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1.1 Underground Cables

Construction of Underground Cables:

A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended. For instance, the 3-conductor cable shown in Fig. 11.1 is used for 3-phase service. The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable.

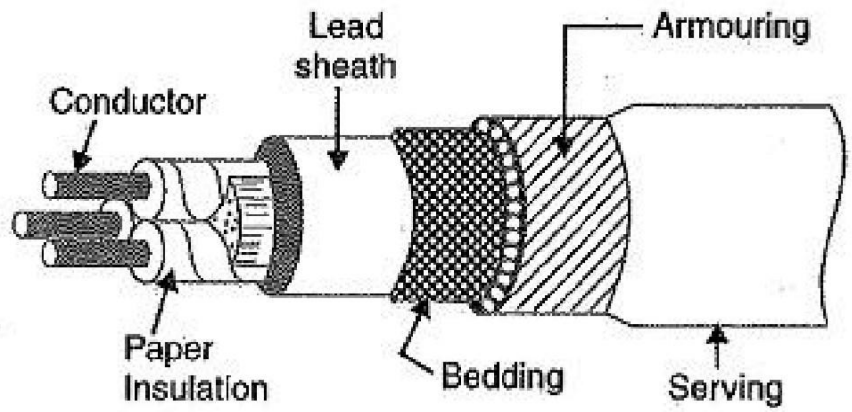

Fig. 11.1 Construction of a Cable

Insulation

Each core or conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the voltage to be withstood by the cable. The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound.

Metallic sheath

In order to protect the cable from moisture, Conductor gases or other damaging liquids (acids or alkalies) in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation

Bedding

Over the metallic sheath is applied a layer of bedding which consists of a fibrous material like jute or hessian tape. The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.

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Armouring:

Over the bedding, armouring is provided which consists of one or two layers of galvanised steel wire or steel tape. Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling. Armouring may not be done in the case of some cables.

Serving:

In order to protect armouring from atmospheric conditions, a layer of fibrous material (like jute) similar to bedding is provided over the armouring. This is known as serving.

It may not be out of place to mention here that bedding, armouring and serving are only applied to the cables for the protection of conductor insulation and to protect the metallic sheath from mechanical injury.

Insulating Materials for Underground Cables:

The satisfactory operation of a cable depends to a great extent upon the characteristics of insulation used. Therefore, the proper choice of Insulating Materials for Underground

Cables is of considerable importance. In general, the insulating materials used in cables should have the following properties :

- High insulation resistance to avoid leakage current.
- High dielectric strength to avoid electrical breakdown of the cable.
- High mechanical strength to withstand the mechanical handling of cables.
- Non-hygroscopic e., it should not absorb moisture from air or soil. The moisture tends to decrease the insulation resistance and hastens the breakdown of the cable. In case the insulating material is hygroscopic, it must be enclosed in a waterproof covering like lead sheath.
- Non-inflammable.
- Low cost so as to make the underground system a viable proposition.
- Unaffected by acids and alkalies to avoid any chemical action. No one insulating material possesses all the above mentioned properties.

Therefore, the type of insulating material to be used depends upon the purpose for which the cable is requiredand the quality of insulation to be aimed at. The principal of Insulating Materials for Underground Cables are rubber, vulcanized Indiarubber, impregnated paper, varnished cambric and polyvinyl chloride.

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Classification of Underground Cables:

Classification of Underground Cables may be in two ways according to

The type of insulating material used in their manufacture
The voltage for which they are manufactured.
However, the latter method of Classification of Underground Cables is

generally preferred, according to which cables can be divided into the following groups :
Low-tension (L.T.) cables – up to 1000 V
High-tension (H.T.) cables – up to 11,000 V
Super-tension (S.T.) cables – from 22 kV to 33 kV
Extra high-tension (E.H.T.) cables – from 33 kV to 66 kV
Extra super voltage cables – beyond 132 kV
A cable may have one or more than one core depending upon the type of service for which it is intended. It may be

- single-core
- two-core
- three-core
- four-core etc.

For a 3-phase service, either 3-single-core cables or three-core cable can be used depending upon the operating voltage and load demand.

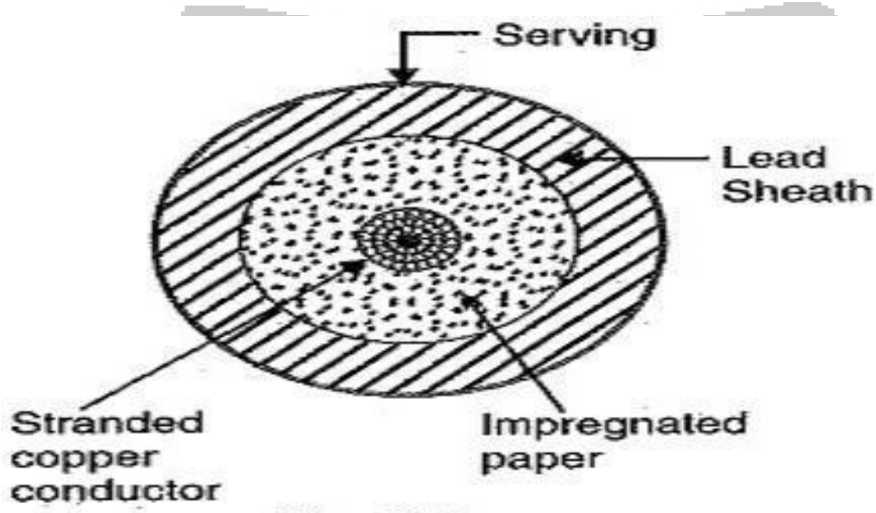

Fig. 11.2

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Fig. 11.2 shows the constructional details of a single-core low tension cable. The cable has ordinary construction because the stresses developed in the cable for low voltages (up to 6600V) are generally small. It consists of one circular core of tinned stranded copper (or aluminum) insulated by layers of impregnated paper. The insulation is surrounded by a lead sheath which prevents the entry of moisture into the inner parts. In order to protect the lead sheath from corrosion, an overall serving of compounded fibrous material (jute etc.) is provided.

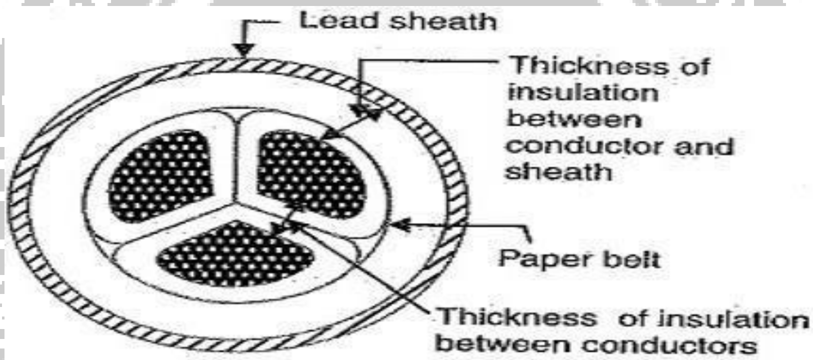

Fig. 11.3

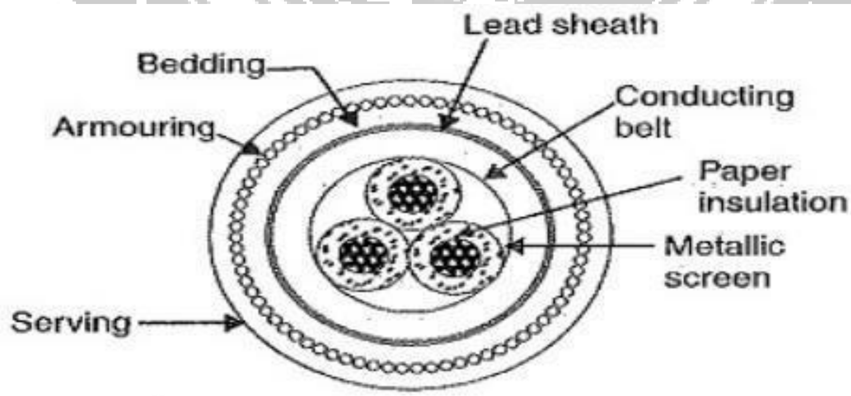

Fig. 11.4

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1.2 ELECTRIC LIGHTING

The three main categories of electric lights are incandescent lamps, which produce light by a filament heated white-hot by electric current, gas-discharge lamps, which produce light by means of an electric arc through a gas, such as fluorescent lamps, and LED lamps, which produce light by a flow of electrons across

Domestic Lighting

The requirement of illumination varies from place to place such as study rooms, drawing room, verandah, bedrooms, and toilets, Incandescent lamps, fluorescent lamps, and compact fluorescent lamps (CFL) are well suited for domestic lighting. It should be remembered that, it is economical to have white walls, as it increases the reflection rather than colored walls.

Industrial Lighting

Sufficient light in factories increases production, and quality of work and reduces accidents. Investigations have been carried out in several industries to determine the influence of lighting on production; results indicate that with an illumination of about 200 lux, the production is equal to that obtainable in good daylight.

Advertisement Lighting

This type of lighting is used to attract the public and to increase sales. Dress materials, domestic appliances, sign boards, automobiles, cosmetics, etc. come under this category and are illuminated at road junctions, public places, etc. Almost all types of lamps with reflectors are used for advertisement lighting.

Street Lighting

The purpose of street lighting is to promote safety and convenience to pedestrians, vehicles, police supervision, and other purposes. The level of illumination required for streets will vary depending upon a traffic road or other type of road. High illumination should be provided on traffic roads and shopping centers. The most important factors to be considered in street lighting are visibility, the case of erection, and maintenance. Less importance will be given to color rendering.

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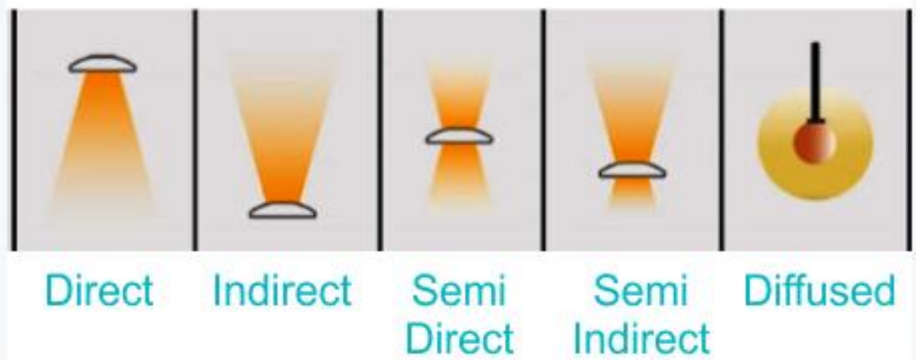
Types of Lighting Schemes



- Direct lighting
- Semi-direct lighting
- Indirect lighting
- Semi-indirect lighting
- General lighting

Direct Lighting

In this method of the scheme, about 90 to 100% of the light from the source is directed towards the working plane or object or surface to be illuminated. The remaining about 10% of the total flux goes to the other direction or the upper hemisphere. Light may be directed on the working plane by the use of suitable reflectors or bracket lamps or by additional pendant fittings.

