ELECTRICAL MAINTENANCE

CABLES AND CABLE ACCESSORIES

TRAINING MANUAL
Course EXP-MN-SE130
Revision 0

ELECTRIC MAINTENANCE

CABLES AND CABLE ACCESSORIES

CONTENTS

1. OBJECTIVES

Following this presentation, the electrician (or future electrician) will be able to:

- Use property and correction tables to determine the cable section and type (for installation).
- Match cable types to uses.
- Identify and differentiate the cables used for electrical, power, control, fire resistance and communications applications, and cables in other disciplines.
- Differentiate high and low voltage uses, and the use of copper and aluminium conductors.
- Interpret the different means of laying cables: buried, via raceways, under ducts, etc.
- Plug, connect any type of cable – or at least know which technology to use.
- Lay a raceway or duct with the right technique.
- Test a low or high voltage cable.
- Interpret and detect incorrect connections and couplings.
- Select a cable!
- Use this document and apply the content carefully.

2. INTRODUCTION

Part of site, or factory, construction is implemented and, clearly, carried out, by electricians: the "***electrical installation"*** budget.

This "electrical installation" includes the ***cables and their connections***. This part (almost always) represents the highest percentage of the budget in terms of both equipment and personnel.

After the installation, electricians will obligatorily be required to replace, lay, disconnect and connect cables and use multiple ***connection accessories*** in the context of maintenance.

In addition, academic-type training and vocational training rarely mention cables in any detail. Newly trained electricians find out what glands, cable ladder racks and crimp lugs are on the job, not forgetting the differences between low voltage and high voltage connections, etc.

Electricians find themselves in engineering offices and cannot differentiate between a stranded core cable and a rigid core cable and have no real idea which cable conduits and raceways to use. They mix up copper and aluminium conductors, are unable to calculate which sections to use (or use the software without really understanding the results), etc…

On the site itself, even so-called "experienced" electricians tend to use inappropriate cables and lay/connect them any old how…..

Extended armoured cables, flexible cables connected without lugs, telephone cable used for 220V, cables running in the wrong places over "other" cable trays, etc., are all (relatively) frequent sights even on our Total sites which are supposed to carefully comply with installation and safety standards …… (and no, I am not exaggerating!)

It is well worth dedicating one course to cables and related material! There is much to be said about these elements!

3. CABLE STRUCTURE AND CONSTRUCTION

Without differentiating between the various types of use (low, high voltage, etc.) let us consider what a "ducted" cable consists of, i.e. cables which run buried or through a raceway. As for the "bare" cable, the only on-site use is to connect the ground.

Aerial bare cable networks require the use of a specific technology, which will not be covered in this course.

Cables are intended to transport electric current. They must be able to fulfil this role safely in terms of equipment and individuals.

Cables (generally) consist of three main parts:

- The conductor
- The insulation
- Mechanical protection

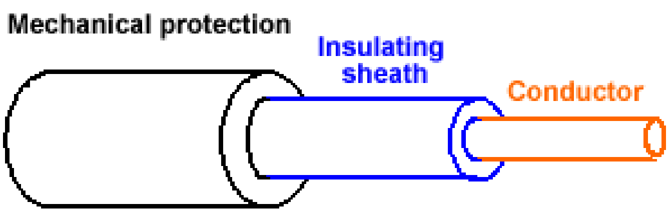


Figure 1: Construction of a 'standard' cable

The conductor transports the electric energy. Several conductors sharing the same cable will be mutually separated and isolated.

Should the mechanical protection be damaged, the insulation (if the insulation sheath is not damaged) must not be affected. In this case, the insulation sheath will be the only effective protection and also provide mechanical protection.

3.1. THE CONDUCTOR

The conductor must have low resistivity (low resistance). This characteristic can be procured using certain metals.

The conductor must also have other physical properties. It must be ductile and flexible. A ductile metal may be pulled and stretched without breaking, this is a basic quality which is required when manufacturing cables. There are, however, other factors which constructors (or users) will require from a cable: weight and cost. Silver is one of the best metal conductors, but it is easy to understand why copper is preferred as a conductor.

Aluminium is also increasingly used as a metal conductor. Aluminium has 1.6 times more resistivity than copper, and the same current therefore requires a larger section, however aluminium is (far) less expensive and much lighter (*you can clearly feel the difference when you "pull" on the cables).*

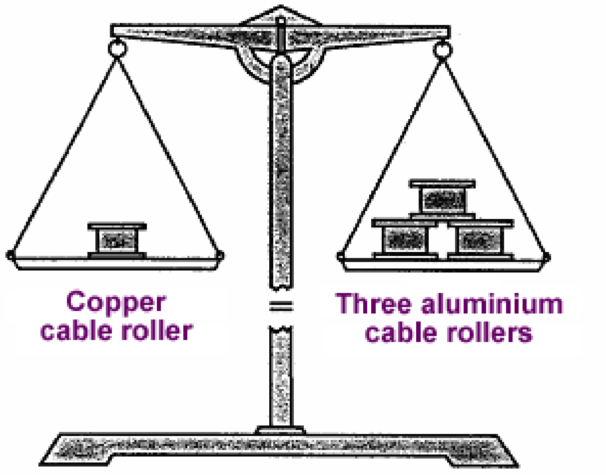


Figure 2: Cu conductor/Al conductor

3.1.1. Conductors and materials

As you will (most probably…) remember, several other good conductive materials exist. Bronze, brass, tin, steel, etc. are all examples, however, for various "technical" reasons (malleability, to name just one), they could not be used as cable conductors.

In fact, only two materials are used in cables to carry electricity i.e. copper and aluminium.

Material	Symbol	Resistivity in ρ microhms – mm²/mm at 20°C
Silver	Ag	16.29
Copper	Cu	17.24 to18.50
Gold	Au	24.4
Aluminum	Al	28 to 29.50
Platinum	Pt	98.-
Constantan	CuNi	≈ 500

Table 1: Resistivity of standard metal conductors

Aluminium has the following drawbacks (as compared with copper):

- More difficult to connect
- Electrolytic corrosion
- Is not (no longer) used for small sections (< 16mm²)

Until the last decade (up to the year 2000), Aluminium cables were "banished" from Total construction sites. Nowadays, considering the progress made in terms of connections, anti-corrosion protection, and (clearly) the constant increase in cost concerns (in favour of aluminium), aluminium electricity cables are used on sites.

3.1.2. (Cable) Conductor manufacturing modes

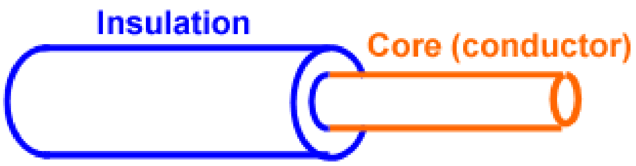


Figure 3: A cable with one single conductor

Cables have one or several conductor "raceways". These conductors are known as cores.

Cables may be single core or multi core. Rigid core cables all have small sections (up to 6mm²). Larger sections systematically have stranded cores or flexible cores.

Single core cables may have one single conductor, which will be a rigid core cable. Other cables will have stranded cores, i.e. a core made up of several rigid conductors.

The third cable type is flexible with a core consisting of a multitude of rigid conductors with small sections. Flexible core cables can also be known as stranded core cables, however the "wires" are narrower and are not wound into a spiral (stranded core), but simply grouped into stands.

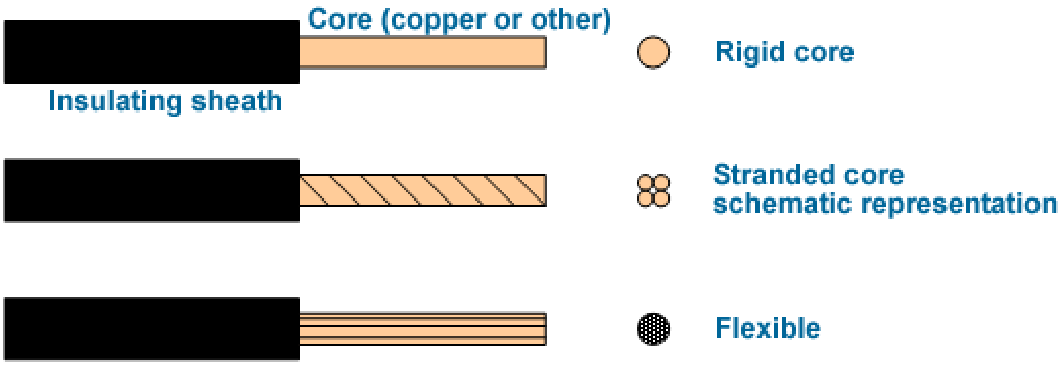


Figure 4: The 3 different types of cable cores

Stranded core cable:

The conductor core of this type of cable consists of six rigid "wires" wound into a spiral around a seventh central conductor.

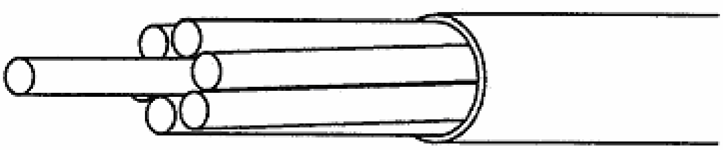
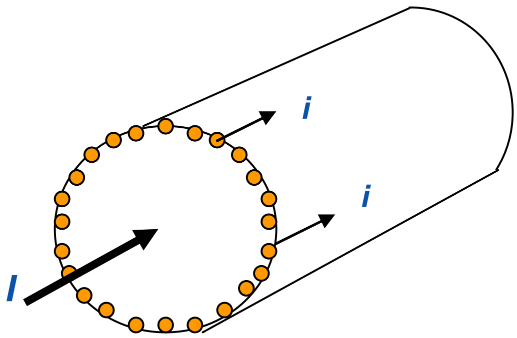


Figure 5: Stranded core

Stranded cores have sections of between 2.5mm² and 600mm² (maximum standard section) for low voltage cables.



Stranded cores enable greater flexibility, although less than flexible cables, obviously...

The number of "wires" in the conductor core is also multiplied due to a physical phenomenon, i.e. the capillarity of the electric current.

Figure 6: Capillarity of the current in a rigid core conductor

The current circulates at the periphery, and on the surface of the conductors, therefore, by multiplying the number of rigid conductors, we amplify the surface area. This also explains why you will never find square bars in a bus (electrical panel), but rather several back-to-back bars.

Stranded cores consist of (standard version), 7, 19, 37, etc. wires. The section of the wires will vary. Smaller sections give more flexible cables.

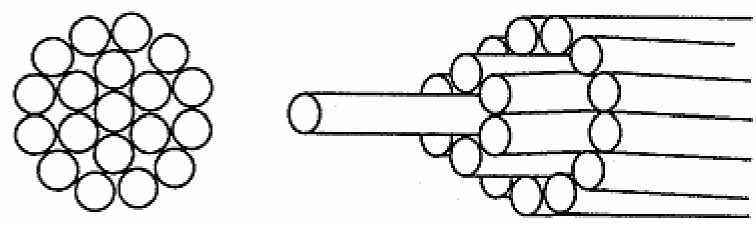


Figure 7: Stranded core with 19 conductors

Power cables have one or several stranded cores (see paragraph below).

3.1.3. Conductor and cable shapes

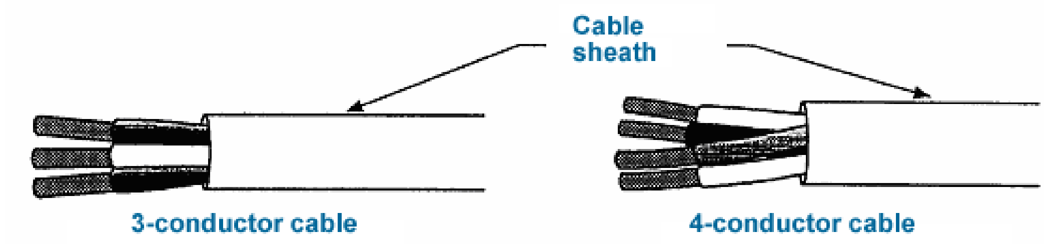


Figure 8: Examples of multi-connector cables

Most cables have a round section (shape). Conductor cores also generally have a round section. Therefore, the space between the conductors (with the insulation) and the protective sheath must be filled.

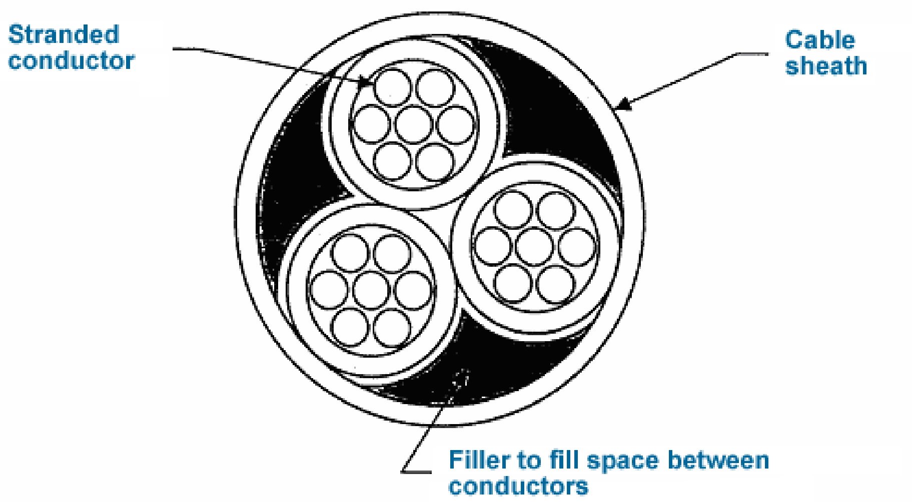


Figure 9: Occupation of the space between the conductors in a cable

Most multi-conductor cables are manufactured in this way. Large sections require large amounts of packing, which explains why these cables are manufactured by changing the shape of the conductor cores and using wedge shapes.

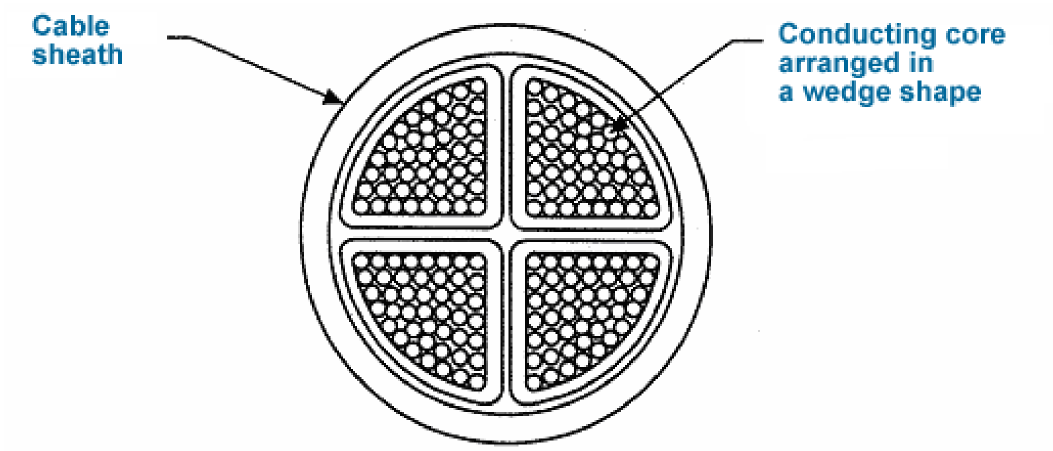


Figure 10: Wedge-shape cable manufacturing methods

This manufacturing method reduces the quantity of packing required. The cable diameter is also minimised, and the shape of the conductors is adapted as shown on the following figure for cables with 2 or 3 conductors (large section).

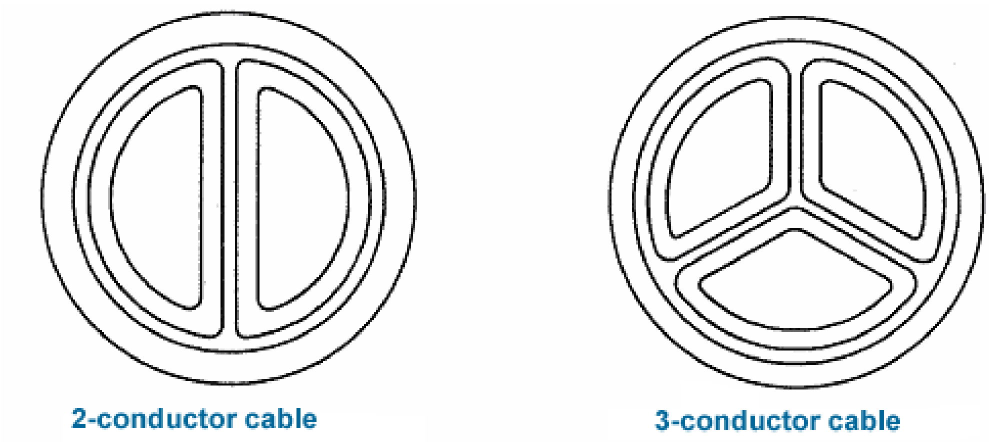


Figure 11: Cable manufacturing method as per the number of conductors

3.2. INSULATION

3.2.1. The properties of the insulation

The main function of the insulation on the conductor core of a cable is to "prevent the electricity from escaping" from the cable in question, and prevent any external contact with a live section (a person touching the conductor). The insulation is required to be flexible, to support differences in temperature and resist mechanical constraints and external "attacks". The main property required is however high electric (or dielectric) resistance (or resistivity).

The insulation of an electricity cable must have the following properties:

- High electric resistance
- A certain level of flexibility
- Resistance to temperature changes
- Mechanical resistance to impact and external aggression (chemical, atmospheric, etc.)

3.2.2. Insulation components

PVC is the most frequent material used. *PVC is the abbreviation of Polyvinylchloride.*

The **main advantages of PVC** are:

- Good insulation properties (high resistance)

- Water resistant
- Low cost
- Easy to colour
- Resistant mechanical rigidity

The **main drawbacks of PVC** are:

- Becomes soft at temperatures of above 70°C
- Becomes brittle at temperatures below 0°C

Some PVC types can resist temperatures of up to 85°C, but most types remain within the above interval (0 - 70°C).

Other materials used for cable insulation are, among others:

- Vulcanised rubber
- Synthetic rubber
- Silicone (derived from silicon)
- Paper (treated with resin)

Paper insulation has been used in HV cables, and has now been replaced by synthetic rubber for (almost) all applications. It is however still used in some flexible cables which require greater flexibility.

Synthetic rubbers are used in the presence of low or high temperature.

Silicon is used for (very) high temperature, i.e. approximately 150°C.

3.3. MECHANICAL PROTECTION

The main function of mechanical protection is to prevent damage to the insulation of the conductive core, which could cause electrocutions, sparks or start fire.

The cable sheath

The sheath is the mechanical protection for the cable.

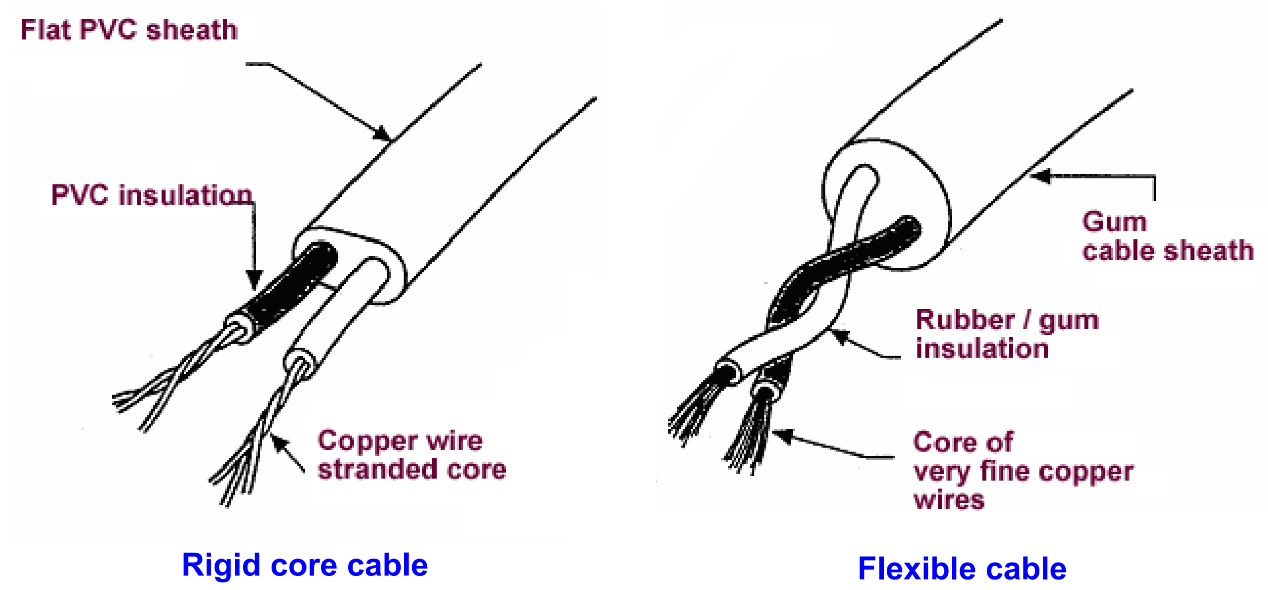


Figure 12: Different cable sheaths (mechanical protection)

The cable type shown is used to connect bedside lamps or washing machines, fridges, etc.

Most cable protective sheaths are in PVC, rubber is used for cables requiring extra flexibility. This type of cable is mainly used for domestic distribution, in tertiary applications/offices where little risk of mechanical damage exists.

This paragraph is a general presentation of the composition and manufacture of cables. We will consider other types of mechanical protection later on.

3.4. CABLING

Now that we have our cables, we have to install, support and connect them. Electric cables are also known as electric wires, cabling wires, cabling connections, etc. depending on their use in our industry.

Many cabling principles and systems exist, which are mainly named on the basis of the mechanical protection function used both for the cable itself and for the laying method.

The laying/installation of the cables will depend on

The **cable type**:

- Sheathed cables
- Steel wire armoured cables
- Mineral insulated metal sheathed cables (MIMS)

The **laying method**:

- In conduits (steel, PVC, etc)
- In pits
- In cable trays
- Aerial (bare cable – not covered in this course)

Other factors such as:

- The type of mechanical protection to be used
- Installation cost and time
- Environment conditions (humid, smoke, acid, etc.)
- Possibilities for extensions

Applicable standards:

- Architectural constraints (e.g. no aerial or visible cables, "aesthetic" cable trays to be used)
- Duration of the site
- …/…

Cable types are defined below and will also be considered in the following chapters with laying methods.

3.4.1. Sheathed cables (insulation)

These are the visible cables which "lie around" at home, in stores, in the office, or even on sites (during construction). This is the cheapest and quickest means of laying cables. Cables are protected by their own sheaths only, providing ***minimal mechanical protection***.

Most sheathed cables have a (external) PVC sheath which could also be in:

- Synthetic or natural rubber
- Agglomerate PVC

- Braid (metal or other)

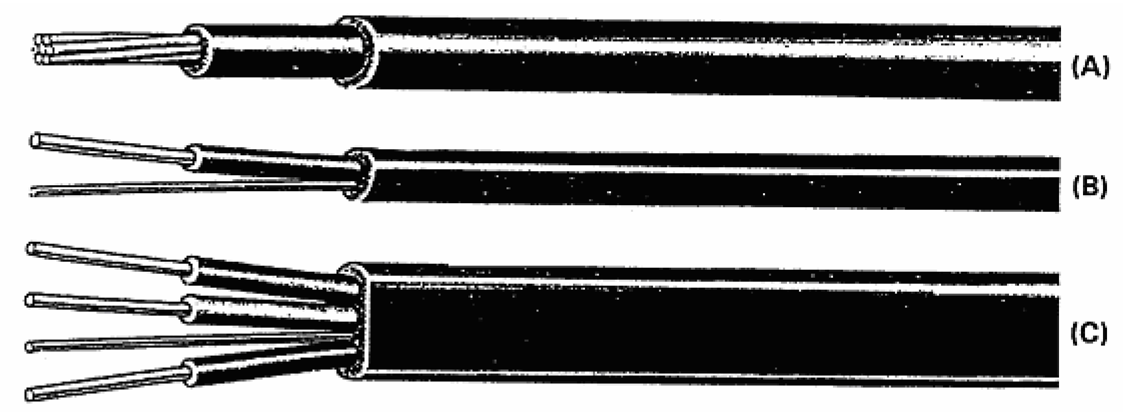


Figure 13: Different PVC sheaths

The 3 cable types shown correspond to:

a) a stranded core conductor

b) a conductor, rigid core with a ground

c) three conductors, rigid core with a 4th ground conductor

3.4.2. Armoured cables

Cables are protected mechanically with an armour if a risk of "attack" exists (impact, compression, rodents, etc.).

This cable type is frequently installed in this industry due to the permanent risk of mechanical damage.

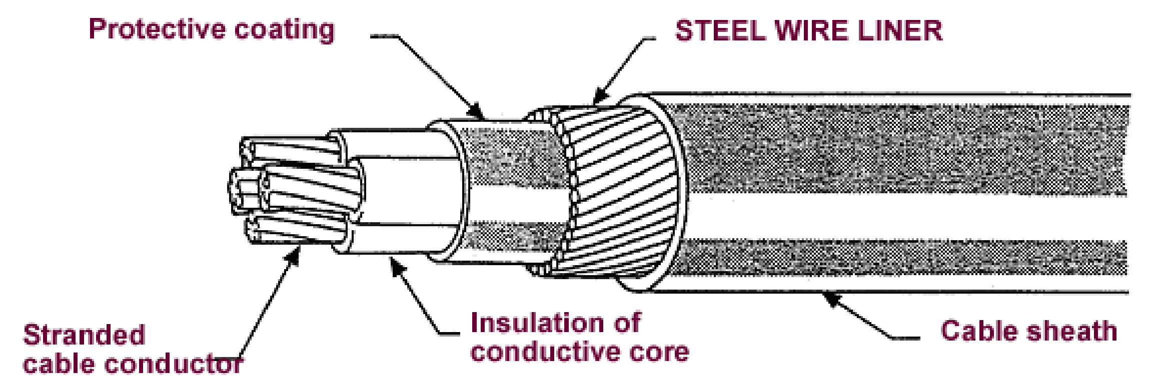


Figure 14: Steel wire armoured (SWA) cable

The conductors and their insulation are protected by a sheath, band or braid (term as applicable) in metal or even plastic. There may be several sheaths/armours. However, this complementary mechanical protection more generally consists of steel wire armour (SWA) as shown in the figure.

The armour may also consist of

- A band of helicoidally wound steel (foil).
- A band (or sheath) of aluminium.

These armoured cables may be installed directly in contact with equipment and/or installed on cable trays, in pits, in conduits, etc.

3.4.3. Mineral insulated cables

These cables have a mechanical protection consisting of a metal sheath. This is why their full name is "mineral insulated metal sheathed cables" or MIMS cables. These types of cables can be found in our industry with "fire resistant cables", i.e. cables used to resist fire in safety circuits and at-risk areas.

They are also used for certain instrumentation cables such as the thermocoupled cables installed for ambiance.

Two types of metal sheaths exist:

- Mineral Insulated Copper Sheath (MICS).
- Mineral Insulated Aluminium Sheath (MIAS).

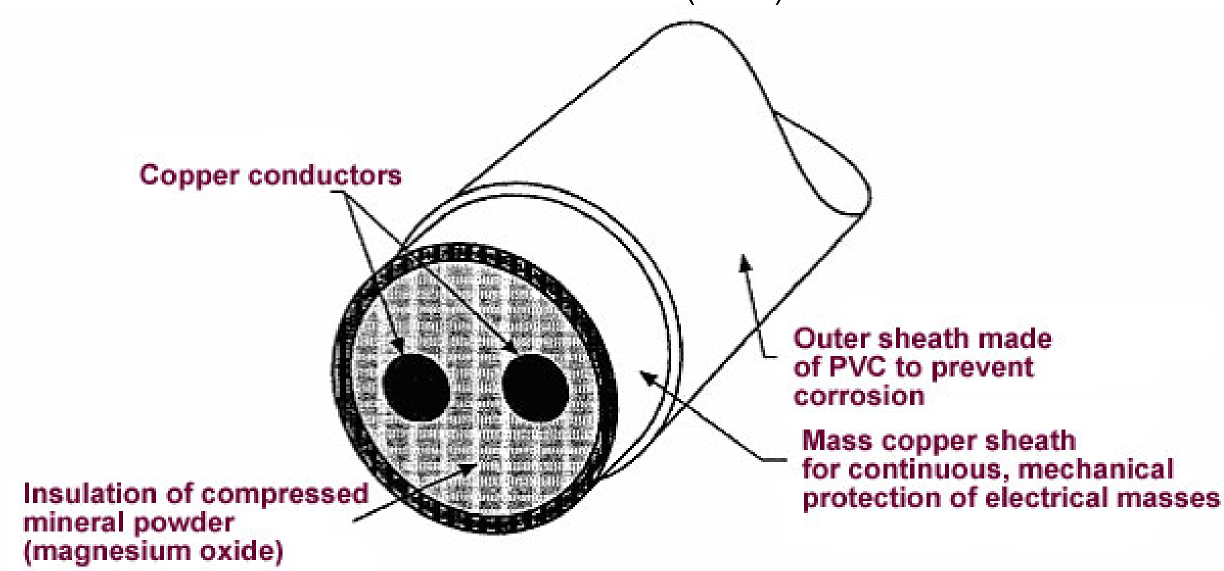


Figure 15: Construction of a mineral insulated cable

The conductors in this type of cable are insulated at high pressure using magnesium oxide powder.

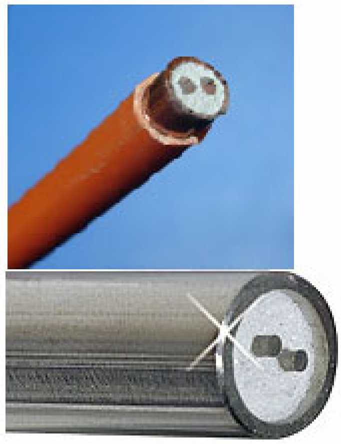


Figure 16: Section of high temperature resistant cables

These cables (generally and additionally) have a PVC sleeve over the metal sheath to protect against corrosion and ensure good resistance to humid atmospheres. These cables are connected with special glands to avoid humidity entering inside the cable.

See the chapter concerning these cables which (generally speaking) you should not find on sites as ***they are banished in Total specifications, however, they do exist all the same!***

4. LOW VOLTAGE CABLES

***Reminder* - AC**:

- Very low voltage is up to 50V.
- Low voltage (LV) is up to 1000V (1kV).
- 1kV + is high voltage (HV). The term MV for medium voltage is still used in many documents however this reference (MV) has disappeared officially.

4.1. CONSTRUCTION OF THE WIRE

An "electric" wire is a cable consisting of 1 conductor with, as seen in the previous chapter, a conductor core, an insulation envelope and (possibly) additional mechanical protection. An electric cable consists of at least 1 conductor and a maximum of ‘x’ conductors.

With electrical distribution, this maximum ‘x’ is 37, the telephone, instrumentation or IT cables may include more conductors. (See the instrumentation course).

Let us consider the construction of the main conductor in detail.

4.1.1. Conductor core

4.1.1.1. General characteristics

The core must satisfy the following conditions:

- ***Good conductivity*** to reduce losses when transporting energy. Materials must therefore be carefully chosen (value of maximum ρ)
  - Copper: ρ = 18.51mΩ.mm²/m at 20°C
  - Aluminium: ρ = 29.41mΩ.mm²/m at 20°C
- ***Mechanical resistance*** adequate to avoid the rupture of the conductor under forces during laying, attachments, and the tightening of the conductors.
- Good ***flexibility*** to simplify the transit of the conductors in the conduits, keep to the piping route, and supply mobile devices.
- Excellent ***anti-corrosion*** properties for atmospheric elements and chemicals.
- Satisfactory ***reliability*** of the ***connections*** via good resistance to the physico-chemical effects of contacts.

4.1.1.2. Classes of flexibility

The standard defines a range of nominal sections for conductor cores, assigned to four classes, with increasing levels of flexibility.

- Class 1 : solid & rigid
- Class 2 : rigid, stranded
- Class 5 : flexible
- Class 6 : flexible *(or flexible '+', used for e.g. cables for arc welding, cables on coiling units)*

Nominal section (mm²)	Conductor cores – Number of stands x strand diameter in mm	
	Class 1	Class 2
1.5	1 x 1.38	7 x 0.50
2.5	1 x 1.78	7 x 0.67
4	1 x 2.25	7 x 0.85
6	1 x 2.76	7 x 1.04
10	1 x 3.57	7 x 1.35
16	1 x 4.50	7 x 1.70
25	1 x 5.65	7 x 2.14
35	1 x 6.60	7 x 2.52
50	7 x 2.93	19 x 1.78
70		19 x 2.14
95		19 x 2.52
120	19 x 2.85	37 x 2.03
150	19 x 3.20	37 x 2.25
185		37 x 2.52
240	37 x 2.85	61 x 2.25
300	37 x 3.20	61 x 2.52
400		61 x 2.85
500		61 x 3.20
630		127 x 2.52
800		127 x 2.85
1000		127 x 3.20

Nominal section (mm²)	Conductor cores – Number of stands x strand diameter in mm	
	Class 5	Class 6
0.5	16 x 0.20	28 x 0.15
0.75	24 x 0.20	42 x 0.15
1	32 x 0.20	56 x 0.15
1.5	30 x 0.25	85 x 0.15
2.5	50 x 0.25	140 x 0.15
4	56 x 0.30	228 x 0.15
6	84 x 0.30	189 x 0.20
10	80 x 0.40	324 x 0.20
16	126 x 0.40	513 x 0.20
25	196 x 0.40	783 x 0.20
35	276 x 0.40	1107 x 0.20
50	396 x 0.40	702 x 0.30
70	360 x 0.50	909 x 0.30
95	475 x 0.50	1332 x 0.30
120	608 x 0.50	1702 x 0.30
150	756 x 0.50	2109 x 0.30
185	925 x 0.50	2590 x 0.30
240	1221 x 0.50	3360 x 0.30
300	1525 x 0.50	4270 x 0.30
400	2013 x 0.50	
500	1769 x 0.60	

Table 2: Construction of conductor cores

In practice, rigid core cables (class 1) can only be used as a cable up to 6².

4.1.1.3. Substance

Cores may be:

- In annealed, bare, or metal-coated copper
- In bare, or metal-coated aluminium or aluminium alloy
- In metal-plated aluminium with or without a metal coating

The metal coating may be:

- For copper: tin, a tin alloy or lead
- For aluminium: copper, nickel or tin

4.1.1.4. Aluminium-Copper equivalence

Aluminium is authorised for sections of more than 2.5mm².

For identical electrical resistances:

$$\frac{Alusection}{Coppersection} = \frac{\rho AL}{\rho Cu} = \frac{29.41}{18.51} = 1.59$$

This leads to the selection of the aluminium core section immediately above that of a copper conductor according to the standardised scale for conductor sections.

Cu section in mm²	1.5	2.5	4	6	10	16	25	35	50	70	95	120	150	185
Al section in mm²	2.5	4	6	10	16	25	35	50	70	95	120	150	185	240

Table 3: Cu/Al equivalence for identical conductors

4.1.2. Insulation envelope

4.1.2.1. General characteristics

This insulation envelope must ensure the good insulation of the conductor core and have the following properties:

- **General properties for good insulation**

  - high resistivity
  - excellent dielectric rigidity
  - low electric losses

- **Specific properties for the use of conductors and cables**

  - Excellent resistance to aging
  - Good resistance to cold, heat and fire
  - Not sensitive to vibrations and impacts
  - Good reactions in case of aggression by chemicals

4.1.2.2. Main synthetic substances used for insulation envelopes

- **Thermoplastic materials**

  The temperature causes a reversible variation in plasticity. This applies for:

  - ***Poly vinyl chloride (PVC)*** which is frequently used due to its good electrical and mechanical properties and its resistance to cold, heat aging, water and routine chemicals and to the spreading of flames. However, the combustion of this substance involves the emission of toxic and corrosive products.

  - ***Polyethylene (PE),*** whose remarkable properties make it a preferred insulation substance (particularly for HV). The combustion of this substance does not involve the emission of toxic and corrosive products.

- **Cross-linked elastomers and polymers**

  They are elastic, i.e. able to accept major deformations. This applies for:

  - ***Cross-linked polyethylene (PR),*** mainly used for temporary overloads and unfavourable heat environments. The good resistance of this substance to cold and the absence of corrosive gas emissions during combustion could also be noted.

- ***Ethylene-propylene copolymers***, for rigid cables and particularly for flexible cables. This material ensures mediocre resistance to oils and little resistance to the spreading of flames, but does not emit toxic products during combustion. Also used for HV.

- ***Silicone rubber***, which has excellent resistance to extreme temperatures (between -80°C and + 250°C) and to external agents, leading to remarkable aging properties.

Type of insulation	Maximum operating temperature (°C)
Poly vinyl chloride (PVC)	Conductor: 70
Cross-linked polyethylene and ethylene – propylene (EPR)	Conductor: 90
Silicone rubber	Conductor: 90

Table 4: Maximum operating temperatures for insulation

4.1.3. Protective sheath

When selecting the material for protective sheaths, you must account for:

- The external constraints exercised on the cable.
- Operating conditions, maximum temperature.
- Installation conditions, minimum temperature.
- The type of insulation envelope used, particularly in terms of heat resistance.

The materials used are:

- Insulation materials, such as those used for the insulation envelope (see above paragraph).
- Lead or a lead alloy.

Lead sheaths offer:

- Full sealing.
- Excellent chemical inertness.

- Sensitivity to vibrations and repeated deformation.
- Mediocre mechanical properties which require protection in the form of an armour or laying in conduits or in a cable tray.
- Vulnerability to certain forms of electrochemical or electrolytic corrosion.

4.2. SYMBOLIC REPRESENTATIONS

I.e. symbolic representations for conductors and cables

4.2.1. Representation standards

The conductors and cables defined by the UTE (**U**nion **T**echnique de l'**É**lectricité) standard are designated on the basis of a standardised system or the traditional UTE system depending on whether the drawings are concerned by the current standardisation applied by the CENELEC (**E**uropean Committee for Electrotechnical Standardization) or not.

The two representation systems are included in NF C30-022 and HD 361 and include a set of symbols laid out from left to right, in the order.

An extract is shown below.

Designation HAR CENELEC: Meaning	Symbol		Designation NF - USE: Symbol	Meaning
Standardized series Official national series Other national series	H A FR-N	**Series type**	U	Cable subject to an UTE standard.
300/300V 300/500V 450/750V 0./1kV	03 05 07 1	**Nominal voltage**	250 500 1,000	250V 500V 1,00V
PVC Vulcanized rubber Cross-linked polyethylene	V R X	**Flexibility and type of the core**	# S	Rigid core Flexibility core
Steel band wrapping the conductors Steel armour	D Z4		# A	Copper Aluminium
PVC Vulcanized rubber Cross-linked polyethylene	V R N	**Insulation envelope**	C R V	Vulcanized rubber Cross-linked polyethylene Poly vinyl chloride
Round cable "Dividable" flat cable "Non-dividable" flat cable	# H H6	**Packing**	G O 1	- Vulcanized sheath - No packing, or packing not included in sheath - Protective and assembly sheath form the packing
Copper Aluminium	# -A	**Non-metal protective sheath**	-2 C N V	Thick protective sheath Vulcanized rubber Polychloroprene or equivalent PVC
Round, solid & rigid Round, stranded & rigid Sector-shaped, stranded & rigid Sector-shaped, solid & rigid Class 5 flexible cable for fixed installation Class 5 flexible cable Class 6 flexible cable Flexible cable for welding Extra-flexible for welding	-U* -R* -S -W* -K -F H -D -E	**Metal coating**	P F Z	Lead sheath Steel armour Zinc or other metal
The designation may be completed with the indication of a green-yellow conductor in the cable - cable without G-Y; n x S - cable with G-Y; n G S N = n° of conductors S= Section G= ground (G-Y)		**Cable shape**	# M	Round cable Flat cable

Table 5: Symbolic representations of cables

#: No of letter
** For cables with aluminium cores, the hyphen preceding the symbol must be removed*

4.2.2. LV service voltage (identification of insulation)

Low voltage cables have a **service voltage limited** by the values 'U' (service voltage) and 'Um' (test voltage) which are **systematically indicated on all cables**, etched or printed at regular intervals along the outer insulation.

This could also be indicated as U_0/U, with (official definition):

- U_0: RMS voltage assigned between phase and ground, particularly used as a reference value for testing.
- U: RMS voltage assigned between phases, particularly used as a reference value for testing. $U = U_0 \times \sqrt{3}$

Standards are:

- 300/300V corresponding to reference 03 cables
- 300/500V correspondant aux câbles référence 05 (U 500V)
- 450/750V corresponding to reference 07 cables (H 07 RN-F)
- 0.6/1kV corresponding to reference 1 cables

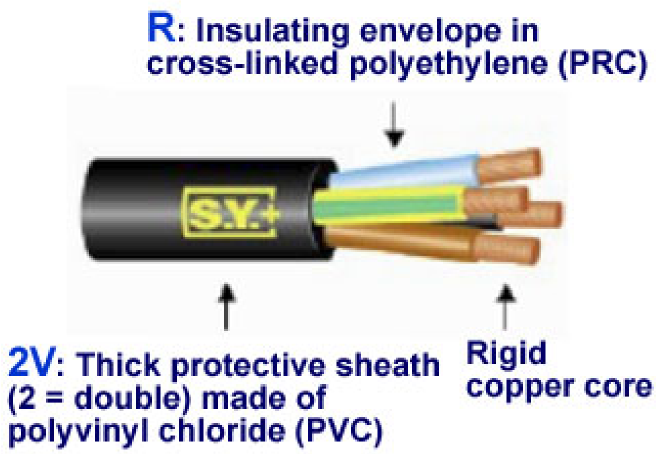
The service voltage of a cable (U) must be at least equal to the network voltage.

Example: a cable indicating **300/500V cannot be used** for **380/220V** distribution, as network maximum 'U' is 380V.

In practice, 0.6/1 kV cables are used for 3x380V (or 3x400V) distribution for cables with rigid cores or stranded cores. 450/750V cables generally have flexible cores.

4.2.3. Examples of representations

4.2.3.1. U-1000 R2V 4G2.5 cable



U: cable subject to an UTE standard
1,000: nominal voltage = 1,000V
R: insulation envelope for cross-linked polyethylene conductors (PR)
2V: thick protective sheath (2 for double) in polyvinyl chloride
4G: 4 conductors for which the u is (obligatorily) sheathed in a green-yellow colour insulation envelope
2.5: section of the conductor core (per conductor)

Figure 17: U1000 R2V cable

Applications: these cables are equipped with a thick sheath and are frequently used in industrial installations where they resist severe operating conditions.

4.2.3.2. H07 V-U cable

H: standardized series
07: nominal voltage = 450/750V
V: PVC insulation envelope
-U; rigid, solid, round copper core

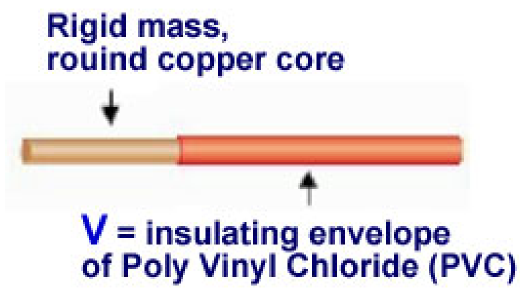
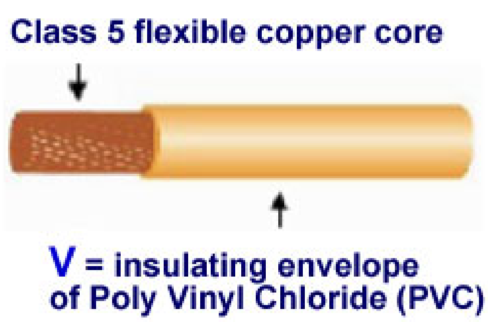


Figure 18: H07 V-U cable

Applications: used in circuits in accommodation and offices (in laying conduits, see chapter later in this course)

4.2.3.3. H05 V-K cable

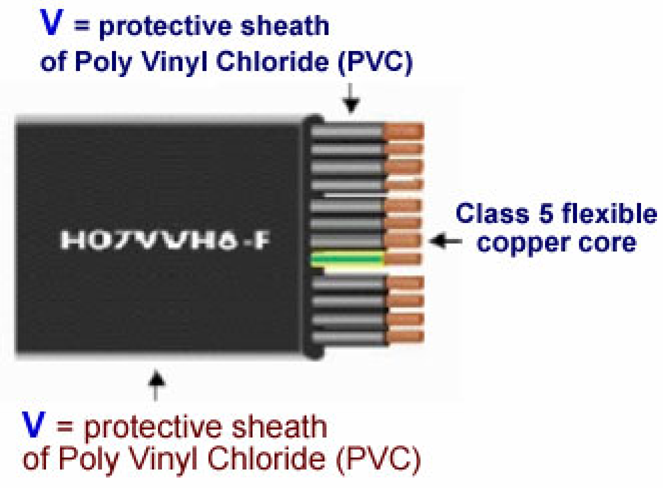


H: standardized series
05: nominal voltage = 300/500V
V: PVC insulation envelope
-K: class 5 copper flexible core

Figure 19: H05 V-K cable

Applications: used for the wiring and cabling of electrical cabinets and devices (use recommended for connections subject to vibrations and deformations.

4.2.3.4. H07 VVH6-F cable



H: standardized series
07: nominal voltage = 450/750 V
V: PVC insulation envelope
V: PVC protective sheath
H6: "Non-dividable" flat cable
-F: class 5 copper flexible core

Figure 20: H07 VVH6-F cable

Applications: flexible flat cables used to supply bridge crane trolleys and various machines-tools which move in the same plane and require the use of tight lips.

4.2.3.5. U-1000 ARVFV cable

U: cable subject to an UTE standard.
1,000: nominal voltage = 1,000V
A: aluminium core, *Marker 1: (flexible stranded aluminium core)*
Marker 2: plastic band along the conductor (optional)
R: insulation envelope for cross-linked polyethylene conductors (PR or XLPE) *marker 3*
Marker 4: very thin intermediate protection acting as packing
V: polyvinyl chloride (PVC) impervious sheath *marker 5*
F: metal coating = steel armour *marker 6*
V: polyvinyl chloride (PVC) protective sheath *marker 7*

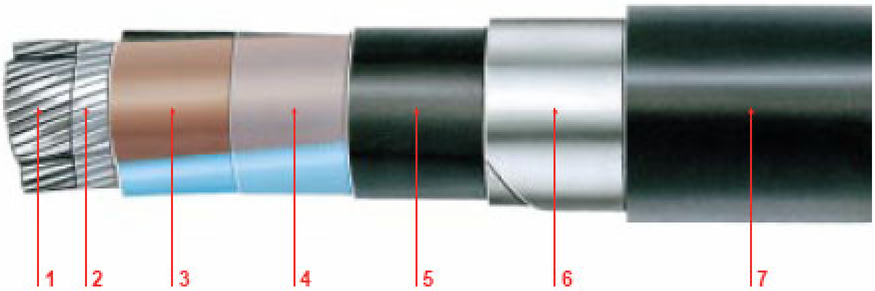


Figure 21: U1000 ARVFV cable

Applications: these cables are equipped with an impervious sheath and an armour, they are a reinforced version of U-1000 R2V and U-1000 AR2V cables and can be used for all industrial installations requiring mechanical protection.

4.2.3.6. H05 VVC4V5-F cable

H: standardized series
05: nominal voltage = 300/500V
V: PVC insulation envelope
V: PVC inner sheath
C4: screen (copper wire braid)
V: PVC external sheath
-F: class 5 copper flexible core

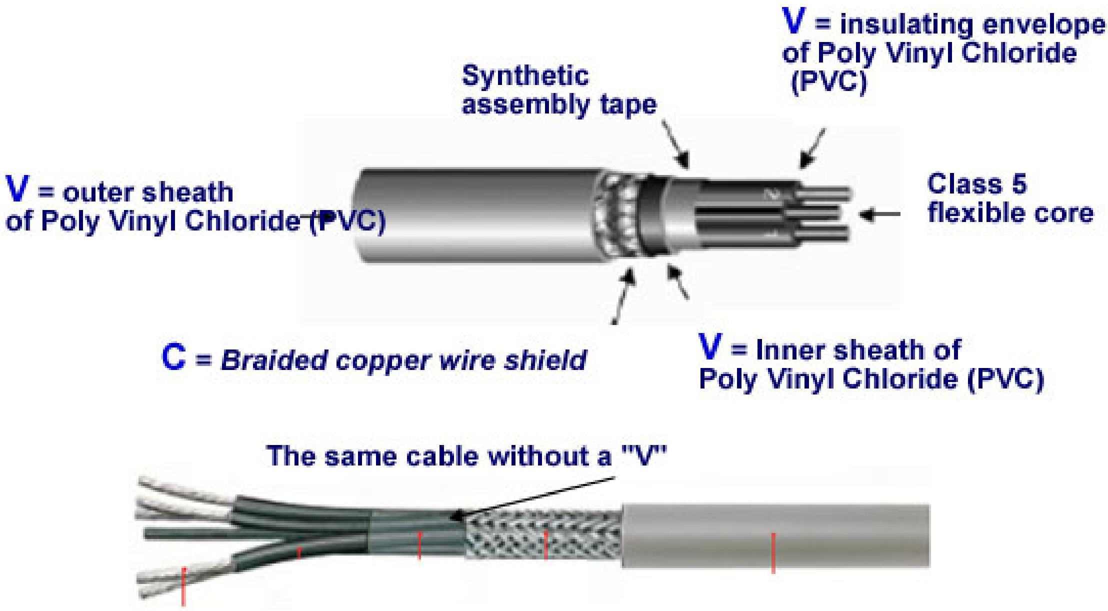


Figure 22: H05 VVC4V5-F cable

Applications: these flexible cables are intended for use on machine-tools and on industrial installations for fixed or mobile connections. They are highly resistant to mineral oils and cutting fluids.

4.3. IDENTIFICATION OF INSULATED CONDUCTORS

I.e. colour coding as per NF C15-100 (2002 edition).

The following provisions (a, b & c), apply to piping consisting of insulated conductors and multi-conductor cables with circular or sector-shaped cores. These provisions concern power supply cables with a maximum of 5 conductors (3Ph + N + G). Control and command cables (in addition to the 5 conductors) will now (systematically) have ground conductors (green-yellow insulated wire).

4.3.1. Texts

If the circuit **includes a ground**, this conductor must be identified with dual colouring: ***green and yellow.***

If the circuit **does not include a ground**:

- With multi-conductor cables, cables with a conductor identified with the dual colouring ***green and yellow must not be used.*** However, if only cables with dual green and yellow colouring are available, for the required section, this cable may be used providing the conductor with the dual ***green and yellow*** colouring ***is not used***.

- With insulated cables, conductors identified with the dual ***green and yellow colouring must not be used.***

If the circuit includes a **neutral conductor**, this conductor must be identified with the colour: ***pale blue.***

If the circuit **does not include a neutral conductor**:

- With multi-conductor cables, the conductor identified with ***pale blue*** colouring may be used for another purpose with the exception of as a ground.

- With insulated cables, conductors identified with the ***pale blue colouring must not be used.***

Conductors identified with colours other than green-yellow or pale blue, or with other elements (e.g. figures) may be used for any purpose, other than as grounds or neutral conductors.

If piping consists of insulated conductors, in circuits other than those used exclusively for telecommunications and measurements, conductors with dual green-yellow colouring must not be used.

Should mono-conductor cables be used, it is not necessary to identify the insulation with continuous colouring. However, in this case, the ends of conductors must be identified in a long-term manner during installation.

- The ground must be identified with dual ***green and yellow*** colouring.
- The neutral conductor must be identified with ***pale blue*** colouring.

However, neutral conductors with a smaller section than the corresponding phase conductors do not require identification.

These provisions also apply to bare conductors

If non-standard conductors and cables are used, identification must be applied in an appropriate manner (e.g. rings or other coloured devices) at any location where the conductor envelope is visible, and, under all circumstances, near to each connection. The colours used must comply with those defined in paragraphs a, b & c above.

To summarise:

- ***The dual green and yellow colouring is exclusively reserved for the protective conductor (ground).***
- ***The yellow or the green colouring, alone, may not be used on power distribution cables.***
- ***There are no mandatory colours for phase conductors (UTE standard) irrespective of the cable type.***
- ***The neutral conductor must have pale blue colouring (colour of the insulation envelope or a ring at the ends).***

4.3.2. Identification table for insulated conductors

Circuits	Insulated conductors	Multi-conductor cables		E.g. Ph colour Ph Ph Ph N PE
1 Single conductor	Ground	Ground conductor systematically		
2 conductors Phase - Neutral	Phase* Neutral*	Ph* N	X Ph* N	
2 conductors Phase - Phase	Phase* Phase*	Ph** Ph**	Ph** Ph** X	
3 conductors Phase - Neutral + Ground	Phase* Neutral Protection	PE Ph* N		
3 conductors Phase – Phase + Ground	Phase* Phase* Protection	Ph** Ph** PE		
3 conductors 3 Phases	Phase* Phase* Phase*	Ph** Ph** Ph**	Ph** X Ph** Ph**	
4 conductors 3 Phases + Neutral	Phase* Phase* Phase* Neutral	Ph* N Ph* Ph*	X Ph* N Ph* Ph*	
4 conductors 3 Phases + Ground	Phase* Phase* Phase* Protection	Ph** PE Ph** Ph**		
5 conductors 3 Phases + Neutral + Ground	Phase* Phase* Phase* Neutral Protection	PE Ph* N Ph* Ph*		
* any colour except pale blue and dual green-yellow colouring		* any colour except pale blue and dual green-yellow colouring * any colour except dual green-yellow colouring X: do not use		

Table 6: Identification of conductors in power distribution cables

The identification of conductors must only be considered as an assumption and the polarities of the conductors must be checked prior to any intervention.

4.4. CONSTRUCTION OF LV CABLES

I.e. the technological part of cable manufacture, irrespective of shape, how many conductors, and of which sections.

4.4.1. Power cables

If you require a 9x 60mm² cable, i.e. nine 60mm² conductors with the same "outer layer", you will never find this component. If you need a few kilometres of this cable, a constructor will most certainly manufacture this cable especially for you at (more or less) reasonable prices.

However, if you just need 32 metres of this cable, you will need to settle for adapting standard cables. For this section, install two 5x70mm² cables in parallel.

Let us consider these manufacturing standards.

4.4.1.1. Sections, numbers of conductors & types

General construction overview, and, as seen above,

- The green and yellow colouring is reserved for the ground.
- Pale blue colouring is "in principle" for the neutral conductor.
- There is no mandatory colour for phase conductors.

Number of conductors in the circuit	Fixed cable		Mobile cable
	Stranded/rigid core cables		Flexible core cable
	Section ≤ 25mm²	Section > 25mm²	
2	Ph, Ph	Ph, Ph	Ph, Ph
	Ph, N	Ph, N	Ph, N
3	Ph, Ph, Ph	Ph, Ph, Ph	Ph, Ph, Ph
	Ph, N, Ph	Ph, N, Ph	Ph, N, Ph
	PE, Ph, Ph	Ph, Ph, PE	PE, Ph, Ph
	PE, Ph, N	Ph, N, PE	PE, Ph, N
4	Ph, Ph, Ph, N	Ph, Ph, Ph, N	Ph, Ph, Ph, N
	Ph, PE, Ph, Ph	Ph, Ph, Ph, PE	Ph, PE, Ph, Ph
	Ph, PE, N, Ph	Ph, N, Ph, PE	Ph, PE, N, Ph
	Ph, PE, N, Ph	Ph, N, Ph, PE	Ph, PE, N, Ph
5	Ph, Ph, PE, N, Ph	Ph, Ph, Ph, N, PE	Ph, Ph, PE, N, Ph
> 5	Ground: separate green and yellow conductor All other conductors: black colour with numbering, number 1 = neutral if a neutral conductor exists		
"Standard" colours for insulated conductors used in manufacturing in Europe			
Phase colour: Ph		**Neutral: N**	**Ground: G**
: black brown pale blue		pale blue	green and yellow

Table 7: Power cable types, sections, insulation colours, combinations

4.4.1.2. Metric/imperial conversions

We must often use both unit systems on our sites. With the ***European system***, conductors are expressed in terms of their ***section in mm²,*** which is convenient for applying formulas directly……

The ***British and Americans*** use the ***AWG*** (American Wire Gauge) system up to section 4/0 (or 0000) and use an old standard, the ***MCM or kcmil*** (thousands of circular mils) where: ***1kcmil = 0.5067mm²*** for larger sections.

The target when calculating/determining a cable, is to identify the section, therefore the following mm²/inch² or square inch (sq.in) conversion table could be of use.

Square inches	mm²	Square inches	mm²	Square inches	mm²	Square inches	mm²
0.0020	1.290	0.0060	3.871	0.0100	6.452	0.25	161.29
0.0025	1.613	0.0065	1.194	0.0145	9.355	0.30	193.55
0.0030	1.935	0.0070	4.516	0.225	14.52	0.40	258.06
0.0035	2.258	0.0075	4.839	0.04	25.81	0.50	322.58
0.0040	2.581	0.0080	5.161	0.006	38.71	0.60	387.10
0.0045	2.903	0.0085	5.484	0.10	64.52	0.75	783.87
0.050	3.226	0.0090	5.806	0.15	96.77	1.00	645.16
0.0055	3.548	0.0095	6.129	0.20	129.03	1.25	806.45
						1.50	967.74

Table 8: sq.in/mm² conversions

The following table shows conversion rates for MCM (or kcmil) for "large" sections.

MCM	mm²	MCM	mm²	MCM	mm²	MCM	mm²
100	50.7	350	177.3	600	304.0	850	430.7
150	76.0	400	202.7	650	329.4	900	456.0
200	101.3	450	229.0	700	354.7	950	481.4
250	126.7	500	253.4	750	380.0	1000	506.7
300	152.0	550	278.7	800	405.4		

Table 9: MCM/mm² conversions

The following table shows the AWG equivalences with sections in mm² and sq.in.

