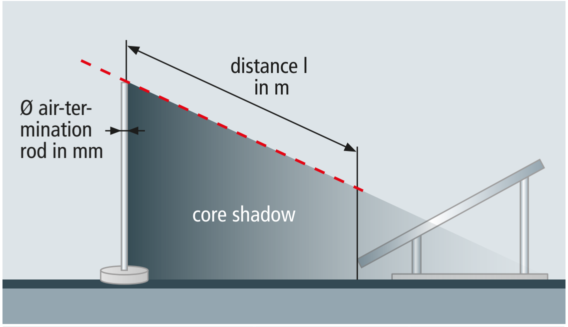
Core shadows on solar cells

The distance between the solar generator and the external lightning protection system is absolutely essential to prevent excessive shading. Diffuse shadows cast by, for example overhead lines, do not significantly affect the PV system and the yield. However, in case of core shadows, a dark clearly outlined shadow is cast on the surface behind an object, changing the current flowing through the PV modules. For this reason, solar cells and the associated bypass diodes must not be influenced by core shadows. This can be achieved by maintaining a sufficient distance. For example, if an air-termination rod with a diameter of 10 mm shades a module, the core shadow is steadily reduced as the distance from the module increases. After 1.08 m only a diffuse shadow is cast on the module (**Figure 9.18.4**). Annex A of Supplement 5 of the German DIN EN 62305-3 standard provides more detailed information on the calculation of core shadows.

Special surge protective devices for the d.c. side of photovoltaic systems

The U/I characteristics of photovoltaic current sources are very different from that of conventional d.c. sources: They have a non-linear characteristic (**Figure 9.18.5**) and cause long-term persistence of ignited arcs. This unique nature of PV current sources does not only require larger PV switches and PV fuses, but also a disconnector for the surge protective device which is adapted to this unique nature and capable of coping with PV currents. Supplement 5 of the German DIN EN 62305-3 standard (subsection 5.6.1, Table 1) describes the selection of adequate SPDs.

To facilitate the selection of type 1 SPDs, **Tables 9.18.1 and 9.18.2** shown the required lightning impulse current carrying capability I_{imp} depending on the class of LPS, number of down conductors of the external lightning protection systems as well as the SPD type (voltage-limiting varistor-based arrester or voltage-switching spark-gap-based arrester). SPDs which comply with the applicable EN 50539-11 standard must be used. Subsection 9.2.2.7 of CENELEC CLC/TS 50539-12 also refers to this standard.



Ø air-termination rod	x factor	= distance l
10 mm	108	1.08 m
16 mm	108	1.76 m

Figure 9.18.4 Distance between the module and the air-termination rod required to prevent core shadows

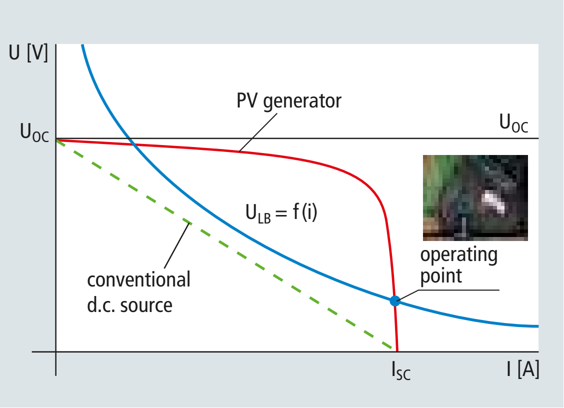


Figure 9.18.5 Source characteristic of a conventional d.c. source versus the source characteristic of a PV generator. When switching PV sources, the source characteristic of the PV generator crosses the arc voltage range

Class of LPS and max. lightning current (10/350 µs)		**Number of down conductors of the external lightning protection system**			
		< 4		**≥ 4**	
		Values for the voltage-limiting type 1 SPDs or type 1 combined SPDs (series connection) based on a selection of $I_{8/20}$ (8/20 µs) and $I_{10/350}$ (10/350 µs)			
		$I_{SPD1} = I_{SPD2}$ $I_{8/20} / I_{10/350}$	$I_{SPD3} = I_{SPD1} + I_{SPD2} = I_{total}$ $I_{8/20} / I_{10/350}$	$I_{SPD1} = I_{SPD2}$ $I_{8/20} / I_{10/350}$	$I_{SPD3} = I_{SPD1} + I_{SPD2} = I_{total}$ $I_{8/20} / I_{10/350}$
I or unknown	200 kA	17/10	34/20	10/5	20/10
II	150 kA	12.5/7.5	25/15	7.5/3.75	15/7.5
III and IV	100 kA	8.5/5	17/10	5/2.5	10/5

Table 9.18.1 Selection of the minimum discharge capacity of voltage-limiting type 1 SPDs (varistors) or type 1 combined SPDs (series connection of varistors and spark gaps); according to CENELEC CLC/TS 50539-12 (Table A.1)

Class of LPS and max. lightning current (10/350 μs)		Number of down conductors of the external lightning protection system			
		< 4		≥ 4	
		Values for the voltage-switching type 1 SPDs or type 1 combined SPDs (parallel connection)			
		$I_{SPD1} = I_{SPD2}$ I_{imp}	$I_{SPD3} = I_{SPD1} + I_{SPD2} = I_{total}$ I_{imp}	$I_{SPD1} = I_{SPD2}$ I_{imp}	$I_{SPD3} = I_{SPD1} + I_{SPD2} = I_{total}$ I_{imp}
I or unknown	200 kA	25	50	12.5	25
II	150 kA	18.5	37.5	9	18
III and IV	100 kA	12.5	25	6.25	12.5

Table 9.18.2 Selection of the minimum discharge capacity of voltage-switching type 1 SPDs (spark gaps) or type 1 combined SPDs (parallel connection of varistors and spark gaps); according to CENELEC CLC/TS 50539-12 (Table A.2)

Figure 9.18.6 DEHNcombo YPV SCI type 1 combined arrester for protecting photovoltaic systems from surges and partial lightning currents

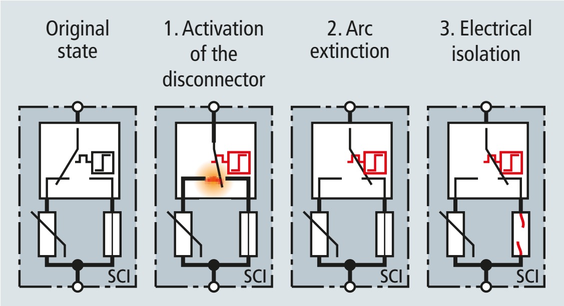


Figure 9.18.7 Switching phases of the three-step d.c. switching device integrated in DEHNguard M YPV SCI … (FM)

Figure 9.18.8 DEHNlimit PV 1000 V2 spark-gap-based type 1 combined arrester

Type 1 d.c. arrester for use in PV systems: Multipole type 1 + type 2 combined d.c. arrester, DEHNcombo YPV SCI (FM)

With their integrated SCI technology, DEHNcombo YPV SCI (FM) combined arresters (**Figure 9.18.6**) fulfil the above mentioned requirements. In addition to the proven fault-resistant Y circuit, DEHNcombo YPV SCI (FM) features a three-step d.c. switching device (SCI technology). This d.c. switching device consists of a combined disconnection and short-circuiting device with Thermo Dynamic Control and a fuse in the bypass path. This circuit (**Figure 9.18.7**) safely disconnects the arrester from the generator voltage in case of an overload and reliably extinguishes d.c. arcs. Thus, DEHNcombo YPV SCI (FM) allows to protect PV generators up to 1000 A without additional backup fuse. This arrester combines a lightning current arrester and a surge arrester in a single device, thus ensuring efficient protection of terminal equipment. With its discharge capacity I_{total} of 12.5 kA (10/350 μs), it can be flexibly used for the highest classes of LPS. DEHNcombo YPV SCI (FM) is available for voltages U_{CPV} of 600 V, 1000 V and 1500 V and has a width of only 4 modules. Therefore, DEHNcombo YPV SCI (FM) is the ideal type 1 combined arrester for use in photovoltaic power supply systems.

Voltage-switching spark-gap-based type 1 SPDs, for example DEHNlimit PV 1000 V2 (**Figure 9.18.8**), are another power-

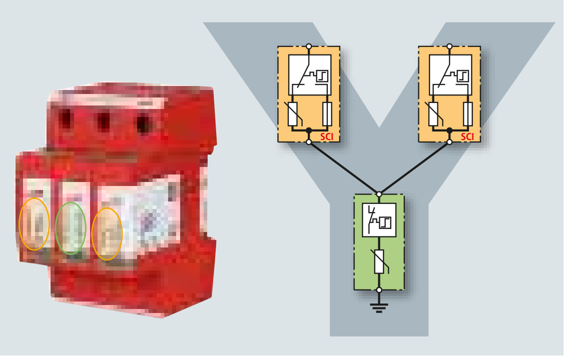


Figure 9.18.9 Modular DEHNguard M YPV SCI … (FM) type 2 surge arrester with fault-resistant Y circuit and three-step d.c. switching device

Figure 9.18.10 Ready-to-install type 2 DEHNcube YPV SCI 1000 1M surge arrester

ful technology that allows to discharge partial lightning currents in case of d.c. PV systems. Thanks to its spark gap technology and a d.c. extinction circuit which allow to efficiently protect downstream electronic systems, this arrester series has an extremely high lightning current discharge capacity I_{total} of 50 kA (10/350 µs) which is unique on the market.

Type 2 d.c. arrester for use in PV systems: DEHNguard M YPV SCI … (FM) and DEHNcube YPV SCI …

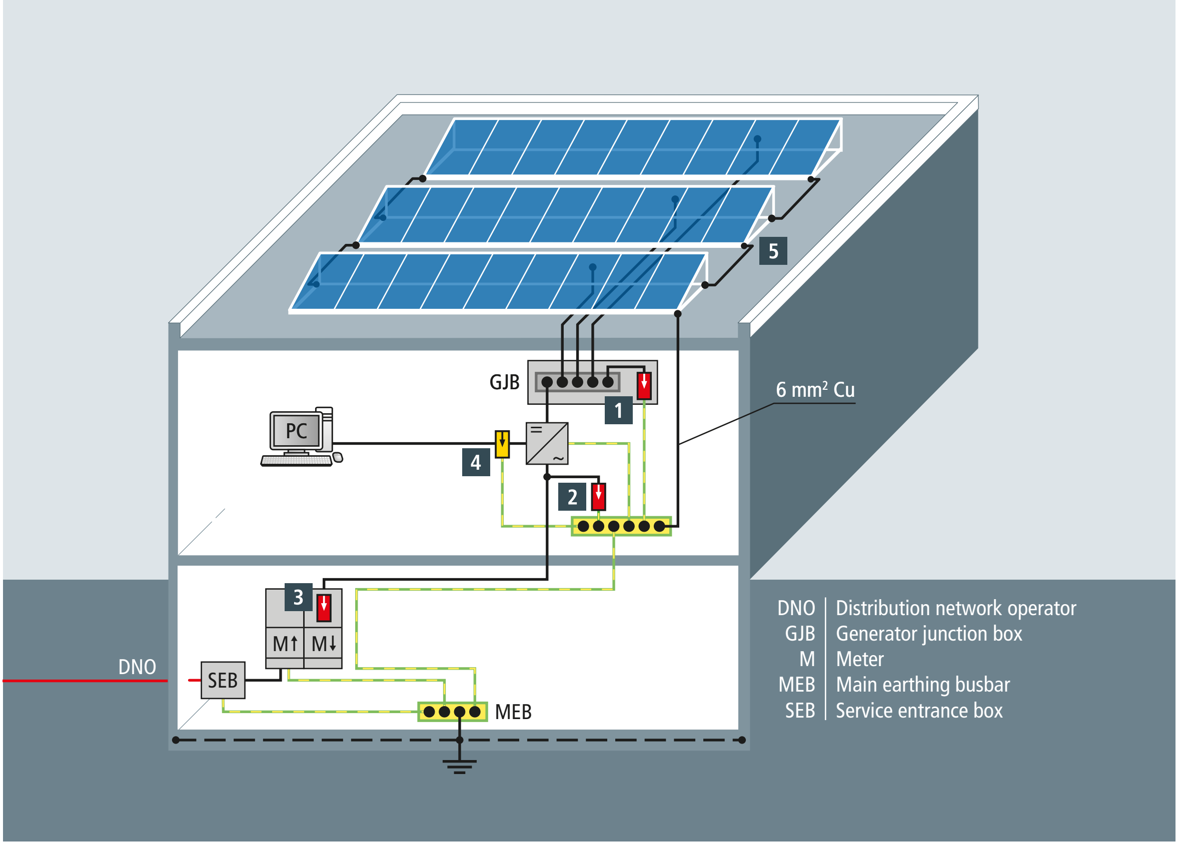
Reliable operation of SPDs in d.c. PV circuits is also indispensable when using type 2 surge protective devices. To this end, the DEHNguard M YPV SCI … (FM) and DEHNcube YPV SCI … surge arresters also feature a fault-resistant Y protective circuit and the SCI technology (**Figure 9.18.9 and 9.18.10**) and are also connected to PV generators up to 1000 A without additional backup fuse.

Figure 9.18.11 DEHNguard type 2 SPD integrated in the inverter for the a.c. and d.c. side

The numerous technologies combined in these arresters prevent damage to the surge protective device due to insulation faults in the PV circuit, the risk of fire of an overloaded arrester and puts the arrester in a safe electrical state without disrupting the operation of the PV system. Thanks to the protective circuit, the voltage-limiting characteristic of varistors can be fully used even in the d.c. circuits of PV systems. In addition, the permanently active surge protective device minimises numerous small voltage peaks. Thus, the SCI technology increases the service life of the entire d.c.-side PV system.

Selection of SPDs according to the voltage protection level U_p

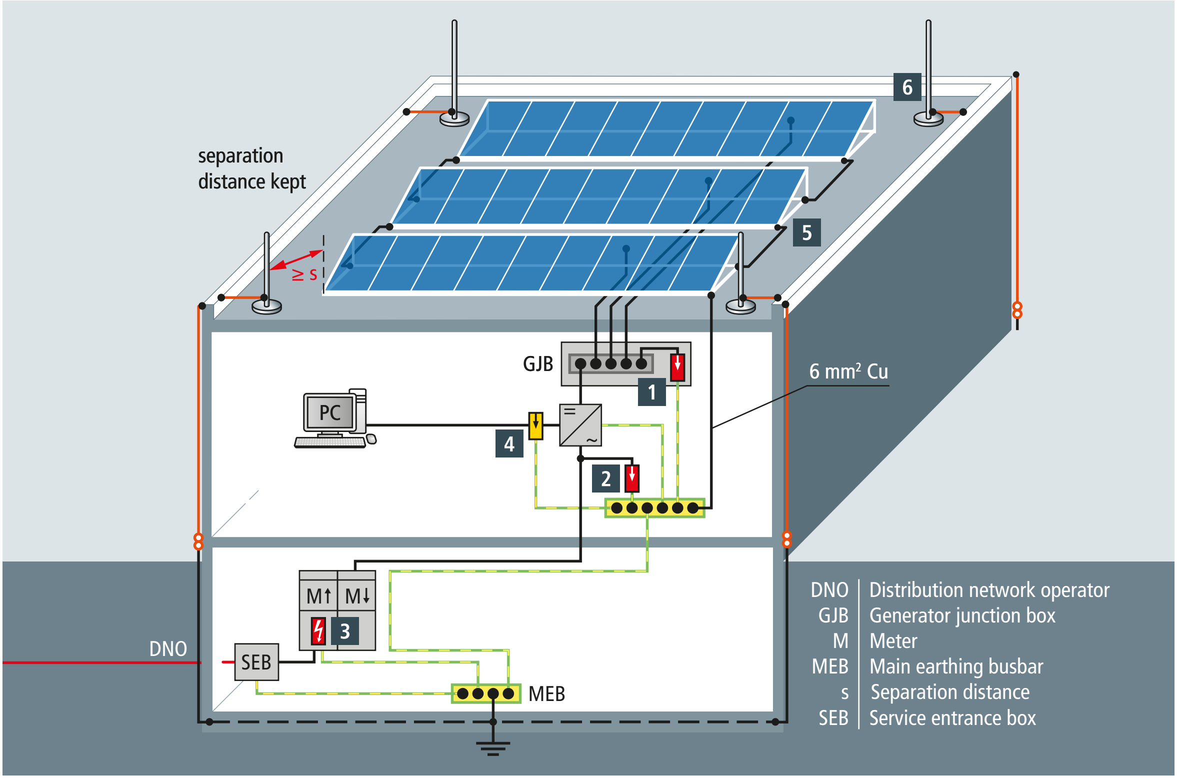
The operating voltage on the d.c. side of PV systems differs from system to system. At present, values up to 1500 V d.c. are possible. Consequently, the dielectric strength of terminal equipment also differs. To ensure that the PV system is reliably protected, the voltage protection level U_p of the SPD must be lower than the dielectric strength of the PV system it is supposed to protect. The CENELEC CLC/TS 50539-12 standard requires that U_p is at least 20 % lower than the dielectric strength of the PV system. Type 1 or type 2 SPDs must be energy-coordinated with the input of terminal equipment. If SPDs are already integrated in terminal equipment, coordination between the type 2 SPD and the input circuit of terminal equipment is ensured by the manufacturer (**Figure 9.18.11**).



DNO	Distribution network operator
GJB	Generator junction box
M	Meter
MEB	Main earthing busbar
SEB	Service entrance box

No. in Fig.		SPD * FM = Floating remote signalling contact	Part No.
d.c. input of the inverter			
1	Per MPPT	DEHNguard DG M YPV SCI 1000 FM *	952 515
	For 1 MPPT	DEHNcube DCU YPV SCI 1000 1M	900 910
	For 2 MPPTs	DEHNcube DCU YPV SCI 1000 2M	900 920
a.c. output of the inverter			
2	TN-S system	DEHNguard DG M TNS 275 FM *	952 405
Low-voltage input			
3	TN-C system	DEHNguard DG M TNC CI 275 FM *	952 309
	TN-S system	DEHNguard DG M TNS CI 275 FM *	952 406
	TT system	DEHNguard DG M TT CI 275 FM *	952 327
Data interface			
4	Two pairs, even with different operating voltages up to 180 V	BLITZDUCTOR BXTU ML4 BD 0-180 + BXT BAS base part	920 349 + 920 300
Functional earthing			
5	Functional equipotential bonding	UNI earthing clamp	540 250

Figure 9.18.12 Building without external LPS – situation A (Supplement 5 of the DIN EN 62305-3 standard)



DNO	Distribution network operator
GJB	Generator junction box
M	Meter
MEB	Main earthing busbar
s	Separation distance
SEB	Service entrance box

No. in Fig.		SPD * FM = Floating remote signalling contact	Part No.
d.c. input of the inverter			
1	Per MPPT	DEHNguard DG M YPV SCI 1000 FM *	952 515
	For 1 MPPT	DEHNcube DCU YPV SCI 1000 1M	900 910
	For 2 MPPTs	DEHNcube DCU YPV SCI 1000 2M	900 920
a.c. output of the inverter			
2	TN-S system	DEHNguard DG M TNS 275 FM *	952 405
Low-voltage input			
3	TN-C system	DEHNventil DV M TNC 255 FM *	951 305
	TN-S system	DEHNventil DV M TNS 255 FM *	951 405
	TT system	DEHNventil DV M TT 255 FM *	951 315
Data interface			
4	Two pairs, even with different operating voltages up to 180 V	BLITZDUCTOR BXTU ML4 BD 0-180 + BXT BAS base part	920 349 + 920 300
Functional earthing / External lightning protection system			
5	Functional equipotential bonding	UNI earthing clamp	540 250
6	Air-termination system	Air-termination rod with concrete base (8.5 kg)	101 000 + 102 075

Figure 9.18.13 Building with external LPS and sufficient separation distance – situation B (Supplement 5 of the DIN EN 62305-3 standard)

Figure 9.18.14 Determination of the protected volume using the protective angle method

Application examples:

Building without external lightning protection system (situation A)

Figure 9.18.12 shows the surge protection concept for a PV system installed on a building without external lightning protection system. Dangerous surges enter the PV system due to inductive coupling resulting from nearby lightning strikes or travel from the power supply system through the service entrance to the consumer's installation. Type 2 SPDs are to be installed at the following locations:

- d.c. side of the modules and inverters
- a.c. output of the inverter
- Main low-voltage distribution board
- Wired communication interfaces

Every d.c. input (MPP) of the inverter must be protected by a type 2 surge protective device, for example DEHNguard M YPV SCI … (FM), that reliably protects the d.c. side of PV systems. The CENELEC CLC/TS 50539-12 standard requires that an additional type 2 d.c. arrester be installed on the module side if the distance between the inverter input and the PV generator exceeds 10 m.

The a.c. outputs of the inverters are sufficiently protected if the distance between the PV inverters and the place of installation of the type 2 arrester at the grid connection point (low-voltage infeed) is less than 10 m. In case of greater cable lengths, an additional type 2 surge protective device, for example DEHNguard M … 275, must be installed upstream of the a.c. input of the inverter as per CENELEC CLC/TS 50539-12.

Moreover, a type 2 DEHNguard M … CI 275 (FM) surge protective device must be installed upstream of the meter of the low-voltage infeed. CI (Circuit Interruption) stands for a coordinated fuse integrated in the protective path of the arrester, allowing the arrester to be used in the a.c. circuit without additional backup fuse. DEHNguard M … CI 275 (FM) is available for every low-voltage system configuration (TN-C, TN-S, TT).

If inverters are connected to data and sensor lines to monitor the yield, suitable surge protective devices are required. BLITZDUCTOR XTU, which features terminals for two pairs, for example for incoming and outgoing data lines, can be used for data systems based on RS 485.

Building with external lightning protection system and sufficient separation distance s (situation B)

Figure 9.18.13 shows the surge protection concept for a PV system with external lightning protection system and sufficient separation distance s between the PV system and the external lightning protection system.

The primary protection goal is to avoid damage to persons and property (building fire) resulting from a lightning strike. In this context, it is important that the PV system does not interfere with the external lightning protection system. Moreover, the PV system itself must be protected from direct lightning strikes. This means that the PV system must be installed in the protected volume of the external lightning protection system. This protected volume is formed by air-termination systems (e.g. air-termination rods) which prevent direct lightning strikes to the PV modules and cables. The protective angle method (**Figure 9.18.14**) or rolling sphere method (**Figure 9.18.15**) as described in subsection 5.2.2 of the IEC 62305-3 (EN 62305-3) standard may be used to determine this protected volume. A certain separation distance s must be maintained between all conductive parts of the PV system and the lightning protection system. In this context,

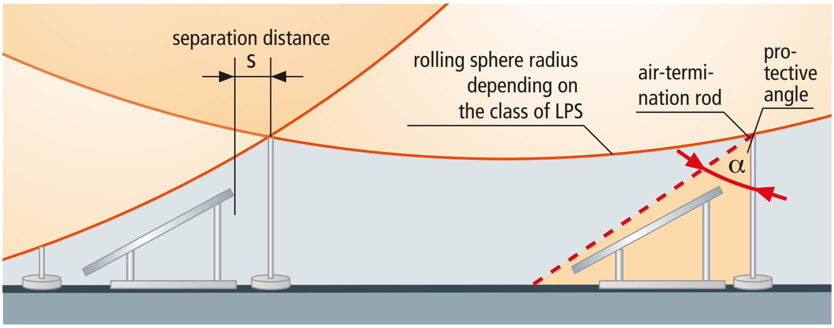


Figure 9.18.15 Rolling sphere method versus protective angle method for determining the protected volume

Figure 9.18.16 DEHNcube YPV SCI 1000 1M type 2 arrester for protecting inverters (1 MPPT)

core shadows must be prevented by, for example, maintaining a sufficient distance between the air-termination rods and the PV module.

Lightning equipotential bonding is an integral part of a lightning protection system. It must be implemented for all conductive systems and lines entering the building which may carry lightning currents. This is achieved by directly connecting all metal systems and indirectly connecting all energised systems via type 1 lightning current arresters to the earth-termination system. Lightning equipotential bonding should be implemented as close as possible to the entrance point into the building to prevent partial lightning currents from entering the building. The grid connection point must be protected by a multipole spark-gap-based type 1 SPD, for example a type 1 DEHNventil M … 255 combined arrester. This arrester combines a lightning current arrester and a surge arrester in a single device. If the cable lengths between the arrester and the inverter are less than 10 m, sufficient protection is provided. In case of greater cable lengths, additional type 2 DEHNguard M surge protective devices must be installed upstream of the a.c. input of the inverters as per CENELEC CLC/TS 50539-12.

Every d.c. input of the inverter must be protected by a type 2 PV arrester, for example DEHNcube YPV SCI … (**Figure 9.18.16**). This also applies to transformerless devices. If the inverters are connected to data lines, for example to monitor the yield, surge protective devices must be installed to protect data transmission. For this purpose, BLITZDUCTOR XTU with actiVsense technology can be provided for lines with analogue signal and data bus systems such as RS485. It automatically detects the operating voltage of the useful signal and adjusts the voltage protection level to this operating voltage.

High-voltage-resistant, insulated HVI Conductor

Another possibility to maintain the separation distance s is to use high-voltage-resistant, insulated HVI Conductors which allow to maintain a separation distance s up to 0.9 m in air. HVI Conductors may directly contact the PV system downstream of the sealing end range. More detailed information on the application and installation of HVI Conductors is provided in this Lightning Protection Guide or in the relevant installation instructions.

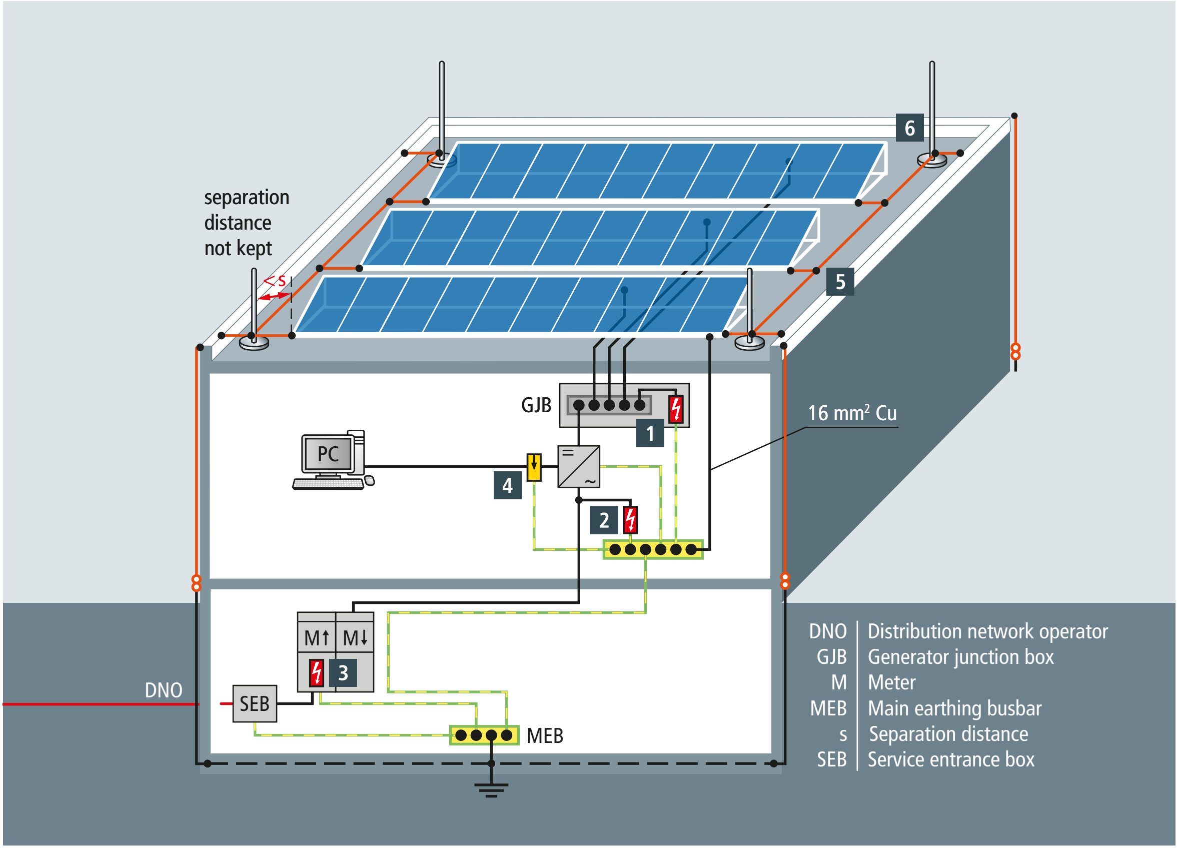
Building with external lightning protection system with insufficient separation distance s (situation C)

If the roofing is made of metal or is formed by the PV system itself, the separation distance s cannot be maintained. The metal components of the PV mounting system must be connected to the external lightning protection system in such a way that they can carry lightning currents (copper conductor with a cross-section of at least 16 mm^2 or equivalent). This means that lightning equipotential bonding must also be implemented for the PV lines entering the building from the outside (**Figure 9.18.17**). According to Supplement 5 of the German DIN EN 62305-3 standard and the CENELEC CLC/TS 50539-12 standard, d.c. lines must be protected by a type 1 SPD for PV systems.

For this purpose, a type 1 and type 2 DEHNcombo YPV SCI (FM) combined arrester is used. Lightning equipotential bonding must also be implemented in the low-voltage infeed. If the PV inverter(s) is (are) situated more than 10 m from the type 1 SPD installed at the grid connection point, an additional type 1 SPD must be installed on the a.c. side of the inverter(s) (e.g. type 1 + type 2 DEHNshield ... 255 combined arrester). Suitable surge protective devices must also be installed to protect the relevant data lines for yield monitoring. BLITZDUCTOR XTU surge protective devices are used to protect data systems, for example based on RS 485.

PV systems with microinverters

Microinverters require a different surge protection concept. To this end, the d.c. line of a module or a pair of modules is directly connected to the small-sized inverter. In this process, unnecessary conductor loops must be avoided. Inductive coupling into such small d.c. structures typically only has a low energetic destruction potential. The extensive cabling of a PV system with microinverters is located on the a.c. side (**Figure 9.18.18**). If the microinverter is directly fitted at the module, surge protective devices may only be installed on the a.c. side:



No. in Fig.		SPD * FM = Floating remote signalling contact	Part No.
d.c. input of the inverter			
1	Per MPPT	DEHNcombo DCB YPV SCI 1000 FM *	900 066
a.c. output of the inverter			
2	TN-S system	DEHNshield DSH TNS 255	941 400
Low-voltage input			
3	TN-C system	DEHNventil DV M TNC 255 FM *	951 305
	TN-S system	DEHNventil DV M TNS 255 FM *	951 405
	TT system	DEHNventil DV M TT 255 FM *	951 315
Data interface			
4	Two pairs, even with different operating voltages up to 180 V	BLITZDUCTOR BXTU ML4 BD 0-180 + BXT BAS base part	920 349 + 920 300
Functional earthing / External lightning protection system			
5	Functional equipotential bonding	UNI earthing clamp	540 250
6	Air-termination system	Air-termination rod with concrete base (8.5 kg)	101 000 + 102 075

Figure 9.18.17 Building with external LPS and insufficient separation distance – situation C (Supplement 5 of the DIN EN 62305-3 standard)

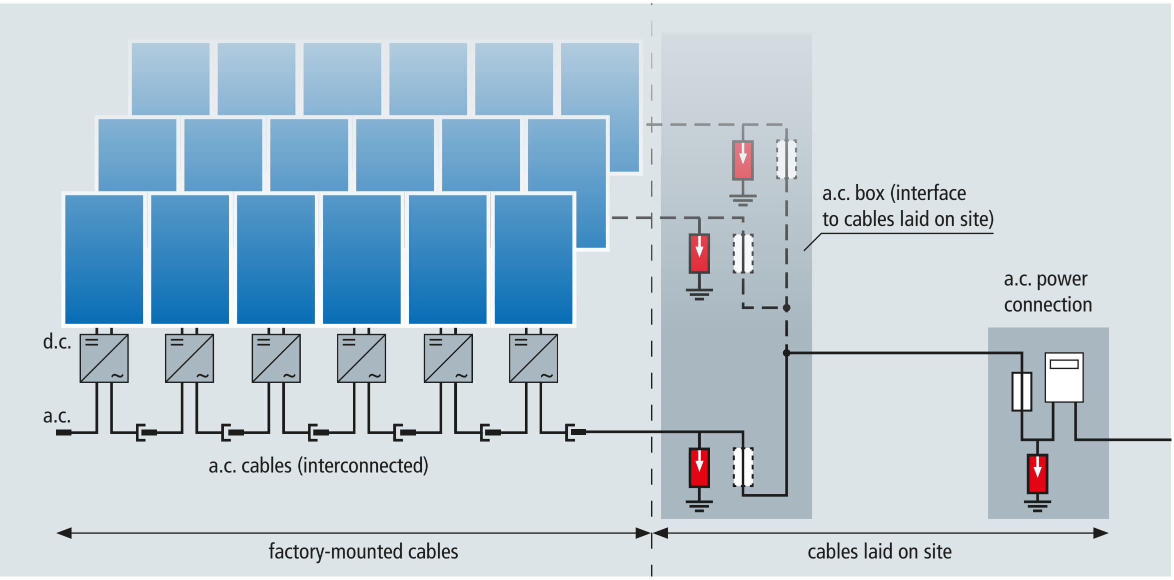


Figure 9.18.18 Example: Building without external lightning protection system; surge protection for a microinverter located in the connection box of the on-site cables

- Buildings without external lightning protection system = type 2 DEHNguard M...275 arresters for alternating/three-phase current in close proximity to the microinverters and DEHNguard...275 CI at the low-voltage infeed.
- Buildings with external lightning protection system and sufficient separation distance s = type 2 arresters, for example DEHNguard M...275, in close proximity to the microinverters and lightning current carrying type 1 arresters at the low-voltage infeed, for example DEHNventil M...255.
- Buildings with external lightning protection system and insufficient separation distance s = type 1 arresters, for example DEHNshield...255, in close proximity to the microinverters and lightning current carrying type 1 DEHNventil M...255 arresters at the low-voltage infeed.

Independent of particular manufacturers, microinverters feature data monitoring systems. If data is modulated to the a.c. lines via the microinverters, a surge protective device (for example DEHNbox DBX KT BD) must be provided on the separate receiving units (data export/data processing). The same applies to interface connections with downstream bus systems and their voltage supply (e.g. Ethernet, ISDN).

Solar power generation systems are an integral part of today's electrical systems. They should be equipped with adequate lightning current and surge arresters, thus ensuring long-term faultless operation of these sources of electricity.

Lightning and surge protection for free field PV power plants

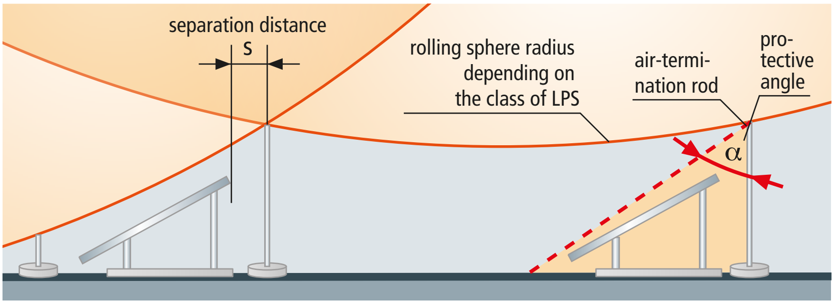


Figure 9.19.1 Rolling sphere method vs. protective angle method for determining the protected volume

With an annual newly installed capacity of some gigawatts, free field PV power plants are becoming an integral part of modern power supply systems in many countries. Today large-scale power plants with a capacity of 100 MW and higher are installed which are directly connected to the medium and high-voltage level. As an integral part of a power supply system, photovoltaic systems must ensure stable grid operation. In addition, possible production losses, which negatively affect the annual performance ratio of the power plant, are recorded by the yield monitoring system. Consequently, the investment volume and a minimum service life of 20 years require that the risk resulting from a lightning strike be assessed and protection measures be taken.

Risk of a lightning strike to structures such as PV power plants

There is a connection between the solar radiation, air humidity and frequency of lightning discharges. Regions with a high solar radiation and air humidity are more susceptible to lightning strikes. The regional lightning frequency (lightning strikes per square kilometres/year) and the location and size of the PV power plant form the basis for calculating the probability of lightning strikes to the plant. PV systems are exposed to local weather conditions such as thunderstorms over decades.

Necessity of a lightning protection system

Damage to PV systems is caused both by the destructive effects of a direct lightning strike and inductive or capacitive coupling of voltages caused by the electromagnetic lightning field. Moreover, voltage peaks resulting from switching operations on the upstream a.c. system can cause damage to PV modules, inverters, charge controllers and their monitoring and communication systems.

Economic damage leads to replacement and repair costs, yield loss and costs for using the reserve power of the power plant. Lightning impulses also cause premature ageing of bypass diodes, power semiconductors and the input and output circuits of data systems, which leads to increased repair costs.

In addition, network operators place requirements on the availability of the energy produced. In Germany, these requirements are based on e.g. the new Grid Codes. Banks and insurance companies frequently also require to consider lightning protection measures in due diligence analyses. The German VdS 2010 brochure (Risk-oriented lightning and surge protection) published by the German Insurance Association (GDV) requires that lightning protection measures (class of LPS III) be taken for PV systems > 10 kW of objects with alternative renewable power supply systems.