Direct light is cut off at an angle of ∘ ∘ below the horizontal line. The heat of the lamp from the working plane should be two-thirds of the lamp spacing. When the lamps are to be mounted at considerable heights from the working plane, the angle of cut-off may be 30∘ the below figure shows the fitting. A trough reflector may be of steel stove-enameled or anodic aluminum or vitreous-enameled. However,

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this direct lighting produces hard shadows.

Advantages of Direct Lighting

- Mounting of lamps is easy
- The light emanating from the lamp is fully utilized on a working plane
- The objects are clearly visible
- Domestic and industrialists prefer direct lighting
- It is cheap (fittings and lamps)
- Extra fittings are not required

Applications of Direct Lighting

- Houses, offices, etc.,
- Industrial lighting

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1.3 DISTRIBUTION OF ENERGY FOR LIGHTING

Energy efficiency refers to the amount of energy required to provide appropriate light. The specific requirements of a lighting system depend on the type of tasks to be accomplished in a particular space.

Defining a specific lighting need is a rather complex task. It involves not only the measuring of (technical) parameters (e.g. illuminance, contrast, colour, temperature, etc.), but it is also

influenced by subjective perceptions, which vary from region to region, or even from person to person. For the purpose of the Technology Radar, different everyday lighting needs can be broadly classified into three groups, according to the types of spaces where light is required.

1. Domestic lighting.

2. Lighting the workplace (i.e. options for commercial and institutional buildings).

3. Lighting outdoor spaces.

There are undoubtedly numerous different specific lighting cases valid for each group. However, for each of these ‘lighting need groups’ it is possible to identify the conventional inefficient lighting technologies that are predominantly used. The search for superior options involves examining the different technical options available and comparing their energy demand

Much more than a lamp

Lamps are sources of artificial light and, therefore, are central elements of any lighting system. In most cases, however, both the quality of light and energy efficiency can be significantly improved by the correct selection of other ‘auxiliary’ elements of the system.

The most common perception sees the lamp as the device required to fulfil our lighting needs. However, when looking for more energy efficient ways to meet our needs, it is preferable to think in terms of lighting systems, i.e. a set of elements, which, by combining different functions and properties, provides

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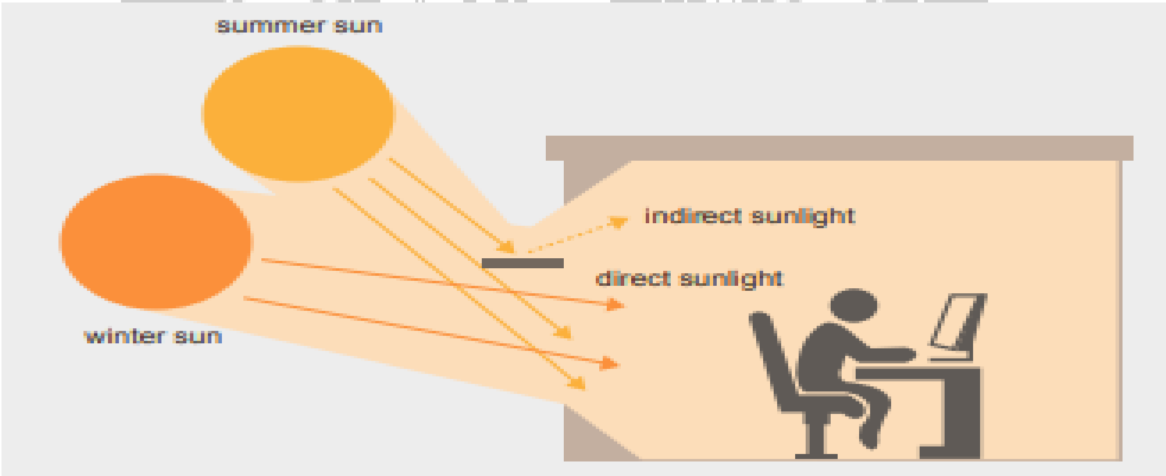
appropriate artificial light and avoids unnecessary energy losses.

The Technology Radar classifies the components that can make up an energy efficient lighting system into five groups:

- Components for improving the use of daylight
- Lighting controls
- Ballasts
- Luminaries
- Electric Lamps

Components for improving the use of daylight



- ➢ Daylight is probably the most "energy efficient" lighting option. It seems also to have positive effects on health and productivity
- ➢ Harnessing natural daylight for lighting indoor spaces can be a complex task.
- ➢ The availability of daylight is constrained by the design of buildings. Issues such as the availability and orientation of windows
- ➢ The floor-to-ceiling height and the layout of the rooms influence the ingress of daylight as well as the options for distributing it within the building.

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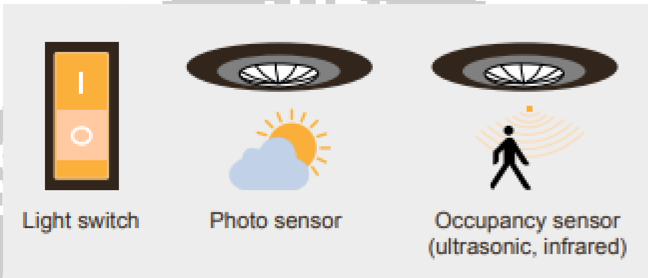
Lighting controls

Lighting control technologies comprise a combination of devices and control strategies that allow for the provision of lighting services that can be varied in accordance with actual levels of natural daylight and the needs of the location.



- Illuminated rooms (e.g. bathrooms), corridors or stairways that are empty during long periods.
- Rooms or corridors with large windows or transparent walls where electric lights are continually on regardless of the supply of natural daylight.

Ballasts

Ballasts are power regulation devices that are required by most electric lamps. The main function of electrical ballast is to ignite the lamp, limit the supply of electrical current, transform the voltage and correct the power factor.
In certain types of lamps, the ballast is already integrated into the commercial product, such as in the case of compact fluorescent lamps. However, for many applications

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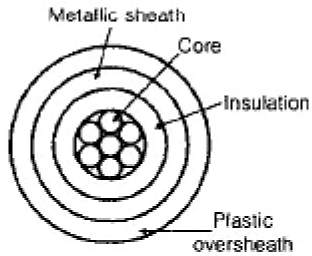
1.4 PAPER INSULATED CABLES



Single core cable

Paper-insulated cables are electrical cables that use paper as the primary insulating material around the conductor. These cables were commonly used in the past for power distribution and electrical transmission, but they have largely been replaced by modern synthetic insulating materials in recent years.

Components of a Paper-Insulated Cable:
Conductor:

The central core of the cable is typically made of copper or aluminum, which carries the electrical current.
Insulation:

The conductor is wrapped with multiple layers of insulating paper. The paper provides electrical insulation between the conductor and the cable's outer components, preventing electrical leakage and ensuring safety.
Insulating Oil:

In some paper-insulated cables, especially in high-voltage applications, the paper is impregnated with insulating oil to enhance the insulation properties and improve heat dissipation.
Protective Sheath:

To protect the insulated core from moisture, chemicals, and mechanical damage, an outer sheath made of materials like lead or lead alloy may be used.

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Protective Sheath:

To protect the insulated core from moisture, chemicals, and mechanical damage, an outer sheath made of materials like lead or lead alloy may be used.

Advantages of Paper-Insulated Cables:

Low cost:

Paper-insulated cables were economical to manufacture, making them a popular choice in the past when alternatives were limited.

Good electrical insulation:

The paper provides a reasonably good level of electrical insulation for lower voltage applications.

Biodegradable:

Being made of paper, these cables are more environmentally friendly compared to modern synthetic cables.

Disadvantages and Limitations:

Limited temperature resistance:

Paper-insulated cables are not suitable for high-temperature environments, as the paper can deteriorate and lead to a loss of insulation integrity.

Larger size:

Paper insulation requires thicker layers to achieve the same level of insulation as synthetic materials, leading to bulkier and heavier cables.

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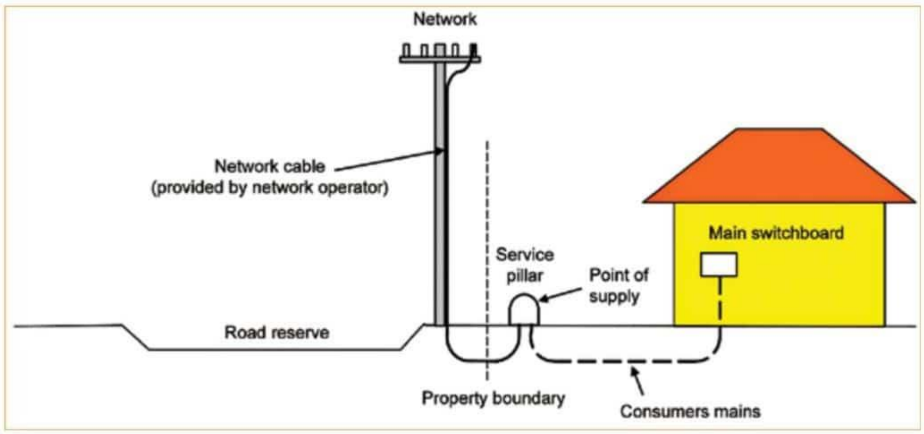
1.5 UNDERGROUND RESIDENTIAL DISTRIBUTION SYSTEMS



Underground Residential Distribution Systems (URD Systems) refer to electrical power distribution systems designed to deliver electricity to residential areas through underground cables instead of overhead power lines. URD systems have become increasingly popular in urban and suburban areas due to various advantages they offer over traditional overhead distribution systems.

Components of Underground Residential Distribution Systems:

Primary Feeders: These are high-voltage underground cables that carry electricity from the substations to the neighborhoods or communities. Primary feeders are typically installed in larger conduits to accommodate the higher voltage levels.

Secondary Feeders: Secondary feeders are lower-voltage cables that branch off from the primary feeders and distribute electricity to individual residential customers. They are usually installed in smaller conduits, and the voltage is stepped down to a safer level for residential use.

Pad-Mounted Transformers: These transformers are installed in various locations within the residential areas to further step down the voltage to a level suitable for individual households. Pad-mounted transformers are placed above ground and housed within protective enclosures.

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Service Lateral Cables: These are the underground cables that connect individual homes to the secondary feeders or pad-mounted transformers. Service lateral cables deliver electricity from the distribution system to the individual meters on residential properties.

Advantages of Underground Residential Distribution Systems:

Aesthetics: One of the primary advantages of URD systems is that they are more aesthetically pleasing than overhead power lines. The absence of visible power lines contributes to a cleaner and less cluttered visual landscape in residential areas.

Reduced Outages: Underground cables are less susceptible to weather-related disturbances, such as high winds, ice, and falling branches, which are common causes of outages in overhead distribution systems.

