BASIC Electrical Knowledge

Cables

1. General

Cables form an important part of any installation but, because they are static, and in normal service are very reliable, they do not always receive the attention that they deserve.

There are three categories of cables associated with industrial installations - power cables, control cables, and special cables, for example, communications and data transmission circuits. It is the first two categories which are described in this chapter. A power cable contains one, two, three or four cores each consisting of a copper conductor surrounded by insulating material; a control cable usually has many cores and is known as a 'multicore' cable. Aluminium is sometimes used as a conductor material; although its conductivity is less than that of copper, it is somewhat cheaper. less Corrosion problems, however, preclude its use on Shell installations, particularly offshore.

2 Power Cables

Cables are designed for both high voltage and low-voltage transmission of power , the general constructions is similar in both cases, high-voltage cables have thicker insulation and usually have smaller conductors than the low-voltage cables which handle the heavier Currents.

one, two, three or four insulated conductors or mechanical protection, wire armor, and a colored outer protective sheath, over the armoring, as shown in Figure 1,

2.1 General Construction

A power cable is made up of one, tow, three or four insulated conductors enclosed in a bedding, for mechanical protection wire armoring is wrapped around the bedding and a colored outer protective sheath usually of PVC is extruded over the armoring as shown in Fig. 1 , each insulated conductor is known as a core .

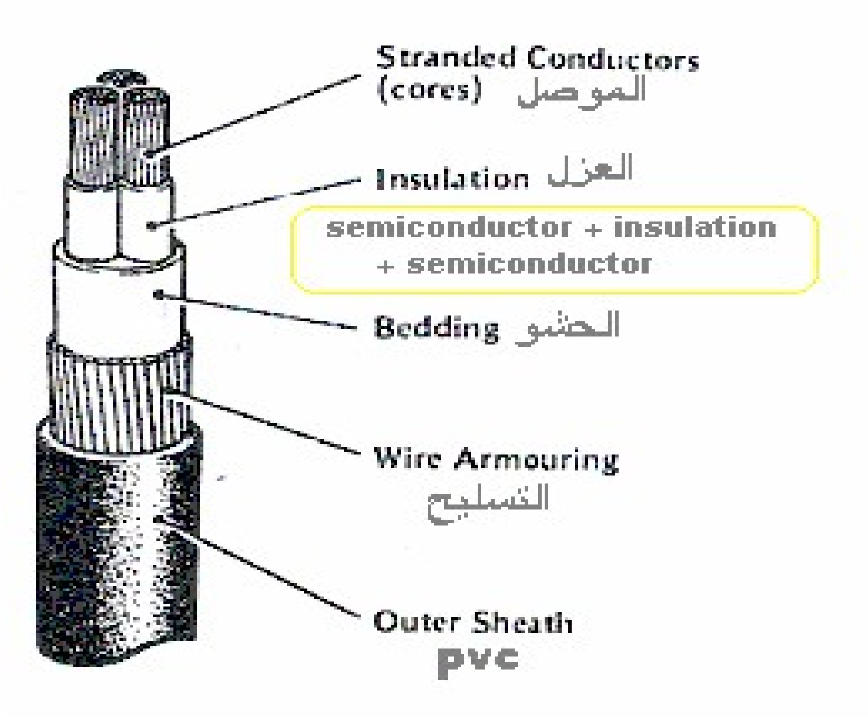

Fig. 1 Three Phase Power Cable

2.2 Conductors

The size of the copper conductor forming one of the cores of a cable is expressed in square millimeters (mm^2), and the current rating of the cable is dependent upon the cross-sectional area of each core. The very smallest cables have conductors consisting of only one strand of copper; larger cables however have stranded conductors consisting of many individual strands or wires laid up together; this gives flexibility, allowing the cable to be bent more readily during installation. To achieve a circular conductor, the number of strands follows a particular progression: 3, 7, 19, 37, 61, 127 etc, the diameter of each strand being chosen to achieve the desired cross-sectional area of whole conductor.

As seen in Figure 2, 3-core and 4-core cables in the larger sizes have conductors with the strands laid up in a segmental formation; this achieves a better space factor and reduces the overall diameter of the cable. It also reduces the inductance of the cable due to decreased spacing between phases.

