CIKIT

Lightning Protection & Earthing Solutions

A HANDBOOK ON LIGHTNING PROTECTION

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Foreword

Lightning, in recent times has shown steep rise in its intensity and frequency and so the fatalities. Due to grave adverse impact of lightning on to human beings, animals and economic assets, the disaster management set up in the country at national, state and corporate level has put lightning mitigation on high priority. To address lightning hazard and avoid losses , India has adopted a research and development based strategy based on three main factors namely Lightning forecast and dissemination , mitigation by installation of lightning protection devices (LPS) and Public Awareness campaign to lightning safety and compliance to it. India Meteorological Department started forecast of lightning from 01 April 2019 and there has been tremendous awareness efforts have been undertaken under Lightning Resilient India Campaign towards lightning, its early warning , Do's and Don'ts and installation of LPS.

Lightning Protection System has been found most challenging. Lack of awareness among the people and absence of well-designed and executed Lightning Protection System is one of the major reasons for the losses. Lightning cannot be avoided whereas the losses can be reduced by installing proper protection systems. Governments at national and state level are committed towards goal of achieving "Lightning Safe India " through various policy level interventions and awareness programmes. There has been phenomenal rise in atmospheric electricity up to the average level of 150-200 kilo amperes (kA) across the country . Soil resistance have also risen significantly. Therefore, while designing a LPS, proper assessment of risks in terms of observed latest atmospheric electric current and soil resistance is a must. It must be carried out as per existing standards of IEC or NFC. I advise to the industries involved in manufacturing of LPS to ensure the properly tested devices should only be sold as it amounts to saving life of human beings. I also advise to government agencies and individuals to ensure proper compliance to risk assessment, exposure risks and tested devices while procurement of LPS. Since most of the casualties are of people belonging to lower income group, the focus areas has been at development of low cost , affordable and accessible Lightning protections devices. At the same time, high end industries need complex but reliable designs. Both the aspects need due attention. Electrical, electronics and Information Technology enables services (ITes) based organisations and industries involved in power generation and transmission, petroleum, chemicals, explosives, mining, railways, aviation, data centres, military installations to households need to ensure adoption of proper LPS.

It gives me immense pleasure to see the initiatives taken by CIKIT Electricals and Technologies team in creating awareness among the people through the series of articles. This collection of articles is not just a refreshing read but a must have handbook for professionals connected directly or indirectly to the Electrical Safety industry. The content is crisp and created in a manner that justifies the time spent on it. My admiration and praise to members of the CIKIT team, for bringing out such a valuable resource out for awareness and knowledge.

I recommend this as a must read for all professionals and Electrical Engineering students and wish the CIKIT team a great future ahead.

(Sanjay Srivastava)

FOREWORD

Lightning, a natural event, can be a cause of concern. Franklin in 1752, by his kite experiment showed lightning is of electric nature. The up and down drafts of wind in the atmosphere separate electric charges leaving negative charges at the bottom and positive charges at the top of the cloud.

Lightning is the most frequent cause of over voltages on electrical Transmission and Distribution System.

Lightning is a gigantic spark resulting from the development of millions of volts between clouds or between cloud and the earth. This is similar to the dielectric breakdown of a huge capacitor.

The voltage between cloud and the earth before a lightning stroke may start at hundreds of million volts between the cloud and the earth. Millions of volts can be delivered to the building, tree, or transmission/distribution line struck. In case of overhead lines "induced voltages" caused by the collapse of the electrostatic field with a nearby stroke and may reach values as high as 500 kV.

The potential gradients that result when stroke current enter the earth on the surrounding surface increases the "step voltage" which is dangerous to human beings and cattle.

There is a need to bring awareness among all concerned regarding lightning protection to protect electrical equipment and life. Proper grounding is most important for effective lightning protection.

I am very happy that Mr.Kamalesh Sundar, MD, CIKIT ELECTRICALS & TECHNOLOGIES is bringing out a book titled "A QUICK GUIDE ON LIGHTNING PROTECTION". I have gone through the draft copy of the book which conforms to international standards. Mr. Kamalesh is a young, energetic, proactive person.

My best wishes to Mr. Kamalesh and his CIKIT team for publishing this most useful book.

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May 22, 2022

Table of Contents

1 External Lightning Protection System 3
1.1 What is Lightning? 4
1.2 Damages due to Lightning Strikes 5
1.3 Overall Lightning Protection System 7
1.4 An Overview of IS/IEC 62305 part 1 10
1.5 The Class of Lightning Protection System 13
1.6 IS/IEC 62305 part2: Risk Management 14
1.7 Factors Influencing Risk components 16
1.8 Risk Management 17
1.9 Assessment of Risk Components 20
1.10 Assessment of Number of Dangerous Events 22
1.11 Assessment of Probability of Damage 24
1.12 Lightning Protection System Design 26
1.13 Protection Angle Method 28
1.14 Rolling Sphere Method 32
1.15 Mesh Method 36
1.16 Down Conductors of LPS 38
1.17 Instructions for Installing Down Conductors 39
1.18 Natural Component as a LPS Conductor 40
1.19 Reinforcement Bars as LPS components 42
1.20 Isolated Lightning Protection System 44
1.21 ESE Lightning Air Terminal 45
1.22 Testing Procedure of ESE Air terminal 47
1.23 Installation of ESE Lightning Air terminal at Different Structures 50
1.24 Test Joints in Lightning Protection System 52
1.25 Selection of Materials for Lightning Protection System 53
1.26 Requirements and Testing of LPS Components 55
1.27 Instructions for Installation of LPS 60
1.28 Inspection and Maintenance of LPS 63
2 Internal Lightning Protection System 66
2.1 Lightning Equipotential Bonding 67
2.2 Separation Distance 68
2.3 Surge Protection Device 73
3 Application 75
3.1 Need of Protection for Tanks against Direct Lightning Strikes 76
3.2 Design of Protection for Oil Storage Tank Against Lightning Strike 78

3.3 Lightning Protection for Solar Farms 81
3.4 Protection of Transmission Lines from Lightning 83
3.5 Protection of Telecommunication Tower from Lightning 84
3.6 UL Guidance for Protection of Heavy-Duty Stacks 86

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1 EXTERNAL LIGHTNING PROTECTION SYSTEM

1.1 What is Lightning?

What is a lightning flash?

According to IS/IEC 62305 Part - 1, lightning flash can be defined as the discharge of charges between the cloud and the earth consisting of one or more strokes.

Types of lightning discharges:

In general, there are four types of lightning discharges. The different types are shown in Figure1.

1) Intra cloud discharges
2) Cloud to Cloud discharges
3) Cloud to Ground discharges and
4) Ground to Cloud discharges

Among these, more than 50% of the lightning flashes occur within the cloud and only the remaining flashes occur from cloud to ground.

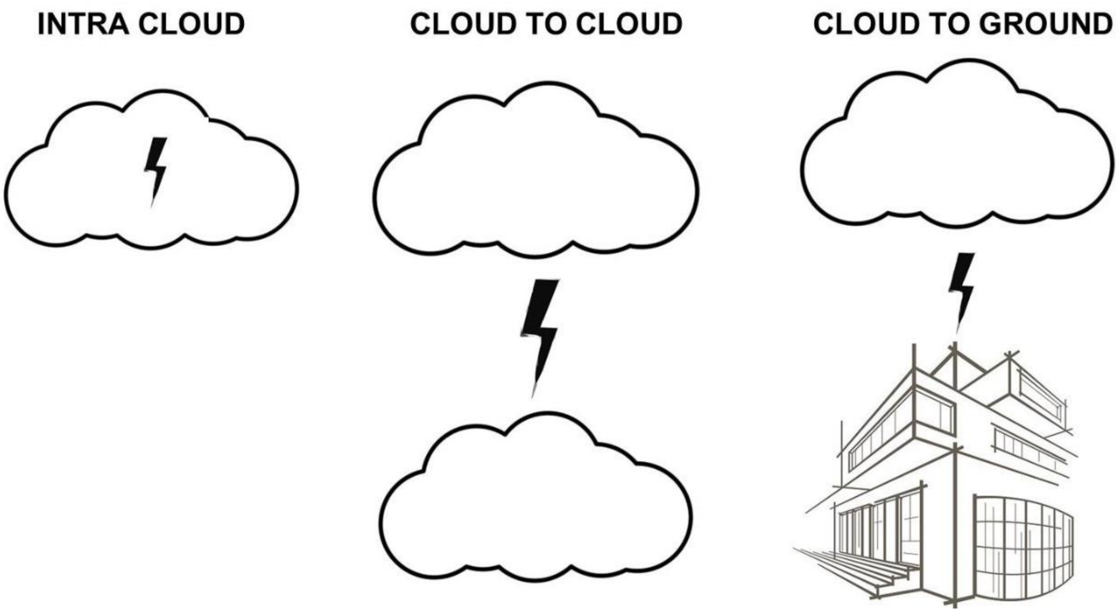

Figure 1. Types of lightning discharges

Cloud to Ground discharge:

During 45% of cloud to ground flashes, the cloud is positively charged at the top, leaving negative charges at the bottom. So, the lightning starts as a negative leader from the cloud and discharges to the ground. In the remaining 5 % flashes, the cloud to ground discharges is initiated as a positive leader from the cloud as the cloud is negatively charged at the top, leaving positive charges at the bottom.

Ground to Cloud discharge:

There are a few extremely rare flashes moving from ground to cloud, are found to occur in high mountain tops and man-made structures that are extremely tall.

1.2 Damages due to Lightning Strikes

Introduction :

Lightning strike is a natural phenomenon of sudden discharge of charges from highly concentrated cloud or any objects. There are no methods or devices that can prevent lightning discharges but the damages can be reduced by proper preventive measures. IS/IEC 62305 describes about the damages due to the lightning strikes and the sources of such damages.

Damages due to Lightning:

Lightning is one of the most destructive forms of nature. Lightning kills more people in India than any other natural disasters. In India, more than 2,500 people are dying every year due to lightning strikes.

Direct lightning strike on the structures is not the only source of damages due to lightning strikes. Lightning strike near the buildings or structures and lightning strikes on power lines can also cause damages to the structures or electrical equipment or may harm the human beings.

Types of Damages:

IS/IEC 62305 categorizes the damages caused by lightning flashes into three types. They are,

1) D1: injury to living beings by electric shock,
2) D2: physical damage,
3) D3: failure of electrical and electronic systems.

Damages caused by a lightning strike depend on the characteristics of the structure to be protected. Some of the most important characteristics are:

- Type of construction,
- Contents and Application,
- Type of service and
- Protection measures provided.

Sources of Damages:

The lightning current is the primary source of damage. IS/IEC 62305 categorises the sources of damages into 4 types based on the point of strike. They are,

1) S1: flashes to a structure,
2) S2: flashes near a structure,
3) S3: flashes to a power or data line,
4) S4: flashes near a power or data line.

The four sources of damages are shown below in Figure 2.

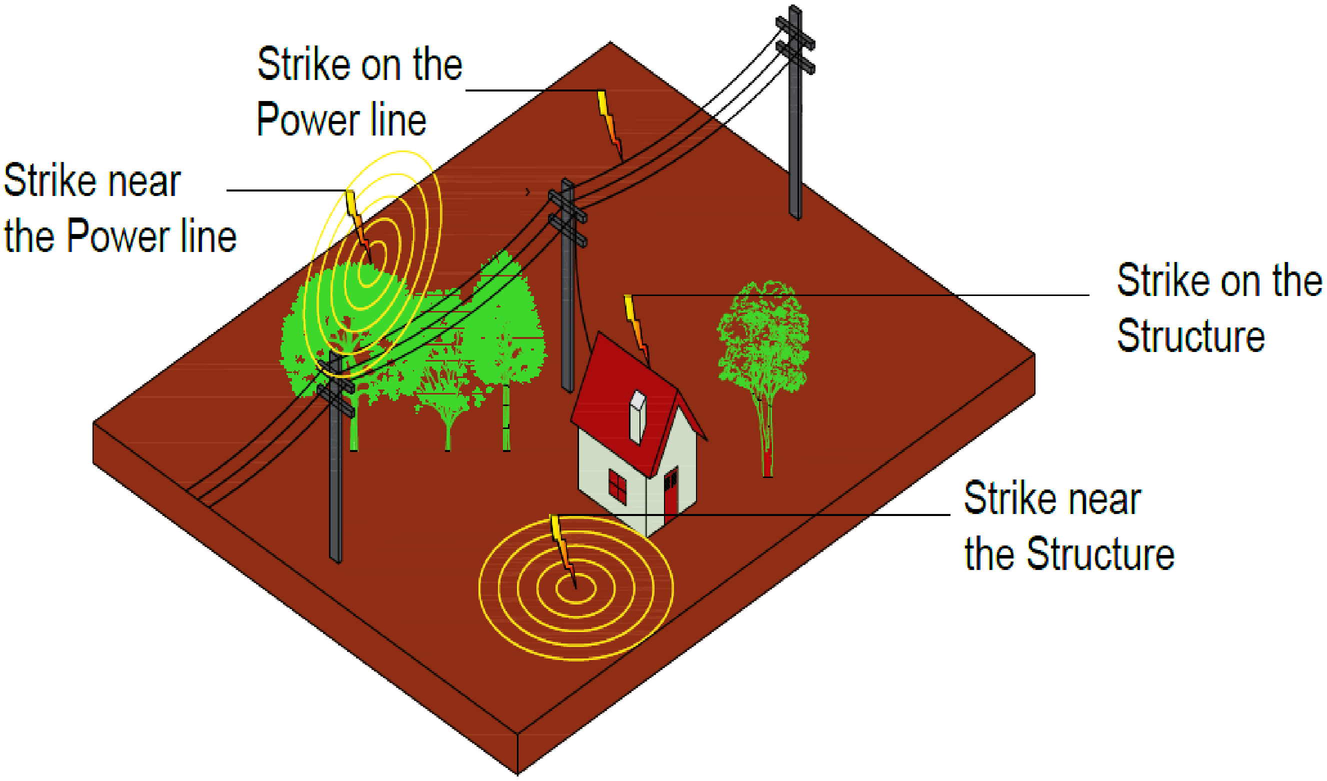

Figure 2. Sources of damages

1.3 Overall Lightning Protection System

Introduction:

Lightning is a natural phenomenon and it cannot be avoided whereas the damages due to lightning can be reduced by providing proper lightning protection system (LPS). A Lightning Protection System consists of both the external and internal lightning protection system. An External LPS provides protection against physical damages whereas an internal LPS provides protection for electrical and electronic systems.

Overall Lightning Protection System:

- An overall Lightning Protection System contains
- Properly designed Air termination system for capturing the Lightning strikes.
- Down conductor system having sufficient cross-sectional area for safely conducting the lightning impulse current from air termination system to earthing system.
- Good earthing system for dissipating the lightning energy into the ground as soon as possible without a considerable increase in Ground Potential Rise.
- Interconnecting the earthing of LA, system earthing and telecommunication system earthing below the ground level to form a single integrated earth termination system.
- Equipotential bonding of exposed water pipes, metal parts, and structures to avoid the difference in potential.
- Surge protection modules for power lines and telecommunication cables.

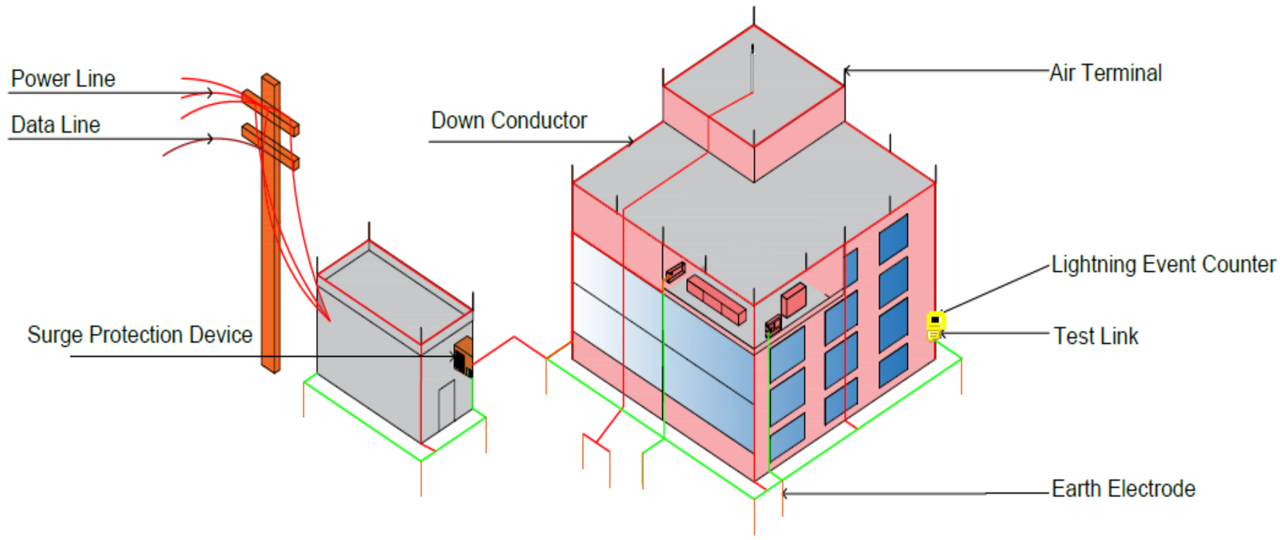

Figure 3. Overall Lightning Protection System

External Lightning Protection System:

An External Lightning Protection System will provide protection to the buildings and structures from the damages due to direct lightning strikes.

An external Lightning Protection System is intended to

1) Safely capture the lightning flash. (Air terminal system)

2) Conduct the lightning current safely from air terminal to the earth. (Down conductor system)

3) Dissipate the lightning current into the earth. (Earth termination system)

Internal Lightning Protection System:

The function of the internal LPS is to protect electrical and electronic equipment inside the structure from the lightning impulse surges by using equipotential bonding or a separation distance along with surge protection devices.

Some of the major sources of transient over-voltages are as follows.

- Lightning
- Industrial and switching surges
- Electrostatic discharges (ESD)
- Nuclear electromagnetic pulses (NEMP)

Among these, lightning is the natural source of impulse surges. The sources of damages due to lightning strikes are shown in Figure 2 and are as follows.

1) Lightning strikes on a structure.

2) Lightning strikes near the structure.

3) Lightning strikes on a transmission line

4) Lightning strikes near a transmission line.

Physical damages due to lightning strikes on the structure shall be protected by using an External Lightning Protection system whereas the electrical equipment shall be protected from lightning impulse currents by using Surge Protection Modules.

The damages of electrical and electronic equipment are either caused by the lightning strikes on the power lines or by the induction due to the impulse currents. Hence this can be classified as the indirect effects of lightning strikes. The indirect effects of lightning strikes are shown below in Figure 3.

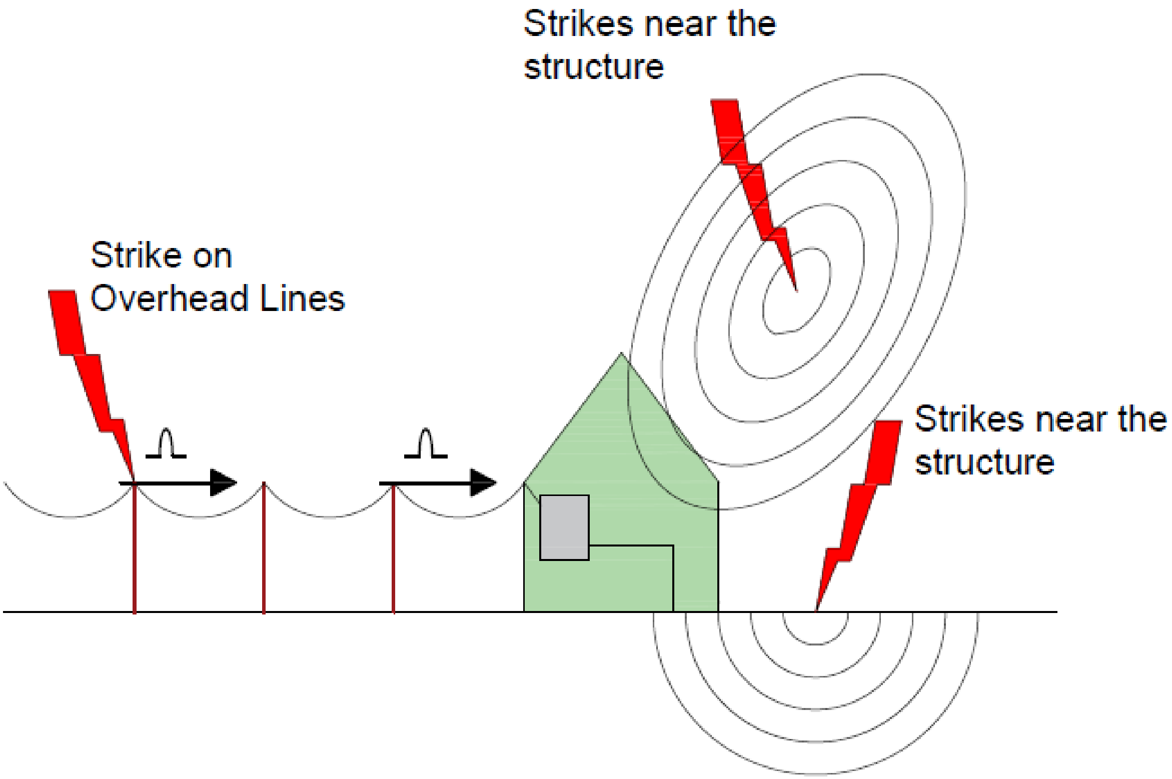

Figure 4. Indirect effects of lightning strikes

The protection against the failure of internal systems due to lightning impulse current limits,

- Surges due to lightning flashes to the structure.
- Surges due to lightning flashes nearby the structures.
- Surges transmitted by lines connected to the structure.
- The magnetic field directly coupling with apparatus.

The system to be protected shall be located inside Lightning Protection Zone 1(LPZ1) or higher. The protection measures for any LPZ shall comply with IS/IEC 62305-4.

1.4 An Overview of IS/IEC 62305 part 1

Introduction:

As per IS/IEC 62305 part 1, there are no methods or devices that can prevent lightning discharges. Lightning strikes on the structure or nearby structures will cause injury to the people and cause damage to the structure themselves. Hence a properly designed and executed lightning protection measures is essential to reduce the losses caused by lightning strikes.

There are four parts of IS/IEC 62305 and the connection between the parts are shown below in Figure 4.