Lower Line Losses: Underground cables have lower electrical losses compared to overhead lines, resulting in slightly more efficient power distribution.

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2.1 ARCHITECTURE OF UNDERGROUND CABLING SYSTEM

In areas where space for cables is limited and crunched, especially the urban regions, underground laying of cables is an efficient method. Telecommunications or electric power can be transmitted through underground cables. Data is transmitted from one point to another using cable laid on the ground instead of the ones hanging from poles and towers in an underground cable system.

Benefits of underground cable laying:

Climate change has made extreme weather conditions more common. In order to have an uninterrupted power supply and telecommunication in place, it is important that our infrastructure is planned and equipped to survive the harsh weather conditions. The following benefits make underground cable systems the preferred choice:

- Longer lifespan – Underground cables have a much greater life expectancy than aerial cables.
- Reduction in maintenance costs – Less exposure to nature's fury like falling tree branches, strong winds and rain lead to fewer maintenance requirements.
- Accident prevention- Aerial cables can collapse on buildings and cars and put anyone near them at the risk of electric shocks. In this regard, underground cable laying is safer.
- Continuous service – Protected from external factors, underground cables provide uninterrupted power or service.
- Zero obstruction – Underground cable systems are completely out of sight and

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cause zero obstruction to properties.

- Minimum space requirement – Aerial cables require a lot of space for installing poles whereas underground cables require a much-limited band of land.

The Procedure & Installation of Underground Cable Laying

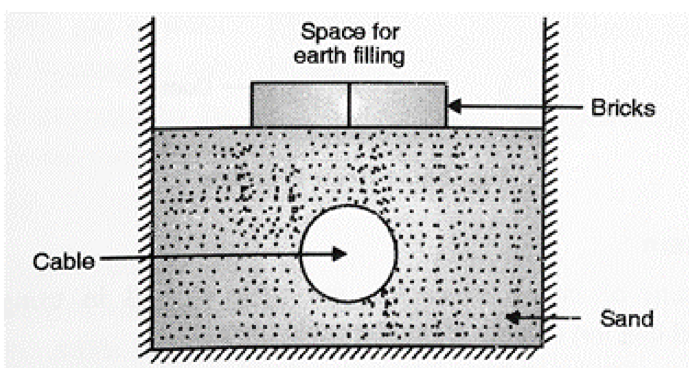
The effectiveness and efficiency of an underground cable system depend on proper cable laying, quality of cable joints and branch connections. There are three methods of underground cable laying.

The procedure followed in each method is as follows:

Direct laying

This method requires digging a 1.5m deep and 0.45m wide trench which is then covered with a layer of sand. The cables are laid in the trench and covered with a 10 cm thick layer of sand. To protect against mechanical injury the trench is then covered with bricks and other materials.

If more than one cable is required to be laid in a trench then a horizontal or vertical inter-axial spacing of 30 cm is provided to prevent mutual heating.



Advantages:

- The simplest and cheapest method of underground cable laying
- The heat generated gets dispersed in the ground.

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Disadvantages:

- High maintenance cost
- Pointing out accurate locations of faults is difficult
- Cable network alterations are difficult.

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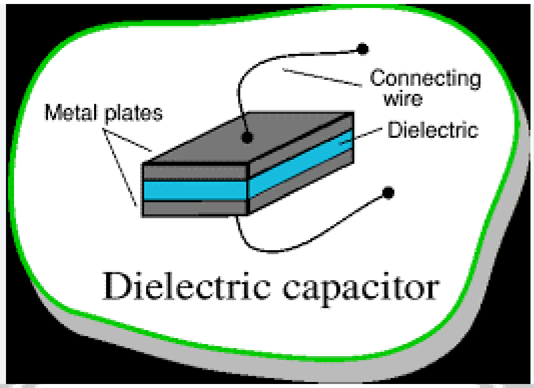
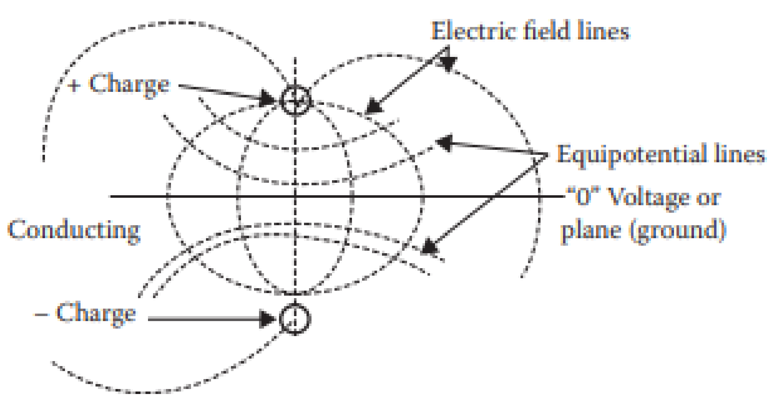
2.2 BASIC DIELECTRIC THEORY OF CABLE:



- Whether being used to convey electric power or signals, it is the purpose of a wire or cable to convey the electric current to the intended device
- Electrical insulation (dielectric) is provided to largely isolate the conductor from other paths or surfaces through which the current might flow

Electric Fields And Voltage:

- Current flow is charge in motion. We might consider the simple case of a conductor carrying current out to a load and then a return conductor as two separate parallel cylinders of charge
- If we neglect the conductor diameter (line of charge), there are electric field lines represented by circles of diameters such that the center of the circles are on the “0” line and each circle passes through the center of the cylinders.
- The voltage at any location is the sum of the voltages due to each charge.
- This then, neglecting the conductor diameter, represents the electric field lines and equipotential (equal voltage lines) lines for an energized current carrying conductor above ground.



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Air Insulated Conductors:

A metallic conductor suspended from insulating supports, surrounded by air, and carrying electric signals or power may be considered as the simplest case of an insulated conductor.

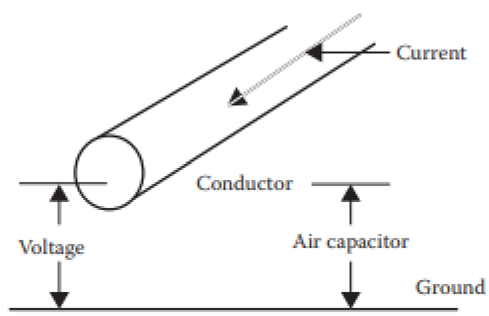
It also presents an opportunity to easily visualize the parameters involved

The charge separation between the conductor and the ground, results in a capacitor and because there is some (generally very small) conduction from the conductor to the ground, a large resistance also exists between the conductor and the ground.

As long as the ground is well away from the conductor, the electric field lines leave the conductor outer surface as reasonably straight lines emanating from the center of the conductor.

Air is not a very good insulating material since it has a lower voltage breakdown strength than many other insulating materials It is low in cost and if space is not a constraint, then it is a widely used dielectric.

As the voltage between the conductor Basic Dielectric Theory of Cable



Insulating To Save Space:

Space is a common constraint that precludes the use of air as an insulator. Imagine the space requirements to wire a house or apartment using bare conductors on supports with air as the insulation.

Let us consider the next step where some of the air surrounding the previous conductor is replaced with a better insulating material (dielectric).

The distribution of voltage from the conductor to the covering surface and from the covering surface to the ground will be in proportion to these impedances.

It is important to note that with ground relatively far away from the covered conductor, the majority of the voltage exists from the covering surface to the ground.

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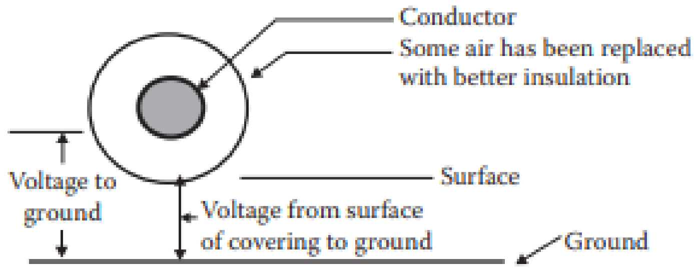
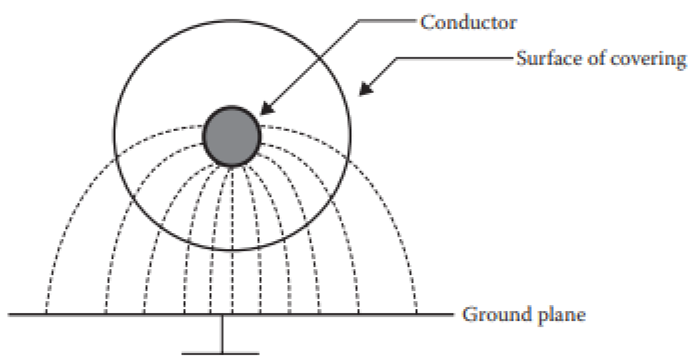


Rising Voltage:

- Return to the metallic conductor that is covered with an insulating material and suspended in air
- When the ground plane is brought close or touches the covering, the electric field lines Recognizing that equipotential lines are perpendicular to the field lines, the bending results in potential differences on the covering surface.



Insulation Shield:

- Imagine that the ground plane was "wrapped" around the conductor with the same thickness of air separating the two.
- Barring surface irregularities at the conductor or ground, the electric field lines would be straight lines taking the shortest path from the conductor to the ground and the equipotential lines would be concentric cylinders around the conductor
- This would form a cylindrical capacitor and would make the most effective use of the dielectric.

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2.3 CONDUCTORS

The fundamental concern of power cable engineering is to transmit electrical current (power) economically and efficiently. The choice of the conductor material, size, and design must take into consideration such items as:

- Ampacity (current carrying capacity)
- Voltage stress at the conductor
- Voltage regulation
- Conductor losses
- Bending radius and flexibility
- Overall economics
- Material considerations
- Mechanical properties

Ampacity:

The current carrying capacity (ampacity) of aluminum versus copper conductors can be compared by referring to many documents.

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Voltage Regulation:

In alternating current (AC) circuits having small conductors and in all DC circuits, the effect of reactance is negligible

Equivalent voltage drop results with an aluminum conductor that has about 1.6 times the cross-sectional area of a copper conductor.

In AC circuits having larger conductors, however, skin and proximity effects influence the resistance value (AC to DC ratio, later written as AC/DC ratio), and the effect of reactance becomes important

Weight:

One of the most important advantages of aluminum, other than economics, is its low density

A unit length of bare aluminum wire weighs only 48% as much as the same length of copper wire having an equivalent DC resistance

Direct Current Resistance:

The conductivity of aluminum is about 61.2% to 62.0% of that of copper. Therefore, an aluminum conductor must have a cross-sectional area about 1.6 times that of a copper conductor to have the equivalent DC resistance

Short Circuits:

Consideration should also be given to possible short circuit conditions, since copper conductors have higher capabilities in short circuit operation. the thermal limits of the materials in contact with the conductor (e.g., shields, insulation, coverings, jackets, etc.) must be considered

Conductor Sizes:

Just as in any industry, a standard unit must be established for measuring the conductor sizes. In the US and Canada, electrical conductors are sized using the AWG system.