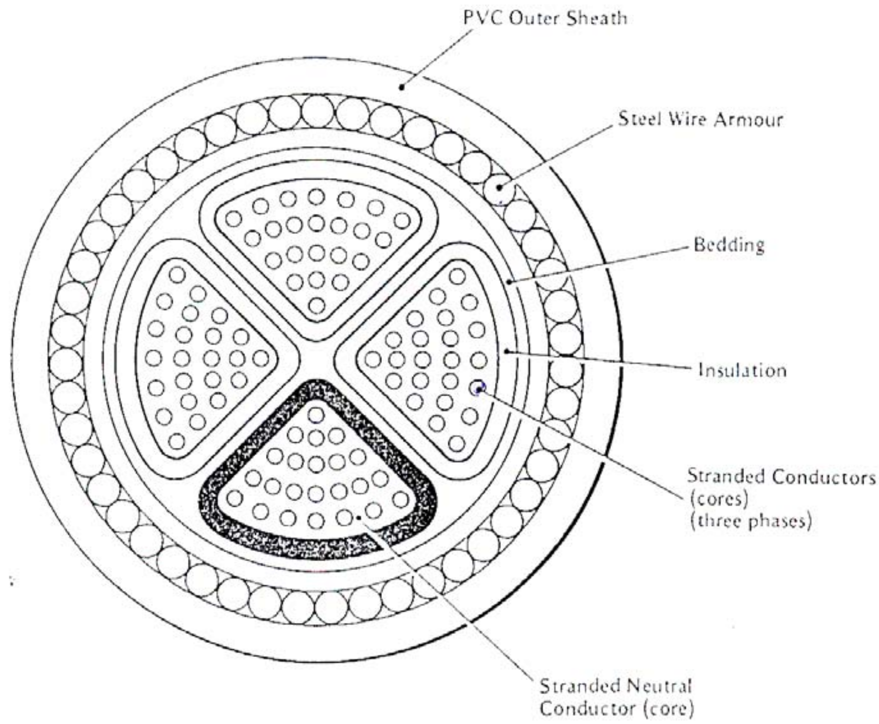

Fig.2
Segmental Cores

Standard conductor sizes range from 1.5mm^2 to 400mm^2 for 2-core, 3-core and 4-core cables, and from 50mm^2 to 1000mm^2 for single-core cables.

2.3 Insulation, Covering and Stress Relief

Natural rubber or oil-impregnated paper is no longer used for the insulation of cables up to 3810/6600V; synthetic materials are now used. For high-vo1tage cables the insulation is ethylene propylene rubber (EPR) and for low-voltage cables it is polyvinyl chloride (PVC). EPR has good electrical properties and is resistant to heat and chemicals; it is suitable for a conductor temperature up to 85^{o}C. PVC is a thermoplastic material, therefore care must be taken not to overheat it; it is suitable for conductor temperatures up to 70°C. PVC insulated cables should not be laid when the temperature is less than 0^{o}C because it becomes brittle and is liable to crack.

High-voltage cables have an earthed metallic screen over the insulation of each core. This screen consists of a lapped copper tape or metallic foil, and its purpose is to control the electric field within the insulation and thus the voltage gradient across it, as shown in Figure 3. Also, it avoids any interaction of the electric stresses due to the voltages on different phase conductors within the same cable.

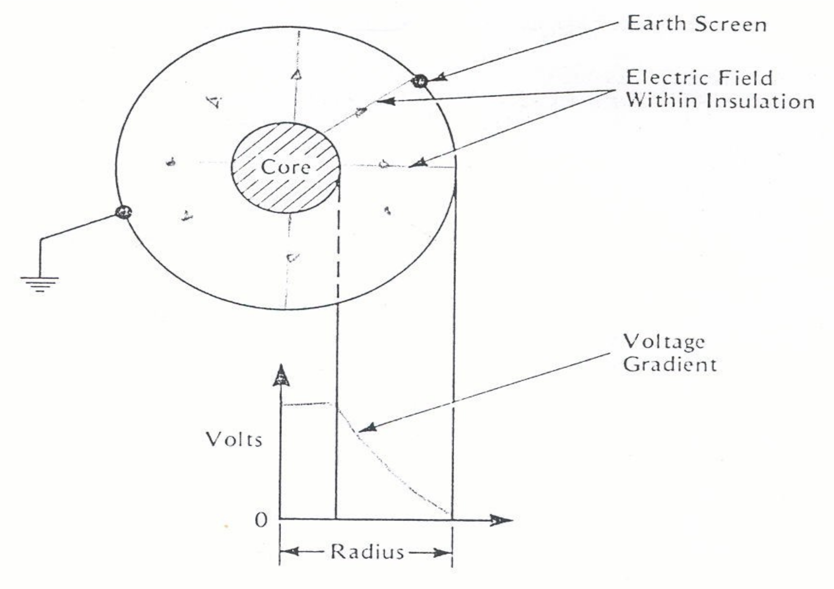

Fig.3
Voltage Gradient Across High Voltage Cable Insulation

Core insulation may be colored red, yellow, blue and black to identify the three phases and neutral. Twin cores are colored red and black. Single-core cables are identified by colored PVC tape applied to the outer sheath.