The risk resulting from a lightning strike must be determined according to the IEC 62305-2 (EN 62305-2) standard and the results of this risk analysis must be considered at the design stage. For this purpose, DEHN + SÖHNE offers the DEHNsupport software. A risk analysis performed by means of this software ensures a technically and economically optimised lightning protection concept which is understood by all parties involved and offers the necessary protection at reasonable costs.

Measures for protecting PV power plants from lightning interference

To ensure effective protection, a lightning protection system with optimally coordinated elements (air-termination system, earth-termination system, lightning equipotential bonding, surge protective devices for power supply and data systems) is required.

Air-termination system and down conductors

To prevent direct lightning strikes to the electrical systems of a PV power plant, these systems must be located in the protected volume of air-termination systems. Design according to the German VdS 2010 guideline is based on class of LPS III. According to this class of LPS, the rolling sphere method (**Figure 9.19.1**) as per IEC 62305-3 (EN 62305-3) can be used to determine the number of air-termination rods. These air-termination rods form a protected volume above module racks, operations buildings and cables. Due to the inductive coupling of interference, it is advisable to install generator junction boxes mounted on module racks and decentralised inverters as far as possible from air-termination systems. The high masts on which CCTV systems are installed also act as air-termination systems. The CCTV system itself must be mounted in such a way that it is located in the protected volume of the mast. All down conductors of these air-termination systems must be connected to the terminal lugs of the earth-

Figure 9.19.2 Lightning protection by means of DEHNiso spacers

termination system. Terminal lugs must be corrosion-resistant (stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti) due to the risk of corrosion at the point where they leave the soil or concrete. Terminal lugs made of galvanised steel must be protected by adequate measures, e.g. Denso tapes or heat shrinkable sleeves.

To mechanically fix the air-termination systems, they can be frequently connected to the module racks. To this end, DEHNiso spacers can be used (**Figure 9.19.2**). The air-termination systems can be connected to the earth-termination system via pile-driven foundations, thus facilitating later maintenance of the premises.

Earth-termination system

An earth-termination system (**Figure 9.19.3**) forms the basis for implementing effective lightning and surge protection measures in PV power plants. In Annex D of Supplement 5 of the German DIN EN 62305-3 standard, an earth resistance R_A of less than 10 Ω is recommended for an earth-termination system. A meshed 10 mm stainless steel wire (20 m x 20 m to 40 m x 40 m) buried below the frost line is durable and has proven its worth in practice. The metal module racks can be used as part of the mesh if they have a minimum conductance according to the IEC 62305-3 (EN 62305-3) standard. Supplement 5 of the German DIN EN 62305-3 standard recommends that metal racks be interconnected. The mesh is frequently installed according to the existing cable trenches and should be closed. The IEC 61936-1 (EN 61936-1) and EN 50522 standards must be particularly observed for the earth-termination systems of the operations buildings. The earth-termination systems of the PV generators and the operations buildings must be interconnected by means of a flat strip (30 mm x 3.5 mm) or a round wire (Ø 10 mm) (stainless steel (V4A), e.g. material No. AISI/ASTM 316 Ti, or copper or galvanised steel). This interconnection of the individual earth-termination systems reduces the total earth resistance. By intermeshing the earth-termination systems, an equipotential surface is created which considerably reduces the voltage stress on the electrical connecting lines in case of lightning interference between the PV array and the operations building. To permanently keep the earth resistance stable over the many years of operation of a PV power plant, the influences of corrosion, soil moisture and frost must be taken into account. Only the areas below the frost line must be considered for the effective earth electrode length. The meshes must be interconnected via adequate lightning-current-tested connection components. The metal mounting systems on which the PV modules are installed must be connected to each other and to the earth-termination system. Mounting systems with a pile-driven or screw-in foundation can be used as earth electrodes (**Figure 9.19.4**) if they have the material and wall thickness specified in Table 7 of the IEC 62305-3 (EN 62305-3) standard. The required minimum length of 2.5 m in the area below the frost line can be added in case of interconnected lightning-current-proof individual elements. Each PV array must be interconnected in such a way that it can carry lightning currents, for example by means of a 10 mm stainless steel wire (e.g. material No. AISI/ASTM 316 Ti) and a UNI saddle clamp (**Figure 9.19.5**).

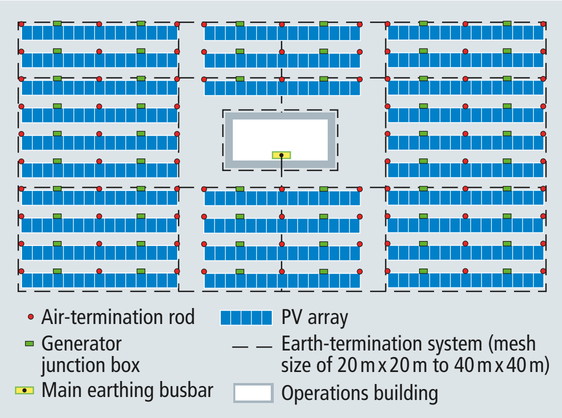


Figure 9.19.3 Earth-termination system as per IEC 62305-3 (EN 62305-3)

Lightning equipotential bonding

Lightning equipotential bonding means directly connecting all metal systems in such a way that they can carry

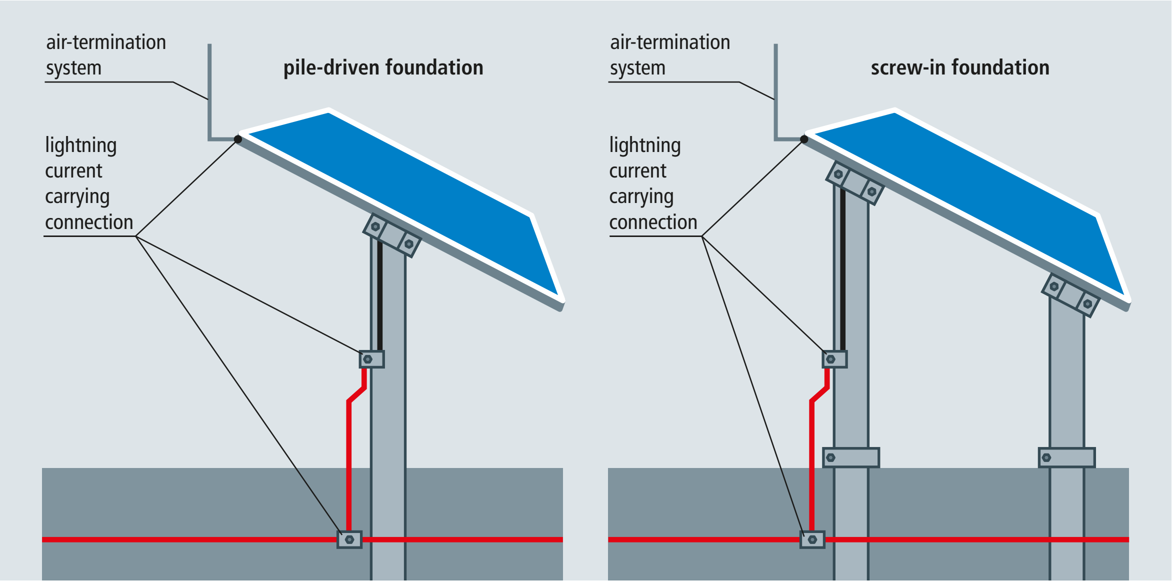


Figure 9.19.4 Pile-driven and screw-in foundation with a lightning current carrying connection between the air-termination system and the earth-termination system

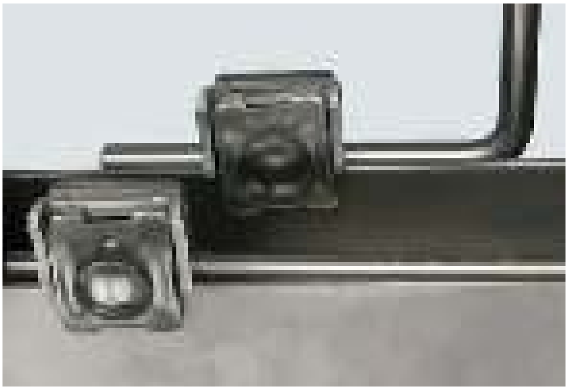


Figure 9.19.5 UNI saddle clamp

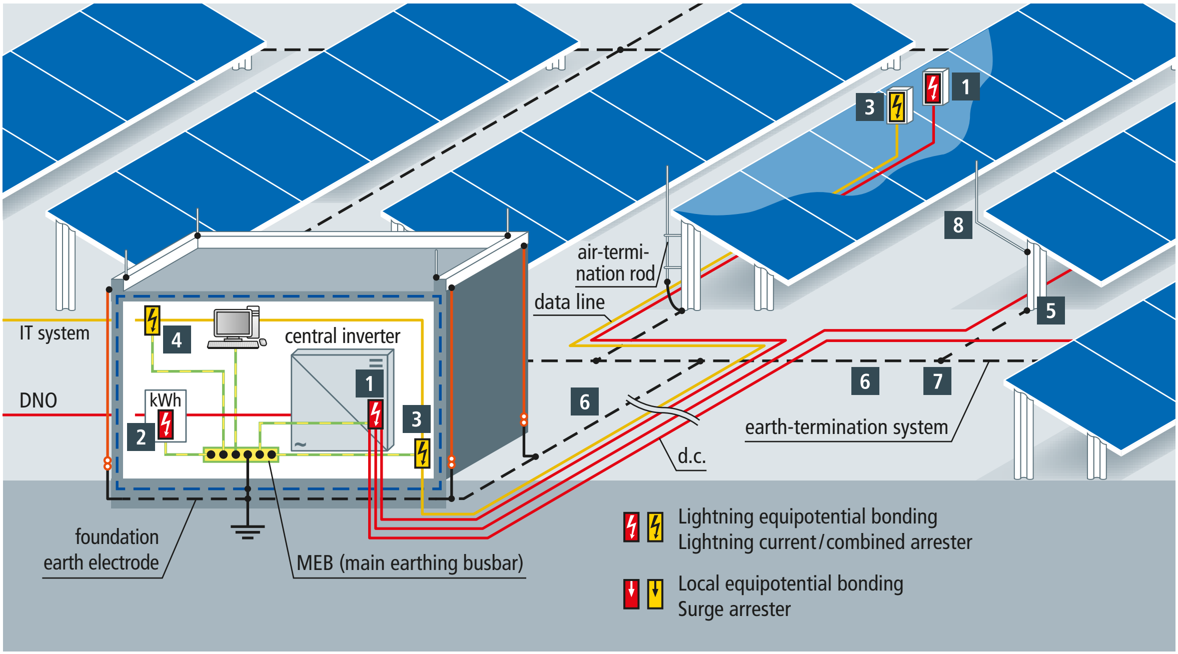
lightning currents. If the modules, cables and the operations building with the weather station are located in the protected volume of the external lightning protection system, it is not to be expected that direct lightning currents are injected into the lines. If the connection to the distribution network operator (DNO) is established on the low-voltage level, this point is connected to the main earthing busbar (MEB) via type 1 lightning current arresters (e.g. DEHNventil) since partial lightning currents are present. The same applies to the incoming telecommunication cables for which type 1 arresters such as BLITZDUTOR or DEHNbox (**Figure 9.19.6**) must be installed.

Solar generator and systems of the external lightning protection system

The air-termination systems of the external lightning protection system are vital. In case of an uncontrolled lightning strike to the PV system, lightning currents will flow into the electrical installation and cause severe damage to the system. When installing the external lightning protection system, it must be observed that solar cells are not shaded, for example, by air-termination rods. Diffuse shadows, which occur in case of distant rods or conductors, do not negatively affect the PV system and the yield. Core shadows, however, unnecessarily stress the cells and the associated bypass diodes. The required distance can be calculated and depends on the diameter of the air-termination rod. For example, if an air-termination rod with a diameter of 10 mm shades a module, only a diffuse shadow is cast on the module if a distance of 1.08 m is maintained between the module and the air-termination rod. Annex A of Supplement 5 of the German DIN EN 62305-3 standard provides more detailed information on the calculation of core shadows.

Cable routing in PV systems

All cables must be routed in such a way that large conductor loops are avoided. This must be observed for the single-pole series connections of the d.c. circuits (string) and for the interconnection of several strings. Moreover, data or sensor lines must not be routed across several strings and form large conductor loops with the string lines. For this reason, power



No. in Fig.	Protection for	SPD * FM = Floating remote signalling contact	Part No.
d.c. input of the inverter			
1	Central inverter + GJB	DEHNcombo DCB YPV SCI 1500 FM *	900 067
a.c. side of the grid connection			
2	TN-C system	DEHNventil DV M TNC 255 FM *	951 305
	TN-S system	DEHNventil DV M TNS 255 FM *	951 405
	TT system	DEHNventil DV M TT 255 FM *	951 315
Data interface			
3	One pair, even with operating voltages up to 180 V	BLITZDUCTOR BXTU ML2 BD 0-180 + BXT BAS base part	920 249 + 920 300
Remote maintenance			
4	ISDN or DSL	DEHNbox DBX U4 KT BD S 0-180	922 400
Earth-termination system			
5	Equipotential bonding	UNI saddle clamp	365 250
6	Earthing conductor	Round wire (Ø 10 mm) St/tZn Round wire (Ø 10 mm) StSt (V4A) Strip steel (30 x 3.5 mm) St/tZn Strip steel (30 x 3.5 mm) StSt (V4A)	800 310 860 010 852 335 860 325
7	Connection element	MV clamp StSt (V4A) alternative: SV clamp St/tZn	390 079 308 220
8	Air-termination system	Angled air-termination tip (including two saddle clamps)	101 110

Figure 9.19.6 Lightning protection concept for a PV power plant with central inverter

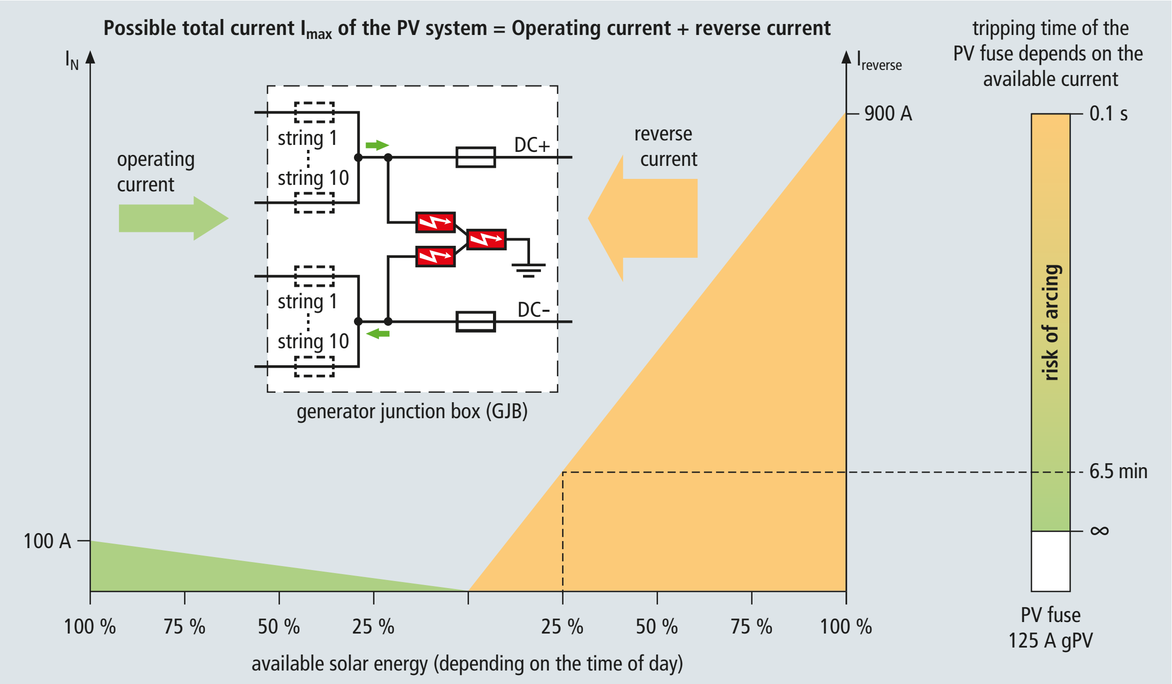


Figure 9.19.7 PV system with I_{max} of 1000 A: Prospective short-circuit current at the PV arrester depending on the time of day

(d.c. and a.c.), data and equipotential bonding conductors must be routed together as far as practicable.

Surge protection measures for PV power plants

Surge protective devices (SPDs) (**Figure 9.19.6**) must be installed to protect the electrical systems in PV power plants. In case of a lightning strike to the external lightning protection system of a free field PV system, high voltage impulses are induced on all electrical conductors and partial lightning currents flow into all sort of park cables (d.c., a.c. and data cables). The magnitude of the partial lightning currents depends on, for example, the type of earth-termination system, soil resistivity on site and the type of cables. In case of power plants with central inverters (**Figure 9.19.6**), extended d.c. cables are routed in the field. Annex D of Supplement 5 of the German DIN EN 62305-3 standard requires a minimum discharge capacity I_{total} of 10 kA (10/350 µs) for voltage-limiting type 1 d.c. SPDs.

SPDs with a sufficiently high short-circuit current rating I_{SCPV}, which is determined by means of the EN 50539-11 standard and must be specified by the manufacturer, must be used. This also applies with respect to possible reverse currents.

In PV systems with central inverters, fuses protect from reverse currents. The maximum available current depends on the actual solar radiation. In certain operating states, fuses only trip after some minutes (**Figure 9.19.7**). Therefore, surge protective devices installed in generator junction boxes must be designed for the possible total current consisting of the operating current and the reverse current and ensure automatic disconnection without arcing in case of overload ($I_{SCPV} > I_{max}$ of the PV system).

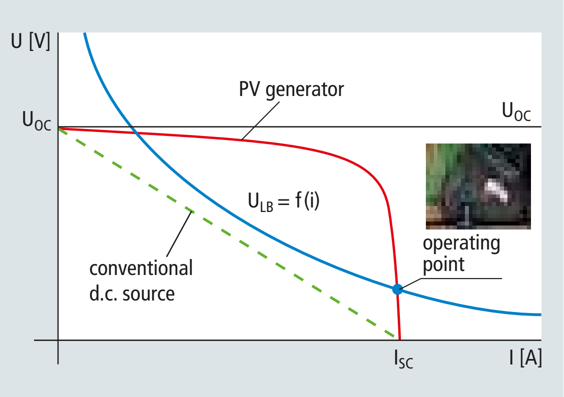


Figure 9.19.8 Source characteristic of a conventional d.c. source versus the source characteristic of a PV generator. When switching PV sources, the source characteristic of the PV generator crosses the arc voltage range.

Class of LPS and maximum lightning current (10/350 µs)		Values for voltage-limiting or combined type 1 SPDs (series connection)				Values for voltage-switching or combined type 1 SPDs (parallel connection)	
		$I_{10/350}$		$I_{8/20}$		$I_{10/350}$	
		Per protective path [kA]	I_{total} [kA]	Per protective path [kA]	I_{total} [kA]	Per protective path [kA]	I_{total} [kA]
III and IV	100 kA	5	10	15	30	10	20

Table 9.19.1 Minimum discharge capacity of voltage-limiting or combined type 1 SPDs and voltage-switching type 1 SPDs for free field PV systems in case of LPL III; according to CENELEC CLC/TS 50539-12 (Table A.3)

Special surge protective devices for the d.c. side of PV systems

The typical U/I characteristic curves of photovoltaic current sources are very different from that of conventional d.c. sources: They have a non-linear characteristic (**Figure 9.19.8**) and a different d.c. arc behaviour. This unique nature of photovoltaic current sources does not only affect the design and size of PV d.c. switches and PV fuses, but also requires that the surge protective devices are adapted to this unique nature and capable of coping with PV d.c. follow currents. Supplement 5 of the German DIN EN 62305-3 standard and the CENELEC CLC/TS 50539-12 standard require safe operation of surge protective devices on the d.c. side even in case of overload.

Supplement 5 of the German DIN EN 62305-3 standard includes a more detailed assessment of the lightning current distribution (computer simulations) than Supplement 1 of the German DIN EN 62305-4 standard. To calculate the lightning current distribution, the down conductors of the lightning protection system, possible earth connections of the PV array and the d.c. lines must be considered. It is shown that the magnitude and amplitude of the partial lightning currents flowing via the SPDs into the d.c. lines does not only depend on the number of down conductors, but is also influenced by the impedance of the SPDs. The impedance of the SPDs depends on the rated voltage of the SPDs, the SPD topology and the type of SPD (voltage-switching or voltage-limiting). The reduction of the impulse form is characteristic of partial lightning currents flowing via SPDs on the d.c. side of the PV system. When selecting adequate surge protective devices, both the maximum impulse current and the impulse load must be considered. These correlations are described in Supplement 1 of the German DIN EN 62305-4 standard.

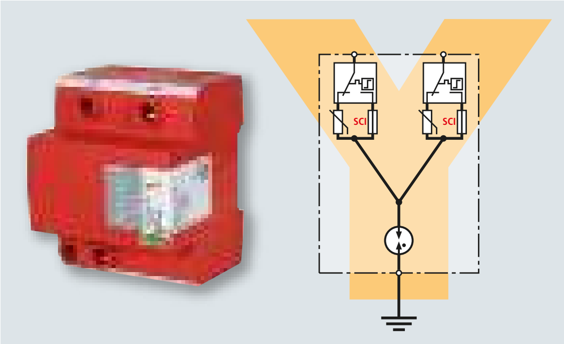


Figure 9.19.9 DEHNcombo YPV SCI type 1 + type 2 combined arrester with fault-resistant Y circuit and three-step d.c. switching device

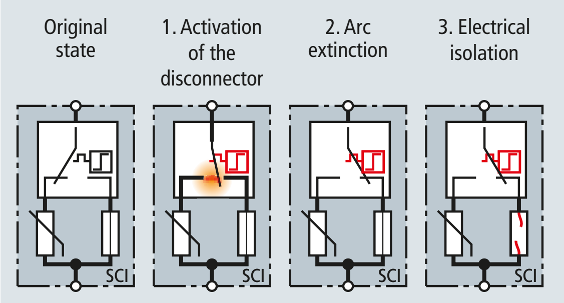


Figure 9.19.10 Switching phases of the three-step d.c. switching device integrated in DEHNcombo YPV SCI … (FM)

To facilitate the selection of adequate arresters, **Table 9.19.1** shows the required lightning impulse current carrying capability I_{imp} of type 1 SPDs depending on the type of SPD (voltage-limiting varistor-based arrester or voltage-switching spark-gap-based arrester). The maximum impulse currents and partial lightning currents of 10/350 µs wave form are considered to ensure that the SPDs are capable of discharging the impulse load of the lightning currents.

In addition to the tried and tested fault-resistant Y circuit, DEHNcombo YPV SCI … (FM) also features a three-step d.c. switching device (**Figure 9.19.9**). This d.c. switching device consists of a combined disconnection and short-circuiting device with Thermo Dynamic Control. The fuse integrated in the bypass path interrupts the current flow in case of a fault

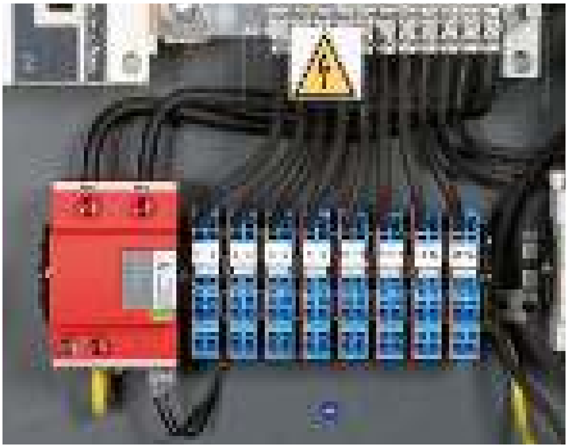


Figure 9.19.11 Surge protective device in a monitoring generator junction box

and puts the entire unit into a safe state (**Figure 9.19.10**). Thus, DEHNcombo YPV SCI … (FM), which is installed at the inverter and in the generator junction box (GJB), reliably protects PV generators up to 1000 A without backup fuse (**Figure 9.19.11**). DEHNcombo YPV SCI is available for 600 V, 1000 V and 1500 V. If string monitoring systems are used, the floating remote signalling contacts for condition monitoring of the SPDs can be integrated in these monitoring systems.

The combination of the numerous technologies integrated in the DEHNcombo YPV SCI combined arrester prevents damage to the surge protective device due to insulation faults in the PV circuit, minimises the risk of fire of an overloaded arrester and puts the arrester in a safe electrical state without disrupting the operation of the PV system. Thanks to the protective circuit, the voltage-limiting characteristic of varistors can now be fully used in the d.c. circuits of PV systems. In addition, the arrester minimises numerous small voltage peaks. Thus, the SCI technology increases the service life of the bypass diodes and the d.c. inputs of the inverters.

PV power plants with decentralised string inverters

If PV power plants with decentralised string inverters are used, most of the power cables are installed on the a.c. side. The inverters are installed in the field underneath the module racks of the relevant solar generators. Due to the proximity to the modules, the inverter assumes typical functions of generator junction boxes.

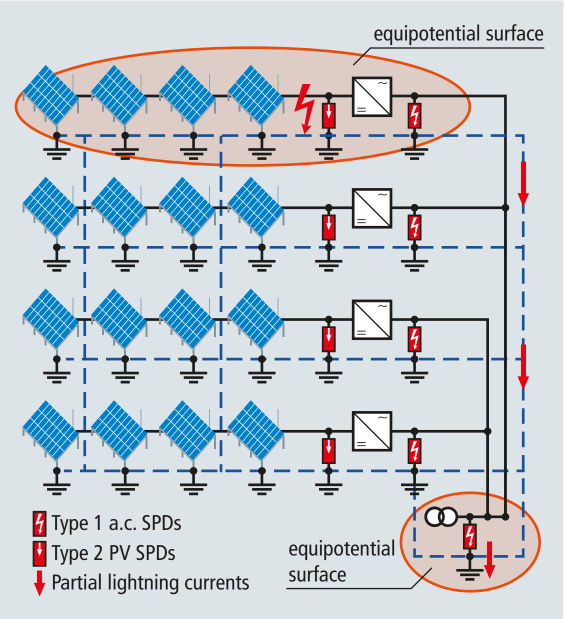
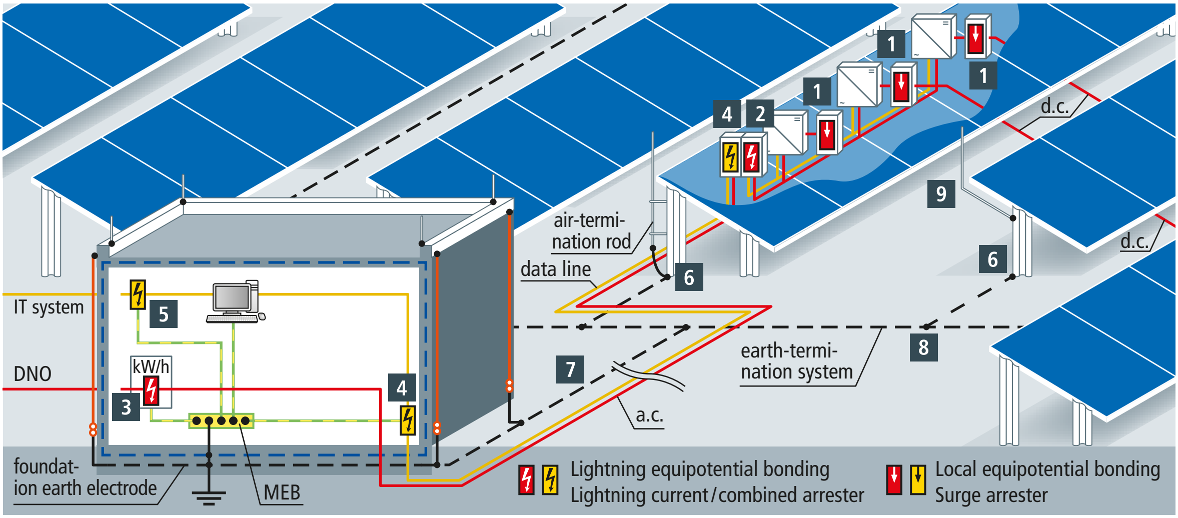


Figure 9.19.12 Lightning current distribution in case of free field PV systems with string inverter

Supplement 5 of the German DIN EN 62305-3 standard describes that the lightning current distribution is influenced by the power cables (string or central inverter). In addition to Supplement 5, **Figure 9.19.12** exemplarily shows the lightning current distribution in case string inverters. If string inverters are installed, the power cables are also used as equipotential bonding conductor between the local earth potential of the PV array hit by lightning and the remote equipotential surface of the infeed transformer. The only difference from plants with central inverters is that in case of PV systems with string inverters the partial lightning currents flow into the a.c. lines. Therefore, type 1 arresters are installed on the a.c. side of the string inverters and on the low-voltage side of the infeed transformer. **Table 9.19.1** shows the minimum discharge capacity of type 1 SPDs depending on the SPD technology. Type 2 SPDs such as DEHNcube YPV SCI are sufficient for the d.c. side of string inverters. If an earth-termination system according to Supplement 5 is installed, the string inverters and the PV array connected to them form a local equipotential surface so that it is not to be expected that lightning currents are injected into the d.c. lines since the arresters limit induced interference. They thus also protect the modules in close proximity from surges. Several a.c. outputs of these outdoor inverters are collected and stored in a.c. boxes. If type 1 arresters such as DEHNshield…255 are installed there, these devices protect all inverter outputs up to a distance of 10 m (conducted). Further a.c. field cables are routed into the operations building where the powerful type 1 and type 2 DEHNventil combined arrester protects the electrical equipment for the grid connection point. Other equipment such as the grid and plant protection, alarm panel or web server which is located less than 10 m (conducted) from this SPD is also protected.



No. in Figure	Protection for	SPD * FM = Floating remote signalling contact	Part No.
d.c. input of the inverter			
1	For 1 MPPT	DEHNcube DCU YPV SCI 1000 1M	900 910
	For 2 MPPTs	DEHNcube DCU YPV SCI 1000 2M	900 920
	Per MPPT	DEHNguard DG M YPV SCI 1000 FM *	952 515
a.c. side of the inverter			
2	TN-S system	DEHNshield DSH TNS 255	941 400
a.c. side of the grid connection			
3	TN-C system	DEHNventil DV M TNC 255 FM *	951 305
	TN-S system	DEHNventil DV M TNS 255 FM *	951 405
	TT system	DEHNventil DV M TT 255 FM *	951 315
Data interface			
4	One pair, with operating voltages up to 180 V	BLITZDUCTOR BXTU ML2 BD 0-180 + BXT BAS base part	920 249 + 920 300
Remote maintenance			
5	ISDN or DSL	DEHNbox DBX U4 KT BD S 0-180	922 400
Earth-termination system/external lightning protection system			
6	Equipotential bonding	UNI saddle clamp	365 250
7	Earthing conductor	Round wire (Ø 10 mm) St/tZn Round wire (Ø 10 mm) StSt (V4A) Strip steel (30 x 3,5 mm) St/tZn Strip steel (30 x 3,5 mm) StSt (V4A)	800 310 860 010 852 335 860 325
8	Connection element	MV clamp StSt (V4A) alternative: SV clamp St/tZn	390 079 308 220
9	Air-termination system	Angled air-termination tip (including 2 saddle clamps)	101 110

Figure 9.19.13 Lightning protection concept for a PV power plant with string inverter

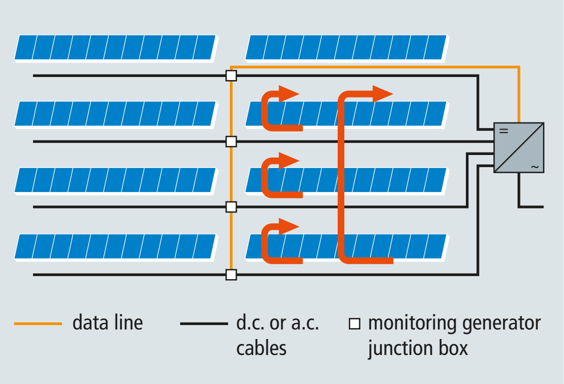


Figure 9.19.14 Basic principle of induction loops in PV power plants

Surge protection measures for information technology systems

Data from the field as well as data acquired from remote maintenance by the plant operator and capacity measurements and control by the grid operator are collected in operations buildings. To ensure that the service staff is able to specifically determine causes of failure via remote diagnostics and eliminate them on site, reliable data transfer must be ensured at any time. The string and inverter monitoring system, weather data acquisition unit, anti-theft protection and external communication system are based on different physical interfaces. Wind and radiation sensors with analogue signal transmission can be protected by DEHNbox DBX. Thanks to its actiVsense technology, DEHNbox DBX can be used for signal voltages up to 180 V and automatically adapts the voltage protection level. BLITZDUCTOR XT is ideally suited to protect an RS 485 interface for communication between the inverters. DEHNgate BNC VC devices are used to protect CCTV systems with coaxial video transmission which is used for anti-theft protection systems. If the sub-stations of large-scale PV power plants are interconnected via Ethernet, DEHNpatch M CAT6, which can also be used for PoE (Power over Ethernet) applications, can be installed. No matter if it is an ISDN or ADSL connection – the data lines of devices which provide a connection to the outside world are also protected by the relevant surge protective devices.

In case of power plants with central inverters, generator junction boxes with additional measuring sensors are installed in the field. In case of power plants with string inverters (**Figure 9.19.13**), their integrated string monitoring system takes over this task. In both cases, the measured values from the field are transmitted via data interfaces. The data lines from the service room are installed together with the power cables (a.c. or d.c.). Due to the short line lengths of field bus systems, data cables are individually routed transversely to the module racks. In case of a direct lightning strike, these transverse connections also carry partial lightning currents which may damage the input circuits and cause flashover to power cables. Large induction loops are formed due to the interaction of power cables, metal module racks rows and data lines (**Figure 9.19.14**). This is an ideal environment for transients caused by lightning discharges which can be injected into these lines. Such voltage peaks are capable of exceeding the insulation strength / dielectric strength of these systems which leads to surge damage. Therefore, SPDs must be installed in these monitoring generator junction boxes or in the decentralised string inverters to protect data transmission. Cable shields must be connected to all connection points in line with the EN 50174-2 standard (section 5.3.6.3). This can also be achieved by indirect shield earthing to prevent malfunction such as ripples and stray currents. BLITZDUCTOR XT, for example, can be used together with an EMC spring terminal of type SAK BXT LR for indirect shield earthing.

Consistent lightning and surge protection for all systems allows to considerably increase the performance ratio of these power plants. The service and maintenance time as well as repair and spare part costs are reduced.

Surge protection for Local Operating Networks (LONs)

Medium	Transceiver	Transmission	Network expansion	Node ➡ Node	Node supply
Two-wire	TP/XF-78	78 kbit/s	1400 m bus / line		Separately
Two-wire	TP/XF-1250	1250 kbit/s	130 m bus / line		Separately
Two-wire	**FTT10-A**	78 kbit/s	2700 m bus / line 500 m open structure	J-Y(ST)Y 2x2x0.8 320 m open structure	Separately
Two-wire	**LPT-10**	78 kbit/s	2200 m bus / line 500 m open structure	J-Y(ST)Y 2x2x0.8 320 m open structure	Via bus cable

Table 9.20.1 Transceivers (most common transceivers are printed in bold) with their transmission rates and maximum network expansion

The LonWorks technology allows to implement distributed automation systems. In this context, intelligent nodes communicate via the LonTalkProtocol®. The neuron chip (3120, 3150 and various enhancements), which accesses a transmission medium via a transceiver and features an I/O circuit for connecting, for example switches, relays, analogue outputs, analogue value measurement systems, is the core of a node (**Figure 9.20.1**).

Transmission media

In addition to the two-wire connection described below, 230 V, optical fibre cable, coaxial cable, LAN and radio transmission is possible.

Two-wire bus cable used as transmission medium

The transceivers for a two-wire bus cable (e.g. J-Y(ST)Y 2x2x0.8) have different transmission rates (kbit/s) and a different maximum network expansion (cable length in metres) (**Table 9.20.1**).

Since the two-wire bus cable can be placed in free space, the devices in the LON building installation are mainly equipped with FFTs (Free Topology Transceivers) and LPT (Link Power Transceivers) (LPTs are compatible with FTTs at the same bus).

The transceivers in FTT / LPT networks have the core / core and core / earth capacitances shown in **Table 9.20.2**. If surge protective devices are installed, their capacitances (core / core and core / earth) must also be considered since the maximum number of transceivers to be used is reduced accordingly (**Table 9.20.3**).