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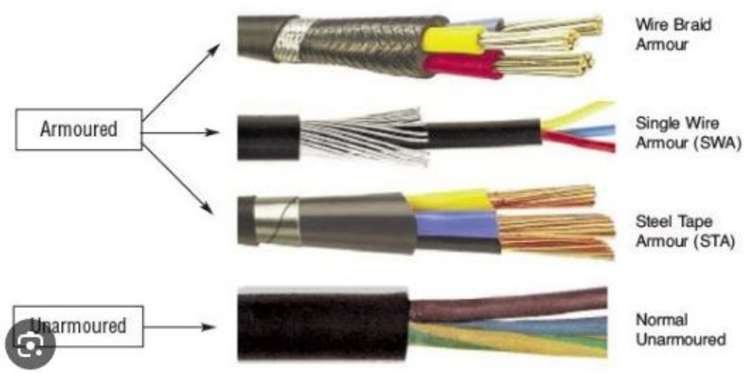
2.4 ARMOUR AND PROTECTIVE FINISHES



- This chapter applies mainly to power distribution cables, certainly in relation to armour, as special considerations apply to wiring type cables and to transmission cables.
- Features relating to the design of both these groups of cables are given with the design aspects in the relevant chapters.
- For lead sheathed paper insulated cables, the two universal types of armour are steel tape (STA) and galvanized steel wire (GSW), usually referred to as single wire armour (SWA).
- Steel tapes are applied over a cushion of bituminized textile materials which also contribute to corrosion protection
- Two tapes are applied helically, each tape having a gap between turns of up to half the width of the tape and the second tape covering the gap and overlapping the edges of the first tape
- By applying the two tapes from the same taping head of the armouring machine the lay length of each tape is identical and the tapes register correctly with each other

Single-core cables:

A problem arises with single-core cables because in their installation formation the armour is situated between the conductors and if a magnetic material is used it causes high induced currents in the armour.

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Armour conductance:

Technical details of the importance of armour conductance with particular reference to wiring cables are discussed

Armouring for polymeric insulated cables:

The lower voltage (i.e. up to 3.3 kV) PVC or XLPE cables which have replaced PILS cables require mechanical protection of a similar standard. For various reasons, such as ease of cable handling and armour conductance, SWA is normally used.

Such cables usually have an extruded PVC over sheath (other extruded materials are used for cables to meet certain performance requirements in fires

Protective Finishes:

- Protective finishes are of particular interest for the protection of metal sheaths, reinforcement and armour in buried distribution and transmission cables.
- Whether the installation is below or above ground, very few cables are supplied without a protective finish.
- For the newer designs of the above categories of cable, an over sheath of extruded PVC or MDPE has become nearly universal. protective finish.
- For the newer designs of the above categories of cable, an over sheath of extruded PVC or MDPE has become nearly universal.

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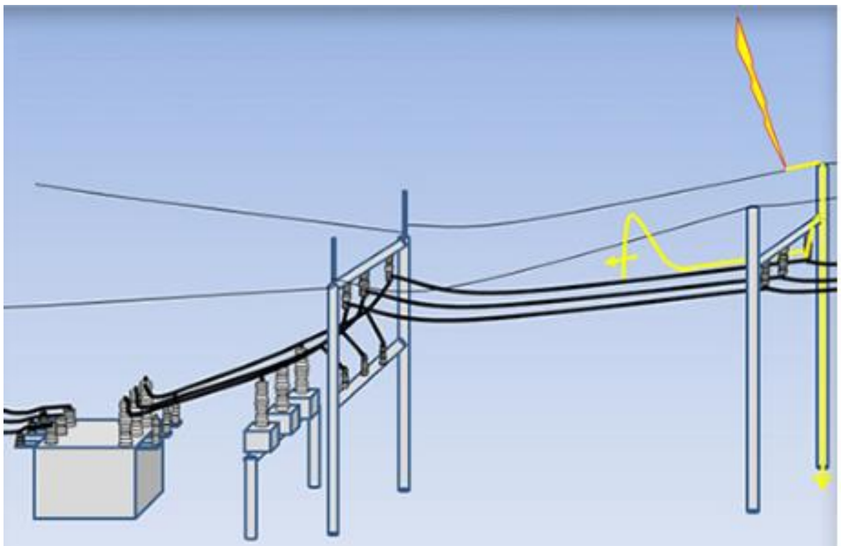
2.5 FUNDAMENTALS OF ELECTRICAL INSULATION MATERIALS



- Electrical insulation materials are utilized to provide protection over the metallic conductors of underground cables. The insulating materials physically enclose the conductor and provide a margin of safety.
- These materials are composed of either synthetic or natural polymers.
- The polymeric insulation material selected for use may vary with the voltage class of the cable.
- Metallic neutrals or tapes are applied over this cable core, and polymeric jackets are applied on the outside of the cable core.

Preferred insulation characteristics of this class of polyolefin-based polymers include:

- Excellent electrical properties
- Low dielectric constant
- Low power factor
- High dielectric strength
- Excellent moisture resistance
- Extremely low moisture vapor transmission

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- High resistance to chemicals and solvents
- Ease of processing and extrusion

Paper-insulated cables were historically one of the first types of polymer used since paper was, and is, readily available from natural sources.

Paper is derived from wood pulp and is a natural polymer based on cellulose. In use, the paper is impregnated with a dielectric fluid (a low molecular weight hydrocarbon) so the practical insulation is actually a two-phase composition.

The dielectric losses of polyolefin's are superior to those of paper/oil insulation systems, and the polymers are considerably more moisture-resistant than paper.

Branching:

When ethylene monomer is converted to ethylene polymer (polyethylene), the polymer chains that form are not always linear

There is a tendency to form side chains or “branches.” These branches are “hanging” off the main chains as appendages. This is a natural event; when polyethylene is manufactured, the process employed always leads to side chains “hanging” off the long main chain.

The chain branching phenomenon contributes to increase in the molecular weight, but does not lead to an increase in the chain length. Branches for various grades of polyethylene

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3.1 Supply Distribution Systems

Parameters Of Electricity Supply Systems:

In the development of early electricity supply systems, many direct and alternating voltages, In the development of early electricity supply systems, many direct and alternating voltages, frequencies, phase numbers and connections were used to achieve the most economical use of capital, but the arrangements discussed below have become predominant in modern systems.

Frequencies and phase numbers:

- A symmetrical 3-phase a.c. system with an earthed neutral and a frequency of 50 Hz or 60 Hz is now used almost universally for main power distribution systems
- Alternating current may be generated without a commutator and transformed to higher or lower voltages by static transformers.
- A 3-phase winding makes efficient use of the armatures of cylindrical machines and of the cores of transformers.
- In a symmetrical 3-phase system the phases are mutually displaced by the same angle,120 °, and the magnitudes of the voltages between the phases are all equal, as are the magnitudes of the voltages between the phases and the neutral.
- A 3-phase supply will excite a magnetic field rotating in a definite direction which is easily reversed.
- The voltage applied to a symmetrical load that is normally connected in delta may be reduced by connecting it in star without the use of a neutral conductor.
- A frequency of 50Hz or 60Hz relates well to the normal speeds of mechanical drives and is high enough to prevent discernible flicker from electric lamps and low enough to avoid undue interference with telecommunications equipment.
- A 3-phase system with loads connected between phase and neutral may be supplied from a 3-phase system without a neutral conductor by the use of a transformer with a star-connected secondary winding.
- single-phase system may be supplied from a transformer connected between two phases of a 3-phase system.

Single-pole-and-neutral system:

In the UK isolated low voltage single-pole-and-neutral systems are used where the total demand is less than 50 kV A and a small number of single-phase loads would be difficult to balance between three phases.

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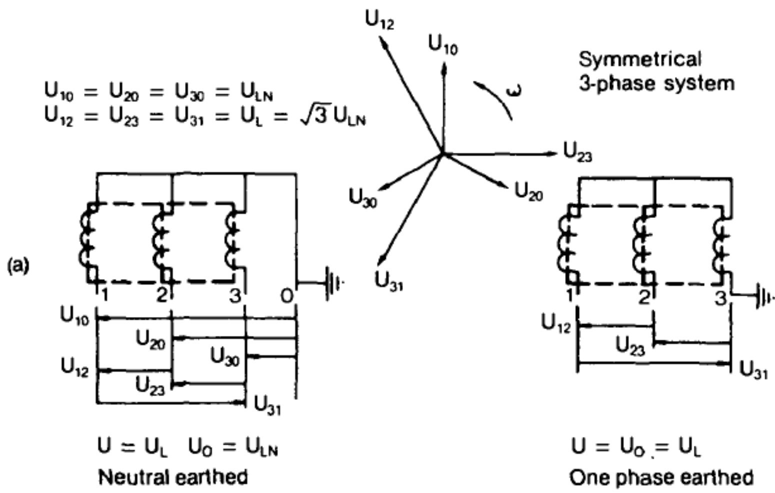

Voltage relationships of some systems currently in use and diagrams showing the arrangements and connections of the secondary windings of the in feeding transformers. The heavy broken lines represent the magnetic cores

Centre-point-earthed single-phase system:

Some systems have two live conductors carrying potentials relative to an earthed neutral that are in phase opposition to each other, If a neutral conductor is provided, the current from loads connected between opposite poles and the neutral will tend to cancel in the neutral, as in the 3-phase system.

Such a system may be supplied from a centre tapped winding on a single-phase transformer

Importance of the neutral conductor:

In all the systems using a neutral conductor to give supply to single-phase loads, its integrity is essential to prevent excessive voltages from being applied to the loads on the less heavily loaded phases.

Cable Networks:

In underground distribution systems, the lower limit of the range of conductor size S that may be used at each voltage level is set by the short-circuit current 1 that could flow and the total operating times T of the protection and switchgear in the approximate relationship S = kI~/T. The result is that a mat of cables in a small range of sizes is operating at each voltage level in most urban and industrial areas.

The cables operating at each voltage level can be arranged into a contiguous network of distributing interconnectors connecting substations that feed in from a higher voltage as well as

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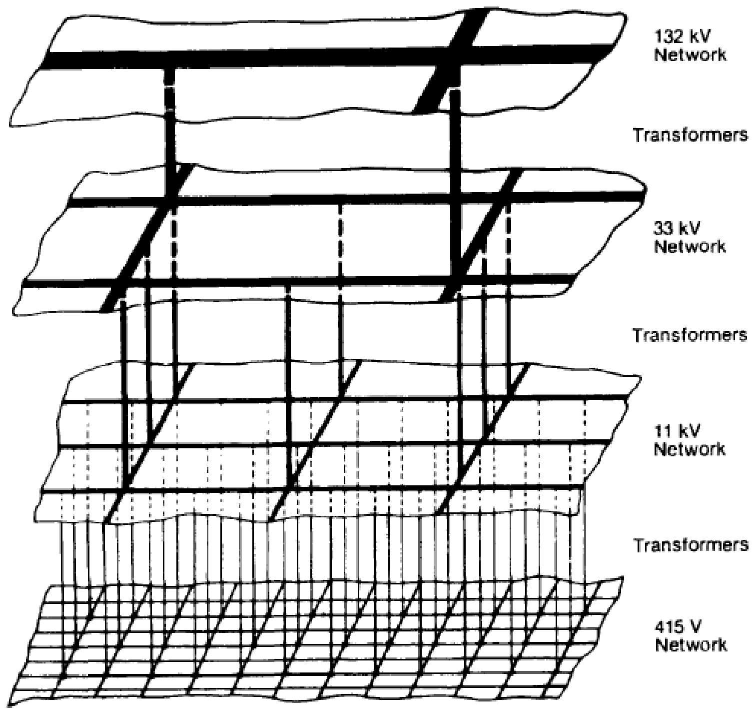
feeding loads directly or through transformers stepping down to a lower voltage network.