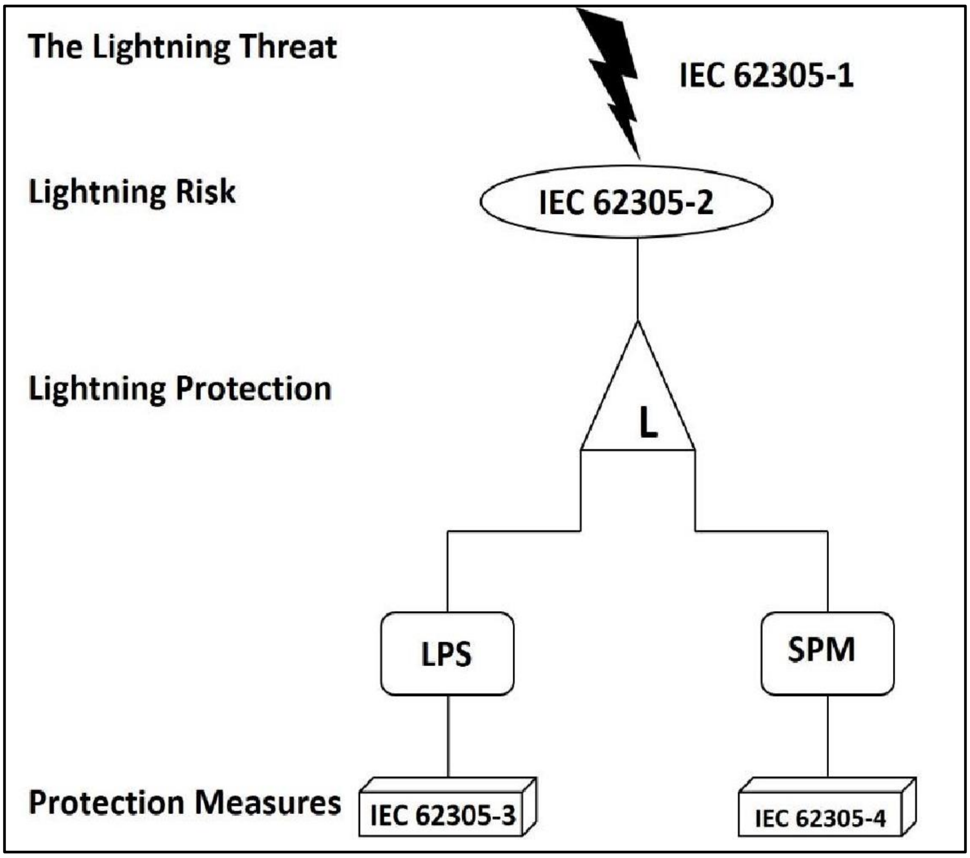

Figure 5. Four parts of IS/IEC 62305

Scope:

IS/IEC 62305 part 1 provides general principles for protecting the structures and the people associated with the structure against lightning strikes.

The following type of structures are not considered in this standard.

- Railway systems
- Vehicles, Ships, Air craft and offshore installations
- Underground high-pressure pipelines
- Pipe, power and tele communication lines.

Damage due to lightning:

The lightning current is the natural source of damage. The lightning can cause three basic type of damages and each damage will result in four different types of losses.

- L1: Loss or permanent injury to human life
- L2: Loss of service to public
- L3: Loss of cultural heritage
- L4: Loss of economic values

Among the losses, loss L4 will be considered as purely an economic loss.

The risks associated with the four types of losses are as follows.

- R1: Risk of loss or permanent injury to human life
- R2: Risk of loss of service to public
- R3: Risk of loss of cultural heritage
- R4: Risk of loss of economic values

Proper preventive measures should be taken to avoid the damages. In order to evaluate whether a lightning protection is needed for a structure or not, a risk assessment as per IS/IEC 62305-2 shall be made.

Lightning Protection Level:

As per IS/IEC 62305, there are four different levels of lightning protection and each level has its own parameters. Some of the parameters for the four lightning protection levels are shown below in Table 1.

S.No	Parameter	LPL I	LPL II	LPL III	LPL IV
1	Maximum peak current (kA) (First +ve impulse)	200	150	100	100
2	Minimum peak current (kA)	3	5	10	16
3	Rolling sphere radius	20 m	30 m	45 m	60 m

Table 1. Parameters for different levels of protection

Lightning Protection Zone:

Protection measures such as LPS, shielding wires, magnetic shields and SPD determine the Lightning Protection Zones (LPZ). The different zones are shown below in Table 2.

S.No	Zone	Threat
1	LPZ 0_A	Threat is due to direct lightning flash and the full lightning electromagnetic field. The internal systems may be subjected to full lightning surge current.
2	LPZ 0_B	This zone is protected against lightning flash. The internal systems may be subjected to partial lightning surge current.
3	LPZ 1	Surge current is limited by current sharing and by the SPDs installed at the boundary.
4	LPZ 2, ..., n	Surge current may be further limited by current sharing and by isolating interfaces and/or additional SPDs at the boundary.

Table 2. Lightning protection zones

The different zones of protection are shown below in Figure.

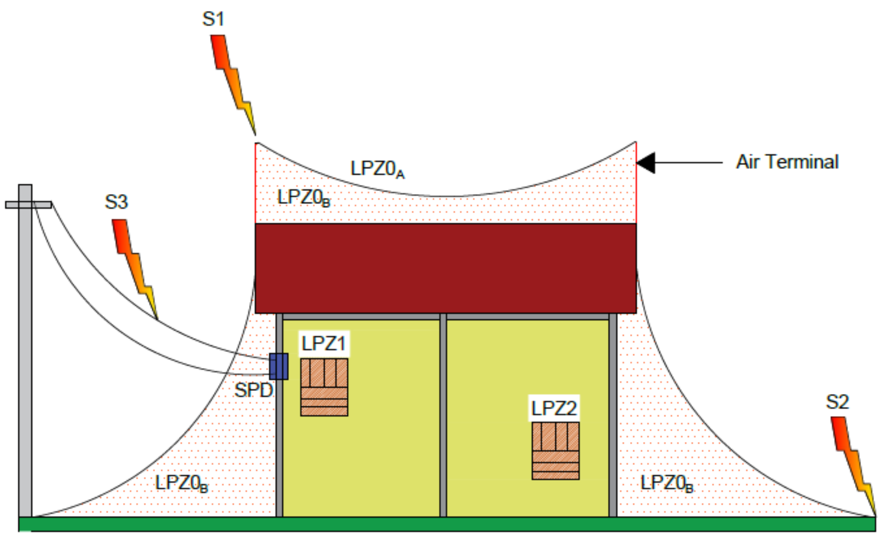

Figure 6. Lightning protection zones

Protection of structures and internal systems:

The structure to be protected shall be made to in LPZ 0B or higher by installing lightning protection system (LPS). An LPS consists of both external and internal lightning protection systems.

The basic components of an external Lightning Protection System are as follows.

1) Air terminal system

2) Down conductor system

3) Earthing system

The function of the internal LPS is to prevent dangerous sparking by using equipotential bonding, separation distance along with SPDs. The LPS shall comply with requirements of IS/IEC 62305 part 3 & part 4.

1.5 The Class of Lightning Protection System

The class of lightning protection system is related to the lightning protection level of the structure to be protected. As per IS/IEC 62305 – 1, the class of LPS corresponding to the lightning protection level is shown below.

Class of LPS	Lightning Protection Level
I	I
II	II
III	III
IV	IV

Table 3. Class of LPS

The factors that depend on the class of LPS and the factors that are independent on the class of LPS are as follows.

Factors Dependent on Class of LPS	Factors Independent on Class of LPS
• Lightning parameters - the maximum and minimum values of lightning parameters. • Rolling sphere radius, mesh size and protection angle. • The distances between the down-conductors. • Separation distance for isolation of external LPS from the structure to be protected. • The minimum length of each earth electrode.	• Lightning equipotential bonding. • The minimum thickness of metal sheets or metal pipes in the air termination systems. • LPS materials, conditions of use & components of LPS. • The material, configuration and minimum cross-sectional area of air-termination conductors, air-termination rods, down-conductors and earth terminations • The Minimum dimensions of connecting bars to the earth termination system.

Table 4. Factors dependent on Class of LPS

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1.6 IS/IEC 62305 part2: Risk Management

Introduction:

Lightning strikes may result in damages to the structures and to electrical equipment. The hazard to a structure may result in

- Damage to the structure and to its contents,
- Failure of associated electrical and electronic systems,
- Injury to living beings

To determine whether LPS is needed or not and to what extent a detailed risk assessment shall be performed as per IS/IEC62305 part 2.

Scope:

IS/IEC 62305 part 2 explains about the risk assessment calculations for a structure due to lightning flashes to earth. Once the calculated risk reaches the tolerable limit, appropriate protection measures have to be adopted to reduce the risk below the tolerable limit.

Risk and Risk components:

The sources of damage, types of damage, losses due to the lightning flash and the corresponding risks are shown below in Table 5.

S.No	Source	Damage	Loss	Risk
1	S1: flashes to the structure	D1: injury to living beings.	L1: Loss of human life	R1: Risk of loss or injury to human life
2	S2: flashes near the structure	D2: physical damage.	L2: Loss of service to the public	R2: Risk of loss of service to public
3	S3: flashes to the lines	D3: failure of internal systems.	L3: Loss of cultural heritage	R3: Risk of loss of cultural heritage
4	S4: flashes near the lines		L4: Loss of economic value	R4: Risk of loss of economic values

Table 5. Damages, Sources, Losses & Risks of lightning strikes

Each risk R, is the sum of its risk components. When calculating a risk, the risk components may be grouped according to the source of damage and the type of damage.

Risk components for a structure due to flashes to the structure:

R_A: Risk component related to injury to living beings inside the structure and up to 3m around down conductors. Loss of type L1 and L4 with possible loss of animals may also arise.

R_B: Risk component related to physical damage caused by dangerous sparking inside the structure triggering fire or explosion. All types of loss (L1, L2, L3 and L4) may arise.

R_C: Risk component related to failure of internal systems caused by LEMP. Losses of type L2 and L4 will occur. Loss of type L1 will occur only in the case of structures with the risk of explosion or other structures where failure of internal systems immediately endangers human life.

Risk components for a structure due to flashes near the structure:

R_M: Risk component related to failure of internal systems caused by LEMP. Losses of type L2 and L4 will occur. Loss of type L1 will occur only in the case of structures with the risk of explosion or other structures where failure of internal systems immediately endangers human life.

Risk components for a structure due to flashes to a line connected to the structure:

R_U: Risk component related to injury to living beings inside the structure. Loss of type L1 and in case of agricultural property loss L4 with possible loss of animals may also occur.

R_V: Risk component related to physical damage due to lightning current transmitted through or along incoming lines. All types of losses (L1, L2, L3 and L4) may occur.

R_W: Risk component related to failure of internal systems caused by induced over voltages. Losses of type L2 and L4 will occur in all cases and L1 only on the structures with the risk of explosion or other structures like hospitals where failure of internal systems will result in loss of human life.

Risk components for a structure due to flashes near a line connected to the structure:

R_Z: Risk component related to failure of internal systems caused by induced over voltages. Losses of type L2 and L4 will occur in all cases and L1 only on the structures with the risk of explosion or other structures like hospitals where failure of internal systems will result in loss of human life.

Composition of risk components:

Risk components to be considered for each type of loss in a structure are listed below.

$$R_1 = R_{A1} + R_{B1} + R_{C1} + R_{M1} + R_{U1} + R_{V1} + R_{W1} + R_{Z1}$$

$$R_2 = R_{B2} + R_{C2} + R_{M2} + R_{V2} + R_{W2} + R_{Z2}$$

$$R_3 = R_{B3} + R_{V3}$$

$$R_4 = R_{A4} + R_{B4} + R_{C4} + R_{M4} + R_{U4} + R_{V4} + R_{W4} + R_{Z4}$$

Among these components R_{C1}, R_{M1}, R_{W1} and R_{Z1} are applicable for structures with risk of explosion and for hospitals.

1.7 Factors Influencing Risk components

Introduction:

IS/IEC 62305 part 2 explains about the damages due to lightning strikes, source of such damages, losses due to lightning and the corresponding risks. There are so many parameters that determine the value of each risk component and one among them is the number of thunderstorm days in a year. In this article we shall explore about the factors that influences the risk components.

Factors influencing risk components:

Some of the factors which influences the risk components are as follows.

1. LPS – Lightning Protection System:

By providing LPS we can reduce the risk caused by lightning flashes to the structure, flashes near the structure and flashes to the line connected to the structure.

2. Coordinated SPD System:

A properly selected SPD is installed in order to reduce the failure of electric and electronics equipment.

3. Isolating Interfaces:

The device used to isolate in order to reduce surges on the lines entering the lightning protection zone.

4. Collection area:

The area must be completely protected to reduce all types of damages and its corresponding losses.

Some of the major factors provided by IS/IEC 62305 part 2 are listed below.

Protection Measures	R_A	R_B	R_C	R_M	R_U	R_V	R_W	R_Z
Lightning Protection System	X	X	X	X[a]	X[b]	X[b]		
Coordinated SPD	X	X			X	X		
Isolating interfaces				X[c]	X[c]	X	X	X
Impulse withstand voltage			X	X	X	X	X	X
Collection area	X	X	X	X	X	X	X	X
Shielding External lines					X	X	X	X
Fire precautions		X				X		
Floor resistivity	X				X			
Note: a- Only for grid like external LPS b- Due to equipotential bonding c- Only if they belong to equipment								

Table 6. Factors influencing risk components

1.8 Risk Management

Introduction:

Lightning strike is a natural phenomenon of sudden discharge of charges from highly concentrated cloud or any objects. Lightning cannot be avoided but the damages can be reduced by proper preventive measures.

IS/IEC 62305 part 2 explains about the damages due to lightning strikes, sources of such damages, Losses due to lightning and the corresponding risks. In this article, we shall explore about the risk management process as specified by IS/IEC 62305 part 2.

Risk and Risk components:

IS/IEC 62305 describes the risk components for each source of damage. Each risk is the sum of different risk components. When calculating the risk, the risk components of same category will be grouped together.

The risk component also depends on the nature of the structure and its purpose. For highly sensitive areas like hospitals and storage of explosives, the lightning strikes near the structure or near the line connected to the structure may also result in loss of human life.

The summary of risk components associated with each type of loss provided by Is/IEC62305 is as follows.

Source of Damage	Flash to a structure S1			Flash near Structure S2	Flash to a line connected to the structure S3			Flash near a line connected to the structure S4
Risk Component	R_A	R_B	R_C	R_M	R_U	R_V	R_W	R_Z
Risk for each type of loss								
R_1	*	*	*a	*a	*	*	*a	*a
R_2		*	*	*		*	*	*
R_3		*				*		
R_4	*b	*	*	*	*b	*	*	*

a – Only for structures with risk of explosion, and for hospitals or other structures where failure of internal systems immediately endangers human life

b – Only for properties where animals may be lost

Table 7. Summary of Risk Components

Risk Management:

IS/IEC 62305 part 2 explains the basic procedure for evaluating the risks associated with the structure to be protected.

1) Identify the characteristics of the structure to be protected.

2) Identify all the losses (L1 to L4) for the structure due to lightning and the corresponding risks (R1 to R4).

3) Evaluate the risk (R1 to R4) by calculating the corresponding risk components for each type of risks.

4) Compare the values R1, R2 and R3 with the tolerable risk RT for evaluating the need of protection. The risk R4 shall be used for evaluating the cost effectiveness.

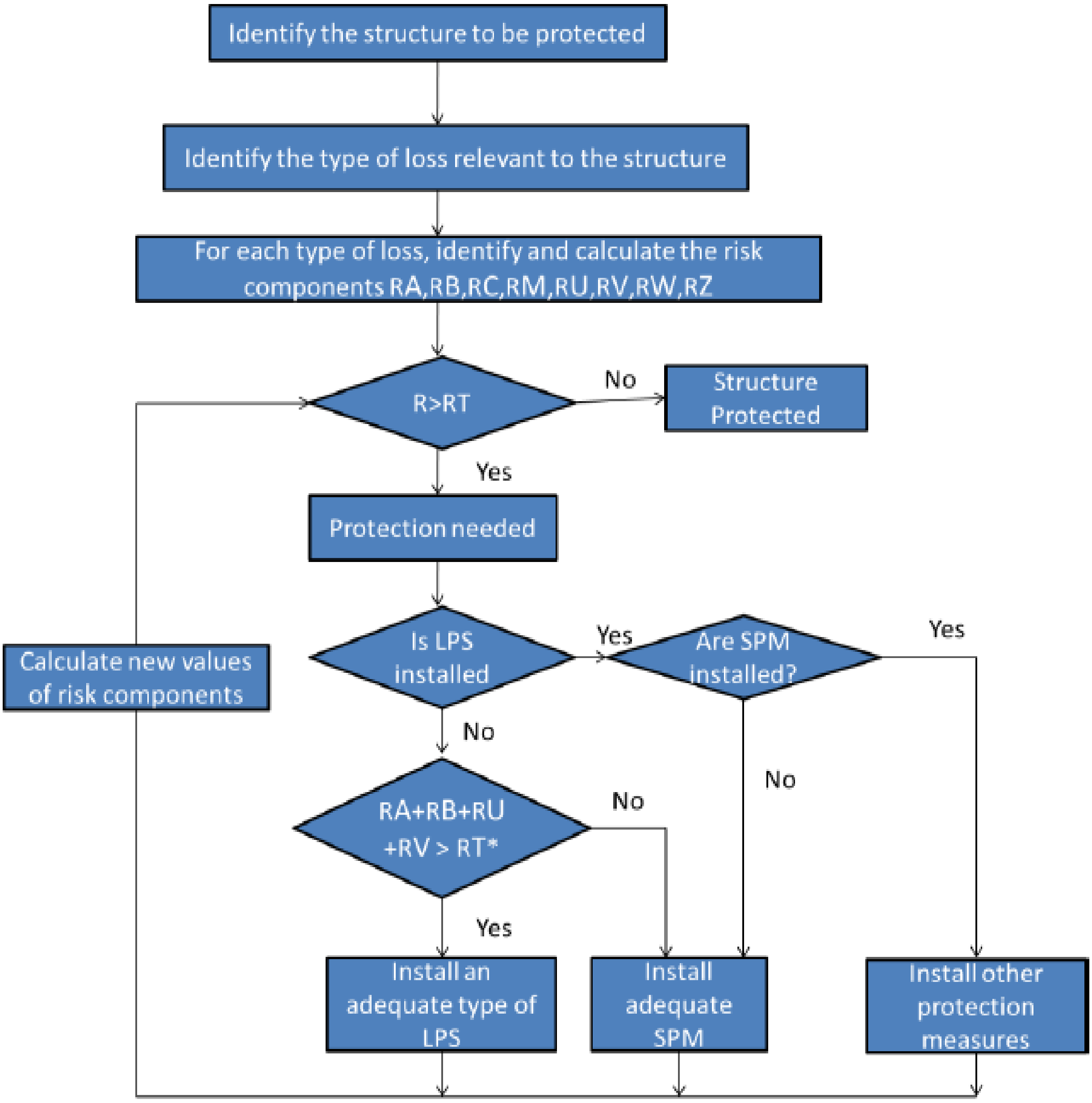
5) Compare the costs of total loss with and without protection measures for evaluating the cost effectiveness of the LPS.

The following procedures shall be followed to evaluate each risk (R1 to R3).

- Identify each component (Rx) of the risk.
- Calculate the individual risk components.
- Calculate the total risk (R).
- Identify the tolerable risk (RT) limit.
- Compare the calculated risk value (R) with the tolerable risk (RT).

  If $R \leq RT$, then lightning protection is not necessary.
  If $R > RT$, protection measures shall be adopted.

Flow chart:



Source: IS/IEC 62305 - 2

1.9 Assessment of Risk Components

Introduction:

Lightning strike is a natural phenomenon of sudden discharge of charges from highly concentrated cloud or any objects. Lightning cannot be avoided but the damages can be reduced by proper preventive measures.

In this article, we shall explore about the assessment of individual risk components and number of dangerous events due to lightning flashes as specified by IS/IEC 62305 part 2.

IS/IEC 62305 describes the risk components for each source of damage. When calculating the risk, the risk components of same category due to different sources should be grouped together.

Each risk component R_A, R_B, R_C, R_M, R_U, R_V, R_W and R_Z shall be expressed by the following general equation:

$$R_X = N_X * P_X * L_X$$

Where,

N_X – number of dangerous events per annum

P_X – probability of damage to a structure

L_X – consequent loss

Number of Dangerous Events:

The number of dangerous events (N_X) depends on the lightning ground flash density (N_G) and the physical characteristics of the structure to be protected, lines connected to the structures and the type of soil.

For protecting a structure, the damages due to the following events should be considered.

- Flashes to the structure to be protected,
- Flashes near the structure to be protected,
- Flashes to a line entering the structure to be protected,
- Flashes near a line entering the structure to be protected,
- Flashes to another structure to which a line is connected.

IS/IEC 62305 explains about 5 different types of average number of dangerous events based on the location of the flashes. They are,

1) Number of dangerous events N_D due to flashes to a structure.
2) Number of dangerous events N_{DJ} due to flashes to an adjacent structure.

3) Number of dangerous events N_M due to flashes near a structure.

4) Number of dangerous events N_L due to flashes to a line.

5) Number of dangerous events N_I due to flashes near a line.

The average number of dangerous events (N) due to lightning flashes in a year depends on the thunderstorm activity of the region and the physical characteristics of the structure to be protected.

The lightning ground flash density N_G shall be defined as the number of lightning flashes per km^2 per year. If the value of N_G for any particular location is not available, we can calculate the value by using the following formula.

$$N_G = 0.1 * T_D$$

Where,

N_G – Lightning Ground Flash Density

T_D – Thunderstorm days per year

The number N, depends on

- The lightning ground flash density N_G
- Equivalent collection area of the structure,
- Factors which depend on the physical characteristics of the structure.

1.10 Assessment of Number of Dangerous Events

Introduction:

IS/IEC 62305 part 2 explains about the damages due to lightning strikes, sources of such damages, Losses due to lightning and the corresponding risks. In this article, we shall explore about the assessment of individual risk components and number of dangerous events due to lightning flashes as specified by IS/IEC 62305 part 2.

Number of Dangerous Events:

The number of dangerous events (N_X) depends on the lightning ground flash density (N_G) and the physical characteristics of the structure to be protected, lines connected to the structures and the type of soil.

The number N, depends on

• The lightning ground flash density NG

• Equivalent collection area of the structure,

• Factors which depends on the physical characteristics of the structure.

Average annual number of dangerous events due to flashes		
N_D	to the structure	$N_D = N_G * A_D * C_D * 10^{-6}$
N_M	near the structure	$N_M = N_G * A_M * 10^{-6}$
N_L	to a line entering the structure	$N_L = N_G * A_L * C_I * C_E * C_T * 10^{-6}$
N_I	near a line entering the structure	$N_I = N_G * A_I * C_I * C_E * C_T * 10^{-6}$
N_{DJ}	to the adjacent structure connected through a line	$N_{DJ} = N_G * A_{DJ} * C_{DJ} * C_T * 10^{-6}$

Table 8. Number of dangerous events

Lightning Ground Flash Density:

The lightning ground flash density N_G is the number of lightning flashes per km^2 per year. If the value of N_G for any particular location is not available, we can calculate the value by using the following formula.

$$N_G = 0.1 * T_D$$

T_D – Number of thunderstorm days

Collection Area :

For simple rectangular structure, the collection area A_D is the area defined by the intersection between the ground surface and a straight line with 1/3 slope from the upper parts of the structure and rotating it around the structure.