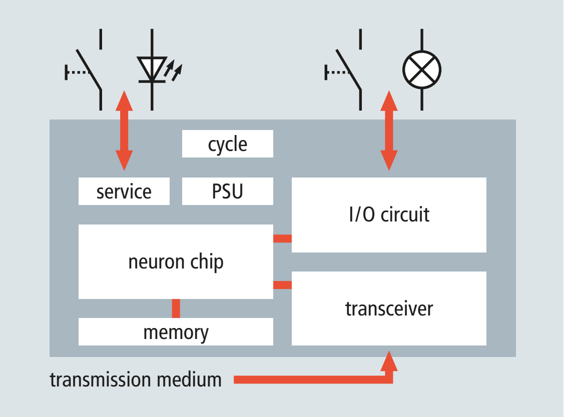


Figure 9.20.1 Structure of a LonWorks node with neuron chip, transceiver and I/O circuit

Surges caused by induction loops

When routing the cables, it must be observed that no induction loops are formed. Therefore, the bus and low-voltage cables leading to the bus devices must be routed in close

Transceiver	Capacitance	
	Core / core	Core / earth
FTT10-A	300 pF	10 max. 20 pF
LPT-10	150 pF	10 pF

Table 9.20.2 Capacitances of transceivers in FTT / LPT networks

Surge protective device	Capacitance	
	Core / core	Core / earth
BXT ML2 BD S 48	700 pF	25 pF

Table 9.20.3 Capacitances of surge protective devices

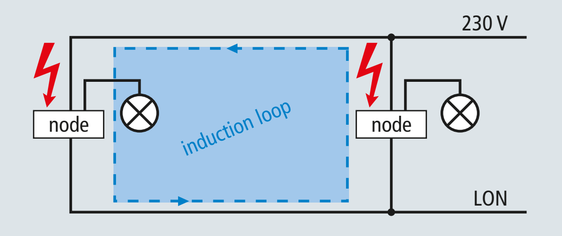


Figure 9.20.2 Induction loop caused by two nodes

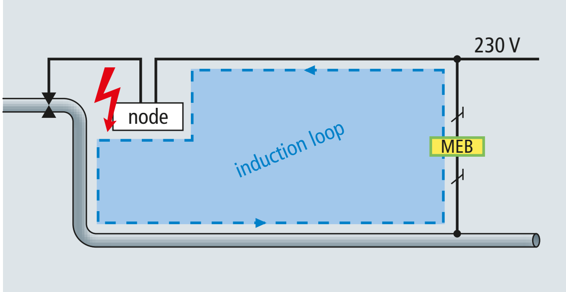


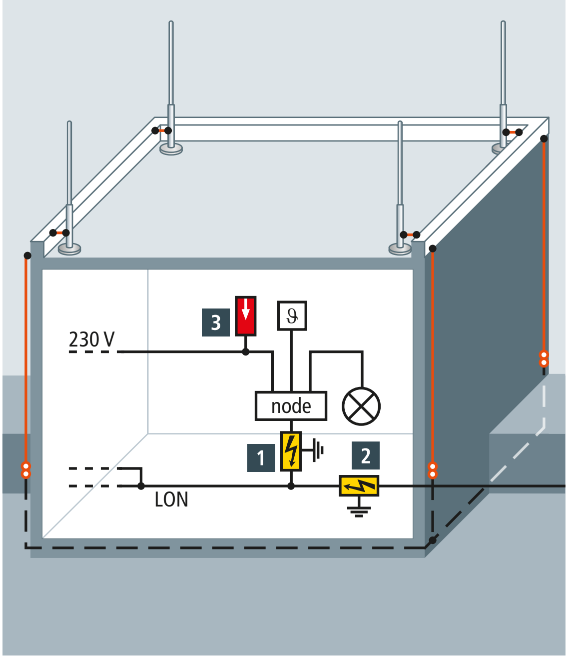
Figure 9.20.3 Induction loop caused by a magnetic valve attached to a metallic pipe

proximity to one another (**Figure 9.20.2**). If a J-Y(ST)Y cable has a dielectric strength of 2.5 kV, this cable can be connected in parallel with a low-voltage cable. However, a distance of 10 mm must be kept after removing the J-Y(ST)Y cable sheath. Loops are also formed if a node is attached to a metallic construction / pipe which is connected to the main earthing busbar (**Figure 9.20.3**). Also in this case, it is advisable to route the cables as close as possible to the construction / pipe.

Surge protection in case of a combination topology

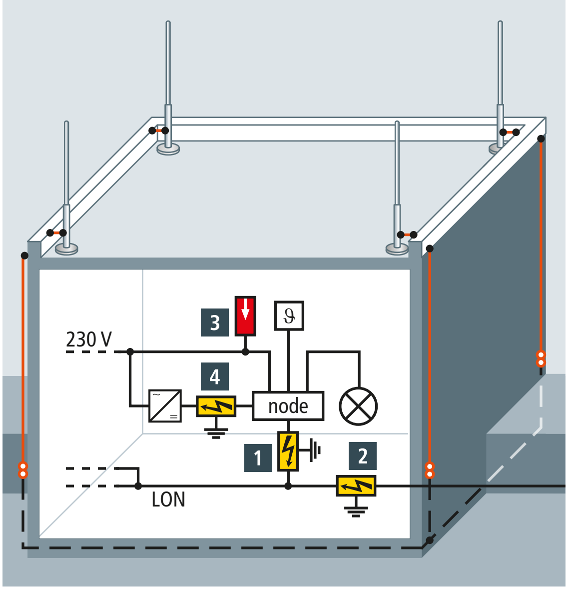
If the inputs / outputs connected to the node are located in close proximity to the node, surge protective devices are not required.

Figure 9.20.4 shows surge protective devices for LPTs which are supplied by means of a two-wire bus cable. **Figure 9.20.5** shows surge protective devices for directly supplied FTTs (typically 24 V d.c.) in case of long connecting cables of power supply units.



No.	Surge protective device	Part No.
1	BXT ML2 BD S 48 + BXT BAS	920 245 920 300
2	see 1 (lightning equipotential bonding)	
3	DR M 2P 255	953 200

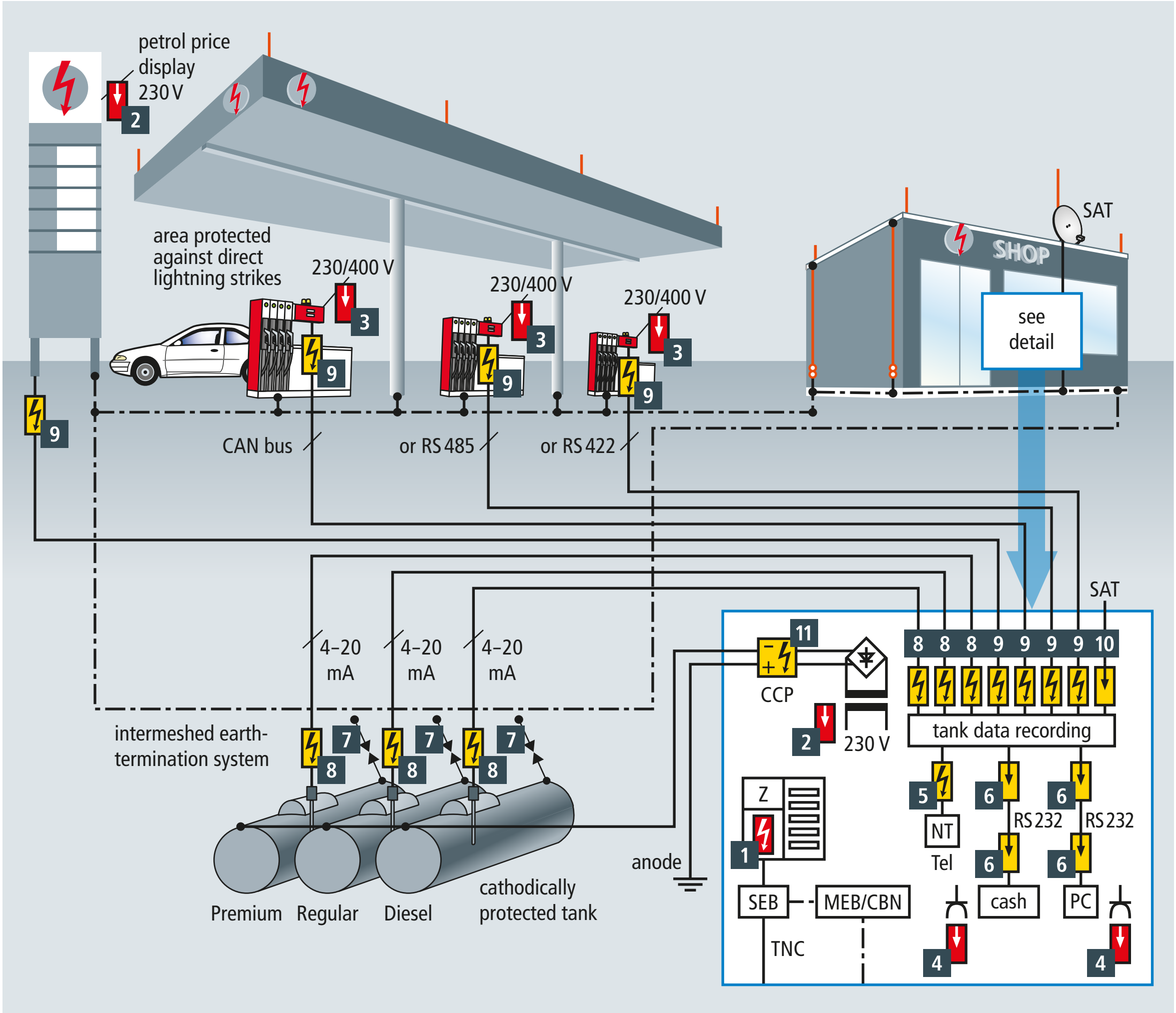
Figure 9.20.4 Surge protective devices for an LPT in a combination topology extending beyond buildings



No.	Surge protective device	Part No.
1	BXT ML2 BD S 48 + BXT BAS	920 245 920 300
2	see 1 (lightning equipotential bonding)	
3	DR M 2P 255	953 200
4	BXT ML2 BE S 24 + BXT BAS	920 224 920 300

Figure 9.20.5 Surge protective devices for an FTT in a combination topology extending beyond buildings

Surge protection for petrol stations



	Use	Type	Part No.
1	T... system, 3~ T... system	DV M T... 255 alternative: DV ZP T...	951... 900 3...
2	TN system, 1~ TT system, 1~	DG M TN 275 DG M TT 2P 275	952 200 952 110
3	TN-S system, 3~ TT system, 3~	DG M TNS 275 DG M TT 275	952 400 952 310
4	1~	DPRO 230	909 230
5	Telephone	BXT ML2 BD 180 + BXT BAS	920 247 920 300
6	25-pin D-Sub	FS 25E HS 12	924 018

	Use	Type	Part No.
7	Zone 1 or 2	EXFS 100	923 100
8	4–20 mA: 2 single cores 4–20 mA: 4 single cores	BXT ML2 BE S 24 BXT ML4 BE 24 + BXT BAS	920 224 920 324 920 300
9	CAN, RS 485, RS 422: 2 single cores CAN, RS 485, RS 422: 2 single cores	BXT ML2 BE HFS 5 BXT ML4 BE HF 5 + BXT BAS	920 270 920 370 920 300
10	Satellite antenna	DGA FF TV	909 703
11	Protective circuit	BVT KKS ALD 75	918 420

Figure 9.21.1 Petrol station with lightning protection system, intermeshed earth-termination system, protective and functional equipotential bonding and surge protective devices

Petrol stations are highly vulnerable to lightning strikes and surges due to their extremely sensitive control and display systems.
In Germany, the necessity of a lightning protection system for petrol stations must be determined amongst others based on a risk analysis according to the German Ordinance on Industrial Safety and Health (BetrSichV), the German technical rules for operating safety (TRBS 2152 Part 3), VDE standards and fire protection requirements of the relevant building regulations.
The German Ordinance on Industrial Safety and Health (BetrSichV) requires to avoid all sources of ignition. Some building regulations specify that structures where a lightning strike can easily occur or can have serious consequences due to their location, type of construction or use must be equipped with permanently effective lightning protection systems.

The risk analysis described in the IEC 62305-2 (EN 62305-2) lightning protection standard can be used to determine possible risks. The system-specific parameters define the existing risk of a structure. If the risk values determined are higher than the tolerable risks listed in the standard, measures (external lightning protection, surge protection, fire alarm systems, etc.) must be taken which reduce the inadmissibly high risks to an acceptable level.
The IEC 60364-1 (HD 60364-1) standard specifies that "property shall be protected against damage as a consequence of overvoltages such as those originating from atmospheric events or from switching".
The surge protective devices recommended in this standard must not be installed in Ex zones (zone 0, 1 and 2), if any. If surge protective devices are located in hazardous zones, adequate measures (e.g. approved enclosures and/or approved surge protective devices) must be taken to avoid ignition.

Equipment located in the forecourt (e.g. petrol price display) and the incoming utility line are vulnerable to direct lightning strikes. Therefore, lightning current arresters are installed at the entrance point into the building.
The fuel dispensers are located underneath a projecting metal roof and are thus protected against direct lightning strikes. For this reason and due to the intermeshed earth-termination system (**Figure 9.21.1**), surge arresters are installed at the entrance point of the lines into the petrol station building and at the entrance point of the lines into the fuel dispenser to protect the lines leading to the fuel dispenser electronics.

A professional external lightning protection system as per IEC 62305 (EN 62305), consistent lightning equipotential bonding and additional surge protection measures are required to protect petrol stations from direct lightning strikes. The table in **Figure 9.21.1** shows which types of surge protective devices can be used to protect the different interfaces and system components.
It is important to interconnect all metal constructions (e.g. pipes, fuel dispenser enclosures, tanks) and to connect them to the earth-termination system of the petrol station building. According to IEC 62305-3 (EN 62305-3), the earth-termination system should have an earth resistance of $< 10\ \Omega$ (recommendation). Spark gaps for use in hazardous areas must be used to connect petrol stations with cathodic corrosion protection to the earth-termination system.

The bus systems, sensors and information technology connections listed in **Figure 9.21.1** are by no means complete and merely serve as examples. They may only be installed based on the information provided in the detailed planning and the requirements and notes of the acceptance body.

Protection from touch and step voltages for sports grounds

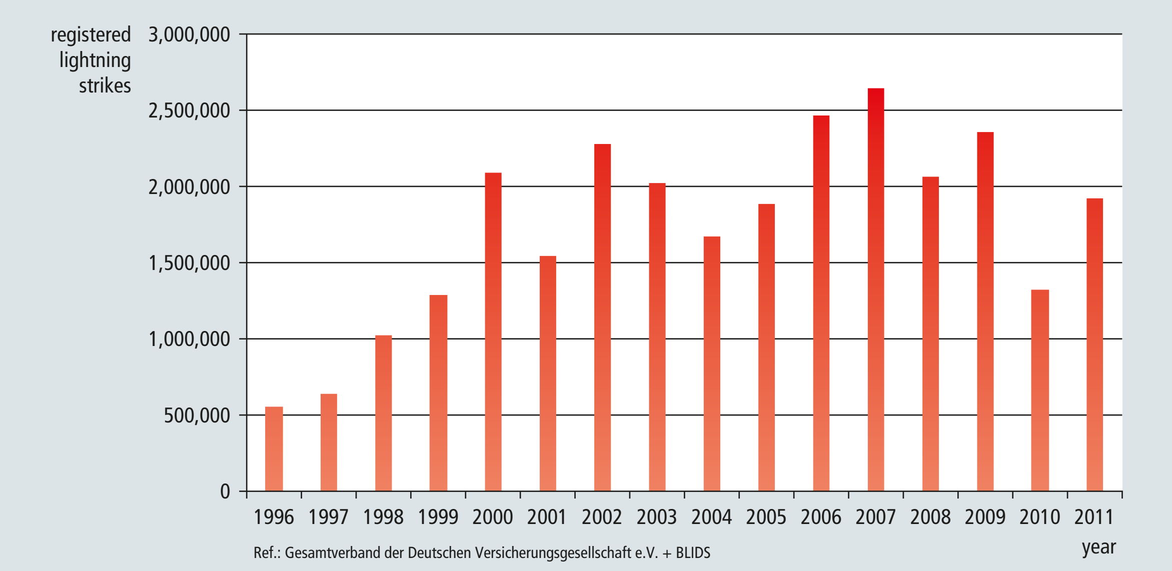
The necessity of lightning protection systems for playing fields and sports grounds as well as the neighbouring spectator galleries is increasingly publicly discussed. Recent damage and the increased thunderstorm frequency (**Figure 9.22.1**) underline that adequate protection measures are required. Lightning strikes to floodlights, spectator galleries, fences or even playing fields pose a high risk to sportspersons and spectators. Persons who are directly hit by lightning or stand next to lightning current carrying parts and carry partial lightning currents themselves as a result of flashover may be seriously injured or may even die. Persons who are not directly hit by lightning, but stand next to the point of strike (potential gradient area) bridge a life-threatening voltage difference with their legs (step voltage) or by touching other persons. This results in injuries such as ventricular fibrillation, cardiac arrhythmia and injuries caused panic. Therefore, the German building regulations of some federal states require the following:

Structures where a lightning strike can easily occur or can have serious consequences due to their location, type of construction or use must be equipped with permanently effective lightning protection systems.
(Bavarian Building Regulation (Bay Bo), section 44)

This article also applies to sports grounds.
Therefore, experts defined organisational guidelines for behaviour and warning notices which preventively warn of lightning hazards. If hazards are recognised in time, dangerous areas can be left and buildings or designated shelters can be sought. Additional lightning protection measures reduce the risk of injuries in critical environments such as floodlights, metal fences and escape routes. More detailed information on this topic can be found in the publications by the German Association for Electrical, Electronic and Information Technologies (VDE) ("Richtiges Verhalten bei Gewitter" [What to do in a thunderstorm]) or by the German Committee for Lightning Protection and Research (ABB) (e.g. "Überlegungen zum Blitzschlag an dem Sportplatz in Wald-Michelbach am 08.08.2008" [Considerations concerning the lightning strike to the sports ground in Wald-Michelbach on 08/08/2008]). Supplement 2 of the latest German DIN EN 62305-3 standard describes how to install fixed protection systems on buildings, lighting systems or spectator galleries.

Lightning protection for buildings / lightning equipotential bonding

Covered stands, locker rooms and club houses provide shelter in case of unexpected heavy rain and thunderstorms. A lightning protection system according to class of LPS III as per IEC 62305-3 (EN62305-3) is at least required for these types of building. For uncovered spectator galleries, class of LPS II must be used according to Supplement 2 of the German DIN EN 62305-3 standard. In case of a lightning strike, partial lightning currents may also flow through metal fences, parts of the spectator gallery, flagpoles or scoreboards. The resulting potential differences lead to uncontrolled flashover which causes fire and endangers persons and animals in close proximity. To prevent this, these parts must be conductively interconnected. **Figure 9.22.2** shows the connection of a lightning protection system to the 230/400 V power supply system at



Ref.: Gesamtverband der Deutschen Versicherungsgesellschaft e.V. + BLIDS

Figure 9.22.1 Number of lightning strikes registered in Germany from 1996 to 2011

Figure 9.22.2 Lightning equipotential bonding by means of DEHNventil M

Figure 9.22.3 DEHNconductor HVI light Conductor

the entry point of the main low-voltage distribution board by means of a DEHNventil combined arrester. The associated lightning equipotential bonding system for metal and electronic systems additionally prevents fire in these structures.

Isolated air-termination system

According to the latest lightning protection standards, isolated air-termination systems are to be used to protect metal floodlight pylons, parts of the spectator gallery, scoreboards and flagpoles against direct lightning strikes. These parts are conductively connected with sensitive electrical / electronic equipment via electrical lines. Isolated air-termination systems such as the DEHNconductor HVI system (high-voltage-resistant, insulated conductor, **Figure 9.22.3**) prevent flashover. Consequently, no lightning currents will travel through the metal floodlight pylons, scoreboards, parts of the spectator gallery and flagpoles, thus preventing dangerous lightning currents from flowing into sensitive electrical systems. **Figure 9.22.4** shows a DEHNconductor HVI system installed on a pylon. The height of the air-termination tip depends on the relevant class of LPS, which must be determined in advance. The high-voltage-resistant, insulated down conductor (HVI Conductor) can be directly installed at the pylon in line with the installation instructions using system-specific accessories. Thus, lightning currents do not enter the pylon and the electrotechnical installation.

Lightning protection for floodlights

Floodlights next to the sideline or spectator galleries should be provided with a lightning protection system. The earth-termination systems of the individual pylons should be connected to one another and to the earth-termination systems of the sports buildings (club houses, locker rooms or technical buildings). These additional connections improve equipotential bonding and the efficiency of the individual foundation earth electrodes. If correctly installed, they form a protected volume in case of a direct lightning strike to the cable routes of the floodlight (**Figure 9.22.5**).

Figure 9.22.4 HVI Conductor installed at a pylon

Standing surface insulation, touch and step voltage (potential control)

Persons standing directly next to lightning current carrying floodlight pylons, fences, flagpoles or covered stands during a lightning strike bypass high potential differences with their

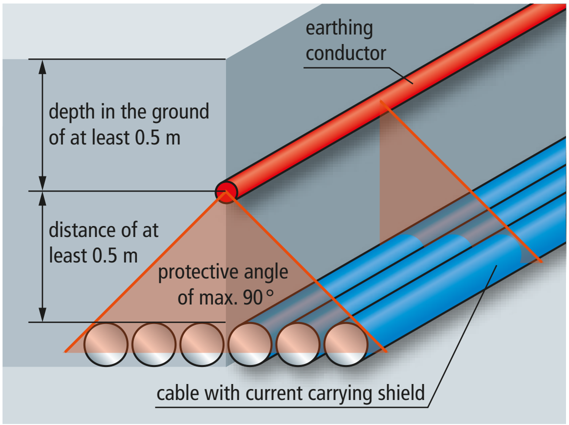


Figure 9.22.5 Protected volume for a cable route

legs (step voltage) or may directly touch conductive structures (touch voltage). The resulting risk of injury can be reduced by insulating the standing surface (standing surface insulation). This measure reduces the risk of impermissibly high touch and step voltages following a lightning strike. According to IEC 62305 (EN 62305), an insulating asphalt layer of at least 5 cm around these parts is sufficient. As an alternative, CUI Conductors with dielectric strengths ≥ 100 kV (1.2/50 µs) can be used.

Potential control as per Supplement 1 of the German DIN EN 62305-3 standard also allows to reduce step voltages. To this end, additional earthing conductors are buried around the pylons or metal spectator galleries and are interconnected (**Figure 9.22.6a**). Consequently, the potential difference in the potential control area is reduced and the lightning current is evenly distributed in the ground. When the distance from the pylon increases, the depth increases as well by 0.5 m (**Figure 9.22.6b**). The more evenly the earth electrodes are installed, the lower the potential difference (step voltage). Thus, the risk of injury is considerably reduced.

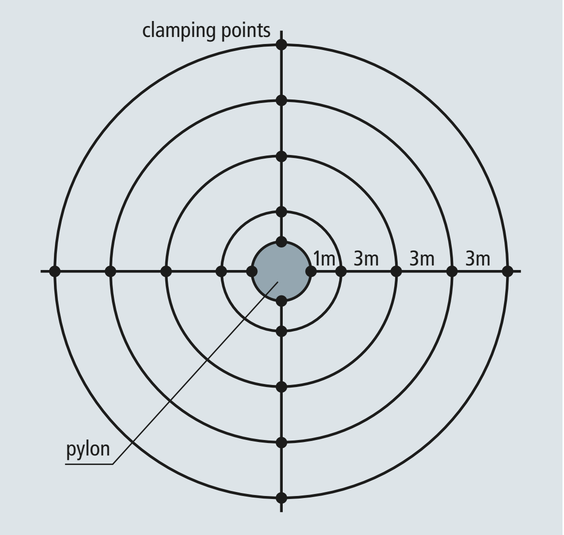


Figure 9.22.6a Potential control on a pylon

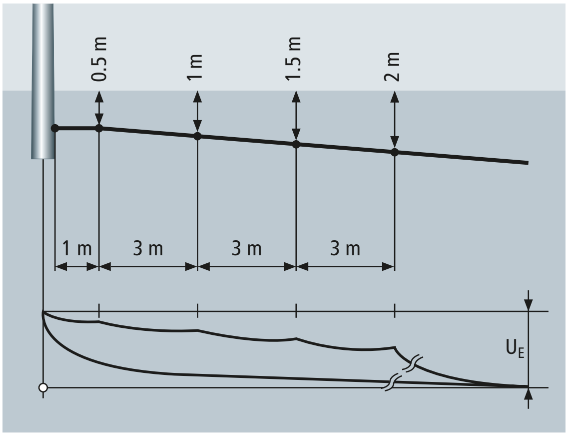


Figure 9.22.6b Potential control on a pylon

Lightning and surge protection for golf courses

Golf courses by nature extend over large areas and include many facilities such as club houses, caddy/trolley sheds (frequently with integrated driving range), locker/change rooms, halfway houses, shelters and golf cart parking lots/garages (with battery charging units). Widespread irrigation and sprinkler systems ensure the quality of the greens. Golf courses are often located in areas where low-voltage power supply is not readily available and receive power from the distribution network operator (DNO) as medium voltage (compact station).

In general, it is advisable to assess the risk resulting from a lightning strike for all concern areas of the golf course as per IEC 62305-2 (EN 62305-2) and to plan protection measures based on the results of this risk analysis.

Lightning protection measures are a combination of external lightning protection and lightning equipotential bonding for all service lines entering and leaving the building such as the metal gas and water pipes as well as power supply feeder and control lines.

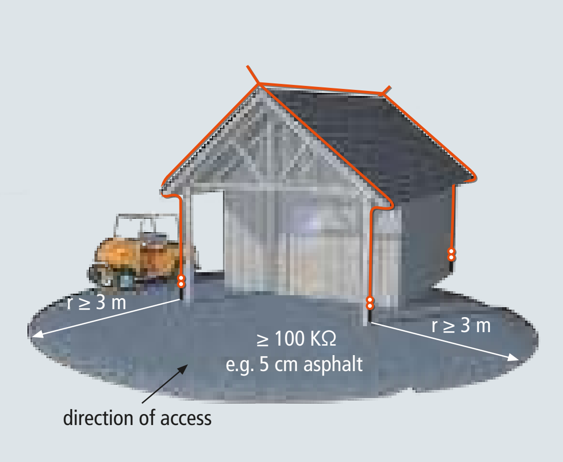


Figure 9.23.1 Protection of a shelter with one entrance and defined direction of access against step and touch voltage

Equipotential bonding measures in accordance with IEC 62305-3 (EN 62305-3) are e.g.

- Use of type 1 lightning current arresters (e.g. DEHNventil) for electrical lines
- Direct equipotential bonding of metal systems.

Protection against transients (resulting from indirect lightning interference or switching operations on the electrical supply system) is achieved by using type 2 surge arresters (e.g. DEHNguard), thus increasing system safety and availability. Normative information is given in IEC 62305-4 (EN 62305-4), IEC 60364-4-44 (HD 60364-4-443) as well as EN 50174-2.

Shelters

Shelters, for example on golf courses, must not only protect golfers from storm and rain, but also from lightning interference.

An external lightning protection system in combination with feasible measures to reduce inadmissibly high step and touch potentials at the entrance and in the shelter are required in case of a lightning strike (**Figure 9.23.1**). Shelters should not be installed at exposed locations (on hills, at the edge of a forest, underneath isolated trees). For more detailed information, please refer to chapter 9.28.

Club house

The power supply feeder cable to the main low-voltage distribution board is often located in the basement of the club house together with different sub-distribution boards supplying power to the restaurants, halfway house, offices, shops, and other detached buildings. Regardless of whether an external lightning protection system exists, a type 1 combined arrester should be installed in the main low-voltage distribution board to prevent potentially damaging lightning currents entering via the power supply feeder cable (**Figure 9.23.2**). The sub-distribution boards are equipped with type 2 surge arresters.

Telephone/data lines usually terminate in a dedicated service room of the club house. In the simplest case, several telephone lines and lines for data/internet access (U_{k0} lines) enter the building.

A type 1 combined arrester for IT equipment is installed for the U_{k0} lines near the entrance point into the building.

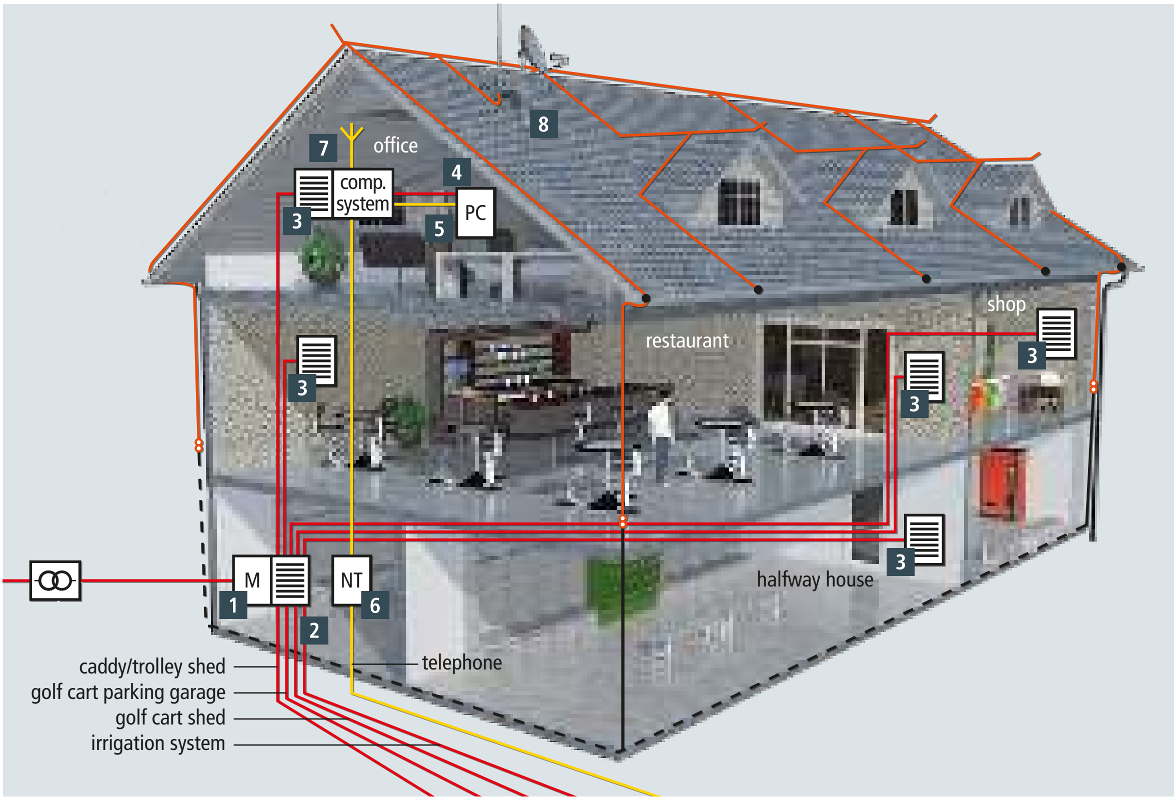
Office communication and RFID systems for ball machines, access control and renting of golf carts play an important function. Therefore, the network card should be protected by a surge arrester for LAN connections and the power supply by a type 3 surge arrester.

It is equally important to protect the protective circuit for the transmit/receive antenna of the RFID system or for the TV and radio satellite antenna near the entrance point into the building.

Caddy/trolley shed with integrated driving range

Measures to avoid inadmissibly high step and touch voltages in case of lightning interference are imperative. Protection measures are to be taken for highly frequented entrance and shelter areas. To this end, numerous measures can be employed, for example keeping a surface resistance ≥ 100 kΩ within a limited protective area of 3 m around the down conductor (e.g. 5 cm asphalt).

As described above, lightning equipotential bonding has to be implemented for the different systems directly at the entrance point into the building and, if necessary (depending on the



	Protection measures	System	Type	Part No.
1	Combined arrester (DIN rail)	TN-C system TN-S system TT system	DEHNventil DV M TNC 255 DEHNventil DV M TNS 255 DEHNventil DV M TT 255	951 300 951 400 951 310
	Combined arrester (busbar)	TN-C system TN-S system TT system	DEHNventil DV ZP TNC 255 DEHNventil DV ZP TT 255 DEHNventil DV ZP TT 255	900 390 900 391 900 391
2	I_{uv} → building exit < 15 m, lightning current arrester (DIN rail)	TN-S system TT system	4 x DEHNbloc DB M 1 255 3 x DEHNbloc DB M 1 255 + 1 x DEHNgap DGP M 255	961 120 961 120 + 961 101
3	Surge arrester (DIN rail)	TN-S system TT system	DEHNguard DG M TNS 275 DEHNguard DG M TT 275	952 400 952 310
4	Surge arrester (socket outlet)	All system configurations	DEHNflex DFL M 255 STC 230 module for socket outlets SFL Protector SFL PRO 6X	924 396 924 350 909 250

	Interface		Type	Part No.
5	LAN data network		DEHNpatch DPA M CAT6 RJ45S 48	929 100
6	Telephone	1 trunk 2 trunks	BLITZDUCTOR BXT ML2 BD 180 + BXT BAS base part BLITZDUCTOR BXT ML4 BD 180 + BXT BAS base part	920 247 + 920 300 920 347 + 920 300
7	WLAN antenna		DEHNgate DGA G BNC + angled fixing plate	929 042 + 106 329
8	Satellite antenna		DEHNgate DGA FF TV	909 703

Figure 9.23.2 Surge protection for the low-voltage and IT supply lines of a club house

	Protection measures	System	Type	Part No.
1	Combined arrester (DIN rail)	TN-S-System TT-System	DEHNventil DV M TNS 255 DEHNventil DV M TT 255	951 400 951 310
2	Surge arrester (socket outlet) Surge arrester (DIN rail)	All system configurations	DEHNflex DFL M 255 DEHNrail DR M 2P 255	924 396 953 200
	Interface		**Type**	**Part No.**
3	WLAN antenna		DEHNgate DGA G BNC + angled fixing plate	929 042 + 106 329

Figure 9.23.3 Caddy/trolley shed with integrated driving range protected against surges as well as step and touch voltage

results of the risk analysis), further surge protection measures upstream of the terminal device have to be provided (**Figure 9.23.3**).

The same protection measures as for the club house or the caddy/trolley shed with driving range have to be taken for the golf cart parking garage and the cart shed.

Irrigation system

Water is mostly is pumped from reservoirs. The necessary pumps are installed in underground ducts and are controlled and monitored from a service station (**Figure 9.23.4**).

The pressurised water pipe runs throughout the entire golf course. Sprinkler systems which are supplied by branch pipes water the individual greens and tees. The water flow is controlled via magnetic valves which are installed either directly at the sprinkler or in ground-level boxes. The magnetic valves which activate the individual sprinklers are controlled by decoders. Data transmission and power supply for the valves (e.g. 35 V/1 Hz, 1.1 A) is provided by a two-wire ring conductor. In some cases, this two-wire cable can be longer than 10 km. Connecting cables to the magnetic valves, however, do not exceed 150 m to limit any excessive voltage drop.

The long two-wire ring conductor and the extremely long conductors to the magnetic valves provide the highest risk in terms of surges. In practice, therefore corresponding surge protective devices are installed on the two-wire ring conductor at intervals not exceeding 150 m. For locally earthing the surge protective devices, suitable corrosion-resistant earth-termination systems (earth rods or radial earth electrodes) are installed. These should be implemented simultaneously with the installation of the pressurised water reticulation pipe and the two-wire ring conductor.