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3.2 Types Distribution Cable:

- Generally, distribution cables are designated according to the nominal system voltage on which they are intended to operate.
- The standard system voltages used in the UK are 1.9/3.3kV, 3.8/6.6kV, 6.35/11kV, 12.7/22kV and 19/33kV.
- Cables are also manufactured for use on 8.7/15 kV systems for the export market.
- The design of these cables is dictated by the mechanical rigours associated with their installation conditions and not simply by their electrical duty.
- Under normal operating conditions, the ratio of some systems designed to enable continued operation with a fault to earth on one phase, the voltage on the two sound phases will rise towards the phase-to-phase voltage

Category A:

- Where earth faults are cleared as rapidly as possible but in any case within one minute.

Category B:

- This category comprises those systems which, under fault conditions, are operated for a short time only with one phase earthed. This period should, in general, not exceed 1 hour, but a longer period can be tolerated as specified in the relevant cable standard.

Category C:

- This category comprises all systems which do not fall into categories A or B.
- In addition, the cable standards recommend cables of the same nominal voltage ratings for both category A and B systems.
- In most cable standards, the period for which cables are allowed to operate under category B conditions is extended up to 8 hours on any single occasion.
- When cables are expected to operate for longer periods with one phase earthed, cables of the next voltage higher should be specified, thus effectively increasing the insulation between phase conductor and earth.
- For paper insulated cables of the belted type, it is necessary only to increase the thickness of belt insulation to cater for category C systems.
- Designs are therefore provided for category C systems with voltage designations of 3.3/3.3 kV, 6.6/6.6 kV and 8.7/11 kV. The value of 8.7kV for the belted 11 kV category C system is chosen to provide consistency with the U0 value for screened 8.7/15 kV cables.

Design and Applications

22 kV and 33 kV cables

- 33 kV cables are widely used for distribution inpublic supply systems.
- XLPE insulated cables have had increasing use as an alternative to paper insulated types.
- The use of 22 kV cables for distribution in public supply is confined to the north-east they are used 33 kV cables used elsewhere.

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11 kV and 15kV cables

- 11 kV is the main distribution voltage between 240/415V and 33kV.
- Although 6.6kV systems were once common they have now largely been converted to 11 kV.
- The corresponding single-core cable, generally un-armoured, was used for short interconnectors or for very high currents requiring large conductors.

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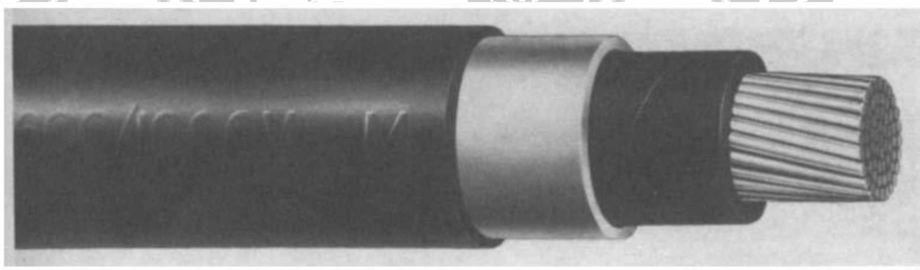
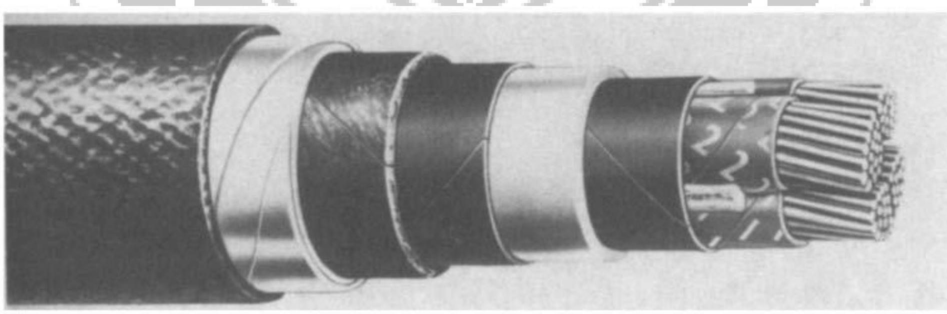
3.3 Paper Insulated Distribution Cables:

- The insulation consists of helically applied paper tapes with a small gap between turns
- The registration of tapes in relation to each other is important to avoid successive butt gaps in a radial direction
- When cables are bent for drumming and laying, the paper tapes have to slide over each other without undue creasing, wrinkling or tearing and are therefore applied with a gap between turns.
- For bending reasons the mechanical design requirements are as important as electrical aspects in relation to insulation thickness, certainly for low voltage cables.
- These mechanical requirements cover such features as the angle and lapping tension during paper application
- The conductors in multicore cables are usually sector shaped up to 11 kV and oval for 33 kV. Solid aluminium is used extensively at 1 kv



Belted construction:



- The cable design with a 'belt' of insulation over the laid-up cores is the most economical in terms of total material cost. Such cables are nearly always used up to 6.6 kV and are the most common type at 11 kV.
- The spaces between the cable cores under the belt are filled with jute or paper.
- the main insulation consists of paper tapes precisely applied, the filler insulation has to be softer and less dense so as to be compressed into the space available and is weaker electrically.
- Stresses in the fillers have to be limited to an acceptable level and therefore belted cables are not generally used at voltages greater than 11 kV.

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3.4 PVC Insulated Cables

- Paper insulated cables were being used for industrial distribution and as fully impregnated non-draining paper had not then been completely accepted it was necessary to adopt some form of limitation of the amount of impregnating compound in the cable to minimise compound drainage problems.
- This caused either reduction in quality or increased insulation thickness.
- The use of PVC provided cables of excellent quality which were clean and much easier to handle.
- A particular feature of the early development was associated with the fact that, where as wiring cables have circular conductors, the conductors of power cables were sector shaped and the larger sizes pre-spiralled.
- Shaped-solid aluminium conductors had emerged as a strong competitor to copper at the same time.
- The use of shaped dies to extrude PVC to the profile of the conductor presented great concentricity problems which led to the 'float-down' or 'tubing-on' extrusion technique.
- This involves extruding the PVC as an oversize circular tube which is drawn to a snug fit on the conductor by a combination of vacuum and controlled conductor/extrusion speeds.

Applications:

- Especially as PVC from the outset had to compete with impregnated paper, the most important factor to be taken into account was the amount of softening at raised temperatures due to its thermoplastic nature.
- This can result in deformation of the insulation due, for example, to conductor thrust at bends. Paper cables will withstand fairly high short time
- overloads and consequently the fuse co-ordination does not need to be particularly refined.
- PVC cables need adequate protection against overload or alternatively a reduced rating has to be assigned to them

Industrial cables:

- Industrial usage covers distribution in and around factories at voltages up to 3.3 kV.
- PVC cables have been almost universally used throughout the world since around 1960 and over current protection does not present any serious problem.
- In the UK the conductors have been stranded copper or solid aluminium.

Public supply:

- Apart from house service cables, PVC has not been used for public supply in the UK because of the over current protection problem. Normal distribution systems provide little or no protection for the cables, e.g. two electricity supply companies operate with a solid.
- This is not so in many other countries and there has been widespread use of PVC.

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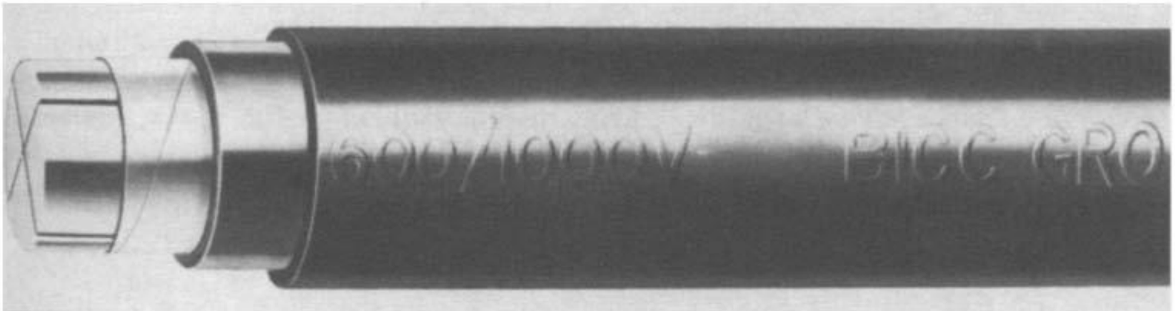

Coal mining:

- Much power cable is used for fixed installation along underground roadways to take the supply from a main colliery shaft to the working face.
- Because the point of use is constantly changing, the individual cable lengths are fitted with couplers to enable the distribution system to be moved around as required.
- In the UK the standard voltages are 3.3 kV and 6.6 kV, with some requirement at 11 kV.

High voltage cables:

- Reference to the use of PVC for HV cables is made in a later section.

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3.5 Polymeric Insulated Distribution Cables for 6-30 kV

- In the 6-30 kV cable range there has been a world-wide swing away from paper to polymeric insulation for distribution cables.
- In the UK, in terms of usage, the scale of change has been smaller and its speed slower than in many other countries but, because much of the UK cable is made for export.
- The pattern of manufacture has moved substantially towards an increased proportion of cable with polymeric insulation.
- Trends in the comparative costs of the cables themselves can be expected to have influenced the change, but another factor is that it has become increasingly difficult to secure, at reasonable cost, the skills required to joint and terminate the traditional paper cable.
- This is especially the case in the less developed countries.

Field Of Use:

- Initially the thermoplastic polyethylene insulation was the most popular with many kilometers of cable installed in Germany.
- HDPE has superior electrical properties to LDPE but is more rigid; HDPE is more crystalline than LDPE and thus capable of operating at a higher temperature and it has been assigned a sustained rating of 80°C, in comparison with 70°C for LDPE.
- Its saturation moisture content is approximately a fifth of that of low density materials; nevertheless, its greater stiffness has mitigated against its wider acceptance.
- Generally the use of EPR has been confined to those applications where its property of greater flexibility can be used to advantage, but in Italy and Spain EPR has been used widely throughout the voltage range.
- Although 132kV cables have been manufactured with EPR, the higher loss angle and poorer thermal resistivity make it a poor competitor against XLPE at higher voltages.
- While EPR has excellent resistance to ozone and electrical discharges and the material was for this reason preferred to PE during the 1960s, changes in manufacturing techniques have led to a reduction in discontinuities and size of voids within PE cables to such an extent that advantage can no longer be taken of this positive characteristic.