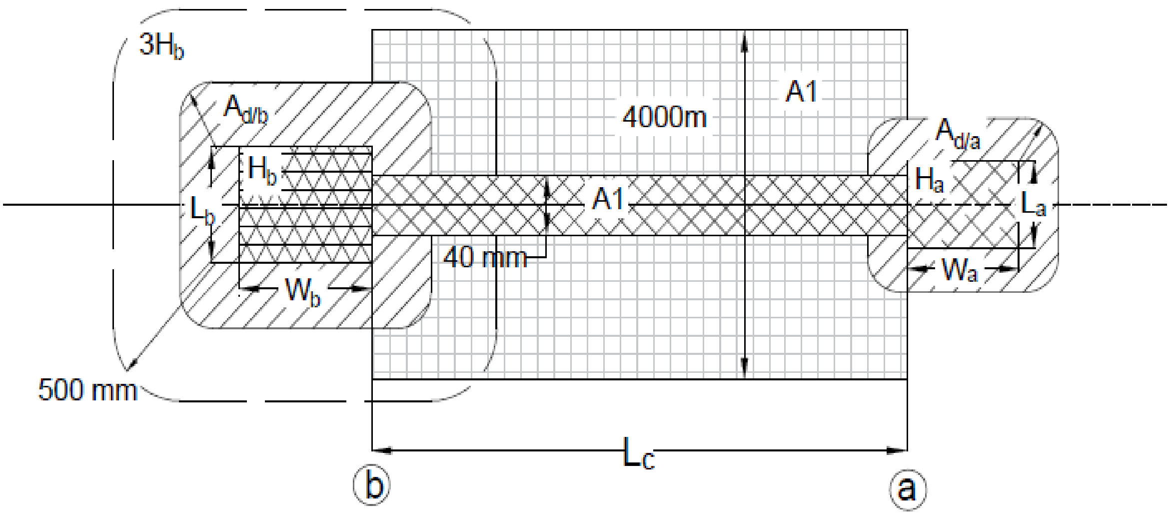


Figure 7. Collection Area

From the above formulae for calculating the number of dangerous events, we can observe that there are five different collection areas based on the location of the strike

.

Collection Area	Definition	Formula
A_D	Collection area of rectangular structure	L * W + 2 * (3 * H) * (L + W) + π * (3 * H)2
A_{DJ}	Collection area of adjacent structure (rectangular)	L * W + 2 * (3 * H) * (L + W) + π * (3 * H)2
A_M	Collection area of flashes near the structure	2 * 500 * (L + W) + π * 5002
A_L	Collection area of flashes striking the line	40 * LL
A_I	Collection area of flashes near the line	4000 * LL

Table 9. Collection area

IS/IEC 62305 part 2 provides the values of all the factors (C_D, C_I, C_E, C_T, C_{DJ}) involved in the calculation of number of dangerous event under Annexure A of IS/IEC62305 part 2.

1.11 Assessment of Probability of Damage

Introduction :

IS/IEC 62305 part 2 explains about the damages due to lightning strikes, sources of such damages, Losses due to lightning and the corresponding risks. In this article, we shall explore about the assessment of individual risk components and the probability of damages due to lightning flashes as specified by IS/IEC 62305 part 2.

Probability of Damage (P_x):

The second important parameter in calculating the risk due to lightning strikes is the probability (Px) of damage. For every risk component, there exists a probability of damage. The different probability of damages corresponding to the risk components are as follows.

- Probability P_A - a flash to a structure will cause injury to living beings by electric shock.
- Probability P_B - a flash to a structure will cause physical damage.
- Probability P_C - a flash to a structure will cause failure of internal systems.
- Probability P_M - a flash near a structure will cause failure of internal systems.
- Probability P_U - a flash to a line will cause injury to living beings by electric shock.
- Probability P_V - a flash to a line will cause physical damage
- Probability P_W - a flash to a line will cause failure of internal systems
- Probability P_Z - a lightning flash near an incoming line will cause failure of internal systems

Calculation:

IS/IEC 62305 part 2 provides the procedure for calculating the different probabilities of damages corresponding to the risk components. The formulae for calculating the probabilities as specified in Annexure B of IS/IEC 62305 part 2 are as follows.

$$P_A = P_{TA} * P_B$$

$$P_C = P_{SPD} * C_{LD}$$

$$P_M = P_{SPD} * P_{MS}$$

$$P_U = P_{TU} * P_{EB} * P_{LD} * C_{LD}$$

$$P_V = P_{EB} * P_{LD} * C_{LD}$$

$$P_W = P_{SPD} * P_{LD} * C_{LD}$$

$$P_Z = P_{SPD} * P_{LI} * C_{LI}$$

Among these probabilities, P_A and P_U are related to injury to living beings due to electric shocks. The injuries due to electric shocks are mainly because of the step and touch potentials. The terms P_{TA} and P_{TU} depends on the protection measures taken against the step and touch potentials.

The probabilities P_B and P_V are related to the physical damages due to lightning strikes on structure and power lines respectively. The probability P_B mainly depends on the class of LPS.

The probabilities P_C, P_M, P_U, P_W and P_Z are related to the failure of internal systems. The internal systems shall be protected from the lightning impulses by using Surge Protection Devices. From the above formulae we can observe that these probabilities depend on the factor SPD.

All the parameters and factors involved in calculating the probability are provided in Annexure B of IS/IEC 62305 part 2.

1.12 Lightning Protection System Design

Introduction:

A lightning strike is a natural phenomenon of sudden discharge of charges from a highly concentrated cloud or any object. Lightning cannot be avoided, rather the damages can be reduced with proper preventive measures. The complete protection includes a properly designed and executed external and internal lightning protection system.

Lightning Protection System:

The designing of a lightning protection system can be divided into 2 major parts,

1. Risk assessment

2. Designing

Risk assessment:

Risk assessment measures the risk due to lightning strikes and the probability of damages. IS/IE 62305 - 2 explains the damages due to lightning strikes, the source of such damages, losses due to lightning and the corresponding risks.

The damages caused by the lightning strike as specified in IS/IEC62305 part 2 are as follows.

1) Loss of human life / Injury (D1)
2) Physical damage (D2)
3) Electrical / Electronic components (D3)

We have already explained about the sources of damages, losses, risks and risk components in our previous articles.

Design of lightning protection system:

IS/IEC 62305 -3 has given the procedure for designing lightning protection for both external as well as internal system.

1. Lightning design shall be done with respect of class of lightning protection system.

2. The position of the air termination system shall be designed by using the following placement methods as specified by IS/IEC 62305-3

1) Protection Angle Method

2) Rolling Sphere Method

3) Mesh Method

3. The distance between down conductors will depends on the class of lightning protection.

4. IS/IEC 62305 has given the arrangement of earth termination system.

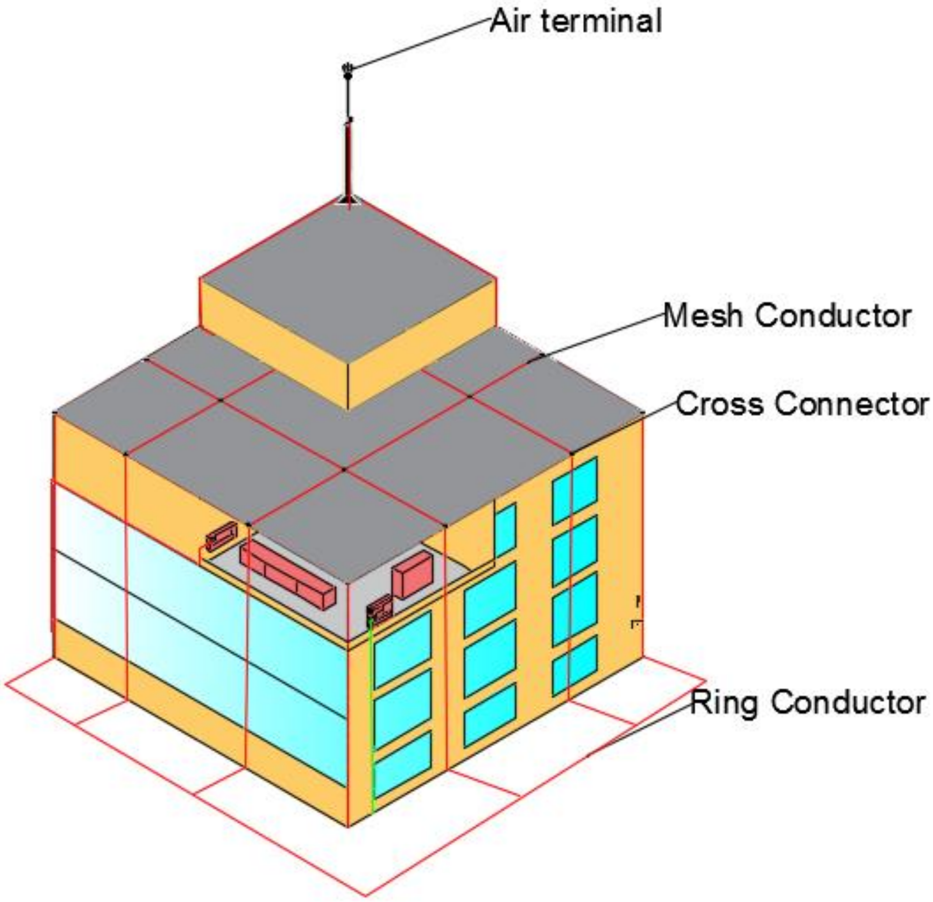


Figure 8. LPD Design

1.13 Protection Angle Method

Introduction :

There are no methods or devices that can prevent lightning discharges. The lightning protection system (LPS) can be installed to protect the structures against lightning.

An external Lightning Protection System is intended to

1) Capture the lightning flash to a structure. (Air terminal system)

2) Conduct the lightning current safely from air terminal to the earth. (Down conductor system)

3) Dissipate the lightning current into the earth. (Earthing system)

The air termination system can be composed of rods, catenary wires or meshed conductors.

The following methods are used to determine the position of air termination system.

1) Protection Angle Method

2) Rolling Sphere Method and

3) Mesh Method

Protection Angle Method:

The structure is considered to be protected if it is fully situated within the volume protected by the air-termination system. PAM can be used for the placement of following air termination systems,

- Vertical rod air-termination system

- Wire air-termination system

- Wires combined in a mesh

The volume protected by a vertical air termination rod will be in the shape of a right circular cone and hence it is also called as Cone of Protection method. The semi-apex angle will be α and it depends on the class of LPS and the height of air-termination system from the reference plane.

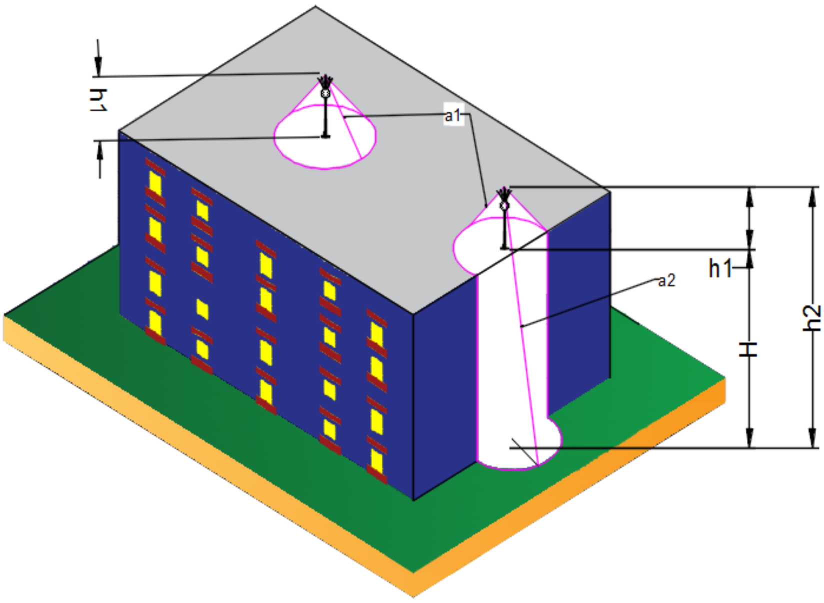


Figure 9. Protection Angle Method

From the figure,
H –height of the building
h1 –physical height of air terminal rod
h2 –overall height of air terminal from ground reference plane.
α1 –protection angle corresponds to height h1
α2 –protection angle corresponds to overall height (H + h1)

The protection angle for various heights of air-terminals can be found by using the following graph. Based on the height and protection angle, we can calculate the protected area.

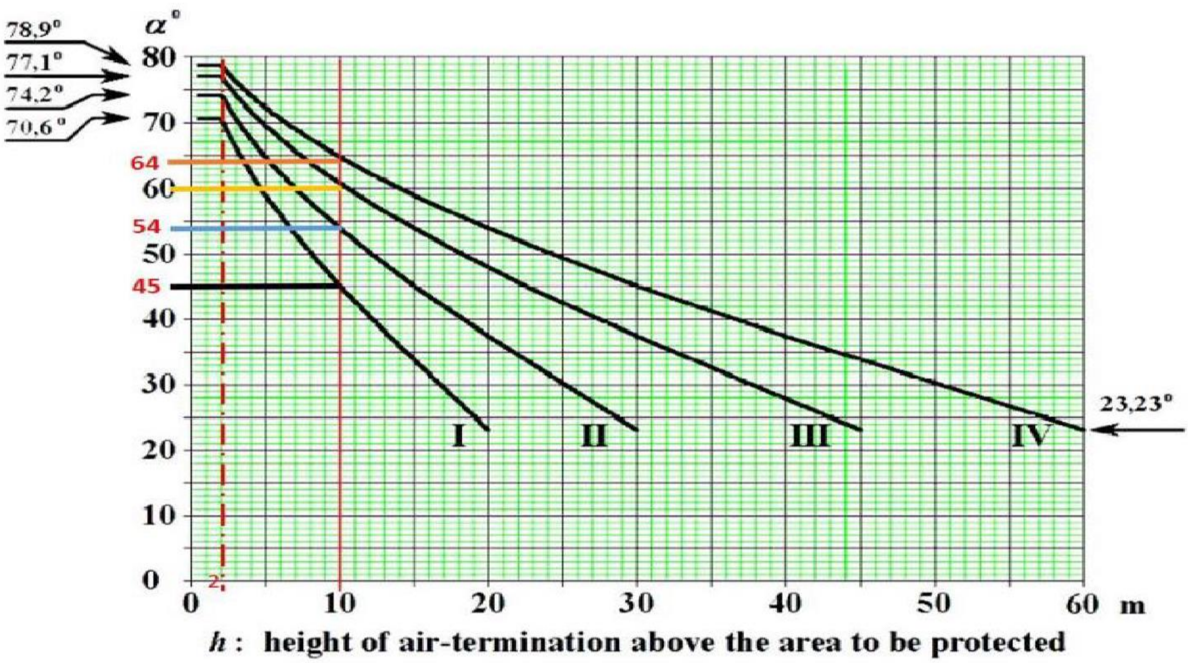


Figure 10. PAM Graph

The angle will not change for values of h below 2m. In PAM, each level of LPS has its limitation on the height of air-terminal (LPL I -20m, LPL II -30m, LPL III –45m & LPL IV-60m), beyond which this method is not applicable.

Example:

Let us consider an air-terminal with overall height of 10m. We can find the protection angle for all the four levels from the graph.

S. No.	LPL	Protection Angle (α)	Protection distance in m
1	I	45	10.00
2	II	54	13.76
3	III	60	17.32
4	IV	64	20.50

Table 10. PAM sample calculation

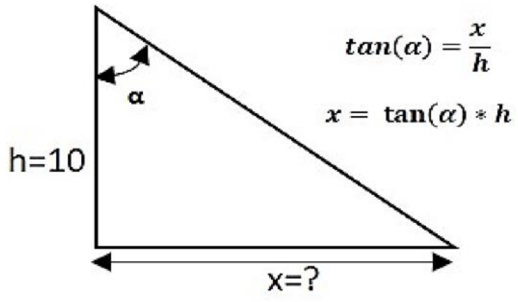


Figure 11. PAM sample calculation

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Similarly, we can find the protection distance for any height and any levels of protection. If a structure to be protected cannot be covered using a single air terminal we have to go for multiple terminals placed as per the coverage distance and all the terminals should be inter connected to form a network. The placement of air terminal using PAM is shown below.

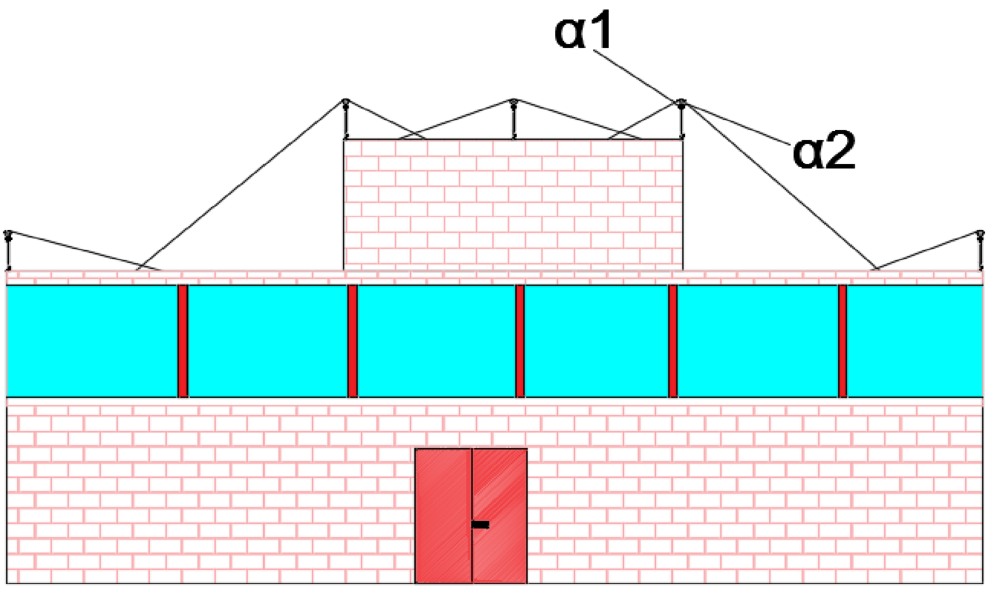

Figure 12. PAM air terminal placement

Using the same method, we can calculate the protection area for wire air-termination system as shown.

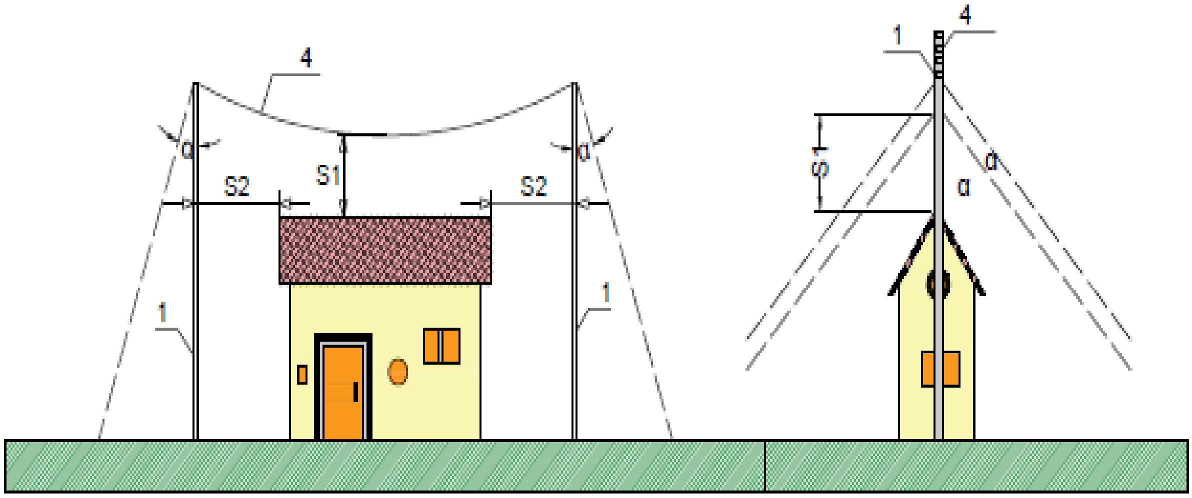

Figure 13. PAM wire air termination system

1.14 Rolling Sphere Method

Introduction :

There are no methods or devices that can prevent lightning discharges. The lightning protection system (LPS) can be installed to protect the structures against lightning. IS/IEC 62305-3 specifies the following three methods to determine the position of air termination system.

1) Protection Angle Method
2) Rolling Sphere Method and
3) Mesh Method

Protection angle method is suitable for simple shaped buildings and it also has limitations on the height of the air terminal. The mesh method is suitable where plane surfaces are to be protected. Whereas rolling sphere method can be used in all the cases.

Rolling Sphere Method:

In this method, an imaginary sphere of radius 'r' is rolled over the structure to be protected in all possible directions. The structure is considered to be protected if the sphere doesn't make any contact with the structure. The sphere should have contact only with the air terminal and on the ground. The radius of the sphere depends on the level of protection.

The radius of the rolling sphere for different classes of LPS are as follows:

S.No	Class of LPS	Rolling Sphere Radius r(m)
1	I	20
2	II	30
3	III	45
4	IV	60

Table 11. Rolling sphere radius

The radius of the rolling sphere with respect to the peak value of the current in the lightning that strikes the structure,

$$r = 10 * I^{0.65}$$

Where, I -peak lightning current in kA.

The rolling of sphere over the structure is shown below.

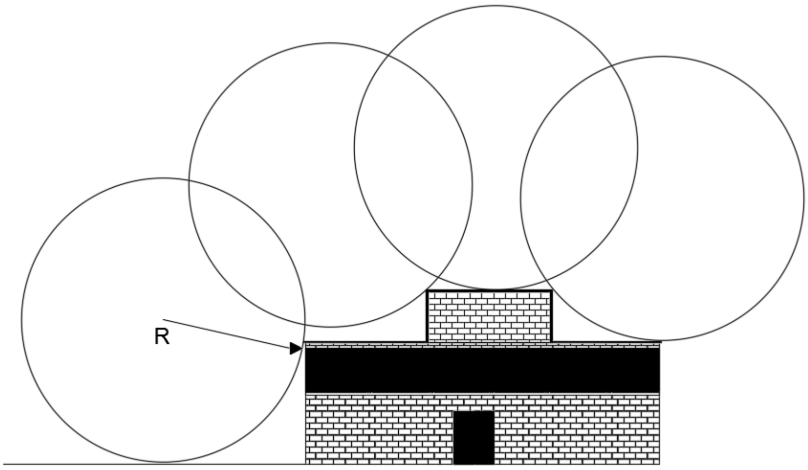

Figure 14. Rolling Sphere Method

If the height of the structure is greater than 60m then additional protection measures of installing vertical conductors for the top 20% has to be provided to reduce the effect of side flashing.