2.4 Cable Stress Relief

The copper screen is often terminated in a 'stress cone', which may be seen in Figure 7. This is to spread the electric stress which would otherwise tend to concentrate where the screen is cut off at a cable end and could lead to breakdown. This is further discussed in para. 6.4

2.5 Bedding

The bedding consists of a layer of PVC extruded over the core insulation as a base for the armouring.

2.6 Armouring

Mechanical protection of the cable is provided by a single layer of wire strands laid over the bedding. Steel wire is used for 3-core or 4-core cables, but single-core cables have aluminium wire armouring. With 3-core or 4-core cables the vector sum of the currents in the conductors is zero, and there is virtually no resultant magnetic flux. This is not so however for a single-core cable, where eddy-current heating would occur if a magnetic material were used for the armouring. Armouring is described as Steel Wire Armoured (SWA) or Aluminium Wire Armoured (AWA).

2.7 Outer Sheath

The outer sheath of extruded PVC protects the armouring and the cable against moisture and generally provides an overall protective covering.

High-voltage cables are identified by outer sheaths coloured red; a black sheath indicates a low-voltage cable (see also para. 7)

2.8 Selection of Power Cables

The following considerations are taken into account when selecting a power cable for a particular application:

(a) The System Voltage and Method of Earthing

A low-voltage system usually has a solidly earthed neutral so that the line-to-earth voltage cannot rise higher than (line volts) ÷ √ 3. However, cables for low-voltage use are insulated for 600V rms score to earth and 1000V rms core to core.
High-voltage cables used in Shell installations are rated 19000/3300V or 3810/6600V or 6600/11000V, phase/line. In selecting the voltage grade of cable, the highest voltage to

earth must be allowed for. For example, on a normal 6.6kV unearthed system, a line conductor can achieve almost 6.6kV to earth under earth-fault conditions, To withstand this, a cable insulated for 6600/11000V must therefore be used.

(b) The Normal Current of the Cable

The conductors within a cable have resistance, and therefore R^2 heating occurs when currents pass through them, The maximum permissible temperature of the cable depends upon the material of the insulation, and a conductor size must be chosen so that this temperature is not exceeded. Tables giving the continuous current-carrying capacities of different cables are given in manufacturers' literature and in the Regulations for the Electrical Equipment of Buildings published by the Institution of Electrical Engineers.

The temperature of a cable depends not only on the rate of heat input due to the passage of load current but also on the rate at which the heat can be carried away. When using the tables of current ratings it is important to note whether they refer to cables laid in the ground laid in ducts or laid in air. De-rating may be necessary if a number of cables are run in close proximity to each other.

Another consideration in selecting a cable is the voltage Drop (IR) from the source of supply to the load. A drop of 1V in a 440V circuit is of little consequence, but it is a significant percentage when the circuit operates at 24V,

(c) Abnormal Currents in the Cable

One abnormal condition is a sustained overload; a cable must be protected so that an overload cannot persist long enough to cause damage to the insulation by overheating. For example, for PVC cables laid in air, the overload must not be greater than 1.5 times the continuous maximum rated current and must not persist for longer than four hours.

Another abnormal condition is when a cable has to carry a through short-circuit current. In this case the temperature of the conductor may be allowed to rise to a higher value, say 150°C, for the short interval between the onset of the fault and its disconnection. The short-circuit current that a given cable can withstand depends upon the speed with which the protection operates. For example, a PVC cable having conductors of $185mm^2$ has the following short-circuit ratings:

46kA for 0.2 s
20.3kA for 1.0 s
11.7kA for 3.0 s

The 0.2s rating would be suitable for use with fuse protection, but where relay-operated circuit breakers are concerned, a longer time rating would be necessary. Again, tables of short-circuit ratings are available in manufacturers' literature.