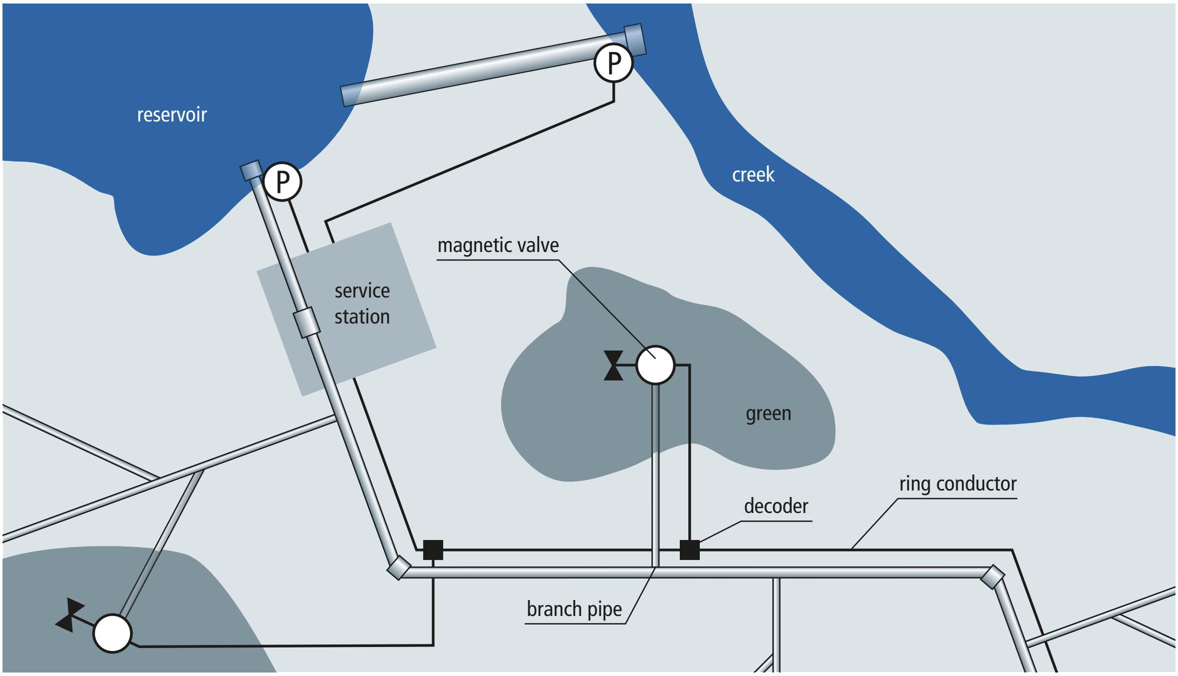
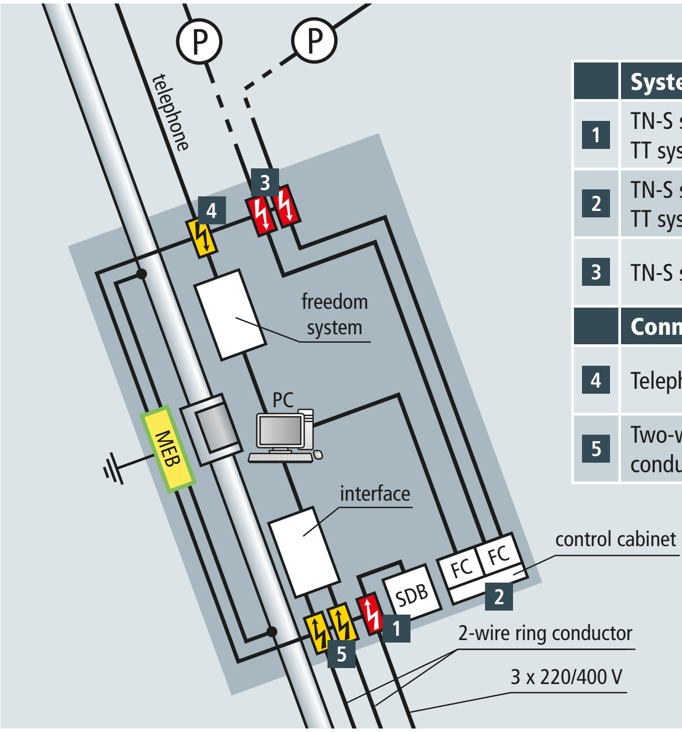


Figure 9.23.4 Pressurised pipe with branch pipes, magnetic valves, two-wire ring conductor and decoders



	System	**Type**	**Part No.**
1	TN-S system TT system	DV M TNS 255 DV M TT 255	951 400 951 310
2	TN-S system TT system	DG M TNS 275 DG M TT 275	952 400 952 310
3	TN-S system	DB M 1 760 FM (3x) + DG S WE 600	961 175 952 077
	Connection	**Type**	**Part No.**
4	Telephone U_{K0}	BXT ML2 BD 180 + BXT BAS base part	920 247 920 300
5	Two-wire ring conductor	BVT ALD 36	918 408

Figure 9.23.5 Service station with power distribution board, control cabinet of the irrigation system, PC, interface and data management system

Service station

Lightning equipotential bonding has to be implemented at the entry point into the service station for the pressurised water pipe, the two-wire ring conductor, the IT and the power supply feeder cable and the pump line.

It depends on the building size whether further surge protection measures are necessary for the internal conductors upstream of the corresponding control systems (**Figure 9.23.5**).

The described practical solutions are just examples. Lightning and surge protection have to be individually adjusted to the natural and structural conditions.

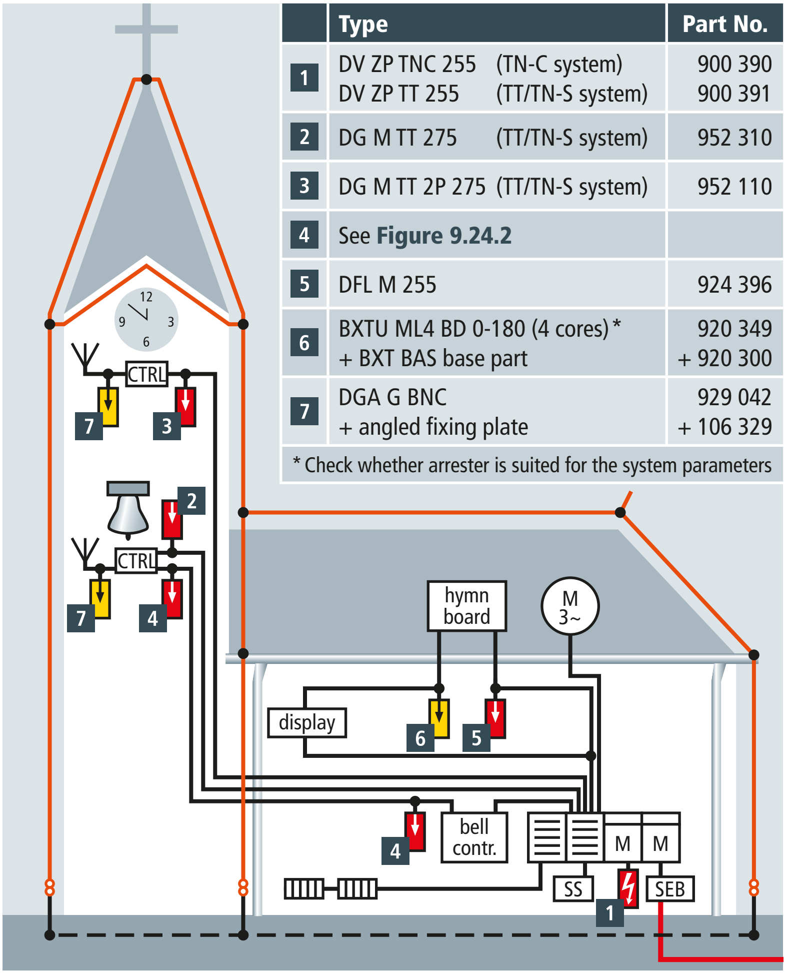
Surge protection for churches

Churches are buildings of high cultural value and places of public assembly. Therefore, they must be equipped with permanently effective lightning protection systems as described in chapter 18 of Supplement 2 of the German DIN EN 62305-3 lightning protection standard.
The IEC 62305-4 (EN 62305-4) lightning protection standard describes how to implement surge protection measures. Moreover, the IEC 60364-1 (HD 60364-1) standard requires that "property shall be protected against damage as a consequence of overvoltages such as those originating from atmospheric events or from switching" (section 131.6.2).

Figure 9.24.1 shows an example of the standard equipment of a church. The circuit of the control line of the bell controller is illustrated in detail in **Figure 9.24.2**.
If the separation distance s is maintained between the down conductors / lightning current carrying parts and the cables installed in the steeple, flashover is not to be expected, however electromagnetic coupling may occur. The following measures can be taken to minimise electromagnetic coupling:

- Short cable lengths
- No / little loop formation

If these measures are not feasible, surge protective devices must be installed.



	Type	Part No.
1	DV ZP TNC 255 (TN-C system) DV ZP TT 255 (TT/TN-S system)	900 390 900 391
2	DG M TT 275 (TT/TN-S system)	952 310
3	DG M TT 2P 275 (TT/TN-S system)	952 110
4	See **Figure 9.24.2**	
5	DFL M 255	924 396
6	BXTU ML4 BD 0-180 (4 cores) * + BXT BAS base part	920 349 + 920 300
7	DGA G BNC + angled fixing plate	929 042 + 106 329

* Check whether arrester is suited for the system parameters

Figure 9.24.1 Principle of external and internal lightning protection for a church with steeple

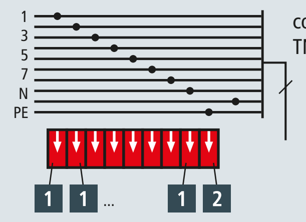
Lightning equipotential bonding

A lightning protection system requires lightning equipotential bonding for metallic systems and all buried cables entering the building. In case of churches, equipotential bonding must always be established for the low-voltage supply and other cables, if any (e.g. escape lighting).

Surge protection

The cables in the bell tower and nave such as the cables of the electric clock mechanism and the bell controller are frequently long and / or form loops. These two systems are time synchronised via the DCF 77 signal.
If the electrical hymn board is not radio controlled, electromagnetic coupling is to be expected.

In addition to the systems described before, the pipe heating system, electronic organ and sound system are also highly susceptible to electromagnetic coupling.
In the example shown, a separate earthing conductor to the main earthing busbar is not required for type 2 surge protective devices (230 V or 230/400 V) for power supply systems since the first surge protective device is already earthed.



control line NYY-J 10 x 2.5 mm^2
TN-S or TT system

	Type	Part No.
1	DG S 275	952 070
2	DGP C S	952 030

Figure 9.24.2 Example of surge protective devices for the bell controller

Surge protection for light strips

For economic reasons, fluorescent tubes (with a diameter of 26 mm or 16 mm) and electronic ballasts are used for light strips in industrial, commercial and agricultural buildings.

In high halls, light strips with an extremely narrow-beam illumination are installed. In this case, the regular replacement of luminaires alone (about 16,000 lighting hours in case of 26 mm tubes, about 20,000 lighting hours in case of 16 mm tubes) entails high costs since aerial lift devices are required and the luminaires are usually replaced outside working hours.

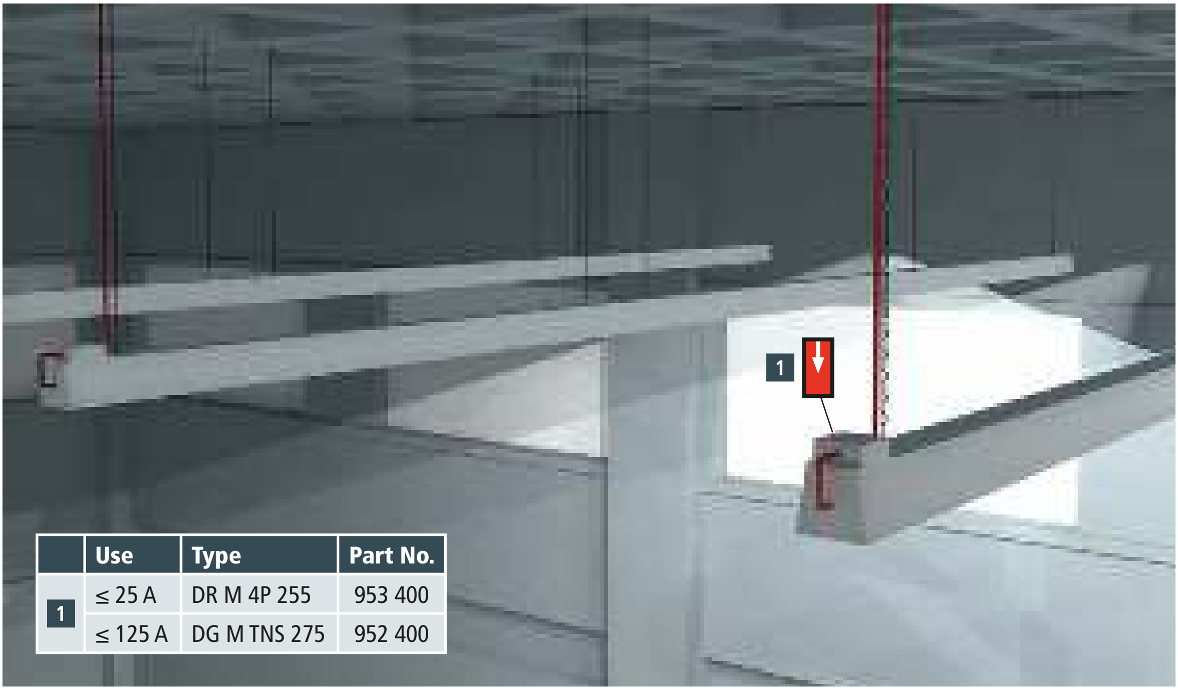
But what if individual electronic ballasts are destroyed by surges or an entire light strip fails? In this case, immediate action is required since the necessary minimum illumination is frequently no longer ensured which may lead to a decrease in work performance and accidents.
The IEC 60364-4-44 (HD 60364-4-44) standard deals with the "protection against overvoltages of atmospheric origin or due to switching". Section 443.3.2.2 describes that surge protective devices (type 2 or type 3 arresters) can be used for commercial buildings.
The often long supply lines of the light strips are highly susceptible to surges. Even a type 2 surge arrester or type 1 combined arrester in the power distribution board cannot prevent that the voltage peak is displaced into the lamps. Therefore, an additional surge arrester must be installed in close proximity to the light strip.

The risk of surges entering the light strips is considerably reduced if the frequently used class I light strips (PE connection) are installed. If light strips feature luminaires with double or reinforced insulation, the light strip cables are often routed in a metal rail and are thus largely protected due to shielded design of the metal rail.

In practice, light strips are operated with alternating current (230 V / 50 Hz) and three-phase current (3x 230/400 V / 50 Hz). For both types of supply, the maximum number of luminaires to be connected depends on the cross-section of the series connected cables. To be able to consider the inrush currents of the electronic ballasts for the fuses, the luminaire manufacturer specifies the maximum number of the relevant luminaires depending on the rated currents of the overcurrent protective devices. This means that only 13 T26/58 W twin-lamp electronic ballasts may be connected to e.g. a 16 A circuit breaker with characteristic B although the operating current is 13 x 0.58 A = 7.54 A. Since luminaires do not cause overload, the line must only be protected against short-circuits. The volt-

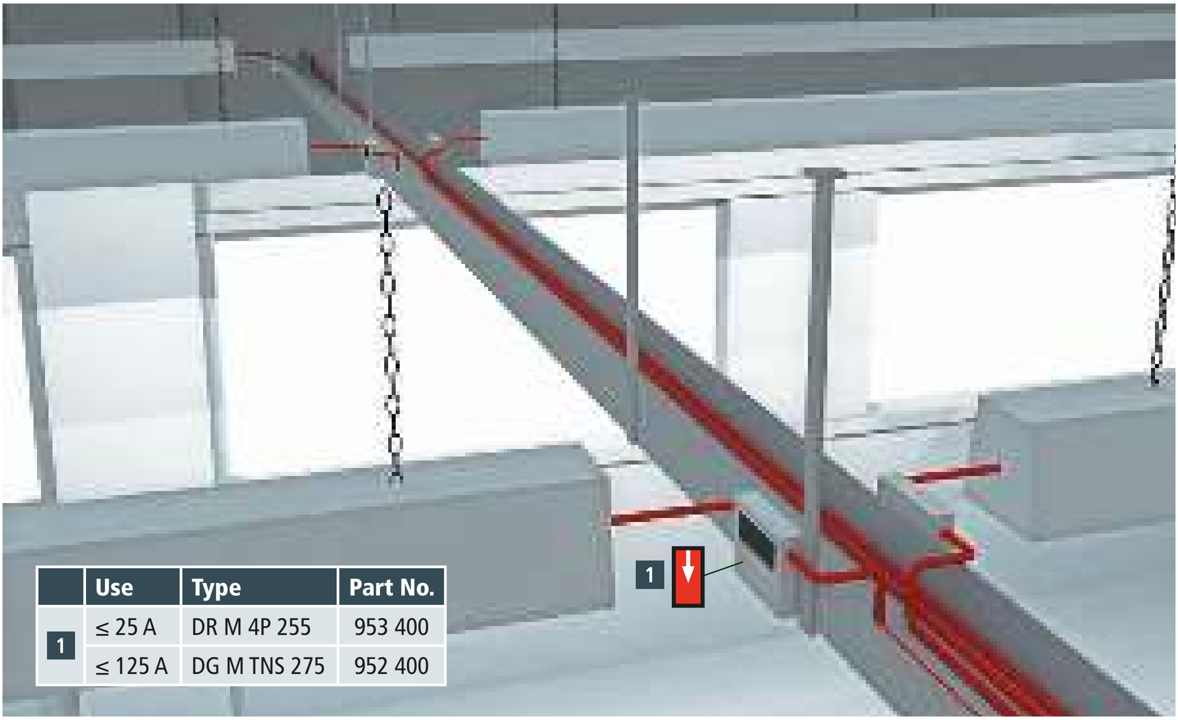

	Type	Part No.
1	DFL M 255	924 396

Figure 9.25.1 Type 3 surge arrester installed in an office luminaire



	Use	Type	Part No.
1	≤ 25 A	DR M 4P 255	953 400
	≤ 125 A	DG M TNS 275	952 400

Figure 9.25.2 Type 2 / type 3 surge arrester in a flush-mounted enclosure installed on the mounting rail of a light strip



	Use	Type	Part No.
1	≤ 25 A	DR M 4P 255	953 400
	≤ 125 A	DG M TNS 275	952 400

Figure 9.25.3 Type 2 / type 3 surge arrester in a flush-mounted enclosure installed on a cable tray

age drop is also not determined depending on the rated current of the overcurrent protective device, but on the operating current of the luminaires.

In practice, type 3 surge arresters are used to protect small-sized light strips operated with alternating current with backup fuses up to 16 A (**Figure 9.25.1**). Thanks to their compact design, these surge arresters can be installed in the luminaire housing.

For light strips operated with three-phase current with backup fuses up to 25 A, it is advisable to use DIN rail mounted type 3 surge arresters in a flush-mounted enclosure with an adequate degree of protection which can be directly installed on the DIN rail (**Figure 9.25.2**). This type of installation is recommended for the supply lines of pendent luminaires (length of several metres).

The flush-mounted enclosure should be installed at the cable tray if the light strips described above are mounted next to a ceiling (**Figure 9.25.3**).

If powerful light strips are supplied with three-phase current (nominal current > 25 A) via long cable distances, larger cross-sections must frequently be installed due to the voltage drop and the loop impedance. In such cases, the cable cross-section close to the connection point of the light strip is reduced to the cross-section to be connected to the terminal (in the majority of cases 2.5 mm^2) via a junction box. To this end, it is advisable to install type 2 surge arresters which are available for TN-S and TT systems. These surge arresters may only be used for backup fuses up to max. 125 A which is out of the question due to the short-circuit load on the light strip wiring.

Surge protection for lifts

The function of lifts is to transport persons and goods in private and commercial buildings. Hydraulic lifts are frequently used for low lifting heights, otherwise counterbalanced cable lifts are used. Passenger lifts have a speed of about 1 m/s and higher (medium-sized buildings/multi-storey buildings up to 8 m/s and next generation of multi-storey buildings up to 17 m/s). Goods lifts have transportation capacities up to 5 tonnes.

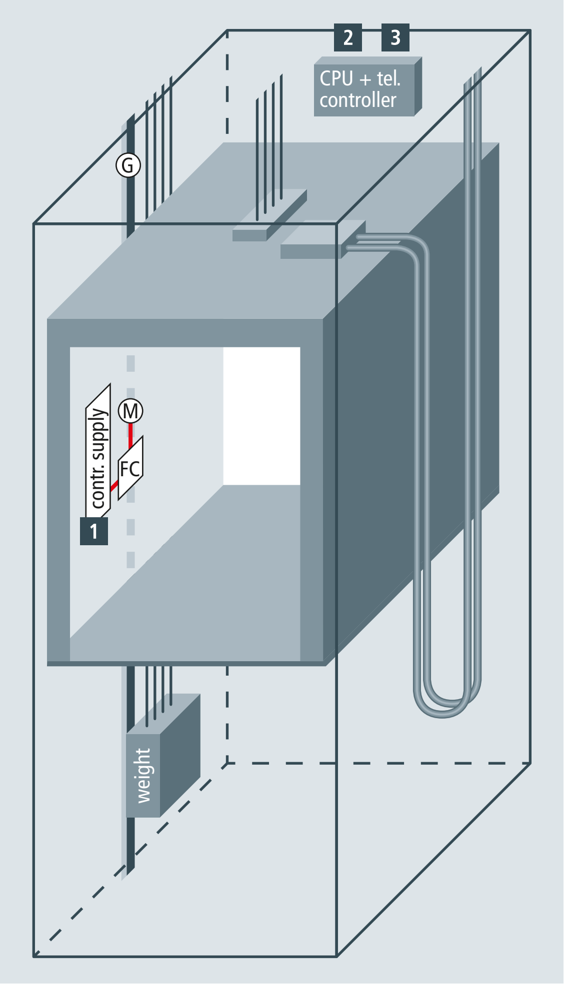
Lifts fulfil several functions such as:

- Smooth starting and stopping controlled by a frequency converter
- Traffic optimisation measures (e.g. no stop in case of full load, priority travels, behaviour of lifts in case of fire)
- Energy saving function (cabin lighting and ventilator are switched off in case of empty travels or standstill)
- Power supply function (the kinetic energy generated by goods transport to the ground floor and empty travels to the top floors is fed into the power supply system)

These functions can only be fulfilled by means of highly sensitive electronic systems.

Lift manufacturers take various measures to reduce injection into the lift cabling/technology to an acceptable level. Be it shielded metallic distribution boards or the type of cable routing or cable – all these measures cannot prevent that conducted transients damage the lift.

The peripheral units of lifts such as floor panels or floor displays are connected to prewired plug-in connecting cables. Thus, surge protective devices are only required for the mains connection, the telephone line and the fire alarm system, if any (**Figure 9.26.1**).



	Use	Type	Part No.
1	TN-S system TT system	DG M TNS 275 DG M TT 275	952 400 952 310
2	Telephone U_{K0}/ extension	BXT ML2 BD 180 + BXT BAS	920 247 920 300
3	Fire control panel ➡ PLC	BXT ML2 BE S 24 + BXT BAS	920 224 920 300

Figure 9.26.1 Surge protective devices for a lift

Surge protection for smoke and heat extraction systems

To be able to safely leave a structure in case of fire, escape routes must be kept free of smoke which causes orientation and breathing problems.
Smoke and heat extraction systems are both equipped with manual call points and automatic detectors which detect the smoke or heat produced and extract it from the escape route via electromechanically or pneumatically driven windows or domelights. In addition to this main function, the windows or domelights are also used for ventilation. For this purpose, additional switching devices are available which are capable of issuing switching commands of lower importance. Since the availability of smoke and heat extraction systems must be ensured even in the event of power failure, the fire control panels are equipped with accumulators which supply the smoke and heat extraction systems. Therefore, the actuators of the windows and domelights are dimensioned for d.c. operation.

The surge protective devices in the examples described below are dimensioned based on a voltage of 24 V d.c. which is commonly used in this industry. Moreover, electromechanically driven domelights with a maximum nominal current of less than 1.8 A or 4 A d.c. are used.

Structure with non-metal roof and external lightning protection system

Embedded or protruding roof-mounted structures on structures with external lightning protection system must be located in the protected volume of air-termination systems as per IEC 62305-3 (EN 62305-3) under consideration of the separation distance s if the following limit values are exceeded:

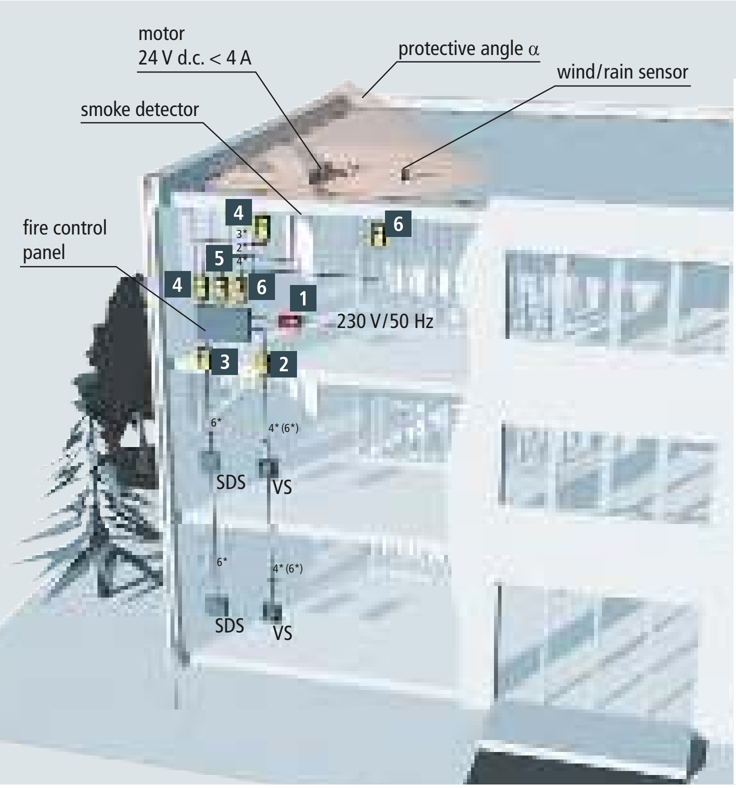
Embedded or protruding metal roof-mounted structures:

- ➡ Height above the roof level: 0.3 m
- ➡ Total area of the roof-mounted structure: 1.0 m^2
- ➡ Length of the roof-mounted structure: 2.0 m

Embedded or protruding non-metal roof-mounted structures:

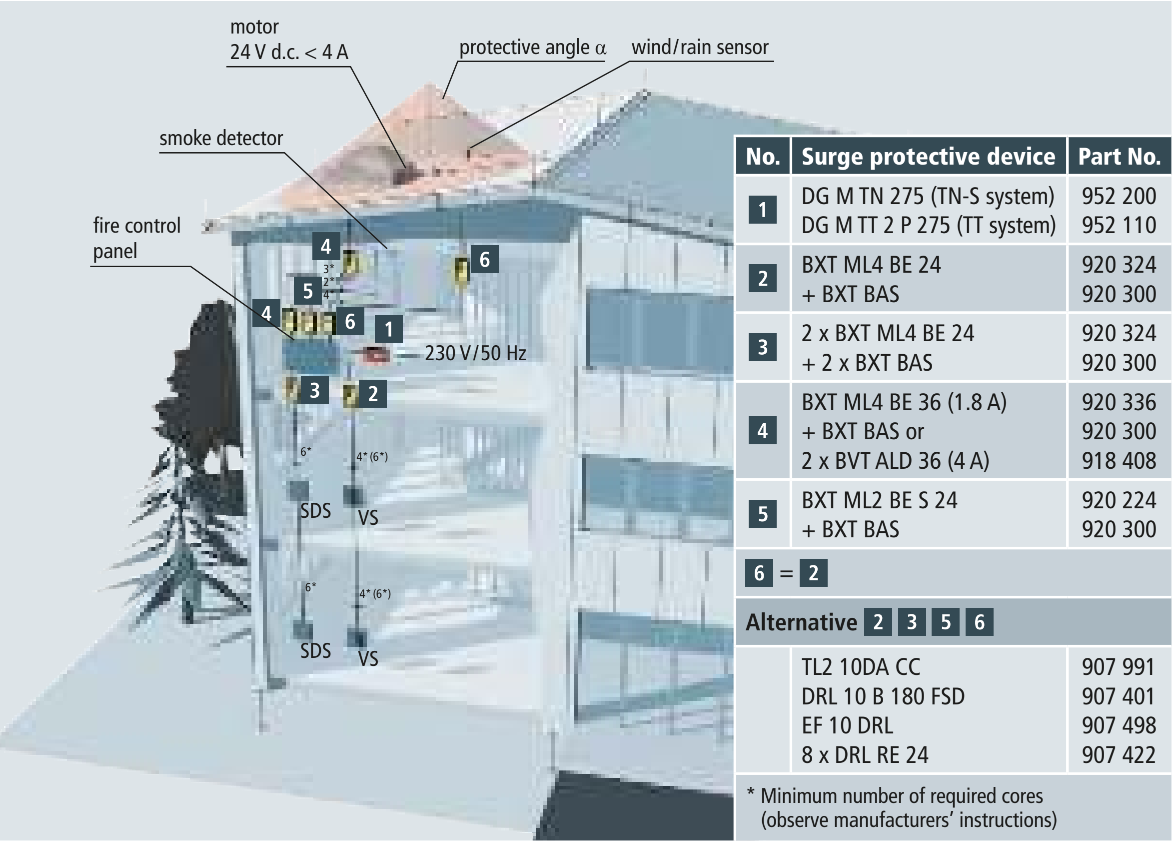
- ➡ Height above the air-termination system: 0.5 m

Due to the above requirements, domelights of a certain size must be protected against lightning strikes. If air-termination rods are installed, the domelights are located in LPZ 0_B which means that no lightning current is injected into the equipment



No.	Surge protective device	Part No.
1	DG M TN 275 (TN-S system) DG M TT 2 P 275 (TT system)	952 200 952 110
2	BXT ML4 BE 24 + BXT BAS	920 324 920 300
3	2 x BXT ML4 BE 24 + 2 x BXT BAS	920 324 920 300
4	BXT ML4 BE 36 (1.8 A) + BXT BAS or 2 x BVT ALD 36 (4 A)	920 336 920 300 918 408
5	BXT ML2 BE S 24 + BXT BAS	920 224 920 300
6 = 2		
Alternative 2 3 5 6		
	TL2 10DA CC DRL 10 B 180 FSD EF 10 DRL 8 x DRL RE 24	907 991 907 401 907 498 907 422
* Minimum number of required cores (observe manufacturers' instructions)		

Figure 9.27.1 Domelight located in the protected volume of an air-termination rod on a non-metal roof of a structure with external lightning protection system



No.	Surge protective device	Part No.
1	DG M TN 275 (TN-S system) DG M TT 2 P 275 (TT system)	952 200 952 110
2	BXT ML4 BE 24 + BXT BAS	920 324 920 300
3	2 x BXT ML4 BE 24 + 2 x BXT BAS	920 324 920 300
4	BXT ML4 BE 36 (1.8 A) + BXT BAS or 2 x BVT ALD 36 (4 A)	920 336 920 300 918 408
5	BXT ML2 BE S 24 + BXT BAS	920 224 920 300
6 = 2		
Alternative 2 3 5 6		
	TL2 10DA CC DRL 10 B 180 FSD EF 10 DRL 8 x DRL RE 24	907 991 907 401 907 498 907 422

* Minimum number of required cores (observe manufacturers' instructions)

Figure 9.27.2 Domelight located in the protected volume of an air-termination rod on a metal roof of a structure with metal down conductor (steel frame, interconnected reinforced concrete or earthed metal facade)

installed in this zone (**Figure 9.27.1**). A surge arrester prevents inductive coupling in this zone.

Structure with metal roof and external lightning protection system

In contrast to structures with non-metal roofs and external lightning protection system, different normative requirements are placed on the lightning current carrying capability of metal roofs which are used as air-termination system:

1. The metal roof can be used as natural air-termination system if the manufacturer confirms that it suited for this purpose (DIN EN 62305-3, Supplement 4).
2. The metal roof does not have the required thickness t' (IEC 62305-3 (EN 62305-3), Table 3) and must be protected against direct lightning strikes by means of air-termination systems since perforation can cause fire due to the highly flammable materials (or wooden boards) underneath the tin roof and the ingress of water can no longer be prevented. The air-termination systems must be interconnected by means of lightning current carrying conductors if there is no other lightning current carrying connection (e.g. by means of tested terminals, brazing, welding, squeezing, seaming, screwing or riveting).
3. The metal roof has the required thickness t (IEC 62305-3 (EN 62305-3), Table 3)

There are two types of down conductors for the metal roofs described before:

A. The walls consist of an interconnected lightning current carrying steel reinforcement or a steel frame construction. In both cases, the separation distance does not have to be considered since either the current is very low due to the high number of current paths (reinforcements) or the low inductance (steel beams) does not cause puncture to other metal systems. Metal façades which are connected to the earth-termination system at intervals of 15 m at the lowest point (ground) also meet the requirements described above.

No.	Surge protective device	Part No.
1	DG M TN 275 (TN-S system) DG M TT 2 P 275 (TT system)	952 200 952 110
2	BXT ML4 BE 24 + BXT BAS	920 324 920 300
3	2 x BXT ML4 BE 24 + 2 x BXT BAS	920 324 920 300
4	BXT ML4 BE 36 (1.8 A) + BXT BAS or 2 x BVT ALD 36 (4 A)	920 336 920 300 918 408
5	BXT ML2 BE S 24 + BXT BAS	920 224 920 300
6 = 2		
Alternative 2 3 5 6		
	TL2 10DA CC DRL 10 B 180 FSD EF 10 DRL 8 x DRL RE 24	907 991 907 401 907 498 907 422

* Minimum number of required cores (observe manufacturers' instructions)

Figure 9.27.3 Domelight located in the protected volume of an air-termination rod on a metal roof of a structure equipped with conventional arresters

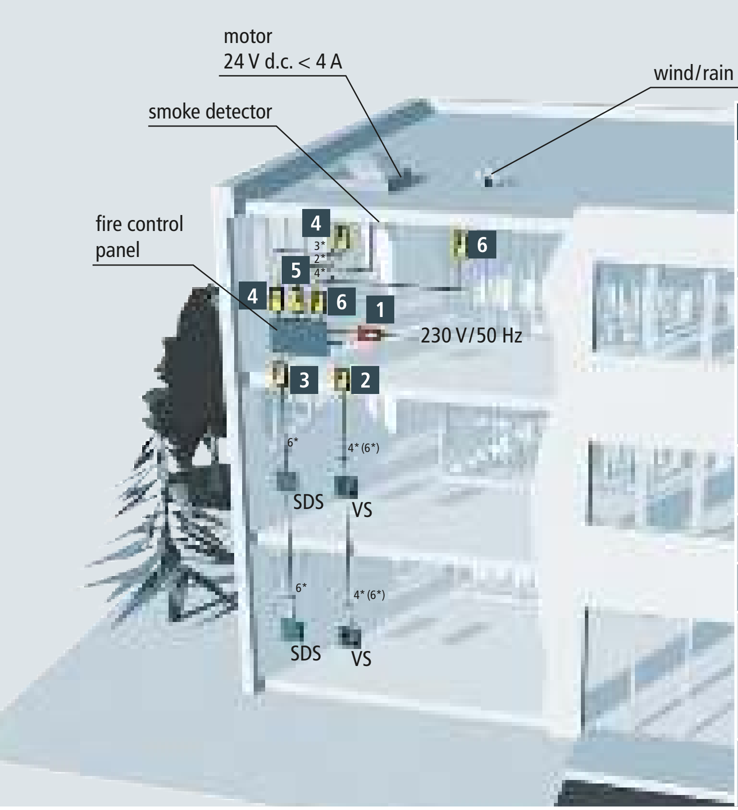
B. The walls consist of non-conductive material (bricks, wood, etc.) and the down conductors are connected to the earth-termination system at the intervals required by the class of LPS.

Different combinations of air-termination systems (see 1., 2., 3.) and down conductors (see A., B.) can be used. Ignitable sparkover does not occur in structures with air-termination systems and down conductors in the combinations 1.+A., 2.+A. or 3.+A. Air-termination systems must be installed to prevent lightning strikes to the domelights. Thus, the domelights are protected against direct lightning strikes, however, they are not located in LPZ 0_B since the air-termination systems directly conduct the lightning current to the metal roof, thus spreading the lightning current over a large area. In view of the fact that lightning may also strike in the vicinity of the domelights, it is recommended to install a lightning current arrester (**Figure 9.27.2**).

A structure with a metal roof and conventional down conductors is considered to be critical (**Figure 9.27.3**). In case of a lightning strike, the lightning current will be evenly distributed between the down conductors. Nevertheless, the structure is still at risk and the relevant separation distance must be maintained. Air-termination systems must also be installed to prevent direct lightning strikes to this type of structure, however, the domelight is not located in LPZ 0_B. Since partial lightning currents may flow into the structure via the cable for the drive of the smoke and heat extraction system, a lightning current arrester must be installed. Due to their size, structures with domelights typically have several down conductors which prevent overload of the lightning current arrester.

Structure without external lightning protection system

No distinction has to be made between metal or non-metal roofs since every direct lightning strike to the structure pre-



No.	Surge protective device	Part No.
1	DG M TN 275 (TN-S system) DG M TT 2 P 275 (TT system)	952 200 952 110
2	BXT ML4 BE 24 + BXT BAS	920 324 920 300
3	2 x BXT ML4 BE 24 + 2 x BXT BAS	920 324 920 300
4	BXT ML4 BE 36 (1.8 A) + BXT BAS or 2 x BVT ALD 36 (4 A)	920 336 920 300 918 408
5	BXT ML2 BE S 24 + BXT BAS	920 224 920 300
6 = 2		
Alternative 2 3 5 6		
	TL2 10DA CC DRL 10 B 180 FSD EF 10 DRL 8 x DRL RE 24	907 991 907 401 907 498 907 422

* Minimum number of required cores (observe manufacturers' instructions)

Figure 9.27.4 Domelight located on a non-metal roof of a structure without external lightning protection system

sents a fire hazard. Lightning current arresters are not capable of coping with direct lightning strikes to the domelights. Therefore, surge arresters must be installed to protect the structure from inductive coupling (**Figure 9.27.4**).

General instructions on lightning protection for shelters

About 1.5 million lightning incidents are registered in Germany each year. Lightning is fascinating to watch, but also extremely dangerous. Annually, thunderstorms kill people and animals and destroy material assets. Especially people exposed in the open such as golfers and hikers are at risk. Severe lightning injuries and fatalities are reported each year from all over the world, especially on golf courses. For this reason, shelters are vital to protect golfers from lightning interference. In the following, general instructions on lightning protection measures for shelters will be provided.