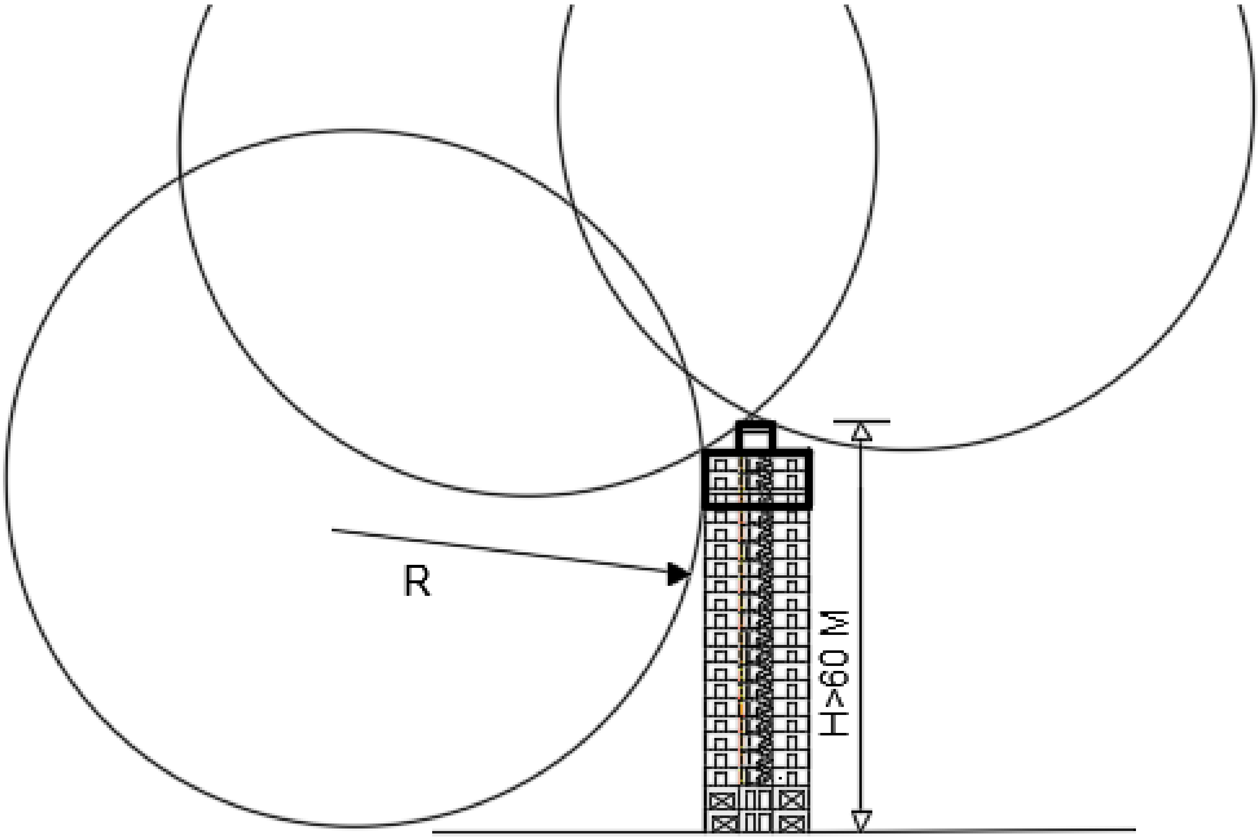

Figure 15. RSM for taller structures

Let us consider a rod air terminal placed at the top of a building. The protection provided by the air terminal as per rolling sphere method for different classes of LPS are shown herein:

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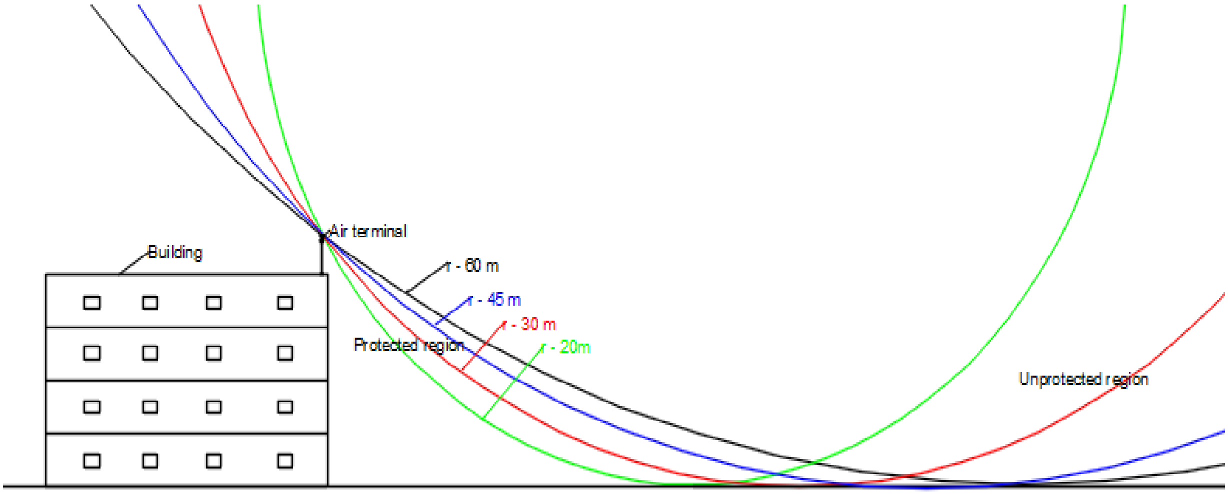


Figure 16. RSM for different levels

From the above image, we can find that the protected region varies for different classes of LPS and different heights of air terminal. The air terminals should be placed in such a way that the sphere does not make any contact with the structure to be protected.

Penetration distance :

The distance between the two air terminals should be chosen in such a way that, the protection is provided for all the objects placed on the surface to be protected. The protection of the objects placed on the surface can be ensured by calculating the penetration distance of the rolling sphere. The distance between the level of air terminals and the least point of sphere in the space between the air terminals is called penetration distance. By comparing the penetration distance with the height of the object placed between the air terminals, we can find whether the object placed is protected or not.

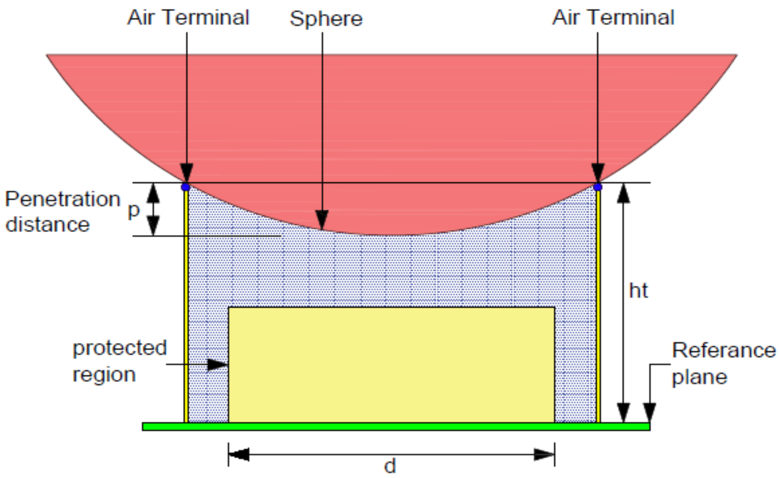


Figure 17. Penetration distance

Let us consider an object of height 'h' placed on the surface to be protected. Let 'h_t' be the height of the air terminal, 'p' be the penetration distance and 'd' be the distance between the two terminals. In this case, the penetration distance should be less than the difference between the height of air terminal and height of the object to be protected.

$$p < (h_t - h)$$

Distance between air terminals:

The penetration distance of the rolling sphere below the level of conductors in the space between the conductors can be calculated by using the below formula provided by IS/IEC62305-3.

$$p = r - [r^2 - (d/2)^2]^{1/2}$$

Where,
p – penetration distance
r – radius of rolling sphere
d – distance between the air terminals

For attaining a particular penetration distance, we can derive the required distance between the air terminals from the above equation.

$$d = 2 * [2*p*r - (p)^2]^{1/2}$$

If there are no objects protruding from the structure to be protected, then the penetration distance can be increased up to the height of the air terminal to provide maximum protection. At this condition, the distance can be calculated by substituting the value of height of air terminal (h_t) in place of penetration distance (p). The distance should always be lesser than the calculated value.

$$d = 2 * [2*h_t*r - (h_t)^2]^{1/2}$$

Sample Calculation:

Based on the above formula for finding the distance between the air terminals, let us calculate for different heights (0.5m,1mand1.5m) of air terminals for four different classes of LPS.

S.No	Height ht (m)	Distance between air terminals			
		LPL I r - 20m	LPL II r - 30m	LPL III r - 45m	LPL IV r - 60m
1	0.5	8.89	10.91	13.38	15.46
2	1	12.49	15.36	18.87	21.82
3	1.5	15.2	18.73	23.04	26.66

Table 12. RSM sample calculation

From the above analysis, we can conclude that the distance between the air terminals (d) in rolling sphere method depends on two factors.

1) Height of the air terminal and
2) Radius of the rolling sphere

Among these two factors, the radius of rolling sphere is a constant value which depends on the class of LPS as specified by IS/IEC 62305-3. Hence for particular class of LPS, the distance between the air terminals purely depends on the height of air terminal.

1.15 Mesh Method

Introduction :

The buildings and structures shall be protected from lightning strikes by installing well designed and executed lightning protection system (LPS). An External LPS provides protection against physical damage and life hazards whereas internal LPS provide protection for electrical and electronic systems.

The following methods are specified by IEC62305 -3 to determine the position of air termination system.

1) Protection Angle Method

2) Rolling Sphere Method and

3) Mesh Method

In mesh method, the mesh size depends on the level of protection.

S. No.	Class of LPS	Mesh Size W_m (m)
1	I	5x5
2	II	10x10
3	III	15X15
4	IV	20x20

Table 13. Mesh Size

The following conditions should be fulfilled for protecting a structure by using Mesh Method.:

1) Air termination conductors are positioned on

- Roof edge lines,
- Roof overhangs,
- Roof ridge lines having slope < 1/10.

2) The mesh dimensions should not be greater than the values specified by IS/IEC 62305 part 3.

3) The lightning current should have at least two distinct metal routes to earth termination.

4) Any structures protruding from the surface outside the volume won't be protected by this method.

5) The route should be the shortest and most direct route.

If the structure to be protected has different roof levels, we have to install mesh of suitable size on all the roof levels and the mesh of different roofs should be interconnected. An Example of mesh protection system for flat roof structure is as follows

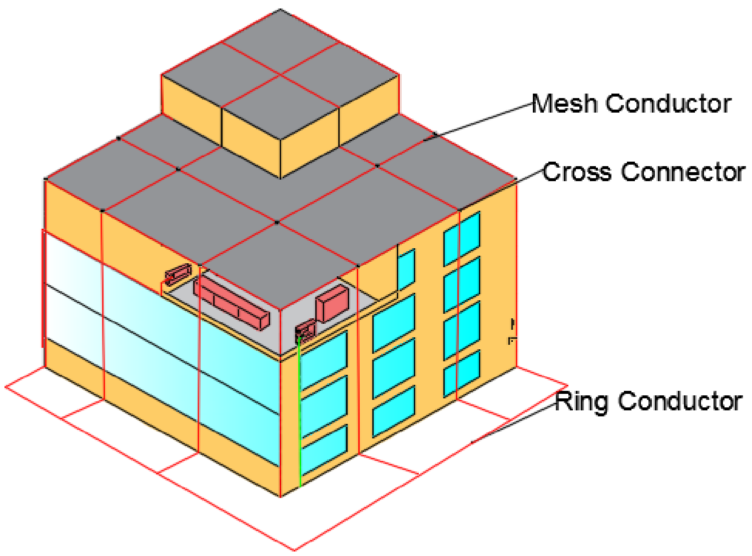


Figure 18. Mesh - Flat roof structure

For buildings with some items protruding from the flat surface, PAM is commonly used along with the mesh method. The protection provided by the air termination rod can be calculated as explained in Article 1.13 as per IS/IEC 62305. The example for such condition is as follows:

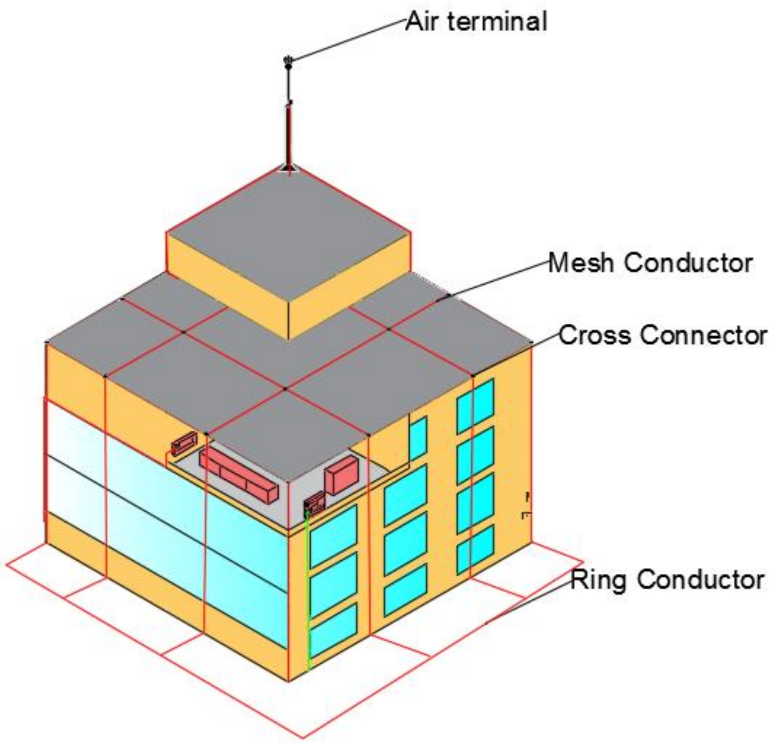


Figure 19. Mesh – Structure with protrusion

1.16 Down Conductors of LPS

What is a Down conductor?

A Down conductor is a part of an external Lightning Protection System that is designed as the shortest and the most direct dedicated path to conduct the lightning current from the air terminal safely into the mother earth. The down conductors should be laid at regular intervals for providing multiple parallel current paths for the lightning impulse current. The routing should be as straight as possible with least number of bends and joints. Also, equipotential bonding is to be done to those parts of the structure that are conductive.

What is the need for multiple down conductors?

The Lightning protection Standard IS/ IEC 62305 – 3 states that at least 2 down conductors are required for a non- isolated LPS and sometimes it requires multiple down conductors. The proper positioning of down conductors reduces the risk of side flashing and electromagnetic interferences.

The distance between the down conductors depends on the level of protection. The distance provided by IS/IEC 62305 for different levels of protection are tabulated below.

CLASS OF LPS	Distance between Down Conductors (m)
I	10
II	10
III	15
IV	20

Table 14. Distance between down conductors

For an isolated LPS, at least 1 down conductor is required for air termination consisting of rods on masts made up of metal or reinforcing steel.

1.17 Instructions for Installing Down Conductors

- The down conductor should not be installed in gutters or water spouts as the corrosion rate will be higher because of the moisture content.

- Loops on the down conductors should be avoided.

- A down conductor can be installed on the surface of the wall if it is made up of non-combustible material. If the wall is made of readily combustible material, it should be installed at a distance of 0.1 m away from the wall by using some mounting brackets. If the 0.1m distance cannot be maintained then the conductor should have a minimum cross section of at 100 mm^2.

- A metal facade, reinforcing rods of walls or concrete, steel structural frames, a metallic drain pipe can be used as natural down conductors.

- If a down conductor needs to be installed in a cantilevered part of the structure, an additional distance must be left besides the height taken at tip of a man's fingers when he stretches his arm vertically.

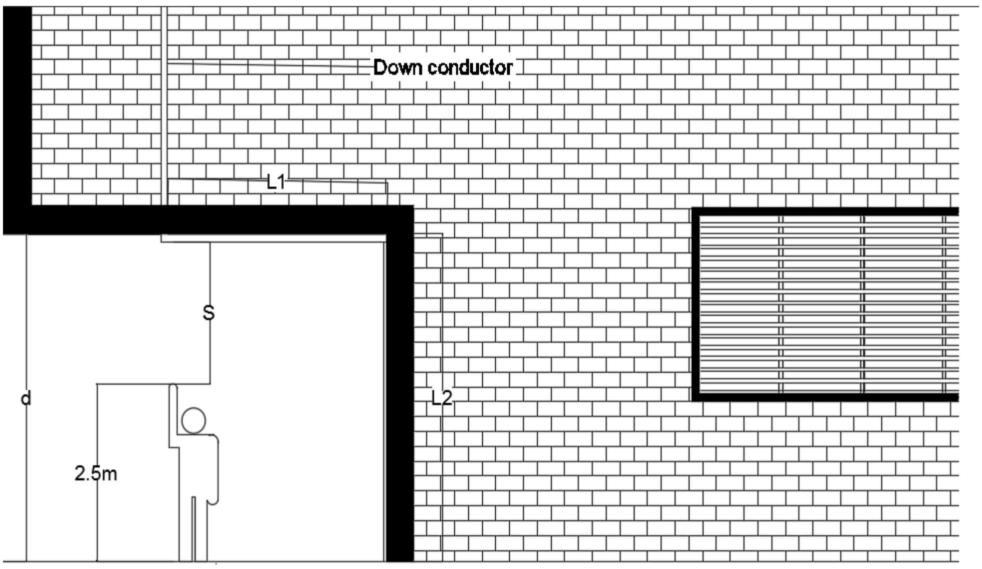


Figure 20. Down conductor on cantilevered part

In this case,

$$d > 2.5 + s$$

1.18 Natural Component as a LPS Conductor

Metallic Roofing:

LPS conductors and rods should be able to withstand the stress due to wind and other weather conditions. Metal covering of outer parapet walls may be used as a natural component of the air-termination, if there is no risk of fire due to melting of metal. The conductors should be able to withstand the partial lightning impulse current flowing through them.

The metallic roof may be perforated by a lightning flash at the striking point. As a result, water will leak through the roof. If water leaking is not acceptable then a separate air-termination system should be installed.

Roof made of conductive sheets should meet the minimum thickness requirements as specified by IS/IEC 62305 part 3.

Flush-mounted and protruding structures on the roof surface should be protected by means of air-termination rods.

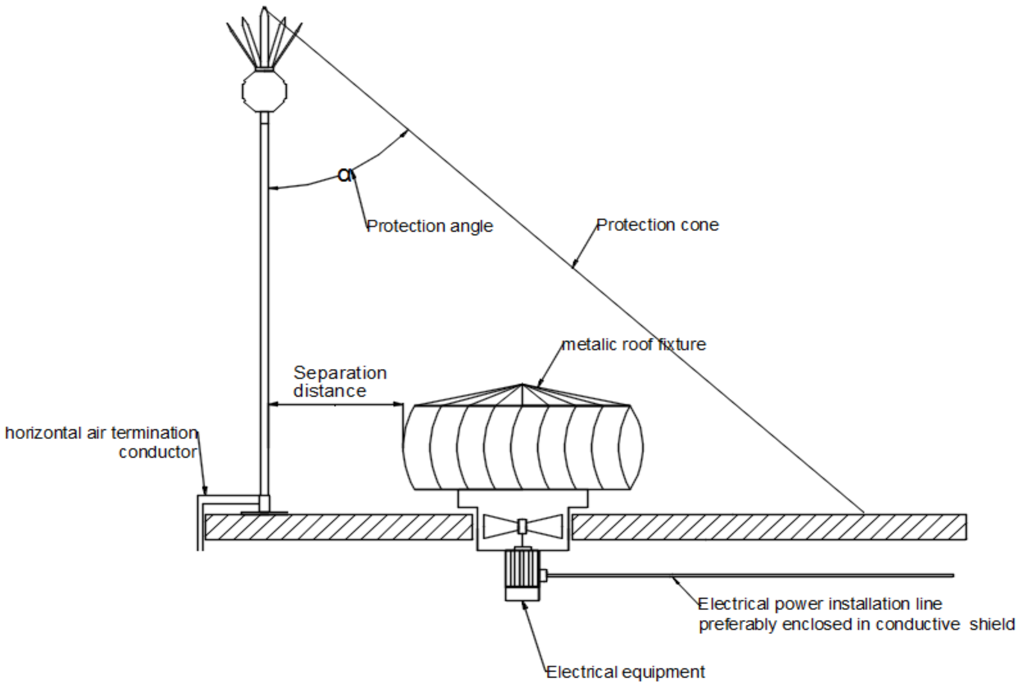


Figure 21. Protection for protruding structures

Natural Components:

1. The metal in the reinforced concrete of the structure:

   The electrical continuity of the rod should be ensured and the interconnections should be proper.

   In the case of pre-stressed concrete, the mechanical stress due to the passage of lightning current through the metals also has to be considered.

2. The interconnected steel framework of the structure;

If the interconnected reinforcing steel framework is used as down conductors, then ring conductors are not necessary.

Let us consider a residential building, which utilises the natural components (reinforcement bars) of the building as down conductor with external ring earthing being installed below the ground level. For this condition, the down conductors should be connected to reinforcement bars near the roof of the building and the connections to external ring earth electrodes are taken from the reinforcement bars at a height of 1.5m above the ground level.

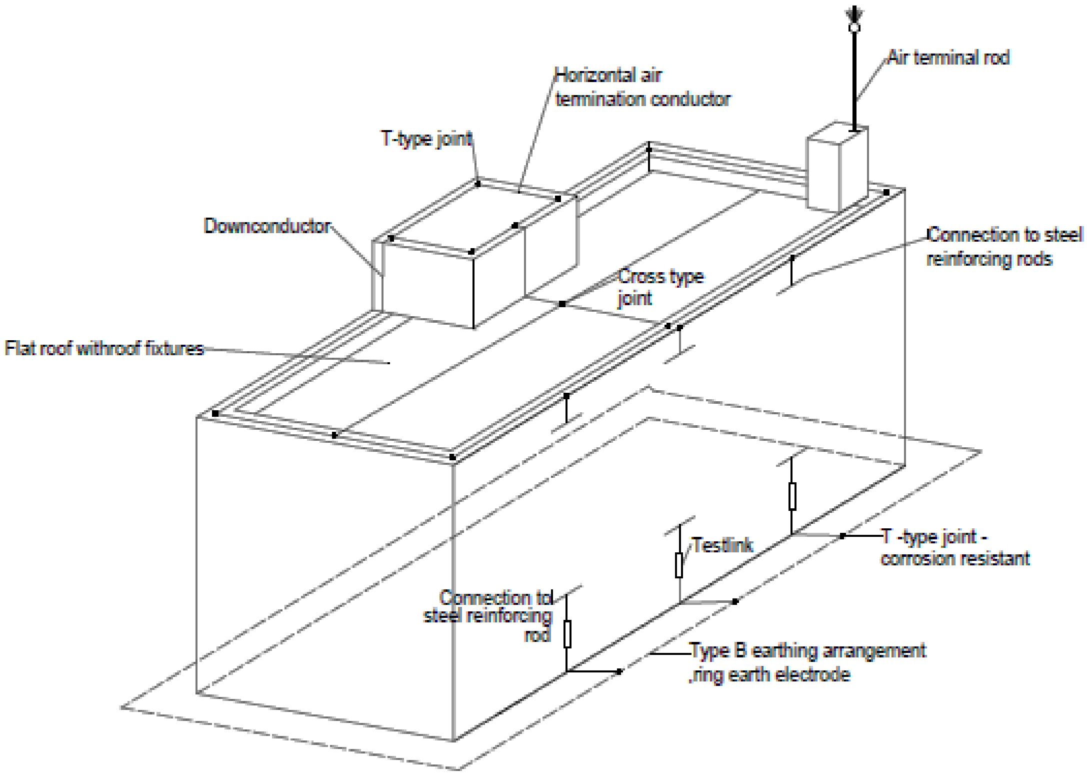


Figure 22. Natural components as LPS components

1.19 Reinforcement Bars as LPS components

Introduction:

IS/IEC 62305 suggests the usage of natural components of the structures to be protected as Lightning Protection System (LPS) components. The reinforcement bars in concrete can be used as natural down conductor and natural earth termination components. The connections to reinforcement rods shall be made with the approval of the builder and the concern civil engineer.