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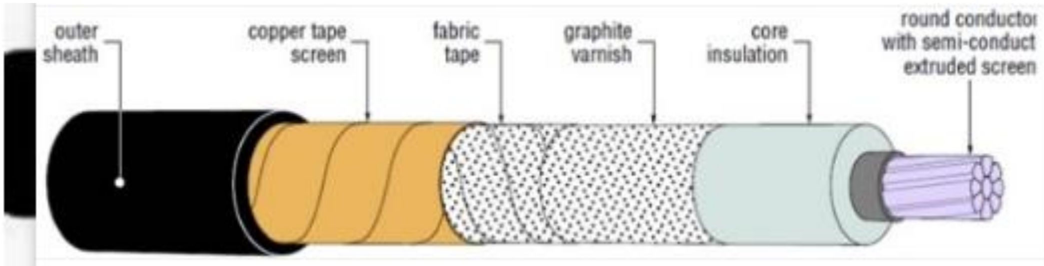
4.1 Pressurized Paper Insulated Cable



- Over the years a large variety of cables with pressurized insulation have been developed and put into service.
- Two designs, both fluid-filled, one at low pressure and one at high pressure, now account for the vast majority of new installations throughout the world.
- Using gas pressures still find some application and it is convenient to divide designs into groups.
- Each group may in turn be split into self-contained designs with lead or aluminium sheath and designs in which the cable is pulled into a pre-installed steel pipe, the pipe being subsequently filled with the pressurizing medium of insulating liquid or gas.
- They also have potential for use at 750 kV and 1000 kV. Gas-pressurised cables, however, are limited to 132 or 275 kV according to design and this is associated with somewhat inferior electrical breakdown strength.

Fluid-filled cables:

- There can be some confusion about the interpretation of the generic description of a fluid-filled (FF) cable and, in particular, the coupling of the term 'low pressure' with it.
- In general, when no other description is given, FF cable is taken to mean a self contained cable which operates at a maximum static sustained pressure of 5.25 bar with transient pressures up to 8 bar.
- This is the conventional cable which has very wide usage and is discussed in chapter 30.

Unreinforced sheath LPFF cable:

- use of a cable which operates at a pressure which is sufficiently low to be withstood by a specially alloyed lead sheath having no reinforcement.
- The pressure has therefore to be kept below 1 bar, which limits its application to fairly flat routes.

Mollerhoj cable:

- Type of cable which has been used in Denmark at voltages up to 132kV.
- It is a truly self-contained cable because after the installation has been completed the ends are sealed and there are no feed tanks.
- The cores are laid side by side in fiat formation under a lead sheath.

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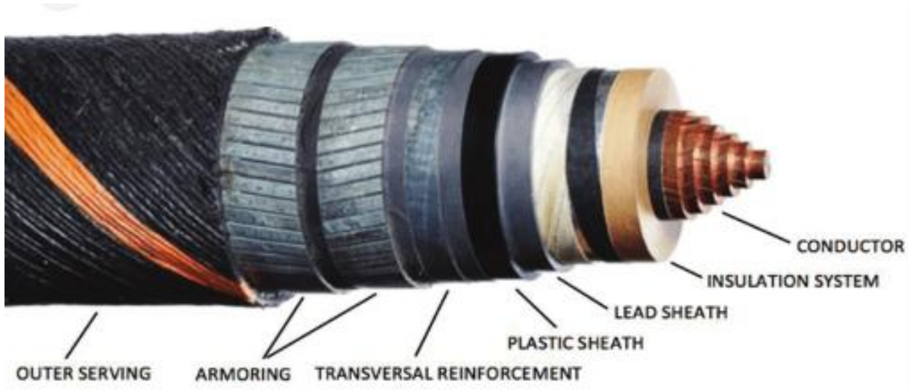
4.2 Self-contained Fluid-filled Cables:



- The fluid-filled cable is the most widely used type of transmission cable throughout the world and for a long time in the UK has been the only design used for new installations at 275 kV and 400 kV.
- Originally known as the oil-filled cable, the name was changed to fluid-filled to take into account the fact that the most widely used impregnants today are synthetic fluids.
- This is still so today with a capability to meet future requirements for 750 kV and 1100 kV cables, l together with further up-rating of 400 kV overhead lines.

Cable Design Features:

Construction:

- The standard design consists essentially of copper or aluminium conductors, paper insulation and an aluminium or reinforced lead sheath designed to withstand a sustained internal pressure up to 5.25 bar, with transient pressures up to 8 bar.
- In general, higher pressures might enable economies to be obtained in fluid feeding arrangements but would usually be insufficient to justify the associated increase in the cost of cable and accessories.
- The basic concept is one of full impregnation of the whole of the insulation at all times by a low viscosity hydrocarbon fluid under pressure.
- As temperature rises, the surplus fluid due to expansion is forced out of the cable into storage tanks and reverse flow takes place on cooling.
- The cable is filled with fluid at the time of impregnation and sheathing and is subsequently kept in this condition throughout its life.
- To avoid the need for numerous stop-joints in such applications, the cable sheath has to be reinforced to withstand the hydrostatic pressure, in the above case 30 bar, and the cable needs to be partially drained under vacuum to control the flow during jointing at the lower end.
- Ducts to provide channels for fluid flow have to be incorporated in the cable design and are indicated.

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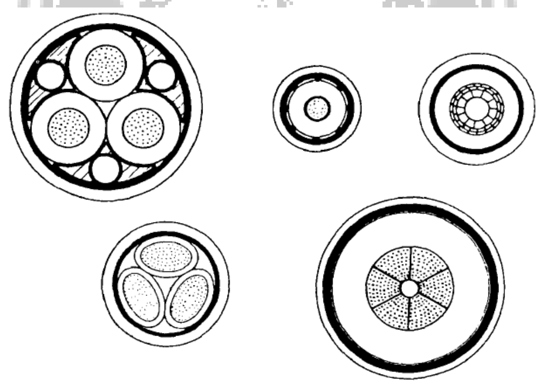
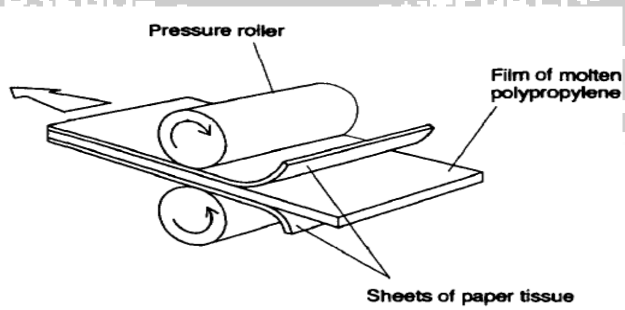
- For single-core cables a duct is normally included in the centre of the conductor, although for the short cable lengths which are used as terminations for 3-core cables the fluid channel may be on the outside of the insulation.
- For 3-core cables having fillers between the cores, the duct is formed by the use of an open helix of steel or aluminium strip incorporated into the filler.
- The normal size range comprises single-core cable with conductors from 120 to 2500 mm 2 and 3-core cables from 120 to 630 mm 2, although at 33 kV the range extends downwards to 70 mm 2.
- The former general practice to strand circular wires around an open steel spiral duct to form a hollow centre in single-core conductors now only applies for sizes of 150 mm 2 and below.
- Instead, a self-supporting ring is formed from segmental wires and this may form the basis for additional layers of circular wires, flat strips or segments applied with alternating direction of lay.
- Compared with paper, the benefit of the lower dielectric loss angle and lower permittivity on the current rating.
- It can be seen that at a voltage of 1100 kV there is still a useful current capability and that there are significant increases down to about 220kV.





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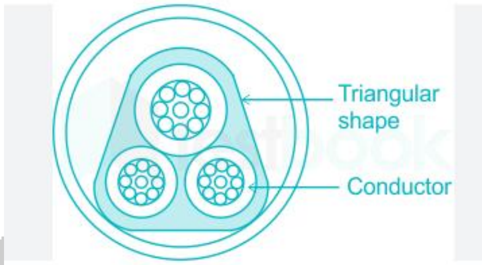
4.3 Gas Pressure Cables:



- There are two basic types of paper insulated gas pressure cables, one type employing gas within the dielectric to suppress ionization, and other type applying gas pressure external to a diaphragm to maintain the dielectric under compression under all service conditions.
- Cable types which employ a gas pressure external to the diaphragm are the gas compression cables and the high pressure gas-filled (HPGF) pipe type cable.

Internal Gas Pressure Cables:

- In this type of cable the insulation is saturated with nitrogen gas under a nominal pressure of 14 bar, which suppresses discharges which may otherwise have occurred in any cavities within the insulation.

i) Mass impregnation of the dried paper insulation with a viscous impregnant

ii) The application of paper tapes pre-impregnated with a petroleum jelly type of compound

- The early designs of mass-impregnated cable were known as the impregnated pressure (IP) cable and the first commercial installation
- Problems were encountered as a result of gas absorption by the impregnating compound, which caused frothing when the cable was being degassed, sometimes

causing a blockage in the gas pipes or in the annulus below the metal sheath.

- Because of these problems and the improvements made in the self contained fluid-filled cable, commercial applications ceased at the end of the early
- The application of the pre-impregnated paper tapes follows standard dry paper

lapping techniques, but as the core does not need to be dried and impregnated after the insulating process, the papers are dimensionally stable and the original lapping tensions

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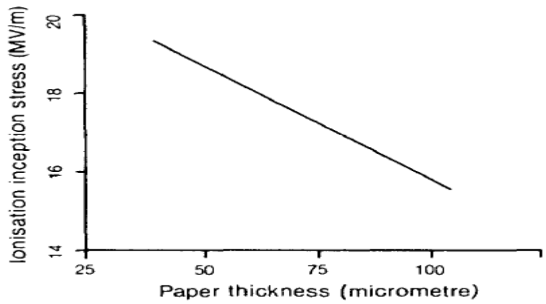

External Gas Pressure Cables:

- The gas compression cable 6 is designed to facilitate the use of high electrical stresses by maintaining the dielectric in the fully impregnated state under all service conditions by the application of gas pressure external to a diaphragm sheath to prevent void formation within the dielectric.
- It was first introduced as a self-contained cable, the gas pressure being applied between a diaphragm lead sheath applied directly over the cable and an outer reinforced gas retaining lead sheath.
- Oval shaped stranded conductors are used for single cores.
- The conductor is usually screened with carbon loaded paper tapes and insulated with paper tapes and the core is screened with metallised paper or non-ferrous metal tapes.
- The single-core or 3-core cable is dried and impregnated in a conventional cable vessel, the impregnant being a viscous compound.