A.W.G.	Diameter in mm	Section		A.W.G.	Diameter in mm	Section	
		Sq.in	Mm²			Sp.in	mm²
0000	11.68	0.166	107.2	24	0.51	0.000317	0.204
000	10.40	0.132	85.03	25	0.45	0.000252	0.16
00	9.26	0.105	67.43	26	0.40	0.000200	0.12
0	8.25	0.0829	53.5	27	0.36	0.000158	0.10
1	7.34	0.0657	42.5	28	0.32	0.000126	0.08
2	6.55	0.0521	33.7	29	0.29	0.0000995	0.06
3	5.83	0.0413	26.7	30	0.26	0.0000789	0.05
4	5.19	0.0328	21.2	31	0.23	0.0000626	0.04
5	4.60	0.0260	16.6	32	0.20	0.0000496	0.03
6	4.11	0.0206	13.3	33	0.18	0.0000394	0.025
7	3.67	0.0164	10.5	34	0.16	0.0000312	0.020
8	3.26	0.0130	8.3	35	0.14	0.0000248	0.016
9	2.91	0.0103	6.7	36	0.13	0.0000196	0.012
10	2.59	0.00815	5.3	37	0.11	0.0000156	0.010
11	2.31	0.00647	4.2	38	0.10	0.0000128	0.0079
12	2.05	0.00513	3.3	39	0.09	0.0000098	0.0063
13	1.83	0.00407	2.6	40	0.08	0.0000078	0.0050
14	1.63	0.00323	2.1	41	0.07	0.0000062	0.0040
15	1.45	0.00256	1.6	42	0.06	0.0000049	0.0031
16	1.29	0.00203	1.3	43	0.055	0.0000039	0.0025
17	1.15	0.00161	1.03	44	0.052	0.0000031	0.0020
18	1.00	0.00128	0.82	45	0.045	0.0000024	0.0016
19	0.91	0.00101	0.65	46	0.040	0.0000019	0.0012
20	0.81	0.000802	0.51	47	0.035	0.0000015	0.0010
21	0.72	0.000636	0.41	48	0.0315	0.0000012	0.0008
22	0.64	0.000505	0.32	49	0.0280	0.00000096	0.0006
23	0.57	0.000400	0.25	50	0.0250	0.00000076	0.0005

Table 10: AWG/mm²/sq.in conversions

4.4.1.3. Stranded/rigid core (power) cable manufacturing standards

Figure 23: U1000 R2V cable (traditional)

Let us consider the most frequently used cable manufacturing standard, the U-1000 R2V and its US/GB equivalent, XLPE/PVC, for insulation materials. *'G' for ground implies that one of the conductors is insulated with the dual green and yellow colouring.*

Section in mm²	Conductor construction	Maximum acceptable current		Book external diameter in mm	Bend radius mm	Weight kg/km
		Aerial	Buried			
Copper conductor						
1x1.5	Class 1	-	-	5.3	48	40
2x1.5	Class 1	26	37	8.9	53	120
3G1.5	Class 1	26	37	9.4	56	135
4G1.5	Class 1	23	31	10.1	61	160
5G1.5	Classe1	19	26	10.9	65	185
1x2.5	Class 1	-	-	5.5	50	55
2x2.5	Class 1	36	48	9.7	58	150
3G2.5	Class 1	36	48	10.2	61	175
4G2.5	Class 1	31	41	11.0	66	205
5G2.5	Classe1	26	34	11.9	71	245
1x4	Class 1	-	-	6.1	55	70
2x4	Class 1	49	63	10.6	64	195
3G4	Class 1	49	63	11.2	67	230
4G4	Class 1	42	53	12.1	73	280
5G4	Classe1	35	44	13.1	79	330
1x6	Class 2	-	-	6.9	62	95
2x6	Class 2	63	80	12.1	73	270
3G6	Class 2	63	80	12.8	77	325
4G6	Class 2	54	66	13.9	83	390
5G6	Class 2	45	55	15.2	91	475
1x10	Class 2	-	-	7.8	70	135
2x10	Class 2	86	104	13.9	83	385
3G10	Class 2	86	104	14.7	88	475
4G10	Class 2	75	87	16.1	97	575
5G10	Class 2	63	73	17.6	106	700

Table 11: U-1000 R2V manufacturing ranges from 1.5 to 10mm²

Highlighted: example/exercise 2 at the end of the course

Section in mm²	Conductor construction	Maximum acceptable current		Book external diameter in mm	Bend radius mm	Weight kg/km
		Aerial	buried			
Copper conductor						
1x16	Class 2	-	-	8.8	79	195
2x16	Class 2	115	136	15.9	95	545
3G16	Class 2	115	136	16.9	101	680
4G16	Class 2	100	113	18.5	111	850
5G16	Class 2	84	85	20.3	122	1030
1x25	Class 2	138	144	10.4	94	290
2x25	Class 2	149	173	19.2	115	820
3G25	Class 2	149	173	20.5	123	1030
4G25	Class 2	127	144	22.5	135	1295
5G25	Class 2	106	121	24.7	148	1575
1x35	Class 2	169	174	11.4	103	385
2x35	Class 2	185	208	21.2	127	1065
3x35	Class 2	158	174	22.6	136	1350
4x35	Class 2	133	146	24.9	149	1690
5G35	Class 2	133	146	27.4	164	2080
1x50	Class 2	207	206	12.7	114	505
2x50	Class 2	225	247	24.2	145	1435
3x50	Class 2	192	206	25.9	155	1825
4x50	Class 2	161	173	28.5	171	2305
5G50	Class 2	161	173	31.6	190	2840
1x70	Class 2	268	254	14.5	131	700
3x70	Class 2	246	254	30.0	180	2540
4x70	Class 2	206	213	33.3	200	3210
5G70	Class 2	206	213	36.8	221	3980

Table 12: U-1000 R2V manufacturing ranges from 16 to 70mm²

Highlighted: Example/exercise 3 at the end of the course

Section in mm²	Conductor construction	Maximum acceptable current		Book external diameter in mm	Bend radius mm	Weight kg/km
		Aerial	Under ground			
Copper conductor						
1x95	Class 2	328	30.1	16.6	149	950
3x95	Class 2	298	301	34.3	206	3430
4x95	Class 2	250	253	38.1	229	4375
1x120	Class 2	382	343	18.2	164	1185
3x120	Class 2	346	343	37.9	227	4290
4x120	Class 2	291	288	42.4	254	5500
1x150	Class 2	441	387	20.2	182	1455
3x150	Class 2	395	387	42.2	253	5285
4x150	Class 2	332	325	46.9	281	6745
1x185	Class 2	506	434	22.5	203	1815
3x185	Class 2	450	434	47.5	285	6620
4x185	Class 2	378	364	52.9	317	8480
1x240	Class 2	599	501	25.2	227	2365
3x240	Class 2	538	501	53.4	320	8605
4x240	Class 2	452	420	58.8	353	10870
1x300	Class 2	693	565	27.8	250	2940
3x300	Class 2	621	565	58.1	349	10510
4x300	Class 2	522	474	65.0	358	13515
1x400	Class 2	825	-	31.4	283	3470
1x500	Class 2	946	-	35.0	315	4770
1x600	Class 2	1088	-	29.8	358	6145
3x50 + 35	Class 2	161	173	27.8	167	2210
3x70 + 50	Class 2	206	213	32.1	193	3050
3x95 + 50	Class 2	250	253	35.9	216	3920
3x120 + 70	Class 2	291	288	40.3	242	5020
3x150 + 70	Class 2	332	325	43.9	264	5985
3x185 + 70	Class 2	378	364	48.6	292	7260
3x240 + 95	Class 2	452	420	55.0	330	8500

Table 13: U-1000 R2V manufacturing ranges of 95mm² maximum (as standard)

You will notice that, in the last table, multi-conductors stop at 240mm². Beyond this, weight becomes excessive and single-wire distribution is used, with several cables per phase and specific laying instructions. Refer to the paragraph on "cable trays" and "troughs".

4-conductor cables also exist. One of the conductors has a smaller section, to enable distribution via 3 Ph + E or, if the neutral is distributed with reduced protection, via 3 Ph + N. Refer to the "Earth and Neutral" course (earthing and protecting the Neutral).

The U-1000 AR2V cable (aluminium core) is manufactured (always as standard) based on a section of 35mm² and has 1, 3 or 4 conductor versions without an earth. The following table shows large sections and enables comparison with copper conductors.

Section in mm²	Conductor construction	Maximum acceptable current		Book external diameter in mm	Bend radius mm	Weight kg/km
		aerial	Buried			
Aluminium conductor						
1x240	Class 2	439	388	24.8	224	885
3x240	Class 2	409	388	52.5	315	4080
4x240	Class 2	343	326	58.8	353	4995
1x300	Class 2	508	440	27.3	246	1100
3x300	Class 2	471	440	58.1	349	4985
4x300	Class 2	395	370	65.0	390	6150
1x400	Class 2	663	-	30.6	275	1395
1x500	Class 2	770	-	35.0	315	1780
1x630	Class 2	899	-	39.8	353	2275
3x70 + 50	Class 2	157	165	32.0	193	1540
3x95 + 50	Class 2	190	196	35.3	216	1920
3x120 + 70	Class 2	221	223	39.9	240	2445
3x150 + 70	Class 2	255	252	43.3	260	2835
3x185 + 70	Class 2	291	283	48.1	289	3485
3x240 + 95	Class 2	343	326	53.9	324	4405

Table 14: U-1000 AR2V manufacturing ranges from sections of 240mm²

For cables with armours, i.e:

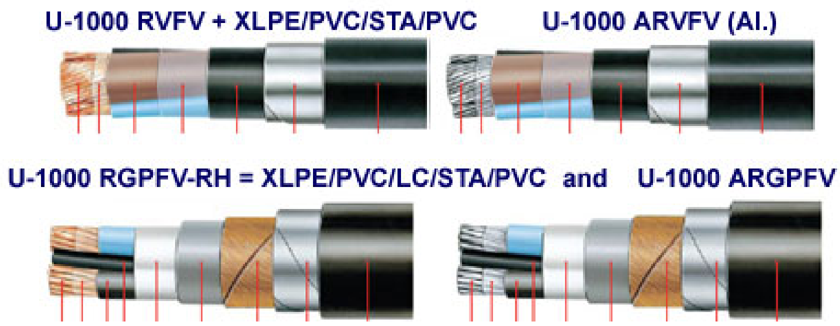


Figure 24: Power distribution cables with armours

- U-1000 RVFV or US/GN equivalent: XLPE/PVC/STA/PVC, with steel armour.
- U-1000 RGPFV – RH (résistant aux hydrocarbures), en anglo-saxon XLPE/PVC/LC/STA/PVC, avec feuillard d acier + une gaine plomb.

Manufacturing standards for sections and the number of conductors per cable are (practically) identical. The difference resides in the maximum acceptable current (apply the coefficient of 0.9 from the above U1,000 R2V tables), and in the weight, for copper or aluminium cores.

4.4.1.4. Flexible core (power) cable manufacturing standards

Figure 25: Flexible core cables, H07 RN-F type

Manufacturing standards for H07 RN-F or EPR/PCP type cables (flexible power cable) differ from the previous standards. Let us consider these manufacturing ranges.

NB: no acceptable current for "underground" use is indicated for these cables, as their installation is prohibited unless aerial.

These cables are designed in copper only (for flexibility).

Section in mm²	Conductor construction	Maximum acceptable aerial current (A)	Book external diameter in mm	Bend radius mm	Weight kg/km
Copper conductor					
2x1	Class 5	19	8.4	25	100
3G1	Class 5	19	9.0	27	125
4G1	Class 5	17	9.9	30	145
5G1	Class 5	17	11.0	33	175
1x1.5	Class 5	-	5.6	23	50
2x1.5	Class 5	26	9.0	27	115
3G1.5	Class 5	26	9.7	29	140
4G1.5	Class 5	23	10.7	32	170
5G1.5	Class 5	19	11.7	35	210
1x2.5	Class 5	-	6.4	26	65
2x2.5	Class 5	36	10.5	32	165
3G2.5	Class 5	36	11.3	34	200
4G2.5	Class 5	31	13.0	39	260
5G2.5	Class 5	26	13.6	41	305
1x4	Class 5	-	7.6	31	100
2x4	Class 5	49	12.8	39	245
3G4	Class 5	49	13.8	42	295
4G4	Class 5	42	15.1	46	370
5G4	Class 5	35	16.9	51	445
1x6	Class 5	-	8.3	34	120
2x6	Class 5	63	14.2	43	315
3G6	Class 5	63	15.2	46	385
4G6	Class 5	54	16.9	51	480
5G6	Class 5	45	18.8	57	595

Table 15: H07 RN-F manufacturing ranges from 1 to 6mm²

Section in mm²	Conductor construction	Maximum acceptable aerial current (A)	Book external diameter in mm	Bend radius mm	Weight kg/km
Copper conductor					
1x10	Class 5	-	10.4	42	190
2x10	Class 5	86	19.8	60	595
3G10	Class 5	86	21.3	64	727
4G10	Class 5	75	23.2	70	880
5G10	Class 5	63	25.6	77	1070
1x16	Class 5	-	11.4	46	255
2x16	Class 5	115	21.8	66	770
3G16	Class 5	115	23.4	70	950
4G16	Class 5	100	25.5	77	1210
5G16	Class 5	84	28.3	85	1455
1x25	Class 5	138	13.9	56	370
2x25	Class 5	149	26.0	78	1125
3G25	Class 5	149	27.9	84	1390
4G25	Class 5	127	30.9	93	1750
5G25	Class 5	106	34.2	103	2150
1x35	Class 5	169	15.0	60	485
3G35	Class 5	185	31.1	94	1860
4G35	Class 5	158	34.4	104	2270
1x50	Class 5	207	17.5	70	670
3G50	Class 5	225	36.5	110	2505
4G50	Class 5	192	40.2	121	3145

Table 16: H07 RN-F manufacturing ranges from 10 to 50mm²

Section in mm²	Conductor construction	Maximum acceptable aerial current (A)	Book external diameter in mm	Bend radius mm	Weight kg/km
Copper conductor					
1x70	Class 5	268	19.9	80	910
3G70	Class 5	289	41.0	123	3320
4G70	Class 5	246	45.6	137	4195
1x95	Class 5	328	22.5	90	1160
3G95	Class 5	352	46.5	140	3745
4G95	Class 5	298	52.3	157	5460
1x120	Class 5	382	24.7	99	1440
3G120	Class 5	410	51.4	155	5325
4G120	Class 5	346	56.5	171	6685
1x150	Class 5	441	27.2	109	1780
3G150	Class 5	473	56.7	170	6535
4G150	Class 5	395	62.9	189	8230
1x185	Class 5	506	29.1	117	2130
3G185	Class 5	542	60.8	183	7770
4G185	Class 5	450	67.5	203	9835
1x240	Class 5	599	33.1	133	2740
3G240	Class 5	641	70.4	212	10240
4G240	Class 5	538	78.1	235	13305
1x300	Class 5	693	36.7	147	3355
3G300	Class 5	741	78.9	237	12570
4G300	Class 5	621	87.7	263	16300
1x400	Class 5	825	42.0	168	4470
1x500	Class 5	946	47.0	188	5900

Table 17: H07 RN-F manufacturing ranges from 70 to 500 mm²

Other flexible cable types will have the same manufacturing principle. In terms of sections/number of conductors.

4.4.2. Selection of a power cable:

The main criteria are:

- The intensity of the current to be transported.
- Network voltage.
- Cable routing (in pits, cable trays, etc.) to determine the type of insulation required.

Calculating the sections of power cables is covered in the next chapter, the following is simply an initial list of what most actors are required to know when working on an industrial site:

- 3% for lighting circuits.
- 5% for motor supplies.
- 10% including start-up peaks.

The following sizing references should also be familiar:

- A 3 x 25 cable is a cable with three 25 mm² conductors
- A 5 x 50 cable is a cable with five 50 mm² conductors
- A 3 G 25 cable is a cable with three 25 mm² conductors, however one of the conductors is a ground (green-yellow) conductor.
- A 5 G 50 cable is a cable with five 50 mm² conductors, however one of the conductors is a ground (green-yellow) conductor.

4.4.3. Control cables (multi-conductor cables)

4.4.3.1. Cable types

The cables types are identical to those used for power, however, there will be more conductors!

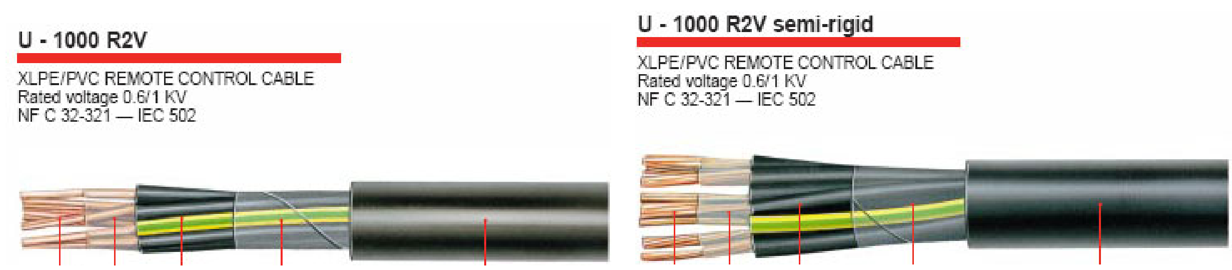


Figure 26: U-1000 R2V type control cable

Figure 27: Control cable with armour

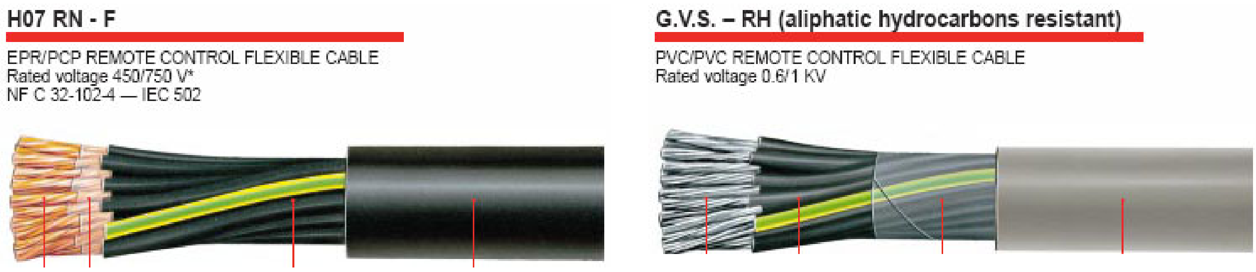


Figure 28: Control cable with flexible core

Control cables are considered as is and multi-conductors are defined as such when they include more than 6 conductors.

A cable with 5 or less conductors is a power cable, however nothing prevents you from using a 3 G 1.5 cable to supply a travel stop, and this cable would then be a control cable.

Take note of the systematic presence of the green-yellow ground conductor. The number of conductors desired (up to 37) includes this ground conductor, indicated by the letter ‘G’.

The expression 24 G 2.5, infers twenty three 2.5mm² conductors for control connections + 1 ground conductor.

4.4.3.2. U-1000 R2V manufacturing ranges

Section in mm²	Conductor construction	Maximum acceptable current		Book external diameter in mm	Bend radius mm	Weight kg/km
		Aerial	buried			
Copper conductor						
6G1.5	Class 1	20	28	11.3	68	195
7G1.5	Class 1	18	26	11.3	68	205
8G1.5	Class 1	17	24	12.1	73	240
10G1.5	Class 1	15	21	14.0	84	300
12G1.5	Class 1	13 .5	19	14.5	87	335
14G1.5	Class 1	12 .5	18	15.2	91	365
19G1.5	Class 1	10.5	15	16.8	101	480
24G1.5	Class 1	9	13	19.8	119	605
27G1.5	Class 1	9	113	20.1	121	655
30G1.5	Class 1	8	12	20.9	125	715
37G1.5	Class 1	7	10	22.5	135	855
6G2.5	Class 1	28	37	12.4	74	265
7G2.5	Class 1	25	34	12.4	74	280
8G2.5	Class 1	23.5	31	13.3	80	315
10G2.5	Class 1	20.5	27	15.5	93	410
12G2.5	Class 1	18.5	26	16.0	96	465
14G2.5	Class 1	17	23	16.8	101	670
19G2.5	Class 1	14.5	20	18.7	112	850
24G2.5	Class 1	13	17	22.0	132	925
27G2.5	Class 1	12.5	17	22.4	134	1010
30G2.5	Class 1	11.5	15	23.2	139	1215
37G2.5	Class 1	10	13	25.1	151	
6G4	Class 1	38	49	13.7	82	365
7G4	Class 1	34	44	13.7	82	390
8G4	Class 1	32	41	14.8	89	450
10G4	Class 1	28	35	17.3	104	540
12G4	Class 1	25.5	33	17.9	107	655
14G4	Class 1	23.5	30	18.9	113	725
19G4	Class 1	20	26	21.0	126	945

Table 18: U-1000 R2V control cable manufacturing ranges

This standard manufacturing table is (practically) identical for armoured cables with rigid/stranded cores (U-1000 RVFV and U-1000 RGPGV). In terms of the number of conductors assigned to the 3 sections considered (1.5 – 2.5 and 4mm²).

Characteristics such as diameter, weight, bend radius, and acceptable intensities are clearly different.

4.4.3.3. H07 RN-F manufacturing range

This refers to flexible core multi-conductor cables:

Section in mm²	Conductor construction	Maximum acceptable aerial current (A)	Book external diameter in mm	Bend radius mm	Weight kg/km
Copper conductor					
5G1,5	Class 5	20	14.5	44	300
7G1.5	Class 5	18	15.7	47	355
12G1.5	Class 5	13.5	18.9	57	480
18G1.5	Class 5	11	22.0	66	695
19G1.5	Class 5	10.5	23.6	71	815
24G1.5	Class 5	9	25.8	77	1005
27G1.5	Class 5	9	26.2	79	1040
36G1.5	Class 5	7.5	29.4	88	1265
5G2.5	Class 5	28	16.7	50	420
7G2.5	Class 5	25	18.0	54	470
12G2.5	Class 5	18.5	21.7	65	680
18G2.5	Class 5	15	25.9	78	1010
19G2.5	Class 5	14.5	27.6	83	1170
24G2.5	Class 5	13	31.1	93	1410
36G2.5	Class 5	10.5	34.9	105	1865
6G4	Class 5	38	19.5	59	585
7G4	Class 5	34	21.5	65	720
12G4	Class 5	25.5	26.1	78	1040
18G4	Class 5	20.5	33.0	99	1455

Table 19: H07 RN-F control cable manufacturing range

The other flexible cable, shown at the start of the paragraph, the GVS-RH, is manufactured with 4 conductor sections (0.75/1/1.5/2.5mm²) with the same number of conductors in each section (between 6 and 37).

Aluminium core conductors are clearly not used for control cables.

4.5. LOW VOLTAGE CONNECTIONS

4.5.1. Installation of LV cables

The following advice applies if you are required to monitor the laying of low voltage cables, irrespective of the cable type. This advice is aimed at all those witnessing installations full of irresponsible elements showing absolute disregard for common sense.

- When laying cables, corner pulleys, rollers, support brackets, etc, must be used.
- The force used to "lay" the cable must not exceed the tension recommended by the manufacturer to avoid deforming the cable.
- Do not exceed the recommended bend radius, a broken cable (with a sharp angle) is a useless cable.
- Never route the cable over sharp edges or abrasive surfaces.
- Cable ends must be covered with insulation. Cables with ends in water will "absorb" this water by capillarity, and water or humidity are not generally compatible with electric currents and voltages. (Entire drums have not been used on certain sites due to low cable insulation,…).

4.5.2. Transmission bars

Bars are sometimes used instead of cables for secondary ***LV distribution panel/transformer*** connections, particularly for high intensities covering short distances.

These bars are in copper and sheathed in metal (with insulation) or directly moulded under an insulation sheath.

With "traditional" industry, this bar system is also used for workshop distribution.

Figure 29: "Canalis" distribution system by Schneider Electric

5. SPECIAL FIRE CABLES

This section concerns "fire resistant" cables: cables which combat the spreading of fire (higher quality than standard cables), i.e. which resist fire by not setting alight, as the insulation is a flame retardant, and cables in mineral insulated copper or aluminium sheathed cables which may continue to carry current during fire.

5.1. CABLE BEHAVIOUR IN CASE OF FIRE

5.1.1. Reaction to fires

This aptitude is appraised as per two classes:

- ***Cable category C2, anti-flame spreading*** (as per NF C32-070).

  When covered with insulation and surrounded by flames, these cables will not spread the fire and the flames will be extinguished without need for external action.

  Examples: U-1000 R2V, H07 V-U, H07 V-R, H07 V-K

- ***Category C1 cable, anti-fire spreading*** (as per NF C32-070).

  When set alight, these cables do not emit flammable volatile products in sufficient quantities to create a secondary fire source. There are characterised by reinforced fire proofing for the envelope and sheath.

  Example: FR-N07

5.1.2. Fire resistant

A ***category CR1 cable*** is considered as "***fire resistant"*** if it does not allow flames to spread and if, when located at the heart of a fire source, it continues to carry current for a limited period, adequate to ensure the safety of individuals.

This applies to cables which must continue to ensure a power supply for a thirty-minute period for emergency lighting, lifts, ventilators, etc. to allow for the evacuation of individuals, despite the presence of a fire source, in establishments or sites open to the public.

The insulation of these cables may be in silicone rubber, (for example) which transforms into a gangue of insulating silica after combustion.

Example: Pyrolyon cable (Alcatel/Gorse) – Precipyr cable (Pirelli) - etc.

A ***category CR2 cable*** has no characteristics in terms of fire resistance.

5.1.3. Emission of smoke

Many PVC insulated cables, even those which combat the spreading of flames or fire, may cause secondary effects on people (during combustion) due to the emission of toxic smoke, which may be dense and will systematically be corrosive.

To minimise these effects, halogen-free cables (no chloride, bromide, fluorite, iodine) are now manufactured.

The materials used (XLPE, PR, EVA, etc.) for the insulation and the external sheath are however still fire resistant (retardant) and emit a (small) quantity of toxic smoke.

5.2. FIRE RESISTANT CABLES

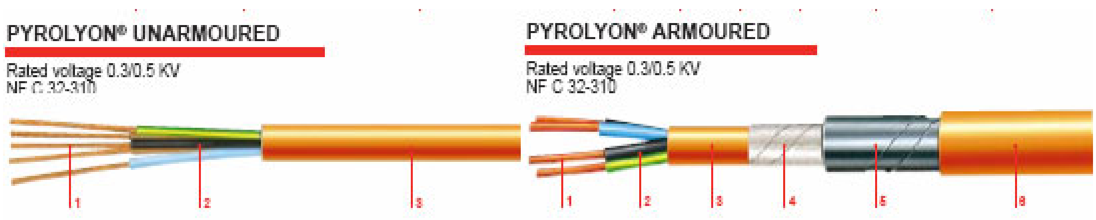


Figure 30: Armoured and non-armoured fire resistant cable type

Construction of the cable:

1. Rigid copper core (solid or stranded)
2. Silicone rubber insulation
3. Intermediate or final protection either in silicone rubber or in orange coloured polyolefin (cable with up to 5 conductors), or brick red coloured polyolefin (cable with 7+ conductors)
4. Gloss coated mica band (option)
5. Armour: either a single copper band (cable with one conductor), or a double band of copper (multi-conductor cables)
6. Final protection – idem 3

"Pyrolion" manufacturing ranges

Section in mm²	Conductor construction	Maximum acceptable aerial current (A)	Book external diameter in mm		Bend radius mm	Weight kg/km
			Minimum in mm	Maximum in mm		
Copper conductor						
2x1.5	Class 1	26	7.6	10.6	105	130
3G1.5	Class 1	26	8.0	11.0	110	150
4G1.5	Class 1	23	9.0	11.9	120	185
5G1.5	Class 1	19	9.9	12.8	130	220
7G1.5	Class 1	18	11.1	13.8	140	260
12G1.5	Classe1	13.5	14.6	17.6	180	440
19G1.5	Class 1	10.5	17.1	20.4	205	630
27G1.5	Classe1	9	21.0	24.1	240	925
37G1.5	Class 1	7	23.9	27.0	270	1210
2x1.5	Class 1	36	9.0	11.9	120	180
3G1.5	Class 1	36	9.5	12.5	125	210
4G1.5	Class 1	31	10.8	13.4	135	270
5G1.5	Class 1	26	11.9	14.7	150	325
7G1.5	Class 1	25	12.9	15.3	160	570
12G1.5	Classe1	18.5	17.1	20.4	205	635

Table 20: Fire resistant cable manufacturing range, with 1.5 - 2.5mm² sections

Section in mm²	Conductor construction	Maximum acceptable aerial current (A)	Book external diameter in mm		Bend radius mm	Weight kg/km
			Minimum in mm	Maximum in mm		
Copper conductor						
2x4	Class 1	49	10.5	13.3	135	250
3G4	Class 1	49	11.1	14.1	140	300
4G4	Class 1	42	12.4	15.3	155	370
5G4	Class 1	35	13.9	16.6	165	460
2x6	Class 2	63	12.0	14.8	150	330
3G6	Class 2	63	12.9	15.6	155	410
4G6	Class 2	54	14.4	17.0	170	520
5G6	Class 2	45	15.8	18.5	185	660
2x10	Class 2	86	14.2	16.5	165	510
3G10	Class 2	86	16.1	17.5	175	630
4G10	Class 2	75	16.6	19.2	195	780
5G10	Class 2	63	18.3	20.9	210	940
1x16	Class 2	107	8,8	10,5	105	320
2x16	Class 2	115	16,2	18,7	190	720
3G16	Class 2	115	17,2	19,8	200	890
4G16	Class 2	100	19,0	21,8	220	1140
5G16	Class 2	84	21,0	23,9	240	1380

Table 21: Fire resistant cable manufacturing range, with 4 - 16mm² sections

Section in mm²	Conductor construction	Maximum acceptable aerial current (A)	Book external diameter in mm		Bend radius mm	Weight kg/km
			Minimum in mm	Maximum in mm		
Copper conductor						
1x25	Class 2	138	10.2	12.4	125	370
2x25	Class 2	149	18.3	22.5	225	1150
3G25	Class 2	149	19.5	23.9	240	1360
4G25	Class 2	127	21.6	26.3	265	1700
5G25	Class 2	106	24.0	29.0	290	2070
1x35	Class 2	169	11.0	13.7	140	490
4G35	Class 2	158	24.5	29.5	295	2200
5G35	Class 2	133	27.1	32.7	330	2710
1x50	Class 2	207	12.6	15.1	150	630
1x70	Class 2	268	14.3	17.4	175	940
1x95	Class 2	328	16.1	19.5	195	1180
1x120	Class 2	382	17.7	21.2	215	1460
1x150	Class 2	441	19.3	23.3	235	1760
1x185	Class 2	506	21.1	25.7	260	2170
1x240	Class 2	599	24.4	29.1	290	2860
1x300	Class 2	693	27.0	32.0	320	3650

Table 22: Fire resistant cable manufacturing range, with 25 - 300mm² sections

5.3. MINERAL INSULATED CABLES

Those cables are (normally) <u>prohibited of installation</u> in (old) Total Specifications, but they do exist! You will find this kind of cables in some package (American made power turbine) and it is better for you, when you will have to replace / repair / terminate it, how to deal with.

If you do not have them on your site, good for you!

5.3.1. Introduction

This paragraph covers Mineral Insulated Metal Sheathed Cables (MIMS). MIMS cable is very tough. It can resist very high temperature. It can stand a lot of mechanical damage; you can knock it, drop things on it and put heavy weights on it without damaging the conductors.

MI cable needs special fittings and tools to terminate the cable correctly. This unit tells you what the cable is made of.

This paragraph also covers in detail how to terminate an M.I. cable correctly.

5.3.2. Mineral insulated cables specificities

MI cables all have the same basic construction. The cables are generally classified as:

- Light Duty (up to 600 Volts) or
- Heavy Duty (up to 1,000 Volts)

MI cables can have as many as 19 cores. These cores range in CSA from 1 mm^2 to 240mm^2

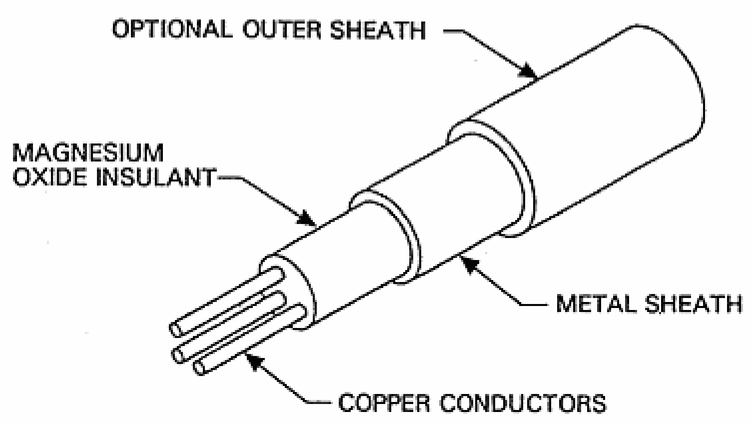
The cable is widely used in industry, especially where there are high temperatures or a high fire risk. MI cables are often used in the petrochemical industry.

MI cables have many advantages over other types of cables. However, MI cables have some disadvantages:

- They are expensive
- They absorb moisture
- They need special glands and seals and are difficult to terminate

5.3.3. Construction

A MIMS cable has a metal sheath made of copper or aluminium. The conductors (copper and aluminium) are insulated from the sheath by highly compressed mineral powder insulation (magnesium oxide)



The M.I. cable sheath is made from a solid-drawn seamless tube of copper or aluminium. Some M.I. cables have a PVC outer-sheath. This outer-sheath may be used to protect the metal sheath against corrosion.

Figure 31: Construction of M.I. Cable

An MI cable can carry between 1 and 19 conductors (cores).

Conductors which are larger than 25mm^2, are usually made into single core MI cables. MIMS cables are also available with 2, 3, 4, 7 or 12 conductors.

Types of Cable

- Light Duty : Up to 600 Volts. For domestic, commercial and light duty uses.
- Heavy Duty : Up to 1000 Volts. For industrial, hazardous and heavy duty uses.
- Finishes : Bare copper or bare aluminium sheath. A PVC (or other material) outer-sheath can be used to protect the cable from corrosion.

The outer sheath is available in different colours. The colours show what the cable is used for:

- Orange (for general purpose work)
- White (emergency lighting)
- Red (Fire alarm circuits),

Use of colours given here as example, but you will have to check your site standards for proper application.

5.3.4. Terminations

M.I. cables need special glands and terminations because the mineral insulation in the cable absorbs moisture very easily. Terminating an MI. cable is a skilled job. The cut end of an MI cable must be sealed to prevent moisture getting into the cable.

The M.I. cable termination consists of two main parts:

- A seal assembly
- A gland assembly

The seal assembly prevents moisture from getting into the MI cable. The gland is used to hold the seal assembly in place and to join the MI cable to another device.

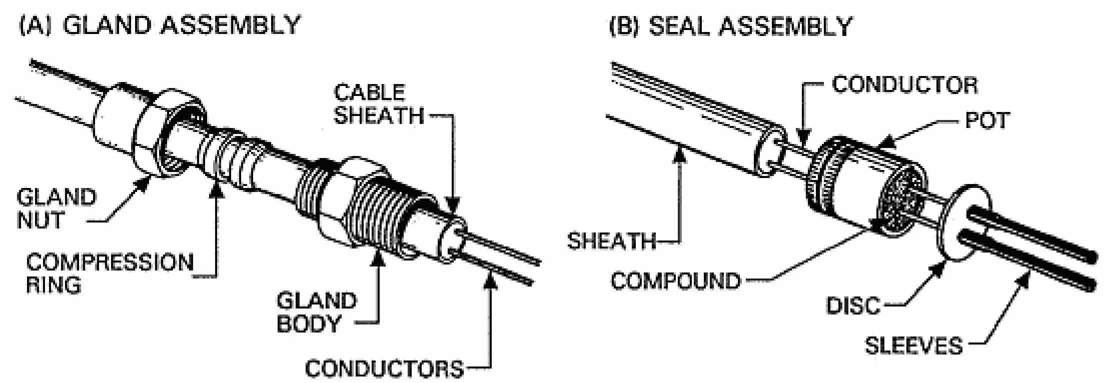


Figure 32: Cable Termination

The figure shows both the seal assembly and the gland assembly used for terminating M.I. cable.

The M.I. cable gland assembly must be placed over the cable before the cable can be sealed with the seal assembly. Special tools are needed to strip the M.I. cable and to fit the seal assembly to the cable.

The seal assembly consists of a special cap called a sealing pot filled with a waterproof substance.

The sealing pot is screwed over the cut end of an MI cable with a pot wrench. The pot is filled with a compound which resists moisture. This compound is compressed into the pot by crimping a sealing disc into the pot end with a special crimping tool.

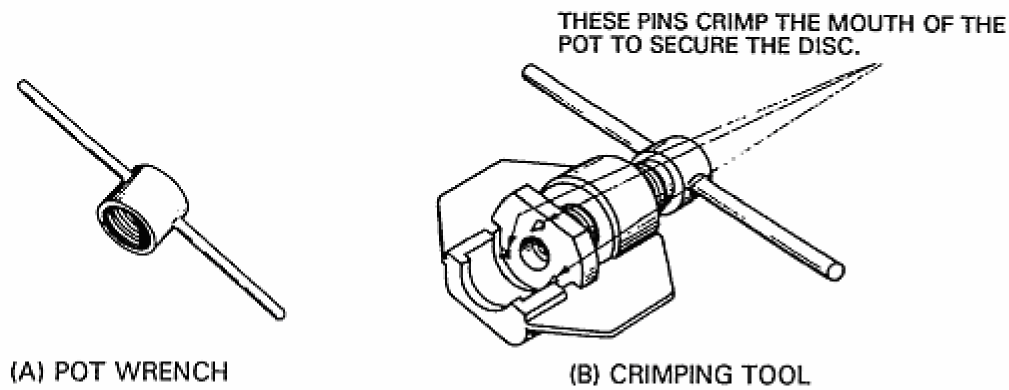


Figure 33: M.I. Cable Tools

5.3.5. How to make an M.I. cable Termination

You must know how to make an MI cable termination correctly. This section tells you exactly what you must do.

The stages to be followed to make an M.I. cable termination are:

- Preparation
- Stripping off the cable sheath
- Fitting the gland and the seal

5.3.5.1. Preparation

1. Have all the tools and equipment you need for making the termination, i.e. junior hacksaw, knife, stripping tools, pot wrench, sealing compound etc.

2. Measure the cable and cut to the correct length using a junior hacksaw. Make sure the cable end is cut off squarely. This makes stripping off the cable easier.

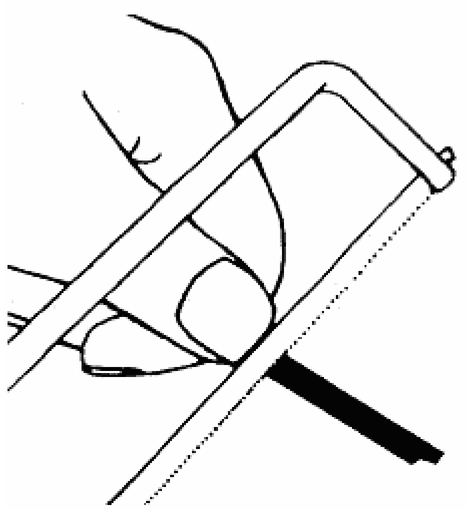


Figure 34: Cutting M.I. Cable to Length

Allow enough length of M.I. cable for conductor tails.

3. If the cable has a PVC outer-sheath then this should be cut back before stripping the metal sheath. Use an electrician's knife to remove the PVC outer-sheath.

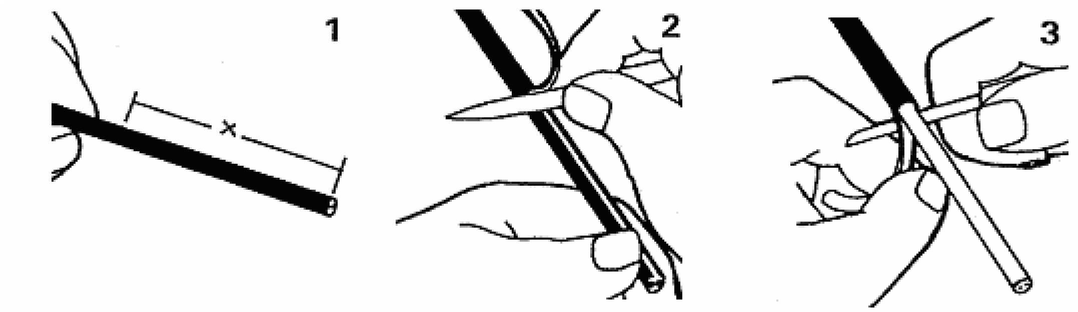


Figure 35: Removing PVC Outer-sheath

5.3.5.2. Stripping the metal Sheath

You cannot strip a metal sheath with pliers. You need a special stripping tool.

1. Mark the place where the metal sheath is to be cut. You must decide how long you want the exposed conductors to be before you strip back the metal sheath (leave too much conductor rather than too little).

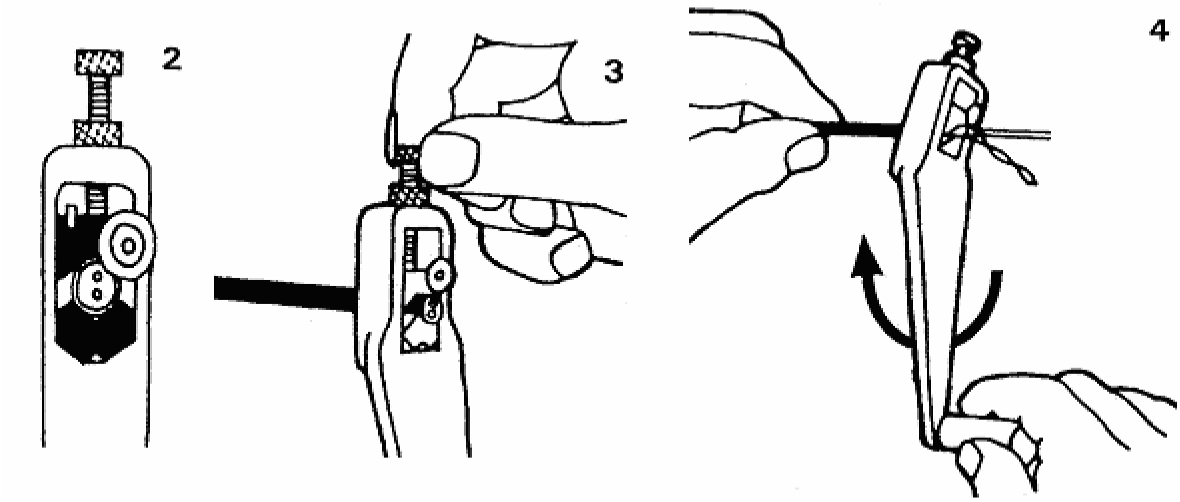


Figure 36: Follow steps 2, 3, 4

2. Place the end of the cable in the stripping tool.

3. Tighten the adjusting screw on the stripping tool.

4. Turn the stripping tool clockwise whilst applying a slight forward pressure. The stripping tool will cut away the metal sheath in a spiral.

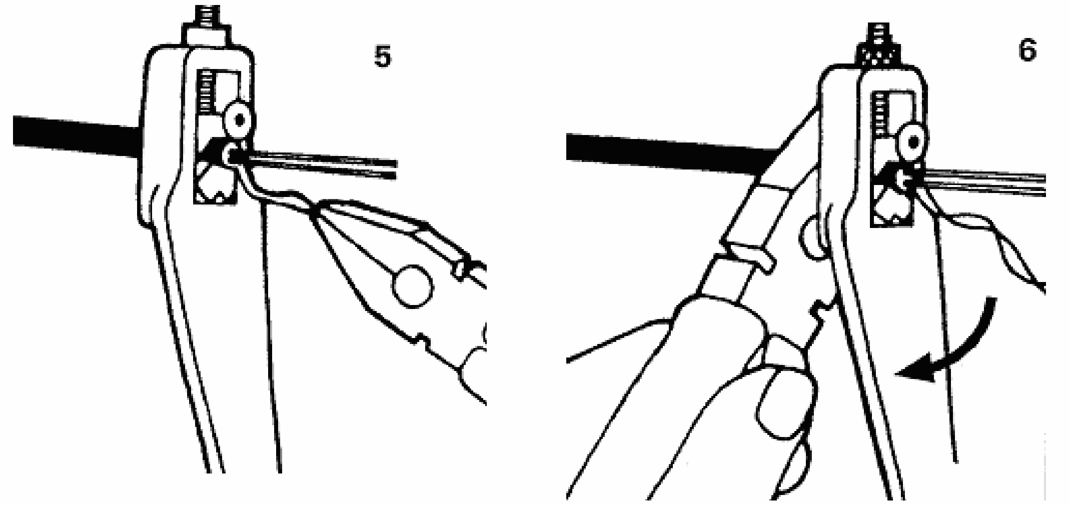


Figure 37: Follow steps 5, 6

5. Remove the long spirals of swarf with pliers when necessary

6. Hold the cable with pliers at the place where you want the stripping tool to stop

7. This produces a clean square edge on the end of the cut cable sheath.

NB: It is very important to have a square edge on the cable sheath. It is difficult to screw the pot onto the sheath if the edge is not square.

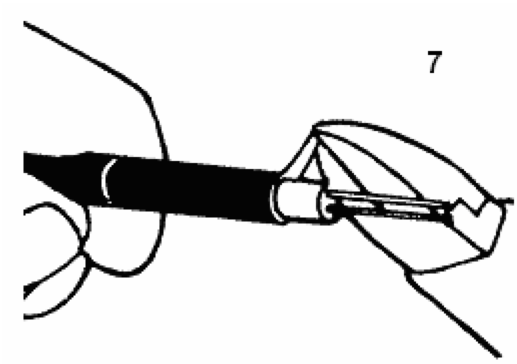


Figure 38: Final step 7

Alternative Method

If you do not have a stripping tool you can use a stripping rod. Stripping rods can easily be made in the workshop. A stripping rod looks like the key you use to open a can of sardines.

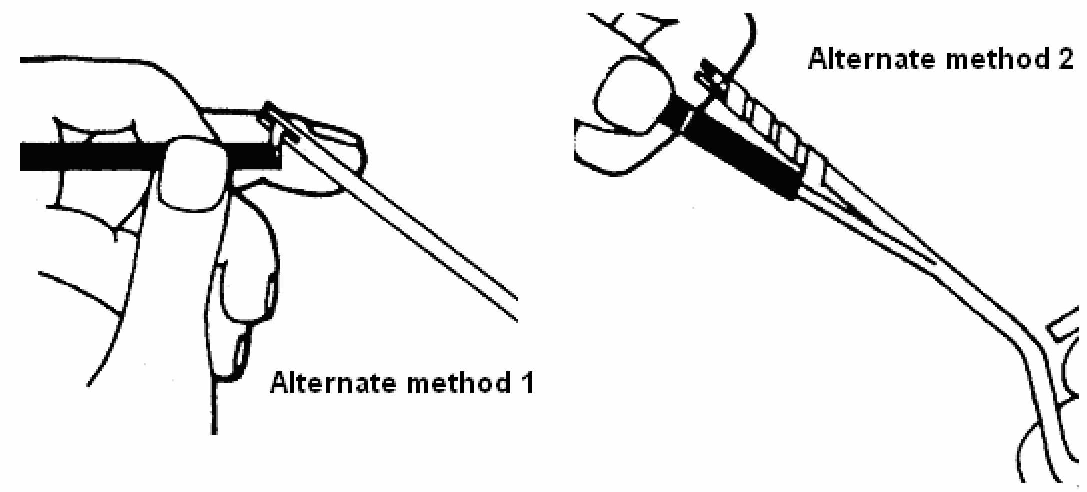


Figure 39: Alternate method steps 1, 2

1. Use a ringing tool to mark the point at which you must cut away the sheath

2. Cut the end of the metal cable sheath with wire cutters

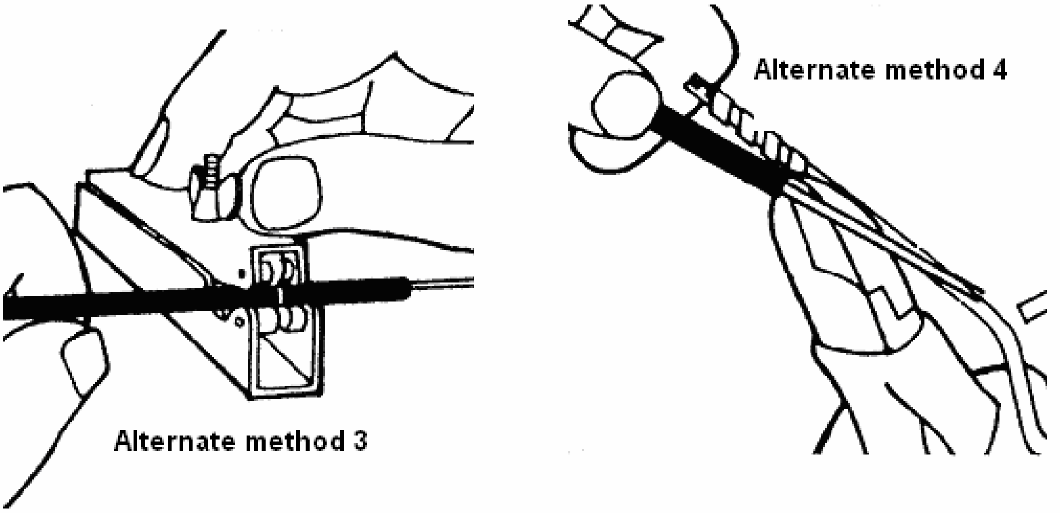


Figure 40: Alternate method steps 3, 4

3. Insert the cut end of the cable sheath into the stripping rod.

4. Twist the stripping rod around the cable and strip away the metal sheath.

5. Cut off the cable metal sheath with wire cutters at the point marked by the ringing tool. Care must be taken at this stage to produce a square edge on the cable sheath

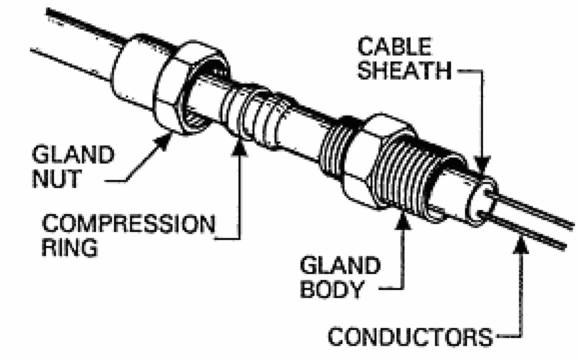


Figure 41: Alternate method step 5

NB: You must be very careful when you "ring" the sheath with a ringing tool. If the ringing is not done correctly you will not get a square edge.

Therefore, it will be very difficult to screw the pot on to the sheath. If you ring the sheath correctly you will get a clean, square cut.

5.3.5.3. Fitting the Gland and Seal

When you have removed the metal sheath and exposed enough of the conductors you are ready to fit the gland and the seal.

1. Place the gland nut, compression ring and gland body over the cable sheath.

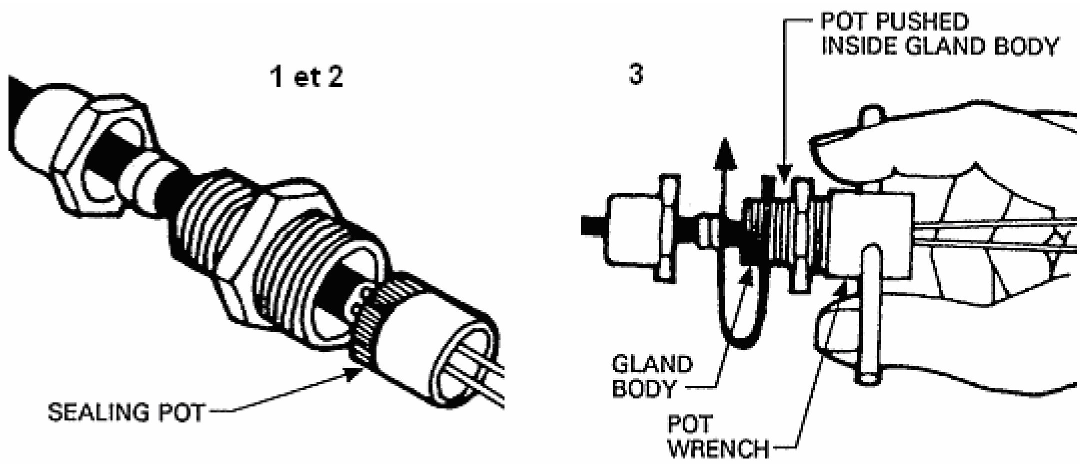


Figure 42: Fitting the gland and seal steps 1, 2, 3

2. Place the sealing pot over the exposed conductors.

3. Place the pot wrench over the pot. Now screw the pot wrench onto the gland body. This will force the pot over the end of the metal cable sheath

4. Keep screwing the pot over the cable until the cable sheath can be seen from the bottom of the pot.

5. Remove any loose powdered insulation by tapping on the cable

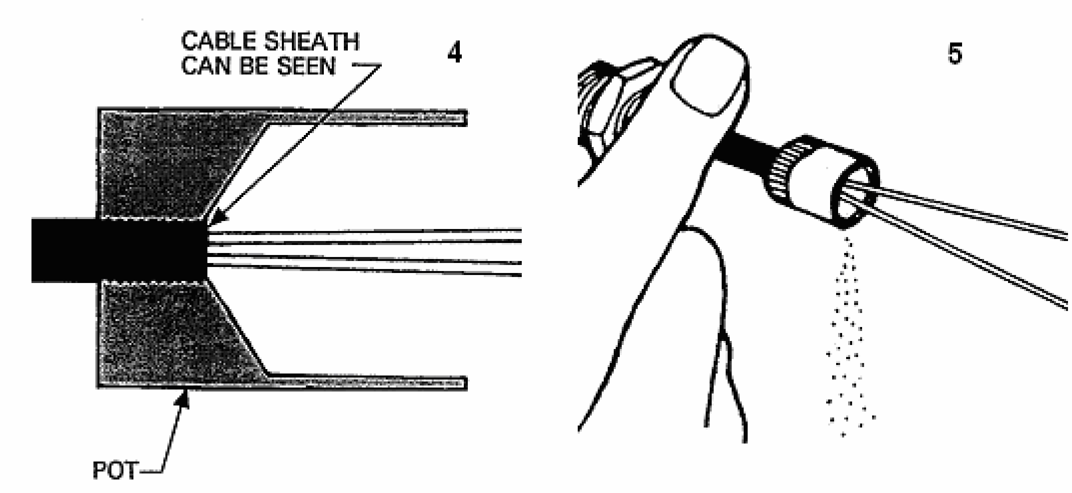


Figure 43: Fitting the gland and seal steps 4, 5

6. The pot is sealed with a disc. The disc has two small holes in it for the conductors. Slide the disc onto the exposed conductors. The disc separates the conductors.

7. Fill the pot with the sealing compound. Fill the pot from one side only to avoid creating an air moisture pocket

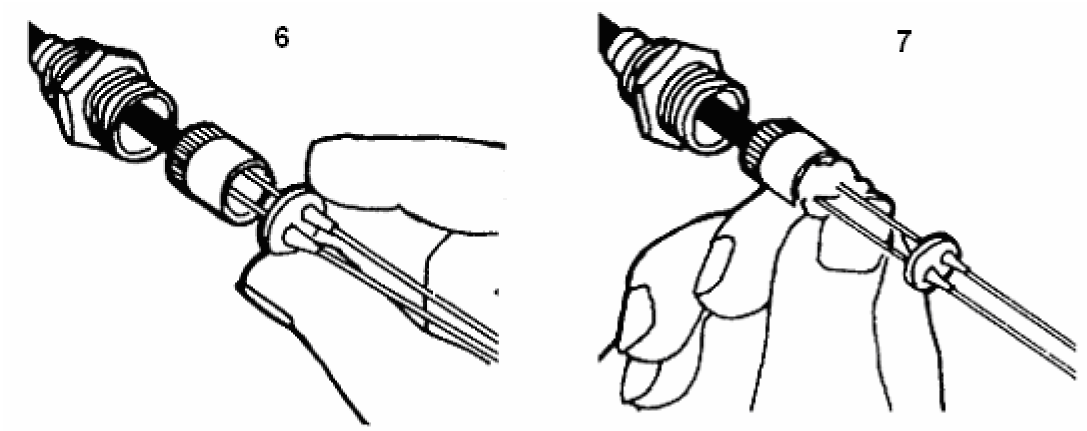


Figure 44: Fitting the gland and seal steps 6, 7

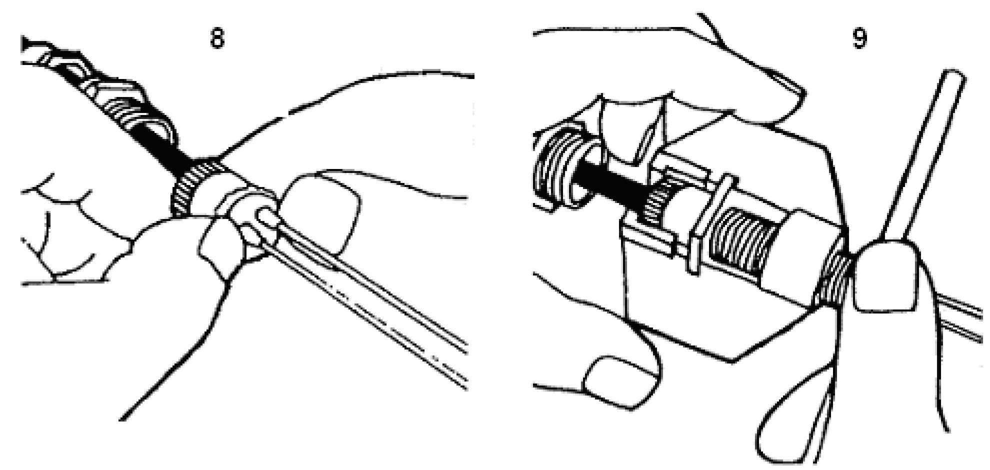


Figure 45: Fitting the gland and seal steps 8, 9

8. Press the disc into the bottom of the pot

9. Fit the crimping tool onto the pot and crimp the bottom of the pot around the disc. Clean off any excess compound from the outside of the pot. The compound in the pot gives a water tight seal to the end of the cable.

10. Slide the gland body over the pot. Slide the gland nut on to the gland body and tighten the gland nut.

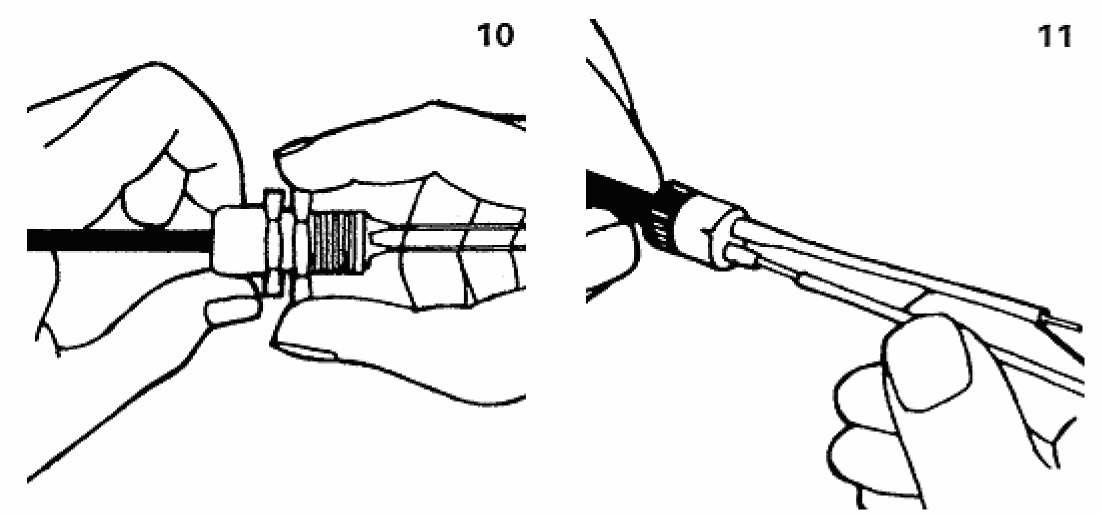


Figure 46: Fitting the gland and seal steps 10, 11

11. Fit insulating sleeves over the conductors and onto the disc stubs.

12. The termination is now completed. The exposed conductors can now be joined to any electrical device.

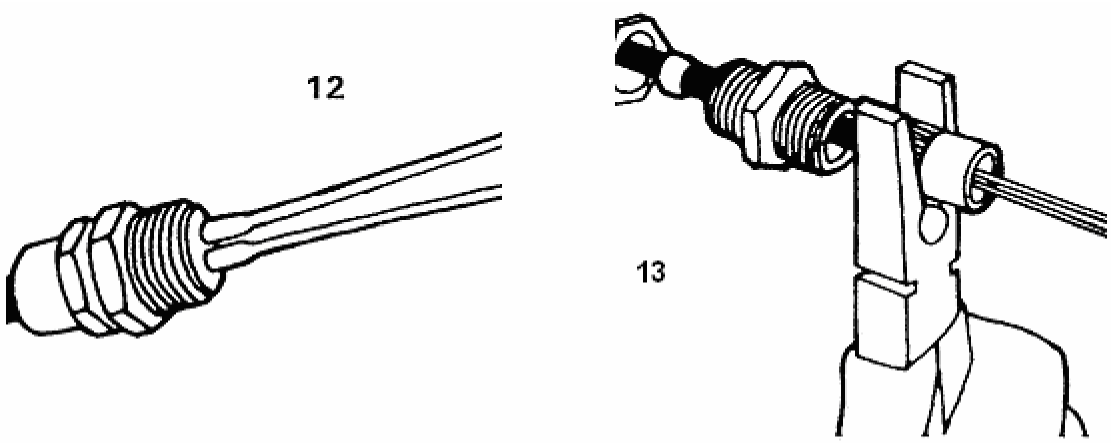


Figure 47: Fitting the gland and seal steps 12, 13

13. Pliers can be used to fit the pot onto the sheath if a pot wrench is not available.

When fitting a Pot Using Combination Pliers, you must make sure that the pot is fitted squarely onto the cable sheath. You must be very careful when you do this.

If a pot wrench is available, use it. The pot wrench is designed to fit the pot squarely onto the sheath.

5.3.6. Advantages and disadvantages of M.I. Cable

5.3.6.1. Advantages

- Fire proof. The copper sheath and magnesium oxide insulation will not burn. The cable will not be damaged even if there is f ire.
- Great mechanical strength. The cable can be bent, flattened and twisted and it will still work. If you hit the cable with a hammer, the dense insulation material will protect the conductors.
- Waterproof. The cable has a seamless metal sheath. If the cable ends are properly sealed the cable can be run underwater.
- Long-Lasting. M.I. cable is made of inorganic materials so it does not decay as it gets older.
- Small diameter. The cable is very thin. It can be run through narrow enclosures.
- High current carrying capacity. M.I. cable can carry more current than other cables of the same size.
- Earthed. The copper sheath acts as an earth so the cable only needs to carry two wires.
- High corrosion resistance. Copper doesn't rust. It resists most kinds of corrosion. A PVC outer sheath can be used when necessary.
- High temperature range. MI. cable can operate continuously in temperatures up to 250°C, (the maximum for PVC cable is 80°C Standard terminations can operate up to 150°C but special terminations can be used for higher temperatures.