Down conductor system:

The reinforcing rods of concrete columns and steel structural frames may be used as natural down-conductors. The electrical continuity of the conductors should be ensured and the interconnections are made by either welding or by using suitable clamps.

Once concrete is filled, we cannot check the condition of the connections and clamps. Hence special care is required for selecting the connectors and all the installations should be documented properly. The lashed joints are not suitable for lightning-current carrying connections due to the risk of the lashing wire exploding and damaging the concrete. So, for lightning-carrying connections welding and clamping are the preferred methods. The materials for such clamps are chosen in such a way that, it does not undergo any chemical reaction when exposed to concrete.

When the reinforcement steel is used as the down-conductor, the rod in the same position has to be used all the way down, thereby providing direct electrical continuity. Where welding to the reinforcing rods is not permitted, clamps or additional dedicated conductors made of steel, mild steel, galvanized steel or copper shall be used. It is recommended that round steel rods of at least 8 mm diameter with a smooth surface be used.

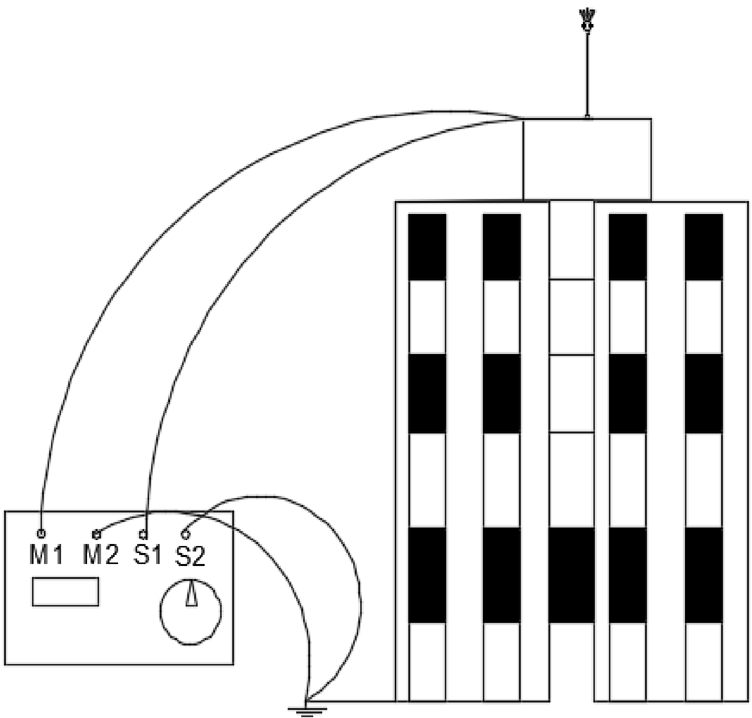


Figure 23. Measurement of overall electrical resistance

This steel structure acts as an electromagnetic shield and protects the electrical and electronics equipment inside the structures from interferences. The current injected into the reinforcing rods will have a large number of parallel paths to the earthing and hence the magnetic field generated by the lightning impulse current in the steel mesh will also be weak due to the low current density. The overall electrical resistance between the uppermost part and ground level should not be greater than 0.2Ω. The measurement can be made by using a testing equipment with four lead configurations by injecting a current in the order of about 10 A.

Those conductive reinforced steel in the concrete structure, when properly used, should form the cage for equipotential of the internal LPS.

IS/IEC 62305 lists the following points as advantages of using reinforcement bars as natural down conductor system components.

- The steel skeleton of reinforced concrete serves as an electromagnetic shield and protects the electrical and electronic equipment from the interference.

- The steel reinforcement in concrete serves the purpose of equipotential bonding of the internal LPS.

- As all the equipment and structure are connected through equipotential bonding, no separation distance is needed.

- The use of reinforcing steel as down-conductors reduces the corrosion problems due to external weather conditions.

- For isolated air termination system, no additional down-conductors are required for masts made of metal or interconnected reinforcing steel.

Earth termination system:

For large structures and industrial plants, the foundation is normally reinforced. The reinforcing bars in concrete are considerably more resistant to corrosion than when they are exposed.

Galvanized steel strips, copper and stainless-steel materials can be used as foundation earth electrodes and can be directly connected to the reinforcement rods. The external earth electrodes in addition to the foundation earthing shall be made of copper or stainless steel.

While using the metallic reinforcement as earth electrode, the mechanical splitting of the concrete should be prevented with proper preventive measures.

Conclusion:

Even though using the reinforcement bars has many advantages, it is nearly impossible to determine the layout and construction of the reinforcement steel after the construction phase. Therefore, the layout of the reinforcement steel should be very well documented with drawings, descriptions and photographs taken during the construction.

1.20 Isolated Lightning Protection System

Introduction:

Lightning strike is a natural phenomenon of sudden discharge of charges from highly concentrated cloud or any objects. Lightning cannot be avoided but the damages can be reduced by proper preventive measures. Tank farms consist of metal tanks of different sizes and the inflammable materials are stored in this tank of different quantity. In such farms, the sudden increase in temperature due to the passage of lightning impulse current may also result in accidents. Hence for such highly sensitive areas, the lightning protection system will be isolated from the structure to be protected which is generally termed as an Isolated Lightning Protection System.

Isolated lightning protection system:

- In an isolated LPS, the air terminal and down conductors are isolated from the structure to be protected.
- An isolated lightning protection system is preferred for structures on which the effect of sudden temperature rise on the down conductor or the electromagnetic due to lightning impulse currents may cause fire accidents or explosions.
- For the structures which contain explosive materials, isolated lightning protection system is preferred.
- In an Isolates LPS, the air terminal is generally installed on a free standing mast adjacent to the structure to be protected in order to maintain electrical separation.
- The separate distance between the air termination or down conductor and the structural metal parts, may be calculated as per IS/IEC 62305-3.

Catenary wires can also be used as air terminals in an isolated LPS.

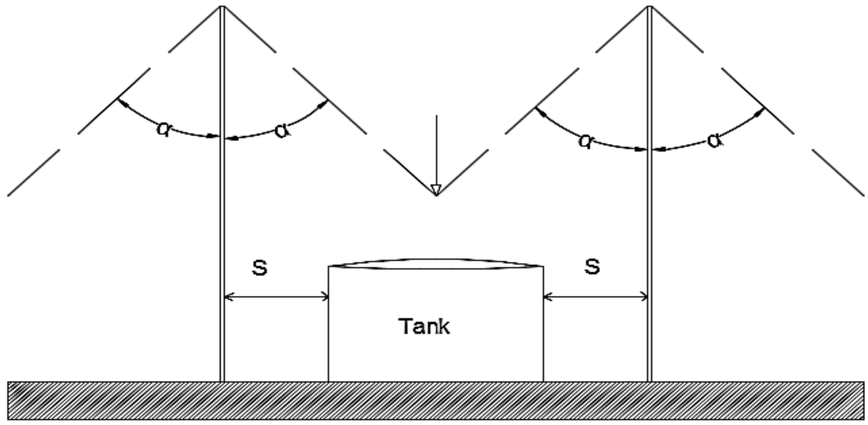


Figure 24. Isolated lightning protection system

Lightning Protection & Earthing Solutions

1.21 ESE Lightning Air Terminal

Introduction:

ESE Air Terminal Rod is an active type air terminal which stimulates continuous upward leader before any other object does within its radius of protection. Due to its earlier triggering of upward leader, the area of protection is much larger when compared to a simple conventional air terminal rod. The area protected by an ESE terminal depends upon the time difference between the streamer raised from an ESE terminal and the streamer raised from other passive components located at same height. If this time difference is higher, the area protected by the air terminal will also be higher. That time difference is generally termed as triggering advance time and it is always expressed in micro seconds (10^{-6} s or us).

Triggering Advance Time (t):

The triggering advance time is defined as the difference in triggering time of an early streamer lightning rod and a simple conventional air terminal rod obtained when both rods are exposed to the same atmospheric & electrical conditions.

$\Delta t = T_{SRAT} - T_{ESEAT}$.

Where,

T_{SRAT} = The mean triggering time of the upward leader of a simple conventional air terminal rod.

T_{ESEAT} = The mean triggering time of the upward leader of an ESE air terminal rod.

As per NFC 17-102/2011, the value of '∆t' should be between 10us and 60us. An air terminal is considered as ESEAT only if the triggering advance time is greater than 10us also the value of '∆t' being greater than 60us, it is to be still considered as maximum 60us for all design calculations.

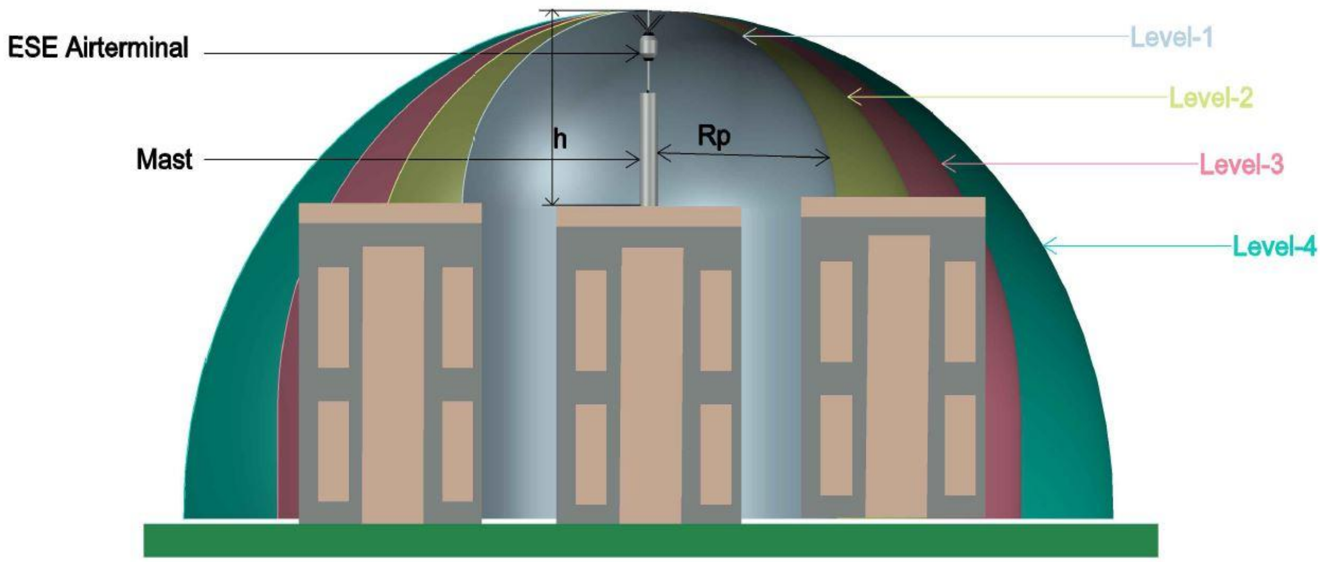


Figure 25. ESE air terminal

Radius of Protection - NFC 17-102/2011:

The radius of protection is the distance between the point where you want to place the (ESE) air terminal rod and the farthest point from the structure or building to be protected. For calculating the radius of protection, it is very important to get the triggering advance time of the device and the height of the mast on which the ESE air terminal rod is mounted upon. The ESE Air terminal should be installed at least 2 meters over the surface of the structure to be protected.

Calculation for Radius of Protection:

For Early Streamer Emission air terminal, the radius of protection for different levels can be calculated using the following equation:

For h ≥ 5m

$$\boldsymbol{R_p(h)} = \sqrt{((\boldsymbol{2rh} - \boldsymbol{h^2}) + \Delta(\boldsymbol{2r} + \Delta)}$$

For 2m ≤ h ≤ 5m

$$\boldsymbol{R_p(h)} = \boldsymbol{h} * \boldsymbol{R_p(5)/5}$$

h - Height (m) of the mast above the surface to be protected

Δ - Δ = Δt x 10^6s

r – Depends on the selected level of protection (in meter)

r = 20 for Level 1 protection ; r = 30 for Level 2 protection

r = 45 for Level 3 protection ; r = 60 for Level 4 protection

The radius of protection provided by an ESE air terminal having triggering advance time of 25us, 40us and 60us at different heights calculated based on the above formula are tabulated below.

Height	ΔT=25μs				ΔT=40μs				ΔT=60μs			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
2	17	20	23	26	25	28	32	36	32	34	39	43
3	25	29	34	39	38	43	49	53	47	52	58	64
4	34	39	46	52	50	57	65	71	63	69	78	86
5	**42**	**49**	**57**	**65**	**63**	**71**	**81**	**89**	**79**	**86**	**97**	**107**
7	43	50	59	66	64	71	82	91	79	87	98	108
9	44	50	60	68	64	72	82	92	79	88	99	109
10	44	51	61	69	64	72	83	92	79	88	99	109

Table 15. Radius of protection

1.22 Testing Procedure of ESE Air terminal

Introduction:

In the ESE system, the internal design arrangement senses lightning down streamers and triggers upward leaders prior to other passive objects in the structure. Since the upward streamer is triggered in advance when compared to other conventional air terminals, the area protected by the ESE terminal will be larger than that of conventional terminals.

NFC 17-102/2011 has given the testing sequence of ESE lightning arresters.

1) Mechanical Dimension Test

2) Environmental Test

3) Electrical Test

4) Early Streamer Emission Test

Mechanical Dimension Test:

During testing, all the dimensions of the air terminals will be physically measured and the actual values will be verified with the dimensions given by the manufacturers.

Environmental Test:

NFC 17/102 explains about two different types of tests to be performed on the ESE air terminal sample to ensure its operation on adverse environmental conditions. The tests are as follows.

- Salt mist treatment test
- Humid sulphurous atmosphere treatment test

Salt Mist treatment:

Salt mist treatment has to be done as per NF EN 60068 –52 standard with level 2 severity. The sample should be subjected to salt & fog (sodium chloride solution) atmosphere for 3 cycle -72 hours

Humid Sulphurous Atmosphere Treatment:

The sample should be tested in a humid sulphurous atmosphere with seven cycles and a sulphur dioxide concentration of 667 ppm (in volume).

Each cycle should be carried for 24 hours. There are two periods

- Heating Period
- Standing Period

Heating Period:

The sample should be tested at a temperature of 40°C 3°C for 8 hours.

Standing period:

The sample should be tested for 16-hour standing period.

The ESE is subjected to the following tests without cleaning after done salt & Sulphur mist test.

Electrical Test:

The ESE air terminal should be tested with a minimum of 100kA lightning impulse current at 10/350 us waveform.

Early Streamer Emission Test:

ESE should be tested for the triggering time given by the manufacturers. The difference between reference wave & measuring wave is the triggering time ‘∆t’.

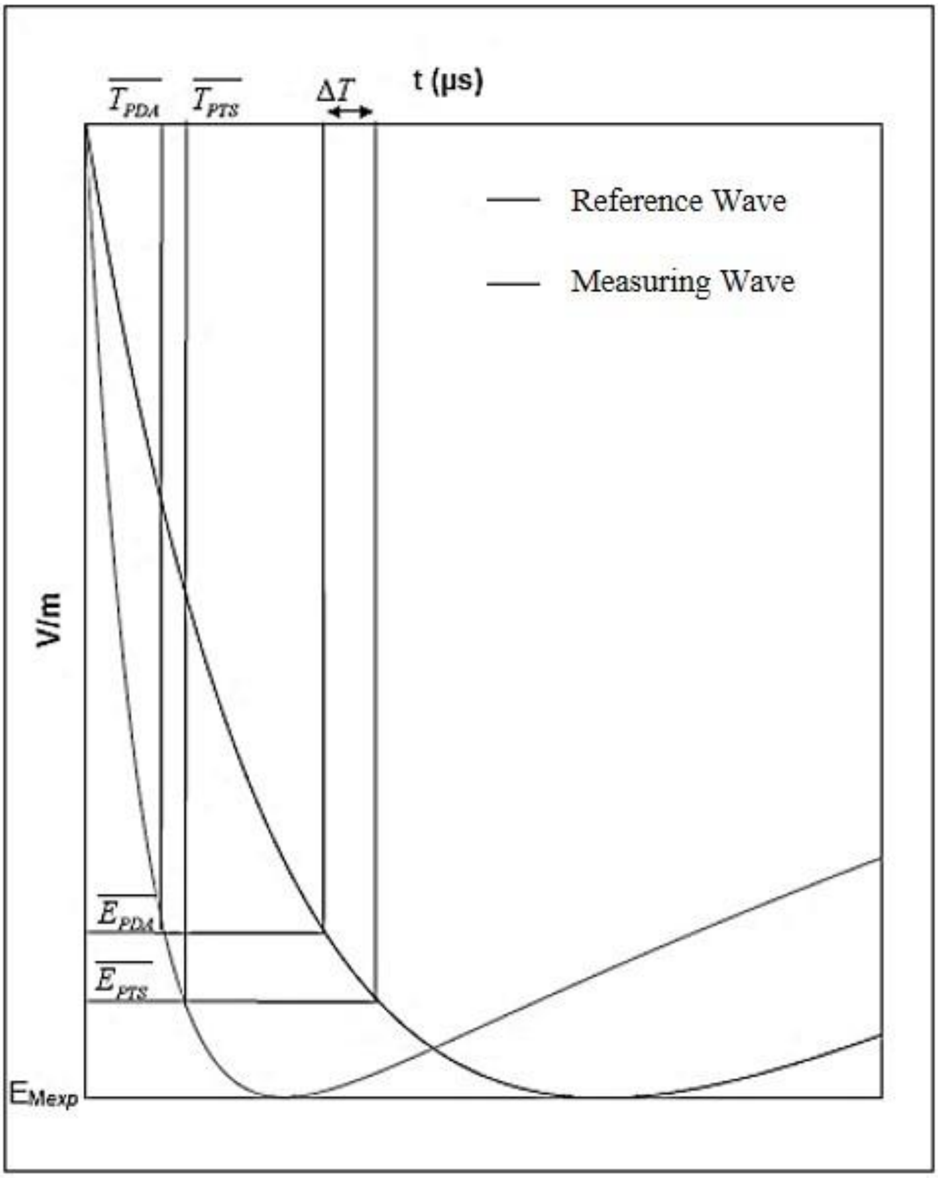
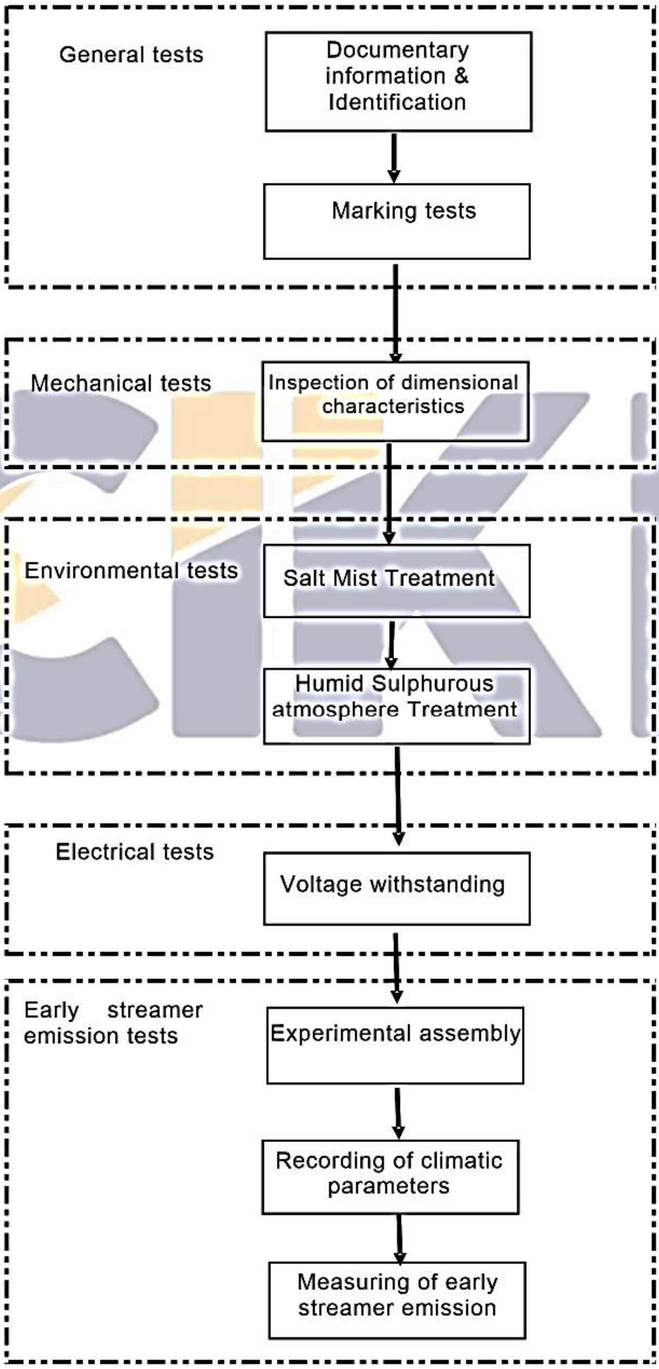


Figure 26. Early streamer emission test waveform

As per NFC 17-102/2011, the value of ‘∆t’ should be between 10us and 60us. An air terminal is considered as ESEAT only if the triggering advance time is greater than 10us, also the value of ‘∆t’ being greater than 60us, it is to be still considered as maximum 60us for all design calculations.

Why do the sequences need to be followed?

The sequence of testing is kept in such a manner to inspect and confirm that the ESE sample after going through the rigorous environmental tests and current carrying tests, the sample is still be able to sense downward leaders and trigger upward leaders at an advanced time than the conventional lightning air terminals. The testing sequence provided by NFC17-102 is as follows.



That's exactly why the standard says that these tests are to be carried out in the same sequence with the same sample as mentioned in their requirements to qualify the sample as an ESE type Air Terminal.