3 Control Cables

Control cables usually have conductors either $1.50mm^2$ or $2.50mm^2$ in cross-section. The insulation, bedding and outer sheath are of PVC, and they are steel wire armoured. Multicore cables are available having 2, 3, 4, 7, 12, 19 and 27 cores, each core being identified by a number on the insulation. The outer sheath of control cables is coloured green.

4 Mineral Insulated Cables

Mineral-insulated (MI) cables are used where the integrity of a circuit is of great importance. They are particularly resistant to fire and are used in circuits, such as communications or emergency lighting, which must continue operational as long as possible after fire has broken out. They are also very robust and resistant to mechanical damage.

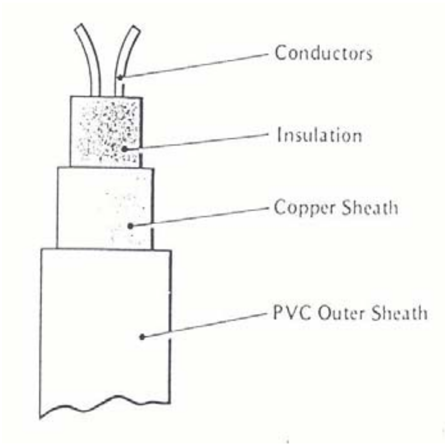

Fig.4

Mineral Insulated Two Core Cable

MI cables are constructed by assembling the single –strand conductor or conductors inside a seamless copper tube.

After threading a number of 'tablets' of magnesium oxide insulating material onto the conductors, the whole assembly - conductors, insulation and copper tube - is drawn down through a series of dies until the magnesium oxide is crushed to a powder and the whole cable is solid. The final appearance is as in Figure 4.

After annealing to make the cable more flexible, an outer sheath of PVC is applied.

MI cables are available in single-core from 1 mm^2 to l50mm^2, in 2-core, 3-core and 4-core from 1mm^2 to 25mm^2, and in 7-core from 1 mm^2 to 4mm^2.

Special jointing techniques and materials must be used for terminating MI cables, and great care must be taken to seal. the cable ends against the entry of moisture.

5 Method of Specifying Cables

There is a 'shorthand' method used to describe the construction of any cable, using abbreviations to indicate the nature of the various materials. For example, a low-voltage cable might be described as:

(Reference)	(1) (2)	(3)	(4)	(5)	(6)	(7)	(8)
Abbreviation	0.6/1kV	STR	CU/	PVC/	PVC/	SWA/	PVC

3-core, l50mm^2

Interpreted this means:

1 0.6kV line to earth
2 1kV line to line
3 Stranded conductor
4 Copper conductor
5 PVC conductor insulation
6 PVC bedding
7 Steel wire armored
8 PVC outer sheath

Another example is:

6.6/11kV STR CU/EPR/SCR/PVC/AWA/PVC/HO_2/HCL
1-core, 630mm^2

Where EPR indicates ethylene propylene conductor insulation
SCR indicates screened
AWA indicates aluminum wire armored.

In particular PVC, when burnt, releases large quantities of HCI and also produces dense black smoke; for example, a 1m Length of cable containing, say,6kg of PVC can completely black out a room 1000m^3 in site within five minutes of the fire starting.

6 Installation

6.1 Cable Runs

Cables may be laid discretely in the ground, run in ducts or clamped to cable trays; the third method is the most common in offshore installations. Each cable must be identified at each end, using a marker bearing the cable number.

There is a practical limit to the conductor size which can be run as a 3-core or 4-core cable - it becomes too stiff and heavy to handle. A 3-phase circuit is then run as three (or four) single-core cables. To minimise the electromechanical forces between the cables under short-circuit conditions, and to avoid eddy-current heating in nearby steelwork due to magnetic fields set up by load currents, the three single-core cables comprising the three phases of a 3-phase circuit are always run clamped in 'Trefoil' formation, as shown in Figure 5.