5.3.6.2. Disadvantages

- Cost. M.I. cable is more expensive than other types of cable.
- Absorbs moisture. The mineral insulation (magnesium oxide) absorbs moisture. The cable ends must be sealed very carefully. MI cable should be tested for moisture before it is terminated. If there is moisture in the end of the cable then all you need to do is cut off about 10 cm. The moisture does not usually go in more than 5 cases
- Difficult to terminate. MI cable must be terminated by a skilled electrician.

5.3.7. Uses

MI cable is used in hazardous conditions. It is used in high temperature areas such as boiler houses, turbines enclosures and furnaces. It is also used for flameproof applications in oil refineries, oil and gas production sites and chemical plants.

6. CABLES SELECTION IN LOW VOLTAGE

We do consider here that we know already having chosen a U-1000 R2V cable, (XLPE/PVC/PVC), with armour or without as they are nearly the only types used in our industry for power supplies

Question is then, which cross-section to choose, how to lay correctly this same cable?

6.1. CABLES SIZING

6.1.1. Voltage drop

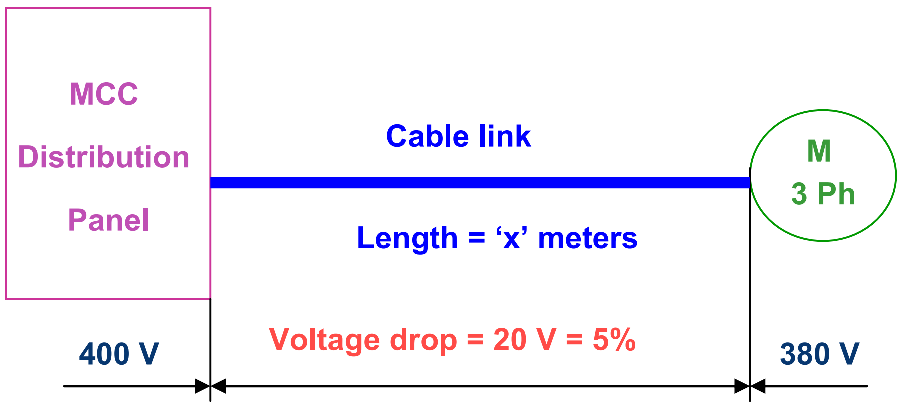


Figure 48: The Voltage drop

The voltage drop is the difference expressed in volts between supply (mains) and arrival (user) of a cable. Its maximum value is a percentage of the main voltage.

- 3 % for lighting wiring systems.
- 5 % for driving force wiring systems.

Starting up for driving force wiring systems a voltage drop of 10 % is usually admitted.

6.1.1.1. Formula

- In D.C. $\Delta u = 2\, l\, I\, Rc$
- In single-phase alternating current $\Delta u = 2\, l\, I\, (Ra \cos\varphi + L\omega \sin.\varphi)$
- In three-phase A.C. $\Delta u = \sqrt{3}\, l\, I\, (Ra \cos.\varphi + L\omega \sin.\varphi)$

With:

***Rc :** conductor resistance in DC at operating temperature Ω/km)*
***Ra :** conductor resistance in AC at operating temperature Ω/km)*
***L :** core inductance (Ω/km)*
***ω :** pulsation equal to 2 ωf (314 for f = 50 Hz)*
***cos.**φ : power factor*
***I :** Carried intensity in normal operating or Id intensity at starting time in the core (A)*
***l :** simple length of cable (km)*

6.1.1.2. Calculation of Voltage Drop:

Voltage drop is often an important factor in LV (Low Voltage) installation. In many cases it determines the size of the cable. It seldom interferes in high voltage installation.

On the tables hereunder, the values of resistance in DC (Rc), in AC (Ra), and of reactance (Lω) are given in order to accurately determine the voltage drop for industrial LV cables.

These tables also indicate direct impedance values Z for: cos φ= 1 - 0.8 - 0.5 - 0.3.

By only multiplying these values by 2 for single-phase and by $\sqrt{3}$ (1.732) for three-phase installation, the voltage drop in volt per ampere and per km of cable can be obtained (multiplying as well by the current and the length).

6.1.1.3. Tables for calculation of voltage drops

Unarmoured cables XLPE/PVC / U1000 R2V copper

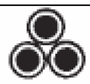
Cross section	Resistance			Reactance at 50 Hz	Impedance at 50 Hz and at 90°C			
					Cos φ			
	D.C. at 20°C	D.C. at 90°C	A.C. at 90°C		1	0.8	0.5	0.3
Sq.mm	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km
	3 or 4 copper conductors (within one cable)							
1.5	12.10	15.43	15.43	0.107	15.43	12.41	7.81	4.73
2.5	7.41	9.45	9.45	0.100	9.45	7.62	4.81	2.93
4	4.61	5.88	5.88	0.094	5.88	4.76	3.02	1.85
6	3.08	3.93	3.93	0.088	3.93	3.20	2.04	1.26
10	1.83	2.33	2.33	0.0785	2.33	1.91	1.23	0.78
16	1.15	1.47	1.47	0.0754	1.47	1.22	0.80	0.51
25	0.727	0.927	0.927	0.0754	0.93	0.79	0.53	0.35
35	0.524	0.668	0.669	0.0754	0.67	0.58	0.40	0.27
50	0.387	0.493	0.494	0.0754	0.500	0.440	0.312	0.220
70	0.268	0.342	0.343	0.0722	0.350	**0.318**	0.234	0.172
95	0.193	0.246	0.247	0.0722	0.257	0.241	0.186	0.143
120	0.153	0.195	0.197	0.0722	0.210	0.201	0.161	0.128
150	0.124	0.158	0.160	0.0722	0.176	0.171	0.143	0.117
185	0.0991	0.1264	0.1290	0.0722	0.148	0.147	0.127	0.108
240	0.0754	0.0961	0.0997	0.0722	0.123	0.121	0.112	0.099
300	0.0601	0.0766	0.0810	0.0691	0.106	0.106	0.100	0.090
	Single copper conductor (conductors in trefoil)							
50	0.387	0.493	0.494	0.0880	0.502	0.448	0.323	0.232
70	0.268	0.342	0.342	0.0848	0.352	0.324	0.244	0.183
95	0.193	0.246	0.247	0.0848	0.261	0.248	0.197	0.155
120	0.153	0.195	0.196	0.0816	0.212	0.206	0.169	0.137
150	0.124	0.158	0.160	0.0816	0.180	0.177	0.151	0.126
185	0.0991	0.1264	0.1285	0.0816	0.152	0.152	0.135	0.116
240	0.0754	0.0961	0.0990	0.0785	0.126	0.126	0.117	0.105
300	0.0601	0.0766	0.0803	0.0785	0.112	0.111	0.108	0.099
400	0.0470	0.0599	0.0645	0.0785	0.102	0.099	0.100	0.094
500	0.0366	0.0467	0.0524	0.0762	0.0925	0.0876	0.0922	0.0884
630	0.0283	0.0361	0.0431	0.0755	0.0869	0.0798	0.0869	0.0850

Table 23: Resistance and impedance of U1000 R2V Cu cable at 90°C

Example of using this table:

A 3 phases motor of 80 kW, with cos φ = 0.8 is supplied in 380 V by a 3x70mm² + G (G separate) cable of 240 m , what is its voltage drop?

The table above is for running conditions, with cable "hot" at 90°C (it could be lower temperature)

Motor takes 152 A at rating power

Table gives for a 70mm² impedance of 0.318 Ω/km

$\Delta u = 0.318 \times \sqrt{3} \times I \text{ (current)} \times l \text{ (length)} = 0.318 \times \sqrt{3} \times 152 \times 0.24 = 20 \text{ V}$

I need at least 400 V available at the busbar to allow the 5% (20 V) maximum voltage drop admissible for a power cable.

It is even advisable to choose a cable of a higher cross section

Unarmoured cables XLPE/PVC / U1000 R2V aluminium

Cross section	Resistance			Reactance at 50 Hz	Impedance at 50 Hz and at 90°C			
	D.C. at 20°C	D.C. at 90°C	A.C. at 90°C		Cos φ 1	0.8	0.5	0.3
Sq.mm	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km
	3 or 4 aluminium conductors (within one cable)							
35	0.868	1.113	1.113	0.0754	1.116	0.936	0.622	0.406
50	0.641	0.822	0.822	0.0754	0.825	0.703	0.476	0.319
70	0.443	0.568	0.569	0.0722	0.573	0.499	0.347	0.240
95	0.320	0.410	0.411	0.0722	0.417	0.372	0.268	0.192
120	0.253	0.324	0.325	0.0722	0.333	0.303	0.225	0.166
150	0.206	0.264	0.265	0.0722	0.275	0.255	0.195	0.148
185	0.164	0.2103	0.2119	0.0722	0.224	0.213	0.168	0.132
240	0.125	0.1603	0.1624	0.0691	0.178	0.171	0.141	0.115
300	0.100	0.1282	0.1309	0.0691	0.148	0.146	0.125	0.105
	Single aluminium conductor (conductors in trefoil)							
50	0.641	0.822	0.822	0.0880	0.827	0.710	0.487	0.331
70	0.443	0.568	0.568	0.0848	0.574	0.505	0.357	0.251
95	0.320	0.410	0.411	0.0848	0.410	0.380	0.279	0.204
120	0.253	0.324	0.325	0.0816	0.335	0.309	0.233	0.175
150	0.206	0.264	0.265	0.0816	0.277	0.260	0.203	0.157
185	0.164	0.2103	0.2116	0.0816	0.227	0.218	0.176	0.141
240	0.125	0.1603	0.1620	0.0785	0.180	0.177	0.149	0.123
300	0.1000	0.1282	0.1304	0.0785	0.152	0.151	0.133	0.114
400	0.0778	0.0997	0.1026	0.0785	0.129	0.129	0.119	0.106
500	0.0605	0.0776	0.0808	0.0766	0.111	0.111	0.107	0.097
630	0.0469	0.0602	0.0645	0.0759	0.100	0.097	0.098	0.092

Table 24: Resistance and impedance of U1000 R2V Al cable at 90°C

We can make table for the same thing at different temperatures (70°C, 50°C,….) applying a correction factor which is seen in the following paragraph, all resistance / impedances calculations being done at the reference temperature of 20°C.

Let us see for other types of cables, this can be useful on site……

Unarmoured flexible cable EPR/PCP / H07 RN-F

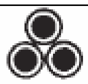
Cross-section	Resistance			Reactance at 50 Hz	Impedance at 50 Hz and at 90°C			
	D.C. at 20°C	D.C. at 90°C	A.C. at 90°C		Cos φ			
					1	0.8	0.5	0.3
Sq.mm	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km
	3 or 4 copper conductors (within one cable)							
* 1	20.00	25.50	25.50	0.111	25.50	20.47	12.85	7.75
* 1.5	13.70	17.47	17.47	0.104	17.47	14.04	8.82	5.34
* 2.5	8.21	10.47	10.47	0.100	10.47	8.44	5.32	3.24
* 4	5.09	6.49	6.49	0.094	6.49	5.25	3.33	2.04
* 6	3.39	4.32	4.32	0.091	4.32	3.51	2.24	1.38
10	1.91	2.44	2.44	0.0879	2.44	2.00	1.30	0.82
16	1.21	1.54	1.54	0.0816	1.54	1.28	0.84	0.54
25	0.78	0.995	0.995	0.0816	1.00	0.84	0.57	0.38
35	0.554	0.706	0.707	0.0785	0.71	0.61	0.42	0.29
50	0.386	0.492	0.493	0.0785	0.499	0.441	0.314	0.223
70	0.272	0.347	0.348	0.0785	0.357	0.325	0.242	0.179
95	0.206	0.263	0.264	0.0785	0.275	0.258	0.200	0.154
120	0.161	0.205	0.207	0.0754	0.220	0.210	0.169	0.134
150	0.129	0.164	0.166	0.0754	0.182	0.177	0.148	0.122
185	0.106	0.135	0.137	0.0754	0.156	0.154	0.134	0.113
240	0.0801	0.1021	0.1053	0.0754	0.129	0.129	0.118	0.103
300	0.0641	0.0817	0.0856	0.0722	0.112	0.111	0.105	0.094
	Single copper conductor (conductors in trefoil)							
50	0.386	0.492	0.493	0.0973	0.502	0.452	0.331	0.241
70	0.272	0.347	0.348	0.0973	0.361	0.336	0.258	0.197
95	0.206	0.263	0.264	0.0973	0.281	0.269	0.216	0.172
120	0.161	0.205	0.207	0.0942	0.227	0.221	0.185	0.152
150	0.129	0.164	0.166	0.0911	0.189	0.186	0.162	0.137
185	0.106	0.135	0.137	0.0911	0.164	0.163	0.147	0.128
240	0.0801	0.1021	0.1053	0.0911	0.139	0.138	0.131	0.118
300	0.0641	0.0817	0.0856	0.0879	0.123	0.120	0.119	0.109
400	0.0486	0.0620	0.0660	0.0848	0.107	0.102	0.106	0.101
500	0.0384	0.0490	0.0538	0.0816	0.097	0.091	0.098	0.094

Table 25: Resistance and impedance of H07 RN-F cable at 90°C

* tinned copper conductor

Armoured cables:

- **XLPE/SWA or STA or BRAID/PVC / U1000 RFFV**
- **XLPE/LC/SWA or STA/PVC / U1000 RGPFV-RH**

Cross-section	Resistance			Reactance at 50 Hz	Impedance at 50 Hz and at 90°C			
	D.C. at 20°C	D.C. at 90°C	A.C. at 90°C		Cos φ			
					1	0.8	0.5	0.3
Sq.mm	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km
	3 or 4 copper conductors (within one cable)							
1.5	12.10	15.43	15.43	0.122	15.43	12.42	7.82	4.75
2.5	7.41	9.45	9.45	0.116	9.45	7.63	4.83	2.95
4	4.61	5.88	5.88	0.110	5.88	4.77	3.04	1.87
6	3.08	3.93	3.93	0.100	3.93	3.20	2.05	1.27
10	1.83	2.33	2.33	0.094	2.33	1.92	1.25	0.79
16	1.15	1.47	1.47	0.0911	1.47	1.23	0.81	0.53
25	0.727	0.927	0.927	0.0911	0.93	0.80	0.54	0.37
35	0.524	0.668	0.669	0.0911	0.68	0.59	0.41	0.29
50	0.387	0.493	0.494	0.0879	0.502	0.448	0.323	0.232
70	0.268	0.342	0.343	0.0879	0.354	0.327	0.248	0.187
95	0.193	0.246	0.247	0.0879	0.262	0.250	0.200	0.158
120	0.153	0.195	0.197	0.0879	0.216	0.210	0.175	0.143
150	0.124	0.158	0.160	0.0879	0.183	0.181	0.156	0.132
185	0.0991	0.1264	0.1290	0.0879	0.156	0.156	0.141	0.123
240	0.0754	0.0961	0.0997	0.0879	0.133	0.132	0.126	0.114
	3 or 4 aluminium conductors (within one cable)							
35	0.868	1.113	1.113	0.0911	1.117	0.945	0.635	0.421
50	0.641	0.822	0.822	0.0879	0.827	0.710	0.487	0.330
70	0.443	0.568	0.569	0.0879	0.576	0.508	0.361	0.255
95	0.320	0.410	0.411	0.0879	0.420	0.382	0.282	0.207
120	0.253	0.324	0.325	0.0879	0.337	0.313	0.239	0.181
150	0.206	0.264	0.265	0.0879	0.279	0.265	0.209	0.163
185	0.164	0.2103	0.2119	0.0879	0.229	0.222	0.182	0.147
240	0.125	0.1603	0.1624	0.0879	0.185	0.183	0.157	0.133

Table 26: Resistance and impedance of armoured cable at 90°C

Overline: see Example/exercise at end of this course

6.1.2. Using pre-calculated charts

Follow the example hereunder and you will understand how to choose a cable (U1000 R2V) in cross section as per power to supply and length of the same cable

In middle of the 5 charts under, are the maximum lengths allowing the indicated voltage drop in the concerned voltage values (380 or 220 V) and in tri or mono distribution.

Power	Rating	Cross-section in mm² for nature of conductors specified														
in KW	in Amperes	1.5	2.5	4	6	10	16	25	35	50	70	95	120	150	185	240
2.5	5	190	325	510	745											
3	6	160	270	420	620											
3.5	7	135	230	365	540	895					COPPER					
4	8	120	200	320	470	785										
4.5	9	105	180	285	420	700					380V 3 PHASES					
5	10	96	165	255	375	630	970									
6	12	79	135	210	315	525	810				COS PHI 0.8					
7	14	68	115	180	270	455	700									
8	16	60	105	160	240	400	610	940								
9	18	51	92	145	215	355	550	850								
10	19		84	130	190	320	500	780					Calculation for 5% dU			
12	23		69	110	160	265	415	640	880							
14	27			94	140	230	355	550	750							
16	31			81	120	200	315	485	655	860				Cable type U1000 R2V 3 or 4		
18	35				110	180	280	430	580	770						
20	38	Maximum Length with 5% dU			98	160	255	390	520	690						
25	48					130	205	315	420	555	760					
30	57						170	260	355	465	640	840				
35	67						145	225	300	400	550	730				
40	76							195	260	350	480	640	745			
45	86							175	235	310	430	565	670	770		
50	95	Heating limit : BANNED USE						160	215	285	385	510	600	695		
60	114								180	235	320	420	500	580	680	
70	133									200	275	365	430	495	580	
80	152										240	315	375	430	510	600
90	171		COPPER								215	280	335	385	445	535
100	190											250	300	350	405	480
120	228												250	290	340	400
140	266													250	290	345
160	304														250	300
180	342															255

Table 27: Calculated length of U1000 R2V Cu cable in 3x380V 50 Hz supply

Example:

For 80 kW , cos 0.8, current is 152A and the maximum length to have the smaller cross-section of cable is 240 m in 70mm² (concordance with first example with impedance tables).

I cannot take a 50mm², it will heat too much and voltage drop would be too high (above 5%)

But with a 3x185mm², the length can be as much as 510 m for a 5% voltage drop and if I use this cable on 240 m, I should have only 24/51 x 5 = 2.35% of voltage drop.

Power	Rating	Cross-section in mm² for nature of conductors specified														
in KW	n Ampere	1.5	2.5	4	6	10	16	25	35	50	70	95	120	150	185	240
1	3	165	280	445	655											
1.5	5	110	185	205	440	725			COPPER							
2	7	84	140	220	325	540	850									
2.5	8	67	110	175	265	435	675			220V 3 PHASES						
3	10	56	92	145	220	365	560	870								
3.5	12	48	78	125	190	315	485	740		COS PHI = 0.8						
4	13	43	68	110	165	275	425	650	905							
4.5	15	37	61	97	145	245	375	580	820							
5	17	33	54	86	130	220	340	520	730	905			Calculation for 5% dU			
6	20		46	73	110	185	285	435	610	760						
7	23		40	63	94	160	245	370	520	650	920					
8	26			56	82	140	215	325	450	575	795			Cable type U1000 R2V 3 or 4		
9	30			49	73	125	190	290	405	510	710					
10	33				65	115	170	260	365	465	640	840				
12	40				54	94	140	220	305	385	530	700				
14	46					80	120	185	260	335	460	600	715			
16	53		Maximum Length with 5% dU			68	105	165	225	290	400	525	630	725		
18	59						94	145	200	260	360	470	560	640		
20	66						85	130	180	235	320	420	500	575	680	
25	82							105	145	190	260	340	400	460	540	645
30	98								120	160	215	280	335	390	450	540
35	115								100	135	185	240	290	330	385	465
40	131			eating limit : BANNED US						115	160	210	250	290	340	405
45	148										145	185	220	260	300	360
50	164										130	170	200	230	270	326
60	107											140	165	195	225	270
70	230			COPPER									140	165	195	230
80	263													145	170	205
90	296														150	180
100	328															160
110	361															145

Table 28: Calculated length of U1000 R2V Cu cable in 3x220V 50 Hz supply

Do not say, the distribution 3x220 V is obsolete! We are using it systematically in lighting distribution from a 400/230V transformer, this to avoid the distribution of the neutral conductor.

Example:

A receptor (a lighting panel) of 45 kW takes 148 A per phase (with cos of 0..8)

The minimum cross section to use is 95mm² (*I could take 70mm² but as this section is in limit, a small "guarantee" is given by increasing the section).*

With 95mm², the cable can be as long as 185 m, but will give 5% voltage drop at full power for this length. For lighting, the maximum Δu recommended is 3%, and consequently I shall have to deal with length and/or cross section.

With a length of (for example) 50 m: no problem, less than 3% drop

With a length of (for example) 150 m, I need a section of 150mm² to be under 3%.

Power	Rating	Cross-section in mm² for nature of conductors specified												
in KW	in Ampere	10	16	25	35	50	70	95	120	150	185	240	300	400
9	18	210	330	515	705	935								
10	19	200	310	490	655	890			ALUMINIUM					
12	23	165	255	405	550	735								
14	27	140	220	345	470	625	875		380V 3 PHASES					
16	31	120	190	300	410	545	765							
18	35	110	170	265	360	480	675			COS PHI = 0.8				
20	38	100	155	245	335	445	625	835						
25	48		125	195	265	350	495	660	800				Cable type U1000 AR2V 3 or 4 wires	
30	57		105	165	220	295	415	555	675	800				
35	67			140	190	250	355	475	575	680	805			
40	76			120	165	220	310	415	505	600	710			
45	86				145	195	275	370	445	530	630	780		
50	95	Maximum Length with 5% dU effective				180	250	335	405	480	570	705	825	
60	114					150	210	280	335	400	475	585	685	800
70	133						175	240	280	345	405	505	590	685
80	152						150	210	255	300	355	440	515	600
90	171							185	225	265	315	390	460	535
100	190								200	240	285	350	410	480
120	228		Heating limit							200	235	295	345	400
140	266										200	250	295	345
160	304		ALUMINIUM									220	280	300
180	342												225	265
200	380													240

Table 29: Calculated length of U1000 R2V Al cable in 3x380V 50 Hz supply

Power	Rating	Cross-section in mm² for nature of conductors specified												
in KW	n Ampere	10	16	25	35	50	70	95	120	150	185	240	300	400
3	10	220	340	540	735	975								
3.5	12	180	285	450	610	815								
4	13	170	265	415	565	750								
4.5	15	145	230	360	490	650	915							
5	17	130	200	315	430	575	805							
6	20	110	170	270	365	490	685	915						
7	23	95	150	235	320	425	595	795						
8	25	84	130	205	280	375	530	705	855					
9	30	73	115	180	245	325	475	610	740					
10	33	66	105	155	220	295	415	555	675	800				
12	40	55	85	135	185	245	345	460	555	660	780			
14	46		74	115	160	210	300	400	485	575	680			
16	53		64	100	140	185	260	345	420	500	590	730		
18	59		58	91	125	165	230	310	375	445	530	655		
20	66			82	110	150	210	280	335	400	475	585	685	
25	82				89	120	165	225	270	329	380	470	555	645
30	98					100	140	185	225	270	320	395	465	540
35	115					85	120	160	195	230	270	335	395	460
40	131						105	140	170	200	240	295	345	405
45	148						93	125	150	180	210	255	305	355
50	164							110	135	160	190	235	275	320
60	197								115	135	160	195	239	270
70	230									115	135	170	105	230
80	263										120	145	170	200
90	295											130	155	180
100	328												140	160
110	351													145
120	394													135

ALUMINIUM

220V 3 PHASES

COS PHI = 0.8

Cable type U1000 AR2V 3 or 4 wires

Maximum Length with 5% dU effective

Heating limit

ALUMINIUM

Table 30: Calculated length of U1000 R2V Al cable in 3x220V 50 Hz supply

Power	Rating	Cross-section in mm² for nature of conductors specified														
in KW	n Ampere	1.5	2.5	4	6	10	16	25	35	50	70	95	120	150	185	240
0.5	2.3	100	165	265	395											
1	4.6	50	84	135	200	335	530				COPPER					
1.5	6.8	33	57	90	130	225	355	565								
2	9	25	43	68	100	170	265	430	595		220V MONO P+N or 2P					
2.5	11.5	20	34	54	80	135	210	340	470	630						
3	13.5	17	29	45	66	110	180	285	395	520			COS PHI 1			
3.5	16	14	24	39	56	96	155	245	335	450						
4	18		21	34	49	84	135	210	295	395	580			Cable type U1000 R2V 2 wires		
4.5	20		19	30	44	75	120	190	260	350	515					
5	23			27	39	68	105	170	235	315	460	630				
6	27			23	32	56	90	140	195	260	385	530				
7	32				28	48	76	120	170	225	330	460	570			
8	36					42	67	105	145	195	290	400	500	620		
9	41					38	60	94	130	175	255	355	440	550		
10	45					34	54	84	120	155	230	320	400	495	615	
12	55						45	70	98	130	190	265	330	410	510	
14	64						38	60	84	110	165	230	285	35	435	560
16	73							53	74	99	145	200	250	305	380	500
18	82							47	65	88	125	15	220	270	340	440
20	91								59	79	115	160	200	245	310	400
25	114									64	98	130	150	195	245	315
30	136										77	105	135	165	205	265
35	159											90	115	140	175	225
40	182											80	100	125	155	200
45	205												89	110	135	175
50	227													98	120	160
60	273														100	140
70	318															115

Maximum Length with 3% dU effective

Heating limit

COPPER

Table 31: Calculated length of U1000 R2V cable in mono 220V 50 Hz supply

6.1.3. Base of calculations

We have considered impedance directly and previous paragraph, but as impedance is a “combination” of resistance and inductance. Consequently let’s go back to those parameters (resistance, inductance) and let’s see as well the influence of temperature with the “corresponding” compensation coefficient.

6.1.3.1. Resistance (in D.C.)

Rc = ρ. l / s *the basic formula with*
Rc: direct current resistance of the conductor in Ω at **20 °C**
ρ: metal resistivity at 20 °C in Ωmm²/m / 0.01724 for copper / 0.02826 for aluminium
l: length in meters
s: real cross-section in mm2

Resistance variation in function of the temperature

To calculate the direct current resistance of one conductor at a temperature other than 20 °C, the following formula is applied:

Rc = Rc 20 (1 + α t)

Rc: resistance at submissive conductor temperature
Rc 20: resistance at 20 °C in Ω
α: numerical temperature coefficient: 0.00393 for copper 0.00403 for aluminium
t: temperature rise

Then we arrive at the temperature coefficient K

K = 1 + αt

Table 32: Coefficient K for resistance compensation

TEMPERATURE OF CONDUCTOR IN °C	COEFFICIENT K	
	Copper	Aluminium
20	1	1
25	1.0196	1.0201
30	1.0393	1.0403
35	1.0589	1.0604
40	1.0786	1.0806
45	1.0982	1.1007
50	1.1179	1.1209
55	1.1375	1.1410
60	1.1572	1.1612
65	1.1768	1.1813
70	1.1965	1.2015
75	1.2161	1.2216
80	1.2358	1.2418
85	1.2554	1.2619
90	1.2751	1.2821
95	1.2947	1.3022
100	1.3144	1.3224

Coefficient to apply to the value of calculated resistance (at 20°C) according to the ambient conditions

6.1.3.2. Inductance

Unarmoured cables: $L = 0{,}05 + \left(0{,}2\ Log\ e\frac{d}{r}\right)$

Armoured cables: $L = 0{,}1 + \left(0{,}2\ Log\ e\frac{d}{r}\right)$

L: inductance coefficient in mH / km
d: distance of cores centres in mm
r: radius of one core in mm
Log.e: Napier's logarithm (Napier's logarithm = Brigg's logarithm x 2.30258591)

We are not going to calculate the inductance of different types of cable, but simply give a typical table with already calculated values, hereafter.

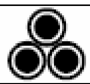
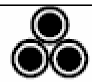
Cross section	XLPE / PVC	XLPE / PVC	XLPE/STA/ PVC XLPE/LC/ STA/PVC	PVC/ STA/ PVC	EPR/ PCP	EPR/ PCP	PVC/ PVC
							
Sq.mm²	mH/km	mH/km	mH/km	mH/km	mH/km	mH/km	mH/km
1,5	-	-	-		0.35	-	0.34
2,5	0.34	-	39	39	0.33	-	0.32
4,	0.32	-	0.37	0.37	0.32	-	0.32
6	0.30	-	0.35	0.35	0.30	-	0.30
10	0.28	-	0.32	0.32	0.29	-	0.29
16	0.25	-	0.30	0.30	0.28	-	0.28
25	0.24	-	0.29	0.29	0.26	-	0.26
35	0.24	-	0.29	0.29	0.26	-	0.26
50	0.24	-	0.29	0.29	0.25	-	0.25
70	0.24	0.28	0.28	0.28	0.25	0.31	0.25
95	0.23	0.27	0.28	0.28	0.25	0.31	0.25
120	0.23	0.27	0.28	0.28	0.25	0.31	0.25
150	0.23	0.26	0.28	0.28	0.24	0.30	0.24
185	0.23	0.26	0.28	0.28	0.24	0.29	0.24
240	0.23	0.26	0.28	0.28	0.24	0.29	0.24
300	0.22	0.25	0.28	0.28	0.24	0.29	0.24
400	-	0.25	-	0.28	0.23	0.28	0.23
		0.25	-	-	-	0.27	-

Table 33: Inductance of typical low voltage cables

6.1.3.3. Impedance

We have resistance and inductance, we can calculate impedance (remember Pythagoras)

$$Z = \sqrt{R_a^{\ 2} + \left(L\omega - \frac{1}{C\omega} \right)^2}$$

R_a: alternative current resistance in Ω/km
L: inductance in H/km
C: apparent capacity in F/km
ω: pulsation equal to 2 π f (314 for f = 50 Hz)

In practice, influence of capacity can be omitted and in such case apply: $Z = \sqrt{R_a^{\ 2} + L^2\omega^2}$

The 2 tables on the following page show practical impedance values which may be used for calculating voltage drop.

These values correspond to a 65 °C medium temperature of the conductor. For specific conditions (at 90°C) refer to the tables already given in previous paragraph (6.1.1) in this chapter

Unarmoured cables

Cross section	Copper conductor cable			Aluminium conductor cable		
	Impedance			Impedance		
	Cos φ=0.3	Cos φ=0.5	Cos φ=0.8	Cos φ=0.3	Cos φ=0.5	Cos φ=0.8
Sq.mm²	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km
Unarmoured low voltage cables						
1.5	4.4	7.2	11.5	-	-	-
2.5	2.7	4.4	6.9	-	-	-
4.0	1.7	2.8	4.4	-	-	-
6	1.17	1.9	2.9	-	-	-
10	0.72	1.14	1.7	1.12	1.88	2.91
16	0.48	0.75	1.13	0.75	1.20	1.86
25	0.33	0.50	0.73	0.50	0.79	1.18
35	0.27	0.39	0.54	0.39	0.59	0.86
50	0.22	0.30	0.40	0.31	0.45	0.65
70	0.18	0.235	0.30	0.24	0.34	0.46
95	0.15	0.190	0.23	0.19	0.26	0.35
120	0.14	0.165	0.19	0.17	0.22	0.28
150	0.124	0.150	0.17	0.15	0.19	0.24
185	0.114	0.130	0.14	0.14	0.17	0.20
240	0.103	0.115	0.12	0.12	0.14	0.17
300	0.097	0.105	0.11	0.11	0.13	0.14

Table 34: Inductance for low voltage cable unarmoured Cu and Al

Armoured cables

Cross section	Copper conductor cable			Aluminium conductor cable		
	Impedance			Impedance		
	Cos φ=0.3	Cos φ=0.5	Cos φ=0.8	Cos φ=0.3	Cos φ=0.5	Cos φ=0.8
Sq.mm²	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km	Ω / km
Armoured low voltage cables						
1.5	4.4	7.2	11.5	-	-	-
2.5	2.7	4.4	6.9	-	-	-
4.	1.72	2.78	4.4	-	-	-
6	1.19	1.90	2.96	-	-	-
10	0.743	1.16	1.78	-	-	-
16	0.501	0.765	1.15	0.772	1.21	1.87
25	0.349	0.512	0.743	0.518	0.793	1.19
35	0.275	0.390	0.551	0.399	0.596	0.88
50	0.226	0.309	0.421	0.316	0.460	0.662
70	0.183	0.239	0.309	0.245	0.342	0.475
95	0.155	0.192	0.237	0.200	0.268	0.358
120	0.141	0.169	0.200	0.176	0.228	0.295
150	0.130	0.152	0.172	0.159	0.200	0.250
185	0.122	0.138	0.150	0.145	0.176	0.211
240	0.114	0.129	0.128	0.131	0.153	0.174
300	0.109	0.115	0.114	-	-	-

Table 35: Inductance for low voltage cable armoured Cu and Al

6.1.4. Short-circuit

If you connect directly on a busbar a small size cable (small cross-section), where calculated Icc is high, do not be surprised if your cable acts like a fuse…., in case of downstream problem (on the connected receptor).

Installed Cables in a distribution, in a network have to withstand during a minimum of time, the Icc capacity.

In order to determine the size of a cable in relation to short-circuit current, following data are needed:

- **I.c.c.**: overload intensity for each core in amperes
- **θ:**cable temperature in °C before overload
- **θ.c.c.**: admissible temperature in °C at the end of overload
- **t:** duration of overload in seconds

I.c.c. and t are data depending on mains and on its protection devices.

The cable temperature before overloading is fixed as follows:

- 70 °C for PVC insulated cables
- 90 °C for XLPE insulated cables
- 90 °C for EPR or silicon rubber insulated cables

In short-circuit cycle, the permissible θ.c.c. temperatures on the core are:

- 160 °C for PVC insulated cables
- 250 °C for XLPE or EPR insulated cables
- 350 °C for silicon rubber insulated cables

These temperatures are those given by standard.

The formula given hereafter and the consequently obtained 'D' values are valid for a duration not exceeding 5 seconds.

The admissible current density in short-circuit is given by the formula: $D = \frac{K}{\sqrt{t}}$

Where:

D: admissible current density in amperes by mm² of cross-section

K: coefficient depending on the conductor nature, on the initial temperature θ at overload moment and on the admissible temperature θ.c.c. at the end of overload.
t: duration of short-circuit in seconds

K is a pre-determined coefficient as per the table hereunder

NATURE OF INSULATION	COEFFICIENT K	
	Copper cond.	Alu. cond.
PVC	115	76
XLPE	143	94
EPR	143	—

$$\text{SECTION} \geq \frac{\text{I.c.c. (A)}}{\text{D (A/sq.mm)}}$$

Table 36: Coefficient K for relation Icc / cable section

Values of D as per the formula here above

Current density: D in Amperes / sq.mm							
Duration of overload (t in seconds)	**0.005**	**0.1**	**0.2**	**0.5**	**1**	**2**	**5**
Copper conductors							
PVC insulated	514	364	257	163	115	81	51
XLPE insulated	640	452	320	202	143	101	64
EFP insulated	640	452	320	202	143	101	64
Aluminium conductors							
PVC insulated	339	240	170	107	76	54	34
XLPE insulated	420	297	210	133	94	66	42

Table 37: Calculated D as per time and type of cable

Example:

With a PVC cable (U1000 R2V), on a busbar at 10 kA, and a time breaking of 1 second (*not a so good breaker)* , density D is 115 (A/mm²)

With a breaker opening in 0.2 second (normal time), this cable can withstand 257 A/mm² ($D = \frac{K}{\sqrt{t}}$)

6.2. CURRENT RATING

Current rating is to be calculated in terms of power and power factor when operating the appliances.

Current rating shall not exceed the admissible capacity of a cable taking into account the different correction factors due to the ambient temperature and the laying conditions.

6.2.1. Definition / formulas

It is the ***intensity*** that the cable has to carry in normal operating conditions.

To calculate **I**, following data shall be known.

- ***P: Power-input***
  - In horse power (HP) (1 HP = 736 W) to calculate I the efficiency of the appliance and the cosines φ will be taken into account.
  - In watts (W) to calculate I the efficiency of the appliance will be taken into account (if the indicated value corresponds to the supplied power and not to the power input) and cosines φ
  - In volt-ampere (VA) it is the apparent power taking into account the efficiency of the appliance and cosines φ.

    0.8 for P ≤ 20 HP
    0.85 for P > 20 ≤ 80 HP
    0.9 for P > 80 HP

- ***U: Mains effective voltage in volts***
  - Voltage between two cores of D.C. or single-phase A.C. supply line.
  - Voltage between 2 phase cores of a A.C. three phase circuit.
- ***Cos. φ: Operating power factor***
  - Cos. φ # 1 for incandescent lamps and heating elements
  - Cos. φ = 0.8 to 0.9 for motors
  - Cos. φ= 0.3 to 0.6 for fluorescent lamps.

NB: 0.8 shall be taken if the cosines φ is not indicated.

6.2.2. Calculation of current rating

As per the basic formulas

Current	Basic formula
direct	$I = \dfrac{P}{U}$
single-phase	$I = \dfrac{P}{U \cos.\varphi}$
two-phase alternating (three-core)	$I = \dfrac{P}{U\sqrt{2}\cos.\varphi}$
alternating three-phase	$I = \dfrac{P}{U\sqrt{3}\cos.\varphi}$

Table 38: Calculation of current rating

I: Current rating (in amperes)

U: Voltage between cores (in volts)

P: Power input (in watts) taking into account the efficiency of the motor.

6.2.3. Pre-calculated current rating tables

Take directly on the tables the (maximum and nominal) current pre-calculated with a cosines phi of 0.8

P in HP	P power equivalent in kW	Effi. δ	P power input in kW	I under 220 V single-phase in A	I under 220 V three-phase in A	I under 380 V three-phase in A
1	0.736	0.8	0.92	5.23	3.01	1.75
1.5	1.104	0.8	1.38	7.84	4.52	2.62
2	1.472	0.8	1.84	10.45	6.03	3.49
2.5	1.840	0.8	2.30	13.07	7.54	4.36
3	2.208	0.8	2.76	15.68	9.04	5.24
4	2.944	0.8	3.68	20.91	12.06	6.98
5	3.680	0.8	4.60	26.14	15.07	8.73
5.5	4.048	0.8	5.06	28.75	16.58	9.60
6	4.416	0.8	5.52	31.36	18.09	10.47
7	5.152	0.8	6.44	36.59	21.10	12.22
8	5.888	0.8	7.36	41.82	24.12	13.96
9	6.624	0.8	8.28	47.05	27.13	15.71
10	7.360	0.8	9.20	52.27	30.15	17.46
12	8.832	0.8	11.04	62.73	36.18	20.95
15	11.04	0.8	13.80	78.41	45.22	26.18
20	14.72	0.8	18.40	104.55	60.30	34.91
25	18.40	0.85	21.65	123.02	70.95	41.08
30	22.08	0.85	25.98	147.62	85.14	49.29
35	25.76	0.85	30.31	172.22	99.33	57.51
40	29.44	0.85	34.64	196.82	113.52	65.73
45	33.12	0.85	38.96	221.37	127.67	73.92
50	36.80	0.85	43.29	245.97	141.86	82.14

Table 39: Calculation current rating, cos phi 0.8 power up to 37 kW

P in HP	P power equivalent in kW	Effi. δ	P power input in kW	I under 220 V single-phase in A	I under 220 V three-phase in A	I under 380 V three-phase in A
55	40.48	0.85	47.62	270.58	156.05	90.35
60	44.16	0.85	51.95	295.18	170.24	98.57
65	47.84	0.85	56.28	319.78	184.43	106.79
70	51.52	0.85	60.61	344.39	198.62	115.00
75	55.20	0.85	64.94	368.99	212.81	123.22
80	58.88	0.85	69.27	393.59	227.00	131.43
85	62.56	0.9	69.51	394.96	227.78	131.89
90	66.24	0.9	73.60	418.20	241.19	139.65
95	69.92	0.9	77.69	441.43	254.59	147.41
100	73.60	0.9	81.78	464.67	267.99	155.17
110	80.96	0.9	89.96	511.15	294.80	170.69
125	92.00	0.9	102.22	580.81	334.97	193.95
135	99.36	0.9	110.40	627.29	361.78	209.47
150	110.40	0.9	122.67	697.01	401.99	232.75
175	128.80	0.9	143.11	813.15	468.97	271.54
200	147.20	0.9	163.56	929.35	535.99	310.34
220	161.92	0.9	179.91	1022.25	589.57	341.36
250	184.00	0.9	204.44	1161.63	669.95	387.90
270	198.72	0.9	220.80	1254.59	723.56	418.95
300	220.80	0.9	245.33	1393.96	803.95	465.49
350	257.60	0.9	286.22	1626.30	937.94	543.07

Table 40: Calculation current rating, cos phi 0.8 power 40 to 260 kW

6.2.4. Current Carrying Capacity

The current-carrying capacity values of the tables under imply some knowledge concerning laying conditions (cables in free air, buried, in pipes...) and the type of current (single-phase or alternating three-phase). Signification of column letter (A to M) is seen in the following paragraph. *(Correction Factors due to laying conditions)*

Current-carrying capacities are those calculated with the IEC 287 formula valid for 2 or 3 single-core cables or a single multicore cable layed:

- In free air (ambient temperature of 30 °C).
- Underground (ambient temperature of 20 °C).

In the following tables, first one is for Copper conductors, second for Aluminium

sq. mm	A	B	C	D	E	F	G	H	I	J	K	L	M
1.5	37	31	32	26	26	23	22	18.5	—	24	19.5	17.5	15.5
2.5	48	41	42	34	36	31	30	25	—	33	27	24	21
4	63	53	54	44	49	42	40	34	—	45	36	32	28
6	80	66	67	56	63	54	51	43	—	58	48	41	36
10	104	87	90	74	86	75	70	60	—	80	63	57	50
16	136	113	116	96	115	100	94	80	—	107	85	76	68
25	173	144	148	123	149	127	119	101	161	138	112	96	89
35	208	174	178	147	185	158	147	126	200	169	138	119	110
50	247	206	211	174	225	192	179	153	242	207	168	144	134
70	304	254	261	216	289	246	229	196	310	268	213	184	171
95	360	301	308	256	352	298	278	238	377	328	258	223	207
120	410	343	351	290	410	346	322	276	437	382	299	259	239
150	463	387	397	328	473	395	371	319	504	441	344	299	—
185	518	434	445	367	542	450	424	364	575	506	392	341	—
240	598	501	514	424	641	538	500	430	679	599	461	403	—
300	677	565	581	480	741	621	576	497	783	693	530	464	—
400	—	—	—	—	—	754	656	—	940	825	—	—	—
500	—	—	—	—	—	868	749	—	1083	946	—	—	—

Table 41: Current carrying capacities for copper conductors

sq. mm	A	B	C	D	E	F	G	H	I	J	K	L	M
35	160	134	137	114	135	120	112	96	150	126	103	90	86
50	188	160	161	134	164	146	136	117	184	154	125	110	104
70	233	197	200	167	211	187	174	150	237	198	160	140	133
95	275	234	237	197	257	227	211	183	289	241	195	170	161
120	314	266	270	224	300	263	245	212	337	280	226	197	186
150	359	300	304	254	346	304	283	245	389	324	261	227	—
185	398	337	343	285	397	347	323	280	447	371	298	259	—
240	458	388	396	328	470	409	382	330	530	439	352	305	—
300	520	440	447	371	543	471	440	381	613	508	406	351	—
400	—	—	—	—	—	600	526	—	740	663	—	—	—
500	—	—	—	—	—	694	610	—	856	770	—	—	—
630	—	—	—	—	—	808	711	—	996	899	—	—	—

Table 42: Current carrying capacities for aluminium conductors

6.3. CORRECTION FACTORS

The current-carrying capacity of a cable is the capacity that causes a temperature rise equal to the admissible temperature of the cable insulation at the surface of the core.

6.3.1. Ambient Temperature

Permissible at 20 °C for underground installation and at
30 °C for installation on cable trays

For other ambient temperatures reference current-carrying capacities shall be multiplied by the correction factor K, given by the formula: $K = \sqrt{\frac{\theta - T}{\theta - t}}$

With
θ: admissible conductor temperature in continuous duty in °C.
T: ambient temperature in °C.
t: temperature is 20 °C for buried cables 30 °C for cables in free air

Ambient temperature	Low-voltage cables	
	Insulation	
	PVC	XLPE or EPR
Underground cables		
10 °C	1.10	1.07
15 °C	1.05	1.04
20 °C	1.00	1.00
25 °C	0.95	0.96
30 °C	0.89	0.93
35 °C	0.84	0.89
Cables in free air		
10 °C	1.22	1.15
15 °C	1.17	1.12
20 °C	1.12	1.08
25 °C	1.06	1.04
30 °C	1.00	1.00
35 °C	0.94	0.96
40 °C	0.87	0.91
45 °C	0.79	0.87
50 °C	0.71	0.82
55 °C	0.61	0.76
60 °C	0.50	0.71
65 °C	—	0.65
70 °C	—	0.58
75 °C	—	0.50

Table 43: Correction factor as per ambient temperature

6.3.2. Admissible Temperature in continuous duty

- LV cables PVC insulated 70 °C
- LV cables XLPE insulated 90 °C
- LV cables EPR insulated 90 °C

6.3.3. Laying Conditions

Uncontiguous laying implies that the free distance between two cables or two cores is at least twice equal to the outer diameter of the largest core or cable.

When that distance is not respected, cables or cores are considered contiguous.
When the horizontal distance between neighbouring cables is twice higher than their outer diameter, no correction factor is necessary.

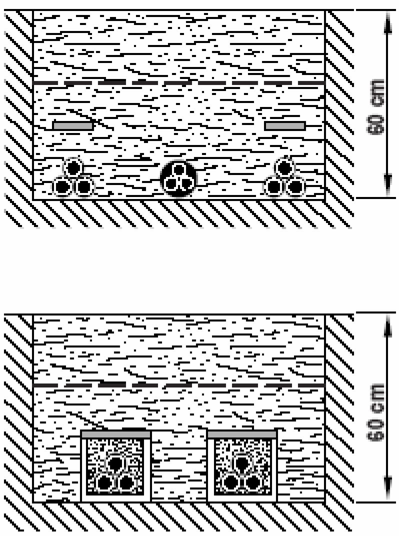
Among all the cables or circuits, those with a current inferior or equal to:

- 70 % of the current-carrying capacity for circuits laid in free air.
- 30 % of the current-carrying capacity for other circuits will not be taken into account.

Equally cores used for control or similar circuits are not taken into consideration.
Correction factors are given for the following cases:

6.3.3.1. Buried cables or buried in ducts filled with sand.

Three-core cables or single-core cables in trefoil formations buried in layers at a depth of 0.6 m in an average thermic soil conductance of 1K. m/W (NF C 15-100).

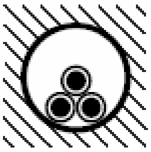
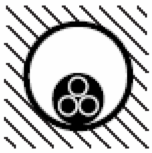


REFERENCE CURRENT - CARRYING CAPACITY		
	single-phase	three-phase
	Column	
PVC	C	D
XLPE	A	B
Copper : **table 41**		Aluminium : **table 42**

K		COEFFICIENT OF PROXIMITY				
		Distance between cables or trefoil formations				
		zero	∅ cable	0.25 m	0.5 m	1.0 m
Number of cables or trefoil formations	2	0.76	0.79	0.84	0.88	0.92
	3	0.64	0.67	0.74	0.79	0.85
	4	0.57	0.61	0.69	0.75	0.82
	5	0.52	0.56	0.65	0.71	0.80
	6	0.49	0.53	0.60	0.69	0.78

Figure 49: Correction factor for buried cables buried in ducts filled with sand

6.3.3.2. Cable laid in pipe embedded in concrete or buried (A).

K		
	0.80	0.80

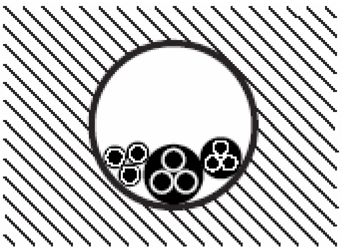
REFERENCE CURRENT - CARRYING CAPACITY		
	single-phase	three-phase
	Column	
PVC	C	D
XLPE	A	B
Copper : **table 41**	Aluminium : **table 42**	

Figure 50: Cables laid in pipe, embedded in concrete or buried. (A)

6.3.3.3. Cables laid in pipe, embedded in concrete or buried (B).

Reference current-carrying capacities are those defined in paragraph above, bearing the coefficient 0.8.

A K coefficient will be applied to those current-carrying capacities in accordance with the table below.



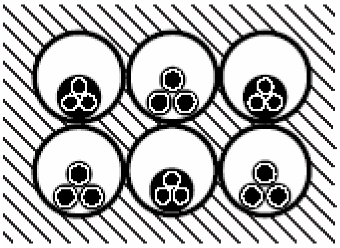
	Number of cables or trefoil formations										
	2	3	4	5	6	7	8	9	12	16	20
K	0.71	0.58	0.50	0.45	0.41	0.38	0.35	0.33	0.29	0.25	0.22

Figure 51: Cables laid in pipe, embedded in concrete or buried. (B)

6.3.3.4. Cables laid in contiguous pipes, in one or several layers embedded in concrete or buried.

Reference current-carrying capacities are those defined in paragraph above, bearing the coefficient 0.8.

Pipes being contiguous, a K coefficient will be applied to those current-carrying capacities in accordance with the table below.

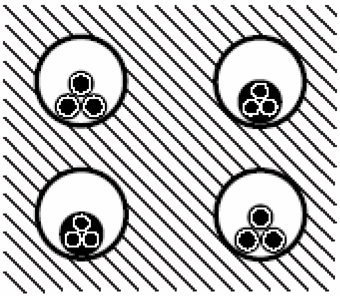


K		Number of pipes in horizontal position					
		1	2	3	4	5	6
Number of pipes in vertical position	1	1	0.87	0.77	0.72	0.68	0.65
	2	0.87	0.71	0.62	0.57	0.53	0.50
	3	0.77	0.62	0.53	0.48	0.45	0.42
	4	0.72	0.57	0.48	0.44	0.40	0.38
	5	0.68	0.53	0.45	0.40	0.37	0.35
	6	0.65	0.50	0.42	0.38	0.35	0.32

Figure 52: Cables laid in contiguous pipes

6.3.3.5. Cables laid in spaced pipes, embedded in concrete or buried.

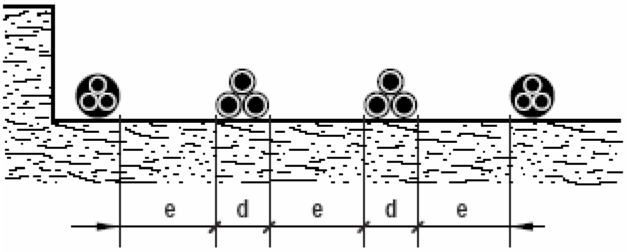
A K coefficient will be applied to those current-carrying capacities in accordance with the table below.



K		Distance between pipes		
		0.25 m	0.50 m	1.0 m
Number of pipes	2	0.93	0.95	0.97
	3	0.87	0.91	0.95
	4	0.84	0.89	0.94
	5	0.81	0.87	0.93
	6	0.79	0.86	0.93

Figure 53: Cables laid in spaced pipes

6.3.3.6. Cables laid spaced, in free air, in single layer, on the ground or on unperforated trays.



K = 1 if e ≥ 2 d

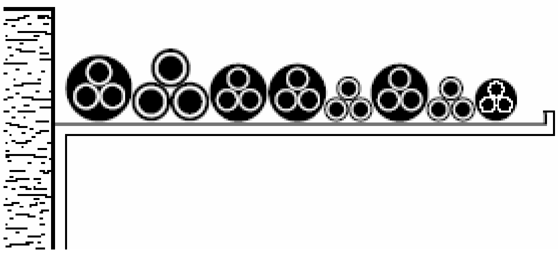
REFERENCE CURRENT - CARRYING CAPACITY		
	single-phase	three-phase
	Column	
PVC	K	L
XLPE	J	G
Copper : table 41	Aluminium : table 42	

Figure 54: Cables laid spaced in free air – unperforated tray

6.3.3.7. Cables laid contiguous, in free air, in single layer, on the ground or on unperforated trays.

Reference current-carrying capacities are those defined in paragraph above.

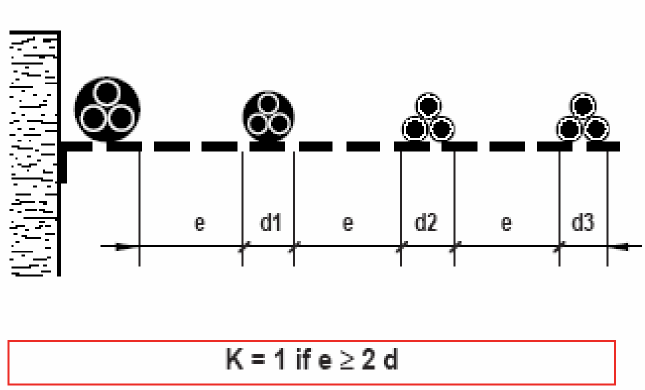
Cables or single-core cables in trefoil formations being contiguous, a K coefficient will be applied to those current-carrying capacities, in accordance with the table below.



	Number of cables or trefoil formations							
	2	3	4	5	6	7	8	≥ 9
K	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.70

Figure 55: Cables laid contiguous in free air – unperforated tray

6.3.3.8. Cables laid spaced, in free air, in single layer, on perforated trays.

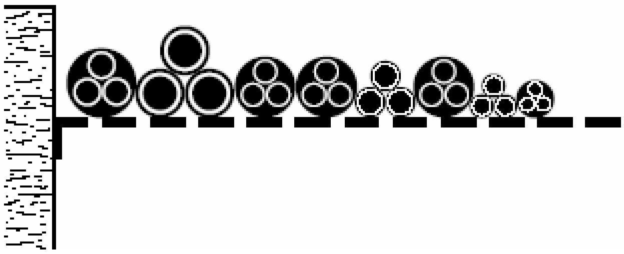


REFERENCE CURRENT - CARRYING CAPACITY				
	SINGLE-CORE		MULTICORE	
	single-phase	three-phase	single-phase	three-phase
	Column			
PVC	F	K	G	H
XLPE	I	J	E	F
Copper : table 41		Aluminium : table 42		

Figure 56: Cables laid spaced in free air – perforated tray

6.3.3.9. Cables laid contiguous, in free air, in single layer, on perforated trays.

Cables or single-core cables in trefoil formations being contiguous, a K coefficient will be applied to those current-carrying capacities, in accordance with the table below.

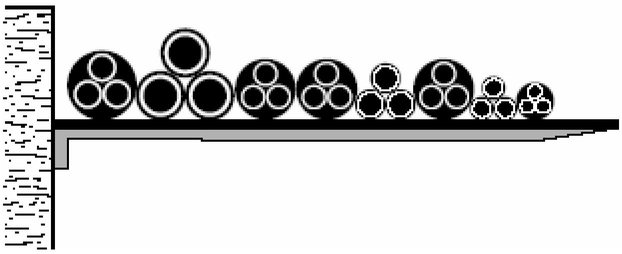


	Number of cables or trefoil formations						
	2	3	4	5	6	7	≥ 8
K	0.88	0.82	0.77	0.75	0.73	0.73	0.72

Figure 57: Cables laid contiguous in free air – perforated tray

6.3.3.10. Cables laid contiguous, in free air, in single layer, on cables ladder or brackets.

Cables or single-core cables in trefoil formations being contiguous, a K coefficient will be applied to those current-carrying capacities, in accordance with the table below.



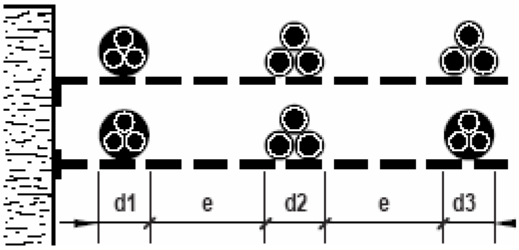
	Number of cables or trefoil formations						
	2	3	4	5	6	7	≥ 8
K	0.88	0.82	0.80	0.80	0.79	0.79	0.78

Figure 58: Cables laid contiguous in free air – cables ladder

6.3.3.11. Cables laid spaced, in free air, in several layers, on perforated trays.

A K coefficient will be applied to those current-carrying capacities in accordance with the table below which will take the number of layers into account.

In each layer, cables or single-core cables in trefoil formations being uncontiguous (e ≥ 2 d) it is not necessary to apply other reduction coefficient.

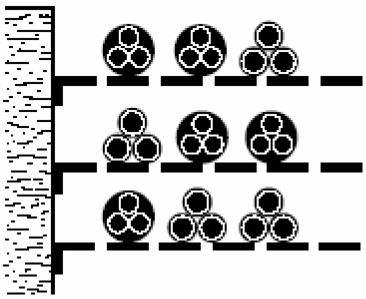


	Number of layers							
	2	3	4	5	6	7	8	≥ 9
K	0.80	0.73	0.70	0.70	0.68	0.68	0.68	0.66

Figure 59: Cables laid spaced in free air – several layers perforated trays

6.3.3.12. Cables laid contiguous, in free air, in several layers, on perforated trays.

Cables being on the one hand contiguous and on the other hand laid in several layers, a K coefficient will be applied to those current-carrying capacities in accordance with the table below taking into consideration those two factors.

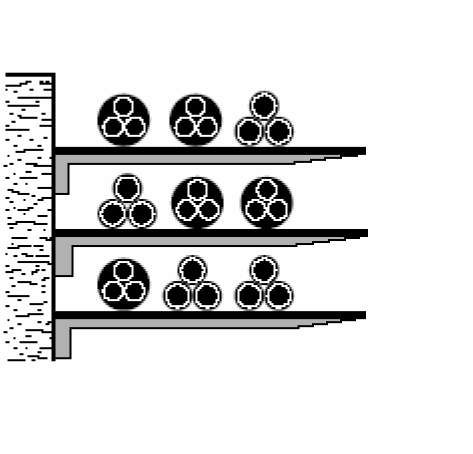


K		Number of cables or trefoil formations in horizontal position						
		1	2	3	4	5	6 - 7	≥ 8
Number of layers	1	1	0.88	0.82	0.77	0.75	0.73	0.72
	2	0.80	0.70	0.66	0.62	0.60	0.58	0.57
	3	0.73	0.64	0.60	0.56	0.55	0.53	0.52
	4-5	0.70	0.62	0.57	0.54	0.52	0.51	0.50
	6-7-8	0.68	0.60	0.56	0.52	0.51	0.50	0.49
	≥ 9	0.66	0.58	0.54	0.51	0.50	0.48	0.48

Figure 60: Cables laid contiguous – several layers perforated trays

6.3.3.13. Cables laid contiguous, in free air, in several layers, on cables ladder or brackets.

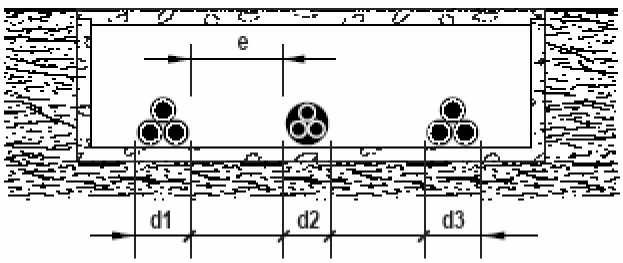
Cables being on the one hand contiguous and on the other hand laid in several layers, a K coefficient will be applied to those current-carrying capacities in accordance with the table below, taking into consideration those two factors.



K		Number of cables or trefoil formations in horizontal position						
		1	2	3	4	5	6 - 7	≥ 8
Number of layers	1	1	0.88	0.82	0.80	0.80	0.79	0.78
	2	0.80	0.70	0.66	0.64	0.64	0.63	0.62
	3	0.73	0.64	0.60	0.58	0.58	0.58	0.57
	4-5	0.70	0.61	0.57	0.56	0.56	0.55	0.55
	6-7-8	0.68	0.60	0.56	0.54	0.54	0.54	0.53
	≥ 9	0.66	0.58	0.54	0.53	0.53	0.52	0.51

Figure 61: Cables laid contiguous – several layers cables layers

6.3.3.14. Cables laid spaced, in ducts without sand.



K = 0.95 with e ≥ 2 d

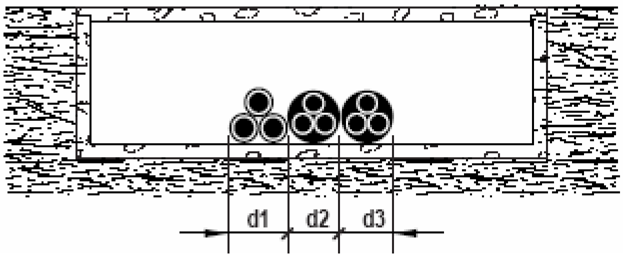
REFERENCE CURRENT - CARRYING CAPACITY		
	single-phase	three-phase
	Column	
PVC	L	M
XLPE	F	K
Copper : table 41	Aluminium : table 42	

Figure 62: Cables laid spaced in ducts without sand

6.3.3.15. Cables laid contiguous, in ducts without sand.

Reference current-carrying capacities are those defined in paragraph above, bearing the coefficient 0.95.