1.23 Installation of ESE Lightning Air terminal at Different Structures

Telecommunication Towers:

Telecommunication towers, are the taller structures which is more prone to lightning strikes. It is difficult to install lightning arresters over the towers. NFC 17 – 102/2011 has given some special measures to install ESE lightning arrester.

- The ESE air terminal should be placed at the tip of the mast to attain required protection.
- From the nearest aerial the ESE should be placed above 2m
- The down conductor can be directly fixed with air terminal by using clamp
- There should be a distance maintained with coaxial cable and down conductor

Inflammable and Explosive Material Storage Area:

Lightning is one of the most destructive phenomena of nature. It causing maximum damage to living beings and to the equipment across the globe. Due to the storage of explosive and hazardous materials in the Oil & Gas Industry, a direct lightning strike or secondary surges could lead to major disaster leading to loss of lives, resources and equipment since the average temperature of it can be around 20,000 degree Celsius.

- The Flammable tanks should be bonded and earthed properly in order to avoid losses.
- The ESE should be installed higher than the flammable area to be protected.
- The down conductor should be taken outside the safety area to avoid electric arc.

High Rise Building:

Taller buildings in general attract lightning strikes, hence an efficiently designed LPS is highly critical to safeguarding these structures from the destruction caused due to lightning. Also, such structures should make sure quality earthing systems and surge protection devices are installed to protect the lives and expensive electronic equipment housed in these structures. National Building Code guidelines to be followed while designing LPS for such tall buildings.

- Since the building height exceeds 60m the 20% of the top should be protected by the lateral protection system.
- Minimum of 4 numbers down conductors must be used and it shall be interconnected by a ring conductor when applicable.
- Two earth pits should be provided per down conductor.

Religious Buildings:

India has got numerous numbers of historical monuments and heritage sites across the length and breadth of the country. Protecting them will result in preserving the rich cultural heritage of our country and the sheer architectural marvel of our ancestors. Every structure is unique in its style, it is necessary to protect that from lightning strikes.

- The ESE should be installed to protect any monuments structure like steeples, towers and belfries.
- Through the main tower from the air terminal the down conductor can be laid directly.

- If the main tower height exceeds 40mtrs it is recommended to provide second specific down conductors through nave ridge.

- A separate lightning air terminal should be given for the non-metallic cross or statue

- Interconnection should be made between ESE system's earthing and electric earthing by an earthing conductor.

The ESE type air terminals and installation are recognized by various countries among the world and many countries have published their own standards for the ESE air terminal. Some of the most complete lightning protection standards which are related to ESE air terminals are listed as follows:

- UNE 21186:2011: «Protección contra el rayo: Pararrayos con dispositivo de cebado» (España).

- NF C 17-102:2011 : «Protection contre la foudre - Systèmes de protection contre la foudre à dispositif d'amorçage» (France).

- NP 4426:2013: «Proteção contra descargas atmosféricas - Sistemas com dispositivo de ionização não radioativo» (Portugal).

- NA 33:2014: «Proteção contra descargas atmosféricas» (Angola).

- NC 1185:2017: «Protección contra rayos - Seguridad integral frente al rayo» (Cuba).

- IRAM 2426:2015: «Pararrayos con dispositivo de cebado para la protección de estructuras y de edificios» (Argentina).

1.24 Test Joints in Lightning Protection System

Lightning cannot be avoided, rather the damages can be reduced with the help of well-designed and executed Lightning Protection System. LPS usually consists of both external and internal lightning protection system.

An external Lightning Protection System consists of,

1. Air terminals

2. Down conductor

3. Earthing system.

Test Joint :

Test Joints act as the intersection of down conductor and the earthing system. The down conductor will be terminated at the Test joints whereas the connections to the earthing system begins at the test joints. Test joints will be provided on each down conductors.

At normal operating conditions the test link will remain in closed position. During the time of inspection, the test link or test joint in every down conductor can be used to isolate the earthing from the lightning protection system.

The test joints will be used for inspecting both the continuity of the down conductor, air terminal interconnections and the earth electrode resistance values.

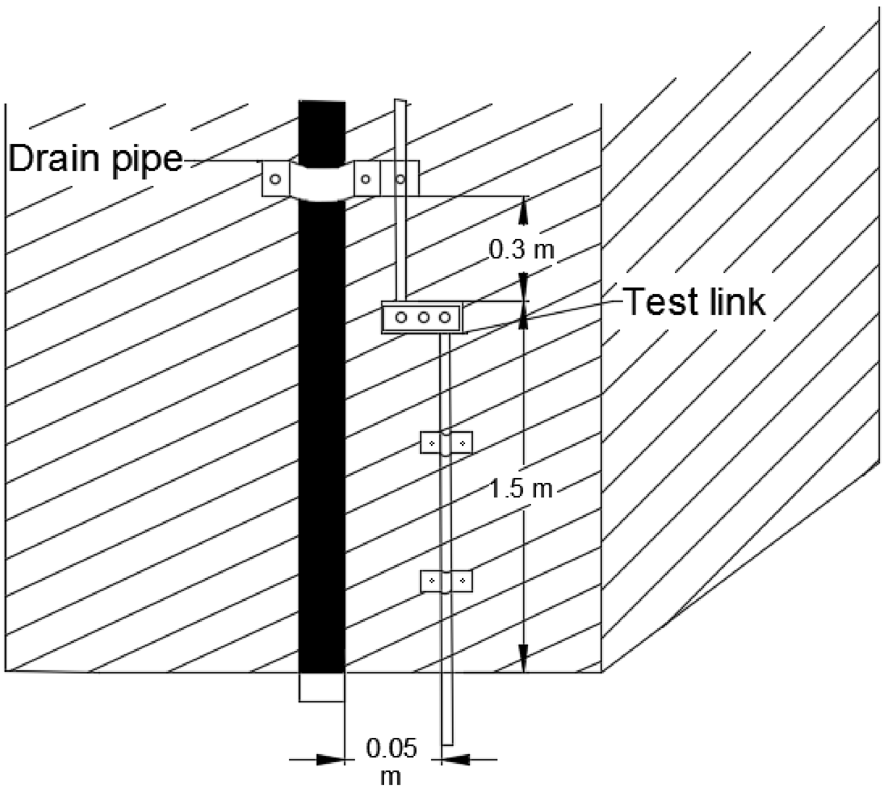


Figure 27. Test link in LPS

1.25 Selection of Materials for Lightning Protection System

Introduction :

The components of Lightning Protection System (LPS) are exposed to direct lightning strikes and corrosive atmosphere. The materials should have high current withstanding capacity and they should be less corrosive. The current carrying capacity depends on the cross sectional area and the materials should be selected based on the local environment.

A material which is most preferable for some site conditions might be the least preferred material for other site conditions due to its chemical properties. Apart from the corrosion of materials due to the local environment, the contact of two dissimilar materials also leads to galvanic corrosion. Hence, IS/IEC 62305 suggests the materials that can be used for different corrosive environments and it has provided the minimum cross sectional area required for different materials of LPS Components.

Minimum Cross sectional area of different materials:

The minimum cross-sectional area of different materials suggested by IS/IEC 62305-3 are as follows.

- Copper, tin plated copper strip, cable, Copper coated steel should have a minimum cross-sectional area of 50mm^2. When mechanical strength of the material is not important then the cross sectional area of the material can be reduced up to 25mm^2.

- For air terminals the minimum cross sectional area should be 176mm^2 for all material and if the mechanical stress due to wind loading is not critical then the cross sectional area can be reduced up to 70mm^2.

- Normal cross sectional area of stainless steel strip, and conductor is 50 mm^2 and it can be increased upto 75 mm^2 when thermal & mechanical factors are considered.

Protection against corrosion:

- The components of LPS shall be made of corrosion resistant materials like copper, aluminium, stainless steel and galvanized steel. Among these materials aluminium shall be used only above the ground level.

- Connections between different materials should be avoided as it leads to galvanic corrosion. Hence the material of the air-termination rods should be compatible with the connecting and mounting element materials.

- Copper parts should not be directly installed over the aluminium material without any protection against the galvanic corrosion.

- Aluminium conductors should not be directly used in concrete limestone surfaces and soil.

- Lead-sheathed steel conductors should not be used as earth conductors.

- Lead-sheathed copper conductors are not suitable for concrete and high calcium content soil.

Aluminium has very good electrical conductivity but it more prone to corrosion on soil and concrete medium. Hence, they can be used for air terminal and down conductor systems above the ground level and connected to earthing system of GI/Copper/SS using proper bimetallic connectors. The fasteners or sleeves for aluminium conductors should be made of similar metal and it should have adequate cross-sectional area to withstand the adverse weather conditions.

1.26 Requirements and Testing of LPS Components

Introduction:

IEC 62561 series of standards deals with the requirements and testing requirements for different components used for the installation of a lightning protection system (LPS). IEC 62561-2 specifies the requirements and tests for the conductors that are used for air termination, down conductor and earthing other than the natural components.

Requirements of LPS components:

While selecting materials for Lightning protection system applications, the following factors should be considered.

- The material, configuration and cross-sectional area of the conductors and rods should be as per the standard specifications.
- Their mechanical and electrical characteristics of the materials should be considered.
- Coated conductors have good corrosion resistance property and the proper adherence of the coating should be ensured.

Earth Rods:

- Earth rods shall be mechanically robust and there should not be any cracking on the material during installation.
- The threads on the coated rods should also be coated.
- For copper coated rods, it should be ensured that no copper is removed from the steel.

Earth Rod coupler:

The earth rod coupler can be used to extend the length of the earth rods. The material of coupler shall be compatible with that of the earth rod. It should be able to withstand the driving forces generated during installation. It should have good corrosion resistance property.
No threads on the earth rod should be exposed when using an external type threaded coupler. In case of an internal type threaded couplers, the mating faces of the earth rods should have proper contact with each other after assembly.

The requirements specified in IEC 62561-2 for LPS components are as follows,

Material , configuration and minium cross-sectional area of air-termination conductors, air-terminal rods, earth lead-in rods and down-conductors[a]			
Material	**Configuration**	**Cross-sectional area mm^2**	**Recommended dimensions**
Copper , Tin plated copper	Solid tape	≥ 50	2 mm thickness
	Solid round [b]	≥ 50	8 mm diameter
	Stranded [b]	≥ 50	1.14 mm up to 1.7 mm strand diameter
	Solid round[c]	≥ 176	15 mm diameter
Aluminium	Solid tape	≥ 70	3 mm thickness
	Solid round	≥ 50	8 mm diameter
	Stranded	≥ 50	1.63 mm strand diameter
Aluminium	Solid tape	≥ 50	8 mm diameter

alloy	Solid round	≥ 50	2.5 mm thickness
	Stranded	≥ 50	8 mm diameter
	Solid round[c]	≥ 176	1.7 mm strand diameter
Copper coated aluminium alloy	Solid round	≥ 50	15 mm diameter
hot dipped galvanized steel	Solid tape	≥ 50	2.5 mm thickness
	Solid round	≥ 50	8 mm diameter
	Stranded	≥ 50	1.7 mm strand diameter
	Solid round	≥ 176	15 mm diameter
Copper coated steel	Solid round	≥ 50	8 mm diameter
	Solid tape	≥ 50	2.5 mm thickness
Stainless steel	Solid tape[d]	≥ 50	2 mm thickness
	Solid round[d]	≥ 50	8 mm diameter
	Stranded	≥ 70	1.7 mm strand diameter
	Solid round[c]	≥ 176	15 mm diameter
Note: For the application of the conductors,			

a - Manufacturing tolerance:-3%.
b - Hot dipped or electroplated: minium thickness coating of 1 µm.there is no requirement to measure the tin plated copper because it is for aesthetic reasons only .
C - Chromium ≥ 16%: nickel ≥ 8 5:CARBON ≤0.08 %
d- 50 mm^2 (8 mm diameter) may be reduced to 25 mm 2 in certain applications where mechanical strength is not an essential requirement.Consideration should in this case,be given to reducing the spacing between the fasteners.
e- Minimum 70 µm radial copper coating of 99.9% copper content
f- The cross-sectional area of stranded conductors is determined by the resistance of the conductor according to IEC 60228
G -If the earth lead-in rod is partially installed in soil it has to fulfil the requirements of Table 2 and Table 3.
h- Applicable for air-termination rods and earth lead-in rods.For air-termination rods where mechanical stress such as wind loading is not critical,a 9.5mm diameter,1-mm long rod may be used.
i- If thermal and mechanical considerations are impotant then these values should be increase to 75 mm^2

Table 16. Minimum requirements of LPS components

Material	Maximum electrical resistivity μΩm	Tensile strength N/mm²
Copper	0.018	200 to 450
Aluminium	0.03	≤ 150
Copper coated aluminium	0.03	≤ 150[b]
Aluminium alloy	0.036	120 to 280
Steel	0.25	290 to 510
Steel (earth electrode)	0.25	350 to 770
Copper coated steel	0.25	290 to 510 [b]
Copper coated steel (earth rods) [a]	0.25	350 to 770 [b]
Stainless steel	0.8	350 to 770
a- Yield/tensile ratio 0.80 to 0.95 b- Based on dimension / tests of only core material of coated conductors.		

Table 17. Electrical and Mechanical characteristics

Testing:

Tests specified in IEC 62561-2 standard are type tests. Air termination rods, down conductors and earth conductors shall be subjected to the following tests to confirm that the components are suitable for lightning protection system applications.

Test for thickness coating on conductors:

For performing the coating thickness measurement test, a specimen of 500mm length can be used. The copper or zinc coating over steel core shall be tested using a Magnetic method instrument as per ISO 2178. Zinc coating shall also be measured in accordance with ISO 1460 or ISO 1461.

Test Positions:

The testing is performed at three different positions of the sample and the positions are as follows.

- 50mm from top
- 50mm from bottom
- Mid-point

For rods, the measurement should be made around the circumference of the specimen at 3 points of approximately 120° separation at each position.

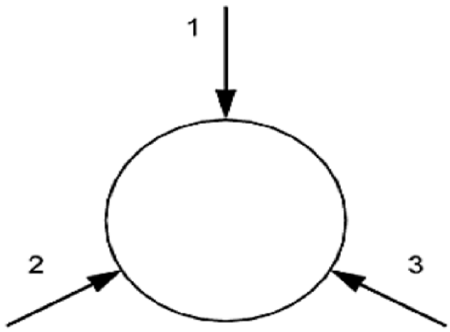


Figure 28. Coating thickness measurement - Rod

For flat specimens, the measurement should be made on both sides of the flat in the middle of the width at each position.

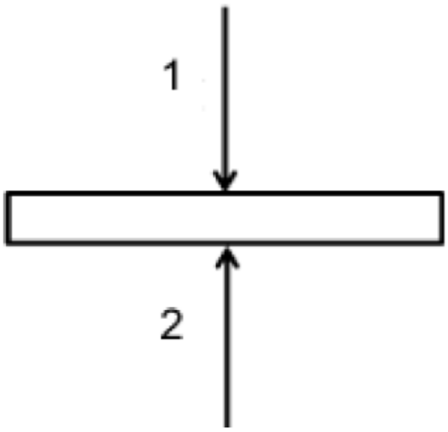


Figure 29. Coating thickness measurement - Flat

IEC 62561 specifies that there is no requirement to measure the thickness of tin plating on copper where it is applied for aesthetic reasons only.

Acceptance Criteria:

- The coating thickness shall be not less than the values specified in the standard.
- Zinc galvanizing coating shall be smooth, continuous and free from flux strains.
- Minimum weight of zinc should be 350g/m^2 for solid round specimen and 500g/m^2 for solid tape specimen.

Bend and Adhesion test:

The coated conductors of 500mm long shall be bent to an angle of 90 degrees. The bending radius should be equal to

- 5 times the diameter for a round conductor.
- 5 times the thickness for tape conductor.

Acceptance Criteria:

After the test, there should not be any sharp edges, cracks or peeling of coating without magnification.

Environmental test:

The electrical resistance over a length of 100mm shall be measured prior to the environmental tests. After measuring the resistance values, the specimens shall be subjected to below tests.

- Salt mist treatment
- Humid sulphurous atmosphere treatment

Acceptance criteria:

- The difference in the electrical resistance value measured before & after the tests shall not be more than 50%.

- There should not be any signs of corrosion on base metal of the specimens without magnification.

Electrical Resistivity Test:

A sample conductor of 1.2m length is taken and the resistance is measured over a 1m distance using micro-ohmmeter. The measure value is corrected to a temperature of 20°C.

From the measured resistance value, the resistivity of the material can be calculated by using the below formula,

$$\rho = (R*a)/l$$

Where,

R – Resistance over 1m length (in Ω)

a – Cross sectional area (in m^2)

l – Unit length (in m)

Acceptance Criteria:

The specimens are deemed to have passed the test, if they comply with the values specifies in the standard.

Tensile Test:

For testing the tensile strength, the specimen shall be tested according to ISO 6892-1.

Acceptance Criteria:

The specimens are deemed to have passed the test, if they comply with the values specifies in the standard.

1.27 Instructions for Installation of LPS

Introduction :

The buildings and structures shall be protected from lightning strikes by installing well designed and executed lightning protection system (LPS). It usually consists of both external and internal lightning protection system. There has to be proper co-ordination between the design and execution to ensure the protection.

An external Lightning Protection System consists of,

1) Air terminals
2) Down conductor
3) Test link
4) Earthing system.
5) Clamps & Fixture

Installation of Lightning Protection system:

If the roof or wall is made of non-combustible material then the components of LPS can be directly mounted on the surface of a wall. Spacers and fixtures made of both conductive or non-conductive materials shall be used for clamping the conductors on the roofs.

If a roof or wall constructed from combustible material, then even the temperature rise due to the flow of lightning impulse current may result in fire or explosion. Hence, IS/IEC 62305-3 insists that special care is required for installation of lightning protection system. The effect of heating on the roofs made of combustible material due to lightning impulse current shall be reduced by implementing the following measures:

- The cross-sectional area of the conductors shall be increased;
- The distance between the conductors and the roof covering shall be increased and
- A layer made of heat-protective material shall be provided between the conductors and the flammable material.

For the structures with flat roofs, the conductors laid on the perimeter of the structures should be installed as close as possible to the outer edges of the roof. The down conductor should be installed in the shortest possible path between the air terminal and earthing system. The number of bends should be as low as possible with least possible joints.

IEC 62305-3 suggests the distance required between the supporting fixtures for both Flat and round rod configurations of down conductors. The spacing details are as follows,

Arrangement	Fixing Centers for Tape, stranded and soft down conductors mm	Fixing Centers for round solid conductors mm
Horizontal conductors on Horizontal surfaces	1000	1000
Horizontal conductors on vertical surfaces	500	1000
Vertical conductors from the ground to 20m	1000	1000
Vertical conductors from 20 m to there after	500	1000

Table 18. Distance between supporting fixtures

For structures with a roof ridge, the conductor should be installed on the roof ridge. For small structures if the structure is protected by the roof ridge conductor, then at least two down-conductors should be installed at the opposite corners of the structure. The instructions given by IEC 62305-3 for installation of air terminal and down conductor for sloped roof are shown below.

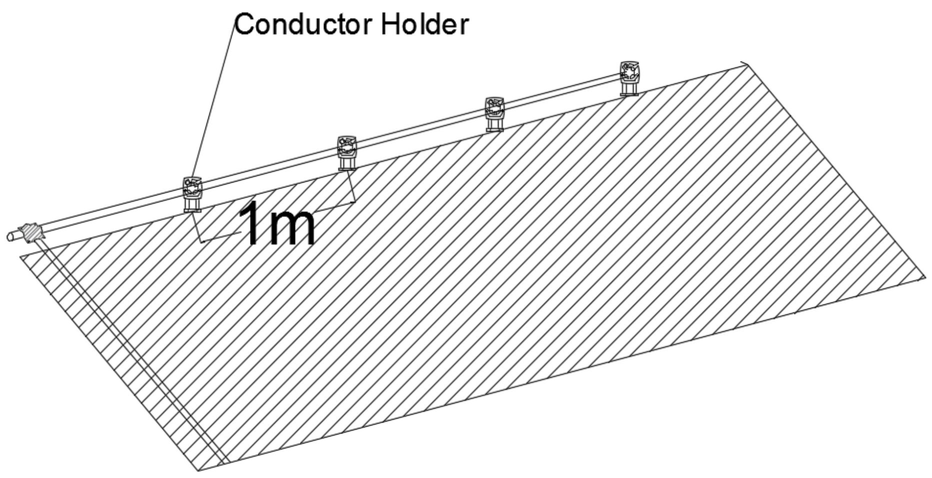


Figure 30. Clamping of down conductor

If the structure has chimney at the top then a separate air terminal rod of suitable height shall be installed for protecting the chimney. It should be ensured that the protection angle provided by the air terminal at the required level is sufficient for protecting the chimney.

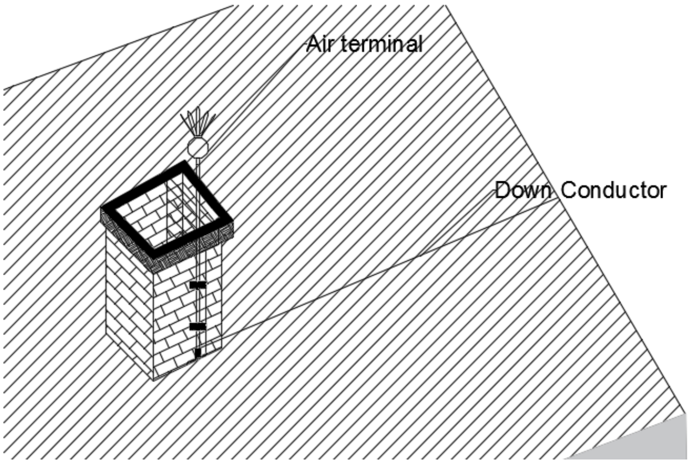


Figure 31. Air terminal for chimney

If the gutters have sufficient thickness and cross-sectional area as specified by IS/IEC 62305-3 then they can be used as natural components for down conductors. The down conductor should not be installed in gutters or water spouts as the corrosion rate will be higher because of the moisture content.

IS/IEC 62305-3 suggests that any metallic structures or pipe lines running adjacent to the down conductors should be connected to establish equipotential bonding for avoiding the potential difference is voltage during the passage of electric current. The test link shall be installed at a height of around 1m to 1.5m above the ground level and the earthing conductors shall be laid at a depth of 0.5m below the ground level.