Shelters, for example on golf courses, must not only protect golfers from storm and rain, but also from lightning interference. For this reason, there is no question that shelters must be equipped with a lightning protection system. Golf course operators have a high duty of care towards their members / golfers. The liability of, for example golf course operators, is based on their duty to implement safety precautions. *"Golf course operators have a duty towards each golf course user to avoid all impending or existing hazards unless this is impossible or unreasonable for the golf course operator. This duty includes both organisational and structural measures. The number, equipment, size and position of lightning-proof shelters heavily depend on the size, location and design of the relevant golf course. Lightning-proof shelters must comply with the latest applicable technical requirements. Limitation of liability due to a lack or insufficient number of lightning-proof-shelters or their insufficient equipment, for example in the form of a relevant notice or a written agreement on limitation of liability, shall be excluded."* (translation of page 7 of the 6/2010 edition of the German "Golfmanager" magazine, author: Daniel Witaschek)

Shelters

Shelters should not be installed at exposed locations (on hills, at the edge of a forest, underneath isolated trees) and near hedges and branches within a radius of about 3 m.

Shelters are only lightning-proof if

- They are equipped with an adequate lightning protection system including potential control
- Conductive systems (e.g. electrical cables) are integrated in the equipotential bonding system and
- Suitable measures are taken to prevent touch voltages

Lightning protection

Frequently, a lightning protection system is simply called a lightning rod. As shown in **Figure 9.28.1**, the lightning protection system of a shelter consists of a rooftop air-termination system (air-termination conductor and / or rod), wall-mounted down conductor (down conductor wire) and earth-termination system (commonly an earth rod). The function of a lightning

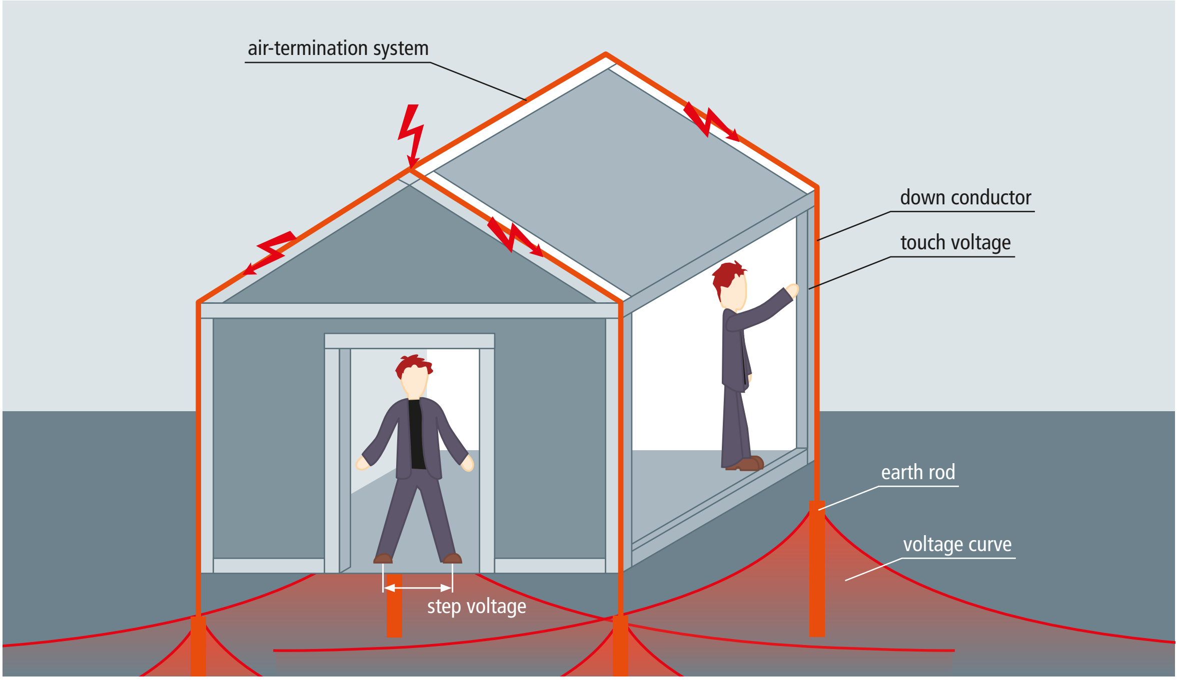


Figure 9.28.1 Risk due to touch and step voltage

rod is to intercept lightning and to safely conduct it to the ground to prevent dangerous sparking, thus protecting the structure from fire and mechanical destruction. The formation of a high lightning voltage in the ground, also referred to as potential gradient area, endangers persons in the shelter. This life-threatening voltage may flow into the feet of a person standing on the ground. It is therefore also referred to as step voltage. Moreover, persons must maintain an adequate safety distance from the lightning rod to prevent dangerous touch voltages (**Figure 9.28.1**).

Effective lightning protection measures that protect golfers, hikers, etc. from lightning interference can be taken for shelters with a relatively low effort. In addition to technical measures, it is equally important that golfers know what to do during a thunderstorm. In an upcoming thunderstorm, they should seek shelter immediately and stay there until the thunderstorm has disappeared.

The following considerations are based on commonly used wood shelters.

Prevention of touch voltages

To prevent dangerous high touch voltages, an adequate safety distance must be maintained between the lightning rod and the persons in the shelter. In a shelter of about 3 m x 3 m with an eaves height of 3 m and the lightning rod shown in **Figure 9.28.2**, 10 cm wooden beams are required.

If the shelter has a minimum height of about 3 m, the safety distance from the rooftop lightning rod (air-termination conductor or rod) is maintained. However, it is more difficult to keep an adequate distance from the outer walls. Therefore, the wall/wall construction where the lightning rod (down conductor wire) is led to the ground must have an adequate wall thickness (**Figure 9.28.2**). To connect the lightning rod to the ground, earth rods (metal rods of a defined length, material suitable for the local conditions) are commonly used. On each down conductor, the earth rods are vertically buried in the ground at a depth of about 6 m to 9 m depending on the type of ground (**Figures 9.28.2 to 9.28.5**).

Log-structured shelters usually have the above mentioned wall thickness. However, the situation is quite different when it comes to shelters with thin wood walls. In this case, the down conductors must be installed directly at the outer edges near the wall construction to ensure the maximum wall thickness (**Figure 9.28.2**). As an alternative, an isolated lightning protection system* can be used.

(* Extensive expert knowledge is required. For this reason, please contact a certified lightning protection specialist (for example, in Germany VDE-certified (Verband der Elektrotechnik Elektronik Informationstechnik) or VDB-certified (Verband Deutscher Blitzschutzfirmen e.V.) lightning protection experts).

Another possibility to maintain the safety distance required to protect shelters in case of a lightning strike is to use highly insulating lightning rods, for example CUI Conductors from

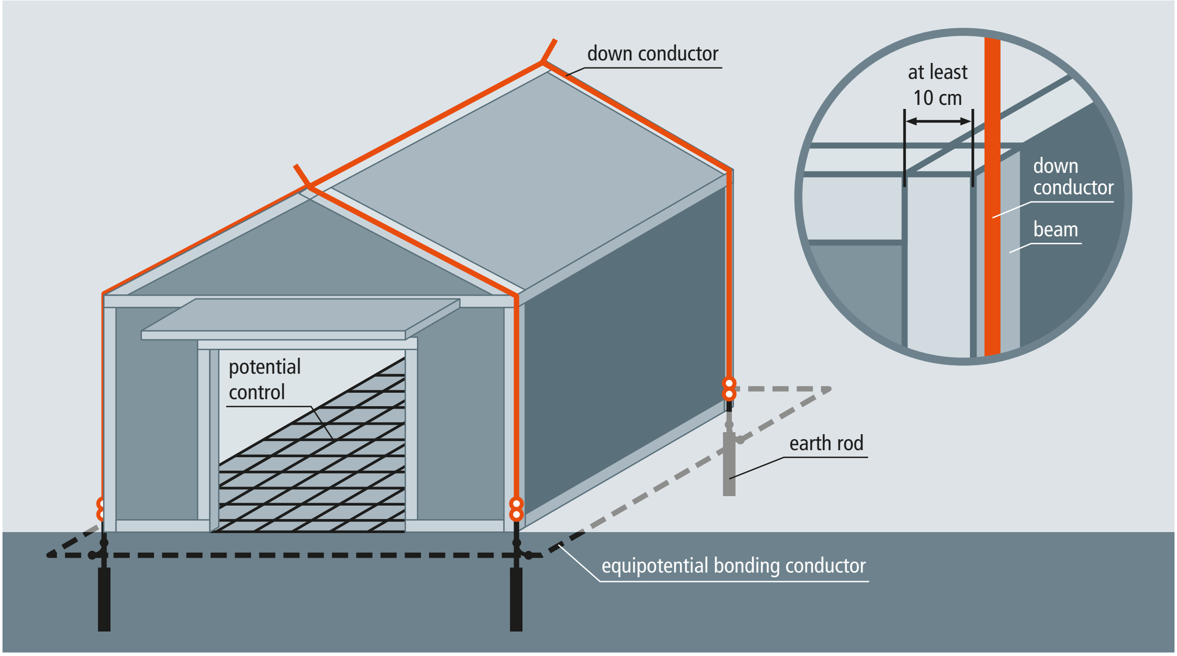


Figure 9.28.2 Installation of a down conductor at the side beams to ensure that the separation distance is maintained

DEHN (**Figure 9.28.3**). This is particularly required for shelters that are even smaller than those described above.

Prevention of step voltages

Dangerous high step voltages resulting from a lightning strike to the lightning rod of a shelter or a nearby lightning strike must be prevented in shelters. There are two options:

a) Prevention of dangerous step voltages by insulating the floor

This means that the floor must be covered by e.g. a 5 cm asphalt layer. As an alternative, a wood floor can be used that maintains a sufficient distance from the ground to ensure adequate ventilation and that remains dry in any circumstance. Moreover, adequate measures must be taken to prevent that plants grow through the shelter (**Figure 9.28.4**).

b) Prevention of step voltages by means of potential control

Another protection measure is potential control, namely the integration of a finely meshed metal grid (e.g. reinforcement steel mat laid in concrete or a buried meshed earth electrode with a mesh size smaller than 0.25 m x 0.25 m) directly in the ground below the standing surface of persons. To ensure a long service life of this metal grid, it is advisable to use 10 mm round conductors made of stainless steel (V4A) (e.g. material number AISI/ASTM 316 Ti). These round conductors are installed max. 0.1 m below the

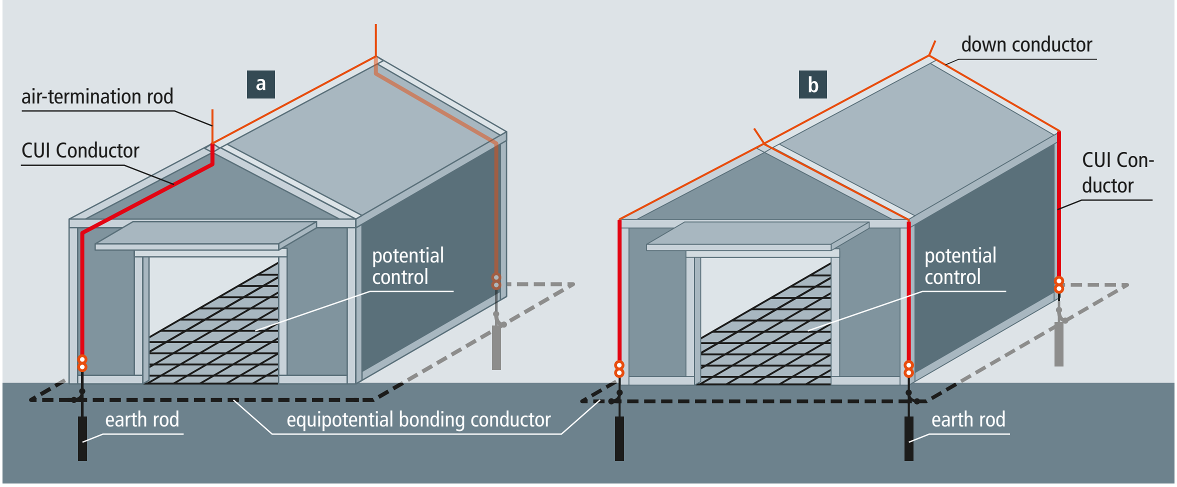


Figure 9.28.3 Installation of a high-voltage-resistant CUI Conductor: a) in case of a small shelter with two air-termination rods; b) in case of insufficient wall thicknesses

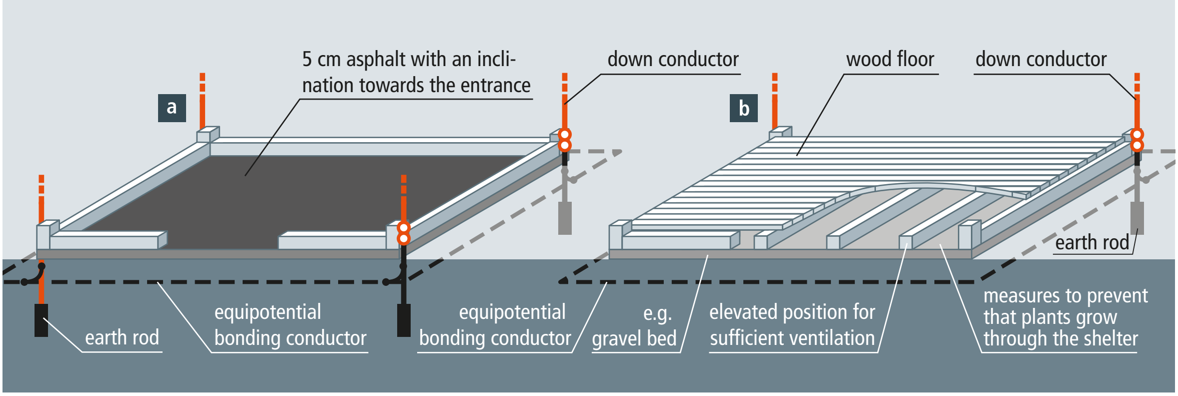


Figure 9.28.4 Insulation of the standing surface to prevent step voltage: a) by means of asphalt; b) by means of a wood floor

ground surface at intervals of less than 0.25 m x 0.25 m and must be connected by means of adequate clamps on all junctions and down conductors (**Figure 9.28.5**).

Shelters located in the protected volume of an isolated air-termination system

Since an air-termination mast (isolated lightning protection system) installed at a certain safety distance protects the shelter from lightning strikes, potential control must be provided in the shelter (**Figure 9.28.6**). Telescopic lightning protection masts with screw-in foundation (Part No. 830 208) from DEHN can be used as air-termination masts. These masts are commonly used for existing shelters where the separation distance from the rooftop air-termination system and the down conductor cannot be maintained due to their small size.

Metal shelters

In metal shelters (roof, walls and floor) golfers are not at risk if they touch the metal construction. An earth-termination system as well as a metal floor or metal grid (potential control) as described before must be installed. Nevertheless, melting of the roof of the shelter must be prevented, in other words the roof material must have a minimum thickness (IEC 62305-3 (EN 62305-3), Table 3, thickness t) to ensure personal protection. If the metal does not have the required thickness, air-termination rods must be installed on the metal roof and must be connected to it in such a way that it can carry lightning currents.

Summary

In general, golfers must stay in shelters for about 30 minutes after they hear the last rumble of thunder. Only then, the thunder cell is far enough away.
Shelters on golf courses or hiking trails require both a lightning rod and adequate measures to reduce the risk of inadmissibly high touch and step voltages. As described above, these measures can be implemented by simple means.

The IEC 62305 (EN 62305) standard series includes fundamentals and an overall lightning protection concept. For more detailed information on lightning protection, please contact approved lightning protection companies or visit *www.dehn-international.com.*

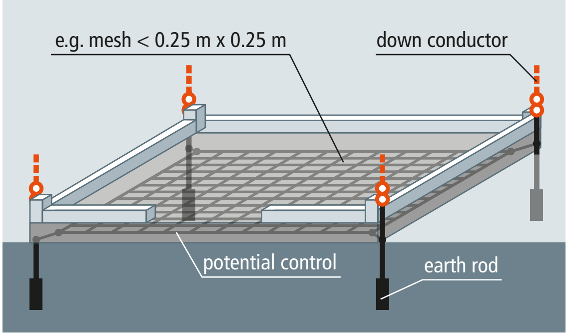


Figure 9.28.5 Potential control to reduce step voltage

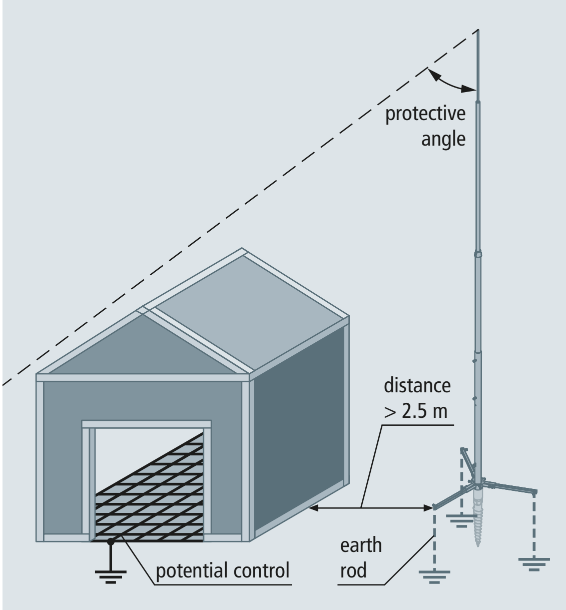


Figure 9.28.6 Isolated lightning protection system with telescopic lightning protection mast

Surge protection for gutter heating systems

Solar radiation and waste heat from buildings may melt ice or snow even under frost conditions. Such melt water then refreezes, preventing water from draining away and causing it to back up. As a result, the roof drainage is blocked and icicles may form which involves an increased risk.

An even more serious problem is a heavy snow and ice build up on the roof that may exceed the maximum load capacity of the roof.
Gutter heating systems prevent damage provided that their reliable function is ensured even under lightning and surge conditions.

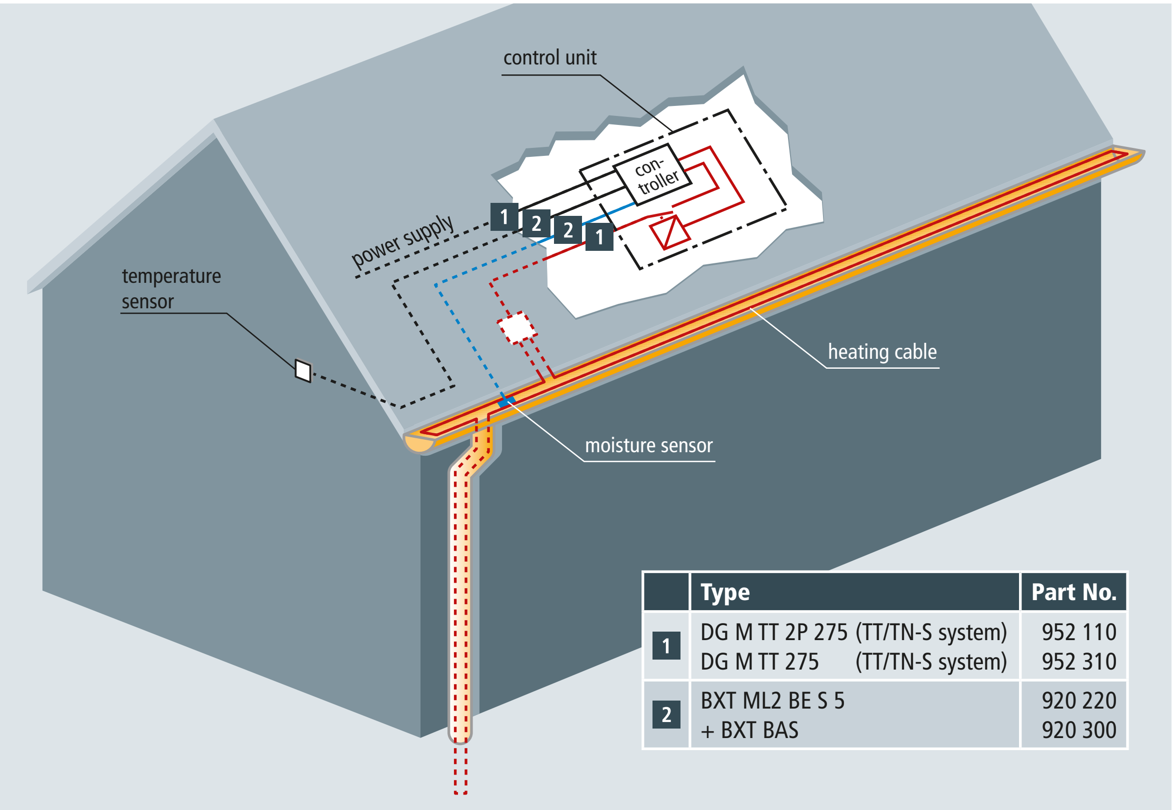
Structure without external lightning protection system

If a structure has no external lightning protection system, it can be assumed that the operator considers the probability of lightning striking the structure to be low. In this case, type 2 surge arresters according to IEC 60364-1 (HD 60364-1) must be used to protect the structure from inductive coupling.

Since both the heating bands and the temperature and moisture sensor are located outside the structure, their connecting cables are exposed to inductive coupling which may cause damage to the structure. For this reason, type 2 surge arresters are installed to protect these cables directly at the entry point into the structure and the feeder cable upstream of the control unit (**Figure 9.29.1**).

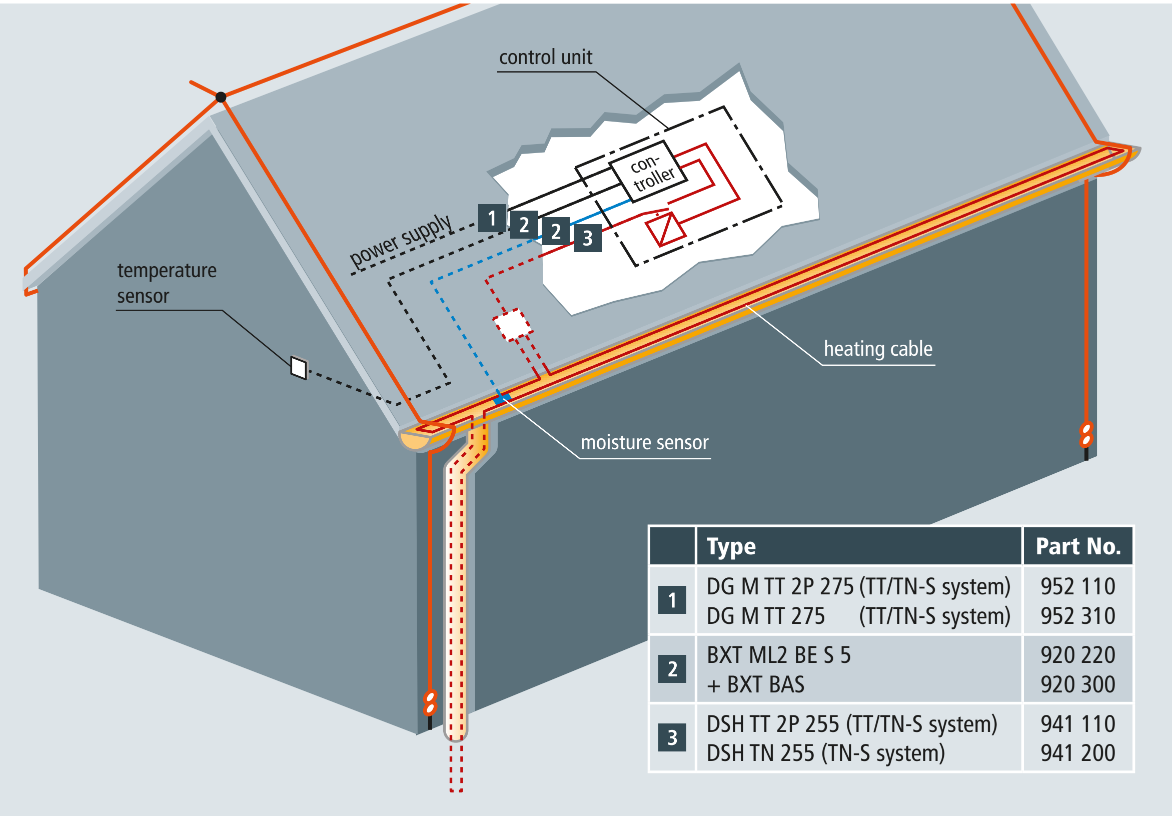
Structure with external lightning protection system

The IEC 62305-1 to 4 (EN 62305-1 to 4) standard must be observed when installing lightning protection systems on structures. In such systems, the gutters and / or downpipes are typically conductively connected to the air-termination systems and are therefore at a high potential in case of a lightning strike. Both the heating band and moisture sensor cables directly contact these lightning current carrying gutters and downpipes, meaning that lightning currents are automatically injected on the cables. For this reason, type 1 lightning current arresters must be installed directly at the point where the cables enter the structure. It must be observed that the lightning current



	Type	Part No.
1	DG M TT 2P 275 (TT/TN-S system) DG M TT 275 (TT/TN-S system)	952 110 952 310
2	BXT ML2 BE S 5 + BXT BAS	920 220 920 300

Figure 9.29.1 Control unit protected by surge arresters in a structure without external lightning protection system



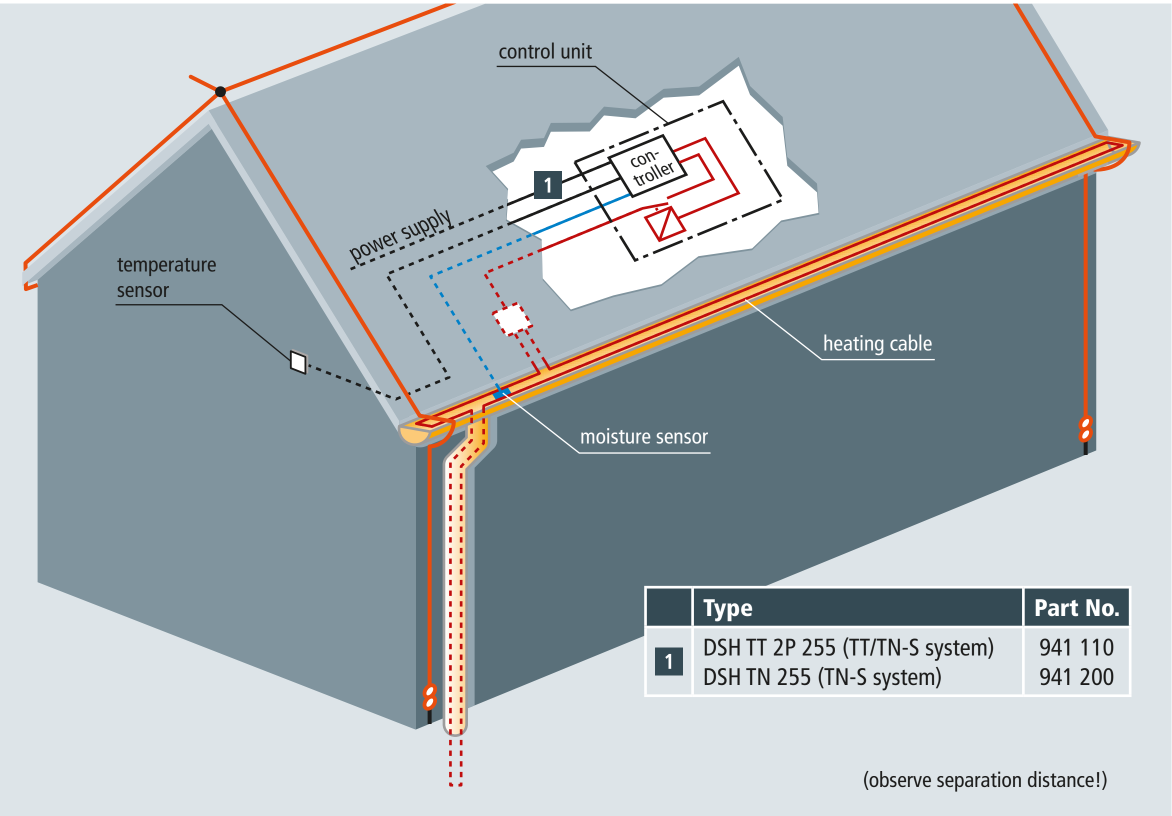
	Type	Part No.
1	DG M TT 2P 275 (TT/TN-S system) DG M TT 275 (TT/TN-S system)	952 110 952 310
2	BXT ML2 BE S 5 + BXT BAS	920 220 920 300
3	DSH TT 2P 255 (TT/TN-S system) DSH TN 255 (TN-S system)	941 110 941 200

Figure 9.29.2 Installation of lightning current and surge arresters if the control unit is located far from the entry point into a structure with external lightning protection system

splits both between the down conductors directly connected to the metallic gutter and the down conductors connected to the air-termination mesh. Even if the external lightning protection system only has four down conductors, lightning currents of less than 10 to 12 kA per core are to be expected in case of LPL III. A type 2 surge arrester must be provided in the feeder cable upstream of the control unit (**Figure 9.29.2**).

Buildings with an interconnected reinforced concrete or steel frame construction (IEC 62305-4 (EN 62305-4)) are an exception. If the air-termination systems ensure that the cables beyond the roof are not hit by a lightning strike, surge protective devices according to **Figure 9.29.1** can be used.

If loss of the control unit is acceptable (the control unit and / or the incoming cables must not present a risk of fire), the structure can be protected by installing combined arresters directly at the point where the cables enter the structure (**Figure 9.29.3**).



	Type	Part No.
1	DSH TT 2P 255 (TT/TN-S system) DSH TN 255 (TN-S system)	941 110 941 200

Figure 9.29.3 Installation of lightning current arresters if the control unit (loss is accepted) is located near the entry point into a structure with external lightning protection

Use of application-optimised type 1 combined arresters in low-voltage installations

Use of application-optimised DEHNshield combined arresters in low-voltage installations

When lightning hits the external lightning protection system of a building, the lightning current is shared between the cables entering the building and the building's earth electrode. To prevent dangerous sparking in the structure to be protected, the IEC 62305 (EN 62305) lightning protection standard encourages to take internal lightning protection measures when installing an external lightning protection system. The standard also requires to establish lightning equipotential bonding by connecting all metal parts directly or, in case of power supply and information technology systems, indirectly via surge protective devices in the structure. The surge protective devices referred to in this standard are type 1 lightning current arresters with an adequate voltage protection level.

Application-optimised DEHNshield type 1 combined arresters combine lightning equipotential bonding up to 50 kA (10/350 μs) lightning impulse currents and surge protection in a single arrester stage. This clearly distinguishes DEHNshield from the currently available varistor-based arresters of this application and performance class.

DEHNshield arresters also provide optimal protection for buildings without external lightning protection system where power is supplied through an overhead line and type 1 arresters are to be installed in the service entrance box according to the German VdS 2031 guideline. DEHNshield combined arresters can be used without additional backup fuse if the installation is protected by backup fuses up to 160 A.

The follow-current-limiting spark gap technology ensures selectivity even with respect to low-value fuses (35 A gL/gG), meaning that upstream fuses are not tripped by mains follow currents.

If lightning hits external equipment (for example a camera mast), partial lightning currents will flow into the building via the earth electrode of the external equipment and the connecting cables. In this context, it must be observed that these lightning currents flowing into the building will not overload the surge protective device (SPD) installed in the building.

Due to their technical parameters which are suited for use in simple and compact electrical installations, DEHNshield arresters are an ideal solution for this field of application (**Figure 9.30.1**).

What is understood by application-optimised use?

A type 1 arrester installed at the entrance point into the building must be capable of carrying the partial lightning currents described above. Type 2 and / or type 3 arresters downstream of the entrance point into the building must be energy-coordinated with this type 1 arrester. The follow current limiting and application-optimised DEHNshield combined arrester with spark gap technology (type 1 SPD) fulfils all these requirements. Thanks to its wave breaker function, DEHNshield is capable of protecting terminal equipment and thus ensures energy coordination with type 2 or type 3 arresters (**Figure 9.30.1**). Varistor-based type 1 arresters are typically not suited for energy coordination.

Figure 9.30.1 Prewired and application-optimised DEHNshield combined arrester with spark gap technology

DEHNshield combined arresters allow cost-optimised and application-specific design and configuration matched to a particular application in line with recognised standards. As space for retrofitting is confined, DEHNshield allows to establish lightning equipotential bonding wherever space is restricted. To this end, however, the parameters of the installation must be observed as is the case when planning new installations and it must be checked whether DEHNshield can be used.

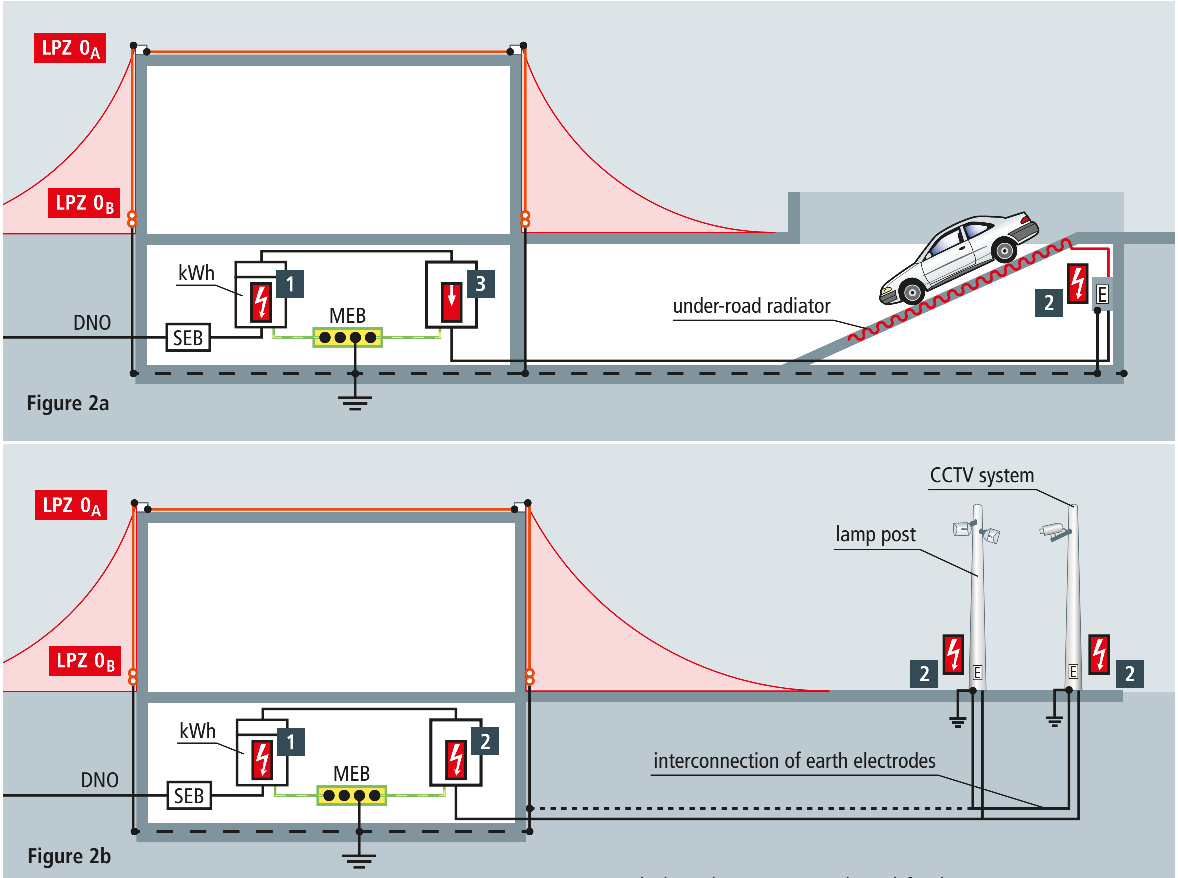
To make the field of application of DEHNshield more transparent, some sample applications are given in the following figures.

Sample applications in Figure 9.30.2

In order to reduce lightning currents, equipment must be directly connected to earth electrodes at points where direct lightning strikes are likely to occur (LPZ 0_A) such as masts with video cameras, lamp posts and under-road radiators. Cameras are frequently used for safety-related evaluation (monitoring systems) and lamp posts are in many cases essential to ensure personal protection (e.g. escape route lighting).

Therefore, the required lightning protection measures must be taken in both cases to ensure full protection. The situation is similar for under-road radiators, except that the area in front of or next to the building is particularly prone to lightning strikes. To ensure personal protection (slip hazard in case of steep entrances and exits of e.g. underground car parks), failure of the heating system as a result of lightning strikes or surges must be minimised.