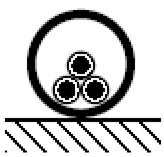
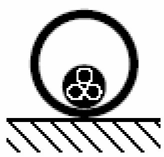
Cables or single-core cables in trefoil formations being contiguous, a K coefficient will be applied to those current-carrying capacities in accordance with the table below.



	Number of cables or trefoil formations										
	2	3	4	5	6	7	8	9	12	16	20
K	0.80	0.70	0.65	0.60	0.55	0.55	0.50	0.50	0.45	0.40	0.40

Figure 63: Cables laid contiguous in ducts without sand

6.3.3.16. Cables laid in spaced pipes, in free air, in single layer.

K		
	0,90	0,90

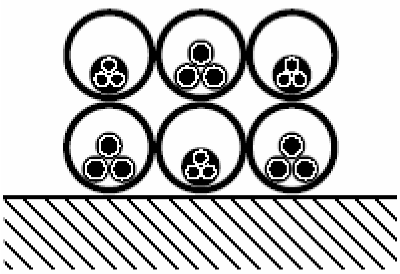
REFERENCE CURRENT - CARRYING CAPACITY		
	single-phase	three-phase
	Column	
PVC	L	M
XLPE	F	K
Copper : **table 41**	Aluminium : **table 42**	

Figure 64: Cables laid in spaced pipes – free air single layer

6.3.3.17. Cables laid in contiguous pipes, in free air, in one or several layers

Reference current-carrying capacities are those defined in paragraph above, bearing the coefficient 0.90.

Pipes being contiguous, a K coefficient will be applied to those current-carrying capacities in accordance with the table below.



K		Number of pipes in horizontal position					
		1	2	3	4	5	6
Number of pipes in vertical position	1	1	0.94	0.91	0.88	0.87	0.86
	2	0.92	0.87	0.84	0.81	0.80	0.79
	3	0.85	0.81	0.78	0.76	0.75	0.74
	4	0.82	0.78	0.74	0.73	0.72	0.72
	5	0.80	0.76	0.72	0.71	0.70	0.70
	6	0.79	0.75	0.71	0.70	0.69	0.68

Figure 65: Cables laid in contiguous pipes – free air single or several layer

6.3.3.18. Thermal resistivity of the ground

Nature of soil	Thermal resistivity of the ground K. m/W	K
Submerged	0.40	1.25
Very humid	0.50	1.21
Humid	0.70	1.13
Normal	0.85	1.05
Dry	1.00	1.00
Very dry	1.20 1.50 2.00 2.50 3.00	0.94 0.86 0.76 0.70 0.65

Table 44: Thermal resistivity of ground

For buried cables, the current-carrying capacities shown in characteristics tables are given for a soil on which thermal resistivity of the ground is 1 K.m/W.

For ground on which thermal resistivity of the soil is different, a factor K shall be applied to reference currents, according to this table.

7. HIGH-VOLTAGE CABLES

7.1. HV CONNECTIONS

HV starts at 1,000 Volts for electric distribution. MV (medium voltage) no longer exists.

The HV connection is therefore the cable connecting any electric element with a service voltage in excess of 1,000 Volts. (HV generator/HV units – HV units/HV motor– HV units/ transformer - …/…

7.1.1. Why do we need HV connections?

Cables are used to transfer energy, i.e. electric power. The formula P= U·I demonstrates that, with the same power, if we increase ‘U’, we must reduce ‘I’, and this is the aim.

A cable, electric wire (copper, aluminium, etc.) has a given section which limits (due to this section) the current carrying capacity. A section corresponds to a maximum number of amperes while the voltage is limited by the insulation (insulation material) of the conductor wire. The number of amperes is also limited by the length of the cable and the material (Cu, Al, etc.).

Therefore, a remote sub-distribution will be equipped with a step-up transformer and a step-down transformer in order to travel as high voltage, reducing losses from connection cables, and enabling voltage to be adjusted by the transformers.

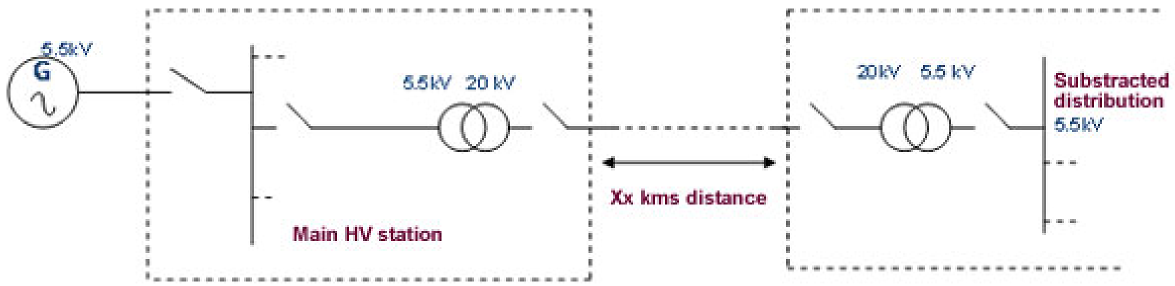


Figure 66: HV connections

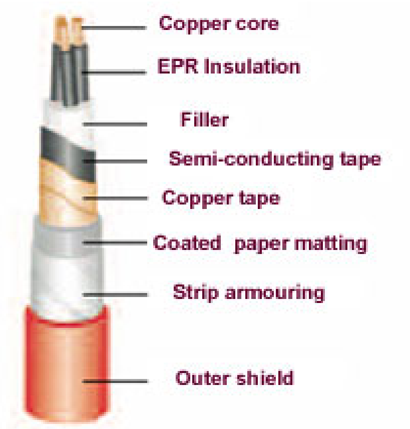
On the site, HV distributions/connections are limited to interconnections between HV generators, the supply of HV/LV transformers and the supply of high power motors with HV (> 1MW).

7.1.2. Manufacturing of high voltage cables

Cables are manufactured according to the standards established by the IEC, and, more precisely, in IEC 502, which specifies the manufacture, sizing (of insulation) and testing of HV cables with a service voltage (U) of 3 - 30kV (higher voltages are rarely present on Total sites).

These cables are manufactured with copper shield on each conductor wire. Service voltage is limited to 10kV for PVC insulation and to 30KV for other insulation (Polyethylene/ethylene-propylene - rubber/cross-linked polyethylene).

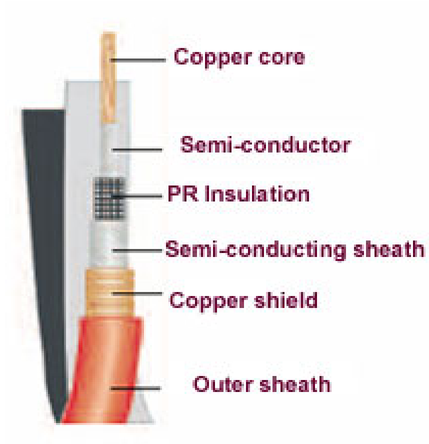
The cables used on the site are radial field cables, however "other" types also exist. The manufacturing method of these three-pole, mono-conductor cables is shown below.



Cable sections (mm^2)	Max. outer diameter (mm)	Current carrying capacity (I)	
		Buried	Unburied
3 x 10	33	72	62
3 x 16	35	94	81
3 x 25	39,5	120	105
3 x 35	43	145	130

Curvature radius: 9 x outer diameter

Figure 67: Three-pole armoured cable with a non-radial field, 6kV



Cable section (mm2)	Max. outer diameter (mm)		Current carrying capacity (I)	
	Sheath	Bunched conductor	Buried	Unburied
3x1x10	18	36	97	92
3x1x16	19,6	39,5	125	120
3x1x25	21,2	42,5	160	155
3x1x35	22,4	45	190	190

Curvature radius: 9 x outer diameter on bunched conductor

Figure 68: Single-pole braided cables (3 mono cables) with a non-armoured non-radial field, 6kV

7.1.3. Service voltage

You will not use a cable selected in 5.5 kV for 20 kV use. It is not the same cable.

However, nothing prevents you from using a 20 kV cable for 5.5 kV distribution. You simply need to justify the decision to the purchasing service, as the 20 kV cable is (obviously) more expensive for the same current-carrying capacity.

The service voltage of a HV cable consists of 3 parameters, Uo, U and Um expressed in kilovolts and shown on the cable description (and etched above) in Uo / U / (Um) format and corresponds to the thickness of the insulation, test conditions (discharge) and the actual service voltage.

- **Uo** is the network voltage, for which the cable will be used, between a conductor and the ground, or between a conductor and a metal shield integrated in the cable.
- **U** is the network voltage between conductors.
- **Um** is the maximal voltage a cable can accept and will correspond to the maximum service voltage.

The standards specify HV cable voltages as per the following "ranges" :

Uo / U / (Um) = 1.8 / 3 (3.6) kV
3.6 / 6 (7.2) kV
6 / 10 (12) kV
8.7 / 15 (17.5) kV
12 / 20 (24) kV
18 / 30 (36) kV

7.1.4. Acceptable currents

The intensity values in the tables below apply to:

- Cables with 3 conductors
- Cables with single conductors laid as clover-leaf formations or aligned
- Non-armoured cables: Aerial, temperature 30°C, cables or cable systems on cable trays, protected from solar radiation and, if more than one cable exists, laid with enough space between them to avoid the effects of "proximity". Spacing ≥ 2 cable diameters.
- Armoured cables: Underground, temperature 20°C, cables or buried cable systems laid in parallel at a depth of 0.80m in a soil with a mean thermal resistivity of 1K.m/W, to ensure that each individual increase in temperature does not influence

the other cables. It is considered that no proximity effects exist between cables with spacing of more than one metre.

Single-pole cables

Nominal section of conductors in mm²	Uo/U (Um) ≤ 6/10 (12) kV								Uo/U (Um) > 6/10 (12) kV and ≤ 18/30 (36) kV			
	Copper conductors				Aluminium conductors				Copper conductors		Aluminium conductors	
	PVC insulated		XLPE or EPR insulated		PVC insulated		XLPE or EPR insulated		XLPE or EPR insulated			
	Aerial	Buried	Aerial	Buried	Aerial	Buried	Aerial	Buried	Aerial	Buried	Aerial	Buried
25	125	135	160	165	96	105	125	125	170	165	130	125
35	150	160	200	195	115	125	150	150	200	195	160	150
50	180	190	235	230	140	150	185	180	245	230	190	180
70	230	235	295	285	175	180	230	220	305	280	235	220
95	280	285	360	340	215	220	280	260	375	335	290	260
120	320	320	420	385	250	250	325	300	425	385	330	300
150	370	360	475	430	285	280	370	335	485	430	375	335
185	425	410	550	485	330	320	425	380	560	490	430	380
240	500	475	650	560	390	370	510	440	860	560	510	440
300	580	540	740	630	455	420	580	500	750	640	590	500
400	670	610	860	720	530	480	680	570	870	720	680	570
500	760	680	990	800	610	540	790	640	1000	810	790	640
630	870	770	1140	910	710	620	920	740	1150	910	930	740

Table 45: Acceptable currents for single-pole cables

Three-pole cables

Nominal section of conductors in mm²	Uo/U (Um) ≤ 6/10 (12) kV								Uo/U (Um) > 6/10 (12) kV and ≤ 18/30 (36) kV			
	Copper conductors				Aluminium conductors				Copper conductors		Aluminium conductors	
	PVC insulated		XLPE or EPR insulated		PVC insulated		XLPE or EPR insulated		XLPE or EPR insulated			
	Aerial	Buried	Aerial	Buried	Aerial	Buried	Aerial	Buried	Aerial	Buried	Aerial	Buried
25	120	130	155	160	93	100	120	125	160	160	125	125
35	145	160	190	190	115	120	145	150	195	190	150	145
50	175	185	225	225	135	145	175	175	230	225	175	175
70	215	230	280	275	165	180	215	215	280	270	220	210
95	260	275	340	330	205	210	260	255	345	330	265	255
120	300	310	385	370	235	240	300	290	395	370	305	290
150	340	345	445	420	265	270	345	325	450	415	345	320
185	385	390	510	470	300	305	395	365	510	465	395	360
240	450	450	590	540	355	350	465	425	600	540	470	420

Table 46: Acceptable currents for three-pole cables

As is the case for low voltage cables, temperatures and laying conditions with correction coefficients must be used. As you will not be required to plan for the installation of HV cables on sites (*although you will be required to replace them!)*, this issue is not covered….

7.1.5. Examples of HV cables

In both of the following examples (in the figures), all voltage ranges are listed. When manufacturing this cable, one single voltage corresponds to the cable, and you must indicate this voltage on the order.

If you have a 20kV network, you need a 12/20 (24) cable.

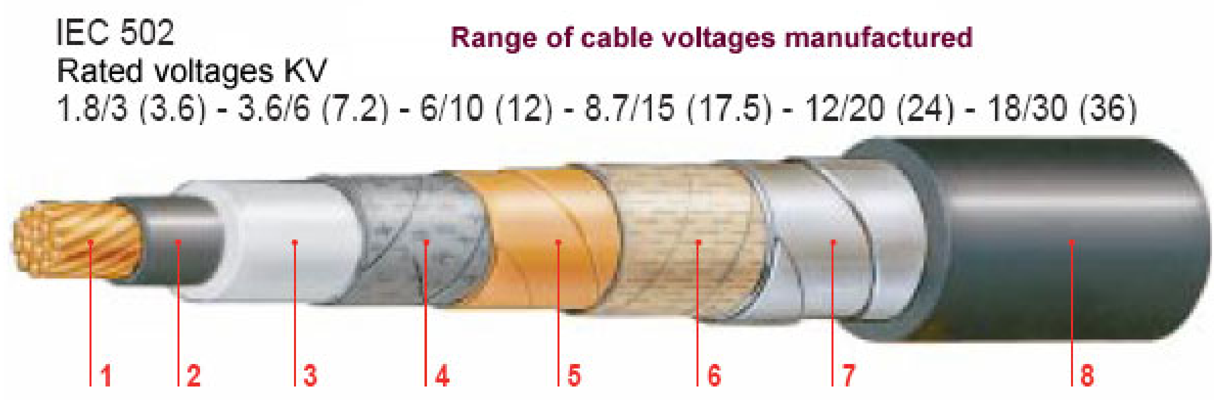


Figure 69: Single-pole cable with radial field/armoured

1. conductor: copper or aluminium
2. semi-conductor: packing or wound band
3. insulation: polyethylene (XLPE) or ethylene propylene (EPR) for all voltages or polyvinyl chloride (PVC) up to 6/10 (12) kV
4. semi-conductor: packing or wound band
5. shield: copper helicoidally wound band
6. inner sheath: polyvinyl chloride
7. armour: simple or double band (or braid) in non-magnetic metal
8. final protection sheath: black polyvinyl chloride or coloured at request.

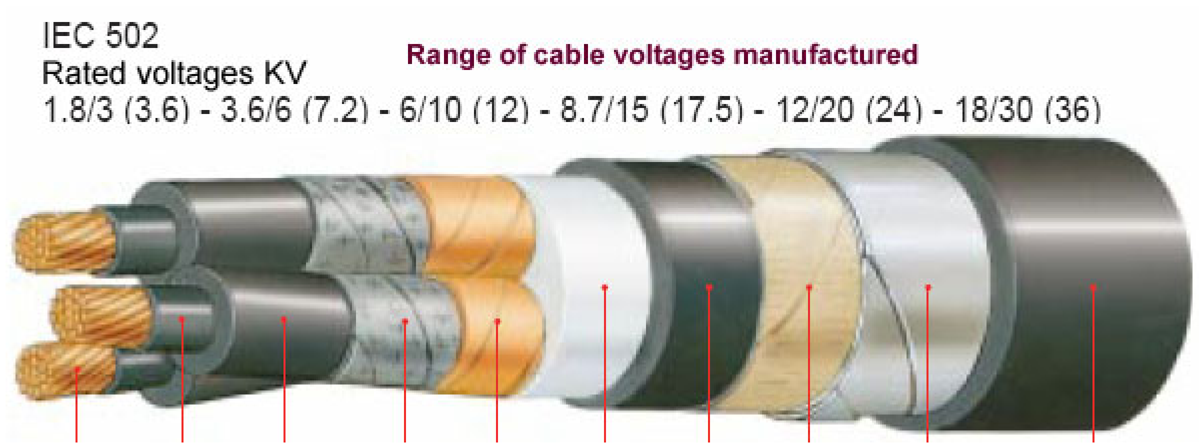


Figure 70: Three-pole cable with radial field/armoured

The same materials are used with (white) packing and an additional layer of PVC.

7.2. AERIAL CABLES

With HV, on the site, cables are the only components concerned, bare cable aerial networks are a distribution network speciality (e.g. EDF) and are not covered in this course.

7.3. UNDERGROUND AND/OR LAID CABLES

HV cables route down specific cable trays, independently from any other routing.

When placed in pits, they may share the same pit as other types of cables.

See chapter below: laying in cable trays and pits.

8. CABLE SUPPORT BRACKETS

8.1. CABLE TRAYS

8.1.1. General

You must start by differentiating the raceways, each level of voltage has an assigned raceway, each electrical field (and related) has a specific raceway or a specific portion of raceway. Each use or field has "its cables" and independent routing must be used per cable type for technical reasons (interference, safety, etc.)

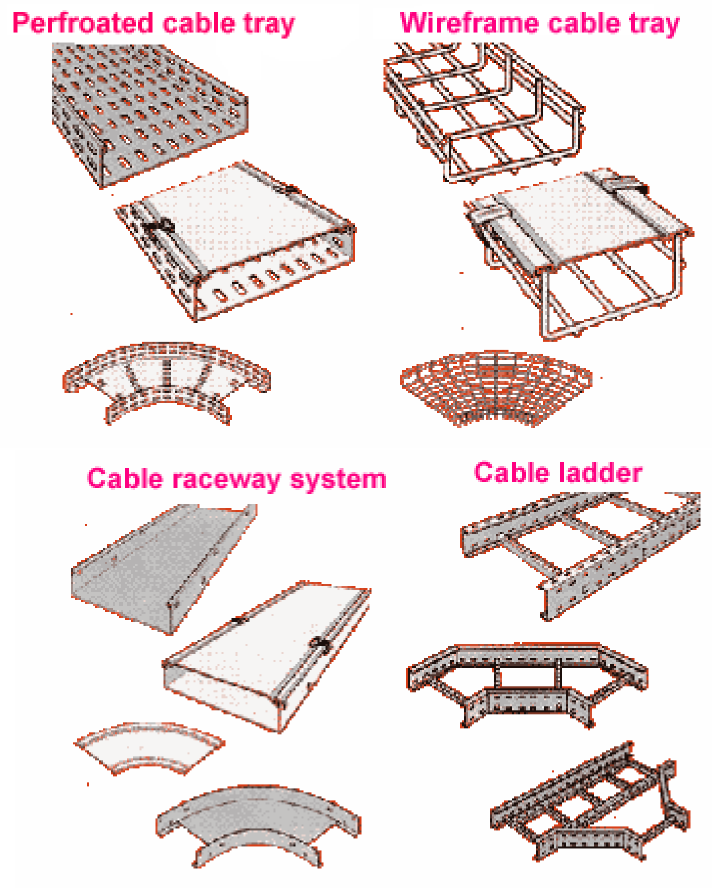
The different raceways on a site are for:

- High voltage
- LV power circuits
- LV control circuits
- Control instrumentation (4-20mA, etc.)
- Low current instrumentation (thermocouples, etc.)/
- Distribution bus instrumentation
- The telephone
- IT
- Ground (as applicable)
- …/…etc

All cables and circuits ‘route' and cross each other according to predetermined rules.

Therefore, please, when on site, do not ask to add a cable to supply your ‘computer’ or control room TV by running the same cable, along (for example) a lightning conductor drop stack …… claiming that it is more convenient

This is not a random example… ask your instructor for an explanation if you do not understand why.



You may have a few surprises: *"how come the compressor comes on when I start the transfer pump?"*

If the cables of vibration sensors or thermocouples run close to the 6 kV cable of the pump, this would explain things….. (Other phenomena could very well not indicate the default trigger factor in case of a rapid transient induction).

Cable trays are in different materials (galvanised steel, stainless steel, fibre glass, PVC, etc.), different constructions (wire, ladder racks, perforated, etc.) and in a range of colours….. Chutes, conduits and tubes (steel or PVC) are all similar to cable trays as they support/guide wires or cables.

Figure 71: Different types of cable trays

The **covers** of cable trays are mainly used to protect cables from the aggression of UV which damage the outer insulation sheath over time, in addition to providing mechanical protection.

8.1.2. Laying of cables

The following are a few tips to be used when aligning cables onto cable trays

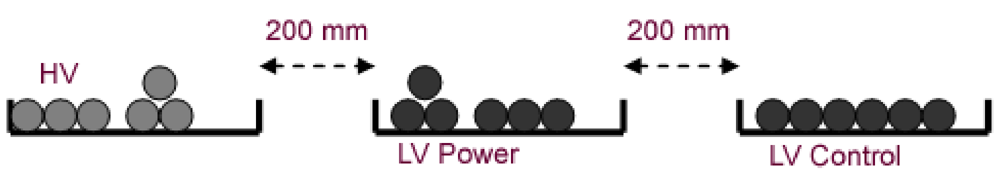


Figure 72: Horizontal distances between cable trays

Whether the cable trays are laid ***vertically or horizontally***, the different types will have a minimum installation distance to be maintained between them.

A distance of 200mm is frequently used, however, check the correct specifications, as this may not be the case.

Cable raceways are mechanically and electronically splinted together using a ground conductor connected to the general ground. This includes PVC and fibre glass cable trays (static electricity!)

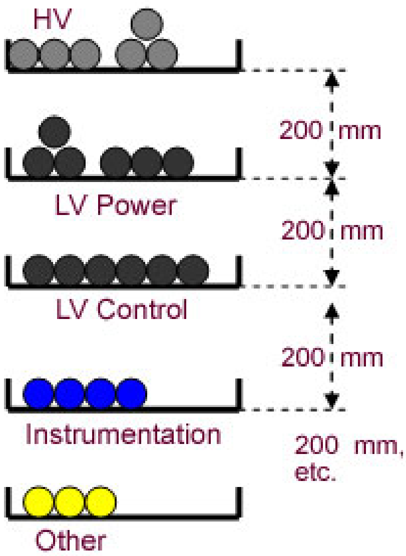


Figure 73: Vertical distances between cable trays

Clover-leaf or aligned formations

This section concerns power cables. A cable carrying three phase current has braided conductors by design to cancel (or minimise rather) the electromagnetic induction produced by each phase (imagine the 3 vectors at 120°, their vector component is zero).

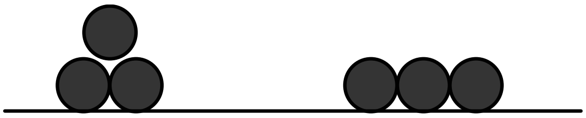


Figure 74: Clover-leaf or aligned formations

Three-phase cables (or three + N) may be laid either aligned or in a clover-leaf formation indifferently, however with high powers, when several single-pole cables form one phase, the clover-leaf technique must be used, where the 3 conductors in the clover-leaf represent the 3 phases.

As a general rule, the ***cables*** must not be "thrown" on the cable trays, but rather ***aligned and attached***. This is not only for aesthetical reasons, but also for maintenance purposes (adding/removing a cable) and to reduce induction phenomena.

If you find cables which are heating up, or even a hot cable tray, this is not necessarily due to a current overload, and may simply be because the cables are incorrectly laid…

8.1.3. Ladder rack

Cable ladder rack is a quick and easy method of transporting heavy – duty cables across long distances and in the worst site conditions as it can withstand high winds heavy snow, sand or dust settlement, or high humidity.

The ladder is very strong and can be mounted in virtually any direction.

Ladder rack is made of steel and hot dipped galvanised.

Ladder rack can often be used in conjunction with cable tray on an installation.

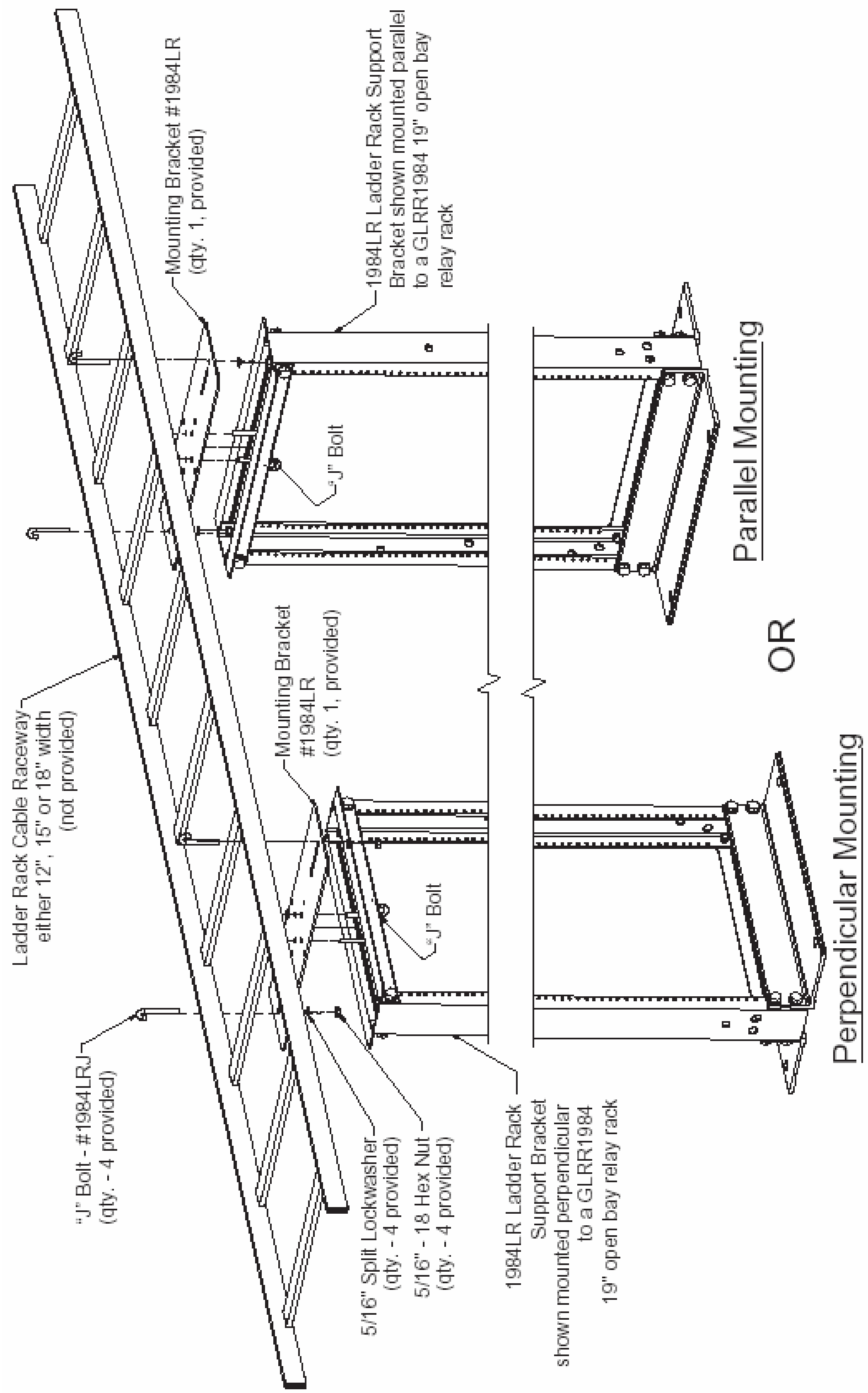


Figure 75: Ladder rack system

You can find ladder racks, on site in switchgear /MCC electrical rooms and even more often in the basement of those rooms.

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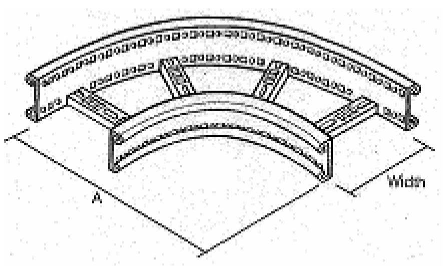
<td>
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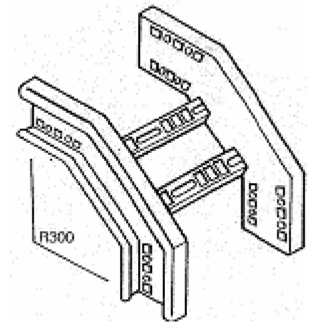
<td>
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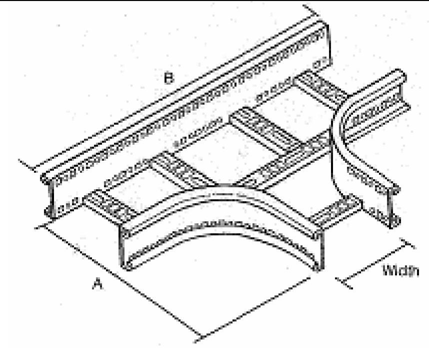
<td>
</td>
</tr>
<tr><td>90° Bend</td><td>90° Outside Riser</td><td>Equal Tee</td></tr>
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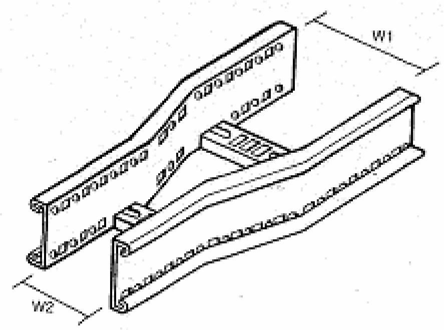
<td>
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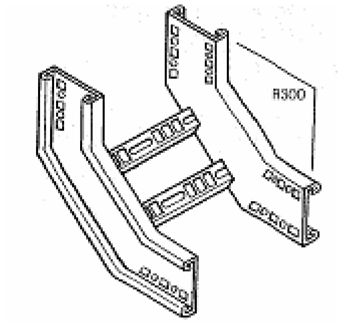
<td>
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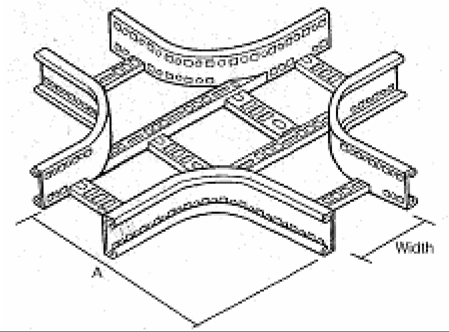
<td>
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</tr>
<tr><td>Straight Reducer</td><td>90° Inside Riser</td><td>Equal Crossover</td></tr>
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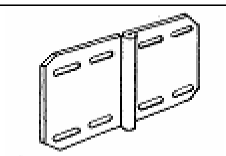
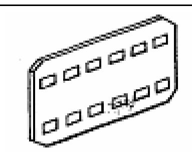
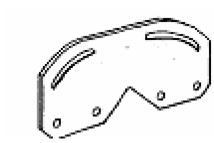
<td></td>
<td></td>
<td></td>
</tr>
<tr><td>Horizontal Hinged Coupler</td><td>Flat Coupler</td><td>Vertical Coupler</td></tr>
</table>

Table 47: Accessories for Ladder Rack

8.1.4. The different types of Cable trays

What types of Cable Tray are available?

- Ladder (As above)

- Solid Bottom
- Trough
- Channel
- Wire Mesh
- Single Rail

8.1.4.1. Ladder Cable Tray provides

Figure 76: Ladder cable tray

- Solid side rail protection and system strength with smooth radius fittings and a wide selection of materials and finishes.
- Maximum strength for long span applications standard widths
- Standard depths
- Standard lengths
- Rung spacing

Standard dimensions as per countries and manufacturers

8.1.4.2. Solid Bottom Cable Tray provides

- Non-ventilated continuous support for delicate cables with added cable protection available in metallic and fibreglass.

- Solid bottom metallic with solid metal covers for cable in environmental air areas
- Standard widths
- Standard depths
- Standard lengths

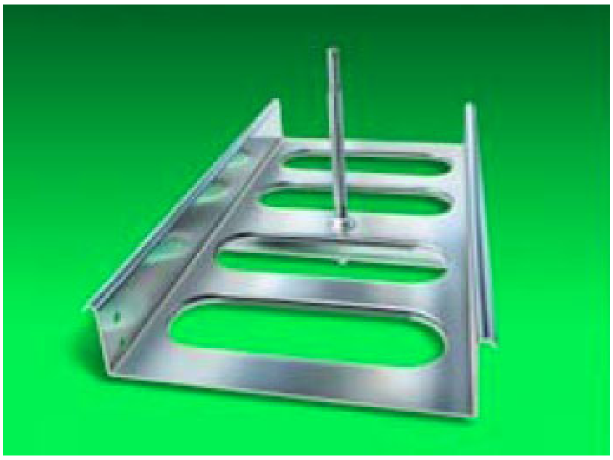
Standard dimensions as per countries and manufacturers

Figure 77: Solid bottom cable tray

Solid Bottom cable tray is generally used for minimal heat generating electrical or telecommunication, computer applications with short to intermediate support spans

This type of tray is not recommended for use on Sites due to the lack of ventilation afforded.

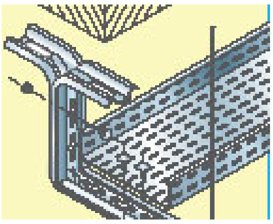
8.1.4.3. Trough Cable Tray provides



- Moderate ventilation with added cable support frequency and with the bottom configuration providing cable support / tying in at very sort distances. Available in metal and non metallic materials.

Figure 78: Trough Cable tray

- Standard widths



- Standard depths
- Standard lengths
- Fixed rung spacing on centre

Figure 79: Perforated Cable Tray

Standard dimensions as per countries and manufacturers

Trough cable tray is generally used for moderate heat generating applications with short to intermediate support spans of 1.5 to 3 m.

The perforated cable tray is also a cable trough type

8.1.4.4. Channel Cable Tray provides

- An economical support for cable drops and branch cable runs from the backbone cable tray system.
- Standard widths in metal systems and in non metallic systems.

Figure 80: Channel Cable tray

- Standard depths in metal systems and 1 in non metallic systems
- Standard length

Standard dimensions as per countries and manufacturers

Channel cable tray is used for installations with limited numbers of tray cable when conduit is undesirable. Support frequency with short to medium support spans of 1.5 to 3 m.

8.1.4.5. Wire Mesh Cable Tray provides

- A job site, field adaptable support system primarily for low voltage, telecommunication and fibber optic cables. These systems are typically steel wire mesh, zinc plated.

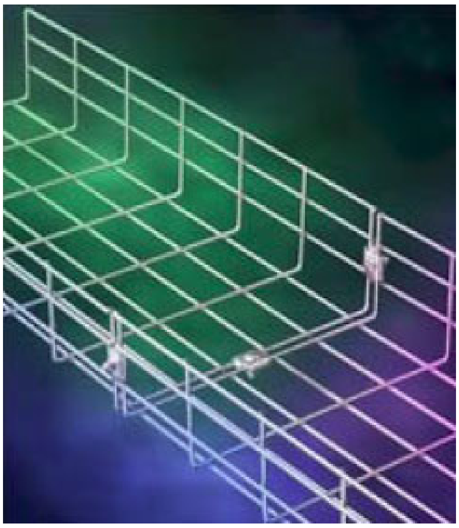


Figure 81: Wire Mesh Cable tray

- Standard widths
- Standard depths
- Standard length

Standard dimensions as per countries and manufacturers

Wire Mesh tray is generally used for telecommunication and fibber optic applications and are installed on short support spans, 1 to 2 m.

8.1.4.6. Single Rail Cable Tray provides

- These aluminium (or other materials now) systems are the fastest systems to install and provide the maximum freedom fort cable to enter and exit the system.

- Single hung or wall mounted systems in single or multiple tiers.
- Standard widths
- Standard depths
- Standard lengths

Figure 82: Single Rail Cable tray

Standard dimensions as per countries and manufacturers

Single Rail Cable Tray is generally used for low voltage and power cables installations where maximum cable freedom, side fill, and speed to install are factors.

8.1.5. Materials / finishes available for the various cable tray systems

- **Steel** (Min. Yield = 33KSI) (35 KSI for Stainless)

  a) Plain: hot rolled pickled and oiled steel per ASTM A569 (Commercial Quality) or A570 (Structural Quality)

  b) Pre-Galvanized: mill galvanized steel per ASTM A653 CS (Commercial) or SS (Structural) G90

  c) Hot Dip Galvanized After Fabrication: plain steel which is hot dipped after fabrication per ASTM A123.

  d) Stainless Steel: type 304 or 316L fully annealed stainless steel

- **Aluminium** (Min.Yield = 23 KSI)

  a) 6063-T6 or 5052-H32 alloy per ASTM B209

- **Fibber Reinforced Plastic (FRP)**

  a) Polyester and Vinyl Ester resin systems available

  b) Meet ASTM E-84 smoke density rating; Polyester 680, Vinyl Ester 1025

  c) Class 1 Flame Rating and self-extinguishing requirements of ASTM D-635.

8.1.6. Cable tray mounting accessories

It is impossible to show all the detailed items which could be used, for one type of cable tray you could find a manufacturer catalogue of 200 pages……

Here are examples of (very) few items.

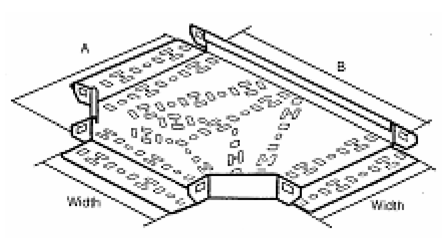
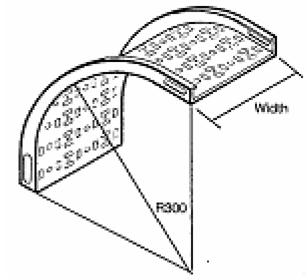
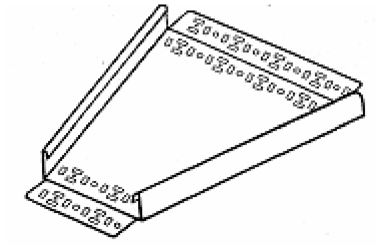
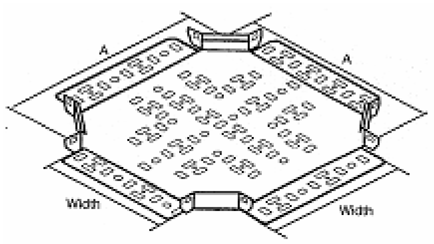
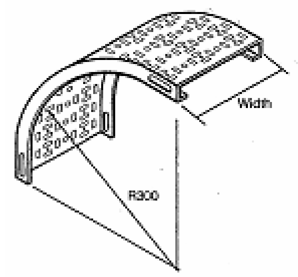
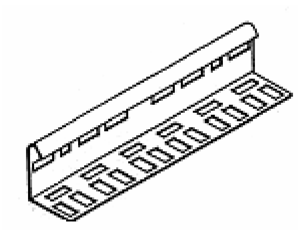
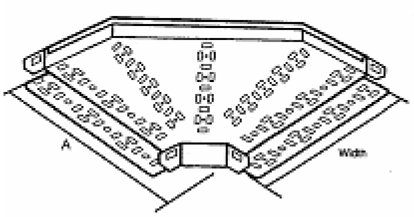
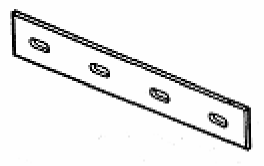
Cable Tray accessories		
		
Equal Tee	90° Outside Riser	Straight Reducer
		
Equal Crossover	90° Inside Riser	External Wrap-over Couple
		
90° Bend	Internal Short Coupler	

Table 48: Accessories for Cable Tray

When these accessories are unavailable for use, the following methods are recommended for the construction of various bends and junctions. It should be noted that all cuts in the metal should be painted with an anti-rust paint.

8.1.7. How to construct a flat 90° Bend

The first step is to mark out the tray (A).

The amount of tray lip to be remove is 2, 3/4 the width of the tray, half of this measurement is drawn either side of the centre line.

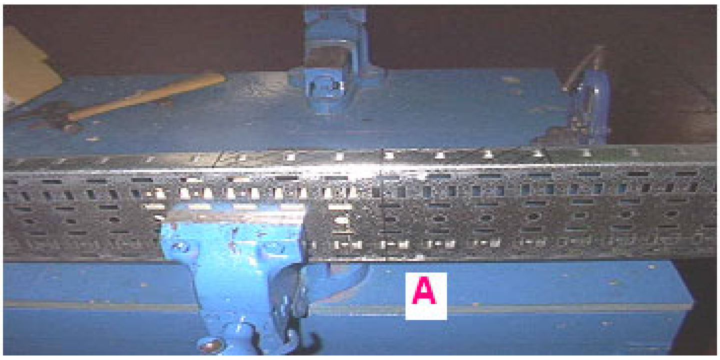


Figure 83: Construct a flat 90° Bend (A)

To remove the lip we can use a small hand grinder (B) or a file (C), but care must be taken when using a hand grinder that the appropriate protective equipment is worn.

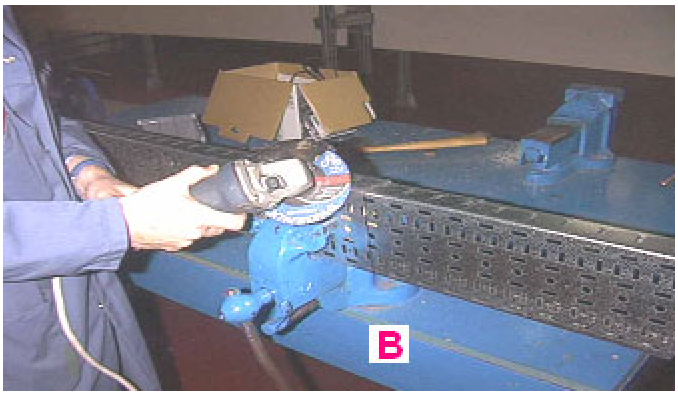


Figure 84: Construct a flat Bend 90° (B)

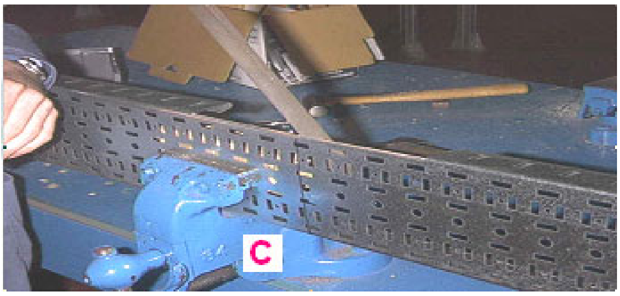
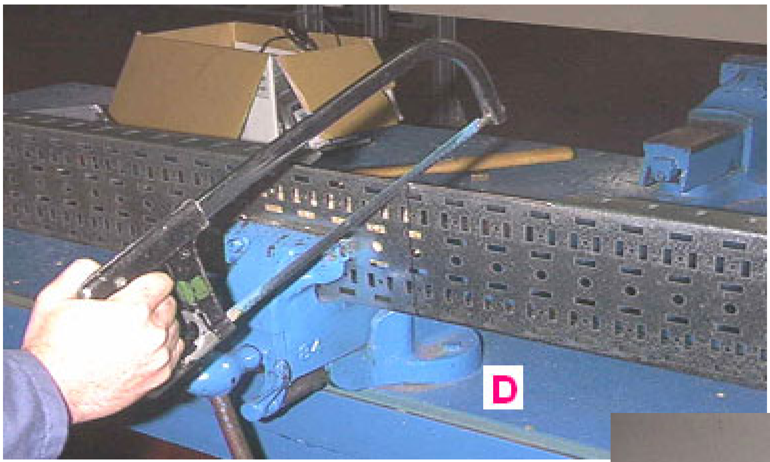


Figure 85: Construct a flat Bend 90° (C



Next we cut down the centre line, care must be taken not to let the tray fall open at this point as it may result in damage to the tray (D).

Figure 86: Construct a flat Bend 90° (D)

Now with a blunt object flatten the tray lip at the point where the tray will bend (E).

Figure 87: Construct a flat Bend 90° (E)

Next bend the tray to 90° and bolt it together (F)

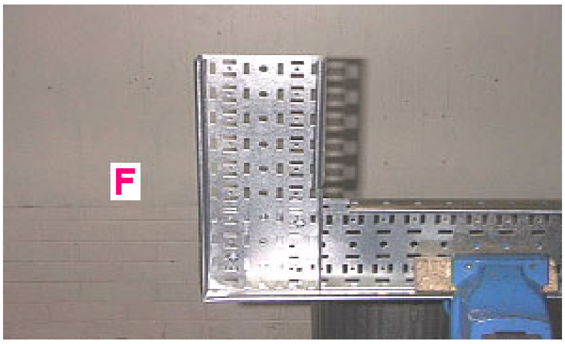
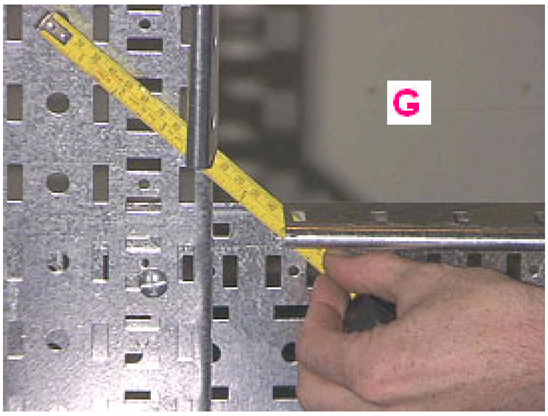


Figure 88: Construct a flat Bend 90° (F)



Now we measure the distance between the 2 internal edges (G).

This will be the measurement for our gusset.

Figure 89: Construct a flat Bend 90° (G)

The gusset is produced by cutting a piece of tray to the measurement required, removing 1 lip completely and bolting it to the 90° bend (H).

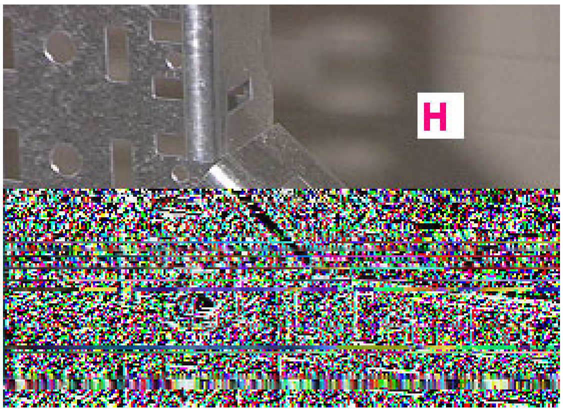
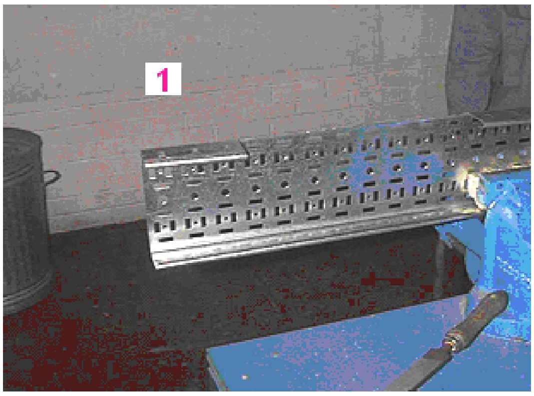


Figure 90: Construct a flat Bend 90° (H)

This completes the 90° bend.

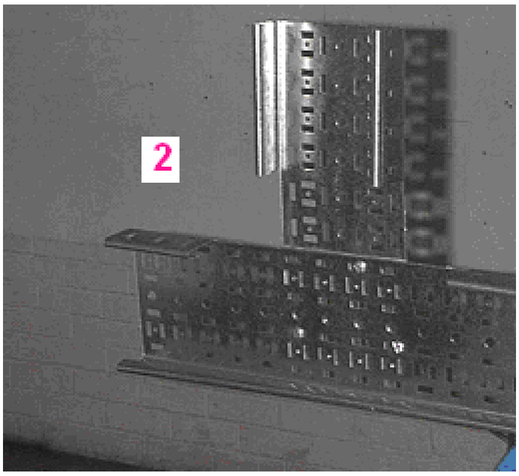
8.1.8. How to construct a Tee Piece



The first step is to mark and remove the tray lip (1).

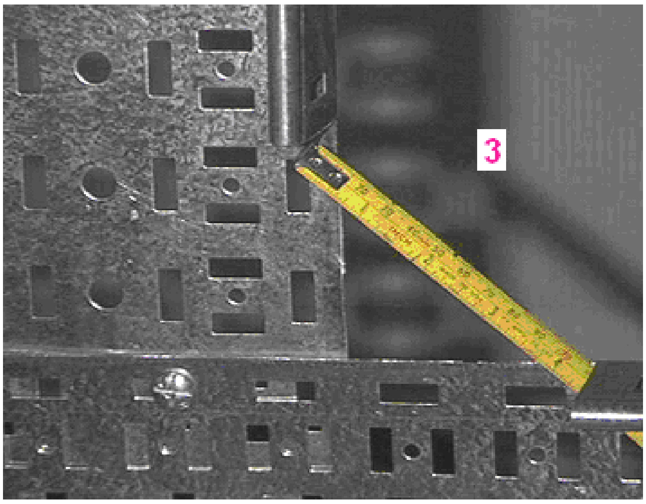
Figure 91: Construct a tee piece (A)

This measurement is twice the width of the tray.



We also remove one and a half times the width of the tray from the piece of tray to be added to the Tee.

Figure 92: Construct a tee piece (2)



The 2 pieces of tray are now bolted together (2)

Next we measure the gussets (3)

Figure 93: Construct a tee piece (3)

Once the gussets have been made, the final step is to bolt the tray together and produce a tee piece (4).

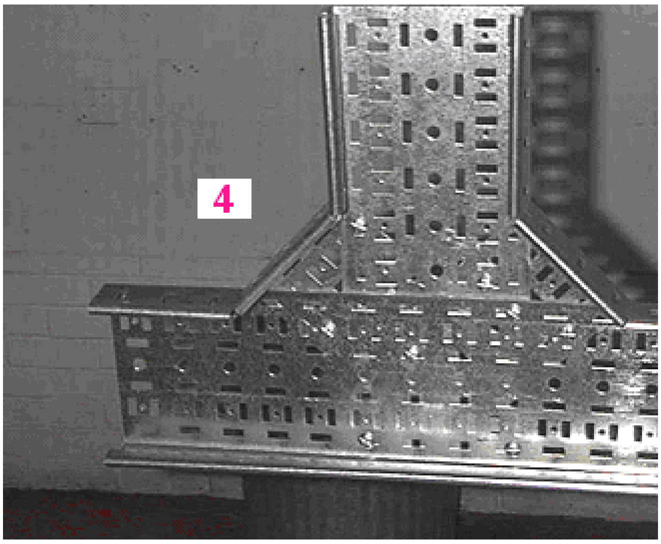


Figure 94: Construct a tee piece (4)

8.1.9. How to construct a 90° External Bend

This perhaps the easiest bend to construct. We first mark the tray out (a).

The lines are drawn 75mm apart, we the cut down all 3 lines on both sides of the tray and bend to 90° as in figures (b) and (c).

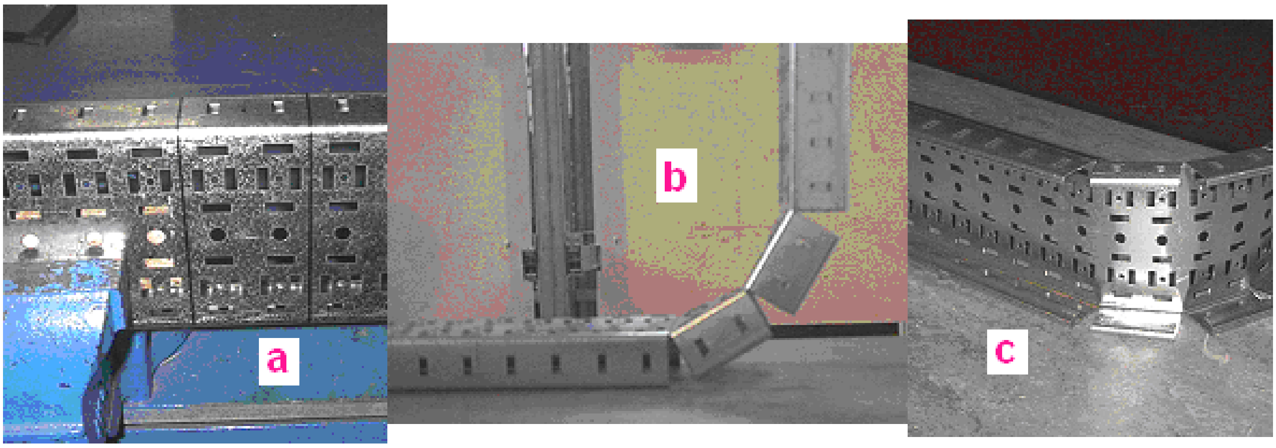


Figure 95: Construct a 90° external bend

To make bending the tray easy try using a round object such as a scaffold tube, handrail etc.

8.1.10. How to construct a 90° Internal Bend

We first mark and remove the tray lip (1). The lines are drawn 75mm apart, next we measure 12mm either side of each of these 3 lines, draw 2 diagonal lines from point A to B and point A to C on all lines and on both edges of the tray and remove.

Next bend to 90° (2)

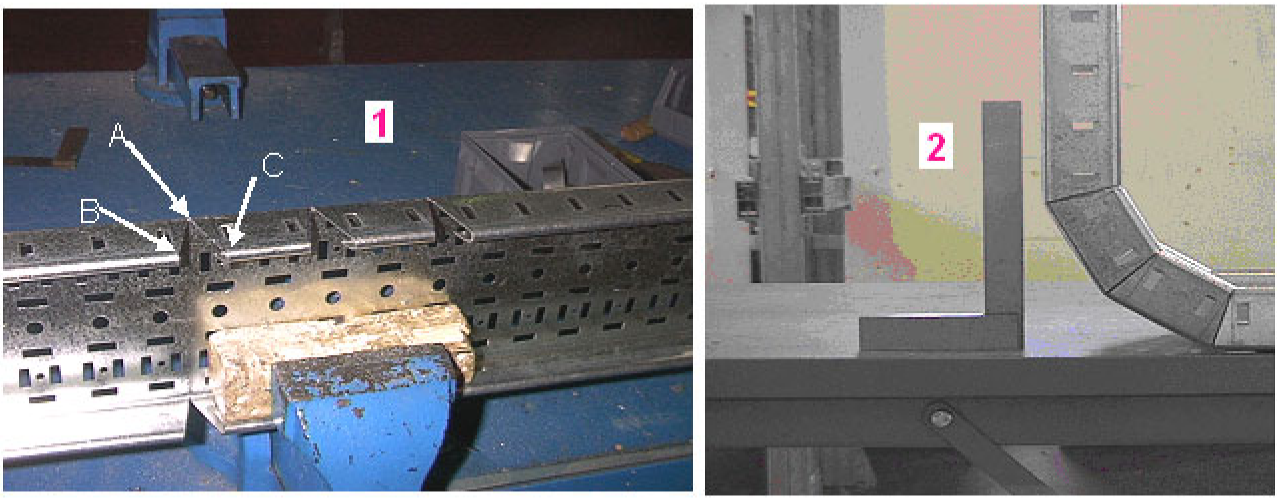


Figure 96: Construct a 90° internal bend

8.1.11. How to construct an offset

First mark the tray (11), draw a centre line, measure approx. 10mm either side of the centre line and draw 2 lines.

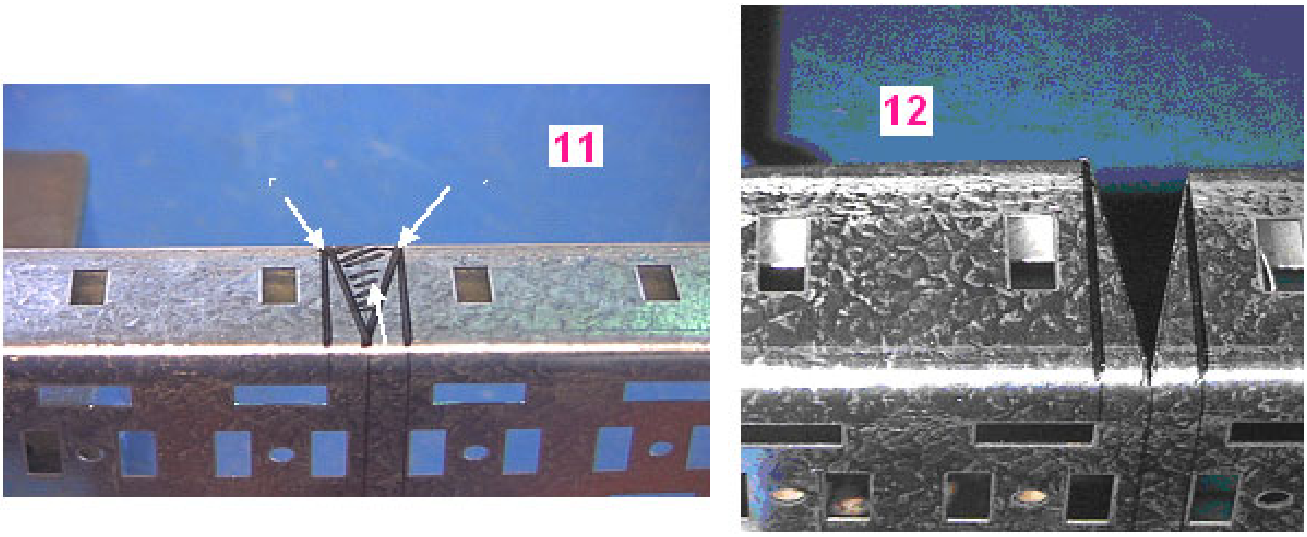


Figure 97: Construct an offset (11) and (12)

Now draw 2 diagonal lines from point A to point B and from point A to point C and remove as in figure (12).

Next bend the tray and measure the size of off set required (13)

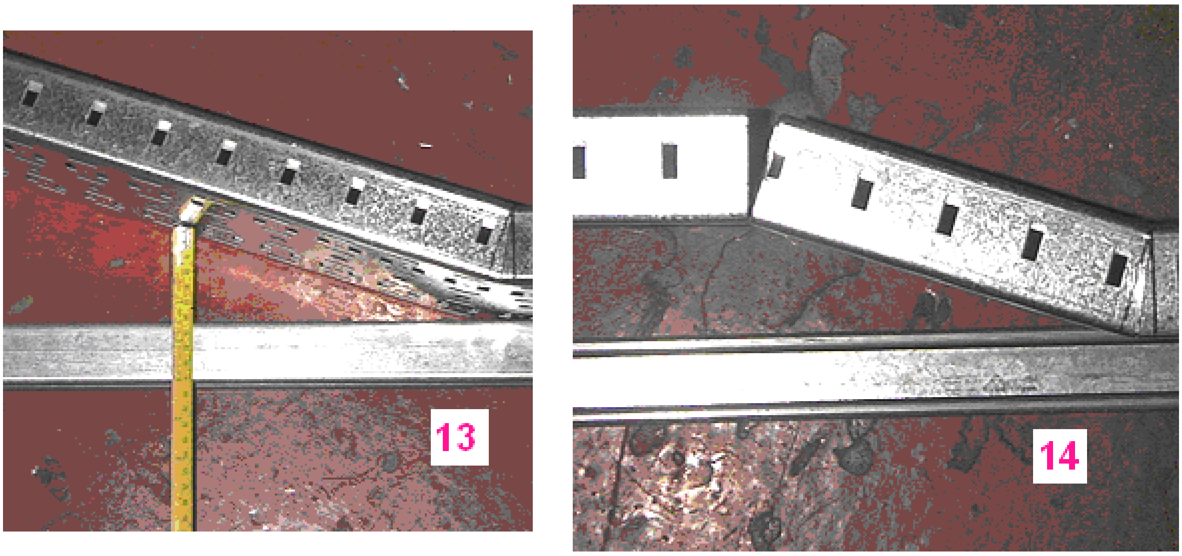


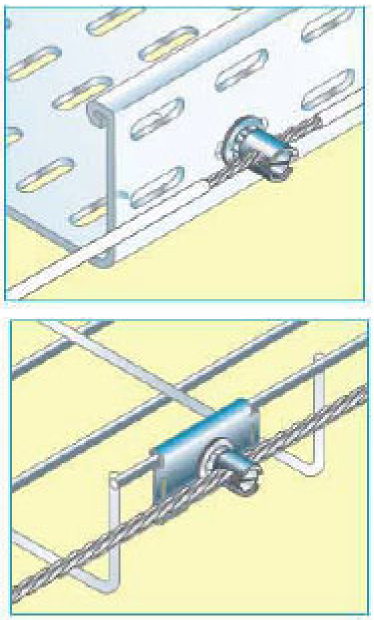
Figure 98: Construct an offset (13) and (14)

Once the size of the off set has been determined, mark all around the tray cut down both edges and bend to the required shape (14).