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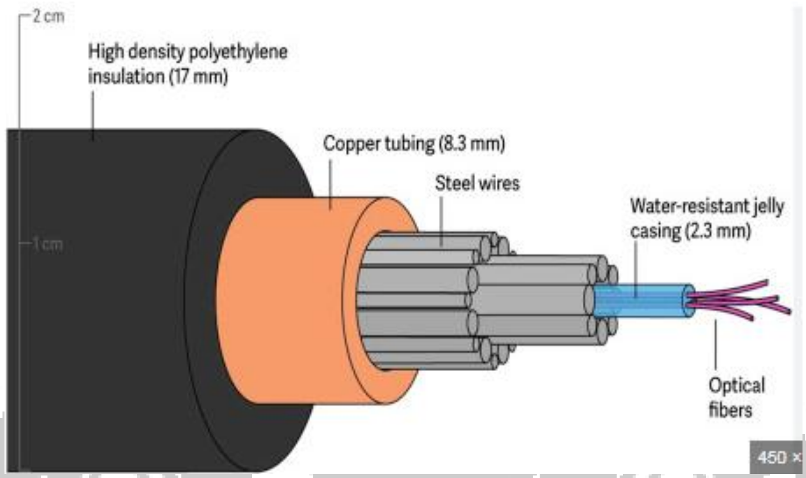
4.4 High Pressure Fluid-filled Pipe Cables



- pressure fluid-filled (HP FF) pipe type cables are used mainly in North America.
- The three insulated conductors are drawn into a steel pipe which is subsequently filled with liquid and maintained under a high pressure.
- The basic principle of the HP FF cable is the same as that of the self-contained fluid filled (SC FF) cable, i.e the insulation is kept fully impregnated at all times.
- To reduce drainage of fluid from the insulation during transit from the factory to site, the cable is impregnated with an impregnant which has a much higher viscosity than that used for the SC FF cable.
- HP FF cables are at present in operation at voltages up to 550 kV (former USSR), 1 but the amount at the maximum voltage is very limited and the highest voltage at which significant quantities of cable have been installed is 345 kV (New York, USA). 2 Cables have been developed for 765 kV operation.

Conductors:

- Both aluminium and copper conductors are used up to a maximum conductor size of approximately 1250 mm .
- Larger sizes are generally not economic because the closeness of the cores in the pipe gives rise to a high proximity loss in the conductor which significantly increases the a.c. resistance

Insulation:

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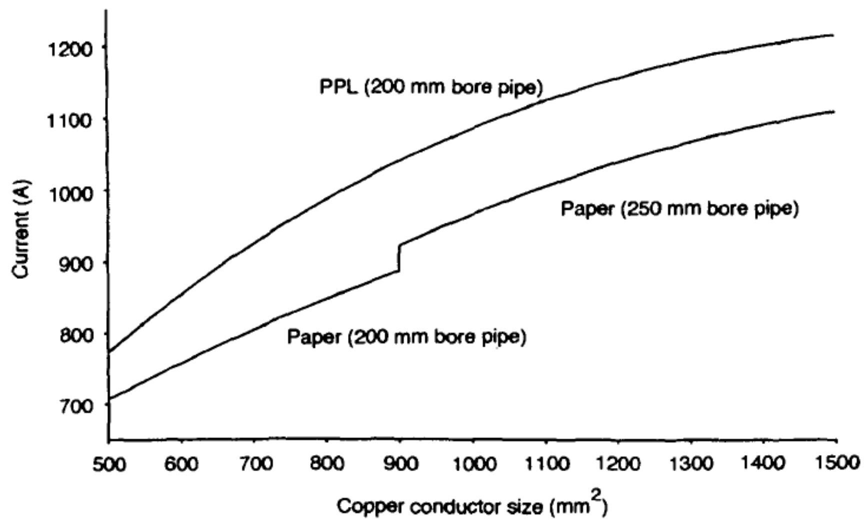
- The requirements for the insulating papers and lapping are generally similar to those already described for SC FF cables. However, in the case of HP FF cables there is an additional requirement for a very firm insulation to minimise deformation due to the side pressures which occur during installation, as previously mentioned.



- The electrical characteristics are similar to those of SC FF cable insulation.

Steel Pipe And Installation:

- The pipes are made of carbon steel complying with appropriate national standards for thickness and testing requirements.
- The size is chosen to permit adequate clearance between the three cores and the pipe.
- It is important to avoid an internal diameter of the pipe of about three times the diameter of the individual cores as it is possible for the cores to align across a diameter and jam during the pulling-in operation.
- A requirement of great importance is a need to have the internal surface smooth and clean so that on final filling with insulating fluid no serious contamination is introduced.

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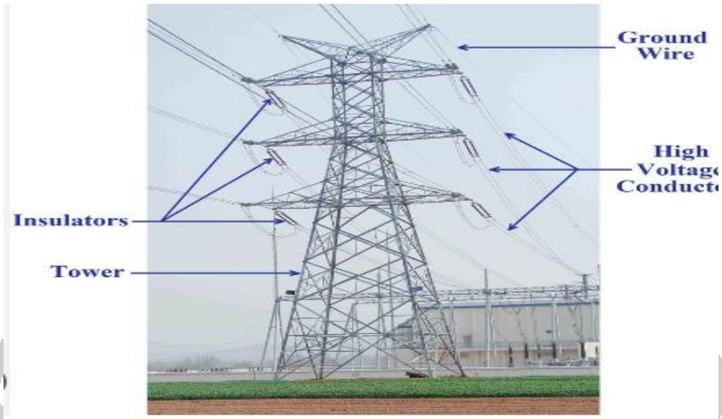
4.5 Polymeric Insulated Cables for Transmission Voltages:



- The operating electrical stresses for polymeric insulation are lower than for FF cables and the insulation thicknesses are therefore greater.
- This leads to the use of a greater volume of material in the cable and the absence of 3-core designs above 33 kV. One advantage is that there is no need for the auxiliary equipment required for pressure-assisted cable systems or for the same arrangements for system maintenance.

Insulating Materials:

- Thermoplastic (linear) polyethylene (PE) and cross linked polyethylene (XLPE) have been the most commonly used polymeric insulants, while ethylene propylene rubber (EPR) has had limited use up to 150 kV.
- The low dielectric losses of polyethylene, both PE and XLPE, make it an attractive proposition at 220 kV and above. The importance of dielectic losses in high voltage.
- This has a significant effect on the relative current ratings.
- XLPE insulated cables are therefore preferred in most countries and are by far the most widely used type of polymeric cable.
- The manufacturing process for PE is simpler, without the complications of cross linking.

Design Of Polymeric Cables:

- As XLPE insulation is by far the most widely used polymeric material it is intended to concentrate on the design aspects of this type of cable**.** However, many of the areas covered apply equally to cables with LDPE, HDPE and EPR insulation.

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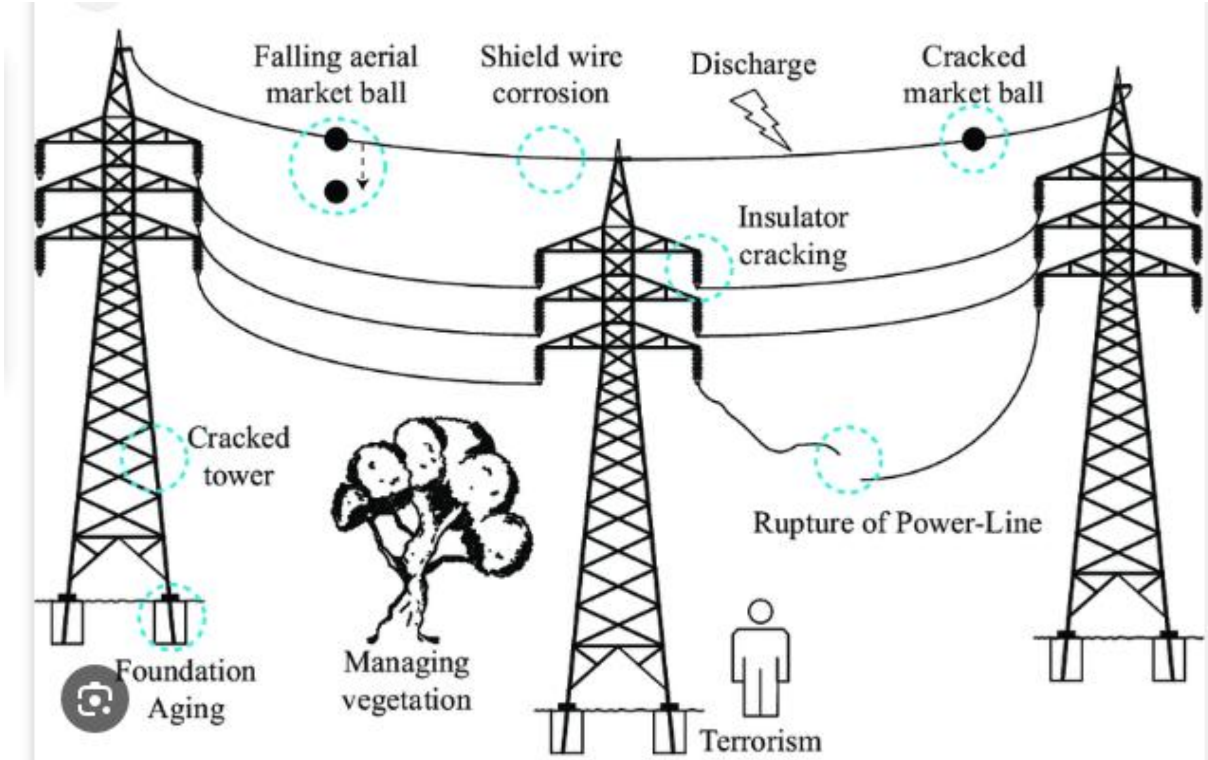
5.1 Installation of Transmission Cables:



The installation situations in which cables are used at transmission voltages fall into five main categories:

(a) For the interconnection of substations within urban areas where the use of overhead transmission is neither environmentally acceptable nor practical.

(b) To form part of a circuit in rural areas where the use of an overhead line is environmentally unacceptable.

(c) To span obstructions within a circuit, such as bridges, rivers, estuaries and in some cases towns.

(d) To replace overhead line connections in the vicinity of a new substation or power station, thereby improving the overall environmental acceptability.

(e) Inside power stations or substations to provide more compact and less obtrusive connections than bus bar or overhead lines.

- The first category is the most common for transmission cable, although most of the considerations discussed below apply to each group.
- Some interesting trends in installation techniques are emerging.

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- Thereby avoiding the problems of route planning and of disruption to vehicular traffic.
- In rural areas the trend is to develop methods of mechanical trenching and cable laying, thereby reducing the cost disadvantage of cables to overhead lines.
- Owing to the high cost per unit length of the transmission cable and the great diversity of types and sizes manufactured, it is relatively rare for a manufacturer to be able to supply any new requirements from stock.
- The more commonly used approach is first to determine and clear a substantial part or preferably all of the cable route.