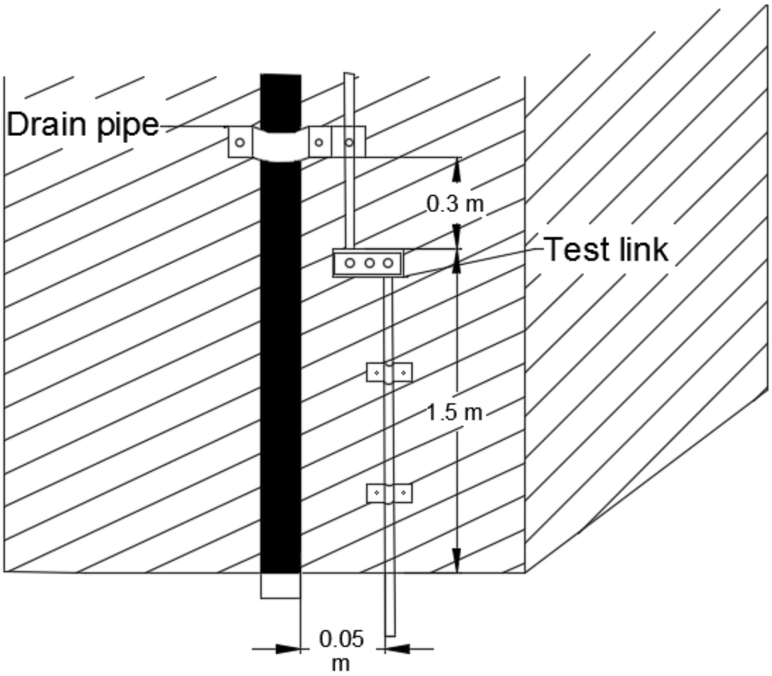


Figure 32. Installation of test joint

1.28 Inspection and Maintenance of LPS

Introduction:

Lightning Protection System (LPS) components tend to lose their effectiveness over the years because of corrosion, weather-related damage, mechanical damage and damage from lightning strokes. Hence, the condition of all the components of LPS should be checked periodically, to ensure the safety of structure and life of the beings connected with the structure. Inspection and maintenance shall not be conducted during threat of thunderstorms. IS/IEC 62305-3 explains about the inspection, testing and maintenance procedures for Lightning Protection System and the details are as follows.

Inspection of LPS:

Since the components of LPS (air-terminal, down conductor, clamps, fixing assembly) are exposed to atmosphere, they are more prone to corrosion and direct lightning strikes which may reduce the performance of the system. Hence the LPS should be inspected periodically.

The inspection includes checking technical documentation, visual inspections, testing and logging in an inspection report. The purpose of this inspection is to ensure that the LPS conforms to this standard in all respects. The interval between the inspection can be determined based on the following factors.

- Classification of structure protected (based on effects of damage).
- Class of LPS.
- Local environment (Ex. Corrosive environment, chemical usage).
- Materials of individual LPS components (Copper, SS, GI).
- Type of surface.
- Type of soil.

IS/IEC 62305 part 3 suggests the maximum time period between the inspection for the different classes of LPS and the details are as follows.

Protection level	Visual inspection year	Complete inspection year	Critical situations [a] [b] complete inspection year
I & II	1	2	1
III & IV	2	4	1
a – LPS utilized in applications involving structures with a risk caused by explosive material should be visually inspected every 6 months b – Critical situations could include structures containing sensitive internal systems, office blocks, commercial buildings or places where high no. of people may be present			

Table 19. Maximum period between inspection of an LPS

The LPS should be visually inspected at least once in every year. For areas with extreme weather conditions, the inspection should be done more often than normal conditions. A total inspection and test should be completed every two to four years.

Visual Inspection:

Visual inspections should be made to make sure that,

- The design was as per the standard.
- The LPS is in good condition.
- There are no loose connections.
- There are no accidental breaks or damages.
- There should not be any signs of corrosion.
- All the connections are proper.
- There should be any additions to the protected structure.
- Proper equipotential bonding should be established.
- Separation distances are maintained.

Testing:

- Performing continuity tests.
- Performing individual and combined earth resistance measurements of the earth-termination system. The results should be recorded in an LPS inspection report.
- If the resistance to earth of the earth-termination system as a whole exceeds 10Ω, the value can be improved by installing additional earth electrodes.

An LPS should be inspected whenever any modification or repairs are made to a protected structure and also following any known lightning discharge to the LPS. The results of testing, visual inspection, condition of air terminals and conductors, effects of corrosion, condition of joints and earth resistance values measured should be documented in an LPS inspection report.

If an inspection shows that repairs are necessary, those repairs should be executed without delay and not be postponed until the next maintenance cycle.

Maintenance of LPS:

The LPS should be maintained at regular intervals to ensure that it continues to fulfil the requirements throughout the lifetime of the system. LPS maintenance should become a part of the overall maintenance schedule of the structure.

The frequency of maintenance of an LPS depends on the following factors.

- Weather and environment
- Exposure to actual lightning strike
- Level of protection

Maintenance procedure contains a list of routine items to be checked to ensure the proper operation of the system. The maintenance procedure for LPS should contain the following items.

- Verification of all LPS components;
- Verification of the electrical continuity.
- Measurement of the earth electrode resistance values.
- Verification of SPDs.
- Re-fastening of the components.

All the maintenance activities carried out for LPS should be recorded and the records should include the details of corrective actions taken. The maintenance report helps us to evaluate the components of LPS and the installation procedure. The maintenance records can be used to update the maintenance procedures to prevent the damages.

2 INTERNAL LIGHTNING PROTECTION SYSTEM

2.1 Lightning Equipotential Bonding

What is lightning equipotential bonding?

The lightning equipotential bonding can be explained as bonding of conducting parts to the Lightning Protection System either by connecting them directly or through Surge protection devices in order to reduce the differences in potential caused during the lightning strikes. This prevents from dangerous sparking that may occur between the external Lightning Protection System and other components.

Metal installations like gas pipes, water pipes, air pipes, heating pipes, shafts of lifts, crane supports etc. shall be bonded together and to the LPS at ground level.

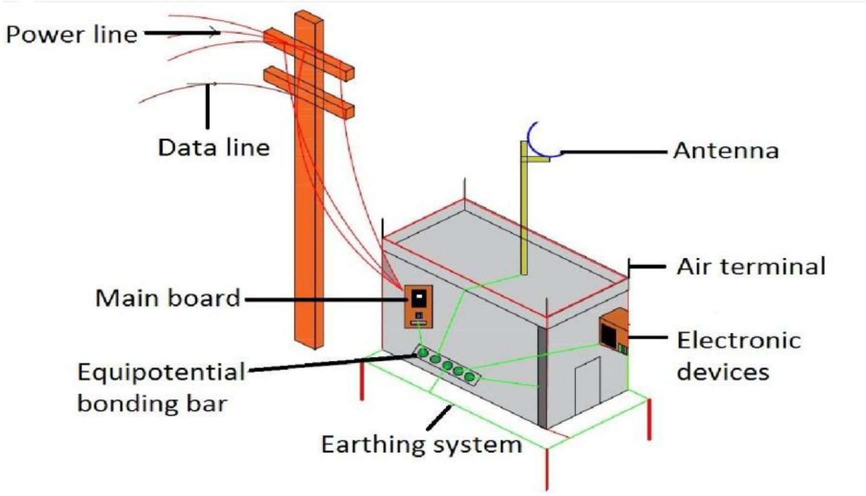


Figure 33. Equipotential bonding

Lightning equipotential bonding should be integrated and coordinated with other equipotential bonding in the structure as shown in the picture above.

When the building height exceeds 30 m, equipotential bonding is performed at 20 m level height and also at every 20 m above that. That is, on such cases the external down conductors, internal down conductors and metals parts are to be bonded.

The conductors used for bonding to the earth-termination system should meet the cross-sectional area requirements as specified by IS/IEC 62305 – part 3 and is independent of class of Lightning Protection system.

2.2 Separation Distance

Introduction :

During the passage of lightning impulse current through the components of LPS, sparking may occur between the conductors and any other metal structures. IS/IEC 62305 suggests that the dangerous sparking between an LPS and metal, electrical and telecommunication installations can be avoided by implementing any one of the following options.

1) Isolation or adequate separation in an isolated LPS.

2) Equipotential bonding or by isolation or adequate separation in a non-isolated LPS.

Equipotential bonding avoids the difference in potential and thus reduces the chances of flashing. In this article, we shall explore about calculating the separation distance for LPS as specified by IS/IEC 632305.

Separation Distance:

Separation distance is the minimum distance required between two conductive parts so that no dangerous sparking can occur. The separation distance provides electrical insulation between the conductors and other metal structures. Adequate spacing should be provided between the down-conductors of LPS and any doors, window or metal structures adjacent to it.

As per IS/IEC 62305, the separation distance (s) can be calculated by,

$$S = \frac{k_i}{k_m} * k_c * l\,(m)$$

Where,

k_i - depends on the selected class of LPS;

k_m - depends on the electrical insulation material;

k_c - depends on the lightning current flowing on the air-termination and the down conductor and

l - length in metre,

The length is calculated from the air-termination or the down-conductor point to the nearest equipotential bonding point or the earth termination. If internal down-conductors exist, they should be taken into account in evaluating the number n.

The value of k_i for calculating the separation distance for different class of LPS is as follows.

Class of LPS	k_i
I	0.08
II	0.06
III and IV	0.04

Table 20. Factor k_i

The value of K_m for different materials for calculating the separation distance as specified by IS/IEC 62305 is as follows.

Materials	k_m
Air	1
Concrete, Bricks & wood	0.5
• **Note 1:** When there are several insulating materials in series, It is a good practice to use the lower value for k_m • **Note 2:** In using other insulation material s, Construction guidance and the value of km should be provided by the manufacturer.	

Table 21. Factor k_m

The value of partitioning coefficient k_c of the lightning current depends on,

- Class of LPS,
- Type of air termination system,
- The overall number the down conductors (n),
- Position of down conductors and
- The type of earth-termination system.

There are two approaches available for finding the separation distance value. They are,

1) Simplified approach
2) Detailed approach

Simplified approach:

In simplified approach, the current flowing through the lengths of the conductors will be constant. The following conditions have to be considered for calculating the separation distance.

k_c - depends on the (partial) lightning current flowing on the down-conductor arrangement

l - vertical length in metre, along the down-conductor, from the point where the separation distance is to be considered, to the nearest equipotential bonding point.

The value of k_c for different numbers of down-conductors provided by IS/IEC 62305 part 3 is as follows.

Number of down conductors (n)	k_c
1 (Only for of an isolated LPS)	1
2	0.66
3 and more	0.44
Note: Values apply for all types B earthing arrangements and for type A earthing arrangements, provided that the earth resistance of neighbouring earth electrodes do not differ by more than a factor of 2. If the earth resistances of single earth electrodes differ by more than a factor of 2, k_c = 1 is to be assumed	

Table 22. Factor k_c

Example:

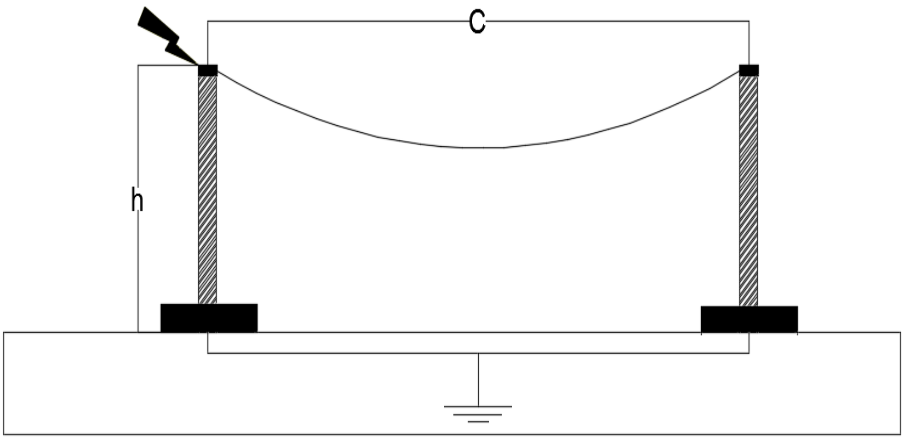


Figure 34. Simplified approach

Detailed Approach:

In a meshed air-termination system and interconnected down-conductor system, there will be multiple parallel paths and the lightning impulse current will get divided among the conductors at every junction. Hence the value of current flowing through one down conductor won't be same as the other down conductor. For these cases, IS/IEC 62305 suggests a more accurate evaluation of the separation distance s.

$$S = \frac{ki}{km} * (k_{c1} * l_1 + \ k_{c2} * l_2 + \cdots + \ k_{cn} * l_n) \ (m)$$

This approach is suitable for evaluation of the separation distance in very large structures or in structures with complex shape. For such complex structures, we cannot apply simplified approach to calculate the separation distance.

$$k_c = \frac{h + c}{2h + c}$$

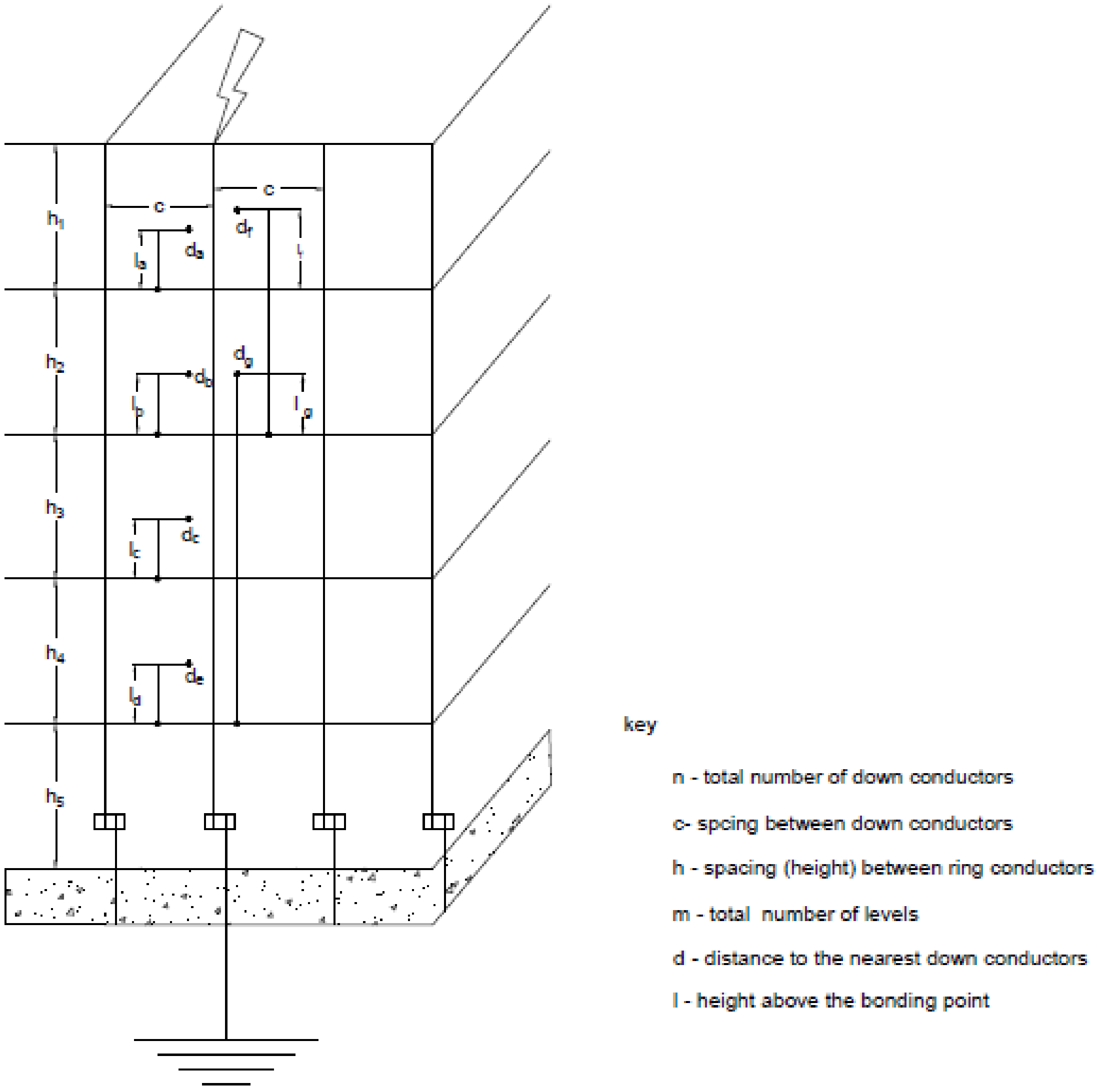


Figure 35. Detailed approach

Let us consider a structure protected by using mesh method and the structure has 24 numbers of down conductors. Based on the current injection point, the current through the down conductor varies. Let us consider three different injection points A, B & C.

Rules for current partitioning:

IS/IEC 62305-3 provides the following instructions for calculating the separation distance.

- Current will get divided by the number of possible current paths into the meshed air-termination system at the injection point.
- Current will be reduced by 50 % at any further joints of the air-termination mesh.
- At the down-conductors, current will be further reduced by 50%, but the value of kc must not be less than 1/n. (n - total number of down-conductors).

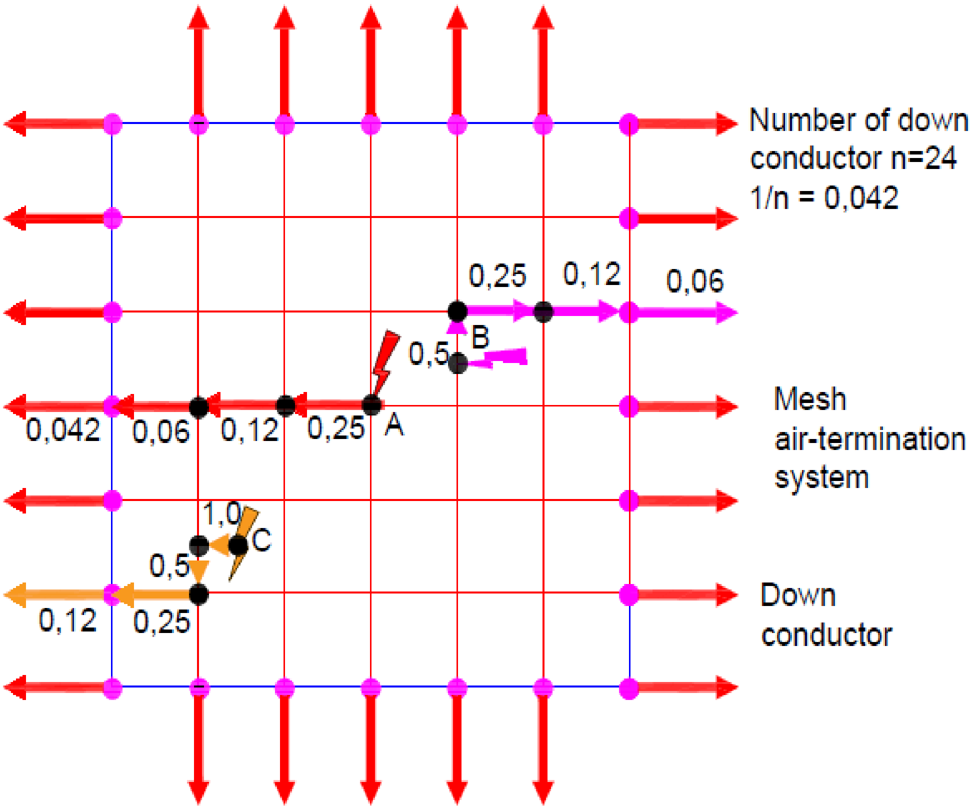


Figure 36. Current partitioning in mesh

- The path along the roof edge to the down-conductor need not to be considered.

- If there are fewer meshes between the point of strike and the edge of the roof, only the relevant values of kc have to be used.

2.3 Surge Protection Device

Introduction

Direct effect and indirect effect of lightning strike can cause damage to the living beings, Structures and the electrical or electronics devices. The main and most effective measure for protection of structures against physical damage is considered to be the lightning protection system (LPS). IEC 62305 explains about the Internal and External lightning protection system. Internal Lightning Protection System will protect the electrical and electronic equipment inside the structure from the lightning impulse surges.

What is Surge?

Surges are very high magnitude and low duration disturbances on the power frequency that causes damage to the electrical & electronic equipment.

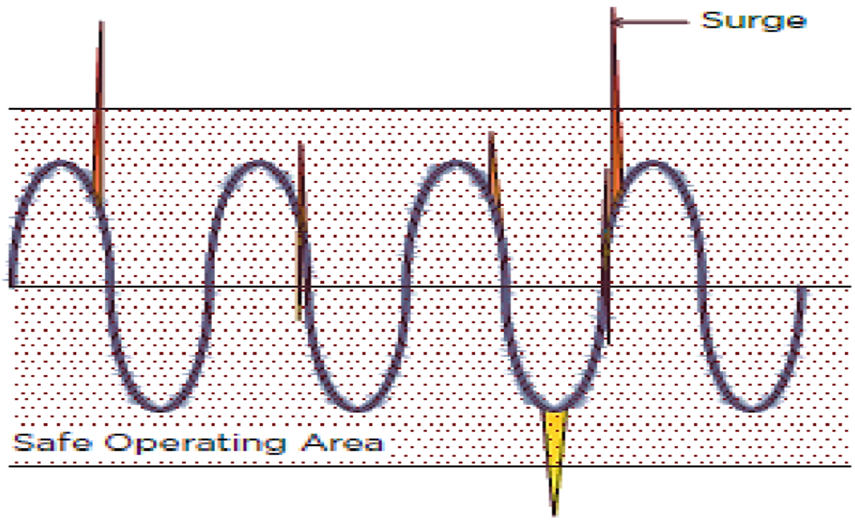


Figure 37. Surge

Lightning Protection Zones:

IEC 62305-4 has differentiated the lightning protection zones based on the strike.

1. LPZ 0A - The zone which is protected from Direct strike by providing external lightning protection.
2. LPZ 0B – The zone which is protected from magnetic field of direct lightning strike
3. LPZ 1 - The zone which is protected from the damage caused by indirect strike. By limiting the surge current due to lightning.
4. LPZ 2….n - The zone which is protected from the damage caused by surges at the boundary.

Surge Protection Device:

Surge Protection Devices (or SPDs) are units combining several protection components. They are designed to be incorporated in an installation to protect all electric, electronic, and data-processing equipment from transient over voltages. They divert the transient surges to the ground thereby protecting the equipment.