When the bends and offsets have been completed, all cuts must be painted with a rust/corrosion protective.

Those "practices" have been done with perforated galvanised steel type cable tray, it would be (nearly) the same work with stainless steel or fibber made cable tray.

8.1.12. Grounding cable tray



Whatever the type of metallic cable tray, it has to be grounded:

- To the general plant grounding system every 15 to 20 m
- To the general plant grounding system at its extremities if length is less than 15 m.

Figure 99: Grounding of cable tray

- All along to the ground wire being connected with specific plots to ensure continuity between lengths.

Refer to Company Standards as well on this point.

8.2. CONDUITS SYSTEMS

8.2.1. General view of conduits

Cables need protection from mechanical damage. Conduit is one of the most common types of protection for cables. Conduit is tubing which gives good mechanical protection in many different situations.

Conduit systems can be used in many environments, e.g. homes, offices and factories. Most conduit systems are used to protect- single-core cables. If the cable is run through conduit then the sheath is not needed.

This paragraph covers both metallic conduit and PVC conduit. It explains the advantages and disadvantages of both systems. It also describes different fittings and methods of termination

We do insist here particularly on metallic conduits. In European practices we use mainly cables and cable trays for distribution when North-American designs are with metallic conduits and wires (inside);

You will find conduits on packages such as power turbines (Solar, G.E.,…), compressors, ….when they come from North America. Therefore, if you need to modify, repair conduits systems, it is better for you to know (at least a minimum) on this particular technology.

8.2.2. The Conduit

Conduit is the name given to the tubing which gives mechanical protection to cables and wires.

Conduit can be classified into two types;

- Metal conduit
- Non-metallic conduit

8.2.3. Metal Conduit

The most common type of metal conduit is steel conduit.

Steel conduit is metal tubing with threaded screw ends.

It is usually made in 2, 3 to 6 meter lengths of black enamelled steel tubing.

It can be galvanised or coated in plastic to prevent corrosion.

The advantages of metal conduit are:

- It gives good mechanical protection
- It makes rewiring easier
- It protects the cable against fire
- It can be used to earth the circuit.

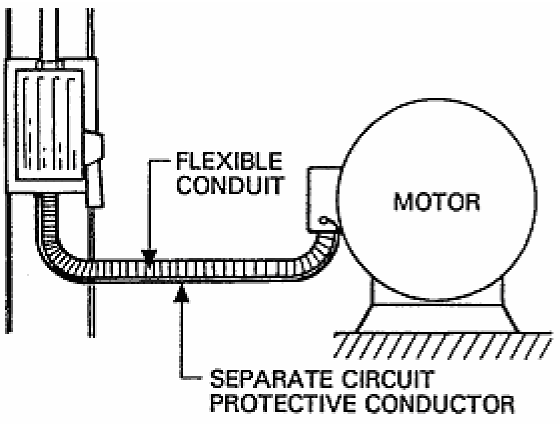
The disadvantages of metal conduit are:

- It can cause moisture to form inside it
- It is expensive
- It corrodes easily.
- Not practical in maintenance (replacing / adding wire)
- It needs more manpower at construction (pulling wires inside).

8.2.3.1. Heavy Gauge Screwed Conduit

This is the most common type of metal conduit. It has screw thread connections. It can be solid drawn (made from one continuous piece of metal) or it can be welded seam. Solid drawn conduit is more expensive but it's often used in industry because it gives leak proof protection.

8.2.3.2. Flexible Conduit



Flexible conduit is used to protect cables which are connected to vibrating machinery. It is made from a steel strip wound in a spiral to form a tube. It is not one continuous tube so it can not be used as an earth.

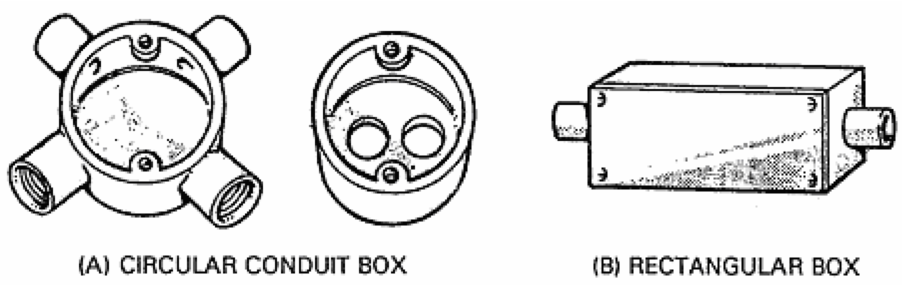
Flexible conduit must have a separate earth conductor.

Figure 100: Connection with a flexible conduit

8.2.4. Metal Conduit Fittings

Manufacturers supply many different fittings for electrical conduit systems; some fittings are shown below:

8.2.4.1. Conduit boxes



Conduit boxes can be circular (A) or rectangular (B)

Figure 101: Circular or rectangular conduit boxes

The boxes are named by the number and type of conduit outlets, e.g. end box, through box, 3 way box, 'Y' box, back-outlet box etc, see hereafter, the most common types

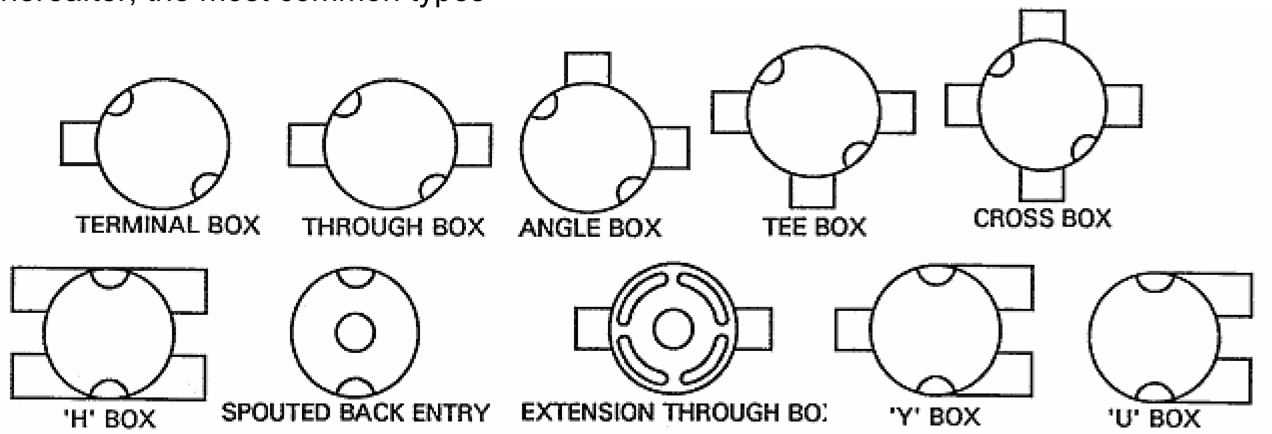


Figure 102: Different Types of Circular Conduit Boxes

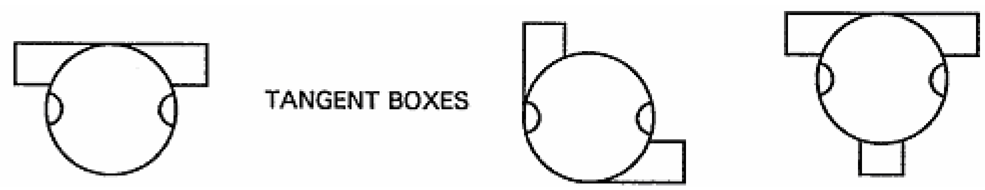


Figure 103: Different Types of Circular Conduit Boxes Tangent Type

Rectangular conduit boxes are also used, especially for socket outlets and switches. See two types of rectangular steel conduit boxes on drawing.

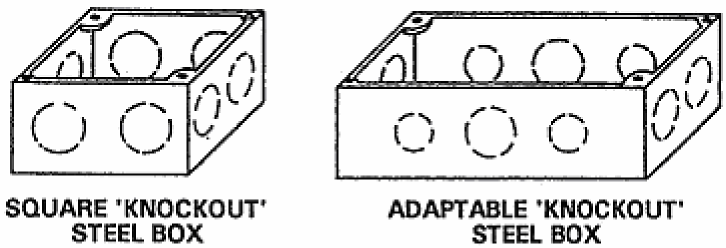


Figure 104: Types of Rectangular Steel Conduit Boxes.

8.2.4.2. Inspection Fittings

Inspection fittings are conduit fittings which can be opened so that cables can be inspected and repaired. Inspection fittings should be used every 10 metres or so in a conduit system.

The three most common inspection fittings are shown hereunder.

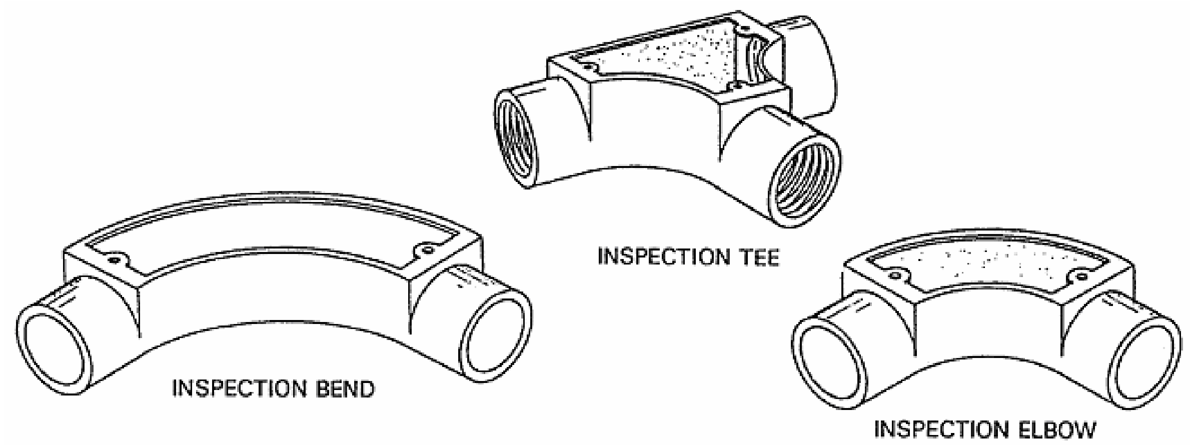
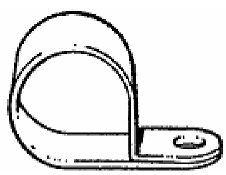
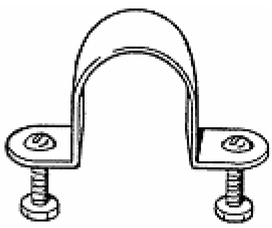


Figure 105: Types of Inspection Fittings

8.2.4.3. Fixing Conduits

All conduits must be securely fixed.

Some common conduit fixings are shown below:

Type of fixing item	Drawing	Function
Clip		This is the simplest kind of conduit fixing. It is used to fix conduit to walls or wooden surfaces
Strap saddle		The conduit is fixed with two screws

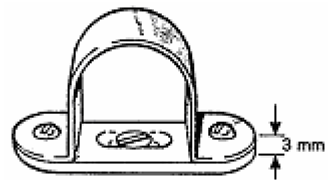
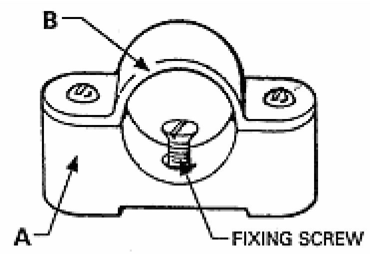
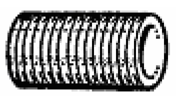
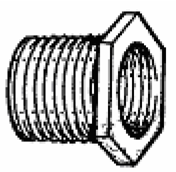
Type of fixing item	Drawing	Function
Spacer bar saddle		The spacer bar holds the conduit clear of the wall.
Distance saddle		1 .Fix part 'A' in position first with a screw. 2. Position the conduit in the gap. 3 Part 'B' holds the conduit in place with 2 screws.

Table 49: Fixing Conduits Items examples

8.2.5. Conduit Accessories

Different fittings are used to connect conduit systems together. Other fittings protect the cable where it enters and leaves terminals.

The most common conduit accessories are shown hereafter.

Fitting	Name	Function
	**Coupler**	A Coupler is a metal tube with an internal thread. It is used to connect 2 equal size conduits together
	**Nipple**	This is used to change an internal thread fitting to an external thread fitting
	**Reducer**	A Reducer has an external thread which fits the size conduit and an internal thread which fits another size conduit. It is used to connect different size conduits.

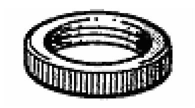
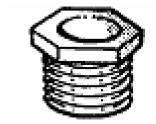
Fitting	Name	Function
	**Locknut (Lock ring)**	A locknut is used to stop conduit fittings from being loose
	**Bush (Bushing)**	A Bush is used to terminate conduit. This bush has an external thread. It is smooth inside so it protects the cable where it comes out of the conduit
	**Stopping Plug**	This is used to seal the end of conduit or to seal an entry on a conduit box. It prevents dirt from getting into a conduit system.

Table 50: Conduits Accessories

8.2.5.1. Terminating Conduit

Circular conduit boxes often have threaded entries. The conduit can be screwed directly into a threaded entry.

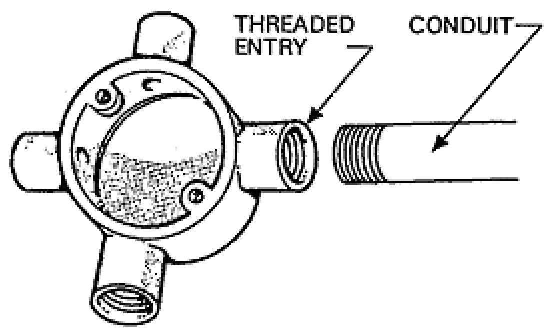
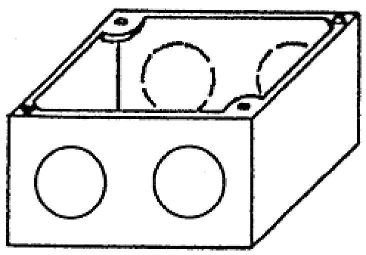


Figure 106: Conduit Screws Directly into a Threaded Entry



Rectangular conduit boxes are often made of thin metal so they have non-threaded entries.

Figure 107. Rectangular Conduit Box with Non-threaded Entry

A special fitting called a "bush" is used to terminate conduit into a, non-threaded entry.

There are two types of bush; male bush (external thread) and female bush (internal thread).

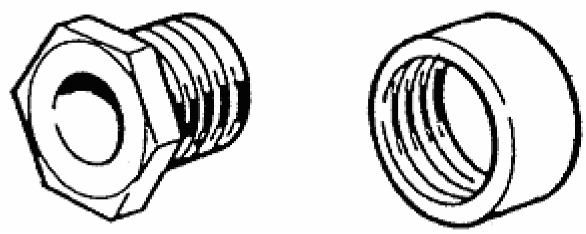


Figure 108. Male and Female Bush.

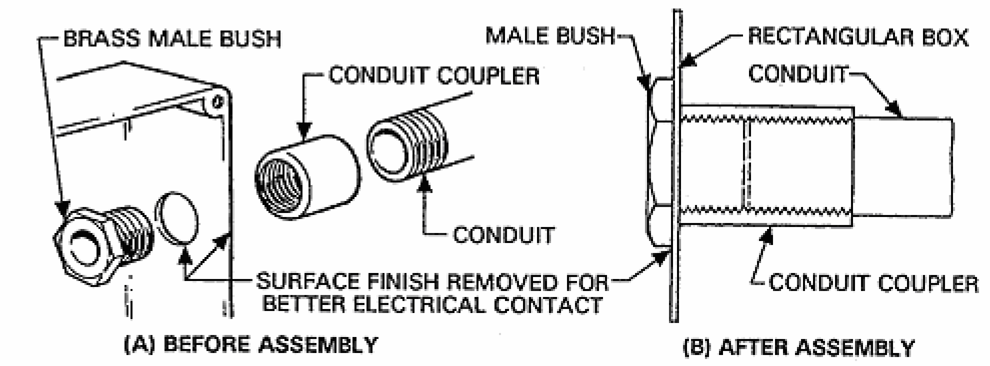


Figure 109. Male Bush and Coupler

A male bush is connected to the conduit with a conduit coupler. Figure shows a male bush and coupler before and after assembly.

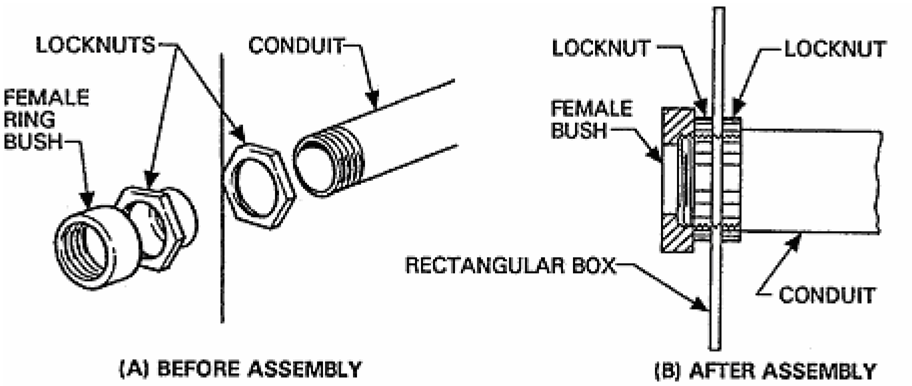


Figure 110. Female Bush and Lock Nuts

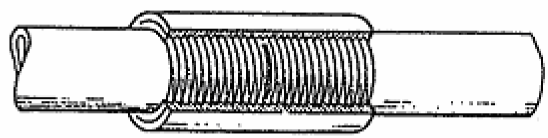
A female bush is connected to the conduit with lock nuts. Figure shows a female bush and lock nuts before and after assembly.

8.2.5.2. Connecting Conduit

When you are installing a conduit system you can join conduits together with a coupler.

The coupler is screwed on to the end of one conduit and the other conduit is screwed into the coupler

Figure 111: Section through Coupler, Showing the Conduits Butting



This method can only be used if one of the conduits can be turned.

Sometime the two conduits which you must connect are fixed in place and they cannot be turned.

When neither conduit is free to turn a running coupler must be used.

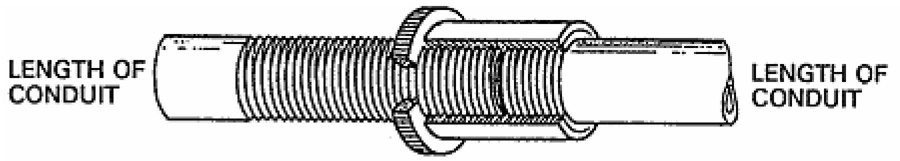


Figure 112: Section through a Running coupler

8.2.5.3. How to fit a Running Coupler.

1. The end of one conduit (conduit 1) must have a long thread. You can make the thread longer with a stock and die, if necessary.

   The thread must be long enough for the lock nut and coupler to fit fully onto the conduit.

   The other conduit, (conduit 2) has a standard thread (half a coupler).

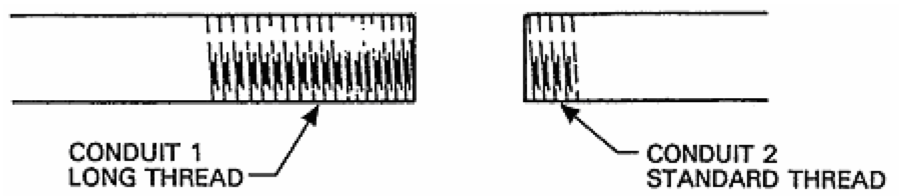


Figure 113: Two Conduits Threaded for a Running Coupler.

2. The locknut and coupler are screwed fully on to the conduit with the longer thread (conduit 1).

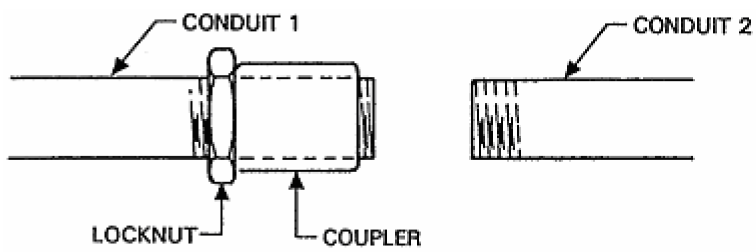


Figure 114: Coupler Fitted on Conduit 1

3. Butt the ends of the two conduits together.

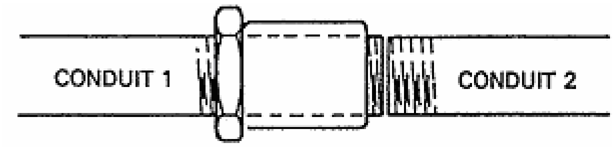


Figure 115: Conduits butted together

4. Screw the coupler onto conduit 2 as far as it will go.

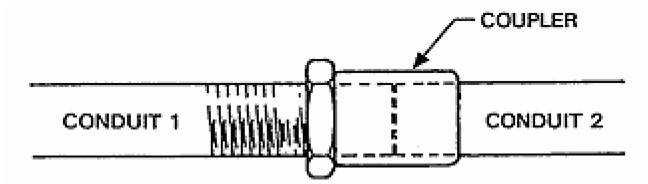


Figure 116: Coupler screwed on to Conduit 2

5. Lock the coupler by screwing the locknut tightly against the coupler.

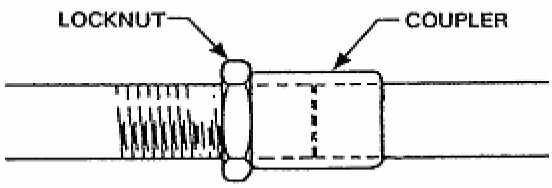
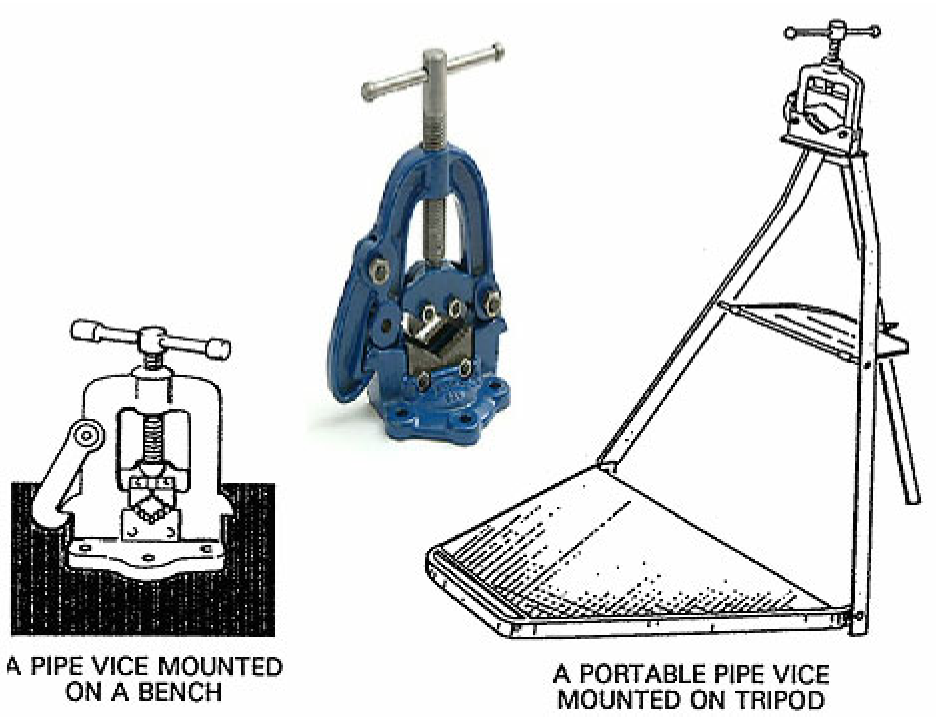


Figure 117: Running Coupler Locked in Place with Locknut.

8.2.6. Cutting and threading conduit



Sometimes a piece of conduit is too long. Then you must cut it and thread it yourself.

Conduit must be held firmly in a pipe vice when you are cutting it or threading it. A pipe vice can be fixed on a bench.

A portable pipe vice can be fixed on a tripod.

Figure 118: Pipe Vices

8.2.6.1. How to Cut Conduit

Conduit should be cut with a hacksaw. It should be cut at a right angle so it will fit into other fixings in the conduit system.

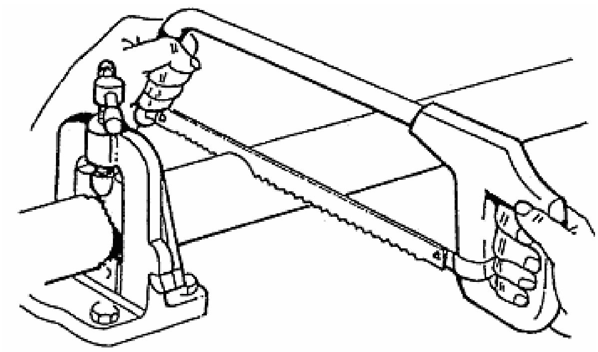


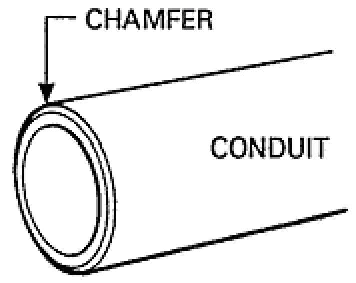
Figure 119: Cutting Conduit

1. Place the conduit in the pipe vice
2. Tighten the vice until the conduit is securely held. Do not over tighten it or you may damage the conduit.
3. Saw the conduit as close to the vice as possible.
4. Keep the saw blade square to the work.

NB: Make steady strokes using the full length of the hacksaw blade, when sawing.

After the conduit has been cut to length it must be threaded. Steel conduit needs a screw thread so the lengths of conduit can be joined together.

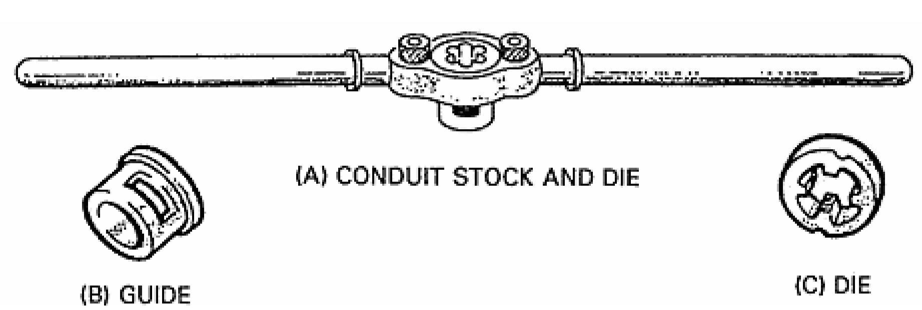
8.2.6.2. Threading Conduit



Before threading, the end of the conduit should be chamfered with a file. This helps the die to start cutting the thread.

Figure 120: Preparation of Conduit before Threading (Chamfer)

Stocks and dies are used to thread the conduit. One type of conduit stock and die is shown in Figure.



The dies and guides can be changed. They are available in all sizes

Figure 121: Conduit Stock, Die and Guide

Slide the stock and die onto the conduit. Apply pressure to the stock and turn the stock in a clockwise direction.

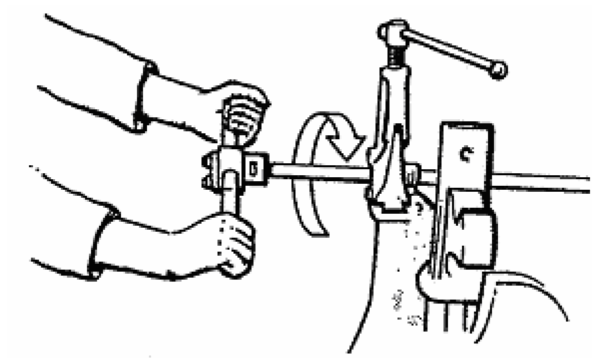
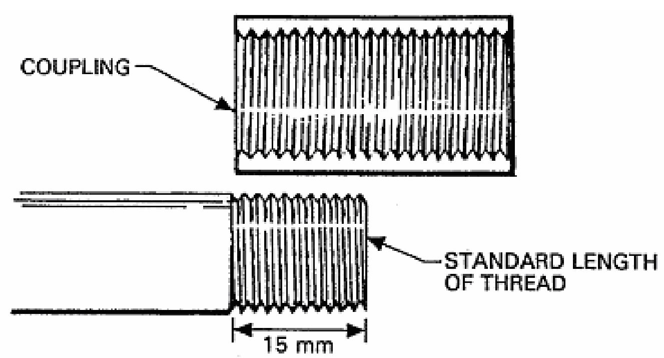


Figure 122: Threading Conduit

Use cutting paste or oil when cutting the thread.

This makes a better thread and makes the die last longer.



Turn the stock back half a turn after each turn.

This clears the swarf from the cutting edges of the die. If the swarf is not cleared the thread may be damaged.

Figure 123: Standard Length of Conduit Thread

Cut the thread to a length of 15mm. This is enough to, fit into a standard conduit fitting or half-way into a coupling.

The conduit must be reamed after Gutting and threading.

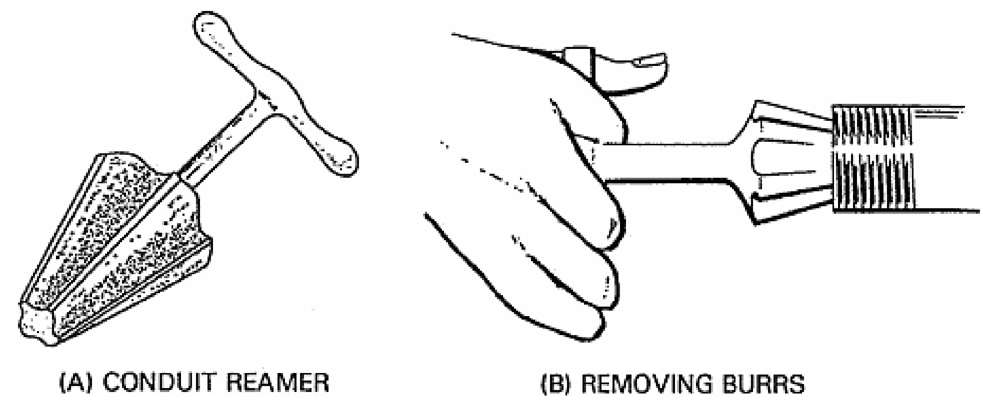


Figure 124: Using Conduit Reamer

Reaming moves the burrs and sharp edges from the inside of the conduit. These must be removed or they will damage the insulation of the cable.

8.2.7. Bending Steel Conduit

Steel conduit is used in industry to protect cable. A conduit system will have many bends and sets in it. A set is a bend of less than 90°. You must learn how to bend and shape steel conduit properly.

Steel conduit can be bent and shaped using a bending machine or a bending block. A bending block is more difficult to use than a bending machine. You should use a bending machine when possible. A bending machine can bend steel conduit to almost any shape or angle.

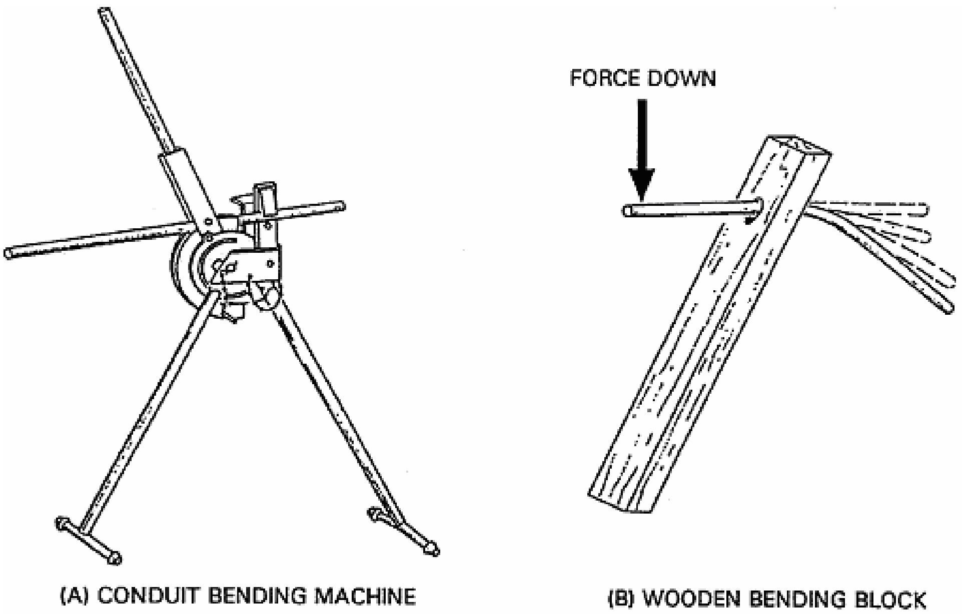


Figure 125: Conduit bending equipment.

The conduit bending machine has different formers for different types and sizes of conduit.

You must use the right former for the conduit you are working on.

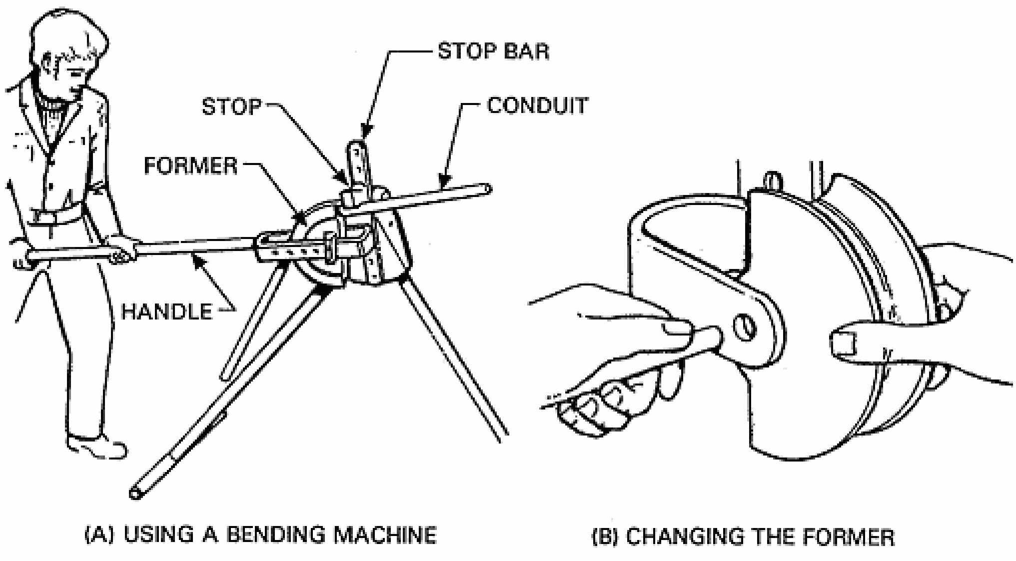


Figure 126: Conduit Bending Machine Operations

There are many different types of conduit benders. Some are hand operated and some are foot operated.

Some tripod-mounted conduit benders also have a pipe vice fitted. And for big size "pipes" you will have to use hydraulic powered bender

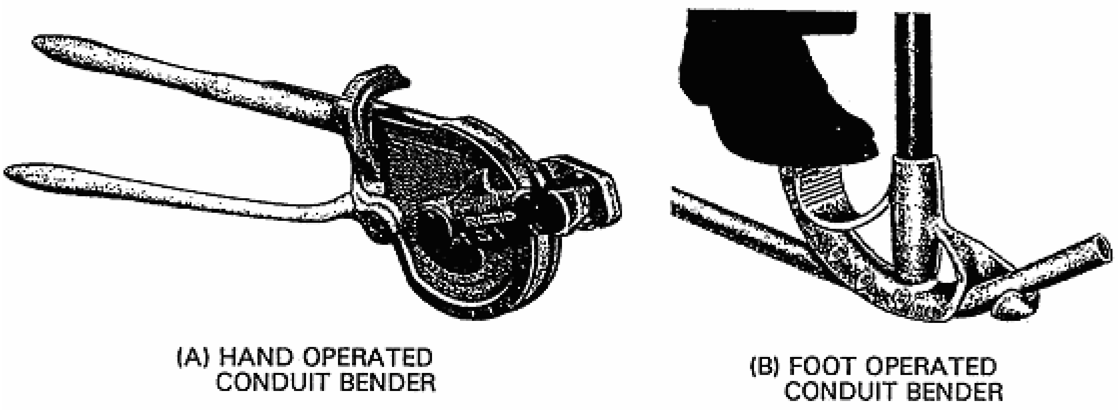


Figure 127: Types of Conduit Benders

8.2.8. PVC Conduit

Steel conduit is very strong and provides good protection for cable. However, it is heavy, difficult to handle and it is expensive. Nowadays, a lot of conduit is made from PVC (Poly Vinyl Chloride). PVC conduit has many advantages.

Methods and materials described hereafter are for industrial type of PVC conduits, for those conduits we could see installed on onshore or offshore installations.

"Our" PVC conduits are sealed, waterproof; those installed in electrical housing (domestic) distribution are in another world where tightness is not an imperative factor.

8.2.8.1. The Advantages of PVC Conduit

- Light; 1/6th of the weight of steel conduit.
- Easy to cut and bend.
- Does not need to be painted
- Low condensation.
- Quick to assemble.
- Resists fire and electricity

8.2.8.2. The Disadvantages of PVC Conduit

- The joints must be glued carefully so the glue doesn't block the conduit
- The joints leak if they are not glued properly.
- It is affected by temperature change. PVC expands and contracts more than steel when the temperature changes.

8.2.8.3. Types of PVC Conduits

- There are many different types of PVC conduit.
- Super high impact PVC is strongest. This is often used in buildings and can be laid in concrete.
- Standard Impact PVC conduit is used for indoor cable systems.
- High Temperature PVC can resist temperatures of 80 - 85°C.
- Flexible PVC conduit can be used on uneven surfaces.

There are many other types of PVC conduit. You should select the conduit that is most suitable for the working conditions.

8.2.9. Cutting and joining PVC Conduit

PVC conduit is easy to cut with a junior hacksaw. You can remove rough edges and burrs with a knife.

The conduit and fittings must be clean and dry before they are joined together.

A special glue (PVC solvent adhesive) is used to hold the joint together.

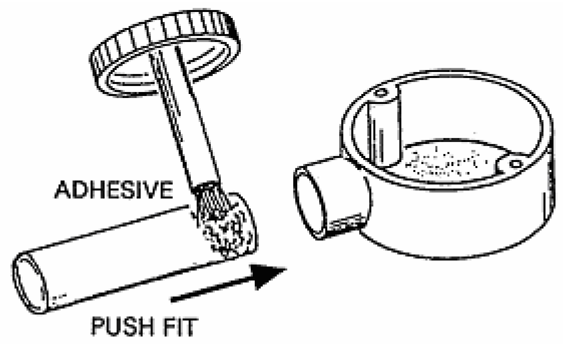


Figure 128: Joining PVC conduit

Both surfaces are covered and then the conduit is pushed in to the fitting. The glue sets after 2 minutes and is completely dry after a few hours.

NB: You must apply the right amount of glue:

- Too much glue may block the conduit.
- Too little glue will not give a good joint.

The glue gives off fumes so be careful not to breathe them in.

8.2.10. PVC Conduit Fittings

PVC conduit fittings are similar to metal conduit fittings. The main difference is that PVC conduit fittings do not need to be threaded.

See hereafter some common PVC conduit fittings.

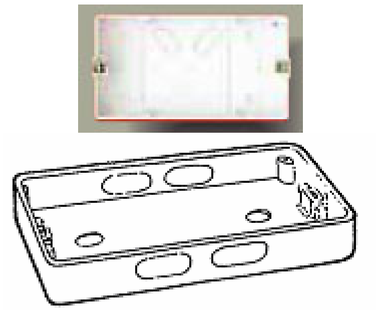
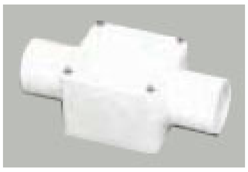
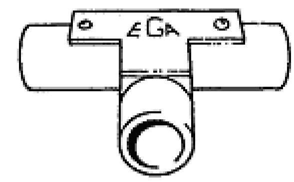
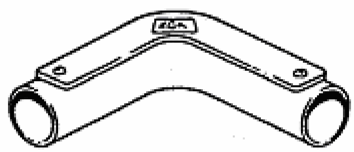
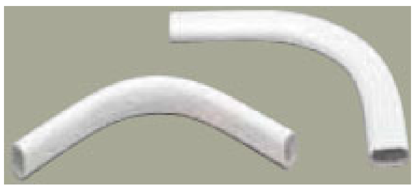
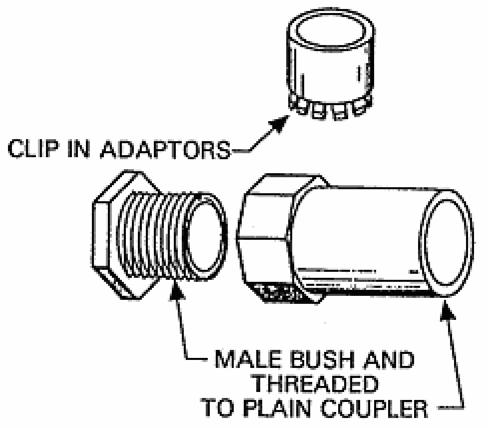
Type	Picture / Drawing	Type	Picture / Drawing
Four way and back outlet BLK or WH. colour		Flush plaster depth switch box	
Through BLK or WH colour			
Angle BLK or WH colour		Tee BLK or WH colour	
Inspection Elbow		Inspection Tee	
Inspection Bend		Normal Bends	

Table 51: PVC Conduit Fittings



PVC fittings are often strengthened with metal. Metal reinforced PVC fittings can support heavy loads such as light fittings.

There are threaded and "clip W' couplers and adapters. These can be used to terminate PVC conduit into standard entries and accessory boxes

Figure 129: Threaded and Clip in PVC Couplers

Expansion Couplings:

PVC conduit expands five times more than steel when the temperature increases.

Therefore, a PVC conduit system gets longer if the temperature rises.

Expansion couplings are fitted into the PVC conduit every 8 metres.

These couplings allow up to 25mm of expansion.

Figure 130: PVC Expansion Coupling

If the conduit must be watertight then special "non-setting" glue is used. This glue expands as the tubing expands and gives a good, watertight seal

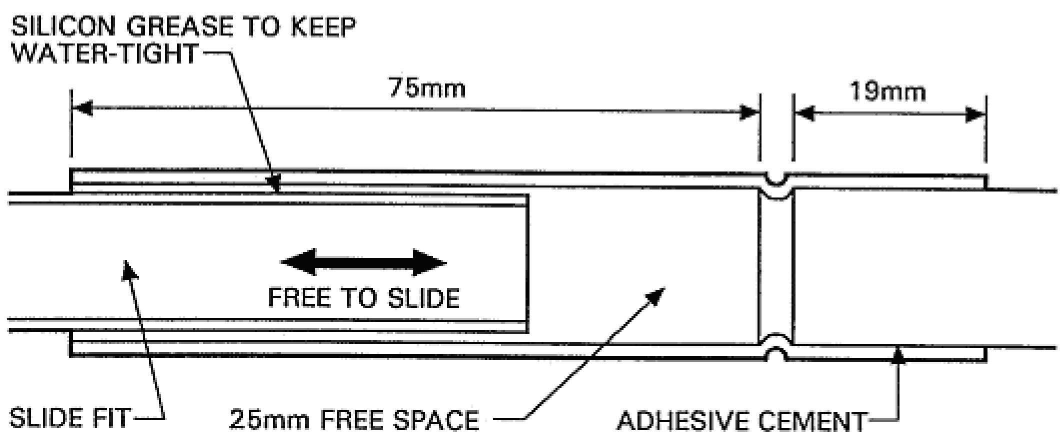


Figure 131: Water-tight PVC Expansion Coupling

8.2.11. Bending PVC Conduit

PVC is flexible so it can be bent by hand. A spring tube-bender is inserted in the PVC conduit when it is bent

Figure 132: Spring Tube Bender

The tube-bender stops the tube from "kinking" when it is bent.

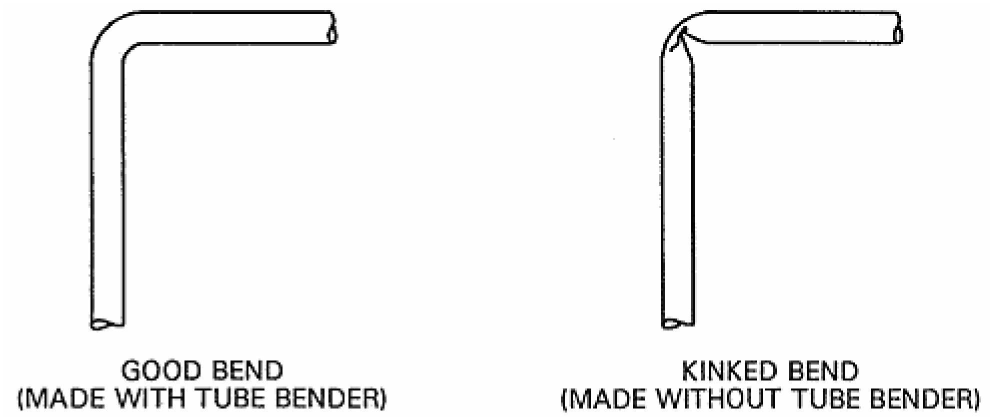


Figure 133: "Kinked" Bend in PVC Tubing

Because PVC tubing is springy it will bend back a little after you bend it. You must bend the conduit to double the angle that you require

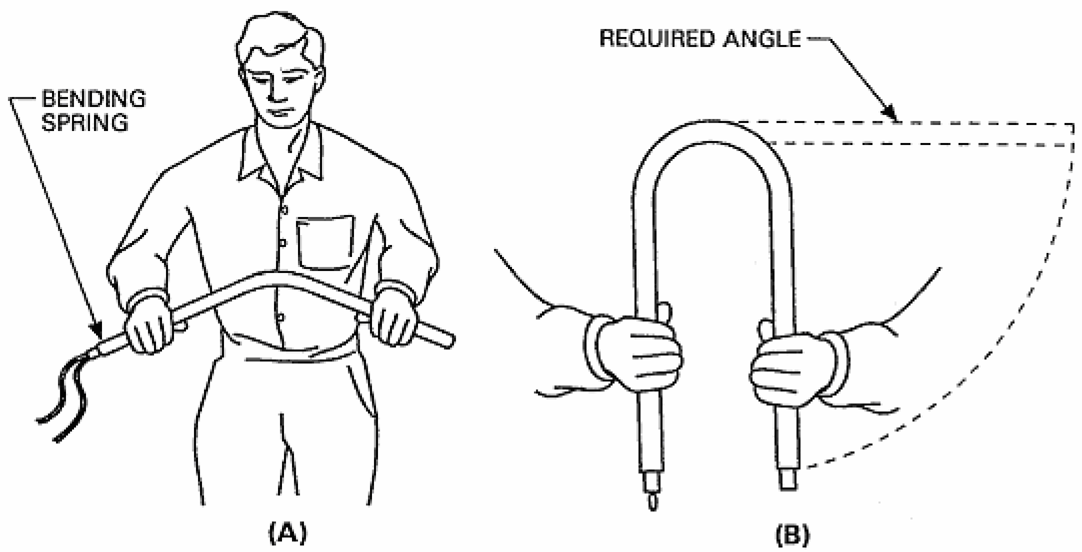


Figure 134: Bending PVC Conduit by Hand

The tube will spring back to the required angle. Because PVC is flexible the angles of the bends do not need to be very exact.

Bending PVC Conduit in Cold Weather

In cold weather you must warm the PVC a little before you bend it. The easiest way to warm it is to rub it with a cloth. The friction will warm the PVC. The PVC should be bent and fixed in position as quickly as possible in cold weather.

8.3. TRENCHES

Laying cable sin trenches looks alike laying cables on cable tray. Distances between different types and voltages as well as buried dimensions must be respected. Total Standards on that matter are describing exactly what to do (and not do), please refer to it.

8.3.1. General Characteristics

8.3.1.1. Trench dimensions

The minimum dimension must be as follows:

Depth:

- The bottom of the trench shall be at 0.8 m from ground surface.
- For road crossing, the bottom of the trench shall be at a minimum depth of 1 m below the road level.
- The road crossing pipes shall be extended up to 0.5 m on each side of the road.

Width:

The width of a trench shall be sized in accordance with:

- Cable diameters
- Spaces between the different types of cables.
- Spaces between each cable (if required, to match cable calculation).
- Spaces between pipes and cables if the trench includes also pipes.
- A minimum space of 0,1 m on each side of the trench between trench sides and the nearest cable.

8.3.1.2. Cables running in parallel with pipes

When a cable runs in parallel with a pipe, the minimum distance shall be 0.2 m between cable and pipe.

8.3.1.3. Crossing of cables

The trench shall be made such as the minimum distance to be left between 2 cables, or one cable and one pipe, at the crossing point shall be 0.2 m.

8.3.1.4. Road crossing

All road crossings, parking areas, or areas on which heavy equipment can pass must be executed by laying protective PVC pipes of 0.15 m minimum diameter embedded in concrete, or with steel pipes.

For road crossings permanent concrete pulling pits may be required.

On road crossings, all pipes (used or not) shall be sealed before back-filling. All non-used pipes shall be equipped with a metallic spare wire to allow pulling of a new cable when necessary.

8.3.1.5. Substation entry

For a substation entry a permanent concrete pulling pit may be required at the end of the trench along the substation wall, if many cables have to be pulled.

8.3.2. Backfilling of a cable trench

8.3.2.1. General composition

The trench shall be back-filled with the following layers (from bottom to top):

One layer of 0.1 m of sand.

One or several layers of cables. If more than one layer of cables is laid, one layer of sand shall be put between two cable layers. (the thickness of this layer have to match with the distance to be left between cable types defined below)

- One 0.1 m layer of sand.

- One layer of mechanical protection devices covering all the cables (except for road crossing for which cables will be pulled inside mechanical protection pipes), if cables are not armoured type.
- One layer of 0.1 m of ground cleared from stones.
- A warning device covering all the cables (bataco, warning screen or plastic sheet).
- One layer of 0,1 m of ground cleared from stones.
- Back-filling with row soil (coming from trench excavation).

The above mentioned back-filling layers shall be compacted by means of water or manual device, to have a back-filling with the same density as the original soil.

8.3.2.2. Sand or ground cleared from stones

As far as possible the contractor shall use sand for the trench back-filling around the cables, to protect them.

In no way the sand use for back filling shall be seaside sand.

If no sand is available this back filling may be made with ground cleared from any stone.

This ground shall be cleaned by screening to remove any strong object above 2-mm diameter, in order to avoid any damage to cables.

8.3.2.3. Row soil

For the final layer, the trench shall be back filled by row soil coming directly from the trench excavation, but cleared from stones or any rubbish material.

8.3.2.4. Mechanical protection for non armoured cables

A mechanical protection must be laid on the upper sand protection bed covering all cables (0.1 m above the highest cable layer).

This material shall be concrete plate, bricks or tiles layer, which must cover all the cables of the trench.

For road crossing, the pipes inside which the cables are pulled do this protection, so no extra protection to cover the trench is required.

8.3.2.5. Warning device

A warning signal material shall be laid 0.1 m above the trench mechanical protection.

This warning signal shall be made by means of either a thin plastic sheet or a plastic wire mesh or batacos. The use of this device is just to inform during a further digging that cables are present below.

8.3.3. Cables arrangement

The cables shall be laid by groups, which have to be separated between them.
Those groups are:

- High voltage cables
- Low voltage cables (power and lighting) and earthing cables
- Control cables
- Telecommunication cables

As noted above, pipes must also be separated from cables.

In those groups the cables shall be either side to side, or separated (if required by the calculation).

Between each group the minimum compulsory space shall be as follows:

- 0.2 m between high voltage and low voltage cables.
- 0, 5 m between high voltage cables and telecommunication cables.
- 0. 2 m between cable and pipes. In case of running of one warm pipe in cable trench, either the space shall be increase; or a heat insulation device shall be laid between pipe and cables to avoid any warming of cables.

In each group, the cables shall be pulled in such a way that easy access of cables from the trench level to the different electrical equipment be allowed.

When single core cables run in trench, they shall be pulled and attached together in trefoil all along the trench.

For road crossings, the following rules shall be applied to pull the cables in PVC or steel protection pipes

- The cables pulled-into one single pipe shall be of the same type.

- No more than one high voltage cable shall be pulled by pipe (in case of single core cables, the 3 cables shall be laid in trefoil on the same pipe).

- No more than three low-voltage power and control cables shall be pulled in the same pipe, if the pipe diameter and length allow pulling of three cables (cables diameter to be considered).

8.3.4. Pulling of Cables

Contractor should take particular care to cable pulling in trenches.

The cable drum shall be installed on a jack on a stabilised area, to allow the drum to run easily (without any effort on the cable).

The trench will be equipped with a sufficient number of cable rollers (in straight line and at each corner of the trench) to avoid any damage to the cables by slipping on the bottom or on trench edge. In case of fully manual pulling, a sufficient number of people shall be available for the pulling.

Mechanical pulling, by winch, shall be allowed only if the winch cable is attached to the electrical cable by means of pulling sock, and if the winch is equipped with a device limiting the strength used to pull the cable.

A cable installed in trench shall be pulled, as far as possible, in one full length. If the necessary length is longer than existing drums, then a junction box is necessary. In this case, competent electricians (which have got manufacturer training in case of high voltage junction box) shall execute the junction box according to Standards.

When installing cable in a trench, the Contractor shall take care to always keep the cable with a bending radius above the minimum limit specified by cable manufacturer.

When cable to be pulled is a short length, coming from a coiled cable, and not from a drum, uncoiling must be done carefully by unrolling the coil to avoid twisting cable by careless handling.

All cables pulled shall have both ends protected by heat shrink sleeve or scotch tape while waiting to be connected, to avoid ingress of humidity.

8.3.5. Trench Layout and Marking

8.3.5.1. Trench layout

The location of a trench is usually chosen in such a way that it will be easily found back, it must be in the safest area for the cable, and as far as possible not in an area which may be needed for a further construction

In general the trenches will be located on the side of the roads, under walkways, or cross side walks. They will be dug on flat areas, on slight slops, or at the bottom of a slope, but never at the highest part of a slope.

8.3.5.2. Trench markers

All trenches will be identified and marked after completion by concrete or wooden blocks, (0,15 X 0,15 X 0,60 m) on top of which the block letter "E" and "Arrow" will be engraved. (Height of letter: 0, 10 m) and painted in red colour.

Those identification blocks will be placed in the axis of the trench itself every 20 meters in straight line, and in each change of direction.

The identification blocks will be installed in the ground in such a way that 0,2m will be left above the soil level.

8.3.6. Typical Schematics

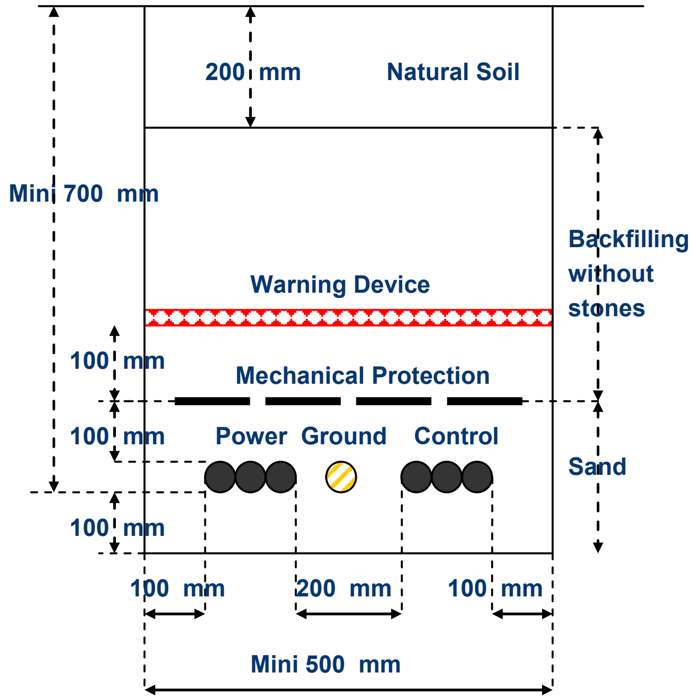


Figure 135: Trench with one lay of cables

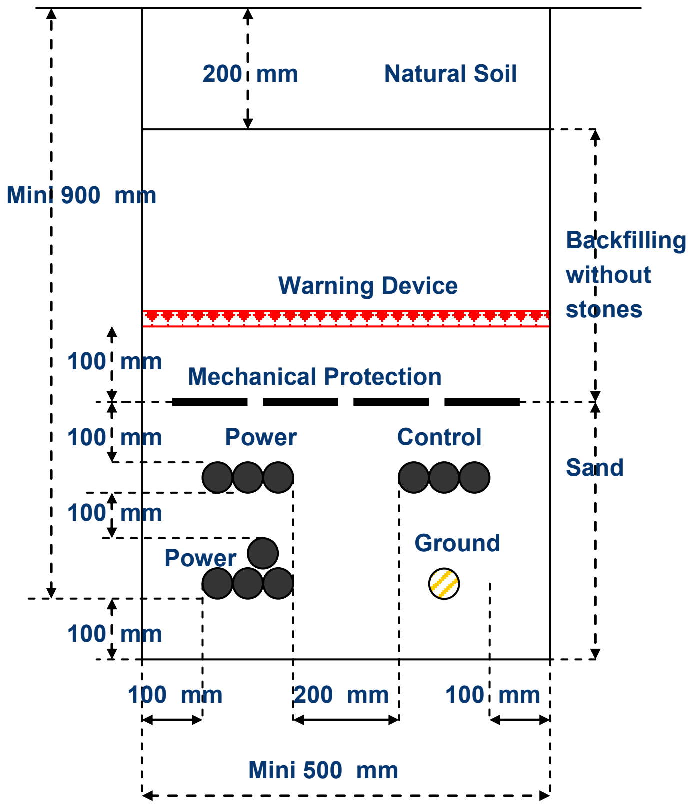


Figure 136: Trench with two layers of cables

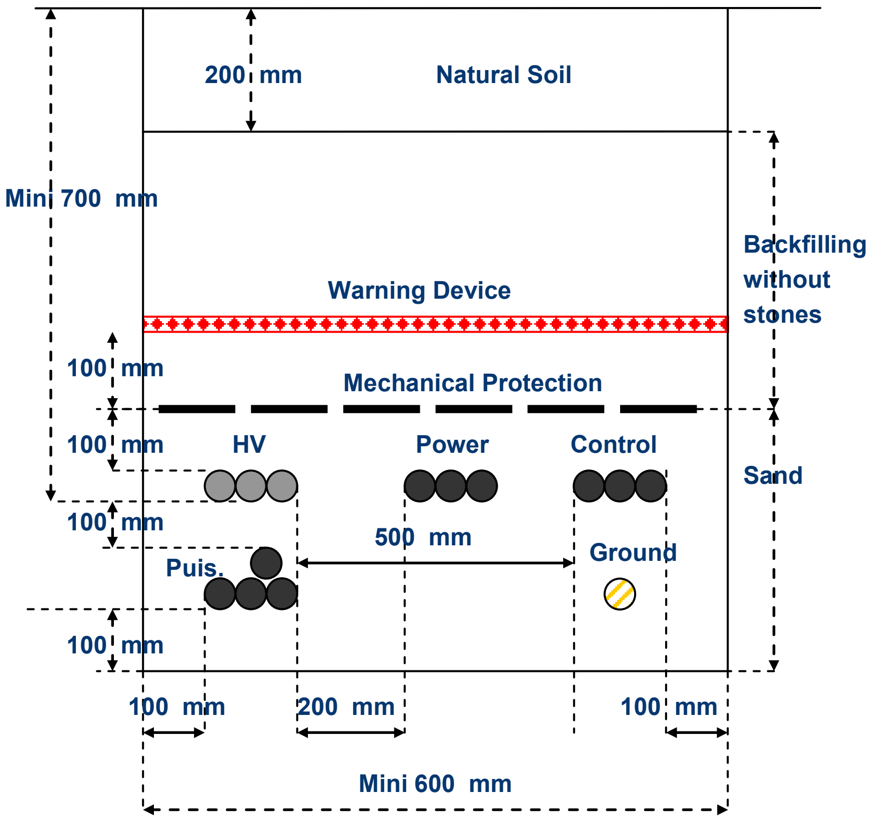


Figure 137: Trench with HV and LV + two layers of cables

9. CONNECTING CABLES

This section refers to the connection of wire ends or of single-pole cables with the accessories and tools relating exclusively to connections.