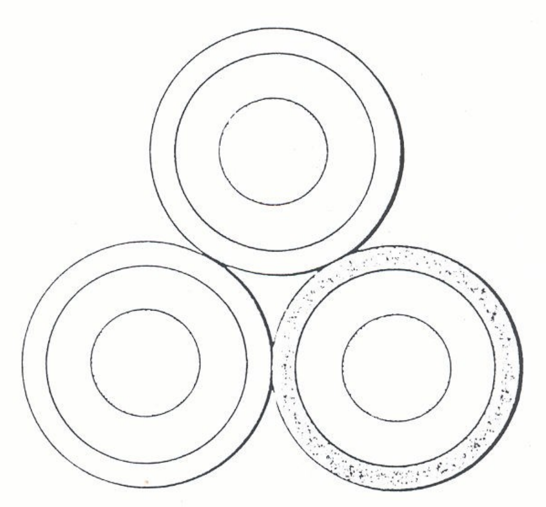

Fig.5
Single Core Cables Laid in Trefoil

At any instant in time the net magnetic flux outside the group of cables due to the three line currents in them approximates to zero because of the symmetrical cable layout.

Heavy current cable runs, such as the low-voltage connections from a transformer, may consist of up to four single-core cables in parallel per phase; all 12 cables are run bunched into four 3-phase sets, each set laid in trefoil. In the case of 4-wire systems the neutral conductor needs a smaller cross-sectional area than that of the phase conductors and may be met by one or more smaller single-core cables in parallel.

6.2 Cable Terminations

A power cable is terminated in an air-insulated cable box in offshore installations; it enters the box through a compression gland which grips the wire armouring and seals the entry of the cable. The outer sheath, armouring and bedding of the cable are stripped back, enabling the cores to be spread to match up with the fixed bushing terminals, and the insulation is removed to expose the conductors.

In some high-voltage onshore installations, especially outdoor ones, the cable box may be filled with compound, a tar-like substance which is poured in hot and then sets hard to exclude moisture. It can only be removed by heating.

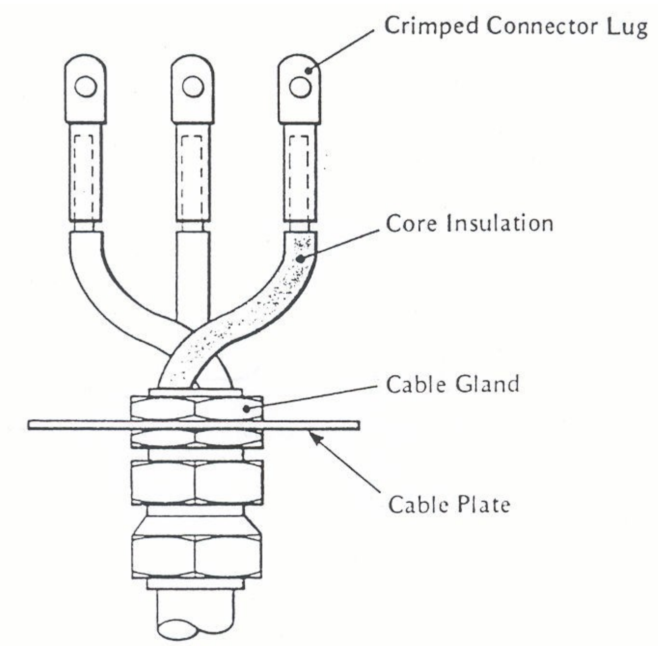

Fig.6
Low Voltage Cable Termination

Conductors are terminated either with lugs bolted to the fixed bushing stems as shown in Figure 6 or, for heavier currents, with cylindrical ferrules which are clamped into terminal blocks. In either case the terminations are crimped onto the conductors using either hand or hydraulic crimping tools. To make a good connection it is vital that the lug or ferrule is the correct size for the particular conductor and that the correct die is used in the crimping tool.

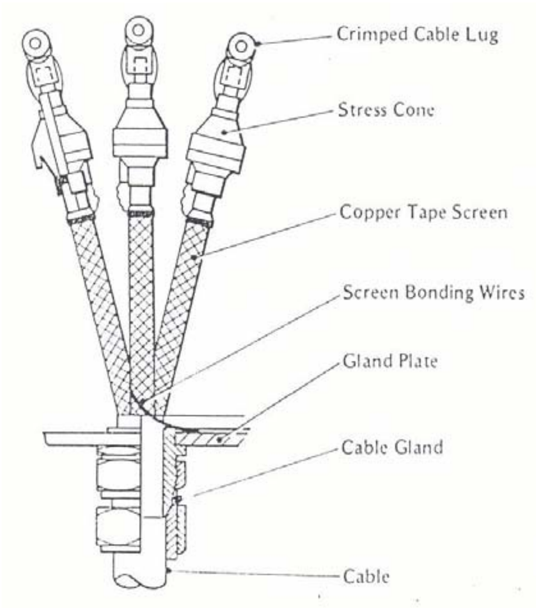

Fig.7
High Voltage Cable Termination

Special measures must be adopted, when screened high-voltage cables are terminated, to prevent a concentrated electric field being developed where the copper screening tape is cut back; this strong electric field could lead to the insulation at that point being so overstressed that a breakdown occurs. Special stress cones are fitted which are bonded to the screening tape; they control the electric stress and reduce the resulting voltage gradients to a safe value. This arrangement is shown in Figure -7.