The earth electrodes of these pieces of equipment must be interconnected. If this connection is performed in contact with



SEB: Service Entrance Box
MEB: Main Earthing Busbar
LPZ: Lightning Protection Zone
DNO: Distribution Network Operator

— — — earth electrodes interconnected in a defined way (to ensure that they are capable of carrying lightning currents)
- - - - - - - - earth electrodes interconnected in an undefined way

No. in Fig.	Surge protective device	Part No.
1	DEHNventil modular DV M TNS 255 (TN-S systems) or	951 400
	DEHNventil modular DV M TT 255 (TT systems) or	951 310
	DEHNventil DV ZP TT 255 (TT systems)	900 391
2	DEHNshield DSH TNS 255 (TN-S systems) or	941 400
	DEHNshield DSH TT 255 (TT systems) or	941 310
	DEHNshield DSH TN 255 (single-phase TN systems) or	941 200
	DEHNshield DSH TT 2P 255 (single-phase TT and TN systems)	941 110
3	DEHNguard modular DG M TNS 275 (TN-S systems) or	952 400
	DEHNguard modular DG M TT 275 (TT systems) or	952 310
	DEHNguard modular DG M TN 275 (TN systems) or	952 200
	DEHNguard modular DG M TT 2P 275 (single-phase TT and TN systems)	952 110

Figure 9.30.2 Application-optimised use of DEHNshield with reference to an under-road radiator at the entrance to an underground car park (2a), a lamp post and a CCTV system (2b)

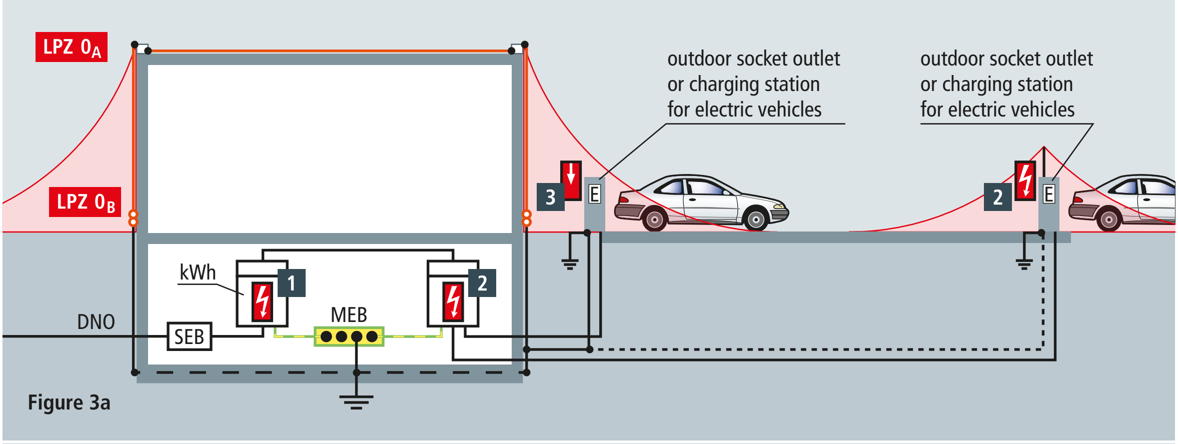


Figure 3a

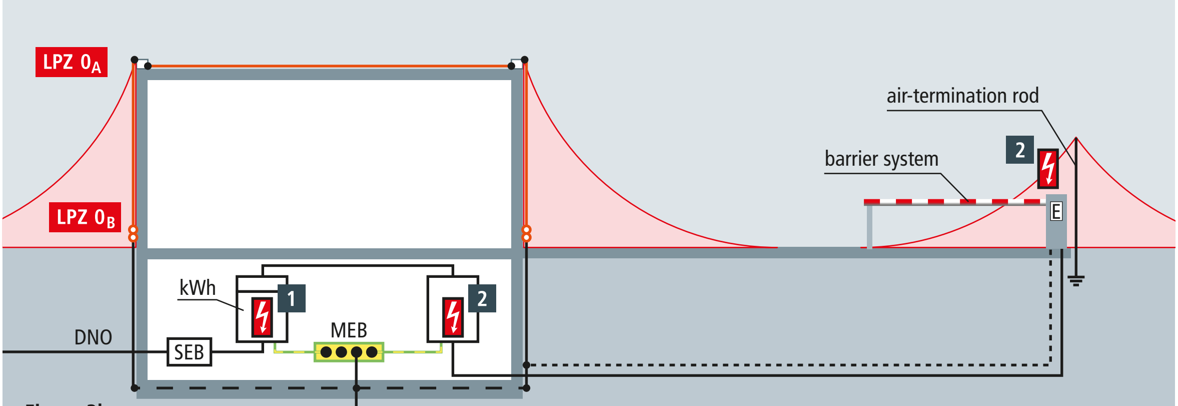


Figure 3b

SEB: Service Entrance Box
MEB: Main Earthing Busbar
LPZ: Lightning Protection Zone
DNO: Distribution Network Operator

— — — earth electrodes interconnected in a defined way (to ensure that they are capable of carrying lightning currents)
- - - - - - - - earth electrodes interconnected in an undefined way

No. in Fig.	Surge protective device	Part No.
1	DEHNventil modular DV M TNS 255 (TN-S systems) or	951 400
	DEHNventil modular DV M TT 255 (TT systems) or	951 310
	DEHNventil DV ZP TT 255 (TT systems)	900 391
2	DEHNshield DSH TNS 255 (TN-S systems) or	941 400
	DEHNshield DSH TT 255 (TT systems) or	941 310
	DEHNshield DSH TN 255 (single-phase TN systems) or	941 200
	DEHNshield DSH TT 2P 255 (single-phase TT and TN systems)	941 110
3	DEHNguard modular DG M TNS 275 (TN-S systems) or	952 400
	DEHNguard modular DG M TT 275 (TT systems) or	952 310
	DEHNguard modular DG M TN 275 (TN systems) or	952 200
	DEHNguard modular DG M TT 2P 275 (single-phase TT and TN systems)	952 110

Figure 9.30.3 Application-optimised use of DEHNshield with reference to a charging station for electric vehicles or an outdoor socket outlet (3a) and a barrier system (3b)

the ground (Supplement 1 of the German DIN EN 62305-3 (VDE 0185-305-3) standard) and possibly extends over the entire cable route up to the building, damage to the cable is prevented if lightning strikes the ground.

Sample applications in Figure 9.30.3

If lightning strikes to external equipment can be ruled out (LPZ 0_B), partial lightning currents still pose a risk when lightning hits the external lightning protection system of the main building. In this case, partial lightning currents may travel through the cables to equipment with a remote earth potential (charging stations for electric vehicles, outdoor socket outlets and barrier systems protected by air-termination rods).

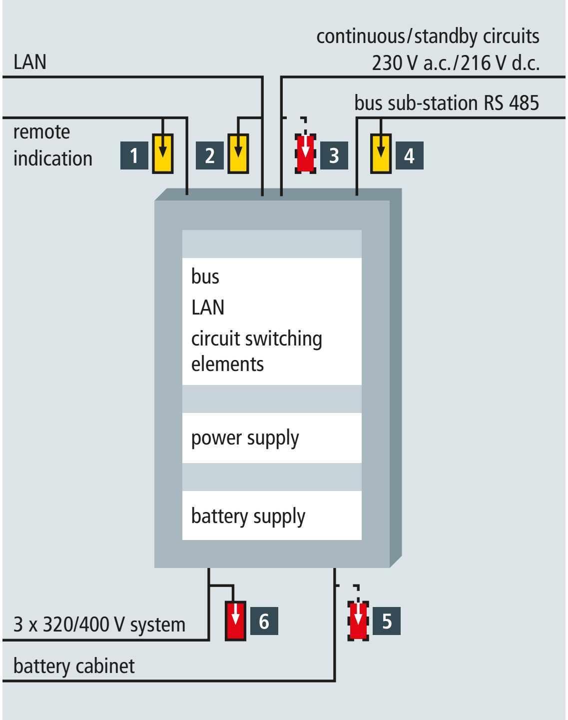
To ensure safe traffic flow, future concepts of charging stations for electric vehicles require high availability as is the case with petrol stations. Since these charging stations are located outside buildings and are equipped with sensitive electrical systems, lightning protection is vital to minimise interference with the installation as a result of lightning strikes and surges. Barrier systems have been protected against lightning strikes and surges over decades to ensure faultless operation. As far as outdoor socket outlets are concerned, lightning and surge protection measures may have to be taken at the design stage, depending on their intended use. An earth electrode is also required for these pieces of equipment to conduct the lightning currents flowing via DEHNshield from the building to earth. Also in this case, the interconnection of earth electrodes is recommended, but not mandatory. Equipment attached to the building, which is directly connected to the earth-termination system of the building and the supply line, can be protected by type 2 arresters.

An application-optimised type 1 arrester such as DEHNshield is suitable for protecting specific applications. This, however, requires that the described measures are implemented consistently and that the technical parameters of the installation to be protected are observed. A properly functioning earth-termination system, for example, is one of the most important aspects for the overall system.

Surge protection for safety lighting systems

The main functions of safety lighting systems are the designation and lighting of escape routes, lighting of work stations with a special risk until work is safely finished and lighting to prevent panic.

In the following, surge protective devices for central power supply systems (CPS) (central battery systems) are described.



No.	Surge protective device	Part No.
1	BLITZDUCTOR BXT ML4 BE 24 * + BXT BAS base part	920 324 920 300
2	DEHNpatch DPA M CLE RJ45B 48	929 121
3	DEHNguard DG M TN 275	952 200
4	BLITZDUCTOR BXT ML2 BD HFS 5 * + BXT BAS base part	920 271 920 300
5	DEHNguard DG M TN 275	952 200
6	DEHNguard M TNS 275 * DEHNguard M TT 275 *	952 400 952 310

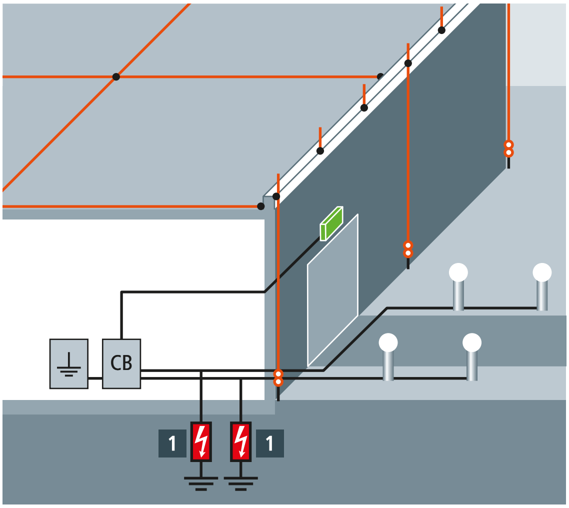
* Observe individual interfaces / system configurations

Figure 9.31.1 Central battery system, feeder cable, battery cabinet feeder cable, bus line, remote indication line, LAN line as well as continuous / standby circuit lines in LPZ 1 and in the same fire compartment

These systems feature the following interfaces:

- Power supply system;
- Battery cabinet;
- Circuit switching elements which, in combination with the system-specific electronic ballasts of the luminaires, ensure continuous / standby operation (individually assigned) and a switched permanent light in the circuit. These elements allow to perform the required test and to monitor the individual lighting systems. Moreover, they incorporate the required overcurrent protective devices which protect the circuit;
- Bus communication with the central battery system / subpanels;
- LAN;
- Remote indication;
- Freely programmable inputs and outputs.

In general, a risk analysis must be performed to determine whether surge protective devices (SPDs) must be installed for the interfaces. To protect the central battery system (e.g.) almost without risk, surge protective devices are required for all interfaces listed above (**Figure 9.31.1**). In **Figures 9.31.1 to 9.31.4** the SPDs, which are normally required to protect the interfaces, are represented with a solid line. Surge protective devices which are installed following a risk analysis are dotted.



No.	Surge protective device	Part No.
1	DEHNsecure DSE M 1 242 (2 x) MVS 1 3 busbar	971 122 900 615

Figure 9.31.2 Lightning equipotential bonding for the circuits of the safety lighting system at the zone transition from the building to the ground

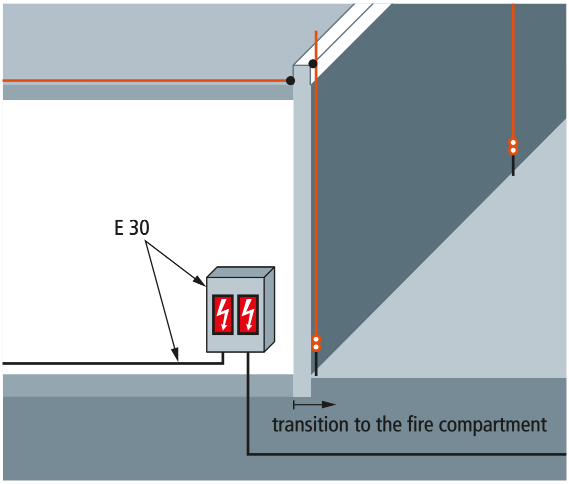


Figure 9.31.3 Lightning equipotential bonding at an E 30 line in an E 30 distribution board (inside of the outer wall)

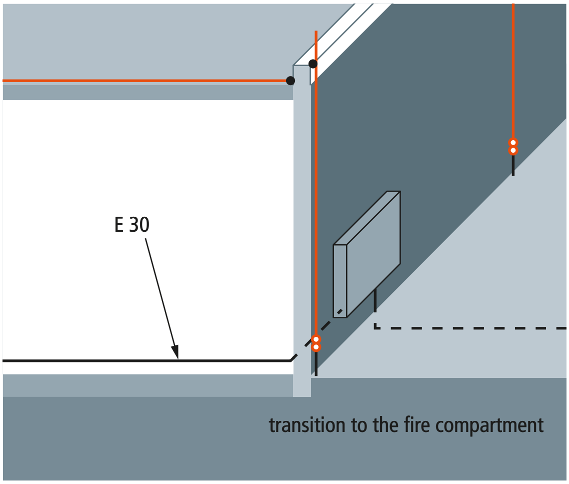


Figure 9.31.4 Lightning equipotential bonding in a conventional distribution board (outside of the outer wall)

While in **Figure 9.31.1** it is assumed that a coordinated type 1 lightning current arrester is installed in the power supply and information technology system of the building, a type 1 SPD is required for the outgoing circuits of the safety lighting system since lightning equipotential bonding is required (**Figure 9.31.2**). Since these circuits are both supplied during a.c. and d.c. operation, the type 1 arrester installed at the zone transition from LPZ 0_A to LPZ 1 (entry point to the building) must be suitable for this purpose. In this case, standard spark-gap-based arresters designed and tested for use in a.c. systems cannot be used due to the lacking zero crossing during d.c. operation which extinguishes the spark gap. DEHNsecure M 1 242, which is both designed for d.c. and a.c. operation (max. backup fuse 10 gl/gG), is ideally suited for this purpose.

The function of the cable network must not only be ensured in case of failure, but also if surge protective devices are used. This means that the surge protective device provided in the cable must be installed in an E 30 distribution board (**Figure 9.31.3**). To this end, the E 30 distribution board must be dimensioned in such a way that the maximum ambient temperature of the surge protective device is not exceeded. To ensure this, the datasheet of the surge protective device must be made available to the manufacturer of the E 30 distribution board.

However, if the cable is led through the outer wall and a surge protective device is installed outside the outer wall, a conventional distribution board, which must be selected according to IP criteria, is sufficient (**Figure 9.31.4**).

Lightning and surge protection for potentially explosive atmospheres

During producing, processing, storing and transporting flammable substances (e.g. fuel, alcohol, liquid gas, explosive dusts), potentially explosive atmospheres where no ignition sources may be present to prevent explosion frequently occur in chemical and petrochemical industrial plants. The relevant safety regulations describe the risk for such plants posed by atmospheric discharges (lightning strikes). In this context, it must be observed that there is a risk of fire and explosion resulting from direct or indirect lightning discharge since in some cases these plants are widely distributed.

To ensure the required plant availability and safety, a conceptual procedure is required to protect parts of electrical and electronic installations of process plants from lightning currents and surges.

Protection concept

Intrinsically safe measuring circuits are frequently used in potentially explosive atmospheres. **Figure 9.32.1** shows the general design and lightning protection zones of such a system. Since maximum system availability is required and numerous safety requirements must be observed in hazardous areas, the following areas were divided into lightning protection zone 1 (LPZ 1) and lightning protection zone 2 (LPZ 2):

- Evaluation unit in the control room (LPZ 2)
- Temperature transmitter at the tank (LPZ 1)
- Interior of the tank (LPZ 1)

According to the lightning protection zone concept as per IEC 62305-4 (EN 62305-4), adequate surge protective devices, which will be described below, must be provided for all lines at the boundaries of the lightning protection zones.

External lightning protection system

The external lightning protection system includes all systems installed outside or inside the structure to be protected for intercepting and discharging the lightning current to the earth-termination system.

A lightning protection system for potentially explosive atmospheres is typically designed according to class of LPS II. Another class of LPS can be chosen in justified individual cases, in case of special conditions (legal requirements) or as a result of a risk analysis. The requirements described below are based on class of LPS II.

Air-termination systems

In potentially explosive atmospheres, air-termination systems must be installed at least according to class of LPS II (**Table 9.32.1**). To determine the relevant points of strike, it is recommended to use the rolling sphere method with a minimum radius according to class of LPS II. However, in case of a lightning strike to the air-termination system, sparking may occur at the point of strike. To prevent ignition sparks, the air-termination systems should be installed outside Ex zones (**Figure 9.32.2**). Natural components such as metallic roof structures,

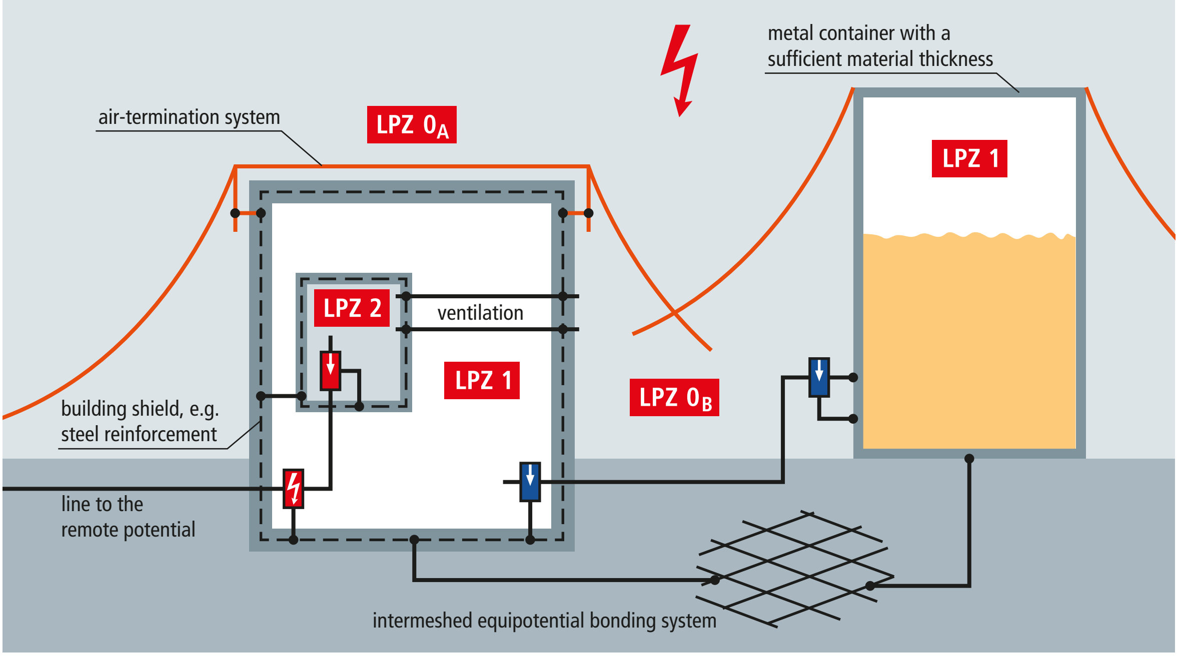


Figure 9.32.1 Basic division of an installation into lightning protection zones (LPZs)

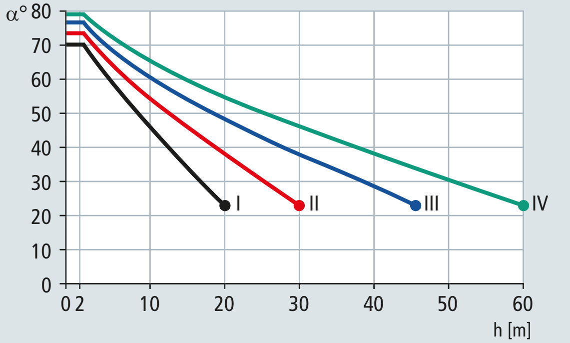
Class of LPS	Protection method			Typical down conductor spacing [m]
	Rolling sphere radius r [m]	Protective angle α	Mesh size w [m]	
I	20		5 x 5	10
II	30		10 x 10	10
III	45		15 x 15	15
IV	60		20 x 20	20

Table 9.32.1 Arrangement of air-termination systems according to the class of LPS

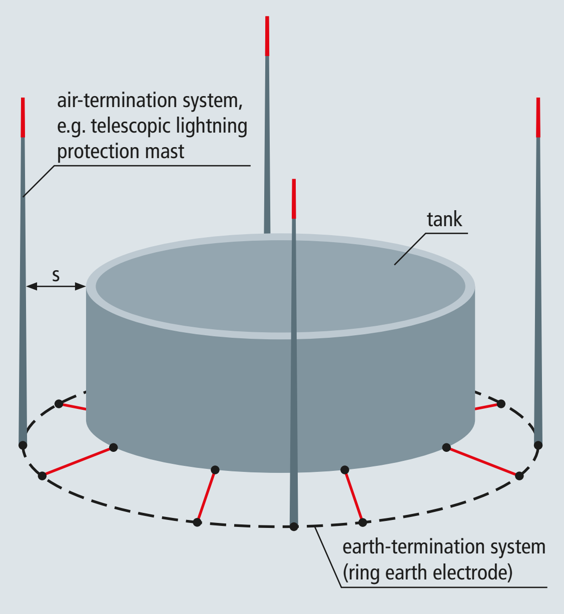


Figure 9.32.2 Air-termination system for a tank with air-termination rods and air-termination cables

metal pipes and containers can also be used as air-termination systems if they have a minimum material thickness of 5 mm according to Annex D 5.5.2 of the IEC 62305-3 (EN 62305-3) standard and the temperature rise and reduction of material at the point of strike do not present additional risks (e.g. reduction of the wall thickness of pressure containers, high surface temperature at the point of strike) (**Figure 9.32.1**).

Down conductors

Down conductors are electrically conductive connections between the air-termination system and the earth-termination system. To prevent damage when conducting the lightning current to the earth-termination system, the down conductors must be arranged in such a way that

- There are several parallel current paths between the point of strike and earth (systems in hazardous areas: one down conductor for every 10 m of the perimeter of the outer roof edges, however, at least four),
- The length of the current paths is as short as possible,
- Connection to the equipotential bonding system is established wherever necessary.
- An equipotential bonding system at ground level at intervals of 20 m has proven its worth.

The reinforcements of reinforced concrete buildings may also be used as down conductors if they are permanently interconnected in such a way that they can carry lightning currents.

Separation distance

If there is an insufficient separation distance d between the air-termination system or down conductor and metal and electrical installations inside the structure to be protected, dangerous proximities may occur between the parts of the external lightning protection system and metal as well as electrical installations inside the building. The separation distance d must not be smaller than the safety distance s (d > s).

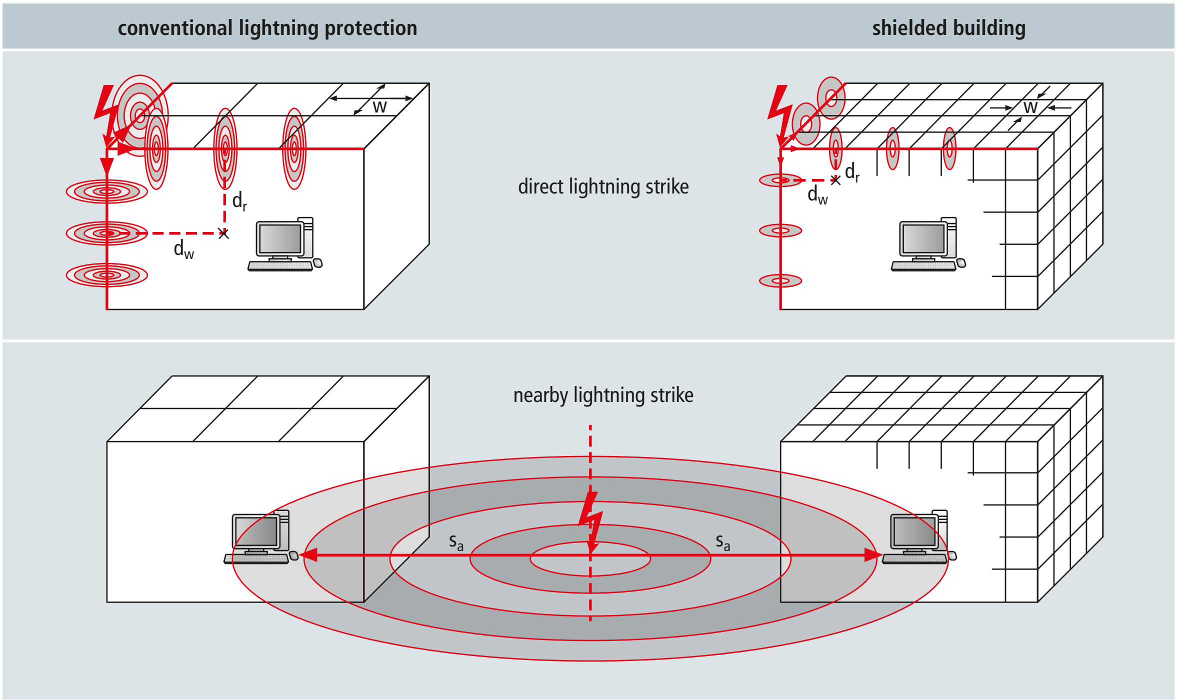


Figure 9.32.3 Shielding of structures by using natural components of the building

Since in practice the lightning current splits between the individual down conductors depending on the impedances, the safety distance must be calculated separately for the relevant building/installation as per IEC 62305-3 (EN 62305-3).

Shielding of buildings

Another measure of the lightning protection zone concept is to shield buildings. To this end, metal facades and reinforcements of walls, floors and ceilings on or in the building are combined to form shielding cages as far as practicable (**Figure 9.32.3**). By electrically interconnecting these natural metal components of the object to be protected to form closed shielding cages, the magnetic field is considerably reduced. Thus, the magnetic field can be easily decreased by a factor of 10 to 300 and an infrastructure for EMC protection can be established at low costs. When retrofitting existing installations, the room shielding must be adapted to the EMC requirements, for example, by means of reinforcement mats.

Surge protection in hazardous areas

The lightning protection and Ex zones are already harmonised at the design stage. This means that the requirements for the use of surge protective devices both in hazardous areas and at the boundaries of lightning protection zones must be fulfilled. Consequently, the place of installation of the surge arrester is exactly defined, that is it must be installed at the transition from LPZ 0_B to LPZ 1. This prevents dangerous surges from entering Ex zone 0 or 20 since the interference has already been discharged. The availability of the temperature transmitter, which is important for the process, is considerably increased. In addition, the requirements of IEC 60079-11 (EN 60079-11), IEC 60079-14 (EN 60079-14) and IEC 60079-25 (EN 60079-25) must be observed (**Figure 9.32.4**):

- ➡ Use of surge protective devices with a minimum discharge capacity of 10 impulses of 10 kA each without damaging the equipment or interfering with the surge protective effect.
- ➡ Installation of the surge protective device in a shielded metallic enclosure and earthing by means of a copper earthing conductor with a cross-section of at least 4 mm^2.
- ➡ Installation of the lines between the arrester and the equipment in a metal pipe earthed on both ends or use of shielded lines with a maximum length of 1 m.

According to the definition in the protection concept, the LPC in the control room is defined as LPZ 2. A surge protective device is also provided at the transition from LPZ 0_B to LPZ 1 for the intrinsically safe measuring line from the temperature transmitter. This surge protective device at the other end of

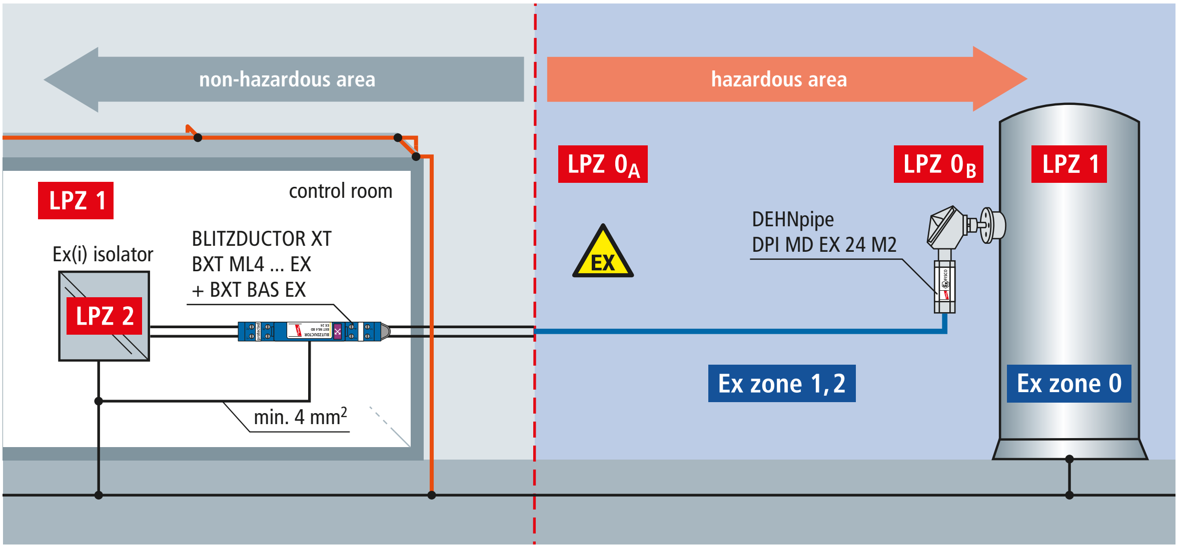


Figure 9.32.4 Surge protective devices in an intrinsically safe measuring circuit

Figure 9.32.5 Surge protective devices for intrinsically safe measuring circuits

the field line which extends beyond the building must have the same discharge capacity as the surge protective device installed on the tank. Downstream of the surge protective device, the intrinsically safe line is led via an isolating amplifier (**Figure 9.32.5**). From there, the shielded line to the LPC is routed in LPZ 2. The cable shield is connected on both ends, therefore no surge protective device is required at the transition from LPZ 1 to LPZ 2 since the electromagnetic residual interference to be expected is significantly attenuated by the cable shield earthed on both ends (see also "Shield treatment in intrinsically safe measuring circuits").

Other selection criteria for surge protective devices in intrinsically safe measuring circuits

Insulation strength of equipment

To ensure that leakage currents do influence the measured values, the sensor signals from the tank are frequently galvanically isolated. The insulation strength of the transmitter between the intrinsically safe 4 … 20 mA current loop and the earthed temperature sensor is ≥ 500 V a.c. Thus, the equipment is unearthed. When using surge protective devices, this unearthed state must not be interfered with.

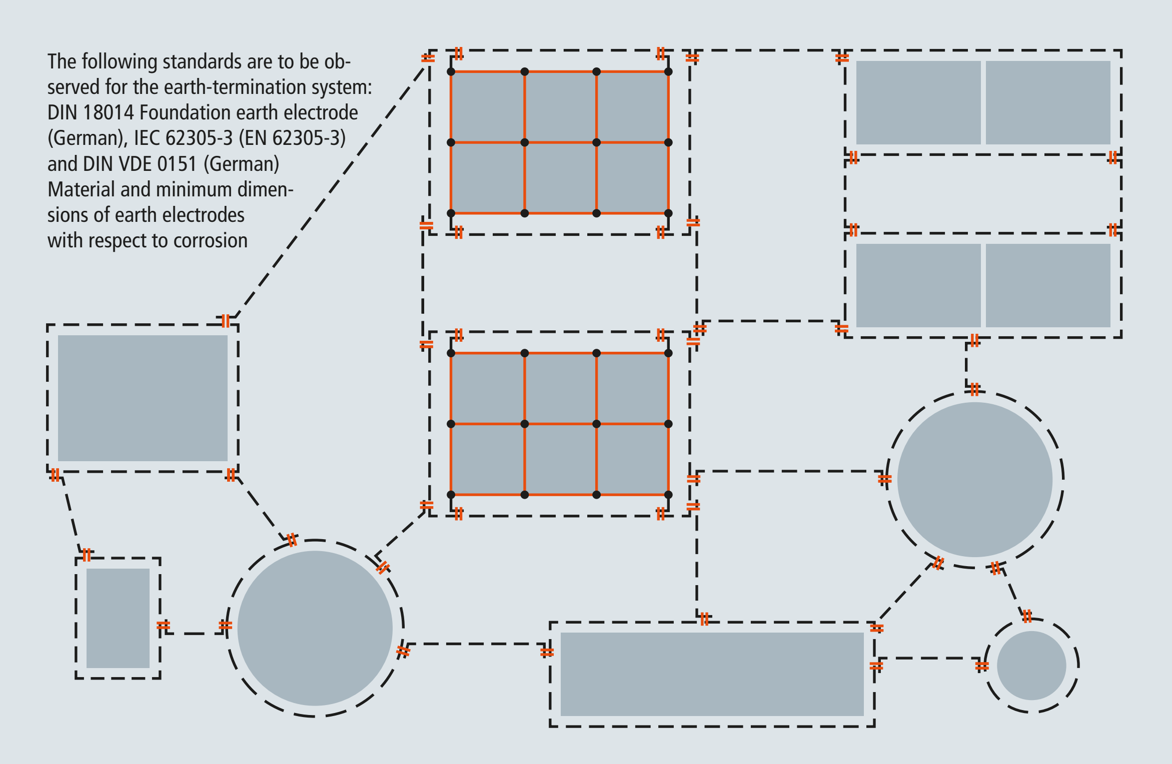


Figure 9.32.6 Example of an intermeshed earth-termination system

If the transmitter has an insulation strength of < 500 V a.c., the intrinsically safe measuring circuit is earthed. In this case, surge protective devices which in case of a nominal discharge current of 10 kA (8/20 µs wave form) have a voltage protection level below the insulation strength of the earthed transmitter must be used (e.g. U_p (core/PG) ≤ 35 V).

Type of protection – Category ia, ib or ic?

The transmitter and the surge protective device are installed in Ex zone 1 so that type of protection ib is sufficient for the 4 … 20 mA current loop. The surge protective devices used (ia) fulfil the most stringent requirements and are thus also suited for ib and ic applications.

Permissible maximum values for L_0 and C_0

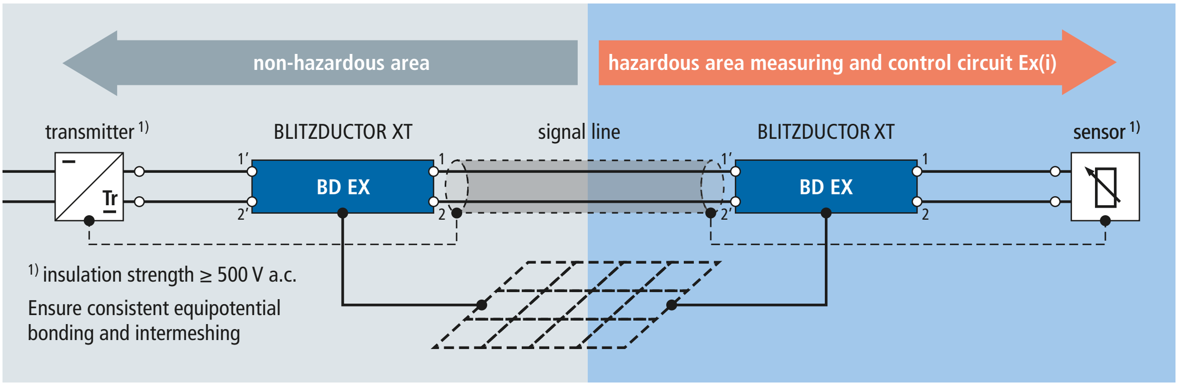
Before an intrinsically safe measuring circuit can be put into operation, it must be demonstrated that it is intrinsically safe. To this end, the power supply unit, the transmitter, the cables and the surge protective devices must fulfil the conditions of intrinsic safety. If required, energy buffers such as the inductances and capacitances of the surge protective devices must be taken into account. According to the EC type examination certificate (PTB 99 ATEX 2092), the internal capacitances and inductances of BXT ML4 BD EX 24 surge protective devices (**Figure 9.32.6**) are negligible and do not have to be taken into account for the conditions of intrinsic safety (**Table 9.32.2**).

Maximum values for voltage U_i and current I_i

According to its technical data, the intrinsically safe transmitter to be protected has a maximum supply voltage U_i and a maximum short-circuit current I_i when used in intrinsically safe applications (**Figure 9.32.7**). The rated voltage U_c of the arrester must be at least as high as the maximum open-circuit voltage of the power supply unit. The nominal current of the arrester must also be at least as high as the short-circuit current I_i of the transmitter to be expected in the event of a fault. If these marginal conditions are not observed when dimensioning the surge arresters, the surge protective device can be overloaded and thus fail or the intrinsic safety of the measuring circuit is no longer ensured due to an impermissible temperature rise on the surge protective device.