This concerns low voltage and high voltage. For the latter category, we must consider that the heads and junctions of multi-pole (three-pole) cables form an undividable assembly with the HV connection unit.

Installation accessories (conduits, cable trays, etc.) and attachment/leak tightness (glands) accessories are covered in the next chapter.

9.1. HV CABLES

The right connection method must be used for each cable type, whether armoured or non-armoured, for single-pole and three-pole cable ends with copper or aluminium conductors and PVC, rubber or mineral insulation.

Figure 138: Examples of HV cable ends

Connecting the conductor itself is not a problem (*it is almost identical to LV for cable-grips and crimping)*, the only real difficulty is ensuring the continuity of the insulation and creating a cable head or HV connection unit with a good quality/insulation value.

9.1.1. "Old" HV cables

Nowadays, with HV distribution, the use of "dry cables" has become standard. Oil bath cables are no longer used, however, as, in the past, this technology was used exclusively (*cable insulated with impregnated paper in oil)*, old cables still require reconnecting, repairing and coupling.

Junction boxes, three pole connection units for these cables, still exist, and when it comes to connecting this type of material, it is impossible to find anyone as this technology is specific and requires time and experience. (I have never personally connected this type of equipment).

If you are required to connect a HV cable with oil insulation on a site

- Never ask a subordinate to do it any way he can…
- Connect this cable yourself or delegate to someone you trust.
- Obtain the equipment, technical instructions and user instructions.
- Be patient, and carefully read the instructions before starting the job.
- Inform your hierarchy that the operation may take some time, at least the full day (with 2 individuals involved).
- Notify your hierarchy that you cannot guarantee the successful outcome of the operation, that the final insulation may not be satisfactory, and that it may be necessary to order another unit and repeat the operation.
- When you have completed the job (satisfactory insulation, no leakage, still in place after a few days) you can add "oil bath HV cable connection unit" specialist to your C.V. and sell it….

With these "old" cables, the insulation is the impregnated paper. This type of insulation still exists, as shown in the figure below, and you may be required to create a cable junction between a three-pole cable and 3 single-pole cables, with mixed insulation, i.e. paper on one side and synthetic insulation on the other.

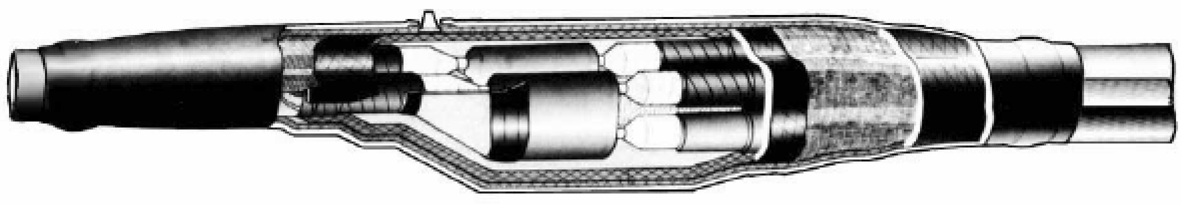


Figure 139: Mixed paper/synthetic junction, three-pole/3 single-pole – 12 - 24 kV

Many manufacturers obtain standard units. Read and follow the technical instructions for connections.

9.1.2. Detachable connectors

As the name implies, this type of connection is based on the "plug-in" principle, with the female connector on the equipment, and the male connector on the cable, (*generally speaking, the opposite can also be found). Extensions have one female connector and one male connector.*

Detachable HV connectors are practically always single-pole in our industry, and, when several cables exist per polarity, there will be one single-pole connector per cable.

The photo shows the connection of the transformer with 4 connectors per phase (and 3 cables connected).

Figure 140: Right detachable external end (cable transformer)

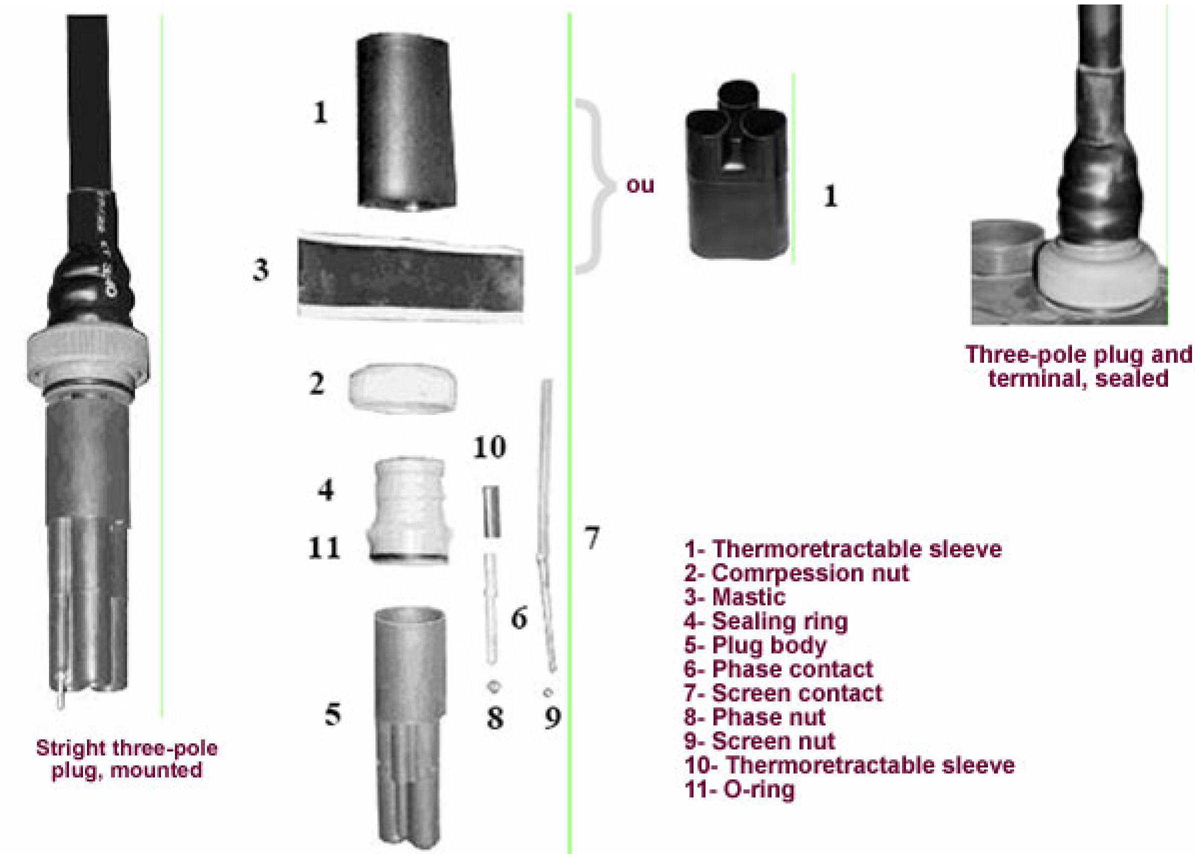


Figure 141: Right three-pole plug and terminal, 6kV

HV three-pole detachable connectors do exist, but I have never personally seen one close up (physically).

This type of three-pole connection is used for transformers.

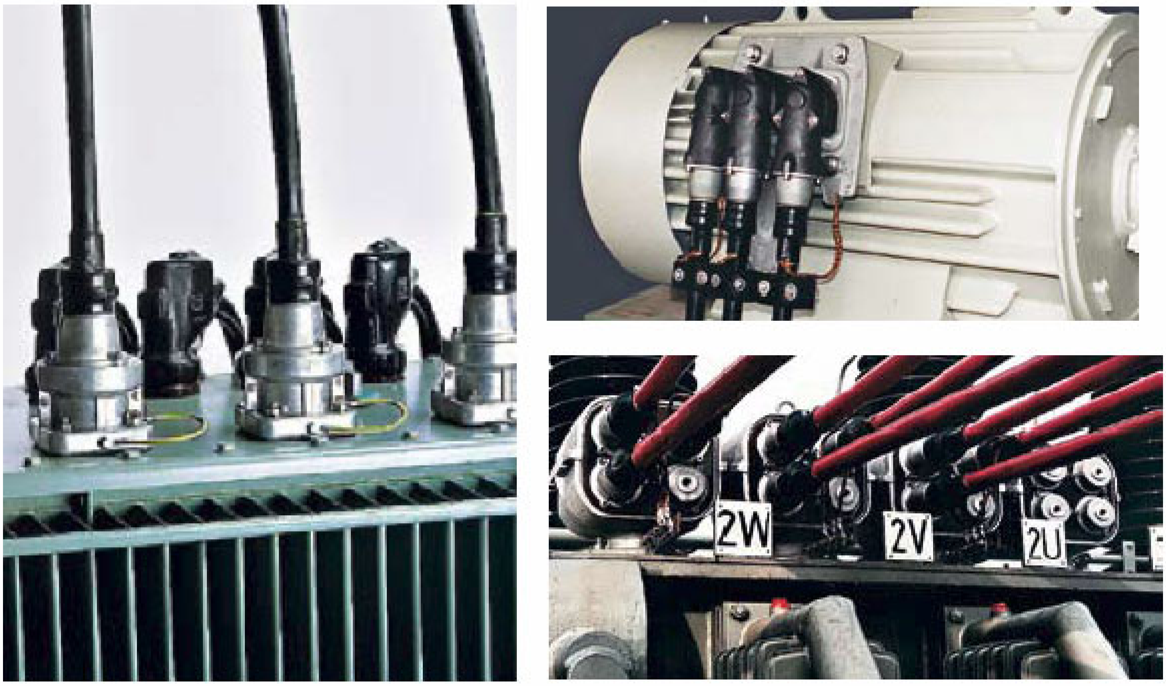


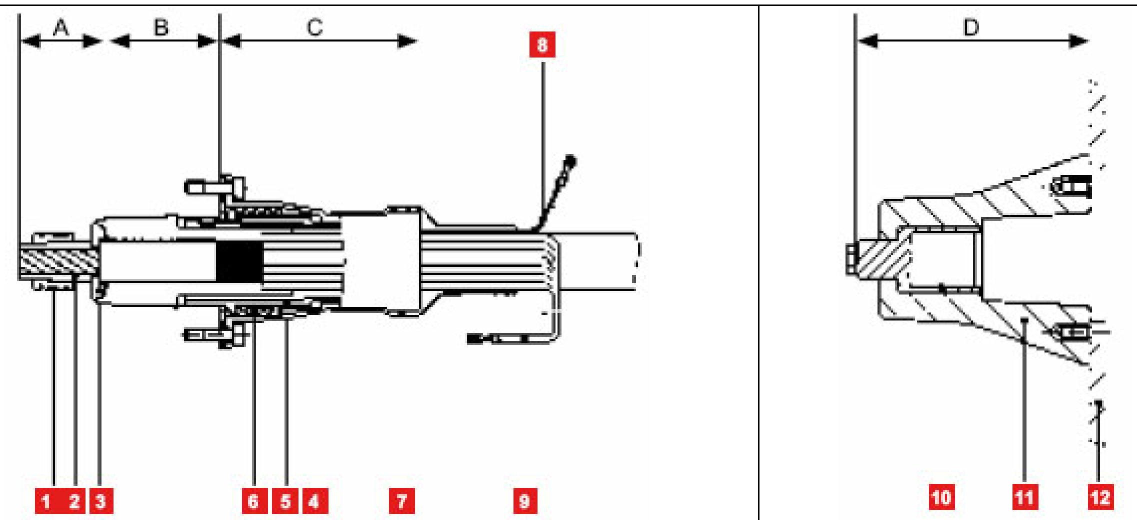
Figure 142: Examples of detachable connectors on HV equipment

A detachable end on a receiver simplifies maintenance and the replacement of the equipment. This does not mean that there is also a detachable terminal at the other end of the cable, the internal ends departing from HV units are generally fixed.

The detachable connectors are equipped (or not equipped) with a mechanical locking system.

With transformers, this may be a bar slotted in the holes of the connectors (created in the moulding for this purpose), and blocked with a padlock or lock.

Construction of a connector:



A: Contact system	***C: Casing***	***D: Connector***
1 : Contact ring	***4 : Cup clamp***	***10 : Contact socket***
2 : Voltage base	***5 : Pressure sleeve***	***11 : Insulation socket***
3 : Support bracket,	***6 : Pressure spring***	***12 : Casing***
	7 : Heat shrinkable sheath	
B: Insulation and control components	***8 : Measurement cable (depending on the model)***	
	9 : Cable shield	

Figure 143: Construction of a detachable connector

Advantages:

- No insulation liquid
- No opening in the cable connection space at the assembly point
- Submersible
- Adapted for outdoor use
- Enables the manufacturer to fully inspect the gas-insulated distribution installations and transformers
- Assembly length shortened by approximately 50% as compared with traditional systems according to IEC 60 859
- Horizontal, vertical and inclined arrangements can be constructed for connections
- Far shorter assembly time
- The use of prefabricated and inspected components ensures optimum safety and reliability
- Assembly errors are minimised
- In case of a "problem", possibility to rapidly separate the cable from the installation

9.1.3. Fixed ends for HV cables

At the second end of the cable (the first end has detachable connectors) connecting a HV unit, cable heads are fixed *(I have never seen a detachable connector on the second end, although it must exist somewhere, why not!)*

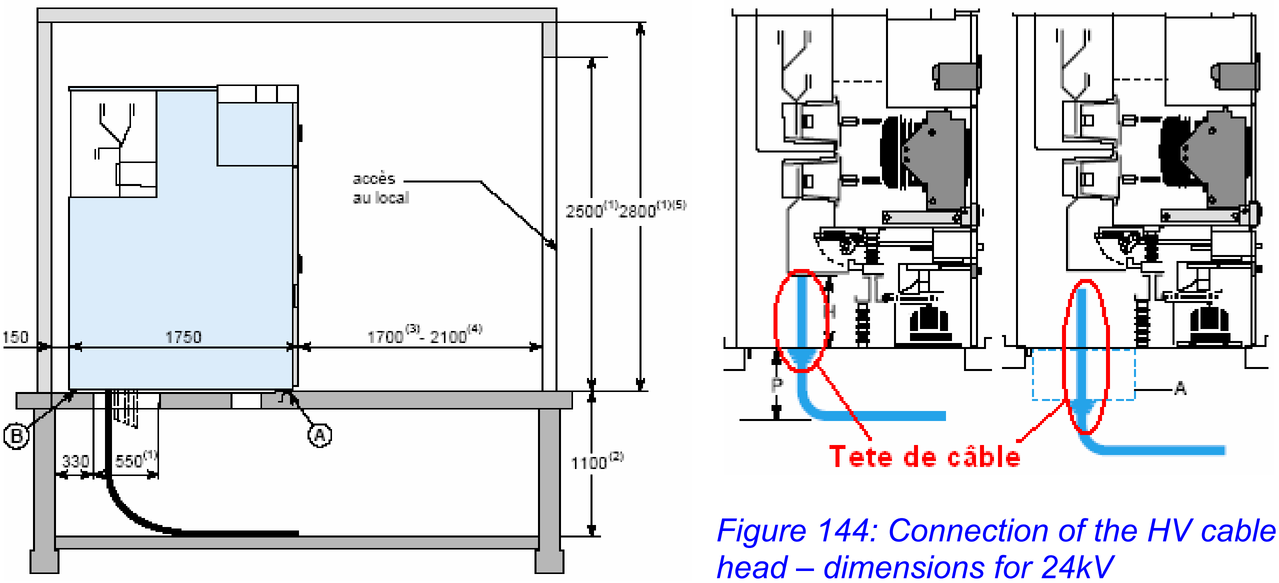


Figure 144: Connection of the HV cable head – dimensions for 24kV

The bend radius and the cable head length must be satisfied as per the cable type (simple insulation, double insulation, armouring, single-pole, three-pole, etc.) and the service voltage.

9.1.3.1. Single-pole ends (dry cable)

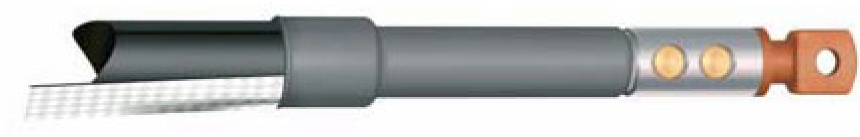


Figure 145: Inner end (HV unit) of a cable with a Cu shield

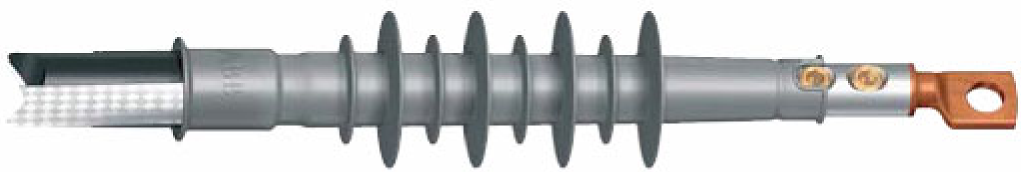
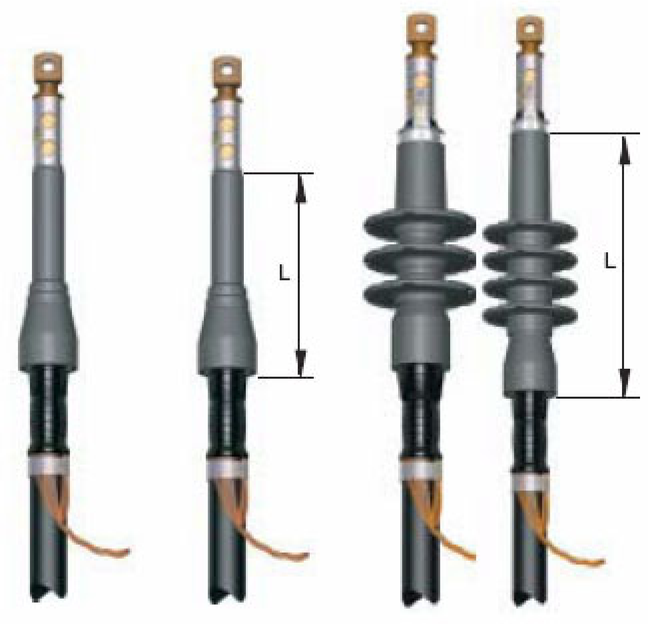


Figure 146: Idem for the outer end

References are assigned per manufacturer, but systematically depend on the cable type and service voltage

XLPE cable ends:



This is the most frequent cable type used on "our" sites

Prefabricated cable head for XLPE head, with 1 or 3 conductors.
This type is for intensive service (multiple start-ups), insulation is (generally) rubber.

Refer to the instructions of the (different) manufacturers for technical details.

Figure 147: Inner and outer ends for XLPE cable and intensive use

9.1.3.2. Multi-pole ends

The type shown is for three-pole cable with a copper shield and armour.

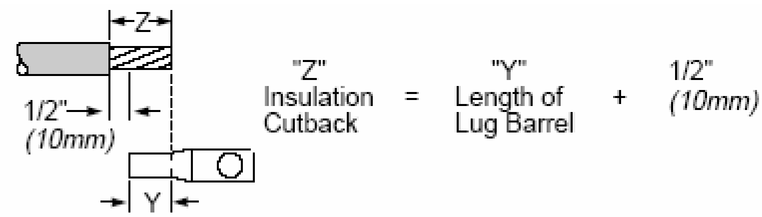
Figure 148: Three-pole cable head for inner and outer connections – 7 - 36kV as per type

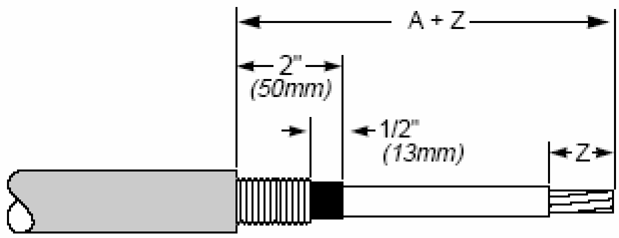
9.1.3.3. Instructions for the construction of a cable head

This requires a single-pole cable, with synthetic insulation (most frequent case): type 15/25/35kV. The following instructions are extracted from a ‘Raychem’ document. Any other manufacturer would issue (practically) the same instructions.

<table>
<tr><th>Check material</th><th>Check for availability of proper equipment before starting</th></tr>
<tr><td>Prepare cable

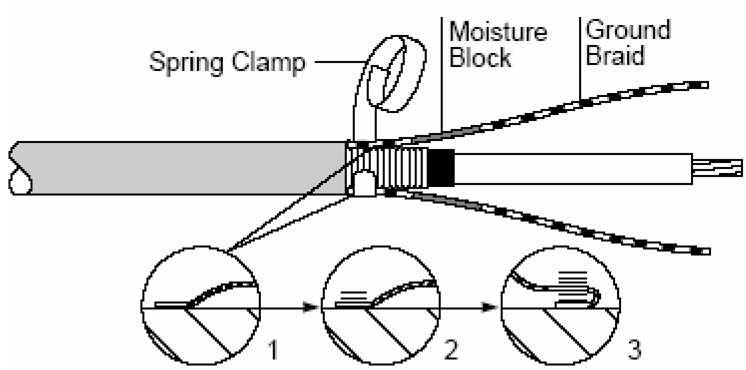
Choose the cable type and follow the directions given.</td><td>
<table>
<tr><th>Voltage Class</th><th>Jacket Cutback A + Z</th><th></th></tr>
<tr><td>15kV</td><td>11" + Z</td><td>(275mm + Z)</td></tr>
<tr><td>25kV</td><td>22" + Z</td><td>(550mm + Z)</td></tr>
<tr><td>35kV</td><td>29" + Z</td><td>(730mm + Z)</td></tr>
</table>
</td></tr>
<tr><td>Insulation cutback

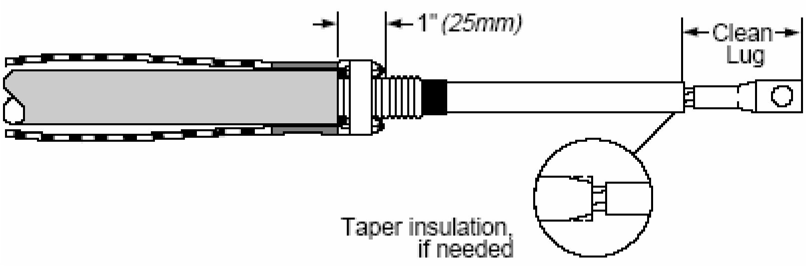
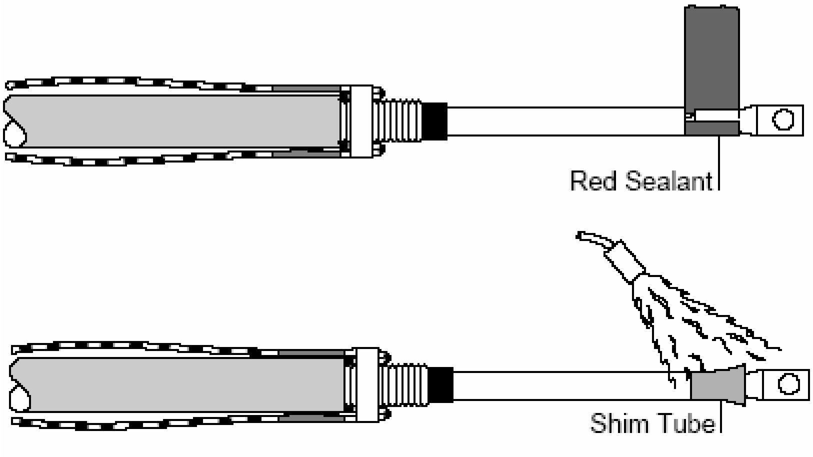
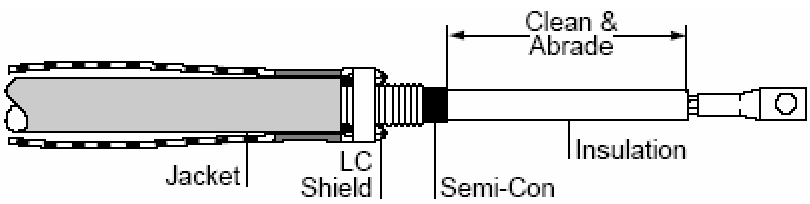
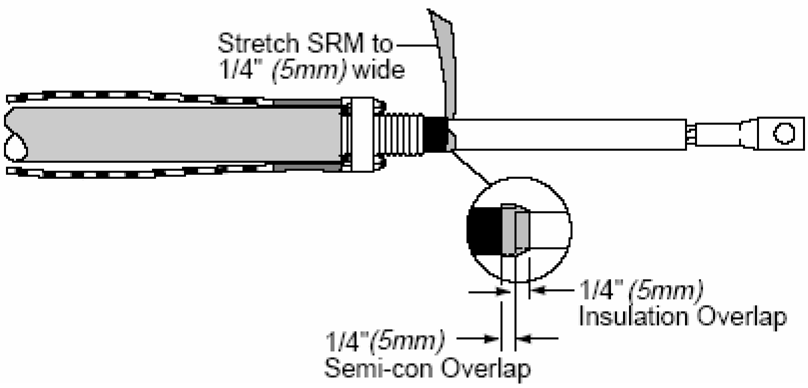
NB: If no lug is used, Z = 2" (50mm)</td><td>
</td></tr>
<tr><td>Cut back cables

Refer to Figure and Table above to prepare the cables as shown for the proper voltage class.</td><td>
</td></tr>
<tr><td>Install ground braid

(1) Flare the moisture blocked ends of the ground braids and place them onto the LC shield butted up to the cable jacket.

(2) Attach the braids to the shield by placing two wraps of the spring clamp over the braids.

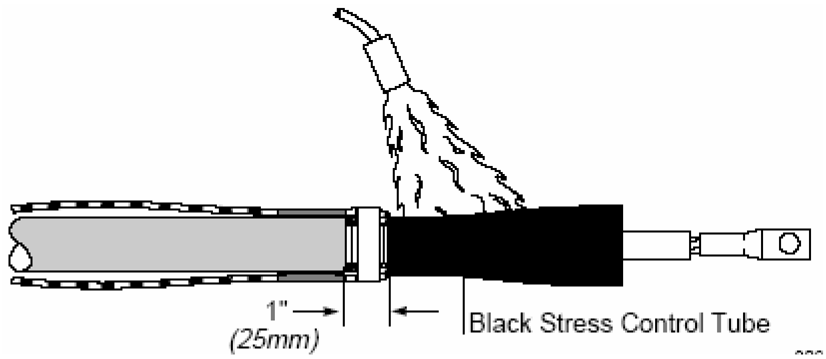
(3) Fold the braids back over the spring clamp wraps. Continue to wrap the remaining clamp over the braids. Tighten clamp by twisting it in the direction it is wrapped and secure with the copper foil tape provided.</td><td>
</td></tr>
</table>

If lug is to be used; install lug. If no lug is used, go to Step 5. After installation, clean and deburr lug as shown. **NB:** If the step between the lug barrel and the insulation is greater than 1/8" (3mm), taper (chamfer) the insulation to meet the lug barrel. Conventional pencilling is not required.	
If 25 or 35kV termination with lug. **If 15kV, Go to Step 5.** **Apply red sealant on lug barrel.** Using light tension, wrap two layers of red sealant around the lug barrel. **Install shim.** Place the shim tube over the red sealant butted against the insulation and shrink into place. Apply heat with a smooth, brushing motion.	
Abrade insulation; clean cable. Abrade the insulation, if necessary, to remove imbedded semi-con. Using an oil-free solvent, clean the cable as shown.	
Apply Stress Relief Material (SRM) at semi-con cutback. Remove backings from the *short angle-cut* piece of SRM. Place tip of SRM at semi-con cutback and stretch to approximately 1/2 its original width. Tightly wrap 3 to 4 layers to fill semi-con step. Overlap semi-con and insulation as shown. Taper SRM down to meet insulation.	

Position black stress control tube; shrink in place.

Position the black stress control tube 1" (25mm)from jacket cutback.

Begin shrinking at ground end and work the torch with a smooth brushing motion around the tube toward the lug end.

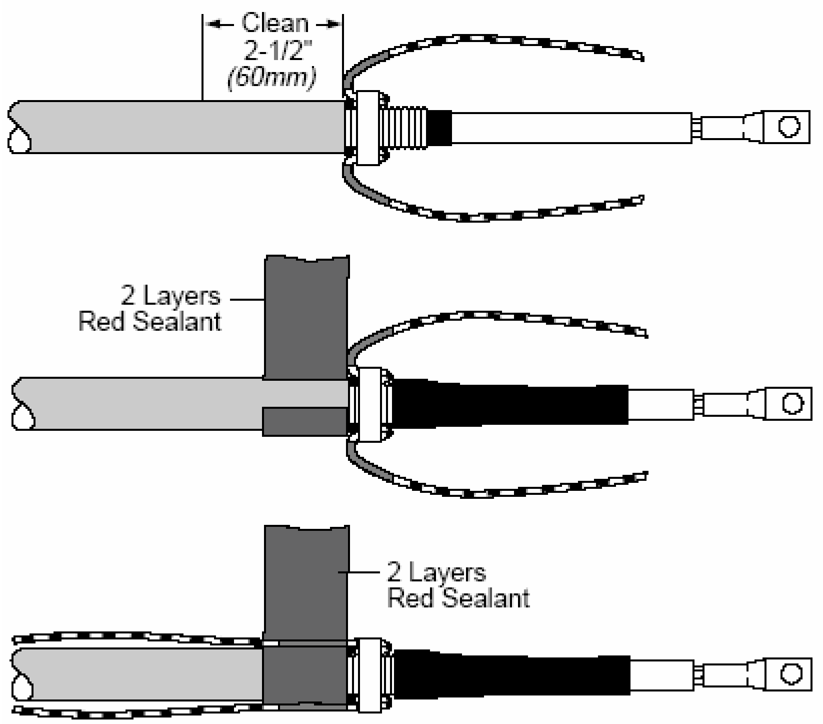


Complete grounding.

Lift ground braids away from the cable jacket. Using an oil-free solvent, clean the jacket for 2-1/2" (60mm)below the jacket cutback point.

Remove the backing from the red sealant. Using light tension, wrap two layers of red sealant onto the jacket under the braids.

Lay the braids back over the jacket and press moisture blocked section of braids into the red sealant. Using light tension, wrap two more layers of red sealant over the braids and first two layers of sealant.

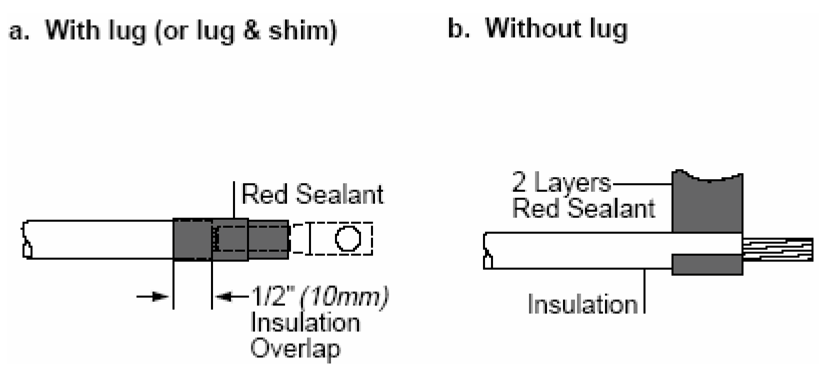


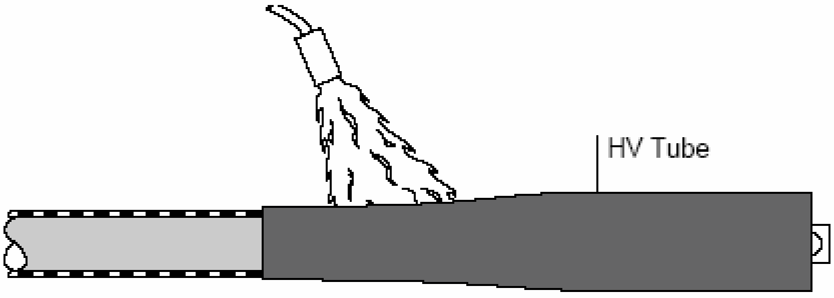
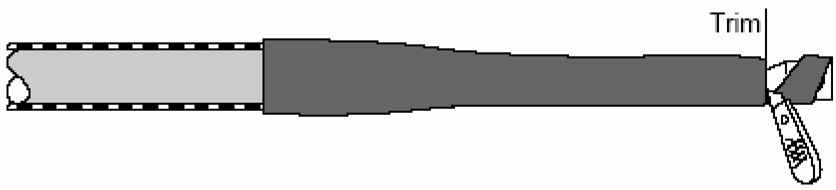
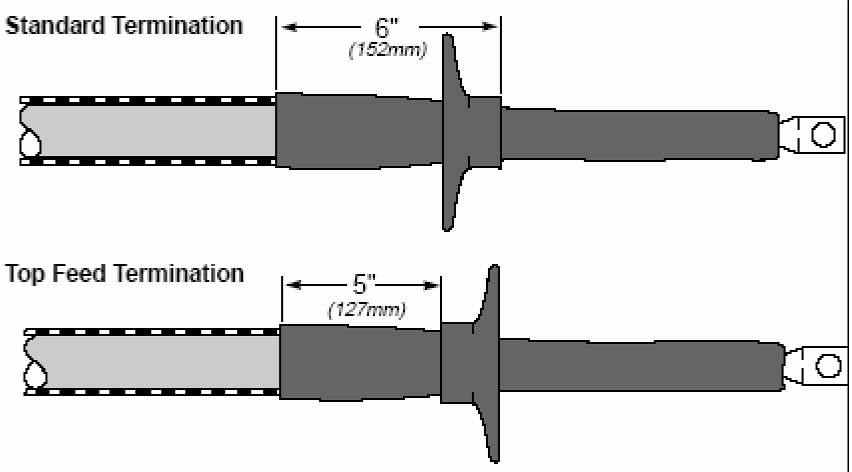
Apply red sealant.

a. With Lug (or lug and shim)
Using light tension, wrap red sealant on lug barrel (or over shim). Build up lug diameter to cable insulation and overlap insulation by 1/2" (10mm).

b. Without Lug
Wrap two layers of red sealant onto the cable insulation as shown.

NB: Sealant will not prevent water ingress between the strands.



Position red HV tube; shrink in place. Position the HV tube at the bottom edge of the red sealant on the jacket. Begin shrinking at the ground end and work to the lug.	
Trim HV tube. **NB:** Allow tube to cool enough to touch before proceeding. If necessary, trim excess tubing from the lug area as shown. Inspect installation; reheat any flat spots or wrinkles. **Indoor termination is complete.** Remaining instructions apply to outdoor terminations only.	
Outdoor terminations only. **Position skirt; shrink in place.** Position the first skirt as shown and shrink in place. Hold the edge of the skirt lightly with pliers. Brush flame tip around outside of skirt collar. Only the collar will shrink.	

Install remaining skirts.

Voltage Class	Total Skirts Used
15kV	2
25kV	3
35kV	4

Referring to the table above, position the remaining skirts (facing the same direction as the first) as required for voltage class and shrink in place.

Check that the skirts have been evenly shrunk and appear symmetrical with no tilt or sag.

Outdoor termination is complete.

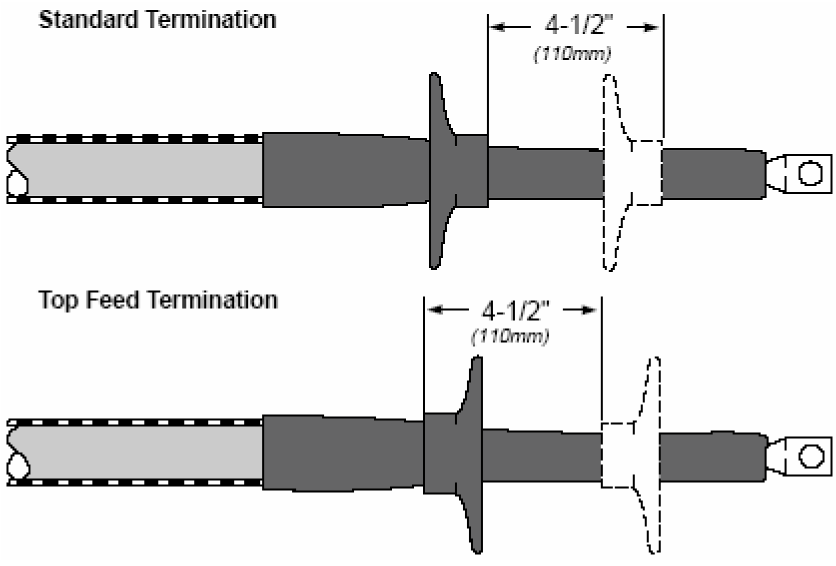


Table 52: Making a HV cable termination

9.1.4. Single or three-pole (junctions) connection unit

HV cables can be damaged on sites, by an over active backhoe loader on shore, a supply boat catching on the offshore cable run or quite simply a cable or a cable head which gives way.

Depending on the cable type, and its voltage, you will need a junction kit and the references of the selected supplier.

Example of Cellpack equipment for a three-pole cable with synthetic insulation (PVC, PE, XLPE, EPR) up to 36 kV. Kits enable the connection of cables of varying sections and conductor materials, even if cable constructions differ in terms of their semi-conductor layer (graphite-coated, strippable or non-strippable) and shield type (copper wire shield or band shield.

Properties

- *Rapid, simple and reliable assembly thanks to the combination of plug-in and heat shrinkable components*
- *Reliable checking of the electric field for all application conditions thanks to permanent elastic silicone field distributors*
- *Wide span of sections, as appropriate for all types of junction sleeves*
- *Unlimited storage duration and immediate use*

Construction

Main kit components:

- *Silicone field distributor components*
- *Blue filling band, field distributor*
- *Heat shrinkable insulation sheaths with thick walls*
- *Copper tubular braid and contact springs*
- *Heat shrinkable outer protective sheath with a thick wall and adhesive*

Material included in the delivery

One kit for three phases, with no junction sleeve, for cables without armour.

Accessories for armoured cables and the junction sleeves required can be ordered separately.

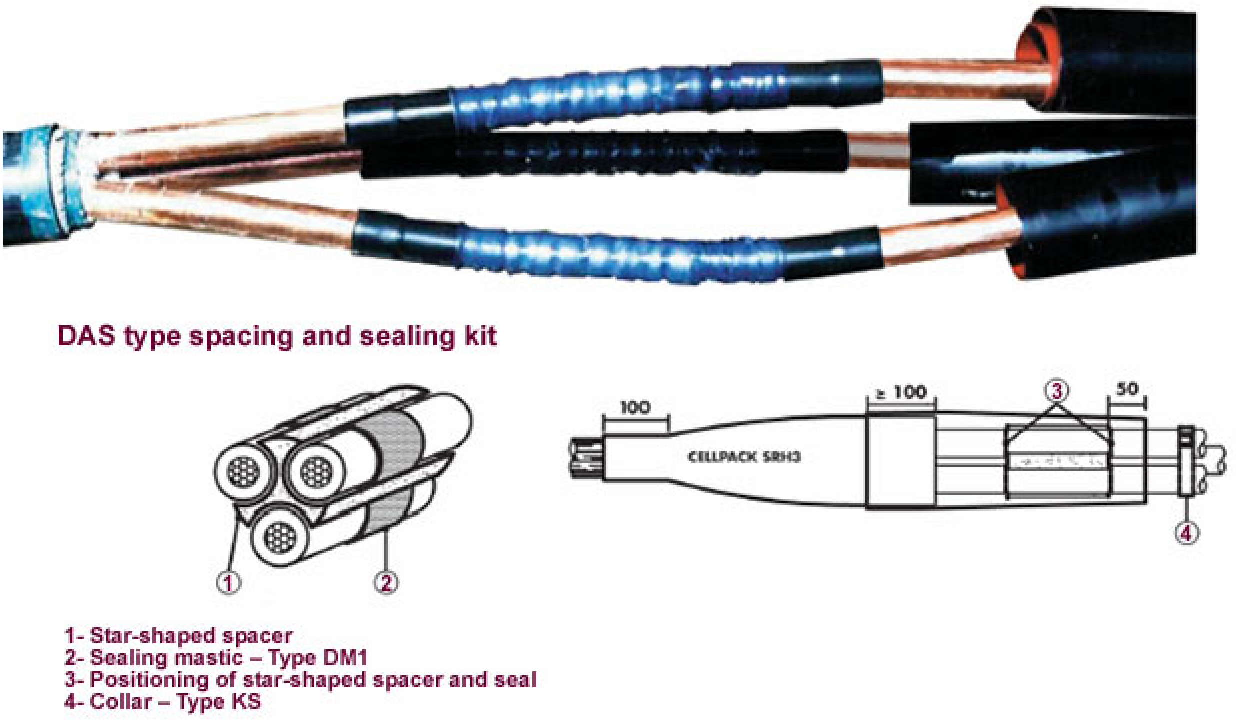


Figure 149: HV cable junction, possible construction and kit

9.1.5. Test of HV cable heads and cables

The single-pole 24kV cable with XLPE insulation shown has had its insulation band (cable head) removed for the photo.

Figure 150: Fault on single-pole 24kV cable

The yellow/brown line (circle) shows an insulation fault (start of priming) in the off-white XLPE insulation sheath. *This cable head, if re-used, will undoubtedly fail at some point.*

Testing the quality of the HV cables and, more particularly, the quality of the cable heads, is an operation to be carried out at construction and commissioning, but also at regular intervals (frequency to be determined) in the context of maintenance. This testing may be carried out by an external organism if the maintenance team does not have the necessary test equipment and/or does not feel qualified…..

An insulation fault will cause a partial (and permanent) electrical discharge.

One (non-destructive) test method involves the detection of the acoustic signal emitted by the 'leaking' discharge.

This method must be applied while equipment is operating normally. The full safety and work permit procedure must clearly be applied prior to accessing the cabinets, as shown on the photo. *(PPE must not be forgotten: the person in the photo should be wearing insulation gloves and safety goggles and use a stool…)*

Figure 151: On-line testing of HV cable heads

The acoustic signal is "captured" at the end of a special insulation pole aimed at the cable (or cable head) to be tested, quite simply using a microphone.

This signal is converted, encoded, assessed and compared for several test modes. E.g. we could test a cable by running the pole along the cable.

Refer to the chapter dedicated to cable and cable head testing, this is just a starting point…

Always remember to connect the braids and casing to the ground…

9.2. LOW-VOLTAGE CABLES

9.2.1. Introduction

Electricity travels from the supply to the load through cables. Cables form a part of all circuits. Every cable has to be connected to some part of the circuit.

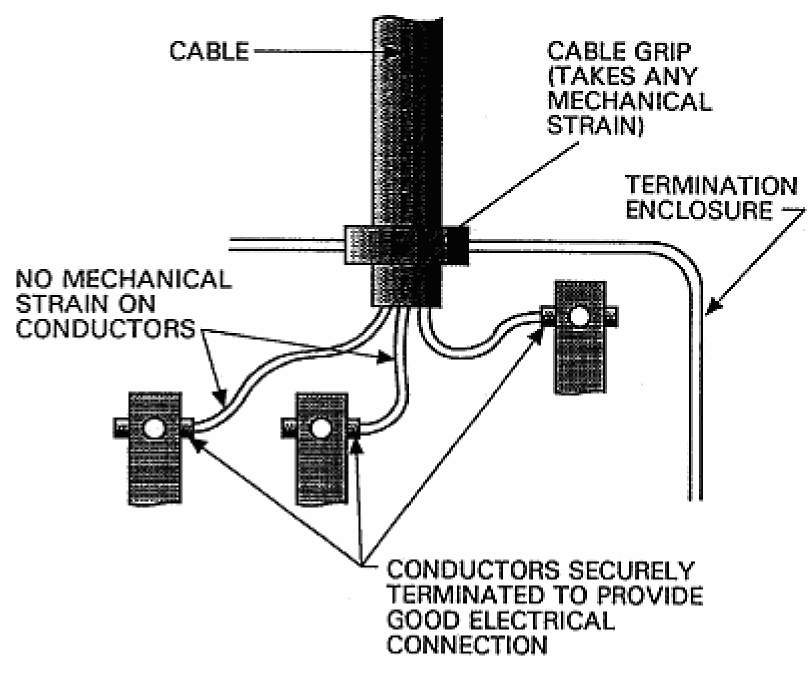
The connection of a cable to any part of the circuit is called a termination. There are many different types of terminations for different conditions and equipment.

Aim here is not to develop the complete technology of terminations inside cubicles, panels, junction boxes, but only to show the accessories such as lugs, terminals, tools to use, etc… If a termination is not done correctly it can cause many problems. A bad termination may overheat and cause a fire. A connection may have very high resistance which can cause problems with the supply to the equipment.

Concerning the "other accessories", meaning the cable glands, the cable trays, the wall crossings, and the different laying cables devices, see next chapter, this paragraph covers the most common types of cable terminations.

Cable terminations are an important part of the electrician's job. Therefore, they must be done correctly using the right tools and equipment.

9.2.2. Cable terminations



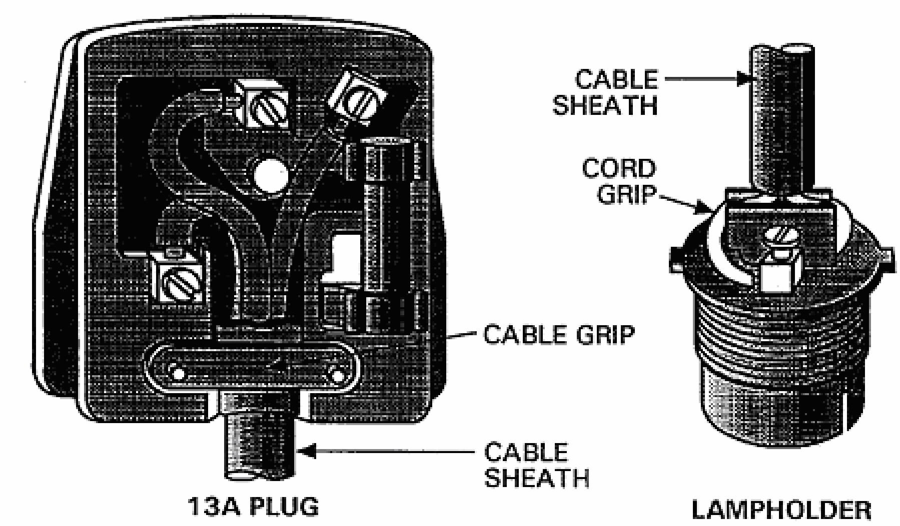
The connection of a cable into a device or piece of equipment is known as a termination. All electrical terminations must be both electrically and mechanically secure.

The termination must be good enough to carry the load current of the circuit. This means that the connections must have a low resistance and the cable must be tightly secured.

Figure 152: Cable Termination.

There should be no mechanical strain on the conductor connections.

The cable should be held firmly in the termination enclosure with a cable grip. Any mechanical strain should be on the cable grip, not on the conductors.



Different kinds of cable grips are used to make sure that no mechanical strain is put on the termination. There are special glands clamps and cord grips for different types of cables and termination enclosures.

Figure 153: Types of cable grips used on small household appliances.

If the conductors in the termination are under mechanical strain then they may become loose. A loose connection could overheat and cause a fire or it could disconnect and break the circuit.

It is important that all terminations meet the following conditions:

- A termination should be electrically and mechanically secure.
- The cable sheath should be intact and undamaged right up to the enclosure of the termination.

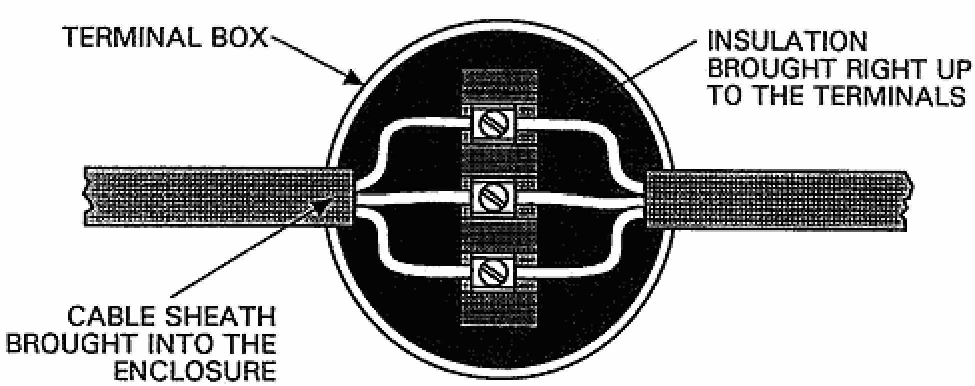


Figure 154: Terminal Connections

- There should be little or no mechanical strain on the conductor connections of the termination.
- The insulation should be intact and undamaged right up to the terminals

- All the strands of the conductor must be intact and securely held in the termination. No loose wires.

9.2.3. Removal of insulation

Before a conductor can be terminated, the cable insulation must be removed.

Removing the sheath and insulation from a cable is called stripping the cable.

Cable stripping can be done using side cutting pliers or a stripping knife.

9.2.3.1. Removing sheath using side cutting pliers

1. Split the sheath along the length of the cable. Be careful not to damage the insulation of the wires.

.2. Peel back the sheath, and cut away the unwanted part. (See figure 14-4).

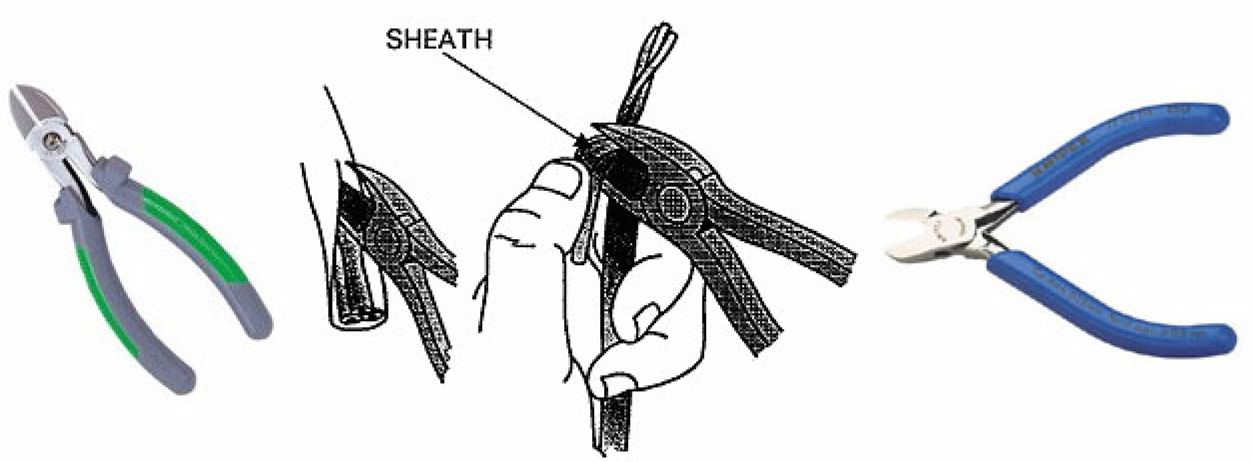
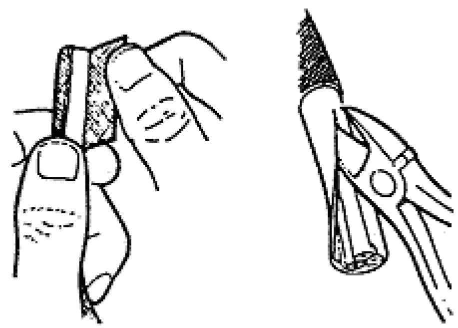


Figure 155: Cut Away the Unwanted Part of the Sheath

3. Check conductor insulation for damage.

4. Where there are two or three layers of protection, they must be removed separately.

Figure 156: Remove Each Layer of Protection Separately.



9.2.3.2. Stripping insulated wires with a stripping knife

The insulation around a wire (conductor) can be stripped with a stripping knife.

A stripping knife should have a short, wide blade with a flat end

Figure 157: Typical Electrician stripping Knife

It is important to hold the knife at an acute angle when cutting the insulation

Make two or three cuts from different sides of the wire. Then pull off the unwanted insulation with a pair of pliers.

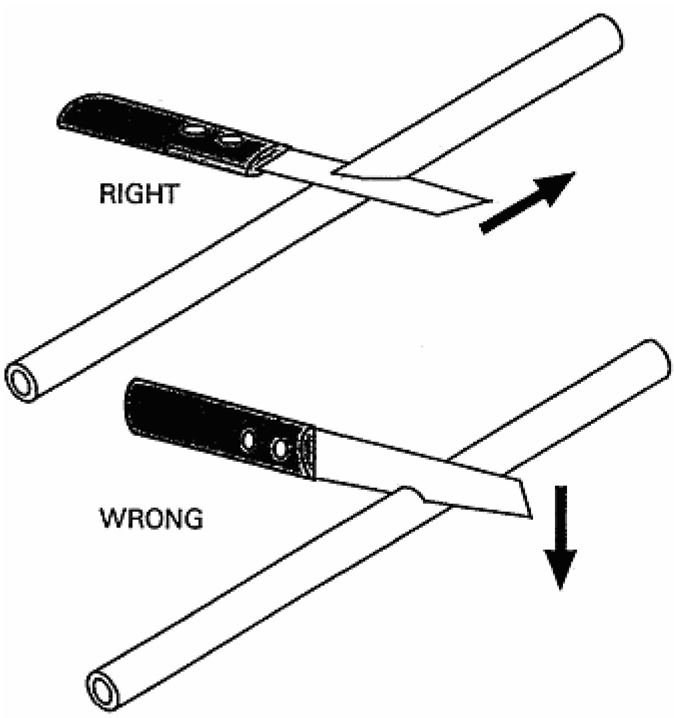


Figure 158: Cutting Insulation with a knife

Do not cut into the conductor

A conductor with a nick (small cut) in it is dangerous in 2 ways

1. It will break after is has been bent a few times.

2. The CSA will be smaller so the resistance in that part of the conductor will be higher. This can cause overheating.

Use wire strippers to strip wire when you can. They do a cleaner, better job.

9.2.4. Wire stripping tools

You can use a special kind of pliers to remove the insulation from a wire. The jaws have "V" shaped notches. When the jaws are closed the notches form a hole. You can adjust the jaws so that they only cut the insulation. They do not cut the wire.

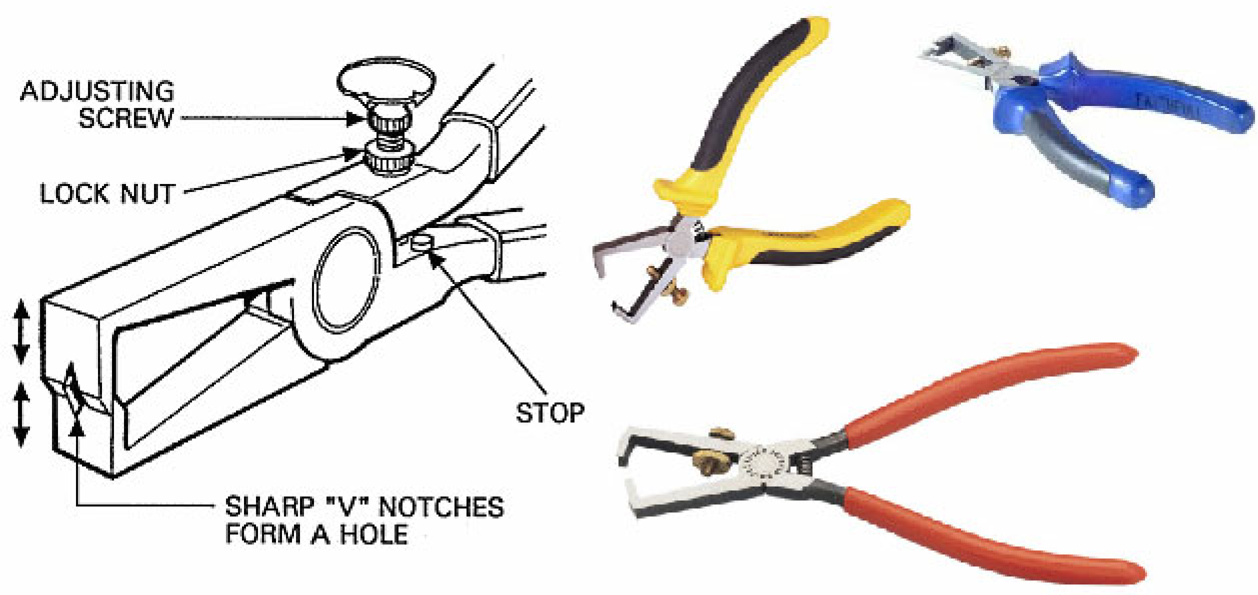


Figure 159: Adjustable Wire Stripping Pliers

<u>How to use wire strippers.</u>

1. Turn the adjusting screw so that the hold in the jaws is the right diameter for the wire.
2. Tighten the lock nut.
3. Place the wire in the V of the bottom jaw and close the pliers over the wire (Part (A) on the figure).
4. Turn the pliers and pull the wire out of the jaws to remove the insulation (Part (B) on the figure).

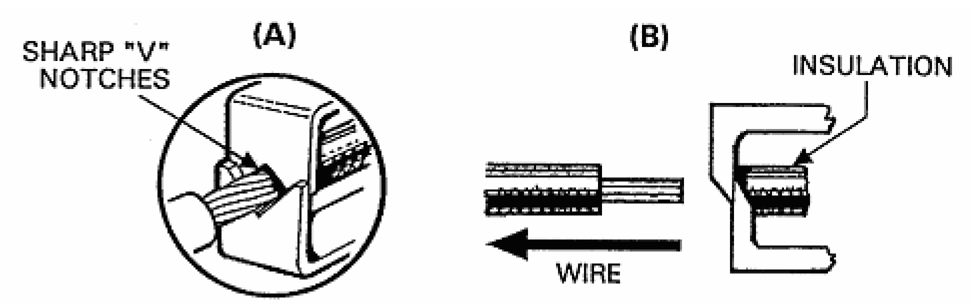
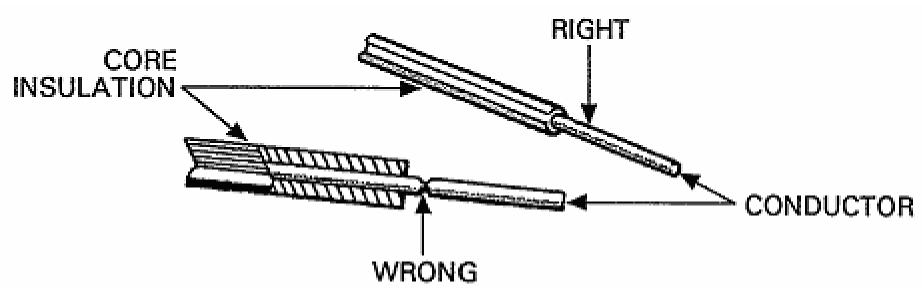


Figure 160: Using Wire Strippers

There are other kinds of wire stripping tools which work on the same principle. When the jaws close they form a hole so that they only cut the insulation. They leave the wire intact.

See the "automatic stripping Pliers" pictures. Some tools even combine the stripping and crimping facilities but in small wire sections

Figure 161: Set of automatic stripping (stripping and crimping) Pliers

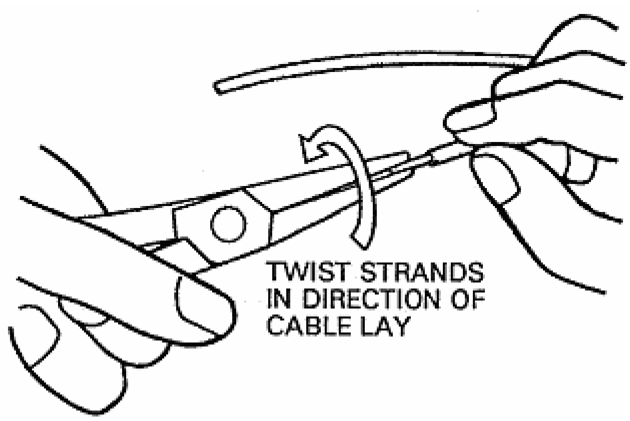


After the insulation has been removed check that the conductor has not been damaged.

Figure 162: Check for Damaged Conductor

A conductor which has been damaged will break easily or it will increase the resistance in the wire.

Therefore you must be careful not to damage the conductor when removing the insulation.



If the cable has a stranded conductor then the strands should be twisted together tightly before termination. Use pliers (flat nose pliers preferably) to twist the strands in the direction of the existing twist (lay) of the cable.

Figure 163: Stranded Cable Preparation

You must make sure that all the strands are fitted into the termination.

If not, the current carrying capacity of the cable will be reduced. Also, loose strands in the termination can cause short circuits.