(a)local restrictions on the length of continuous trench that can be opened;

(b) manufacturing length;

(c) transportable length on one drum;

(d) handling limitations at the site of installation;

(e) induced voltage in the cable sheath;

(f) balancing of minor section lengths on cross-bonded systems;

(g) positioning of joint bays.

In fluid-filled cable installations, the need to install stop joints instead of simple straight through joints is identified and all the materials are then put into manufacture, each drum of cable being manufactured to a specific predetermined length.

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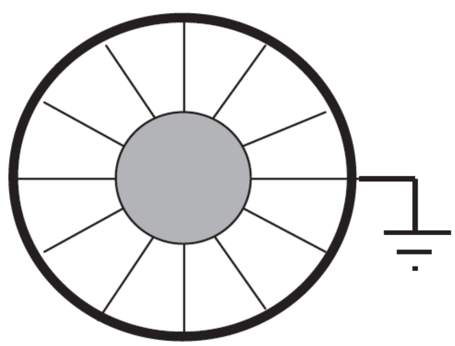
5.2 Splicing, Terminating, and Accessories:

Termination Theory

- The electric fields in a cable, splice, or termination are depicted in two ways.
- These lines radiate outward from the center of the conductor toward the grounded shield.
- The lines are closer together near the conductor, which demonstrates the fact that the electric stress is higher near the conductor.
- The lines get farther apart near the shield and this shows that the voltage stress is lower near that area.
- These lines are at right angles to the flux lines described previously.
- This shows that the voltage difference for a given distance from the conductor is greater there than the same spacing near the shield.

Purpose of a Termination:

- A termination is a way of preparing the end of a cable to provide adequate electrical, mechanical, and environmental properties.
- A discussion of the voltage distribution at a cable termination serves as an excellent introduction to this subject.



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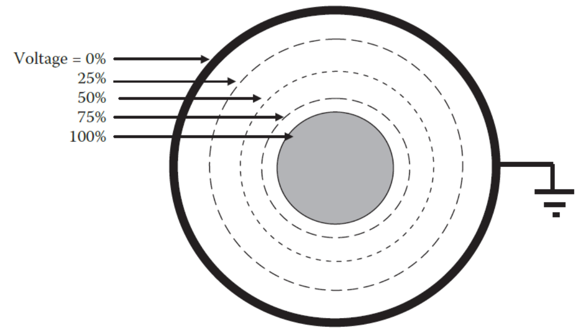
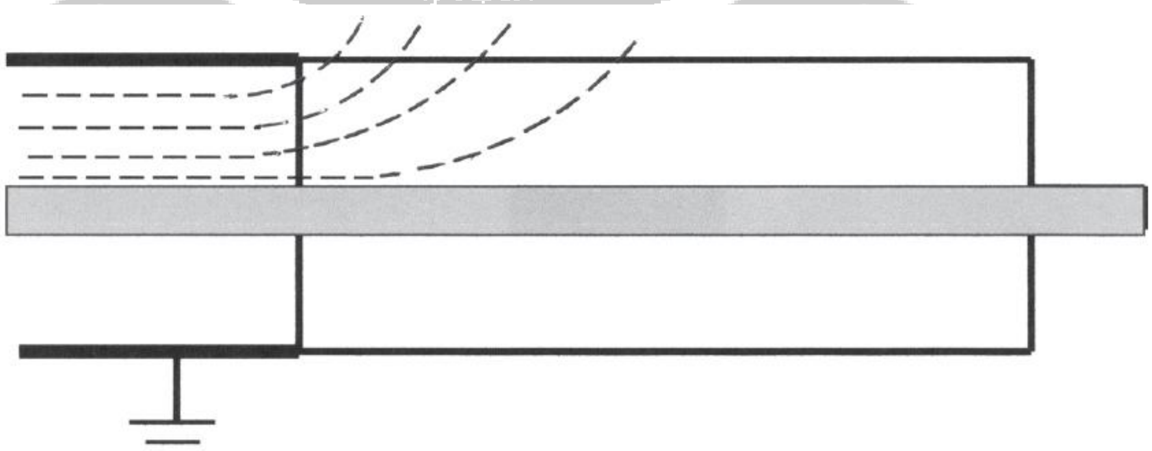


- Whenever a medium or high voltage cable with an insulation shield is cut, the end of the cable must be terminated so as to withstand the electrical stress concentration that is developed when the geometry of the cable has changed
- Whenever a medium or high voltage cable with an insulation shield is cut, the end of the cable must be terminated so as to withstand the electrical stress concentration that is developed when the geometry of the cable has changed.
- As long as the cable maintains the same physical dimensions, the electrical stress will remain consistent.
- When the cable is cut, the shield ends abruptly and the insulation changes from that in the cable to air.
- The concentration of electric stress is now at the end of the conductor and insulation shield.



- To produce a termination of acceptable quality for long life, it is necessary to relieve voltage stresses at the edge of the cable insulation shield.

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- The conventional method of doing this has been with a stress cone.
- A stress cone increases the spacing from the conductor to the shield.
- This spreads out the electrical lines of stress as well as provides additional insulation at this high stress area.
- The ground plane gradually moves away from the conductor and spreads out the dielectric field—thus reducing the voltage stress per unit length.
- The stress relief cone is an extension of the cable insulation.
- Environmental conditions play a significant role in the length of a termination.
- The total distance across any termination defines its leakage distance. A termination with skirts has a creep age distance that includes the whole surface from ground to the energized portion.

Voltage Gradient Terminations:

- Electrical stress relief may come in different forms.
- A high permittivity material may be applied over the cable end
- material may be represented as a long resistor connected electrically to the insulation shield of the cable.

Cold shrink termination with skirts.

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5.3 Sheath Bonding and Grounding:

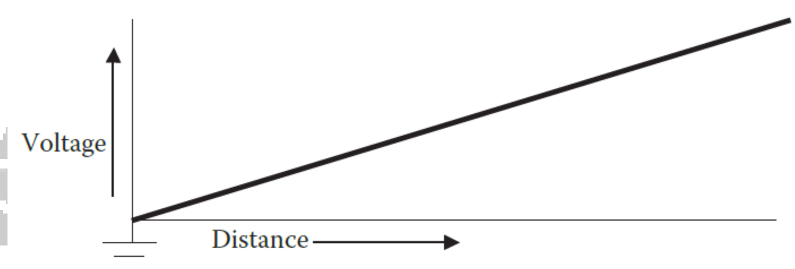
- This discussion provides an overview of the reasons and methods for reducing sheath losses in large cables.
- Sheath refers to a water impervious, tubular metallic component of a cable that is applied over the insulation.
- Shield refers to the conducting component of a cable that must be grounded to confine the dielectric field to the inside of the cable.

Cable A Transformer:

- When alternating current flows in the "central" conductor of a cable, that current produces electromagnetic flux in the metallic shield when present, or in any parallel conductor.
- This becomes a "one-turn" transformer when the shield is grounded two or more times since a circuit is formed and current flows.

We will first consider a single, shielded cable:

If the shield is only grounded one time and a circuit is not completed, the magnetic flux produces a voltage in the shield. The amount of voltage is proportional to the current in the conductor and increases as the distance from the ground increases



Single-point grounding.

Sheath Bonding and Grounding

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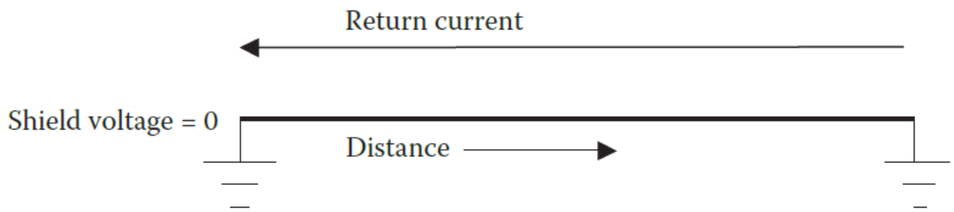
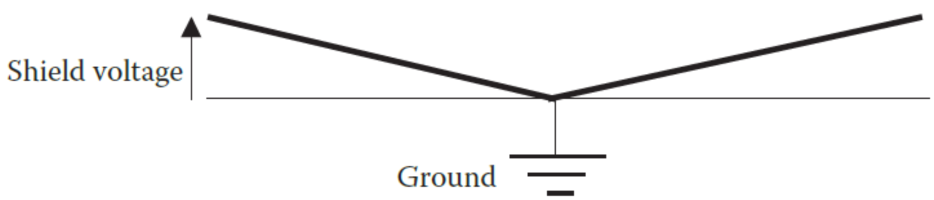


- If the shield is grounded two or more times or otherwise completes a circuit, the magnetic flux produces a current flow in the shield. The amount of current in the shield is inversely proportional to the resistance of the shield.
- The voltage remains at zero, but the same current flows regardless of the distance between the grounds.
- An important concept regarding multiple grounds is that the distance between the grounds has no effect on the magnitude of the current.

AMPACITY:

- If the heat generation in any segment is decreased, such as in the sheath, then the entire cable will have a greater ability to carry useful current.
-



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5.4 Testing of Transmission Cable Systems:

The testing of transmission cable systems is dictated primarily by international, national and user specifications with procedures grouped into five categories:

(a) routine tests on cables and accessories;

(b) special (sample) tests on cables requested by the purchaser;

(c) prequalification tests for XLPE cable and accessories;

(d) type tests on cables and accessories;

(e) site tests on systems after installation.

- Electricity Boards for cables of the paper and PPL insulated type, primarily self-contained fluid-filled cables and cables with polymeric insulation for system voltages of 33 kV and above for non-submarine use.

Paper And Polypropylene Paper Laminate (PPL) Cables:

- Most specifications require electrical tests along the lines illustrated below for fluid filled (FF) cables.
- The DLA is measured at ambient temperature and corrected to 20°C. The voltage range is from U0 to 2U0 for cables up to a U0 of 87 kV and 1.67U0 for higher voltage cables.

Table 39.1 Test voltage and DLA for FF cables

Cable voltage (U_0/U) (kV)	Highest voltage for DLA test (kV)	Maximum DLA				Maximum difference in DLA from U_0 to highest voltage $\times 10^{-4}$		A.C. withstand test (kV)
		$U_0 \times 10^{-4}$		Highest voltage $\times 10^{-4}$				
		Paper	*PPL*	*Paper*	*PPL*	*Paper*	*PPL*	
19/33	38	35	–	43	–	10	–	53
38/66	76	35	–	43	–	10	–	86
76/132	152	33	–	40	–	8	–	162
160/275	230	30	14	34	16	5	4	275
230/400	385	28	14	31	16	4	4	395

- The DLA and high voltage tests for gas-compression and gas-filled cables are carried out at any gas pressure up to 2bar. These cables normally operate at a pressure of approximately 14bar and, as the reduced pressure is not representative of normal service conditions, the test voltages are accordingly reduced.

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