6.3 Single–core Cables

The conductor of a single-core cable and its surrounding metallic armouring act as a current transformer having a 1:1 turns ratio; load current passing through the conductor produces a magnetic flux which, linking with the wires of the armouring, induces an emf in them. If a circuit is provided between the armouring at one end of the cable and at the other, a current flows in the armouring which, if sufficiently large, causes heating. This is shown in Figure 8(a).

To control these circulating currents insulated cable gland adapters are used whereby the body of the gland, and consequently the wire armouring of the cable, is electrically isolated from the earthed gland plate of the cable box by a layer of insulation. Figure 8(b) shows a 3-phase circuit run with single-core cables using insulated cable glands. To control the voltage of the armouring it must be bonded to earth; this is done by deliberately bridging the gland insulation using bonding links. The armouring can be bonded in one of two ways. In Figure 2.8{a) it is bonded at both ends of the cable run (shown in red); the emf induced in the armouring causes currents (IA) to circulate in the armouring which in heavy current circuits may lead to an undesirable temperature rise in the armouring. Alternatively, the armouring may be bonded at one end only as in Figure 2.8(b); there is no circuit for current to flow, but a voltage (EA) is developed across the gland insulation at the unbonded end. Where one end of the circuit is in a hazardous area, it is customary to bond this end so that any arcing that may occur due to emfs induced in the armouring can only take place in the non-hazardous area.

There is one other magnetic problem associated with single-core cables: where such cables enter a cable box or pass through partitions the conductors must pass through holes in the gland plate. If these plates are made of a magnetic material such as steel, the magnetic fields due to the load currents in the conductors induce eddy currents in the gland plate which may cause it to become very hot. For terminating or passing a.c. circuits using single-core cables, gland plates of non-magnetic material must be used.