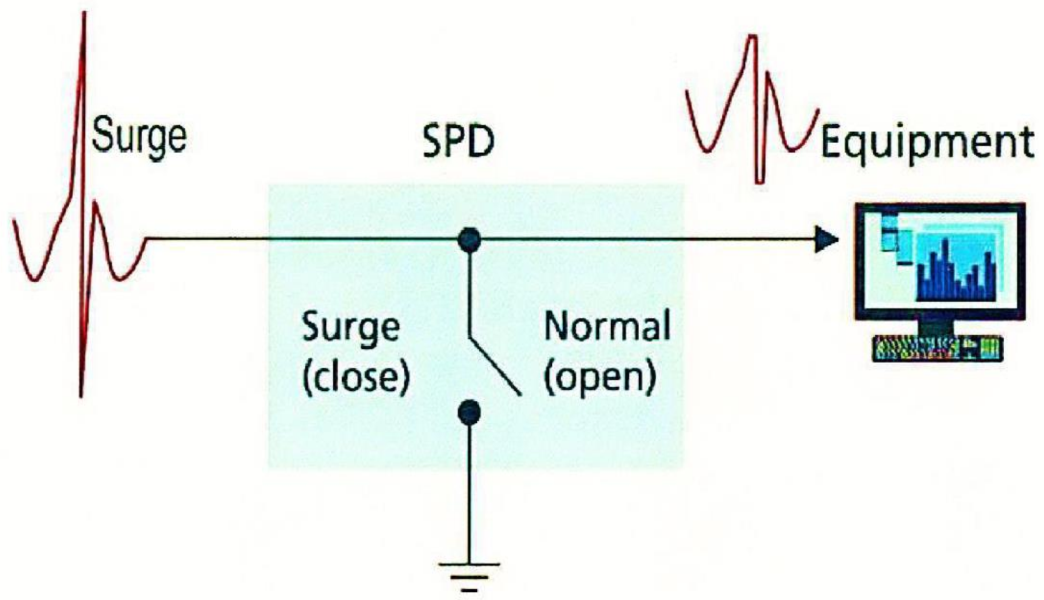


Figure 38. Surge Protection Device

Types of Surge Protection Device:

Type 1 Surge Protectors:

This type of surge protection device need to withstand the surge current of the direct lightning strike. As per EN 61643-11 and IEC 61643-11 standards Class 1 test need to be done by injecting current 10/350 µs impulse current in order to simulate the direct lightning strike consequence.

Type 2 Surge Protectors:

To with stand the transient surges the SPD should be tested Class 2 test as per EN 61643-11 and IEC 61643-11 standards. 8/20 µs impulse current to be inject.

Type 3 Surge Protectors:

To protect the specific equipment from the surges Class 3 test should be done as per EN 61643-11 and IEC 61643-11 standards. Combination of 1.2/50 µs & 8/20 µs current to be inject in order to perform Class 3 test.

3 APPLICATION

3.1 Need of Protection for Tanks against Direct Lightning Strikes

Introduction:

Lightning strike is a natural phenomenon of sudden discharge of charges from highly concentrated cloud or any objects. Lightning cannot be avoided but the damages can be reduced by proper preventive measures. Tank farms consists of metal tanks of different sizes and the inflammable materials are stored in this tank of different quantity.

Lightning strikes on metal tanks

Even the sudden increase in temperature due to the flow of lightning impulse current may result in the explosion at these site conditions. Hence Lightning Protection System is very much essential for these kinds of very sensitive areas. Fugitive emissions are unintended leakage of gases or vapors from pressurized container due to faults or improper maintenance activities. The fugitive emissions may also occur due to the evaporation of inflammable materials in storage tanks. The leakage of highly inflammable vapors from the storage tanks increases the risk of fire and explosion at the tank farms.

Figure 39. Explosion in tank farm

When lightning strikes directly hits the metal storage tanks, the following effects may occur,

- Explosion of tanks may occur along with the outbreak of fire.
- Lightning current flowing through the metal part of the tank may damage the tank.

- While lightning strike, the temperature reaches very high level around the environment which will turn it into the major risk of ignition or fire.

- The high temperature due to lightning may cause puncture in the metal sheet and result in fire or explosion.

- Hotspot on the metal sheet can ignite the fuel kept inside the container.

Steps to be followed

OISD-GDN-180, an exclusive standard for Oil industry explains about the preventive measures for the storage tanks. The measures provided by the standard are as follows.

- Flammable liquid shall be stored in the gastight structure.
- Periodical maintenance should be carried out and the proper operating conditions of all the accessories shall be ensured.
- All the openings to atmosphere should be properly closed at the same time entrance of flame should be arrested.
- Accumulation of the mixture of air and highly inflammable vapour outside the tanks should be prevented.
- The spark gaps between metallic conductors in places where the flammable vapour escapes or accumulates shall be avoided.

3.2 Design of Protection for Oil Storage Tank Against Lightning Strike

Introduction :

Lightning is one of the most destructive phenomena of nature. Due to the storage of explosive and hazardous materials in the Oil & Gas Industry, not only the direct lightning strike but also the increase in temperature on the components due to the flow of lightning impulse current will lead to a huge disaster. In this article we have explained about design of protection for oil storage tank against lightning strikes given in OSID_GDN 180 and IS/IEC 62305-2. The calculation of design of lightning protection can be done by Rolling sphere method and the same is explained in 1.15. IS/IEC 62305-2 has mentioned at least level 2 protection is necessary for the structure with risk of explosion.

Lightning protection in oil tanks

A storage tank made of steel having a wall thickness greater than 4.8mm then the tank can be considered to be self-protected from lightning strikes but the proper bonding to the earth should be ensured.

The Lightning protection for storage tanks can be done by three methods

- By using air terminal
- By using Lightning mast
- By using overhead line

Use of Air terminals:

In this method air terminals will be placed around the perimeter of the surface wall of the storage tank. The protection zone provided by the air terminals depends on

- diameter of tank,
- height of air terminals and
- distance between the air terminal

OSID_GDN 180 has given the calculation for finding the number of air terminals needed for protecting a storage tank of diameter 'D' when the air terminals are placed 20m apart along the perimeter of the tank.

No of air terminal = $(\pi * D)/20$

D- Diameter of storage tank

Example:

Diameter of tank: 30 m

No of air terminals = $(\pi * 30)/20$

No of air terminals = 5

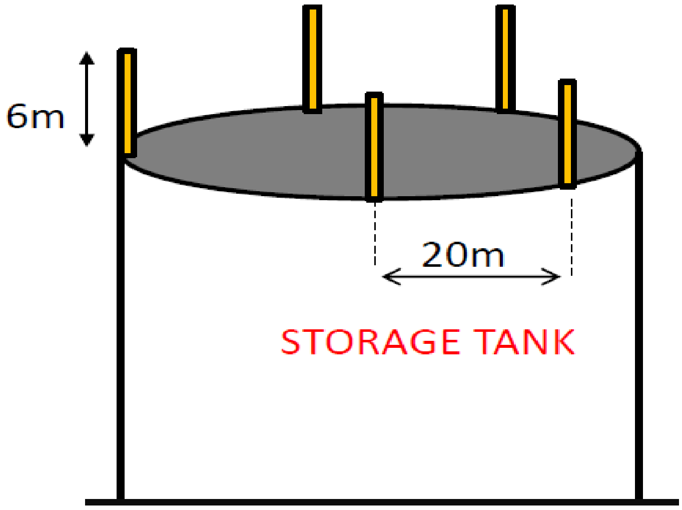


Figure 40. Storage tanks protection - Air terminals

When the air terminals of height 6m are placed at 20m apart, they will protect area up to 18m from the periphery of the tank and the center portion of the tank will remain unprotected.

Use of lightning mast around the tanks:

The height of the mast should be greater than height of storage tank. The following basic needs to be considered for the protection of storage tank by lightning mast:

1. Mast shall be placed 5 to 6m from the tank to reduce the effect of side flashing.
2. The Lightning mast should not be placed 30m away from the tank

The number of lightning mast calculation is same as the calculation of air terminal placed on the wall. Earthing system of the lightning mast will be bonded with the earthing system of tank. Lightning masts are much more expensive as compared to the air terminals on the shell.

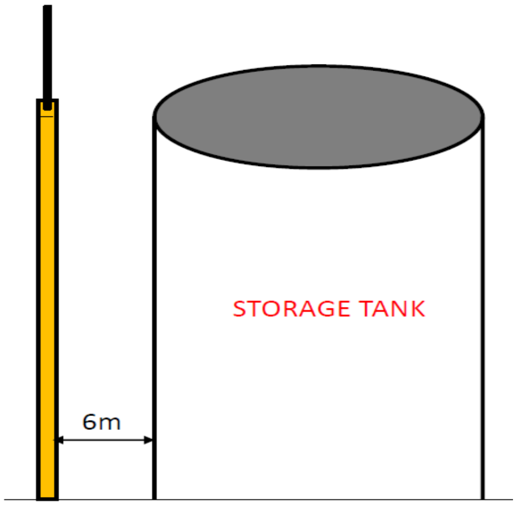


Figure 41. Storage tanks protection - Lightning mast

Use of overhead line:

The air terminal in the form of overhead lines can be used to provide complete protection to the storage tanks. The position and the number of overhead lines can be calculated by using Rolling sphere method. To avoid side flash the minimum distance of 6m between supporting mast holding overhead line and tank shall be maintained. For the overhead protective lines, we have to maintain a clearance of about 8m from the top most point of the storage tank.

The number of overhead lines needed for protecting the storage tanks of different sizes as specified by OISD GDN 180 are as follows.

S.No	Diameter of Tanks (m)	No of Overhead lines
1	6 to 8	1
2	8 to 30	2
3	30 to 80	3

Table 23. Storage tanks protection - Overhead lines

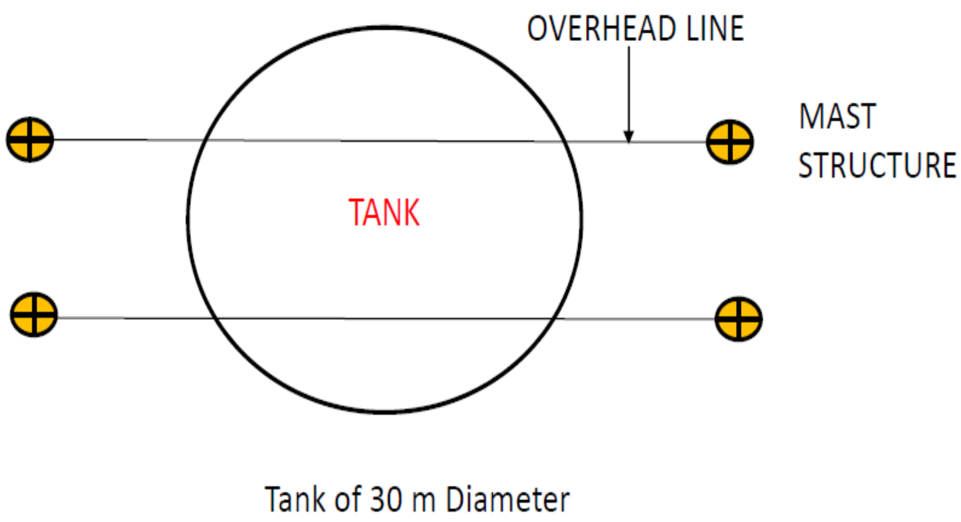


Figure 42. Storage tank protection - Overhead lines

The earthing of the supporting mast shall be bonded with tank's earthing system.

3.3 Lightning Protection for Solar Farms

Introduction :

Lightning is one of the most destructive phenomena of nature. It can cause damage to humans, structures, electrical and electronics equipment. Currently, due to global war0ming, the entire world is moving towards Renewable Energy, and Solar Panels are at high risk due to the possibility of destruction by lightning strikes because of its elevation and the wide spread vacant land areas chosen for the installation of such structures. Redesigning or modification of Lightning Protection System post the installation of these structures isn't advisable as it would attract heavy expenses and hence a properly designed LPS as per relevant standards is mandatory. Lightning could strike and cause damage to the solar panels either directly or indirectly. External protection of solar panel against direct lightning strikes needs an air terminal to intercept the lightning strike, a down conductor to provide a dedicated path and an efficient earthing system to dissipate the lightning current in to the earth. The internal protection of solar panels needs an appropriate surge protection device to protect these solar panels from getting damaged from a surge current caused due to lightning strikes.

The external lightning protection shall be provided by any of the following two methods.

1) Non-Isolated Lightning Protection System

2) Isolated Lightning Protection System

Non-Isolated Lightning Protection System:

Reference: NBC 2016 Part 8 Clause 11.5.1.7

Air terminal height: less than 0.5m

Positioning method: Rolling Sphere Method

Max. distance between air terminals: 15m

Protected Region: (12X9) m using 2 air terminals.

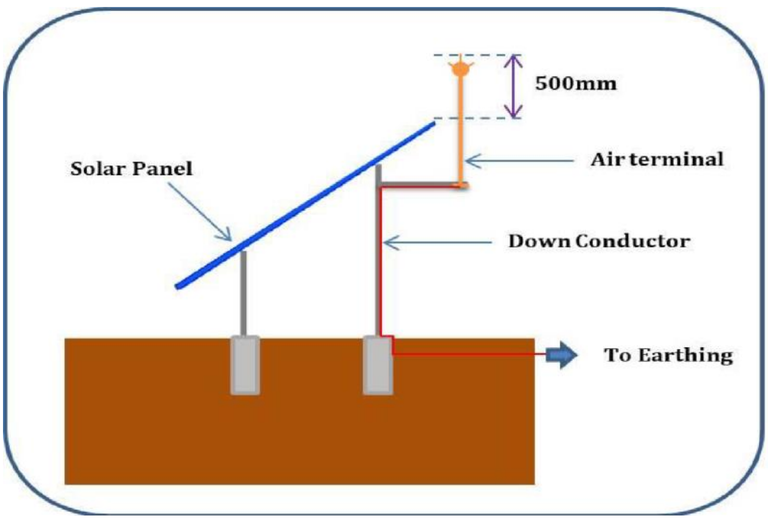


Figure 43. Solar panels protection - Non isolated LPS

As the influence of the shadow of Lightning arrestor arrangement on the solar panel could hamper the performance of the entire solar system, the height of the LA should be restricted to less than 0.5m above the solar panel.

Isolated Lightning Protection System:

Reference : NFC 17-102/2011

Air terminal height: > 5m above solar panels

Radius of Protection: 107 m

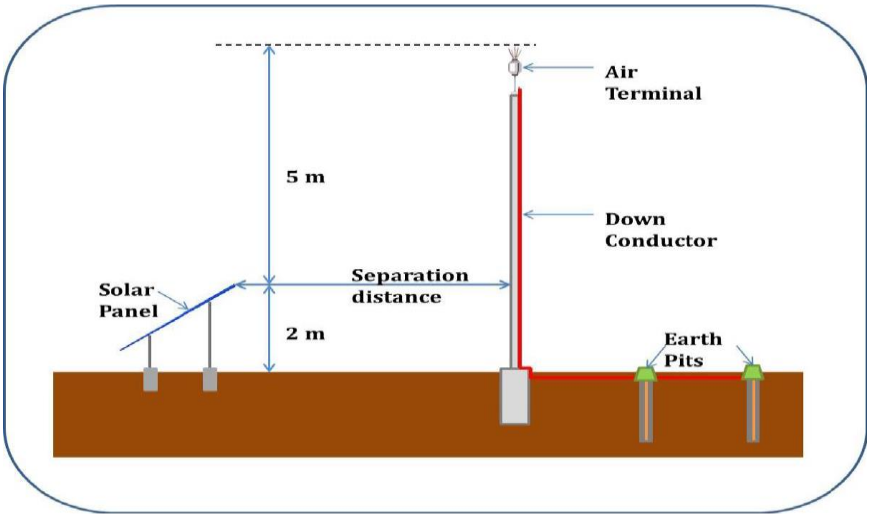


Figure 44. Solar panels protection - Isolated LPS

As we said early, the shadow effect of the solar panel arrangement could affect the performance of entire solar panel. So, we will maintain safe separation distance between LPS and solar panel for avoiding those effects. This separation distance between the solar panel and the Lightning Protection System shall be calculated based on the following parameters.

- Height of the supporting mast.
- Latitude and Longitude of the site.
- Time of operation and
- Seasonal variation

3.4 Protection of Transmission Lines from Lightning

The transmission lines are more to lightning strikes because of the following reasons,

1) Directly exposed to atmosphere,
2) Higher than other structures,
3) Higher charge concentration as they are earthed at every pole,
4) Lower earth resistance

The ground wires at the top of transmission lines act as a shield and protects the live lines from lightning strikes.

The transmission lines are protected from lightning strikes by taking measures like adding overhead ground wires, reducing the tower foot resistance, adding counterpoise wires, increasing insulation, etc.

The overhead ground wires protect the transmission lines from direct lightning strikes. A ground wire is a conductor that runs in parallel to the line conductor and is placed at the top of the tower structure as shown in the picture below.

Figure 45. Ground wires in transmission lines

The ground wire is placed over the tower in such a way that all the lines are placed well within the shielding angle of the ground wires. The height of the shielding earth wire depends on the width of the cross arm.

Since the earth wires are exposed are directly exposed to extreme weather conditions, it should possess sufficient mechanical strength.

3.5 Protection of Telecommunication Tower from Lightning

Telecommunication System:

Telecommunication plays a major role in the industrial revolution which we are currently undergoing – INDUSTRY 4.0. Industrial automation involves communication of the each and every machine with the central hub which helps to monitor and analyse the issues even without direct intervention. The automation is even extended to individual homes which results in SMART HOMES. Thus, the telecommunication devices have become very essential components of our day-to-day life.

Figure 46. LPS for telecommunication tower

Overall Lightning Protection System:

The towers used for telecommunication will be taller than the remaining structures in the premises to avoid the obstacles and interference to the signals which will be transmitted or received through the antenna. These metallic towers are more prone to lightning strikes because of their position and height of the structures and the electronic devices used for transmitting and receiving the data are very sensitive to impulse surges. Hence a complete lightning protection system is very essential for the telecommunication towers to provide uninterrupted and efficient service. The complete protection includes,

1) Properly designed and executed external lightning protection system.

2) Installing Surge protection devices for both power line and data line and

3) Providing a good ground reference.

Positioning of air terminal and equipotential bonding shall be implemented as per IS/IEC62305.

In order to reduce the differences in potential caused due to lightning current, equipotential bonding of conductive parts has to be done either by bonding directly or through surge protection devices.

The telecommunication towers are made up of conductive material and it has transmitter and receiver which is electronic equipment. For protecting the tower from physical damages due to direct lightning strikes, air terminals shall be installed at the top of the tower. For protecting the devices from surges, SPDs shall be installed for both power line and data line.

IS/IEC62305 part 3 suggests that a single earth termination system shall be used for external lightning protection system, SPDs, telecommunication devices and the tower body. Single earth termination system does not mean the presence of single earth electrode. The different earth electrodes used for LPS, SPD, Tower are bonded below the ground level to form a single earth termination system.

3.6 UL Guidance for Protection of Heavy-Duty Stacks

Introduction:

Heavy duty stacks are smoke or vent stack more than 75 feet high, and in which the cross-sectional area of the flue is more than 500 square inches. The guidance provided by UL for protecting the Heavy-Duty Stacks in the application guide is as follows.

Challenges in Protection:

- Since stacks are very high structures, they are more prone to lightning strikes. The chances of side flashes to the stacks are also high. Hence care should be taken on designing the proper lightning protection system and installation should be made as per the design to provide protection to the structure and the people within the zone.

- In addition to the height of the stacks, the one more important factor that has to be considered while designing the protection system of stack is material selection. Since the stack acts as vent for flue gases, the materials used on the top of stack (air-terminal) are more prone to corrosion. Hence the material should possess good corrosion resistance property.

Corrosion Zone:

The top 25 feet of a stack is generally the high corrosion zone and hence a minimum of 1/16 inch coating of lead should be provided for terminals, mounting brackets and conductors. The components used in the upper 25 feet shall be made of materials like copper, copper alloy, bronze or stainless steel. Aluminium components are prohibited in this installation.

Designing:

All components shall be designed by considering Class II protection. The materials of air terminals on stacks shall be solid copper, copper alloy, stainless steel or monel metal.

Air terminal:

- The height of air terminal shall be not less than 18 inches and not more than 30 inches. The diameter shall be not less than 5/8 inch.

- The installation shall be evenly distributed around the top of a round stack at intervals not to exceed 8 feet.

- If the stack is square, the location shall be not more than 2 feet from corners and spaced not more than 8 feet apart.

Down conductor:

- Two numbers of down conductors should be provided for one air terminal.

- If more than one air terminal is installed then all the terminals shall be connected together and there shall be at least 2 down conductors on opposite sides of the stack.

- The natural components of the structure can also be used as a down conductor of the lightning protection system.

- Reinforcing steel in concrete stacks shall be electrically continuous and shall be bonded to the lightning protection system at its upper and lower ends at down-lead locations.

Earthing System:

- The grounding electrode shall be a rod of not less than ½ inch in diameter and made of copper-clad steel, solid copper, or stainless steel. The rod shall extend vertically not less than 10 feet into the earth and below the frost line where possible.

- The bare conductor can also be directly buried from each down conductor in the form of a radial.

- The length of the radial conductor must be at least 12 feet and these conductors must be buried at least 18inch in depth. Any aluminium or aluminium alloy product shall not come into direct contact with earth.

- A ground ring shall be used at a depth of 18 inches under the earth.

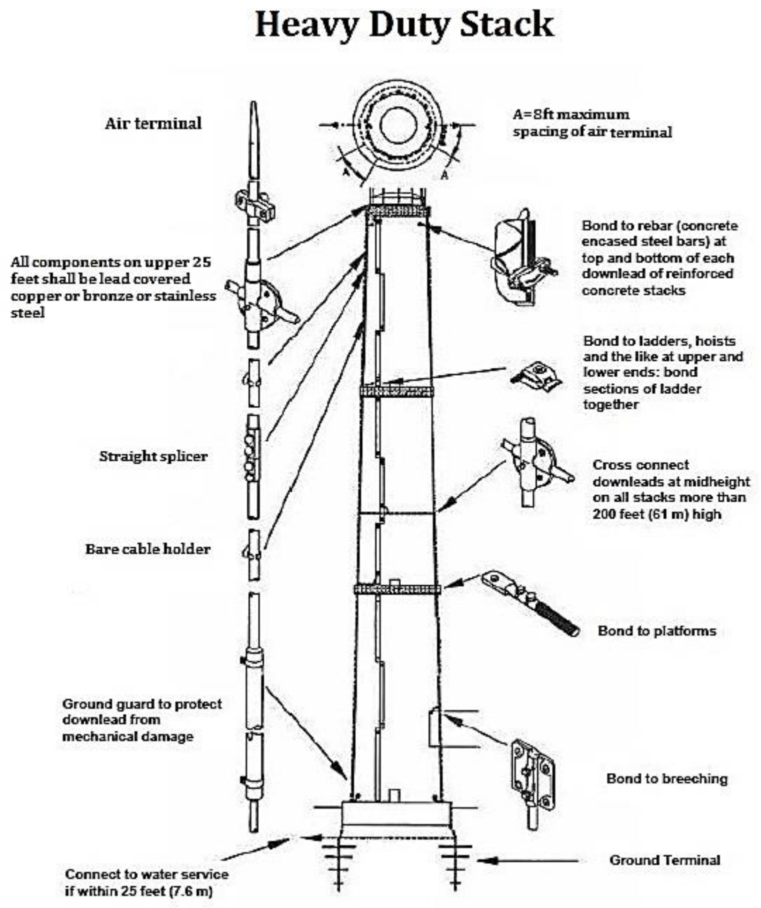


Figure 47. LPS for heavy duty stack

Conclusion:

Stacks above 75ft in height require some special consideration in both design and material used for the system. Materials with good corrosion resistance property should be preferred for the corrosion zone. Aluminium components shall not be used in the corrosion zone and shall not be in direct contact with earth. Aluminium down conductors shall be connected to copper conductors using bimetallic connectors to avoid galvanic corrosion.