9.2.5. Types of terminations and connections

There are many different ways of joining or terminating conductors. The different methods of termination are divided into two groups:

- Heated terminations (eg. soldering, welding)
- Mechanical terminations (clamping, bolting etc.)

This paragraph will cover mechanical terminations only. Soldering will be covered in following chapter

9.2.6. Mechanical terminations

The advantage of mechanical terminations is that they are strong but the connection is not permanent. It can be taken apart easily for repairs or changes to the circuit.

The disadvantages are that the terminals can oxidise and screwed joints can become loose over a period of time *(It is why you need regular maintenance operation of re-tightening the connections)*.

The most common types of mechanical terminations are:

- Pillar Terminals
- Screw Terminals
- Nut and Bolt Terminals
- Strip Connectors
- Claw washers
- Split bolt connectors

9.2.6.1. Pillar terminals

You often see pillar terminals in the plugs on household appliances. A pillar terminal has a hole through the side where you fit the conductor. A set screw is tightened on to the conductor.

If the conductor is small in relation to the hole it should be doubled back.

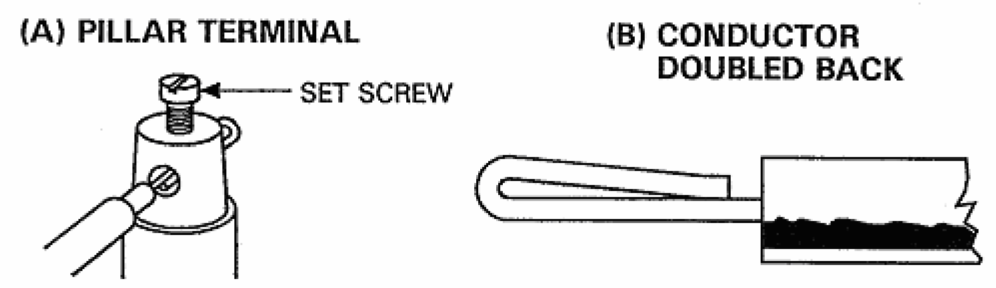


Figure 164: Pillar Terminal

You can put two or more conductors in the same terminal by twisting them together. You must be careful not to damage the conductor by tightening the set screw too much.

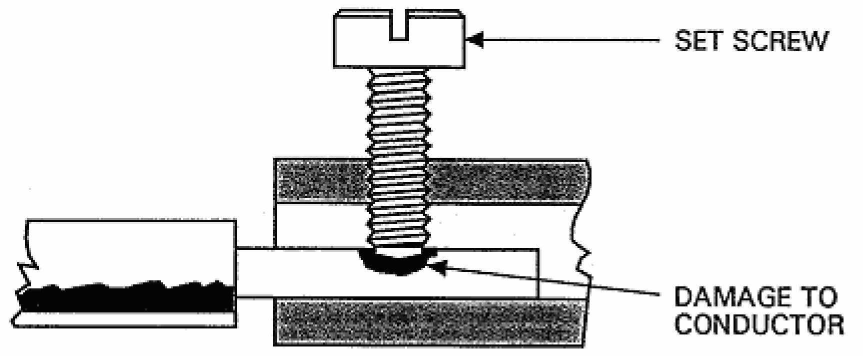


Figure 165: Over Tightening of Set Screw

9.2.6.2. Screwed and nut and bolt terminals

When fastening conductors under screw heads or nuts the conductor should be formed into a loop. You can do this easily using round nosed pliers.

Figure 166: Round noses – half noses – long and short noses pliers

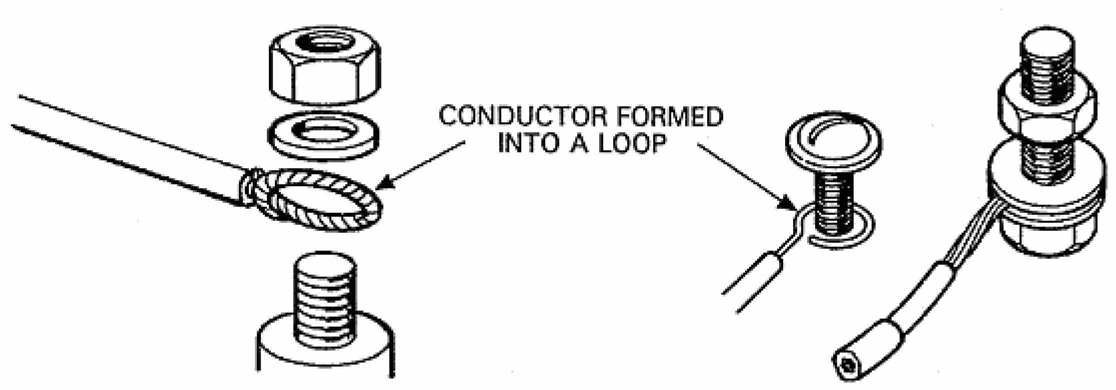


Figure 167: Screw head, Nut and Bolt Terminals

The loop should be placed so that when you tighten the screw or nut you do not cause the loop to open

9.2.6.3. Claw washer

You can use a claw washer to prevent the loop from opening when you tighten the screw.

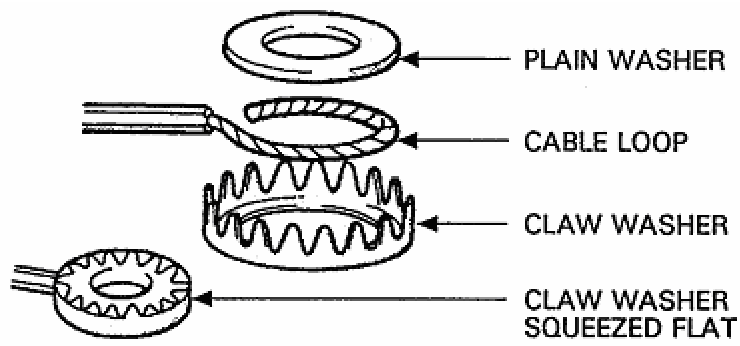


Figure 168: Claw Washer

Place the plain washer on top of the loop. Then place both the loop and the washer on to the claw washer. Squeeze the metal points of the claw washer flat over the terminal loop.

9.2.6.4. Strip connectors

Strip connectors are sometimes called terminal blocks. Strip connectors are a group of brass connectors fitted in a line in a moulded insulated block.

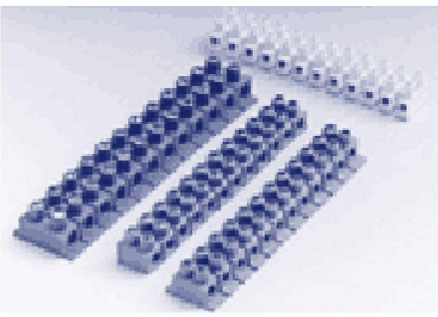


Figure 169: Strip Connector in moulded blocks

The conductors are held in place with a grub screw in the same way that a set screw grips the conductor on a pillar terminal.

The conductors should be pushed well into the connector. This prevents the grub screw only gripping the end of the conductor.

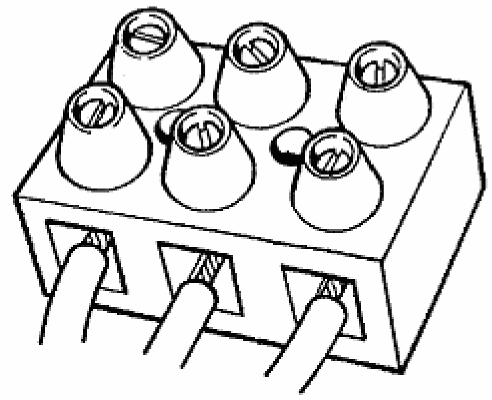


Figure 170: Connections on Strip Connector

It is important to get a good, clean, tight connection.

This will prevent high resistance contacts which would cause the connection to overheat.

It will also prevent loose contacts which might come apart.

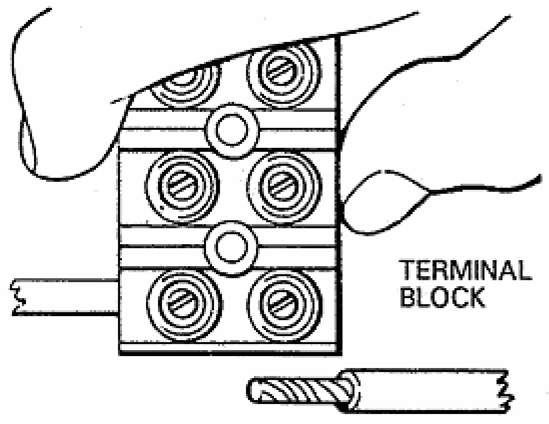


Figure 171: Inserting Conductor into Terminal Block

Some connectors have pressure plates which give better connections.

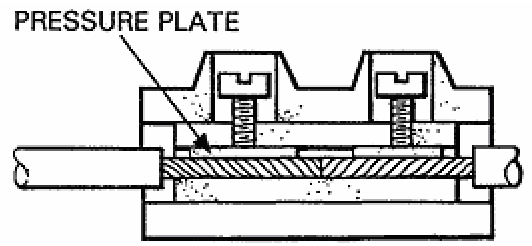
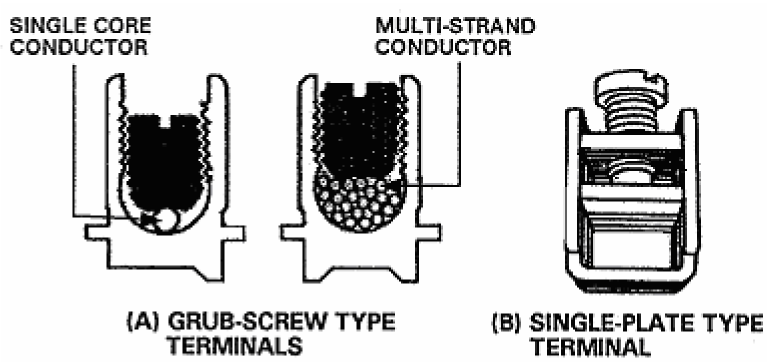


Figure 172: Pressure - Plate Terminal Block

A pressure plate spreads the pressure on the connection and allows better contact between the two conductors.

This is especially important when you are dealing with high current circuits. They are also good for multi-strand conductor terminations.



Grub Screw or pressure plate terminals are normally used for terminations in electrical equipment, eg. switchgear, starters, breakers, contactors, etc.

Figure 173: Switchgear type Terminals

9.2.6.5. Split-bolt connectors

Split-Bolt connectors are used to join two or more cable ends together. They are also called line tap connectors. This is because they are often used to tap off a conductor (line) without breaking the circuit.

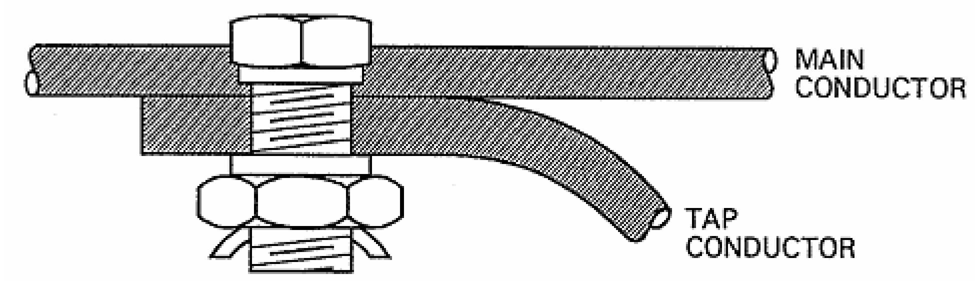


Figure 174: Split-Bolt Connector

9.2.7. Crimped connections

Crimping is a quick and effective way of joining different types of termination devices to cable conductors

Not crimping a rigid core cable; connecting it directly into the terminal block is not a problem; it is even recommended to never use lugs on rigid cores!

But when dealing with stranded core, and even worse with flexible type wire, it becomes a lack of professionalism to not use crimped terminations when the connectors of the receptor are not adapted to receive such wires.

9.2.7.1. The crimp lugs and sleeves

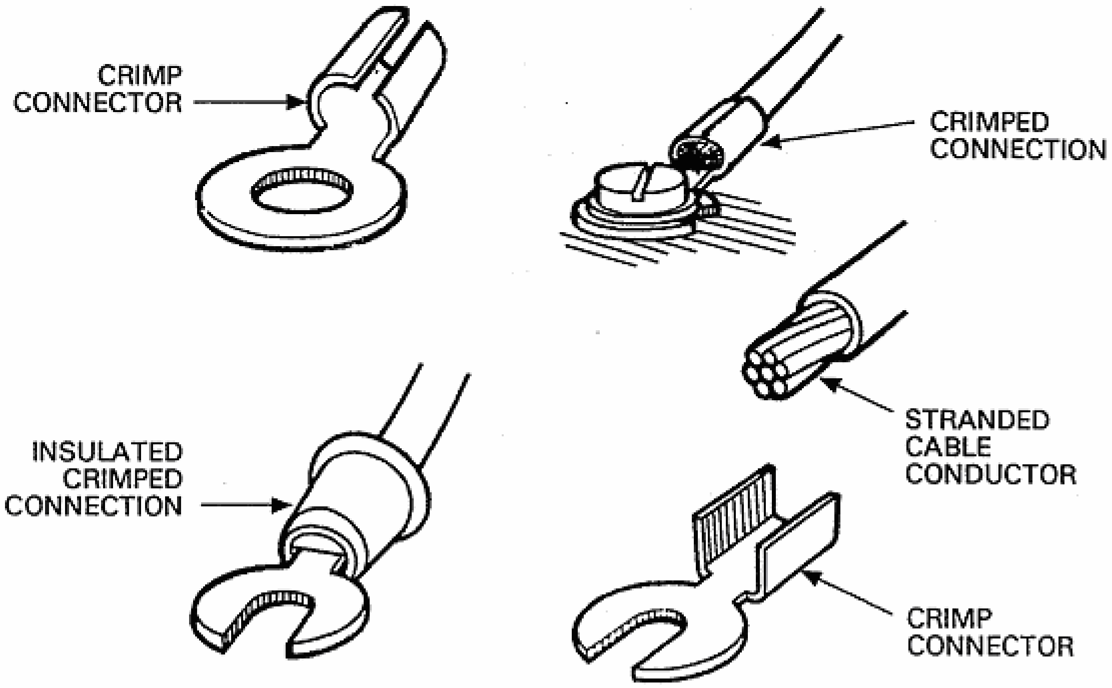


Figure 175: Types of Crimped Terminations (small size wires)

Crimping uses a special tool (crimping tool) to apply enough pressure to form a good connection between the crimp connector and the conductor.

A correctly crimped connection has high mechanical strength and good electrical conductivity.

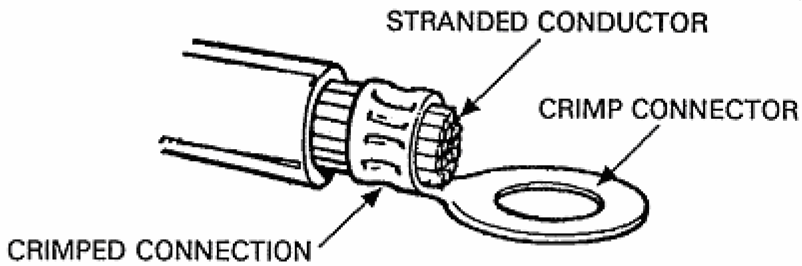


Figure 176: Crimped connection

Crimped connections are quicker and cheaper than soldered connections. Crimped connections are often used for small cables using a hand operated crimping tool.

But before crimping, you need to choose a lug or a sleeve and this according to

- Material of the wire: copper or aluminium – It can be also bimetal, crimped on aluminium cable and connected on a copper base bolt/seat.
- Size of the wire: from 0,5 to 600mm²
- Type of connection: pin, fork, blade, spade, ring, etc…

Figure 177: Panel of lugs / sleeves for Crimping

Obviously, you are not going to crimp the same way, use the same crimping tool with so many different sizes and types.

9.2.7.2. The crimping tools

Hand crimping tools often have jaws which can be changed to fit different shapes and sizes of crimp connectors. You crimp the connection by squeezing the handles shut.

The handles can not be released until full pressure is applied to the connection (except for the "fastener" type crimping tool).

Then the ratchet releases the handles. This ensures that the correct pressure is applied to the crimp connection.

A power operated crimping tool (hydraulic) is used for crimping large conductors of high current cables.

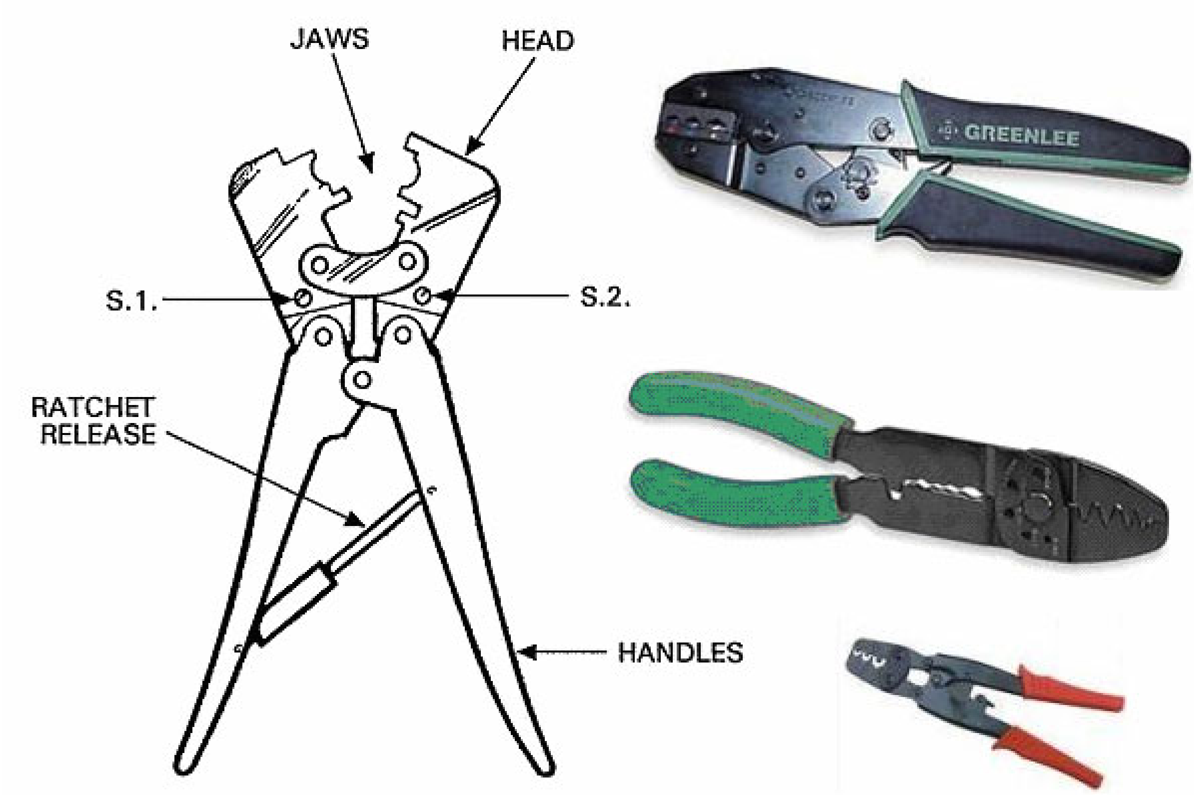


Figure 178: Hand operated crimping tool

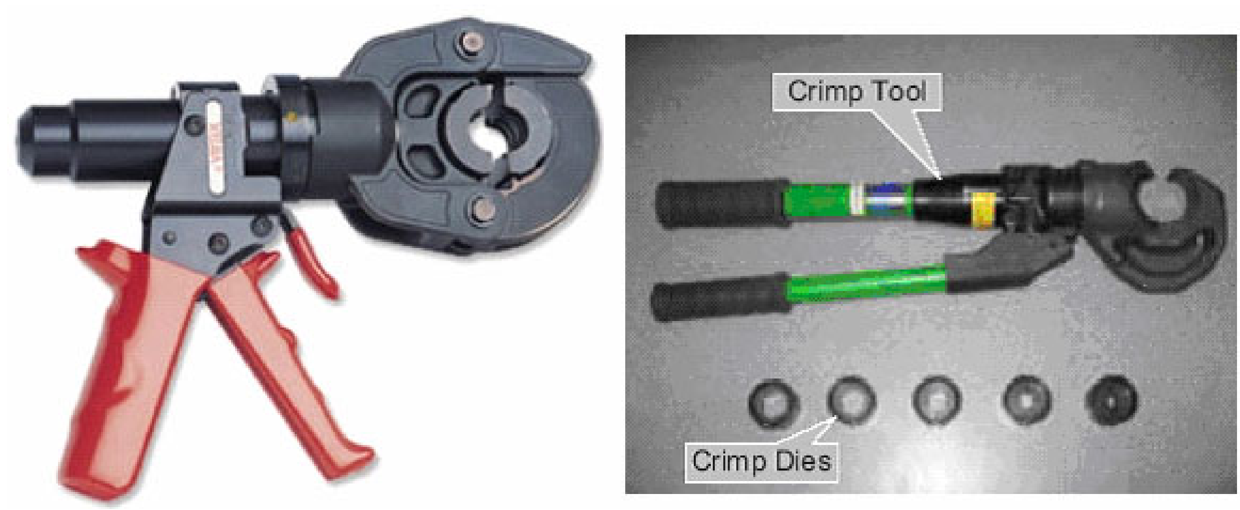


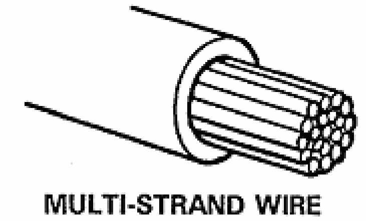
Figure 179: Hydraulic hand operated crimping tool

With that type of tool, making compression crimping, choice of adapted dies is required (function of lug / sleeve diameter.

The hydraulic crimping tool can be hand operated, battery operated or with separated pump which can be as well hand, pneumatic, electrical operated.

Figure 180: Set of hydraulic operated crimping tool (hand, battery, hand pump)

9.2.8. Making a crimped connection



1 Strip the insulation from the end of the stranded conductor.

Figure 181: Remove insulation on the wire

This applies systematically for stranded and flexible cable

2. Twist the strands together with pliers so they all fit into the barrel of the crimp connector.

3. Place the barrel of the crimp connector over the conductor

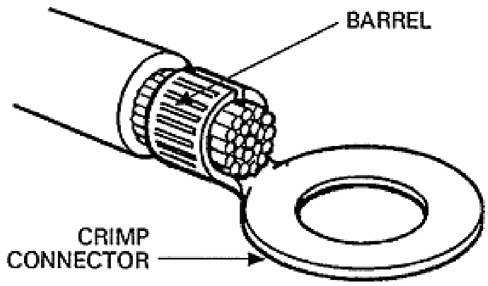


Figure 182: Place Device onto Conductor

4. Place the barrel of the crimp connector into the jaws of the crimping tool

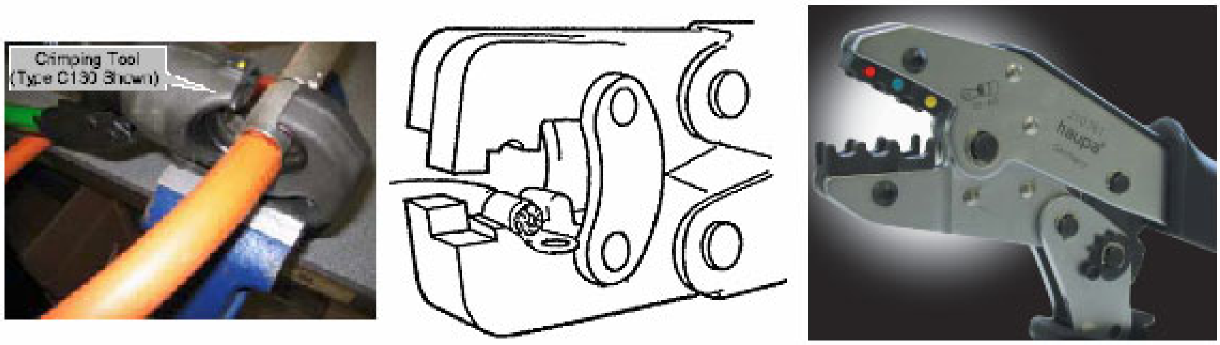


Figure 183: Place Connector in Crimping Tool

5. Crimp the connection by squeezing the handles of the crimping tool, or start to pump
.

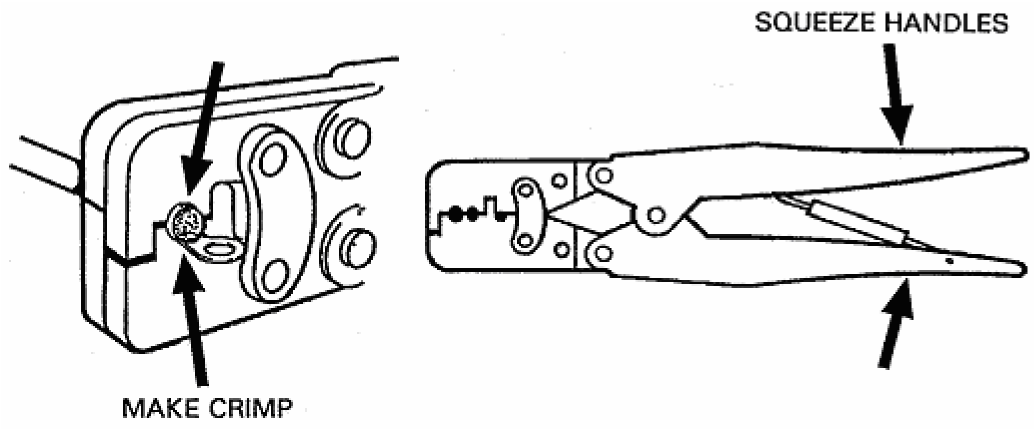
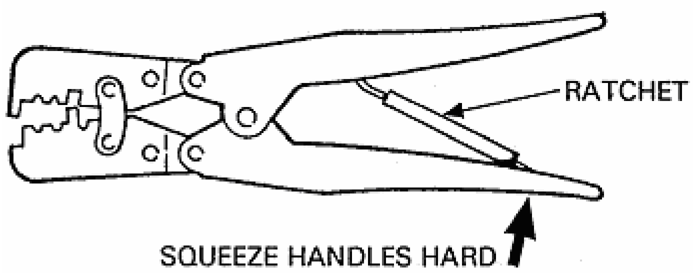


Figure 184: Making a Crimp Connection.

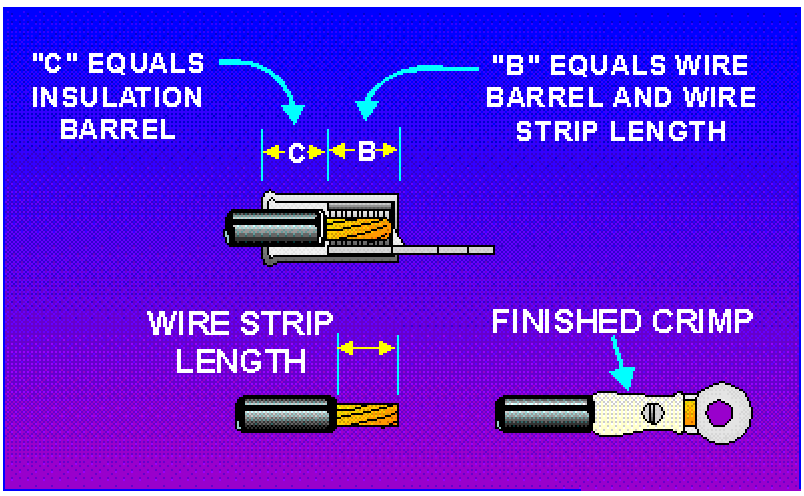
6. Squeeze the handles together until the ratchet releases them (die is completely closed or punch is at maximum with hydraulic unit).



Open the handles and remove the tool from the crimped Connection.

Figure 185: Released Crimping Tool

7. Check for clear and neat connections



The wire has been stripped the correct lenght corresponding to the ‘B’ portion.

The insulation is well inside its barrel

The finished crimp is firmly secured

Figure 186: Resume of crimping method

9.2.9. Use the correct crimping method

With a hand crimping tool, for small lugs, it is a simple operation. Once you have to use hydraulic equipment, it means that you have to connect cables of consequent cross section and:

- Decide to use compression method with dies
  - Select the die in shape / form according to the use
  - Select the die of proper dimension adapted to the diameter of the lug
  - Ensure that the hydraulic pressure is adapted (check with manufacturer recommendation)

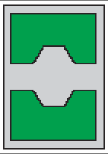
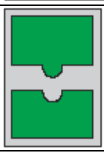
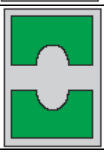
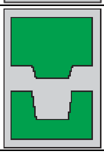
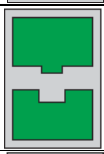
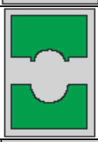
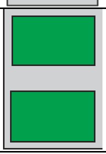
Diagram	Designation	Domains of applications	Sizing
	***Hexagonal crimp***	for crimping ”normal design” Cu tubular cable lugs and connectors tubular cable lugs for switchgear connections,	6 - 1000mm2
	***Mandrel shape crimp***	for crimping ”normal design” Cu tubular cable lugs and connectors, tubular cable lugs for switchgear connections,	0.75 - 400mm²
	***Oval crimp***	for crimping double crimp cable lugs, C clamps, insulated tubular cable lugs and connectors, insulated pin cable lugs,	0.1 -185mm²
	***Trapezoid crimp***	for crimping wire-end sleeves and twin wire-end sleeves.	0,14 - 185mm²
	***Square crimp***	for crimping wire-end sleeves and twin wire-end sleeves.	0,14 - 6mm²
	***WM crimp***	for crimping tube terminals ”standard”	10 - 400mm²
	***Rounding***	for sector wires 90° and 120°	10 sm - 300 sm, 35 se - 300 se
	***Cutting dies***		

Table 53: choice of dies in crimping tool

- Decide to use punching method (die less)

Figure 187: Die less crimping tool with hydraulic pump separated

- Lug bed and punch cover only a range of diameter
- Change bed and punch according to lug diameter if your tool admit it
- Check manufacturer recommendation for number of punches on the lug selected.

- Position the lug correctly

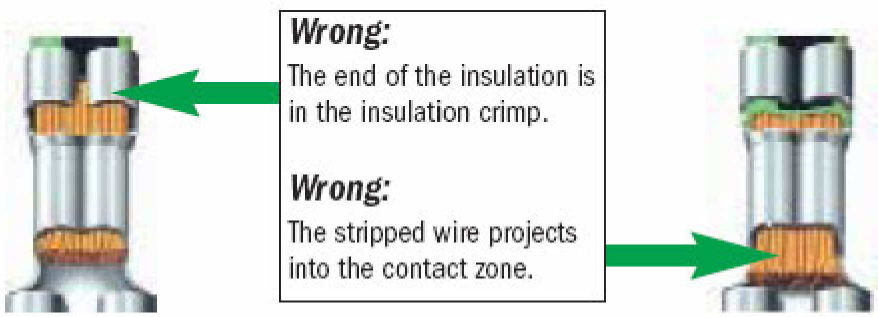


Figure 188: Wrong positions of wire on lugs

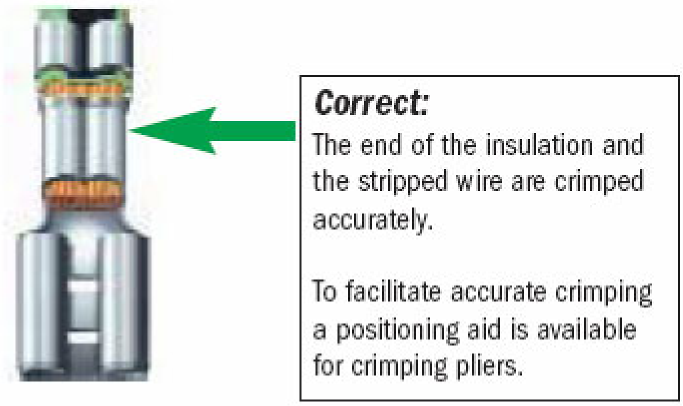


Figure 189: Correct positions of wire on lugs

This position of lug is (of course) valid for all types of lugs and sleeves

With pre-insulated compression lug, do not forget to incorporate the insulation of the wire within the lug part which is dedicated for

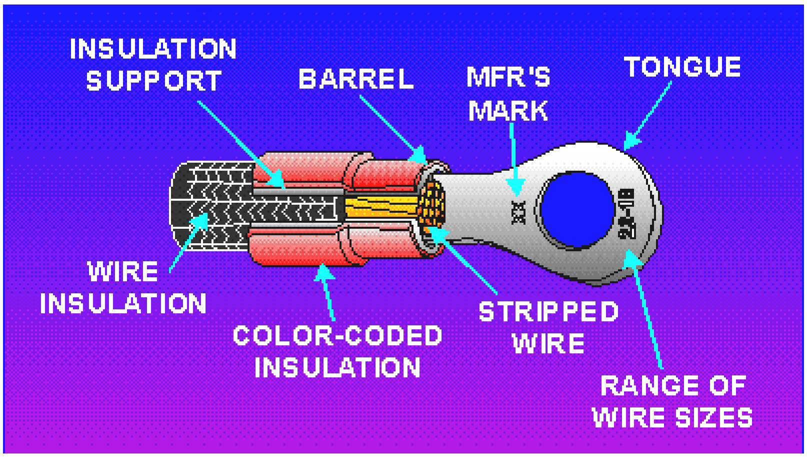


Figure 190: Pre-insulated straight copper terminal lug.

- Crimp the cable lug or connector with the correct tool, taking account of the crimping direction (when several crimps are required

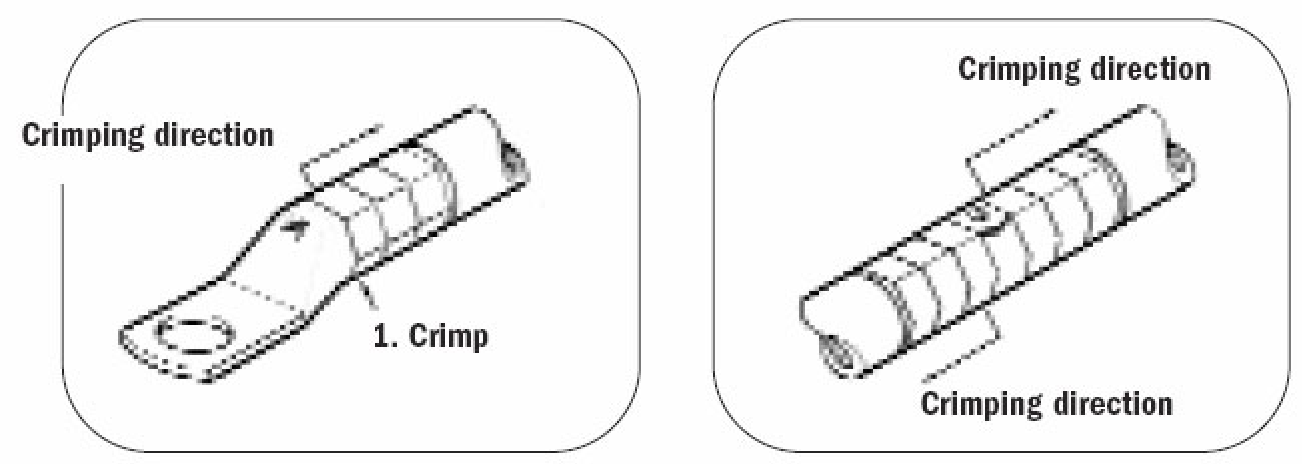


Figure 191: Crimp in correct direction

- Discard the “missed” crimping

Figure 192: “Problems” with Crimping…

This kind of problem (lug cracking) can occur either due to material failure (manufacturer responsibility) or by misuse of the crimping tool (wrong die, over pressure).

- Make at least a double crimp (big size lugs)

The recommended method is to double crimp although single crimps may be suitable for crimping smaller cables.

Each crimp should be at 90° to each other and positioned centrally within the contact crimp area, as shown in figure (hexagonal type die here).

If a single crimp is used, the crimp should be positioned centrally within the 35mm area shown in figure.

Crimp in the order shown to ensure a satisfactory crimp. Consult the factory/manufacturer manual if any additional information or advice is required.

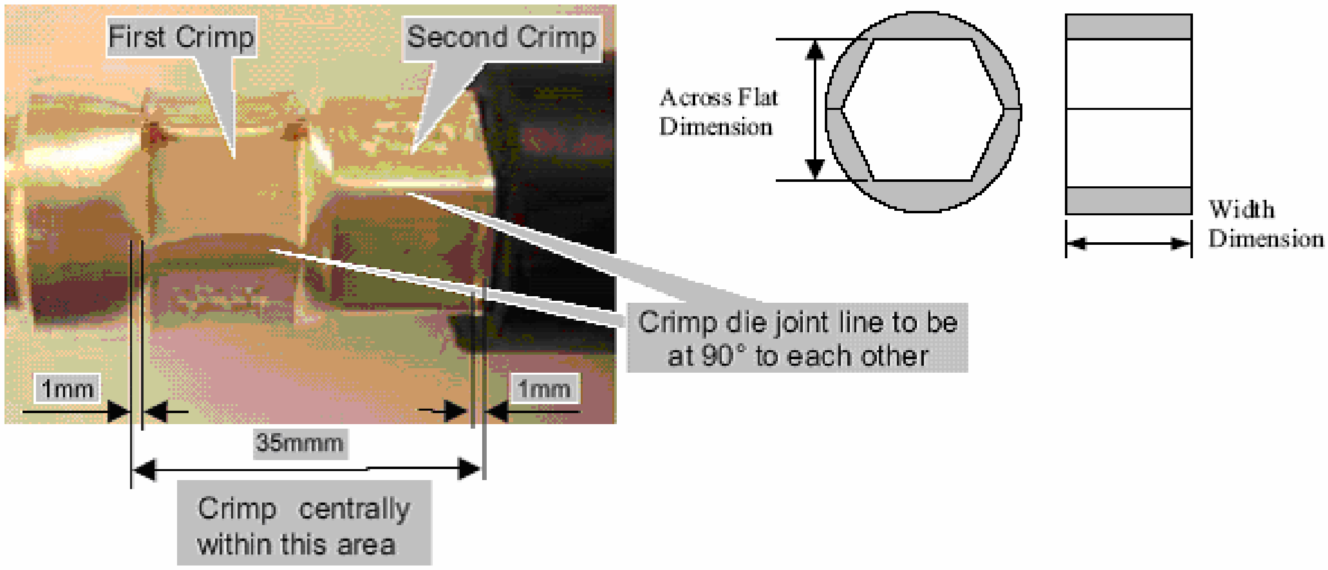


Figure 193: Double crimp recommendation as per die standard dimensions

9.3. CABLE GLANDS

9.3.1. General Functions

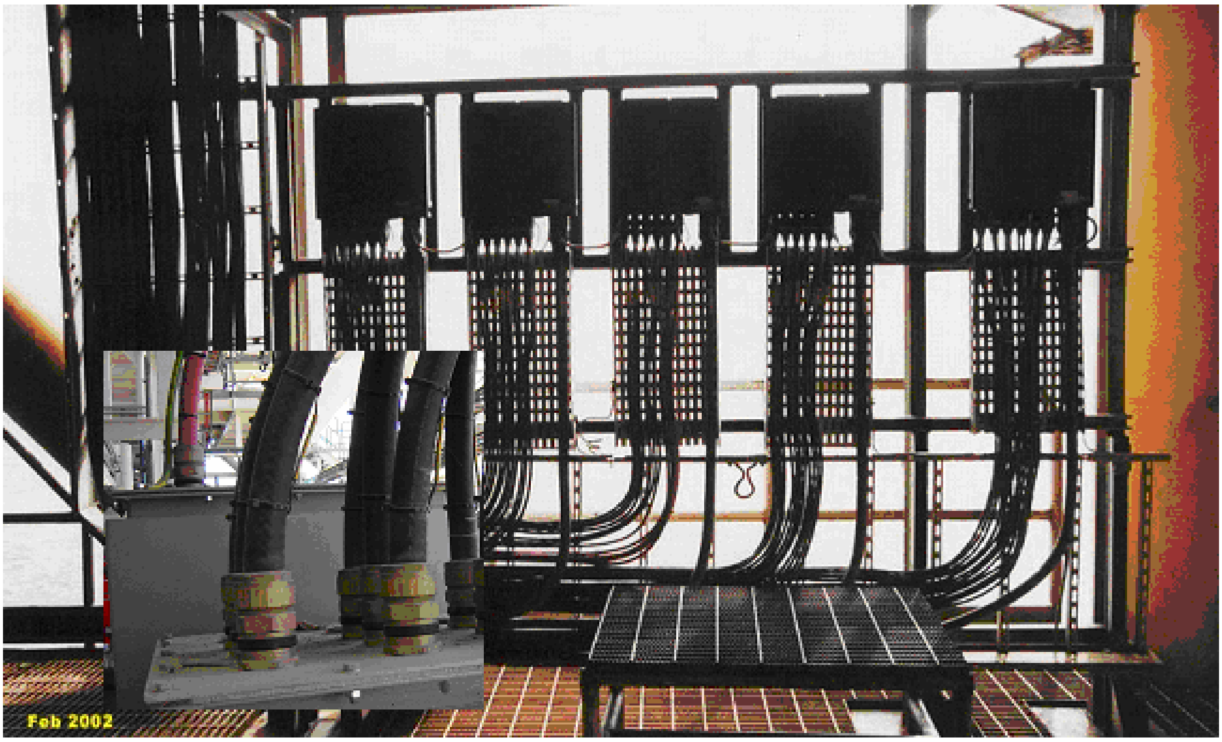


Figure 194: Cable Glands on Platform

Any cable running on site ends in a receptor through a cable gland, the electrical, instrumentation, telecommunication technicians have to deal with this type of item all along their routine works..

- Installing a cable starts by its selection, and there are so many type!
- A badly installed cable gland can be the origin of hazard, fire!
- A cable gland needs time to be installed correctly!

Consequently, be humble and “respect” the cable gland….

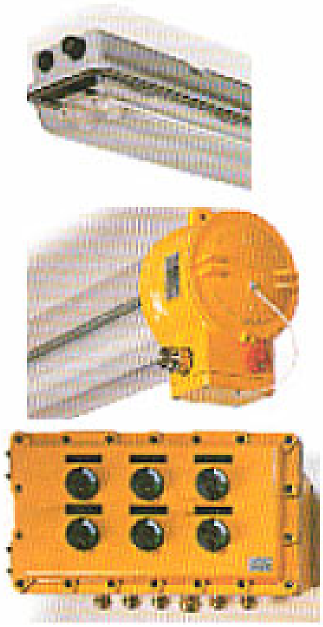


Figure 195: Electrical devices to be connected with cable glands

Functions of cable glands are:

- Make proofing (against water and dust)
- Hang mechanically the cable
- Ensure ground continuity for cables equipped with (metallic) armour / screen
- Ensure the 'Ex' function in hazardous areas

Materials used for cable glands manufacturing are PVC, bronze, brass, steel (stainless or carbon)

- A cable diameter corresponds to one type, one reference of cable gland in its category
- Where is installed a cable gland (indoor, outdoor, humid, hazardous areas,…etc…) defines systematically a category of cable gland.

Type of cable gland:

Industrial type for all application in "safe areas".

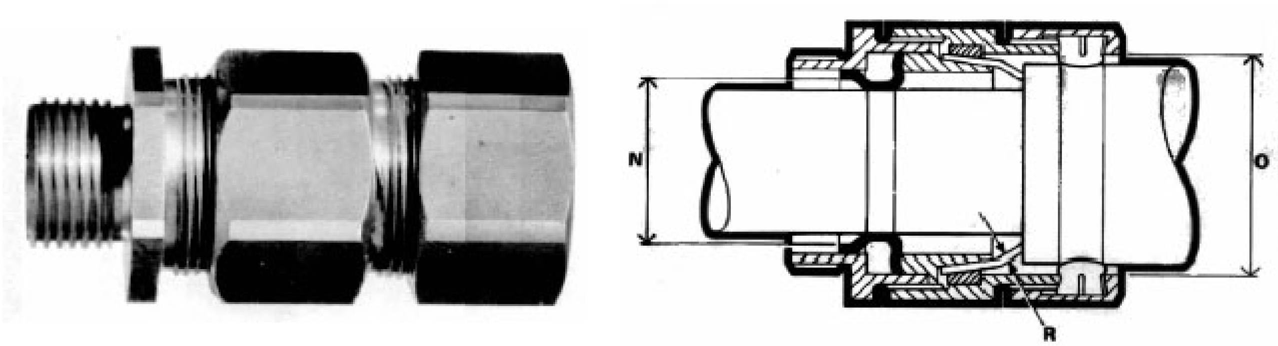


Figure 196: HAWKE Type 152 cable gland

Application Humid or dusty indoor (outdoor when fitted with shroud). For use with SWA elastomer and plastics insulated cables

But on site we do have "risks areas"

Increased Safety Glands (EExe or Ex-e)

For use in hazardous environments

These glands can only be used where no parts of the electrical equipment can produce sparks/arcing or exceeds the gas ignition temperature.

EExe glands are normally recommended for Zone 2 applications but can be used in Zone 1, i.e. indirect entry situations.

Flameproof (EExd or Ex-d) Glands

For use in hazardous environments

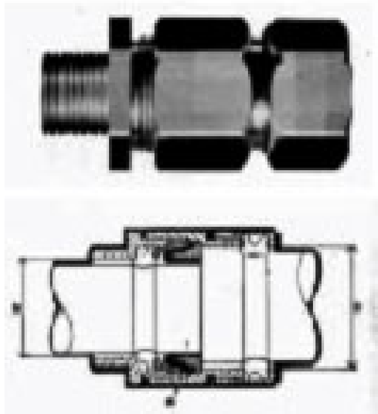


Figure 197: HAWKE Type 501/453/ cable gland

<u>Application</u> Outdoor and indoor
For use with flexible steel wire armoured elastomer and plastics insulated cables

These glands are approved for direct entry applications in Zone 1 areas, IIA, IIB or IIC gas groups with the exception of A2F glands which are for IIA and IIB groupings - may also be used in Zone 2 areas.

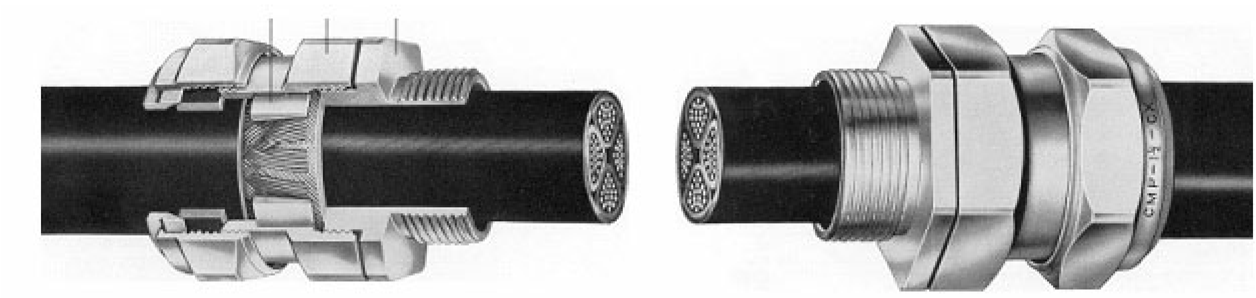


Figure 198: Examples of mounted cable gland

When you have to select a cable gland, take a vendor catalogue…., we cannot expose here all the pages of the different manufacturer's books. Nevertheless, have in mind that in Hazardous Areas, you need Ex type as per European standards (CE for European Community)

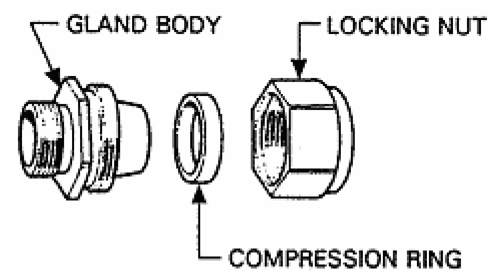
The logo 'Ex' has to be engraved on the cable gland body (mandatory)

Ex cable have to be connected to the ground network even with non armoured cable (static electricity)

Non Ex cable gland are not allowed to be installed in Hazardous Areas

And now, we can go and see how to perform cable gland works with the different types of cables.

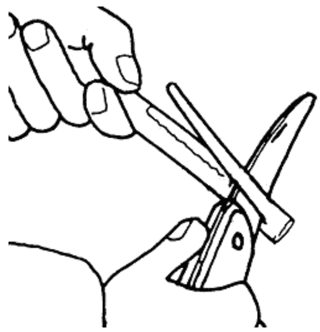
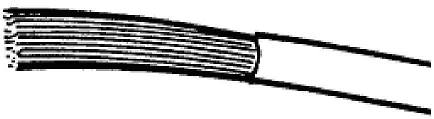
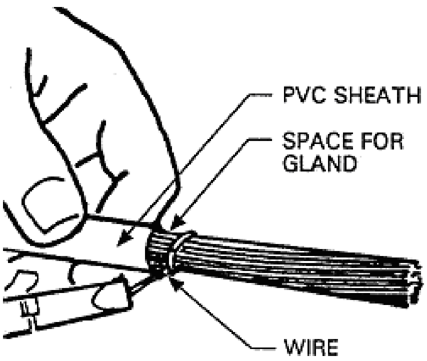
9.3.2. Terminating PVC-SWA Cable

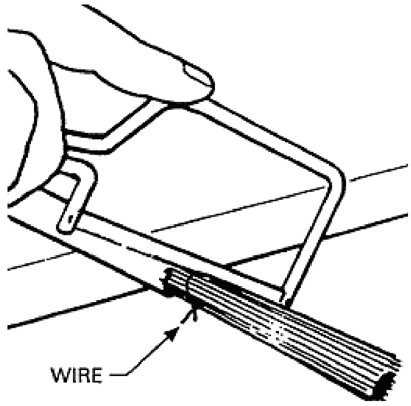
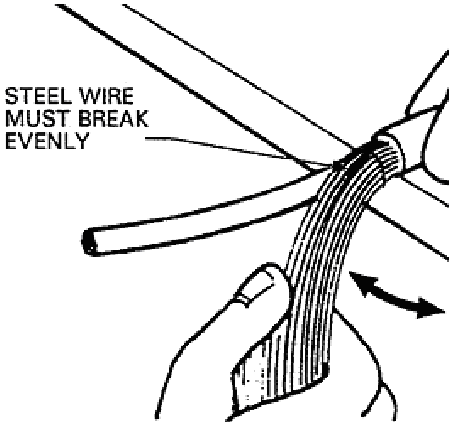
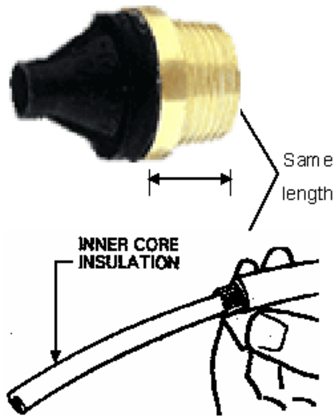
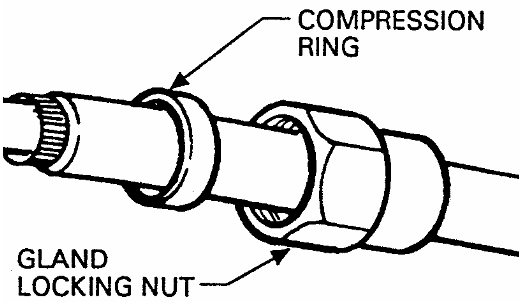


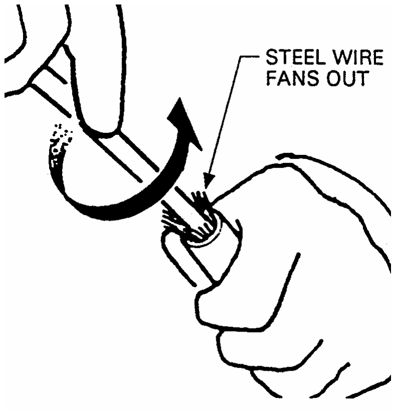
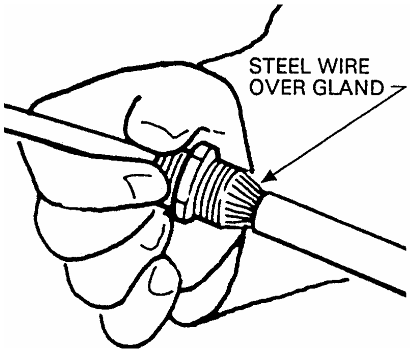
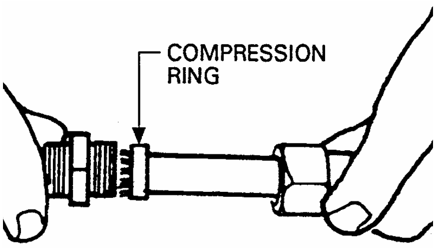
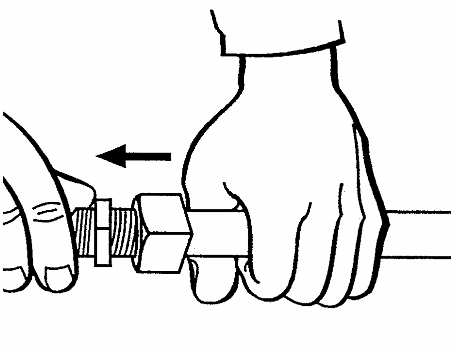
PVC SWA (Single Wire Armoured) cables must be terminated with specific compression glands

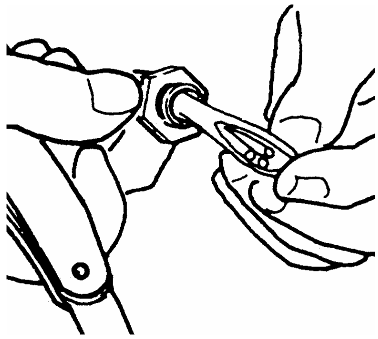
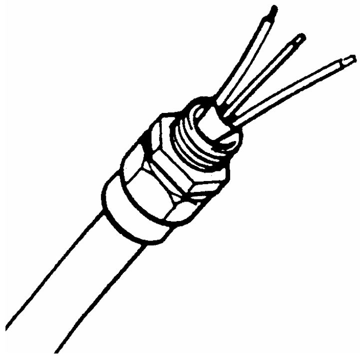
Figure 199: Typical Compression Gland

9.3.2.1. How to Fit a SWA Compression Gland

Mark the place where the cable armour must be cut	
Cut away the PVC sheath with a knife.	
Expose (uncover) the armour.	
Tie a piece of wire around the armour. Leave a space for the gland between the wire and the end of the PVC sheath.	

Cut part way through the armour wire with a hacksaw. If you cut all the way through the armour you may damage the inner core insulation.	
Break off armour wires. The wires must break off evenly. Take only four (4) or five (5) strands at any one time.	
Cut back a little more of the outer sheath so enough of the armour is showing to cover the end of the clamping cone. Now you can see the insulation around the inner core	
Place the gland locking nut and the compression ring over the cable	

Twist the inner core against the lay of the steel wire armour. (Depends on which end off the cable you are making off). The steel wire will fan out.	
Place the main body of the gland over the inner core. Make sure the steel wire goes over the top of the gland.	
Move the compression ring over the steel wire. Make sure the wire is gripped between the compression ring and the gland.	
Move the locking nut over the compression ring and tighten it on to the gland.	

Remove the inner PVC sheath to expose the conductors	
Remove the insulation from the end of each conductor so the conductors can be terminated	

9.3.3. Types of SWA Glands

There are several different types of SWA glands (those which are commonly used on site).

The type of gland that is used for a particular job will depend on working conditions

SWA cable glands are made in different sizes. One gland can fit a range of different cable sizes.

The most common SWA cable glands are:

- Gland BWL gland.
- CW gland.
- Flameproof

9.3.3.1. BWL Gland

The BWL gland is the most basic SWA gland. It can only be used indoors. It has 3 main parts Table, on the following explains the functions of each part of the BWL gland.

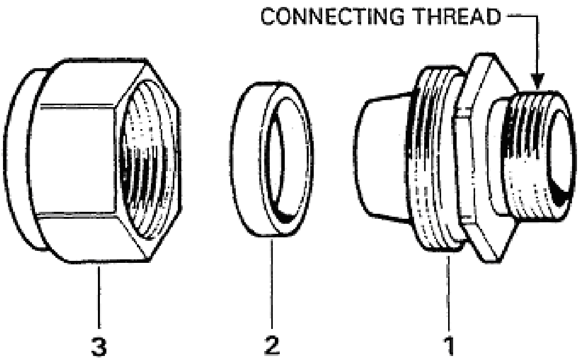


Figure 200: 16-20 BWL Gland

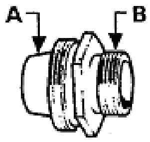
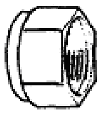
Part	Drawing	Functions
1. Gland body		One end of the Gland Body (A) is cone shaped. The steel wire armour goes over this cone. The inner core of the cable goes through the Gland Body. The other end of the Gland Body, (B) has a screw Thread. This end fits in to the Termination Enclosure.
2. Compression Ring		The Compression Ring goes over the steel wire and holds it in place over the cone shaped end of the Gland Body
3. Locking Nut		The Lock Nut goes over the outer sheath of the cable. It is screwed tight on to the Gland Body over the Compression Ring

Table 54: Parts of a BWL gland and their functions

9.3.3.2. CW Gland

CW glands are weatherproof. This means they are not damaged by the weather. They can be used outdoors. They stop water or sand from getting inside the termination. A CW gland has the same 3 main parts as other SWA glands:

1. gland body,
2. compression ring,
3. locking nut

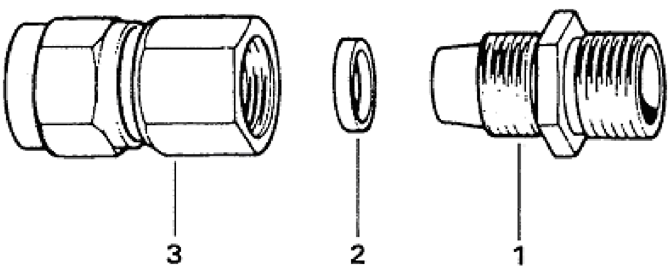
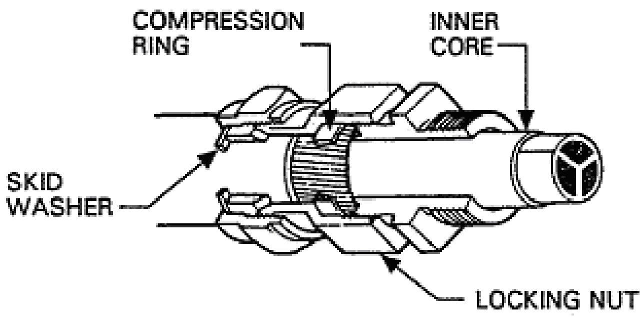


Figure 201: 16 - 21 CW Gland

CW glands have another nut and a washer attached to the locking nut.

The extra nut and washer provide a better seal so that no moisture can get inside the connection. The washer stops the cable from being twisted when the lock nut is tightened. It is called a skid washer.

A CW gland is connected in the same way as other SWA glands. The inner core goes through the gland body. The steel wire armour goes over the cone end of the gland body.



The compression ring goes over the steel wire.

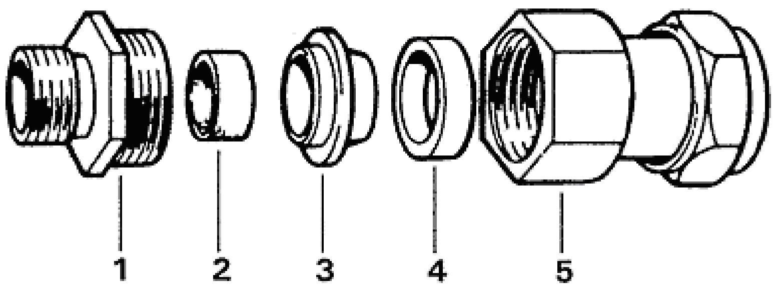
The locking nut locks the compression ring over the steel wire when it is screwed on to the gland body.

Figure 202: 16 - 21 CW Gland (B)

9.3.3.3. Flameproof, Gland

The flameproof gland is weatherproof, waterproof and fireproof.

It can be fitted with a special cover (PCP shroud) so that it can be used in corrosive conditions.



Flameproof glands have an inner ring which forms a pressure-tight seal with the cable bedding.

The flameproof gland has 5 main parts.