Technical data	Transmitter TH02	Surge protective device BXT ML4 BD Ex 24
Place of installation	zone 1	zone 1
Degree of protection	ib	ia
Voltage	U_i max. = 29.4 V d.c.	U_c = 33 V d.c.
Current	I_i max. = 130 mA	I_N = 500 mA
Frequency	f_{HART} = 2200 Hz, frequency modulated	f_G = 7.7 MHz
Immunity level	according to NE 21, e.g. 0.5 kV core/core	discharge capacity of 20 kA (8/20 µs), voltage protection level ≤ 52 V core/core
Tested to	ATEX, CE	ATEX, CE, IEC 6143-21, IECEX
Unearthed 500 V	yes	yes
Internal capacitance C_i	C_i =15 nF	negligibly small
Internal capacitance L_i	L_i = 220 µH	negligibly small

Table 9.32.2 Example of a temperature transmitter



1) insulation strength ≥ 500 V a.c.

Ensure consistent equipotential bonding and intermeshing

Figure 9.32.7 Example of the shield treatment of intrinsically safe cables

Coordination of surge protective devices with terminal equipment

NAMUR recommendation NE 21 defines general interference immunity requirements for process and laboratory equipment (e.g. transmitter). The signal inputs of such equipment must withstand voltages of 0.5 kV between the cable cores (transverse voltage) and 1.0 kV between the cable core and earth (longitudinal voltage). The measurement set-up and the wave form are described in the IEC 61000-4-5 (EN 61000-4-5) basic standard. Depending on the amplitude of the test impulse, a specific immunity level is assigned to terminal equipment. These immunity levels of terminal equipment are documented by test levels (1–4) while test level 1 is the lowest and test level 4 the highest immunity level. The test level can be usually found in the documentation of the device to be protected or requested from the manufacturer of the device. In case of a risk of lightning and surge effects, the conducted interference (voltage, current and energy) must be limited to a value within the immunity level of the terminal equipment. The test levels are documented on the surge protective devices (e.g. P1).

Intermeshed earth-termination system

In the past, separate earth-termination systems were often used in practice (lightning protection and protective earthing separated from the functional earthing). This turned out to be extremely unfavourable and can even be dangerous. In case of a lightning strike, voltage differences up to some 100 kV can occur which may lead to the destruction of electronic components, risks for persons and explosions in potentially explosive atmospheres due to sparking.

Therefore, it is advisable to install a separate earth-termination system for every single building or part of an installation and to intermesh them. This intermeshing (**Figure 9.32.6**) reduces potential differences between the buildings / parts of the installation and thus conducted partial lightning currents. The closer the mesh of the earth-termination system, the lower the potential differences between the buildings / parts of the installation in case of a lightning strike. Mesh sizes of 20 x 20 m (mesh sizes of 10 x 10 m are recommended in potentially explosive atmospheres and when using electronic systems) have proven to be economically feasible. When selecting the earthing material, it must be ensured that the buried pipes do not corrode.

Equipotential bonding

Consistent equipotential bonding must be established in all potentially explosive atmospheres to prevent potential differences between different and extraneous conductive parts. Building columns and structural parts, pipes, containers, etc. must be integrated in the equipotential bonding system so that a voltage difference does not have to expected even under fault conditions. The connections of the equipotential bonding conductors must be secured against automatic loosening. According to IEC 60079-14 (EN 60079-14), supplementary equipotential bonding is required which must be properly established, installed and tested in line with the IEC 60364-4-41 (HD 60364-4-41) and IEC 60364-5-54 (HD 60364-5-54) standard. When using surge protective devices, the cross-section of the copper earthing conductor for equipotential bonding must be at least 4 mm^2.

Lightning equipotential bonding outside the hazardous area

The use of surge protective devices in low-voltage consumer's installations and measuring and control systems outside the hazardous area (e.g. control room) does not differ from other applications (for more detailed information, please also see brochure DS 649 E "Red/Line Selection Guide"). In this context, it must be pointed out that surge protective devices for lines from LPZ 0_A to LPZ 1 must have a lightning current discharge capacity which is described by the 10/350 µs test wave form. Surge protective devices of different requirement classes must be coordinated with one another. This is ensured by DEHN surge arresters.

Shield treatment in intrinsically safe measuring circuits

The treatment of the cable shield is an important measure to prevent electromagnetic interference. In this context, the effects of electromagnetic fields must be reduced to an acceptable level to prevent ignition. This is only possible if the shield is earthed on both cable ends. Earthing the shield on both ends is only permitted in hazardous areas if absolutely no potential differences are to be expected between the earthing points (intermeshed earth-termination system, mesh size of 10 x 10 m) and an insulated earthing conductor with a cross-section of at least 4 mm^2 (better 16 mm^2) is installed in parallel to the intrinsically safe cable, is connected to the cable shield at any point and is insulated again. This parallel cable must be connected at the same equipotential bonding bar as the shield of the intrinsically safe cable (**Figure 9.32.6**).

Moreover, permanently and continuously connected reinforcing bars can be used as equipotential bonding conductor. These are connected to the equipotential bonding bar on both ends.

Summary

The risk of chemical and petrochemical plants due to a lightning discharge and the resulting electromagnetic interference is described in the relevant standards. When using the lightning protection zone concept for designing and installing such plants, the risks of sparking in case of a direct lightning strike or discharge of conducted interference energies must be safely minimised with economically acceptable efforts. The surge arresters used must fulfil explosion protection requirements, ensure coordination with terminal equipment and meet the requirements resulting from the operating parameters of the measuring and control circuits.

Lightning protection systems for gas pressure control and measurement systems

The main functions of gas pressure control and measurement systems are to monitor and calculate gas volumes, automatically operate the stations by means of volume and condition-oriented connection and disconnection of measurement and control systems as well as volume control and monitoring of the gas transport between the distribution network operators.

Certain functional units that are connected to the power supply system are subject to the stipulations of section 3 of the German Ordinance on Industrial Safety and Health (BetrSichV). The operator must ensure compliance with these stipulations which apply to e.g. systems in potentially explosive atmospheres whose components are covered by the 94/9/EC directive, e.g. the installation of devices complying with the requirements of the 94/9/EC directive, their installation according to the state of the art, inspection and testing prior to commissioning and recurrent testing by a competent expert under the responsibility of the company.
The German Technical Rules on Operational Safety (TRBS) specify in greater detail the fundamental requirements of the German BetrSichV to be observed in this context. The German DVGW Code of Practise G 491 describes the requirements for electrical and non-electrical explosion protection of gas pressure control and measurement systems, referring to the existing TRBS as a source of information.

Risk analysis – Determination of the current state

The current state of the system must be determined in a site survey. To this end, the structural conditions, existing documents and possible requirements of property insurers must be observed.

A risk analysis is performed in cooperation with the operator to define the protection measures required to prevent the destructive effects of lightning strikes and surges. To this end, designers use approved regulations that allow to design a complete protection concept.
The IEC 62305 (EN 62305) standard is a reliable design basis for future-oriented lightning protection systems. This standard is used to design, install, inspect and maintain lightning protection systems for structures.
The risk of a lightning strike and the necessity of a lightning protection system for an object to be protected are determined according to IEC 62305-1 (EN 62305-1) and IEC 62305-2 (EN 62305-2). Technically and economically optimal protection measures are selected depending on the risk. The IEC 62305-3 (EN 62305-3) and IEC 62305-4 (EN 62305-4) standards describe how to implement the protection measures determined. Thus, the IEC 62305 (EN 62305) standard is a solid basis for operators and designers. This standard makes it easier to take further protection measures for widespread power supply and information technology systems at lower costs. The IEC 62305-4 (EN 62305-4) standard describes measures for protecting electronic systems.

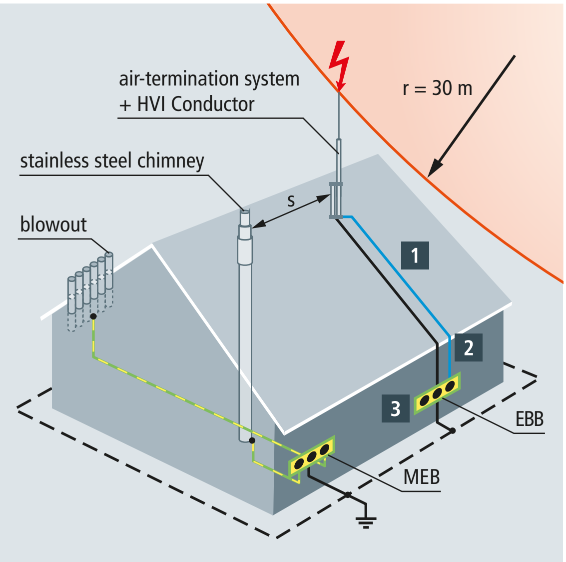
Risk analysis of the gas pressure control and measurement system

The protection of the structure and technical equipment against the effects of a lightning strike and personal protection must be taken into account right from the design stage. For this reason, adequate protection goals are define together with the operator before performing a risk analysis.

In our example, the protection goals would be:

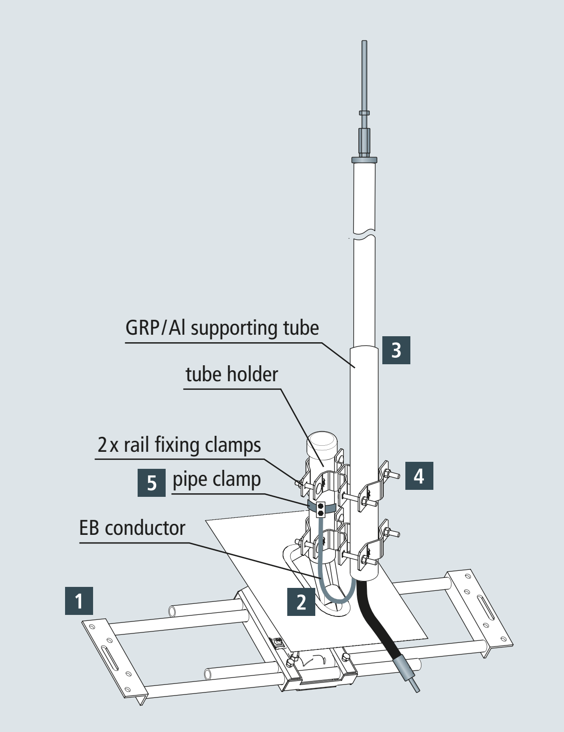
- Fire and explosion protection
- Personal protection
- Protection of the electronics of systems with high availability

At first, the loss factors according to IEC 62305 (EN 62305), the required availability and the risk are determined. This leads to the following loss factors:



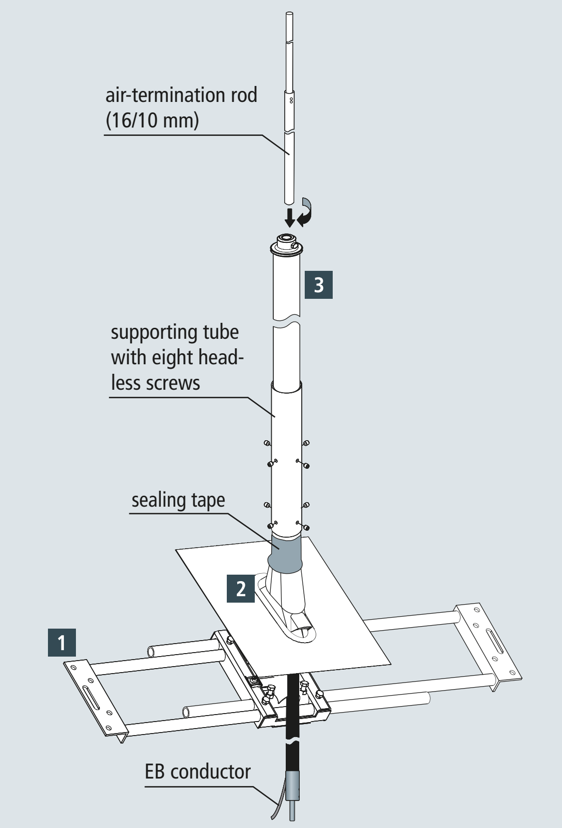
	Components	Part No.
1	Roof conductor holder with angled brace for HVI Conductor	202 830
2	Wall-mounted conductor holder for HVI Conductor	275 229
3	Earthing busbar (2 x 2 terminals)	472 109

Figure 9.33.1 Isolated external lightning protection system for a gable roof



	Components	Part No.
1	Rafter holder	105 240
2	Roof bushing kit	105 245
3	DEHNcon-H HVI Conductor I integrated in the supporting tube with air-termination rod	819 245
4	Rail fixing clamp	105 354
5	Antenna pipe clamp	540 103

Figure 9.33.2 Isolated external lightning protection system for a gable roof – Installation option 1



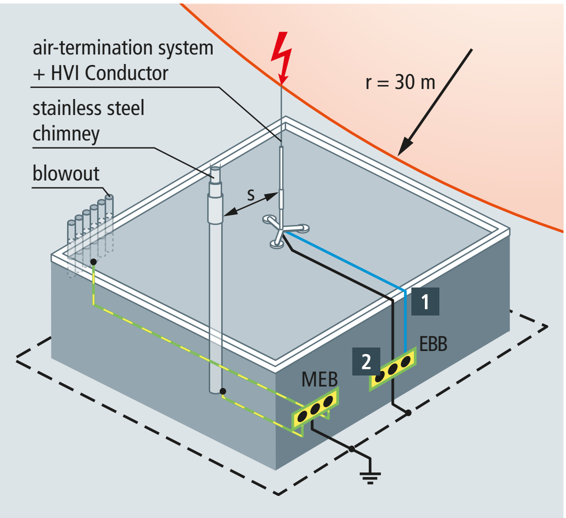
	Components	Part No.
1	Rafter holder	105 240
2	Roof bushing kit	105 245
3	DEHNcon-H HVI Conductor I integrated in the supporting tube with air-termination rod	819 245

Figure 9.33.3 Isolated external lightning protection system for a gable roof – Installation option 2

- L1: Injury or death of persons (loss factor L1 includes the lightning-related ignition source specified in TRBS 2152 Part 3 with regard to explosion protection)
- L2: Loss of service to the public
- L4: Loss of economic value

The example described below was calculated based on IEC 62305-2 (EN 62305-2) by means of the DEHNsupport software. We expressively point out that the procedure shown is only an example. The solution in **Figure 9.33.1** is not binding in any way and can be substituted by other equivalent solutions. In the following, possible protection solutions based on LPL II and the most important characteristics of the example depending on the type of installation are described. A high-voltage-resistant, insulated down conductor (HVI Conductor I) can be installed on (**Figure 9.33.2**) or underneath (**Figure 9.33.3**) the roofing.

If conductors must be installed in Ex zone 1 or 2 due to local conditions, installation instructions No. 1501 must be observed. **Figures 9.33.4 and 9.33.5** show an example of a flat-roofed gas pressure control and measurement system.

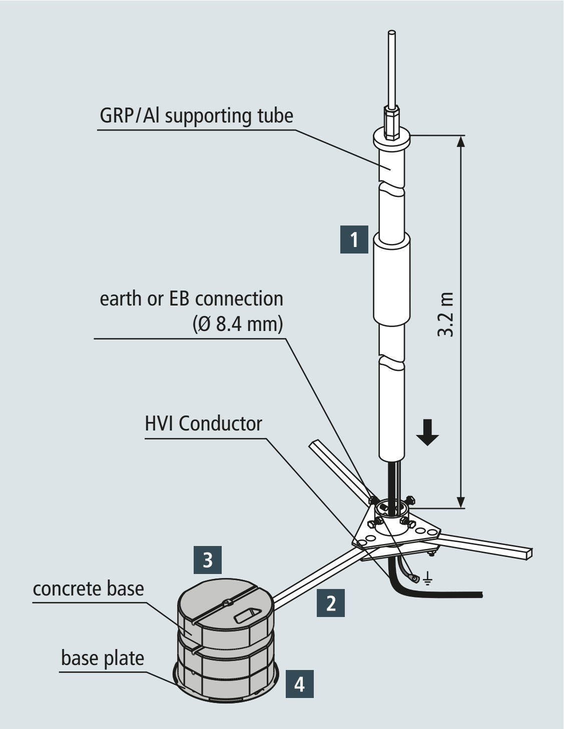


	Components	Part No.
1	HVI Ex W70 holder	275 440
	HVI Ex W200 holder	275 441
	HVI Ex busbar 500	275 498
2	Earthing busbar (2 x 2 terminals)	472 109

Figure 9.33.4 Isolated external lightning protection system for a flat roof

Internal lightning protection – Lightning equipotential bonding – Surge protection

All conductive systems entering the gas pressure control and measurement system from the outside must be integrated in the lightning equipotential bonding system (**Figure 9.33.6**). This is achieved by directly connecting all metal systems and indirectly connecting all live systems via surge protective devices. These surge protective devices must be capable of discharging lightning currents (type 1 SPD: test wave form 10/350 μs). Lightning equipotential bonding should be established as close as possible to the entry point into the structure (zone transition from LPZ 0 to 1 or higher) to reduce high potential differences and dangerous sparkover in potentially explosive atmospheres and to prevent partial lightning currents from entering the structure.



	Components	Part No.
1	HVI Conductor I integrated in the supporting tube with air-termination tip	819 320
2	Tripod for HVI Conductor integrated in the supporting tube	105 350
3	Concrete base	102 010
4	Base plate	102 050

Figure 9.33.5 Isolated external lightning protection system for a flat roof - Installation option 3

Additional protection measures as per IEC 62305-4 (EN 62305-4) for increasing the availability of sensitive electrical systems may be required depending on the immunity level and installation environment of the systems. A combination of surge protection, shielding and supplementary equipotential bonding measures have proven their worth in practice.

No. in Fig. 9.33.6	Protection for	Surge protective device	Part No.
Power supply systems			
1	Three-phase TN-S / TT system	DEHNventil M TT 255 DEHNventil M TT 255 FM DEHNventil ZP TT 255	951 310 951 315 900 391
	Three-phase TN-C system	DEHNventil M TNC 255 DEHNventil M TNC 255 FM	951 300 951 305
	Alternating current TN system	DEHNventil M TN 255 DEHNventil M TN 255 FM	951 200 951 205
	Alternating current TT system	DEHNventil M TT 2P 255 DEHNventil M TT 2P 255 FM	951 110 951 115
Information technology systems			
2	Telecontrol, telecommunication systems	BXT ML4 BD 180 or BXT ML2 BD 180 + BXT BAS	920 347 920 247 + 920 300
Measuring and control equipment			
3	Intrinsically safe measuring circuits and systems	BXT ML4 BD EX 24 or BXT ML2 BD S EX 24 + BXT BAS EX	920 381 920 280 + 920 301
Cathodic protection systems			
4	Cathodic protection system, protective circuit up to 12 A	BVT KKS ALD 75	918 420
	Cathodic protection system, protective circuit exceeding 12 A	DEHNbloc M 1 150 FM + DEHNguard S 150 FM + MVS 1 2 or DEHNbloc M 1 150 + DEHNguard S 150 + MVS 1 2	961 115 + 952 092 + 900 617 961 110 + 952 072 + 900 617
5	Cathodic protection system, sensor measuring circuit	BVT KKS APD 36	918 421
Functionally isolated systems parts			
6	Insulating joints / insulating flanges	EXFS 100 or EXFS 100 KU	923 100 923 101
Equipotential bonding in hazardous areas			
7	Connection of pipelines without ignition sparks	EX BRS 27 or EX BRS 90 or EX BRS 300 or EX BRS 500	540 821 540 801 540 803 540 805

Table 9.33.1 Recommended lightning equipotential bonding components according to Figure 9.33.6

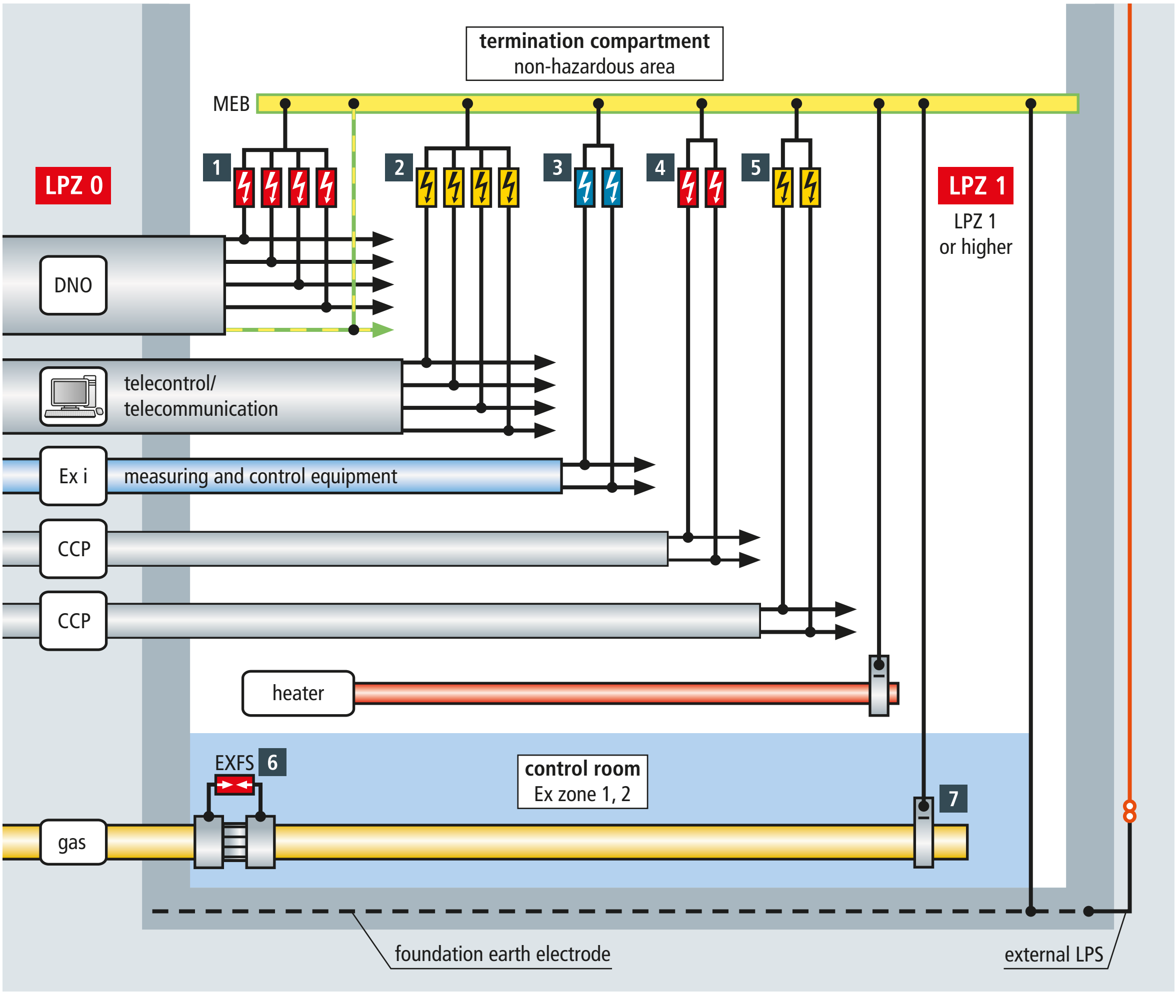


Figure 9.33.6 Lightning equipotential bonding for incoming lines

Lightning and surge protection for yachts

Yachts at sea, at anchor and ashore (e.g. in a dry dock) are vulnerable to lightning strikes. The probability of a lightning strike depends on the local ground flash density N_g which specifies how many lightning discharges occur per km^2 and year. The closer the yacht approaches equatorial waters, the higher the risk to be struck by lightning at sea. In general, the ground flash density is frequently higher ashore (at anchor) than at sea.

If lightning strikes the mast of a yacht, lightning currents travel to the deck. Since several cables are routed on the mast, e.g. to navigation lights, the radio antenna or the anemometer, the lightning current enters the inside of the ship through these cables and spreads over the entire cabling of the on-board system supplying the depth sounder and log. This can damage these systems and result in the ingress of water since these devices are located under the water level. While the ingress of water is noticed at sea and can be eliminated, this often remains unnoticed when the yacht is at anchor in winter and the yacht may sink.

To determine potential points of strike, the electro-geometric model (rolling sphere method) is used. It describes the flash (centre of the rolling sphere) which strikes an object after a certain distance (radius). The smaller the radius, the more effectively lightning strikes are intercepted. In the lightning protection standards, different radii r are assigned to classes of LPS I to IV. Class of LPS I provides maximum protection from lightning strikes. In this case, the system safely handles 99 % of all lightning strikes with impulse currents lower than 200 kA and higher than 3 kA.

Class of LPS III is often used for yachts (see example in **Figure 9.34.1**). This figure allows to assess the risk of a lightning strike to the mast. The information provided below also applies to multi-masted yachts. The points where the rolling sphere touches the yacht are potential points of strike and must be protected.

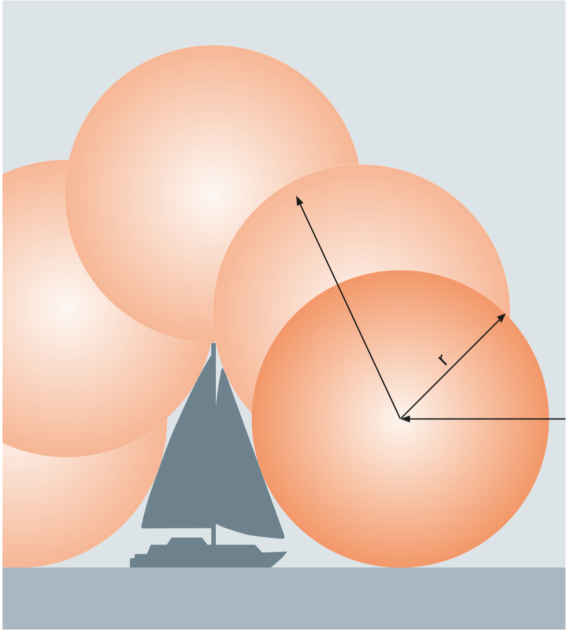


Figure 9.34.1 Determination of the lightning risk for a yacht using the rolling sphere method in case of class of LPS III

Lightning protection

To implement lightning protection measures, a distinction must be made between metal and non-metal masts / bodies of the yacht.

Metal yacht

If the yacht has a metal body which is conductively connected to a metal mast, no additional measures for discharging the lightning current must be taken. If lightning strikes the mast of such a yacht, most of the lightning current is discharged via the mast and partial lightning currents are passed through the stays to the body / bottom and to the water (**Figure 9.34.2**).

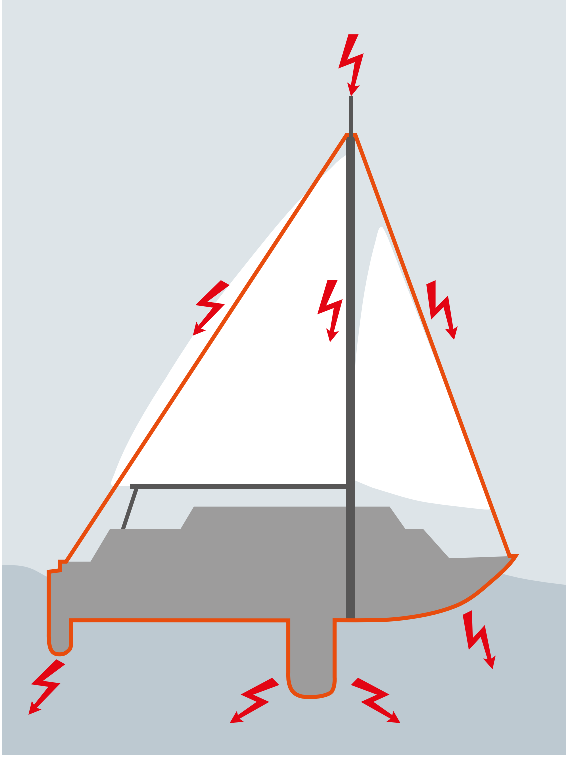


Figure 9.34.2 Lightning current distribution on a yacht following a lightning strike to the mast

Non-metal yacht

Yachts with a wooden or GRP body require additional lightning protection measures.

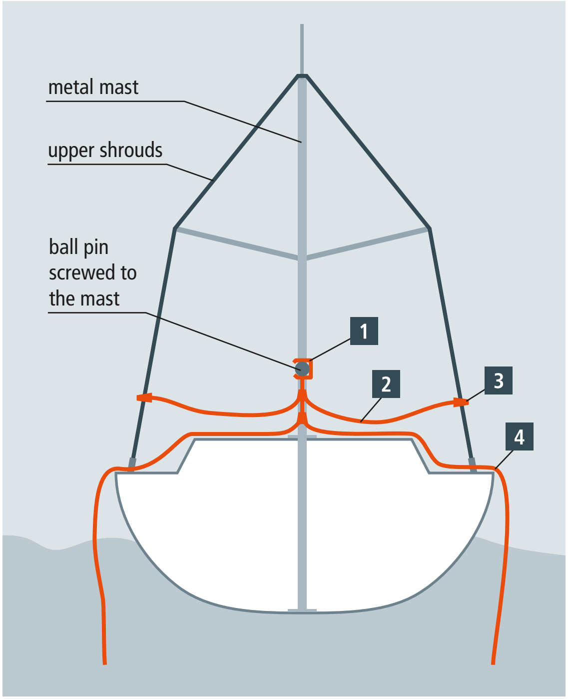
If the mast is made of e.g. wood, an air-termination rod with a thickness of at least 12 mm must protrude at least 300 mm from the mast. The down conductor routed down the mast can be made of copper and should have a minimum cross-section of 70 mm^2. It must be routed in the outdoor area of the yacht and connected to the earth plate. The earth plate must have a surface of at least 0.25 m^2 and must be made of copper or another saltwater-proof material. In case of large yachts, different earth plates may have to be used for the lightning protection and power supply system. In this case, a sufficient distance must be maintained between these earth plates to prevent flashover.

If lightning strikes the air-termination rod on the non-metal mast, the lightning currents must be discharged to the earth plate via the down conductor on the mast and via the shrouds, stays and chain plates. To this end, the mast, shrouds, stays and chain plates must be connected to the earth plate. The copper connecting conductors must have a minimum cross-section of 16 mm^2. All lightning current carrying connections may only be established by screwing, riveting or welding.

Mobile lightning protection in case of a metal mast

A cost-effective mobile lightning protection system, which is frequently used for occasional charters of a yacht, can be easily implemented. To this end, the lower part of the aluminium mast is fitted with a ball pin, which is used as down conductor. A lightning current carrying terminal, which is connected to two other terminals and two braided copper strips of several metres, is screwed to the ball pin. The terminals are connected to the upper shrouds to use them as down conductor. The free ends of both braided copper strips must be immersed at least 1.5 m in the water (**Figure 9.34.3**).

All components and the relevant connections must be capable of carrying lightning currents and must be corrosion-proof. This protection measure can be quickly implemented when a thunderstorm approaches and provides a certain protection against lightning strikes. It is not entirely clear to what extent mobile lightning protection systems provide protection for yachts since the normative requirements for equipotential bonding (personal protection), separation distances, etc. are not observed. It can only be assumed that lightning damage such as punctures of the body can be prevented since most of the lightning current flows through the braided copper strips into the water. Therefore, a fixed lightning protection system always has to be preferred.



	Component	Type/material	Part No.
1	Universal earthing clamp	UEK 25 HG	774 234
2	Multipole earthing cable	e.g. V6TZ3N8	Can be configured via the DEHN earthing and short-circuiting configurator
3	Earthing tongs	Stainless steel	546 001
4	Braided copper strip	Copper	377 007

Figure 9.34.3 Mobile lightning protection for a yacht with a metal mast

Power supply system

The IEC 60364-7-709 (HD 60364-7-709) standard (marinas and similar locations) describes the special requirements for power supply circuits (shoreside power supply system) of water sport vehicles and house boats supplied by public utilities. Water sport vehicles include boats, ships, yachts, motor launches and house boats which are exclusively used for sports and leisure activities.

The information provided only refers to single-phase alternating current power supply systems in a 230 V/50 Hz system (it can be also used for three-phase power supply systems in a modified form). The relevant socket outlets up to 63 A must comply with the IEC 60309-2 (EN 60309-2) standard (CEE design, “blue”).

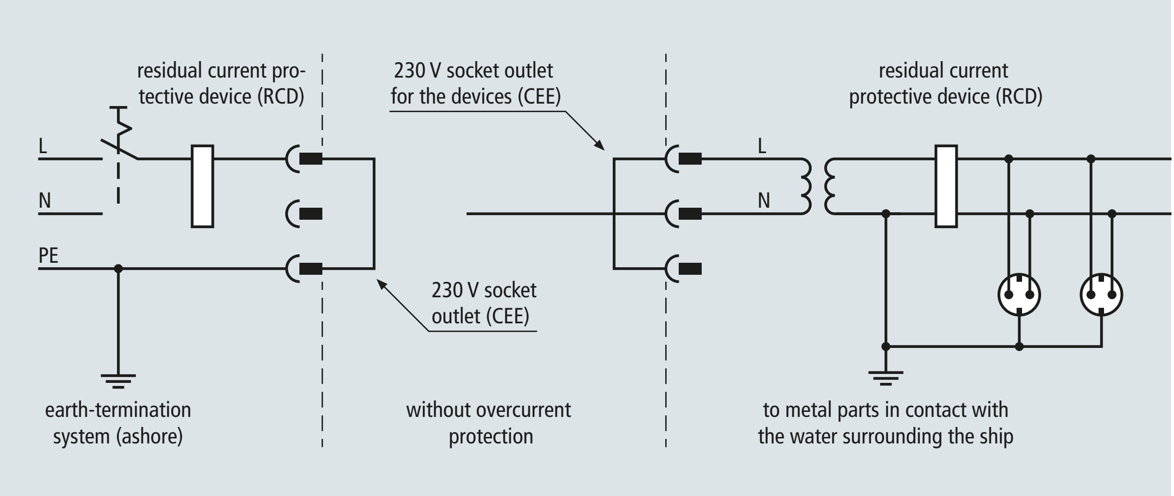


Figure 9.34.4 Use of an isolation transformer to prevent corrosion

For corrosion protection reasons, the protective conductor of the shoreside power supply system must not be connected to the earthed metal parts of the water vehicle. The protective conductor of the shoreside power supply system is not required to protect persons on the yacht against electric shock since an isolation transformer on the yacht ensures protection against electric shock in connection with a residual current protective device (**Figure 9.34.4**).

Equipotential bonding

In general, all protective conductors of the board electronics and all metal parts of yachts must be connected to the common equipotential bonding/earth-termination system of the power supply system. This measure prevents dangerous touch voltage/sparking. The copper protective bonding conductors, which do not carry lightning currents, must have a minimum cross-section of 6 mm^2. For this purpose, stranded, solid or flexible conductors must be used. Flexible conductors should be preferred due to vibrations. In this context, it must be observed that the conductors can be damaged by the corrosive environment (saline, moist) and the capillary effect. Therefore, the cable lug at the ends of the flexible conductors must be sheathed with a heat shrinkable sleeve.

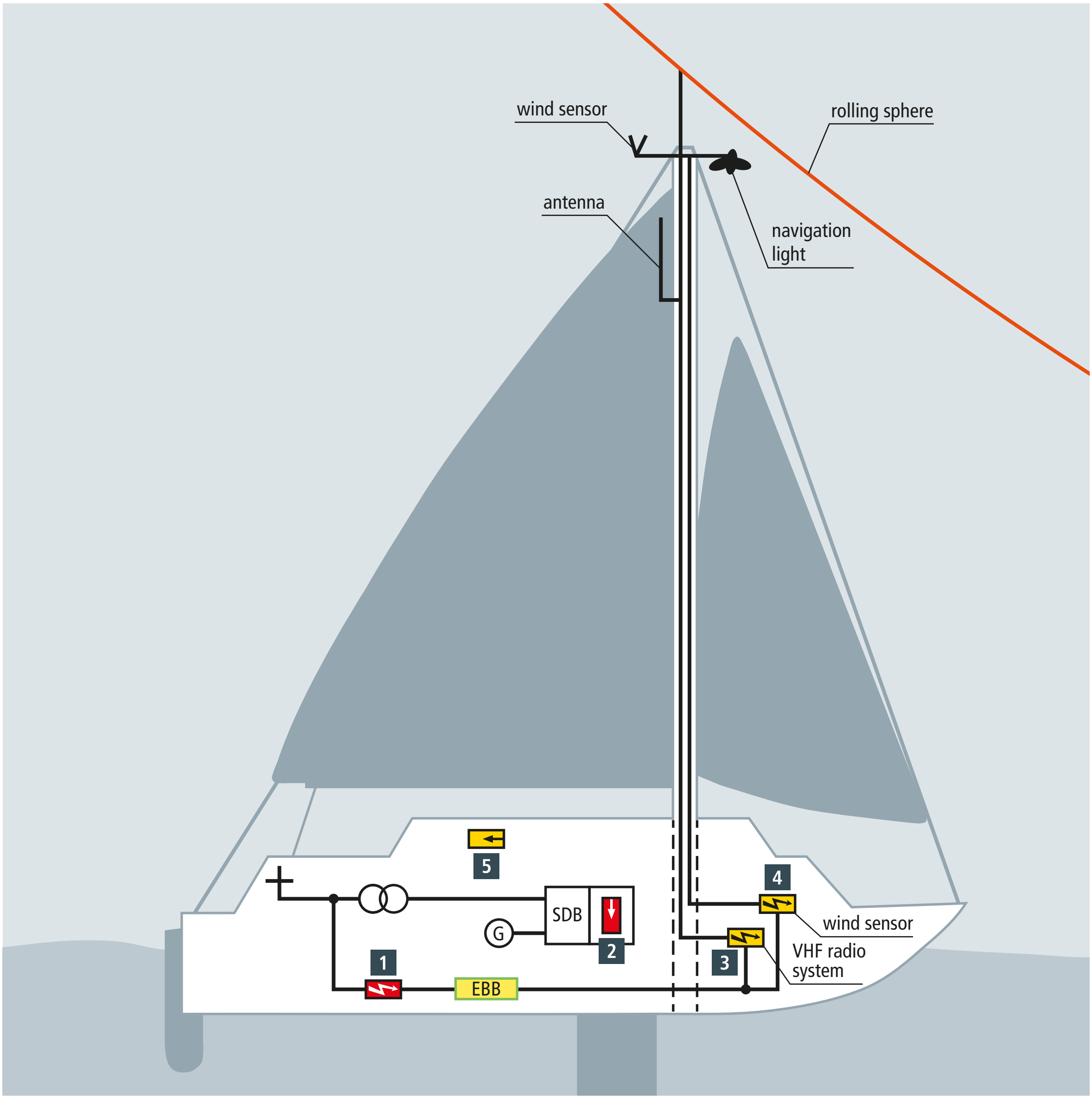
Internal lightning protection/surge protection

A combined arrester, which is directly installed in the power supply system, is one of the most important protection measures (**Figure 9.34.5**). The necessity of such an arrester is shown based on the following two scenarios.