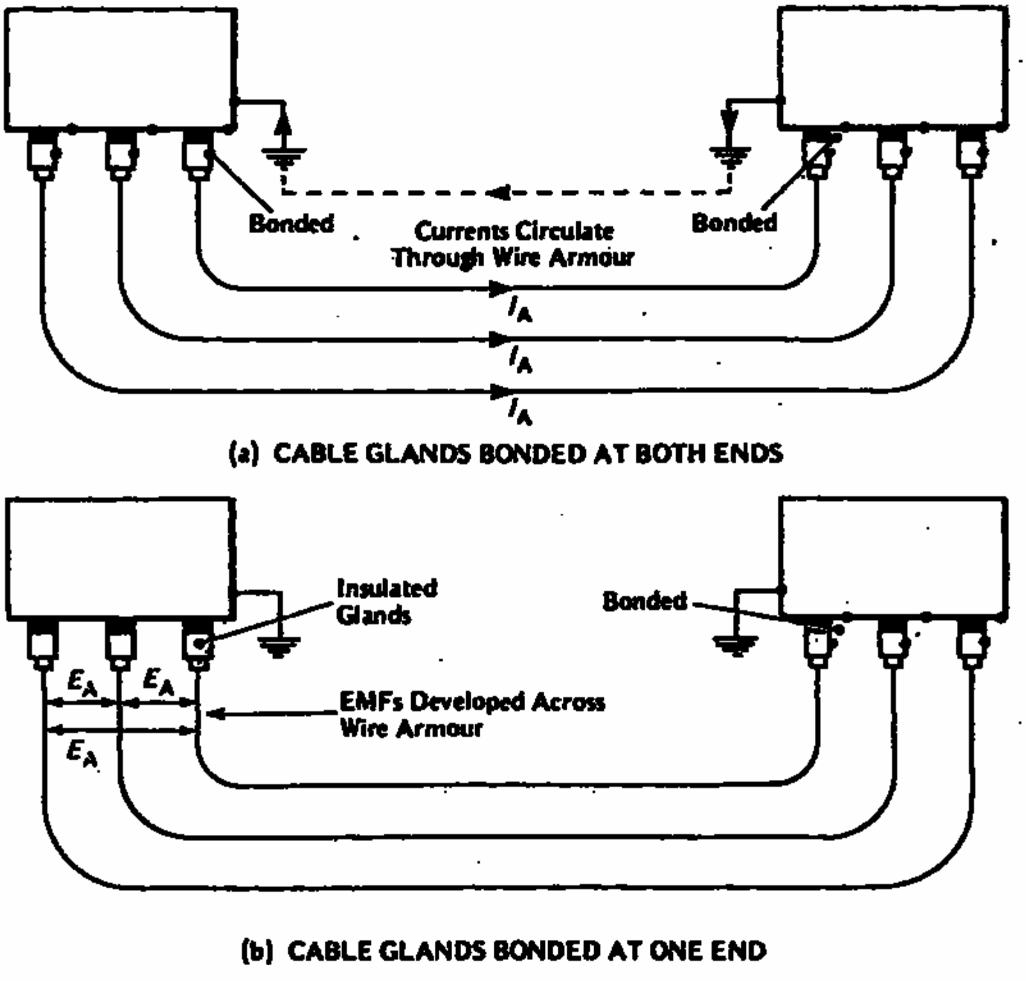

Fig. 8
Insulated Cable Glands

6.4 Control Cables

Control cables are also terminated using compression glands. The sheathing and armouring are stripped back to leave tails of the required length. Each core is identified using plastic ferrules bearing the wire number, and terminated using a crimped connector. The cores are either laced up into suitable runs using plastic cable ties, or secured to cable racks within a control panel.

7 Outer Sheath Colours

Standard colours are used in Shell installations to identify the system to which the various cables belong; they are:

Red	:	High-voltage system
Black	:	Low-voltage system
Green	:	Control and instrumentation system,
Orange	:	Fire and gas detection and telecommunications systems.
Blue	:	Intrinsically safe systems.
Yellow	:	Thermocouple circuits,

Types of Cables

PILC	Paper Insulated, Lead Alloy E sheathed
PILCPVC	Paper insulated, Lead Alloy E sheathed, PVC Oversheath
PILCSWAS	Paper insulated, lead alloy E sheathed, single wire armoured, bitumen
PILCSWAPVC	Paper insulated, lead alloy E sheathed, double steel tape armoured, PVC
PILCDTAPVC	Paper insulated, lead alloy E sheathed, double steel tape armoured, PVC
PVCSWAS	PVC Insulated, single wire armoured, bitumen impregnated hessian/jute
PVCSWAPVC	PVC insulated, single wire armoured, PVC Oversheath
PVCLCSWAS	PVC Insulated, lead alloy E sheathed, single wire armoured, bitumen
PVCLCDTAS	PVC insulated, lead alloy E sheathed, double steel tape armoured, bitumen
PVCLCSWAPVC	PVC insulated, lead alloy E sheathed, single wire armoured, PVC Oversheath
MICC	Mineral insulated, copper covered
MICCPVC	Mineral insulated, copper covered, PVC Oversheath
EPRCSPGWBCSP	EPR insulated, CSP sheathed, galv. Steel wire braids armoured, CSP
XLPESWAPVC	XLPE insulated, single wire armoured, PVC Over sheath.

Notes

1. The lead sheath is required for elastomeric and PVC cables to prevent radial ingress of petroleum based solvents which might permeate through PVC and cause deterioration of insulating materials and might enter and
pass along stranded conductors into equipment terminations.

2. The PVC Over sheath is required as a protection against corrosive conditions which could attack the steel wire armor or lead sheath. Certain conditions may require other types of compounds.

Abbreviations

PVC	POLYVINYL CHLORIDE
SWA	SINGLE WIRE ARMOUR
CPE	CROSS LINKED CHLORINATED POLYETHYLENE
CSP	CHLOROSULPHONATED POLYETHYLENE
EPR	ETHYLENE PROPYLENE RUBBER
HCI	HYDROGEN CHLORIDE
HOFR	CHLOROSULPHONATED POLYETHYLENE OR CHLORINATED POLYETHYLENE COMPOUND (HEAT, OIL, RESISTANT AND FLAME RETARDANT)
Si	SILICON RUBBER
FR	SPECIALLY FIRE RESISTANT
M	MARINE
XLPE	CROSS LINKED POLYETHYLENE