Figure 203: Typical flameproof gland

The 5 main parts are:

1 Gland Body.

2. Inner Sealing Ring.

3. Armour Clamping Cone

4. Compression Ring.

5. Locking Nut Assembly.

The two extra parts are the inner sealing ring (2) and the armour clamping cone (3). Table under explains how the parts fit together and what they all do.

PARTS	FUNCTIONS
1. The Gland Body	The inner core of the cable goes through the gland body. The inner core has a layer of bedding around it.
2. PCP Inner Sealing Ring	This forms a pressure-tight seal around the bedding inside the gland body.
3. Armour Clamping Cone	This does the same job as the cone on the gland body in other SWA glands. The steel armour fits over the cone.
4. Compression Ring (clamping ring)	This goes over the steel armour and holds the steel armour on the cone.
5. Locking Nut Assembly	The lock nut is tightened on to the gland body and locks the compression ring into place. Like the CW gland it has a gland nut which tightens on to the outer sheath and a skid washer which stops the cable from being twisted as the nut is tightened.

Table 55: The parts of a flameproof gland and their functions.

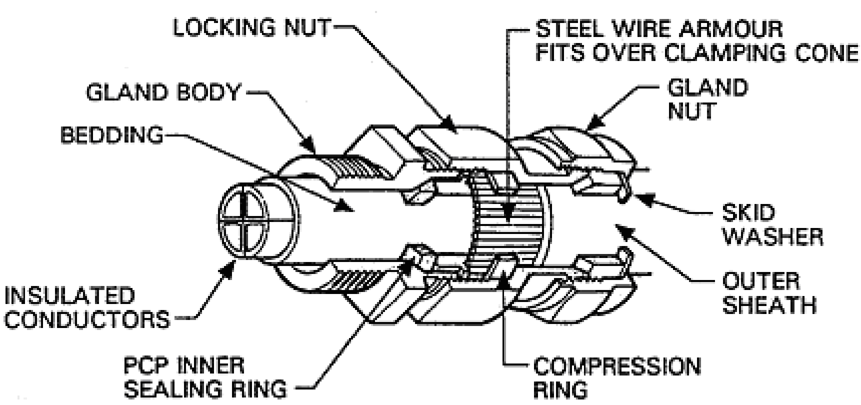


Figure 204: Typical flameproof gland detailed

To check with functions on table

9.3.3.4. How to Fit a Flameproof Gland.

Check with the figure the main parts of the gland.

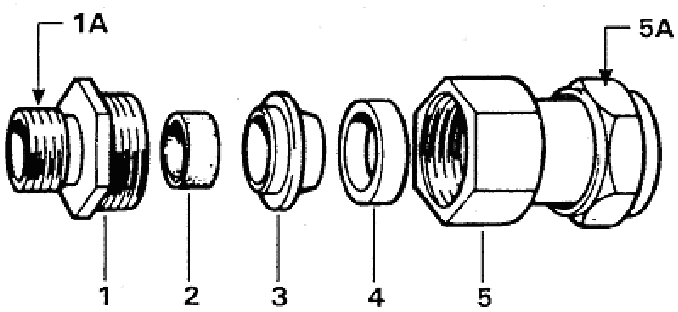


Figure 205: Fit a flameproof cable gland

1. Place the locking nut assembly (5) over the cable.
2. Strip back the outer sheath to expose the armour.
3. Place the compression ring (4) over the armour or the reversible armour clamp over the armour making sure the correct side is used for single wire or braided armour
4. Cut back the armour to expose the bedding.
5. Push the clamping cone (3) over the cable core. Make sure the armour goes over the clamping cone.
6. Push the cable core through the gland body (1).
7. Place the compression ring (4) over the cone end (3) so it holds the armour in place.

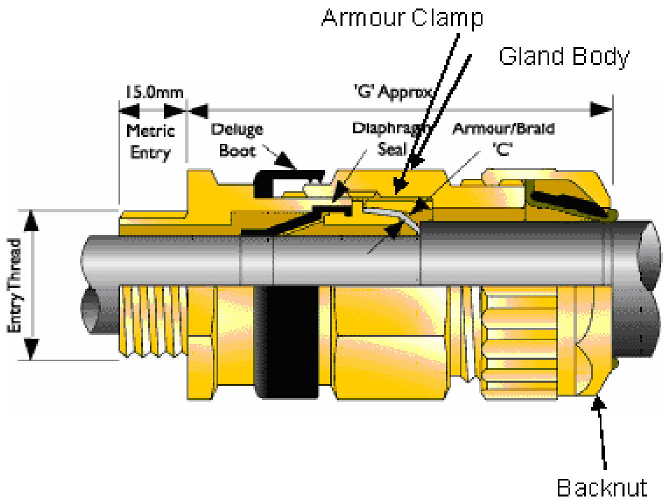


Figure 206: Hawke 501/453 flameproof (coloured)

8. Screw the locking nut (5) on to the gland body (1) so it tightens the compression ring (4) over the armour.
9. Unscrew the locking nut (5) from the gland body (1).
10. Check the compression ring (4) is sealing the armour over the clamping cone (3).
11. Remove the gland body (1) and place the inner sealing ring (2) over the exposed bedding.
12. Push the cable core through the gland body (1) again
13. Screw the locking nut (5) back on to the gland body (1) and tighten it

14. Tighten the gland nut (5A) over the outer sheath of the cable.

15. The threaded end of the gland body (1 A) can now be screwed into the terminal enclosure

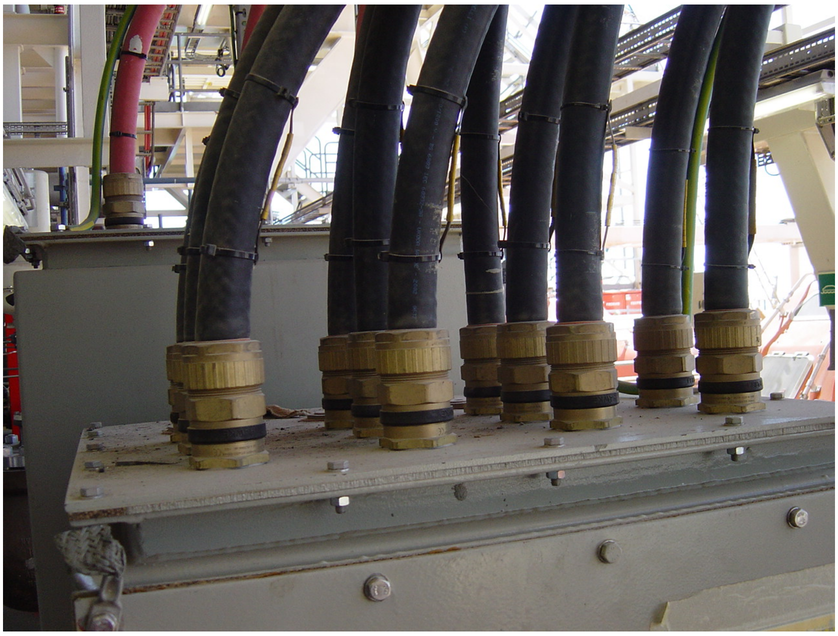


Figure 207: Flameproof cable glands installed on an enclosure

9.3.4. Particularity conduit / cable gland

Function of cable gland is to make sealing at the entrance of the concerned enclosure
With conduit, there is no cable gland, but there is sealing!

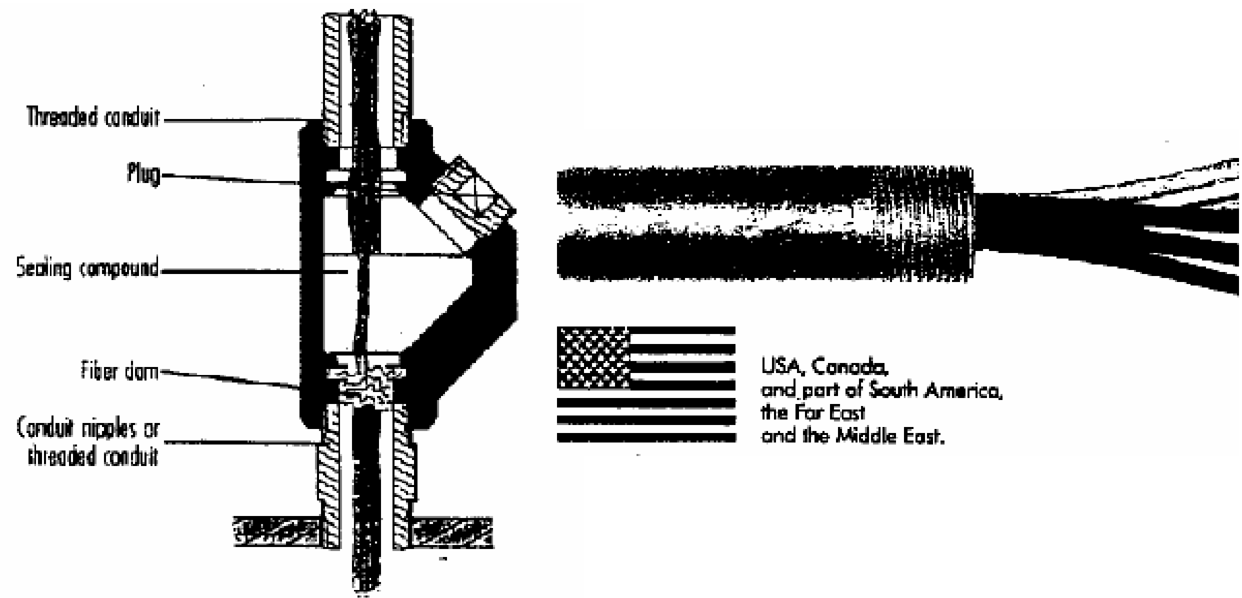


Figure 208: Flameproof conduit sealing

On turbine enclosures (US origin), for example, all enclosures entrance have to be equipped with flameproof arrestor taking place of cable gland. Once the conduit is installed, wires inside, fill this device with specific fire resistant compound, seal it with the plug.

The compound has to occupy all the space inside the flame arrestor, it will harden and take its function of fire / flame "stopper".***Crossing walls***

9.3.5. Crossing a wall

The main function of crossing a wall is to prevent the spreading of flames and slow down the spreading of fire.

Figure 209: Crossing a wall stops flames

Various systems are used. At construction and commissioning, all of these principles ensure initial:

- Sealing from humidity (of varying degrees, depending on the type used)
- Sealing from dust
- Blockage for the intrusion of undesired guests (insects, rodents, serpents, and other, etc.)

Should flames or enough heat be present, all of the systems will dilate, compress the cables, resist the high temperature, become "totally sealed" and

- Stop the spreading of smoke.
- Avoid the spreading of flames.
- Increase the fire stability of structural elements.
- Contain the thermal effects on the area affected.

Let us consider the most frequent types of equipment used to cross walls.

9.3.5.1. Fish tape

Fish tapes are elements which cross walls. During a fire, the intumescent strips contained in the tape will swell, replacing the receding cable sheaths. The expanded product will form a plug which restores the fire-proof nature of a wall or slab.

Figure 210: Fish tape

These systems exist with a range of round and rectangular sections.

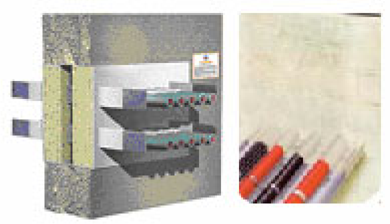
9.3.5.2. Fire bags

Fire bags restore the fire-proof nature of a wall at points where electric cables cross the wall. During a fire, the intumescent material contained in the bags expands and maintains the sealing of the passage for at least 2 hours.

These products are particularly suitable for temporary filling or if (repeat) interventions are frequent.

Figure 211: Fire bags

9.3.5.3. Pre-coated panel



These high density rock wool panels with an intumescent coating restore the fire-proof nature of a wall at points where electric cables cross the wall with or without raceways.

Figure 212: Pre-coated panel

Panels are cut into convenient sections on site. They are placed around cables and raceways, and on seals and components crossing the wall. The appropriate coating is sold with the panel, but supplied separately, and is applied using a spatula.

9.3.5.4. Expanding fire-proof foams and mastics

Intumescent acrylic and silicone mastics in cartridge format and foam restore the fire-proof nature of a slab or wall at construction joints and points where cables cross walls or for small metal tubes.

Figure 213: Fire-proof foams and mastics

They are also used in addition to other filler products, mortar or coated panels.

9.3.5.5. Fire-proof mortar

Mortar intended for the construction of penetration filling as defined in regulations. It restores the fire-proof nature of the wall/slab at points where cables and piping cross for up to 2 hours

Passages of up to 1000 x 700mm can be treated.

Figure 214: Fire-proof mortar (pot of..)

9.3.5.6. Intumescent coating

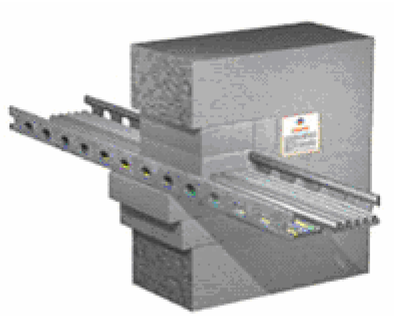
Intumescent coating in aqueous phase prevents the spreading of fire along cables and raceways. It can be applied to mineral wool, steel, aluminium or PVC.

Figure 215: Fire-proof intumescent coating (pot of..)

This coating creates a barrier to fire. The heat causes the coating to form a meringue of heat insulation, enabling the cables to continue to fulfil their function during the initial phases of a fire, for 6 - 45 minutes depending on the quantities used.

This coating does not modify the cable operating properties in terms of heat.

9.3.5.7. Bricks and foam - filler for electric cables



2-hour fire-proof system consisting of flexible bricks combined with cartridges of expanding foam.

Enables cable and conduit surrounds to be tightened and ensures effective protection against the transition of flame.

Figure 216: Bricks and foam

9.3.5.8. Fire-proof blocks

This system involves "bricks" which may be cut to shape

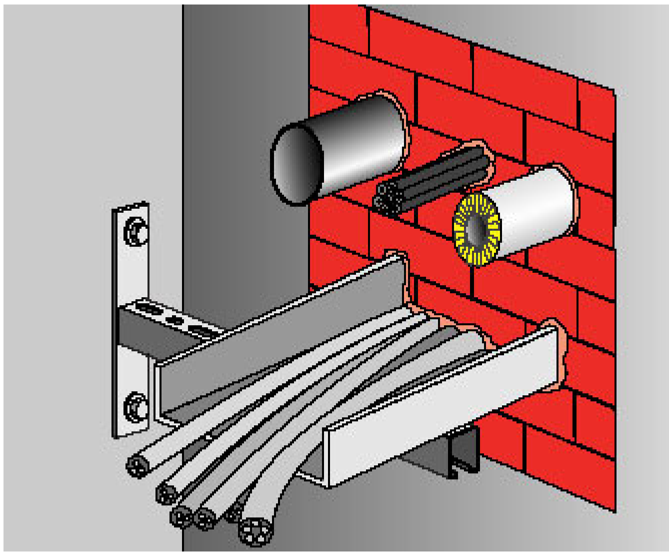
Figure 217: The block (brick) prior to shaping

Description of the product:

- Flexible intumescent blocks made of a bi-component polyurethane foam.

Fields of use:

- Filling for large openings with one or several penetrating elements.
- Temporary or permanent filling of passages for cables and raceways.



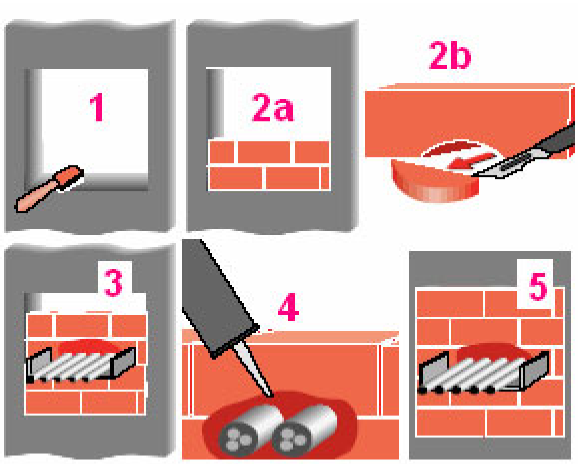
- Temporary or permanent filling of passages for metal pipes, with or without insulation, and for fuel pipes.

Figure 218: Fire-proof blocks - "Hilti" system

Suitable for:

- Walls up to a maximum opening of 130 x 120 cm (52 x 48 inches).
- Floors up to a maximum opening of 90 x 90 cm (36 x 36 inches).
- Wall components in concrete, porous concrete, bricks or gypsum.
- Wall components rated up to 4 hours.
- Floor components rated up to 3 hours.

Implementation:



Opening

1. Clean the opening. All support structures for penetrating elements must be installed in compliance with construction and electricity standards.

Figure 219: Installation of fire-proof bricks

Installation of fire-proof blocks

2a. Lay the blocks If no penetrating element exists, carefully fit the fire-proof blocks in the opening.

2b. Cut the blocks to shape to fit around the penetrating elements

If penetrating elements exist, carefully fit the fire-proof blocks in the opening by cutting them to shape to fit around the shape of the elements.

3. Lay the blocks Continue to fit the fire-proof blocks until the opening is fully closed.

4. Fill the spaces between the cables, blocks, pipes and seals using the fire-proof filling.

5. Identify. The filling of a passage can be identified on a plate for maintenance purposes.

Advantage: enables further penetration or the running through of new cables

- Remove or shape the filler block.
- Fit the penetrating element and re-fit the block according to standards. Fill spaces.

The cables can be run through the seal between the blocks singly or the block can be perforated using a pipe or a sharpened tube.

9.3.5.9. The MCT system

The Multi-Cable Transit system is used on our sites to run cables between pre-sized fire-proof components.

Figure 220: MCT system

The MCT system is designed to adapt to any type of environment and satisfy the main safety requirements:

- fire-proof
- leak-proof
- acoustic protection
- vibrations
- explosion-proof
- rodent-resistant
- EMC version for protection against electromagnetic disturbance

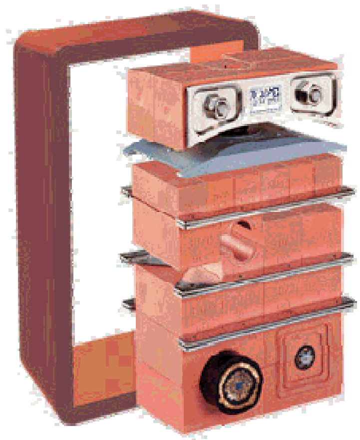


Figure 221: Example of a MCT system

The MCT system is a flexible and adaptable set of frames and modules with

1) a set of frames - to be welded, sealed or screwed in place - equipping the passage in the wall;

2) these frames are fitted with modules adapted to the diameter of the conduits and piping;

3) accessories ensuring the consistency and sealing of the modules installed in the frame.

Frames

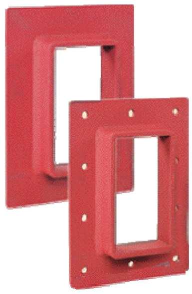
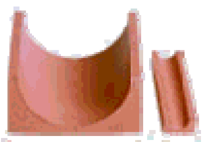
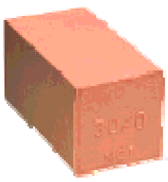
			
Traditional frames	Multiple frames	Frames to be welded	Frames to be bolted into place
	**Rings** fitted in a circular block, in a concrete coring or a metal sleeve.		**Sleeves**: circular frames to be welded or sealed in a wall.

Table 56: MCT frames

Organization of the filling space and selection of modules

The space used by the modules within a frame to run the cables or piping through is called the filling space and represents the usable space.

	**The fixed modules** enable the running through of cables with a diameter of 4 - 114mm and piping with a diameter of up to 330mm. It is essential to select the right module for the cable diameter to ensure satisfactory sealing.
	**Solid modules** fill in the unused space in each frame. They may be replaced at a future date by a pierced module if a cable must be added to the passage.

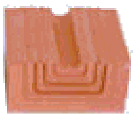
	**Adjustable "Addblock" modules** enable the diameter of modules to be adapted to the cables using the appropriate thickness block. In this way, AddBlock adapts to 66 cable and pipe dimensions. A locking system is fitted on the exterior of each block, enabling the fixing of the block, and hence ensuring it is safe to use, just like a single-block component. You can also insert a hub in the centre of the AddBlock and create a solid module.
	**Sockets and hubs** are mainly used to prepare for the running through of a future cable with an adjustable "AddBlock" module, forming a solid block. If you need to add a new cable, simply remove the hub and run the cable through, re-using the adjustable module.
	**"U-Block" centring modules** enabling the modification of the external dimension of a fixed module or an adjustable module. The centring modules fit around the module and block it via its external lips.

Table 57: Filling of MCT frames

Sealing and closing accessories

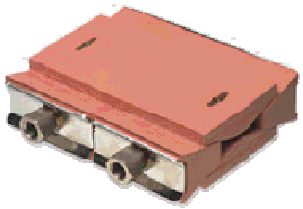
			
STG closing, ATEX approved: placed between the compression plate and the frame. Ensures final sealing and the homogeneity of the compression of the unit.	**Compression plate**: placed in the upper part of the frame and under the STG closing. Compresses the modules using its telescopic screw.	**Attachment plate**: placed between each row of modules. Simplifies assembly and ensures good stability for the unit.	**PTG closing**: may be used as an alternative to the STG closing and its compression plate. May be placed at any location in the frame.

Table 58: Closing of MCT frames

10. DEFECTS AND TESTS

Following the installation of the cables, the maintenance team must check the satisfactory condition of these cables. In reality, there is only one aspect to be checked, i.e. the long-term resistance of the insulation. Dielectric rigidity and cable insulation must remain within an acceptable interval. This applies for the entire length of the cable, and includes connection points.

If a cable with a length of xx metres (or km) is found to have unsatisfactory insulation during testing, this probably only applies at one specific location on the length. How can this location be found?

10.1. GENERAL MAINTENANCE INSTRUCTIONS

10.1.1. Storage

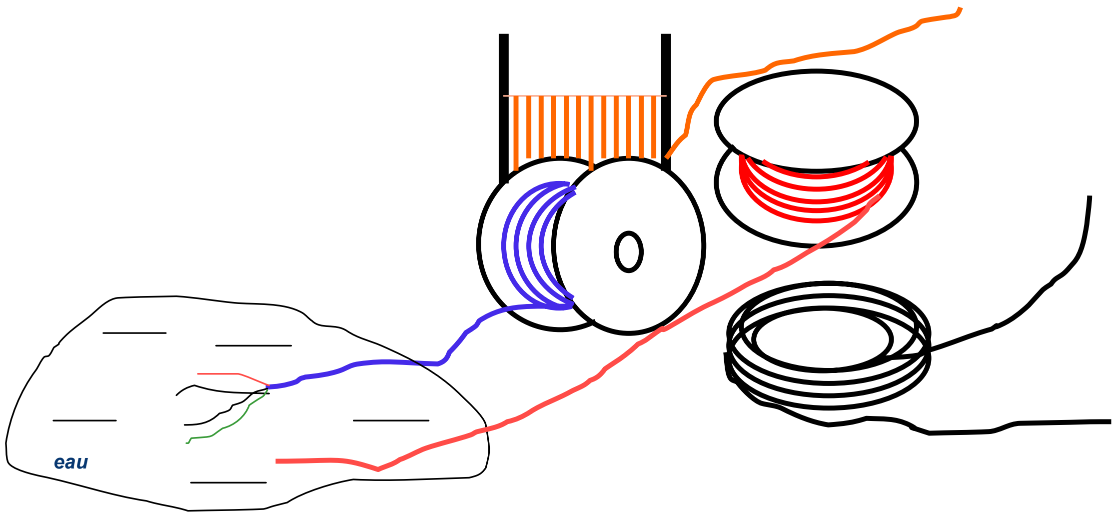


Figure 222: Storage of drums on site (Total)…

This type of "configuration" should remind you of something if you have visited sites (not necessarily Total sites). Cable drums, rolls of cable *used in construction* have been abandoned…..

This is a pain for maintenance personnel who can "rummage through the pile". If the cable required is not in the pile, new cable is ordered, and the surplus will add to the old pile.

We have a problem here!

I could mention the example of a cable which needed changing on a ship

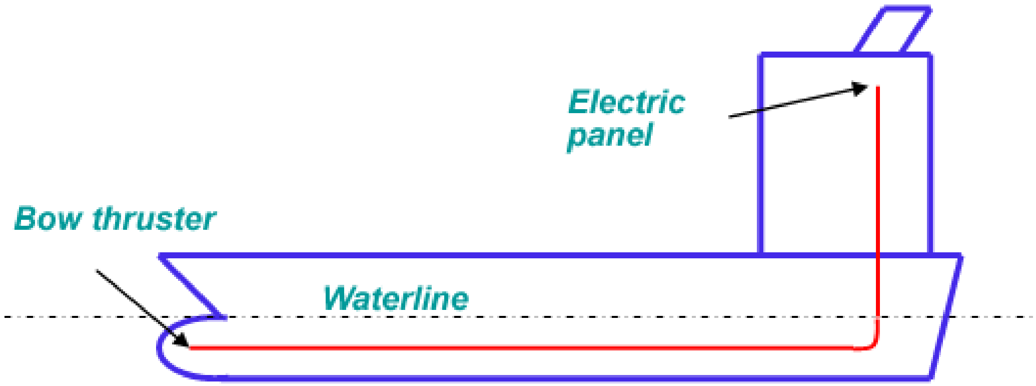


Figure 223: Cable taking up water on a ship

This cable supplied the plugger propulsor. Length = 250m, 3x240mm², copper. It was covered with water near to the electric motor (collision…).

A maximum of 2 weeks later, this cable was leaking water at the LV panel 30m higher up (and 250m distant). Thanks to capillarity, the insulation was practically inexistent throughout the entire length of the cable and it had to be replaced.

Cables on sites which "hang about" over the years, outdoors, with the ends lying on the ground, in water, cannot be particularly insulated either. Add to this an electrician deciding to use the cable and not thinking to check the insulation, or simply use the megohmeter (or even an ohmeter).

The not-so-great insulation may only be identified after the installation…

Conclusion:

- Store cables in a sheltered area if possible (under a canopy) to protect them from bad weather and the sun.
- Apply a sealed "plug" to cable ends and not simply a bit of tape, use a real seal such as a wax plug or a heat shrinkable sheath like those used in the factory (when the cable arrives).
- Re-protect the ends after cutting off a length of cable from a drum. Re-wind and attach the cable appropriately.

10.1.2. Installed cables (or cables to be installed)

10.1.2.1. Covers:

Should the raceways to be used be equipped with covers, there will be a reason for this.

Re-attach and re-install these covers if they have been removed, or if the attachments have simply broken or disappeared.

10.1.2.2. Cable trays/conduits:

These are used to support the cables, which are not designed to "hang" in empty space.

Ensure that all cables have a mechanical support (except for buried cables, obviously…).

Cables are not aligned on raceways simply to look good, this also simplifies the removal/replacement of cables.

If you need to add cables to a raceway:

- start by choosing the right cable tray….
- If several voltage levels exist on one raceway, add the "new" cable near to similar voltages.
- Remember to check for build-up, i.e. the correction coefficient when several power cables run parallel.
- Carefully align the new cables, haphazard cable arrangements are a sign of absent minded work and a lack of professional conscience for electricians, and there for everyone to see….

Let us reconsider the example from the "transformer" course, in the operator course, relating to the installation of power cables on a cable tray.

Installation of power cables on cable trays:

This type of connection, for <u>single-pole cables</u>, between the transformer secondary circuit and the LV panel has been (and is still) used on certain Total sites….

Consequently, the metal raceway is hot… very hot… which implies another drawback: the power of the transformer is reduced.

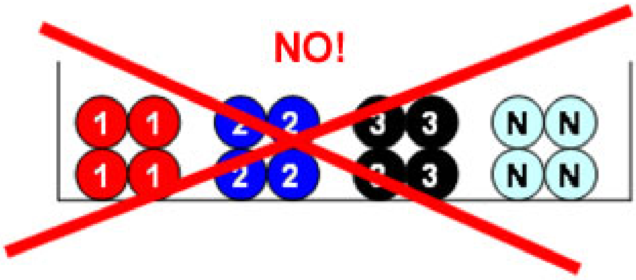


Figure 224: Incorrect cable arrangement on a cable tray

Each single-pole cable (and each phase), starting from the terminals of the secondary circuit of the transformer (or any other item of equipment) must be distributed in clover-leaf format, even for a short distance.

This aims to cancel the induction: the force created by the 3 phases together is hence neutralised. If you have a three-pole cable, this is not a problem.

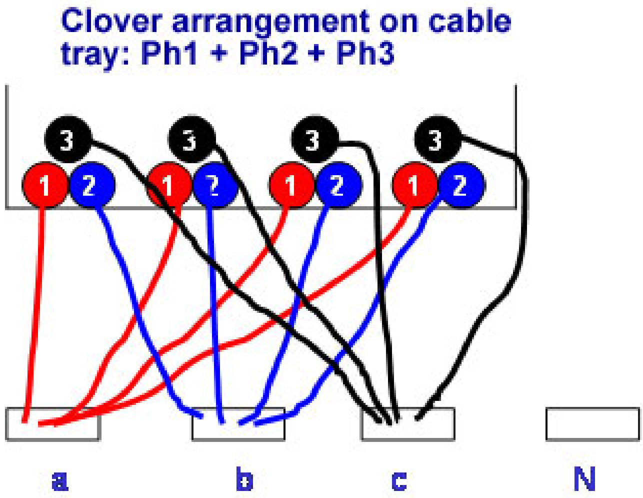


Figure 225: Clover-lead distribution of cables

Neutral cabling:

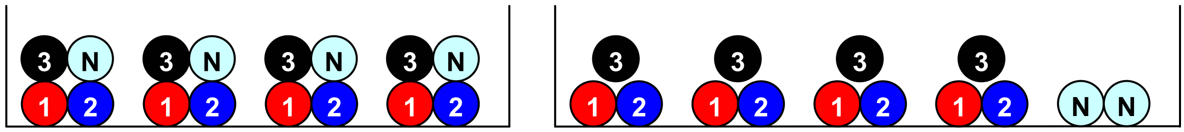


Figure 226: Neutral cabling

There are no formal instructions for the positioning of the single neutral cable *(pale blue colour)*.
It is however preferable to combine this cable with the 3 phases in an unbalanced 3+N distribution.

This said, the neutral cable may be placed separately in a balanced distribution, in which case the Ph+N distribution is secondary.

10.1.2.3. Attachments

The cables are attached to the raceways whether they be vertical or horizontal.

The clamps are placed every 50 cm or 1 m or 1.50 m (decided at construction).

Re-attach the new cables with the previous spacing.

10.1.2.4. Cable arrival

Let us also reconsider the content of the "transformer" course with regards the arrival of single-pole cables in a receiver (transformer, motor, cabinet, etc.).

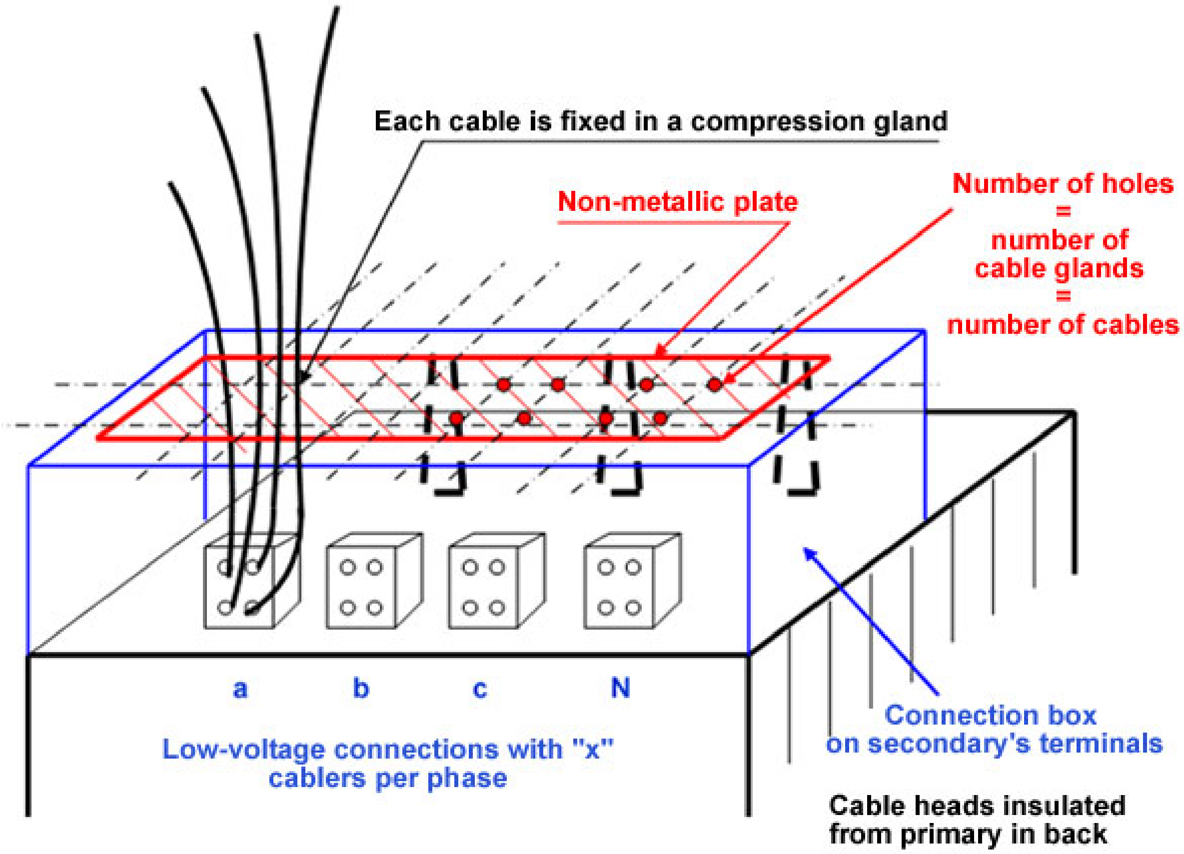


Figure 227: Transformer connection unit

All glands holding ***single-pole cables*** must be installed on a ***non-metal plate.*** The above fig. shows 4 cables per phase = 12 glands (for 3 phases) + X for the neutral, all installed on this **non-metal plate**.

A conductor passing perpendicularly in a metal plate creates induction on the plate.

The EMF induced would then attempt to move the plate (Lenz's law) and would actually heat and deform the plate, producing cracks.

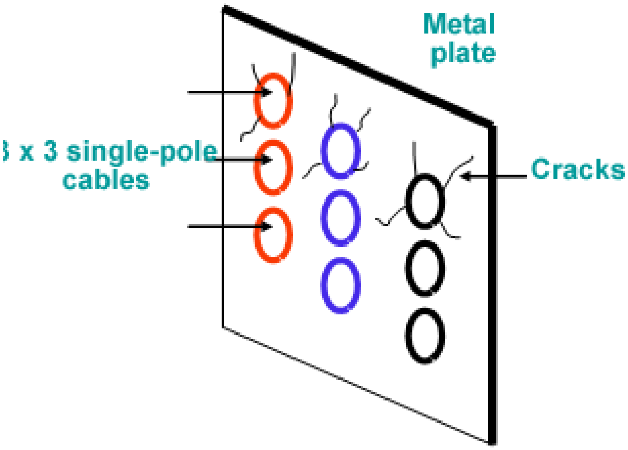


Figure 228: metal plate + single-pole cables = heat + cracks

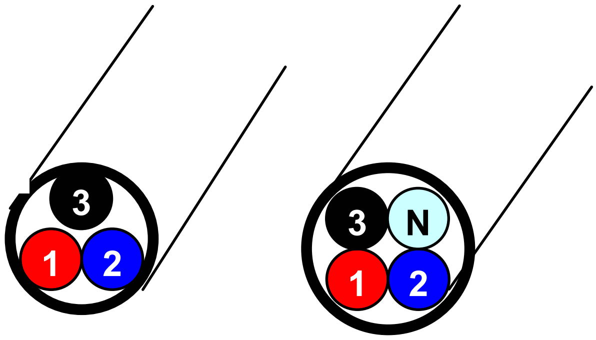


Figure 229: Multi-conductor cables = metal or non-metal plate

If, however, a multi-conductor cable is used (three-phase = 3 in the same cable): this is not a problem, as the induction is neutralised by the 3 phases braided in the cable. The gland can be installed on a metal plate.

10.1.3. Checking insulation

Cables must be checked in view of preventive maintenance, and in turn for each system/item of equipment.

10.1.3.1. Low voltage cables

Insulation resistances must be tested using.

A **1000 V** Megohmeter for a service voltage of 400V, as power cables have U1000 insulation (rigid or stranded core) or 750V (flexible cable).

A **500 V** megohmeter for other service voltages (lower). In principle, cables have 250 or 300V type insulation as a minimum (and 1000V).

The minimum acceptable insulation at the commissioning of cables (according to Total specifications) is

- **50 Megohms** for **400V** cables

- **10 Megohms** for **230V** cables (and less)

These values will necessarily fall over time, and (much) lower values will be found in routine verifications. There is no set value determining the point at which the cable insulation is considered as unsatisfactory. You must decide for yourself!

In practice, we can consider that cable insulation "is not what it could be"

- Below **1 Megohm** for power cables (400V)
- At a few hundred kilo- ohms for other cables

10.1.3.2. High voltage cables

Important!

Reminder of the manufacturing characteristics of the different HV cables:
1.8/3 (3.6) - 3.6/6 (7.2) - 6/10 (12) - 8.7/15 (17.5) - 12/20 (24) - 18/30 (36)

E.g. 12/20(24) cable is used for a 20kV network, which means that there is 12kV between phase and ground, 20kV (normal service voltage) between phases, and 24kV in insulation voltage.

According to standards (and depending on the country), it is "recommended" to test cable insulation at 1.2 or 1.3 (or even 1.5) times the nominal voltage. I was therefore able to see 27 kV applied to a 20 kV cable to test the insulation. The cable (which had no particular insulation fault) therefore underwent **destructive testing** - it failed….

HV cables age, they are tested at commissioning in what we call "extreme" values. The maximum voltage to be applied during routine tests is insulation voltage, i.e. 24kV for the 12/20(24) cable. This recommendation is based on experience.

The value of the insulation of a HV cable (in service) must be approximately a few hundred Megohms.

Identifying a fault on a HV cable, or a "leak" at a specific location implies the use of other methods. See paragraph below.

10.2. IDENTIFYING DEFECTS

10.2.1. Identifying cables

Identifying cable defects should not be mixed up with identifying cables.

Identifying a cable can mean finding an buried cable, buried no-one knows exactly where… or identifying one cable from a set of cables.

10.2.1.1. Identifying cables off-load

This is the gold hunting method. You quite simply run a metal detector over the wall or the floor/ground.

10.2.1.2. Identifying live cables

A cable carrying an electric current produces a magnetic field, therefore we need a means of identifying this magnetic field.

We could also generate a signal on a cable and attempt to locate this signal.

A fault detector can also be a simple "cable finder". Some models indicate the depth of the cable, draw the routing (you need to follow the cable), show the length, and indicate any faults (if the machine is also a fault detector).

Example of equipment:

The "Leica Digicat" system with its "cable locator" (the device with the handle) which can be used independently to find live cables or with a specific generator to trace the position of the buried conduits required.

Figure 230: "Leica Digicat" cable locator

This device is easy to use, however you will still need to follow the manufacturer's instructions …

Figure 231: "Dynatel 2200" system

For low current cables

Extract from the instructions:

Series 2200 cable detectors include an emitter, a receiver and all standard accessories required to locate an buried cable.

- Display of a bar chart and numerical indications
- Three different detection modes
- Direct connection, coupling or induction
- Adjustable sensitivity
- Display of current measurements
- Measurement of depth
- Location of resistance faults (certain faults, extra option)
- The use of the specific generator enables the simultaneous identification of a cable with this type of "locator". If you hold the detector close to a cluster of cables, the device will recognise "its" signal from the cable concerned.

10.2.2. Location of defects

This concerns the different principles and methods used to identify where a cable has a LV or a HV fault.

You clearly need the right detection equipment for each method.

10.2.2.1. Detection of partial discharges

If the electric current in a high voltage cable is significant, the surrounding field can be intense enough to cause the ionisation of air molecules: this is the **Corona effect**.

The Corona effect represents an aggression for installations.

It causes the formation of:

- O_3 (ozone is used for surface treatments)
- Nox (nitro compound derivatives)
- HNO_2, HNO_3 (saltpetre, white powder composed of nitric acid)
- NH_4, NO_3 (ammoniac derivative)

These chemical reactions are likely to damage electric installations (transformers, buses, insulators, ***cable heads***, alternators, etc.) and cause many failures.

The Corona effect is a capacitor fault and does not cause heating. It cannot therefore be detected by infrared thermal analysis.

However, the Corona effect generates ultrasounds which can be detected, located and recorded with an ultrasound detector.

Partial discharges and ultrasound:

The molecular agitation caused by partial discharges due to bad contacts in cable heads, insulators, bus supports or other high voltage elements along the cables generates ultrasound which is easy to detect and record with an ultrasound detector.

Partial discharges cause many failures and significant incidents (fire).

The following is an example of a partial discharge detector, the XDP by ndb Technology.

The XDP enables the detection of the partial discharges associated with the presence of insulation faults on insulated seals and other items of equipment for safety and reliability purposes. It enables the recording and analysis of the measurements taken via the partial discharge management software, XDP-Soft. It detects partial discharges from XLPE/EPR type cables, cable angles and terminations very accurately.

Applications of the XDP

- Checking of the quality of insulation during installation or repair works on buried networks
- Monitoring of the aging of critical seals
- Safety checks prior to live works

Figure 232: Detector of partial discharges - ultrasounds

The user moves the capacitor sensor over the cable seals and the XDP will indicate the current level and partial discharge signal shapes as appropriate. In addition, in analysis mode, the device enables signals to be compared with data base content.

Data base entries have ten benchmark signatures. The XDP will establish a correspondence with the four signatures which most resemble that of the seal.

The principle and method explained in chapter 9.1.5 (Testing of HV cable heads) apply

Partial discharges and variations in electric fields:

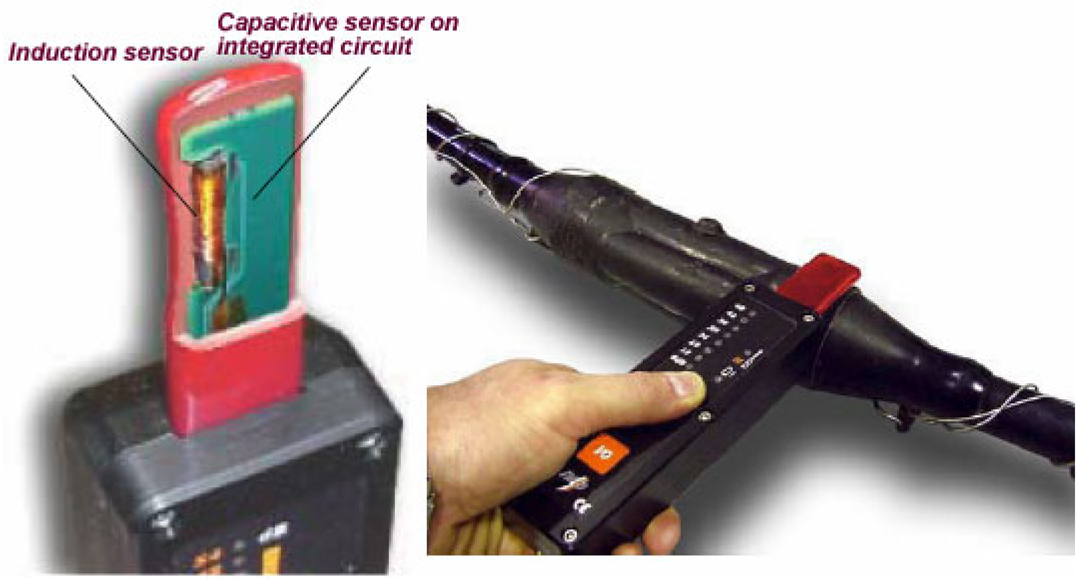


Figure 233: "ndb Technology" PDS detector

The insulated and sealed sensor picks up sudden variations in electric field caused by partial discharges. It integrates capacitor and induction sensors to pick up discharges irrespective of cable configuration.

The visual indicator is a bar chart with eight levels.

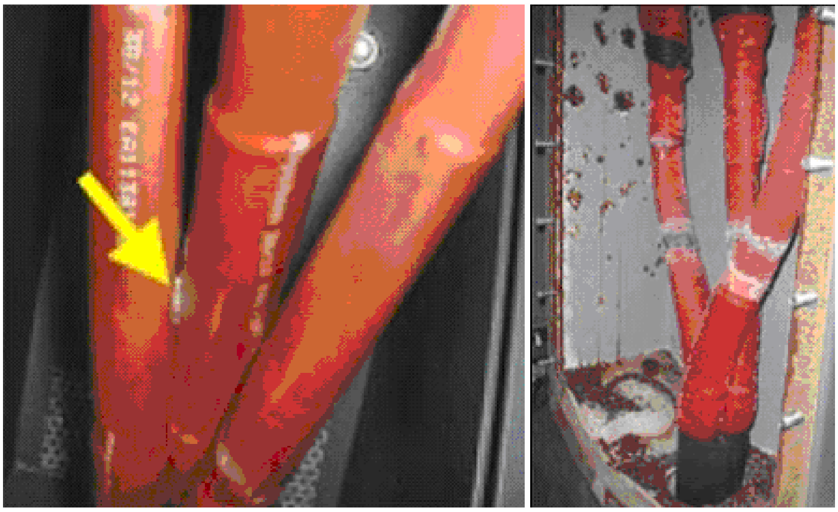
Each level corresponds to double the previous level in intensity (6dB). Graduation: 6 - 54dB. An audio indicator whose frequency is proportional to the intensity displayed enables users to locate faults even if the operation does not enable simultaneous viewing of the display.

Figure 234: Kit PDS detector with poles

Information identified when "listening to" partial discharges

Closed 20 kV units are the primary targets for monitoring partial discharges via ultrasound tracking. With closed units, the detection of electric faults using infrared imaging is not possible (unless IR-transparent filters are fitted).

In the following case, we note that crossing terminals generates a discontinuity in the electric gradient. The white powder observed is quite simply a nitro compound derivative commonly known as nitric acid (HNO_3). You can imagine the medium-term effects on the insulation ...



the equipment was closed, however the ultrasound fault detector has avoided the worst case scenario. The formation of nitro compound derivatives is noted on the upper part of each terminal together with a significant level of corrosion on the metal parts due to the formation of ozone (O_3) generated by the Corona effects.

Figure 235: HV heads, 20kV unit

These methods imply the existence of doubt concerning the quality of a junction, cable head, etc. and the desire to test this specific point. If you are not sure where to start looking, you need to use other methods (with location).

10.2.2.2. Shock waves

Principle:

You need a **shock wave generator**

Figure 236: SWG1000 CD-1 generator (Sébaréseaux)

Characteristics

- **Generator of shock waves** adapted to **low** and **high** (medium) voltage networks
- Five voltage contact studs: **2kV**, **4kV**, **8kV**, **16kV** & **32kV**. (*2kV for LV*)
- Maximum shock energy up to 1750J for all contact studs

Individual shock and continuous pulses adjusted on the basis of rate.

Fields of use for wave generators

Acoustic location of the sound field

Shock wave generators are part of the equipment required for the precise location of faults on power cables using the sound field method. This process consists of loading a pulse generator with high continuous voltage, which will subsequently be discharged into the defective cable via a spark arrester. The fault will breakdown. The noise generated will be amplified and heard at the surface via a soil microphone. The sound intensity of the breakdown will be at maximum above the cable fault. To avoid surveying the full cable segment until the fault, pre- location using a sound pulse device is necessary (this device is generally integrated).

Electric arc process

Should a cable fault not have an Ohm level which is sufficiently low to use the pulse echo technique, the fault will require transformation. With traditional cables, this is achieved using a burner, which burns the faults to a low Ohm level in a long-term manner. Cables insulated using synthetic materials cannot be burned. It is possible to apply short-term transformation (a few milliseconds).

An electric arc is created during this period at the fault, producing a low-Ohm reflection resistance as a measurement pulse for the pulse echo measurement device. The fault is primed by the shock wave generator, which will be connected to the defective cable by the electric arc device. The duration of the arc will depend on the capacity of the shock used (during the passive process), but can also be maintained for a longer period by an arc stabiliser.

Electric arc process (ARM arc pulses)

A high voltage pulse primes an electric arc at the defective point, which transforms it into a short low-impedance fault. A measurement pulse will then be sent to and reflected by the low-impedance fault. ARM enables the priming of a stable electric arc for an extended period thanks to a double shock process.

The fault location pulse is generated by a high intensity capacitor discharge for pulses with a voltage of less than 1000V, enabling the improved location of faults over long and short distances. The fault is identified on the basis of the distribution of two graphs and familiar behaviour, via ARM.

Current pulse method

Any shock wave generator with a power of 1000J (or more) is equipped with a linear coupler enabling the use of the current pulse method in combination with a ***tone tracer*** fitted with a transient current recorder. *This process enables the location of low-impedance faults and intermittent faults.*

Shock wave receiver

The signal generated must be picked up by another device for the precise location of deviation faults for power cables.

Figure 237: Digiphone type shock wave receiver (Sébaréseaux)

Characteristics:

- *Measurement of distances,* numerical display, no range switching.
- Bar chart display, easy location of lines in pulse mode.
- Connectable filter for the effective removal of interference.
- LC screen of the right dimensions for simply and quick identification.
- Microphone with multiple accessories for optimal adjustment to the different surface types.
- Laminated rain-resistant keypad.

The equipment shown is intended as an example. We could use Megger equipment, for example (remember that Megger is a brand).

Figure 238: Megger shock wave receiver and generator

Generator characteristics:

- Compact, portable cable fault location system.
- Dielectric tests up to 40kV
- Burning up to 34 kV
- Shock wave generator: 8/16/34kV, 2000 Joules
- Optional 4-kV shock span
- A.R.M - Arc Reflection Method
- Current pulse
- Voltage relaxation (optional)

- Integrated MTDR tone tracer

Receiver characteristics:

- Location and direction of the fault
- 1 or 2 microphone configuration
- Robust, compact casing, resisting extreme climatic conditions
- Headphones with ambient noise reduction system
- Disconnecting microphone leads
- Detection of faults up to 15m
- Exceptional autonomy
- Cable tracing via the identification of the shock interval
- Numerical filters for the attenuation of ambient noise

The receiver may be used with any other generator of a different brand

10.2.3. Other fault detection systems

For ***low currents***, telecommunications, control, computer & instrumentation cables, avoid using a shock wave generator…..

You could use an "advanced multimeter" to determine the resistance of a ground fault and the distance to the fault.

Figure 239: Dynatel 900 type line analyser

Device with the following functions:

- Multimeters: Vac, Vdc, A(mA), Ohms, 0 - 999 Megohms
- Ground loop location (0 - 1000 ohms at 5%)
- Transmission tests (between -40 & 10dB and up to 20kHz)
- Open circuit fault location (between 0 & 30km with an accuracy of 1 - 5%)
- Resistance fault location (up to 7k.ohms
- Tone tracer: span of 1 - 300m at 0.6% and other spans up to 10km

11. EXERCISES

The main exercise will be for you to practice laying cables and their connections, to gain in terms of practice and experience…

The following is however a cable calculation exercise referring to the tables in the "cable calculations" chapter.

1. Determine the section of a cable (using the tables)

A cable must supply a 35 HP engine at a distance of 30 metres (Engine-panel)
Supply = 400V, 3 phase
The cable has 4 conductors (+ ground) and must resist hydrocarbons
The cable is installed above ground at an ambient temperature of 30°C
The starter current is 6 times the nominal current
Engine yield = 85%, cos phi = 0.8 in normal operating mode, and 0.3 at start-up

2. Calculate the voltage drop with the same cable used above

3. Cable to be calculated depending on the temperature (and length)

Same engine as above, but with an ambient temperature of 60°C and a length of 150 metres.

The correction factor to be applied for an XLPE (*or RFFV or RGPFV) series armoured cable is* 0.71 according to table 43, chapter 6.3.

The maximum acceptable current in the RGPGF cable, 4 G10mm² = 75 x 0.71 = 53 Amperes.

The nominal engine current is 55A, therefore a cable with a larger section is required to account for this correction factor.

4. Check the short-circuit current

We still have the same engine, with a 25mm² cable over 150m

I.e. a CCI current calculated at 2000A for 0.5s at the start

5. On a cable tray with other cables

We still have the same 4 G 25mm² cable

12. GLOSSARY

13. FIGURES

14. TABLES

15. SOLUTIONS TO EXERCISES

The main exercise will be for you to practice laying cables and their connections, to gain in terms of practice and experience…

The following is however a cable calculation exercise referring to the tables in the "cable calculations" chapter.

1. Determine the section of a cable (using the tables)

A cable must supply a 35 HP engine at a distance of 30 metres (Engine-panel)
Supply = 400V, 3 phase
The cable has 4 conductors (+ ground) and must resist hydrocarbons
The cable is installed above ground at an ambient temperature of 30°C
The starter current is 6 times the nominal current
Engine yield = 85%, cos phi = 0.8 in normal operating mode, and 0.3 at start-up

Selection of the cable:

The cable must be XLPE/PVC/LC/STA/PVC - (RGPFV)

Selection of the section:

Intensity with a cos phi of 0.8

$$P = \frac{736 \text{ X } 35}{0.85} = 30310 \text{ watts}$$

$$I = \frac{P}{U.\sqrt{3}.\cos\varphi} = \frac{30310}{400 \text{ X } 1.732 \text{ X } 0.8} = \boxed{55 \text{ Amps.}}$$

With the XLPE/PVC/LC/STA/PVC series, the 4 G 10mm² cable can accept an intensity of 55 amperes (*Table 13* for the *U1000R2V- in this example, we consider the same values – these values are also valid for RGPFV-RH)*

Not all of the tables have been included in the above chapters (otherwise we would have thousand-page courses!)

2. Calculate the voltage drop

With the same cable described above.

The drop in voltage is expressed by the following formula.

$$\Delta u = \sqrt{3}\ I\ l\ (Ra \cos.\ \varphi + L\varpi \sin\varphi)$$

Each cable has its own resistance and inductance, take the following values for a U1000RGPFV cable (XLPE/PVC/LC/STA/PVC)

Ra = 2.33Ω/km & Lω = 0.30 x 10^{-3} x 2πf = 0.30 x 10^{-3} x 314 = 0.094Ω/km = Lω (*values in table 26, chapter 6.1*)

With normal conditions:

$$Ra = 2.33\ \Omega/Km,\ L\varpi = (0.30 \times 10^{-3} \times 314) = 0.094\ \Omega/Km$$
$$Z = Ra \cos.\ \varphi + L\varpi \sin\varphi = 1.92\ \Omega/Km$$

(Value checked in table 26)

$$\Delta u = 1.732 \times 55 \times 0.03\ [(2.33 \times 0.8) + (0.094 \times 0.6)]$$
$$= 2.858\ (1.864 + 0.056)$$
$$= 2.858 \times 1.92$$
$$= \boxed{5.49\ \text{volts}}$$

At start-up: current = 6 times In and cos phi = 0.3
I.e. the values of Ra & Lω taken from the tables in the manufacturer's catalogue

$$Ra = 2.33\ \Omega/Km,\ L\varpi = (0.30 \times 10^{-3} \times 314) = 0.094\ \Omega/Km$$
$$Z = Ra \cos.\ \varphi + L\varpi \sin\varphi = 0.79\ \Omega/Km$$

(Value systematically checked in table 26)

$$\Delta u = 1.732 \times 55 \times 6 \times 0.03\ [(2.33 \times 0.3) + (0.094 \times 0.954)]$$
$$= 17.15\ (0.699 + 0.090)$$
$$= 17.15 \times 0.79$$
$$= \boxed{13.55\ \text{volts}}$$

For power supply, the maximum Δu is 20V (5%), and 40V at start-up (10%). The cable selected, 4 G 10mm², is suitable

3. Cable to be calculated depending on the temperature (and length)

Same engine as above, but with an ambient temperature of 60°C and a length of 150 metres.

The correction factor to be applied for an XLPE (*or RFFV or RGPFV)* series armoured cable is 0.71 according to table 43, chapter 6.3.

The maximum acceptable current in the RGPGF cable, 4 G10mm² = 75 x 0.71 = 53 Amperes.

The nominal engine current is 55A, therefore a cable with a larger section is required to account for this correction factor.

I.e. the 4 G 16mm² cable, for which table 13 (*U1000 R2v but equivalent to RGPFV*) indicates a maximum acceptable current of 100A, which must be corrected with the temperature coefficient.

100A x 0.71 = 71A max current for the 4 G 16

We must recalculate the **fall in voltage**
In normal operating conditions, cos phi = 0.8

Let us consider table 26, which gives the following for a 4 G 16 cable,
Ra = 1.47 & Lω = 0.091Ω/km

$Ra = 1.47\ \Omega/Km,\ L\varpi = 0.29 \times 10^{-3} \times 314 = 0.091\ \Omega/Km$

$Z = Ra\cos\varphi + L\varpi\sin\varphi = 1.23\ \Omega/Km$

(Value of 1.23 checked in table 26)

$$\Delta u = 1.732 \times 55 \times 0.15\,[(1.47 \times 0.8) + (0.091 \times 0.6)]$$
$$= 14.29\,(1.176 + 0.055)$$
$$= 14.29 \times 1.23$$
$$= \boxed{17.58\ \text{volts}}$$

At start-up, cos phi = 0.3

$Ra = 1.47\ \Omega/Km,\ L\varpi = 0.29 \times 10^{-3} \times 314 = 0.091\ \Omega/Km$

$Z = Ra\cos\varphi + L\varpi\sin\varphi = 0.53\ \Omega/Km$

(Value of 0.53 checked in table 26)

$$\Delta u = 1.732 \times 330 \times 0.15\,[(1.47 \times 0.3) + (0.091 \times 0.954)]$$
$$= 85.73\,(0.441 + 0.087)$$
$$= 85.73 \times 0.53$$
$$= \boxed{45.44\ \text{volts}}$$

The drop in voltage in normal operating conditions is acceptable (less than 20V, or 5%), however, at start-up, the drop exceeds 40 V (10%). A larger section is therefore required.

I.e. a 4 G 25mm² cable, table 13 indicates a maximum current of 127A.

We repeat our calculations.

Temperature compensation: 127A x 0.71 = 90A.

In **normal operating conditions, cos phi = 0.8**, the calculation and table 26 give Ra, Lω & Z

$Ra = 0.927\ \Omega/Km$, $L\varpi = 0.29 \times 10^{-3} \times 314 = 0.091\ \Omega/Km$

$Z = Ra \cos.\ \varphi + L\varpi \sin\varphi = 0.80\ \Omega/Km$

and

$\Delta u = 1.732 \ X\ 55 \ X\ 0.15\ [(0.927 \ X\ 0.8) + (0.0911 \ X\ 0.6)]$

$= 14.29\ (0.742 + 0.054)$

$= 14.29 \ X\ 0.80$

$=$ **11.43 volts**

At start-up, cos phi = 0.3 (table 26)

$Ra = 0.927\ \Omega/Km$, $L\varpi = 0.29 \times 10^{-3} \times 314 = 0.091\ \Omega/Km$

$Z = Ra \cos.\ \varphi + L\varpi \sin\varphi = 0.37\ \Omega/Km$

and

$\Delta u = 1.732 \ X\ 330 \ X\ 0.15\ [(0.927 \ X\ 0.3) + (0.091 \ X\ 0.954)]$

$= 85.73\ (0.278 + 0.087)$

$= 85.73 \ X\ 0.37$

$=$ **31.72 volts**

The 2 drops in voltage are within the thresholds of 5 and 10%, the 4 G 25mm² cable is the correct cable.

If we take table 28 (for 380V), we immediately note that the minimum section allowed is 25mm²….

4. Check the short-circuit current

We still have the same engine, with a 25mm² cable over 150m
I.e. a CCI current calculated at 2000A for 0.5s at the start

$$D = \frac{K}{\sqrt{t}}$$

Where K = 143 for the cable concerned

$$D = \frac{143}{\sqrt{0.5}} = 202\ A/mm^2$$

Minimum section: 2000/202 = 10mm²

The XLPE/PVC/LC/STA/PVC (U21000 RGPFV) 4 G 25mm² cable is suitable

5. On a cable tray with other cables

We still have the same 4 G 25mm² cable

This XLPE/PVC/LC/STA/PVC (or U1000 RGPFV-RH) cable accepts a maximum current of 90A with the temperature correction (127A x 0.71) mentioned above

The correction coefficient for 6 cables on the same cable tray is 0.79 according to figure 58

90 X 0.79 = **71 amps**

The nominal current to be carried is 55A, therefore the 4 G 25mm² cable is appropriate for the conditions announced above.