If lightning strikes the air-termination rod or the metal mast of the yacht at anchor which is supplied with electricity, the potential of this yacht is raised above the connection of the shoreside power supply system. A part of the lightning current is passed to the water and flashover to the power cable of the shoreside power supply system will occur depending on the conductivity of the water. This flashover can damage the cables/equipment on the yacht and cause fire. However, it is even more likely that a yacht at anchor, which is supplied with electricity, is threatened by a shoreside lightning strike. In this case, the lightning current flows in the direction of the yacht and causes the damage described above.

If a type 1 combine arrester is installed, it must be ensured that the connection of the earth-termination/equipotential bonding system of the yacht to the protective conductor of the shoreside power supply system does not cause corrosion. The surge protective devices shown in **Figure 9.34.6** consider that the polarity (L, N) is changed, which is typical of earthed socket outlets (not standard-compliant, but may be the case). In this case, the phase conductor (L) and the neutral conductor (N) are twisted until they reach the L and N connections of the on-board supply system. The increased voltage protection level is sufficient for the electric strength of the primary winding.

Irrespective of whether a yacht is made of metal or non-metal material, there is the risk that lightning hits, for example, marine radio antennas or wind sensors installed on the mast, which can damage these pieces of equipment and downstream radio or evaluation devices. Since these pieces of equipment are located in the protected volume (air-termination tip on the



	Surge protective device	Protection for	Part No.
1	DEHNventil DV M TN 255 DEHNgap DGP M 255	Power supply system	951 200 961 101
2	DEHNguard DG M TT 2P 275	Sub-distribution board	952 110
3	DEHNgate DGA AG N	VHF radio system	929 045
4	BLITZDUCTOR BXT ML4 BE 24 + BXT BAS base part	Wind sensor for the navigation system	920 324 + 920 300
5	BLITZDUCTOR BXT ML4 BE 36 + BXT BAS base part	Power supply system of the navigation system	920 336 + 920 300

Figure 9.34.5 Basic surge protection for a yacht (observe the technical data of the manufacturer of the surge protective devices)

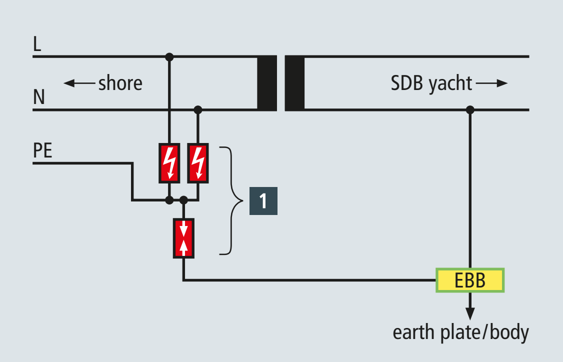
mast), it is not to be expected that lightning strikes them. Adequate surge protective devices are shown in **Figure 9.34.5**. The effects of induced surges and switching overvoltages caused by board generators and UPS systems must also be observed. In this case, it is advisable to use type 2 surge arresters in the distribution board (**Figure 9.34.6**).

Personal protection

The equipotential bonding measures for all connections listed in the above "Equipotential bonding" chapter reduce the risk for persons on the yacht. In the event of a thunderstorm, persons should therefore

- Not stay on deck since potential differences, which present a risk in conjunction with wet skin, can occur due to wet surfaces
- Not touch shrouds, rods or other metal objects
- Check the lightning protection system at regular intervals and do not wait until thunderstorm occurs. In this context, it is important to check whether the equipotential bonding system, namely the connection of all conductive metal devices on board to the lightning protection system, is in good order and condition.

More detailed information can be found in the "Blitzschutz für Yachten" [Lightning protection for yachts] book by Michael Hermann, Palstek Verlag, Hamburg, 2011 (German).



	Surge protective device		Part No.
1	DEHNventil DEHNgap	DV M TN 255 DGP M 255	951 200 961 101

Figure 9.34.6 Detailed view of the shoreside power supply system with a lightning current carrying type 1 combined arrester

Annex

A. References

International standards

CLC/TS 50539-12:2010
Low-voltage surge protective devices – Surge protective devices for specific application including d.c. – Part 12: Selection and application principles – SPDs connected to photovoltaic installations

EN 1127-1:2011
Explosive atmospheres – Explosion prevention and protection – Part 1: Basic concepts and methodology

EN 1993-3-1:2006
Eurocode 3: Design of steel structures – Part 3-1: Towers, masts and chimneys – Towers and masts

EN 10088-1:2014
Stainless steels – Part 1: List of stainless steels

EN 10088-3:2014
Stainless steels – Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes

EN 50162:2004
Protection against corrosion by stray current from direct current systems

EN 50174-2:2009
Information technology – Cabling installation – Part 2: Installation planning and practices inside buildings

EN 50308:2004
Wind turbines – Protective measures – Requirements for design, operation and maintenance

EN 50310:2010
Application of equipotential bonding and earthing in buildings with information technology equipment

EN 50341-1:2012
Overhead electrical lines exceeding AC 45 kV – Part 1: General requirements – Common specifications

EN 50522:2010
Earthing of power installations exceeding 1 kV a.c.

IEC 60050-826:2004
Low-voltage installations – Part 200: Definitions

IEC 60060-1:2010 (EN 60060-1:2010)
High-voltage test techniques – Part 1: General definitions and test requirements

IEC 60068-2-52:1996 (EN 60068-2-52:1996)
Environmental testing – Part 2: Tests, Test Kb: Salt mist, cyclic (sodium chloride solution)

IEC 60079-11:2011 (EN 60079-11:2012)
Explosive atmospheres – Part 11: Equipment protection by intrinsic safety "i"

IEC 60079-14:2007 (EN 60079-14:2008)
Explosive atmospheres – Part 14: Electrical installations design, selection and erection

IEC 60099-4:2004 (EN 60099-4:2004)
Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems

IEC 60309-2:1999 (EN 60309-2:1999)
Plugs, socket-outlets and couplers for industrial purposes – Part 2: Dimensional interchangeability requirements for pin and contact-tube accessories

IEC 60364-1:2005 (HD 60364-1:2008)
Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions

IEC 60364-4-41:2005 (HD 60364-4-41:2007)
Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock

IEC 60364-4-43:2008 (HD 60364-4-43:2010)
Low-voltage electrical installations – Part 4-43: Protection for safety – Protection against overcurrent

IEC 60364-4-44:2001 (HD 60364-4-443:2006)
Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances – Clause 443: Protection against overvoltages of atmospheric origin or due to switching

IEC 60364-4-44:2007 (HD 60364-4-444:2010)
Low-voltage electrical installations – Part 4-444: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances

IEC 60364-5-53:2001 (HD 60364-5-534:2008)
Low-voltage electrical installations – Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control – Clause 534: Devices for protection against overvoltages

IEC 60364-5-54:2011 (HD 60364-5-54:2011)
Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors

IEC 60364-7-701:2006 (HD 60364-7-701:2007)
Low-voltage electrical installations – Part 7-701: Requirements for special installations or locations – Locations containing a bath or shower

IEC 60364-7-702:2010 (HD 60364-7-702:2010)
Low-voltage electrical installations – Part 7-702: Requirements for special installations or locations – Basins of swimming pools, other water basins and fountains

IEC 60364-7-705:2006 (HD 60364-7-705:2007)
Low-voltage electrical installations – Part 7-705: Requirements for special installations or locations – Agricultural and horti-cultural premises

IEC 60364-7-709:2007 (HD 60364-7-709:2009)
Low-voltage electrical installations – Part 7-709: Requirements for special installations or locations – Marinas and similar locations

IEC 60364-7-712:2002 (HD 60364-7-712:2005)
Low-voltage installations – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems

IEC 60664-1:2007 (EN 60664-1:2007)
Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests

IEC 60728-11:2010 (EN 60728-11:2010)
Cable networks for television signals, sound signals and interactive services – Part 11: Safety

IEC 61000-4-5:2005 (EN 61000-4-5:2006)
Electromagnetic Compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test

IEC 61000-4-9:1993 (EN 61000-4-9:1993)
Electromagnetic compatibility (EMC) – Part 4-9: Testing and measurement techniques – Pulse magnetic field immunity test

IEC 61000-4-10:1993 (EN 61000-4-10:1993)
Electromagnetic compatibility (EMC) – Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test

IEC 61400-24:2010 (EN 61400-24:2010)
Wind turbines – Part 24: Lightning protection

IEC 61439-1:2011 (EN 61439-1:2011)
Low-voltage switchgear and controlgear assemblies – Part 1: General rules

IEC 61439-2:2011 (EN 61439-2:2011)
Low-voltage switchgear and controlgear assemblies – Part 2: Power switchgear and controlgear assemblies

IEC 61643-11:2011 (EN 61643-11:2012)
Low-voltage surge protective devices, Part 11: Surge protective devices connected to low-voltage power distribution systems – Requirements and test methods

IEC 61643-21:2000 (EN 61643-21:2001)
Low-voltage surge protective devices – Part 21: Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods

IEC 61643-22:2004 (CLC/TS 61643-22:2006)
Low-voltage surge protective devices – Part 22: Surge protective devices connected to telecommunications and signalling networks – Selection and application principles

IEC 61663-1:1999 (EN 61663-1:1999)
Lightning protection – Telecommunication lines – Part 1: Fibre optic installations

IEC 61663-2:2001 (EN 61663-2:2001)
Lightning protection – Telecommunication lines – Part 2: Lines using metallic conductors

IEC 61936-1:2010 (EN 61936-1:2010)
Power installations exceeding 1 kV a.c. – Part 1: Common rules

IEC 62271-202:2006 (EN 62271-202:2007)
High-voltage switchgear and controlgear – Part 202: High voltage / low voltage prefabricated substation

IEC 62305-1:2010 (EN 62305-1:2011)
Protection against lightning – Part 1: General principles

IEC 62305-2:2010 (EN 62305-2:2012)
Protection against lightning – Part 2: Risk management

IEC 62305-3:2010 (EN 62305-3:2011)
Protection against lightning – Part 3: Physical damage to structures and life hazard

IEC 62305-4:2010 (EN 62305-4:2011)
Protection against lightning – Part 4: Electrical and electronic systems within structures

IEC 62561-1:2012 (EN 62561-1:2012)
Lightning Protection System Components (LPSC) – Part 1: Requirements for connection components

IEC 62561-2:2012 (EN 62561-2:2012)
Lightning Protection System Components (LPSC) – Part 2: Requirements for conductors and earth electrodes

IEC 62561-3:2012 (EN 62561-3.2012)
Lightning Protection System Components (LPSC) – Part 3: Requirements for isolating spark gaps

IEC 62561-4:2010 (EN 62561-4:2011)
Lightning Protection System Components (LPSC) – Part 4: Requirements for conductor fasteners

IEC 62561-5:2011 (EN 62561-5:2011)
Lightning Protection System Components (LPSC) – Part 5: Requirements for earth electrode inspection housings and earth electrode seals

IEC 62561-6:2011 (EN 62561-6:2011)
Lightning Protection System Components (LPSC) – Part 6: Requirements for lightning strike counters

IEC 62561-7:2011 (EN 62561-7:2012)
Lightning Protection System Components (LPSC) – Part 7: Requirements for earthing enhancing compounds

ISO 6988:1985 (EN ISO 6988:1994)
Metallic and other non-organic coatings – Sulfur dioxide test with general condensation of moisture

German standards, guidelines and regulations

BGBl. No. 70 [Federal Law Gazette No. 70] of 27 September 2002 (page 3777)
Regulation for the simplification of law in the field of safety and health protection concerning the provision of work equipment and its use, the safe operation of systems requiring monitoring and the organisation of occupational health and safety (German Ordinance on Industrial Safety and Health (BetrSichV))

BGR 104 – Explosionsschutz-Regeln – Ex-RL – 2013-09
[Regulation No. 104 by the German Social Accident Insurance Institutions – Explosion protection regulations – Ex directive – 2013-09] Regulations to avoid the hazards of explosive atmospheres

DIN 18014:2014
Foundation earth electrode – Planning, execution and documentation

DIN 18384:2012
German construction contract procedures (VOB) – Part C: General technical specifications in construction contracts (ATV) – Installation of lightning protection systems

DIN EN 1991-1-4/NA:2010
National Annex – Nationally determined parameters – Eurocode 1: Actions on structures – Part 1-4: General actions – Wind actions

Supplement 1 of the German DIN EN 62305-2 standard:2013
Protection against lightning – Part 2: Risk management – Supplement 1: Lightning threat in Germany

Supplement 2 of the German DIN EN 62305-2 standard:2013
Protection against lightning – Part 2: Risk management – Supplement 2: Calculation assistance for assessment of risk for structures

Supplement 3 of the German DIN EN 62305-2 standard:2013
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DEHN software

DEHNsupport
Design software for lightning protection systems

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C. Terms and definitions

actiVsense

The actiVsense technology is integrated in universal combined arresters for protecting information technology installations and devices. The arrester automatically detects the signal voltage applied and optimally adapts the voltage protection level to it. Thus, the arrester can be universally used for different interfaces and provides maximum protection for the devices and system circuits connected to it in case of failure.

Breaking capacity, follow current extinguishing capability I_{fi}

The breaking capacity is the uninfluenced (prospective) r.m.s. value of the mains follow current which can automatically be extinguished by the surge protective device when connecting U_C. It can be proven in an operating duty test according to EN 61643-11.

Categories according to IEC 61643-21:2009

A number of impulse voltages and impulse currents are described in IEC 61643-21:2009 for testing the current carrying capability and voltage limitation of impulse interference. Table 3 of this standard lists these into categories and provides preferred values. In Table 2 of the IEC 61643-22 standard the sources of transients are assigned to the different impulse categories according to the decoupling mechanism. Category C2 includes inductive coupling (surges), category D1 galvanic coupling (lightning currents). The relevant category is specified in the technical data. DEHN + SÖHNE surge protective devices surpass the values in the specified categories. Therefore, the exact value for the impulse current carrying capability is indicated by the nominal discharge current (8/20 μs) and the lightning impulse current (10/350 μs).

Combination wave

A combination wave is generated by a hybrid generator (1.2/50 μs, 8/20 μs) with a fictitious impedance of 2 Ω. The open-circuit voltage of this generator is referred to as U_{OC}. U_{OC} is a preferred indicator for type 3 arresters since only these arresters may be tested with a combination wave (according to EN 61643-11).

Cut-off frequency f_G

The cut-off frequency defines the frequency-dependent behaviour of an arrester. The cut-off frequency is equivalent to the frequency which induces an insertion loss (a_E) of 3 dB under certain test conditions (see EN 61643-21:2010). Unless otherwise indicated, this value refers to a 50 Ω system.

Degree of protection

The IP degree of protection corresponds to the protection categories described in IEC 60529.

Disconnecting time t_a

The disconnecting time is the time passing until the automatic disconnection from power supply in case of a failure of the circuit or equipment to be protected. The disconnecting time is an application-specific value resulting from the intensity of the fault current and the characteristics of the protective device.

Energy coordination of SPDs

Energy coordination is the selective and coordinated interaction of cascaded protection elements (= SPDs) of an overall lightning and surge protection concept. This means that the total load of the lightning impulse current is split between the SPDs according to their energy carrying capability. If energy coordination is not possible, downstream SPDs are insufficiently relieved by the upstream SPDs since the upstream SPDs operate too late, insufficiently or not at all. Consequently, downstream SPDs as well as terminal equipment to be protected may be destroyed. CLC/TS 61643-12:2010 describes how to verify energy coordination. Spark-gap-based type 1 SPDs offer considerable advantages due to their voltage-switching characteristic (see WAVE BREAKER FUNCTION).

Frequency range

The frequency range represents the transmission range or cut-off frequency of an arrester depending on the described attenuation characteristics.

Insertion loss

With a given frequency, the insertion loss of a surge protective device is defined by the relation of the voltage value at the place of installation before and after installing the surge protective device. Unless otherwise indicated, the value refers to a 50 Ω system.

Integrated backup fuse

According to the product standard for SPDs, overcurrent protective devices / backup fuses must be used. This, however, requires additional space in the distribution board, additional cable lengths, which should be as short as possible according to IEC 60364-5-53, additional installation time (and costs) and dimensioning of the fuse. A fuse integrated in the arrester ideally suited for the impulse currents involved eliminates all these disadvantages. The space gain, lower wiring effort, integrated fuse monitoring and the increased protective effect due to shorter connecting cables are clear advantages of this concept which is integrated in the DEHNvenCI, DEHNbloc Maxi S, DEHNguard … CI and V(A) NH product families.

LifeCheck

Repeated discharge processes which exceed the specification of the device can overload arresters in information technology systems. In order to ensure high system availability, arresters should therefore be subjected to systematic tests. LifeCheck allows quick and easy testing of arresters.

Lightning impulse current I_{imp}

The lightning impulse current is a standardised impulse current curve with a 10/350 µs wave form. Its parameters (peak value, charge, specific energy) simulate the load caused by natural lightning currents. Lightning current and combined arresters must be capable of discharging such lightning impulse currents several times without being destroyed.

Mains-side overcurrent protection / arrester backup fuse

Overcurrent protective device (e.g. fuse or circuit breaker) located outside of the arrester on the infeed side to interrupt the power-frequency follow current as soon as the breaking capacity of the surge protective device is exceeded. No additional backup fuse is required since the backup fuse is already integrated in the SPD.

Maximum continuous operating voltage U_C

The maximum continuous operating voltage (maximum permissible operating voltage) is the r.m.s. value of the maximum voltage which may be connected to the corresponding terminals of the surge protective device during operation. This is the maximum voltage on the arrester in the defined non-conducting state, which reverts the arrester back to this state after it has tripped and discharged. The value of U_C depends on the nominal voltage of the system to be protected and the installer's specifications (IEC 60364-5-534).

Maximum continuous operating voltage U_{CPV} for a photovoltaic (PV) system

Value of the maximum d.c. voltage that may be permanently applied to the terminals of the SPD. To ensure that U_{CPV} is higher than the maximum open-circuit voltage of the PV system in case of all external influences (e.g. ambient temperature, solar radiation intensity), U_{CPV} must be higher than this maximum open-circuit voltage by a factor of 1.2 (according to CLC/TS 50539-12). This factor of 1.2 ensures that the SPDs are not incorrectly dimensioned.

Maximum discharge current I_{max}

The maximum discharge current is the maximum peak value of the 8/20 µs impulse current which the device can safely discharge.

Maximum transmission capacity

The maximum transmission capacity defines the maximum high-frequency power which can be transmitted via a coaxial surge protective device without interfering with the protection component.

Nominal discharge current I_n

The nominal discharge current is the peak value of a 8/20 µs impulse current for which the surge protective device is rated in a certain test programme and which the surge protective device can discharge several times.

Nominal load current (nominal current) I_L

The nominal load current is the maximum permissible operating current which may permanently flow through the corresponding terminals.

Nominal voltage U_N

The nominal voltage stands for the nominal voltage of the system to be protected. The value of the nominal voltage often serves as type designation for surge protective devices for information technology systems. It is indicated as an r.m.s. value for a.c. systems.

N-PE arrester

Surge protective devices exclusively designed for installation between the N and PE conductor.

Operating temperature range T_U

The operating temperature range indicates the range in which the devices can be used. For non-self-heating devices, it is equal to the ambient temperature range. The temperature rise for self-heating devices must not exceed the maximum value indicated.

Protective circuit

Protective circuits are multi-stage, cascaded protective devices. The individual protection stages may consist of spark gaps, varistors, semiconductor elements and gas discharge tubes (see Energy coordination).

Protective conductor current I_{PE}

The protective conductor current is the current which flows through the PE connection when the surge protective device is connected to the maximum continuous operating voltage U_C, according to the installation instructions and without load-side consumers.

Remote signalling contact

A remote signalling contact allows easy remote monitoring and indication of the operating state of the device. It features a three-pole terminal in the form of a floating changeover contact. This contact can be used as break and / or make contact and can thus be easily integrated in the building control system, controller of the switchgear cabinet, etc.

Response time t_A

Response times mainly characterise the response performance of individual protection elements used in arresters. Depending on the rate of rise du/dt of the impulse voltage or di/dt of the impulse current, the response times may vary within certain limits.

Return loss

In high-frequency applications, the return loss refers to how many parts of the "leading" wave are reflected at the protective device (surge point). This is a direct measure of how well a protective device is attuned to the characteristic impedance of the system.

SCI technology

Direct currents (d.c.) flow on the generator side of a PV system. The surge protective devices used on the generator side can be overloaded due to different scenarios (e.g. impulse load, insulation faults) and must not endanger the PV system. However, insufficient d.c. disconnection capability in a PV system may cause fire. Conventional surge arresters only feature a disconnector in the form of a simple break contact mechanism which is typically used for a.c. devices. Due to the lacking zero crossing of the d.c. source, a d.c. arc may persist and cause fire. The SCI technology patented by DEHN + SÖHNE with active arc extinction is an ideal solution. In case of overload, a contact is opened and a short-circuit is generated (Short Circuit). Thus, a possible switching arc is actively, quickly and safely extinguished. The PV fuse integrated in the short-circuit path immediately trips after the arc has been extinguished and ensures safe electrical isolation (Interruption). Thus, all PV arresters from DEHN + SÖHNE combine surge protection, fire protection and personal protection in a single device.

Series resistance

Resistance in the direction of the signal flow between the input and output of an arrester.

Shield attenuation

Relation of the power fed into a coaxial cable to the power radiated by the cable through the phase conductor.

Surge protective devices (SPDs)

Surge protective devices mainly consist of voltage-dependent resistors (varistors, suppressor diodes) and / or spark gaps (discharge paths). Surge protective devices are used to protect other electrical equipment and installations against inadmissibly high surges and / or to establish equipotential bonding. Surge protective devices are categorised:

a) according to their use into:

- Surge protective devices for power supply installations and devices (Red/Line product family) for nominal voltage ranges up to 1000 V
  - – according to EN 61643-11:2012 into type 1 / 2 / 3 SPDs
  - – according to IEC 61643-11:2011 into class I / II / III SPDs
- Surge protective devices for information technology installations and devices (Yellow/Line product family) for protecting modern electronic equipment in telecommunications and signalling networks with nominal voltages up to 1000 V a.c. (effective value) and 1500 V d.c. against the indirect and direct effects of lightning strikes and other transients.
  - – according to IEC 61643-21:2009 and EN 61643-21: 2010.
- Isolating spark gaps for earth-termination systems or equipotential bonding (Red/Line product family)
- Surge protective devices for use in photovoltaic systems (Red/Line product family) for nominal voltage ranges up to 1500 V
  - – according to EN 50539-11:2013 into type 1 / 2 SPDs

b) according to their impulse current discharge capacity and protective effect into:

- Lightning current arresters / coordinated lightning current arresters for protecting installations and equipment against interference resulting from direct or nearby lightning strikes (installed at the boundaries between LPZ 0_A and 1).
- Surge arresters for protecting installations, equipment and terminal devices against remote lightning strikes, switching overvoltages as well as electrostatic discharges (installed at the boundaries downstream of LPZ 0_B).
- Combined arresters for protecting installations, equipment and terminal devices against interference resulting from direct or nearby lightning strikes (installed at the boundaries between LPZ 0_A and 1 as well as 0_A and 2).

Technical data of surge protective devices

The technical data of surge protective devices include information on their conditions of use according to their:

- Application (e.g. installation, mains conditions, temperature)
- Performance in case of interference (e.g. impulse current discharge capacity, follow current extinguishing capability, voltage protection level, response time)
- Performance during operation (e.g. nominal current, attenuation, insulation resistance)
- Performance in case of failure (e.g. backup fuse, disconnector, fail-safe, remote signalling option)

Short-circuit withstand capability

The short-circuit withstand capability is the value of the prospective power-frequency short-circuit current handled by the surge protective device when the relevant maximum backup fuse is connected upstream.

Short-circuit rating I_{SCPV} of an SPD in a photovoltaic (PV) system

Maximum uninfluenced short-circuit current which the SPD, alone or in conjunction with its disconnection devices, is able to withstand.

Temporary overvoltage (TOV)

Temporary overvoltage may be present at the surge protective device for a short period of time due to a fault in the high-voltage system. This must be clearly distinguished from a transient caused by a lightning strike or a switching operation, which last no longer than about 1 ms. The amplitude U_T and the duration of this temporary overvoltage are specified in EN 61643-11 (200 ms, 5 s or 120 min.) and are individually tested for the relevant SPDs according to the system configuration (TN, TT, etc.). The SPD can either a) reliably fail (TOV safety) or b) be TOV-resistant (TOV withstand), meaning that it is completely operational during and following temporary overvoltages.

Thermal disconnector

Surge protective devices for use in power supply systems equipped with voltage-controlled resistors (varistors) mostly feature an integrated thermal disconnector that disconnects the surge protective device from the mains in case of overload and indicates this operating state. The disconnector responds to the "current heat" generated by an overloaded varistor and disconnects the surge protective device from the mains if a certain temperature is exceeded. The disconnector is designed to disconnect the overloaded surge protective device in time to prevent a fire. It is not intended to ensure protection against indirect contact. The function of these thermal disconnectors can be tested by means of a simulated overload / ageing of the arresters.

Total discharge current I_{total}

Current which flows through the PE, PEN or earth connection of a multi-pole SPD during the total discharge current test. This test is used to determine the total load if current simultaneously flows through several protective paths of a multipole SPD. This parameter is decisive for the total discharge capacity which is reliably handled by the sum of the individual paths of an SPD.

Voltage protection level U_p

The voltage protection level of a surge protective device is the maximum instantaneous value of the voltage at the terminals of a surge protective device, determined from the standardised individual tests:

- Lightning impulse sparkover voltage 1.2/50 µs (100 %)
- Sparkover voltage with a rate of rise of 1kV/µs
- Measured limit voltage at a nominal discharge current I_n

The voltage protection level characterises the capability of a surge protective device to limit surges to a residual level. The voltage protection level defines the installation location with regard to the overvoltage category according to IEC 60664-1 in power supply systems. For surge protective devices to be used in information technology systems, the voltage protection level must be adapted to the immunity level of the equipment to be protected (IEC 61000-4-5: 2001).

Wave breaker function

Due to the technical design of type 1 SPDs, energy coordination of SPDs considerably varies. Experience has shown that even small amplitudes of the 10/350 µs lightning impulse current overload downstream SPDs or even destroy them if varistor-based type 1 lightning current arresters are used. In case of spark-gap-based type 1 arresters, in contrast, virtually the total current flows through the type 1 arrester. Similar to a wave breaker the energy is reduced to an acceptable level. The advantage is that the time to half value of the 10/350 µs impulse current is reduced due to the reduction of the impulse time and the switching behaviour of type 1 SPDs. This considerably relieves downstream SPDs.

All devices of the DEHN + SÖHNE Red/Line and Yellow/Line product family are energy-coordinated. Moreover, all type 1 arresters of the Red/Line family are based on spark gaps and thus feature this WAVE BRAKER FUNCTION.

Yellow/Line SPD class

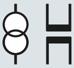
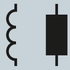
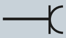
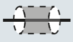
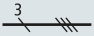
All DEHN arresters for use in information technology systems are categorised into a Yellow/Line SPD class and are marked with the corresponding symbol in the datasheet and on the rating plate.

D. Abbreviations

3G	Mobile radio standard of the third generation (UMTS)
4G	Mobile radio standard of the fourth generation (LTE)
ABB	Ausschuss für Blitzschutz und Forschung im VDE (Committee for Lightning Protection and Research at the VDE)
AC	Area Coupler
a.c.	Alternating Current
ALDIS	Austrian Lightning Detection & Information System
ATEX	Explosion Protection Guidelines by the European Union (French: *AT*mosphère *EX*plosive)
BBU	Baseband Unit
BD	Building Distributor
C	Cable Cabinet
CBN	Common Bonding Network
CCP	Cathodic Corrosion Protection
CD	Campus Distributor
CHP	Combined Heat and Power Station
CP	Consolidation Point
CPS	Central Power Supply System
CPU	Central Processing Unit
CTRL	Controller
d.c.	Direct Current
DCF	Time signal for radio-controlled clocks in Germany
DDC	Direct Digital Control
DIN	Deutsches Institut für Normung (German Standardisation Institute)
DNO	Distribution Network Operator
EB	Equipotential Bonding
EBB	Equipotential Bonding Bar
EMC	Electromagnetic Compatibility
ERP	Earthing Reference Point
Ex	Area in which explosive atmospheres may occur
Ex(i)	Intrinsic safety
EU	Evaluation Unit of Switching Equipment
FBIP	Fire Brigade Indicator Panel
FBOP	Fire Brigade Operating Panel
FC	Frequency Converter
FD	Floor Distributor
FEM	Finite Element Method
FTT	Free Topology Transceiver
G	Generator
GDV	Gesamtverband der Deutschen Versicherungswirtschaft e.V. (German Insurance Association)
GRP	Glass-fibre Reinforced Plastic
gG	Full range protection (general purpose fuse)
gL	Full range cable and line protection (fuse)
GPS	Global Positioning System
HF	High Frequency
HV	High Voltage
HVI	High Voltage Insulation
IEC	International Electrotechnical Commission
I/O	Input/Output
ISDN	Integrated Services Digital Network
IT	Information Technology
ITE	Information Technology Equipment
KD	Key Depot
KEMA	Keuring van Elektrotechnische Materialen te Arnhem (inspection of electrical equipment in Arnhem)
KNX	Building automation standard
LAN	Local Area Network
LC	Line Coupler
LED	Light-Emitting Diode
LEMP	Lightning electromagnetic Pulse
LF	Low frequency
LON	Local Operating Network
LPL	Lightning Protection Level
LPS	Lightning Protection System
LPT	Link Power Transceiver
LPZ	Lightning Protection Zone
LTE	Long Term Evolution (mobile radio standard)
LV	Low Voltage
MLVDB	Main Low-Voltage Distribution Board
M	Meter
M	Motor
MCE	Measuring and Control Equipment
MDB	Main Distribution Board

MEB	Main Earthing Busbar
MOV	Metal Oxide Varistor
MT	Measuring Transducer
MV	Medium Voltage
NT	Network Termination
NTBA	Network Termination for ISDN Basic Rate Access
OFC	Optical Fibre Cable
PE	Protective Conductor
PE	Polyethylene
PEN	Protective and Neural Conductor
PEX	Cross-linked polyethylene
PLC	Programmable Logic Controller
PP	Patch panel
PSU	Power Supply Unit
PV	Photovoltaic
RBS	Radio Base Station
RCD	Residual Current Protective Device
RE	Release Element
RET	Remote Electrical Tilt
RRH	Remote Radio Head
RRU	Remote Radio Unit
SCI	Short Circuit Interruption
SDB	Sub-Distribution Board
SDS	Smoke Detection System
SEB	Service Entrance Box
SELV	Safety Extra-Low Voltage
SEMP	Switching Electromagnetic Pulse
SPD	Surge Protective Device
SPM	Surge Protection Measure
SS	Security Services
StSt	Stainless Steel
T	Transformer Cabinet
TCU	Telecommunications Connection Unit
TE	Transmission Equipment
TMA	Tower-Mounted Amplifier
TO	Telecommunications Outlet
TOV	Temporary Overvoltage
UMTS	Universal Mobile Telecommunications System
U	Utility
UPS	Uninterrupted Power Supply
VDB	Verband Deutscher Blitzschutzfirmen e.V. (Association of German Lightning Protection Companies)
VDE	Verband der Elektrotechnik, Elektronik und Informationstechnik e.V. (German Association for Electrical, Electronic and Information Technologies)
VDEW	Verband der Elektrizitätswirtschaft e.V. (German Association of the Electricity Industry)
VDN	Verband der Netzbetreiber e.V. beim VDEW (Association of German Network Operators at the VDEW)
VDS	Unternehmen des Gesamtverbandes der Deutschen Versicherungswirtschaft e.V. (GDV) mit den Bereichen Brandschutz, Security und Bildungszentrum & Verlag (company of the German Insurance Association which ensures safety in the fields of fire protection, security and training centre & publishing house)
VS	Ventilation Switch
VS/C	Voltage Supply / Choke
ZDC	Zinc Die Casting
ZVDH	Zentralverband des deutschen Dachdeckerhandwerks (German Central Association of Roofers)

E. Technical symbols

Symbol	Description	Symbol	Description	Symbol	Description
	Lightning equipotential bonding; lightning current arrester		Equipotential bonding bar		PE conductor
	Local equipotential bonding; surge arrester		Fuse (general)		N conductor
	Lightning equipotential bonding; TYPE 1 lightning current arrester of the Yellow/Line		Resistor; decoupling element (general)		PEN conductor
	Local equipotential bonding; TYPE 2 - 4 surge arrester of the Yellow/Line		Variable resistor		Earth (general)
	Local equipotential bonding; TYPE 2 - 4 surge arrester of the Yellow/Line		Variable thermistor		Test joint
	Local equipotential bonding; surge arrester (type 2 SPD, type 3 SPD)		Diode		Junction
	Lightning current arrester for use in hazardous areas		Light-emitting diode (LED)		Connecting clamp
	Surge arrester for use in hazardous areas		Bidirectional avalanche diode		Motor
	Combined arrester for power supply and information technology systems		Capacitor		Generator
	Medium-voltage arrester		Signal lamp		Temperature sensor
	Isolating spark gap		Transformer		Socket and plug
	Varistor		Inductor (reactor, winding, coil)		Socket outlet with earthing contact
	Gas discharge tube		Enclosure		Antenna socket
	LifeCheck arrester testing		Meter		Switch/button
LPZ	Lightning protection zone		Inverter		Fuse disconnector
Ex-Zone	Potentially explosive atmosphere		PV module		Circuit breaker
	Hazardous area		Shielded cable		Single-pole representation of the conductors by means of a number/lines

SPD class symbols

Characteristic	Symbol	Description
Discharge capacity of an arrester (according to the categories of IEC 61643-21 (EN 61643-21))	TYPE 1	D1 impulse (10/350 µs), lightning impulse current ≥ 2.5 kA / core or ≥ 5 kA / total • Exceeds the discharge capacity of TYPE 2 – TYPE 4
	TYPE 2	C2 impulse (8/20 µs), increased impulse load ≥ 2.5 kA / core or ≥ 5 kA / total • Exceeds the discharge capacity of TYPE 3 – TYPE 4
	TYPE 3	C1 impulse (8/20 µs), impulse load ≥ 0.25 k / core or ≥ 0.5 kA / total • Exceeds the discharge capacity of TYPE 4
	TYPE 4	Load < TYPE 3
Protective effect of an arrester (limitation below the test levels acc. to IEC 61000-4-5 (EN 61000-4-5))	P1	Test level required for the terminal device: 1 or higher
	P2	Test level required for the terminal device: 2 or higher
	P3	Test level required for the terminal device: 3 or higher
	P4	Test level required for the terminal device: 4
Energy coordination (with another Yellow/Line arrester)	⊕	Arrester has a decoupling impedance and is suitable for coordination with an arrester marked with ❳
	❳	Arrester suitable for coordination with an arrester with decoupling impedance ⊕

Assignment of the SPD classes to the LPZ transitions

Conductor routing	Arrester solution	Exemplary assignment of SPD classes to LPZ transitions		
		To LPZ 1	To LPZ 2	To LPZ 3
From LPZ 0_A	Combined arresters	TYPE 1 P1		
	Cascaded arresters	TYPE 1 ⊕	❳TYPE 2 P1	
		TYPE 1 ❲	⊕TYPE 3 P1	
From LPZ 0_B	Combined arresters	TYPE 1 P1		
	Surge arresters	TYPE 2 P1 or ❳TYPE 2 P1		
	Cascaded arresters	TYPE 2 ❲	⊕TYPE 3	
From LPZ 1	Combined arresters	–	TYPE 1 P1	
	Surge arresters	–	TYPE 2 P1 or ❳TYPE 2 P1	
From LPZ 2	Combined arresters	–	TYPE 1 P1	
	Surge arresters	–	–	TYPE 2 P1
		–	–	TYPE 3 P1
		–	–	TYPE 4 P1

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