1. Underground Cables

The power transmission achieved through cables that are laid underground are called Underground Power Cables. Though the installation cost of these cables is high, it is considered reliable.

An overhead lines can frequently been seen traversing the landscape from a long way away, while underground cables are employed where it is impracticable to use overhead lines, such around plants and substations or where maintenance conditions do not permit the use of overhead construction.

2. Construction of Cables

An **underground cable** essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.The main parts of underground cables are :

***(1) Cores or Conductors**:* The conductor of cable could be of aluminum or copper, cable may have one or more than one core depending upon the type of services for application . It may be:

a- Single Core as shown in fig 5-1 below.
b- Two Core.
c- Three Core as shown in fig 5-2 .
d- Four Core.

1. **Cable sheath** – Protects the cable, against moisture in particular
2. **Wire screen** – Controls the electric field and discharges fault currents
3. **Insulating layer** – Insulates the electric conductor
4. **Electric conductor** – Conducts the current

Fig 5-1 construction of underground cable single core

(2) 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.

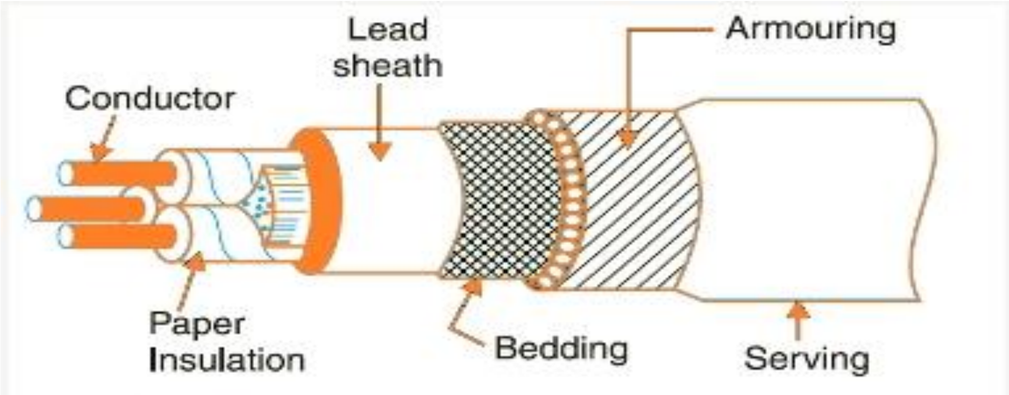


Fig. 5-2 construction of underground cable three core

(3) ***Metallic sheath***: In order to protect the cable from moisture, gases or other damaging liquids in the soil and atmosphere, a metallic sheath of lead or aluminum is provided over the insulation as shown in Fig. 5-2.

(4) *Bedding:* Over the metallic sheath is applied a layer of bedding which consists of a fibrous material , the purpose of bedding is to protect the metallic sheath against corrosion and from mechanical damage.

(5) *Armouring:* Over the bedding, armouring is provided which consists of one or two layers of galvanized 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.

(6) *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.*

3. Classification of underground cables

The underground cable are classified according to voltage capacity and the construction of cable.

(A) Voltage Capacity as shown in fig 5-3 below

- LT Cables :Low tension cables with maximum capacity of 1000 V.
- HT Cables :High tension cables with maximum capacity of 11KV.
- ST Cables :Super tension cables with rating capacity of 22KV- 33KV.
- EHT Cables :Extra High tension cables with rating capacity of 33KV- 66KV.
- Extra Super voltage cables: with maximum voltage rating beyond 132KV.

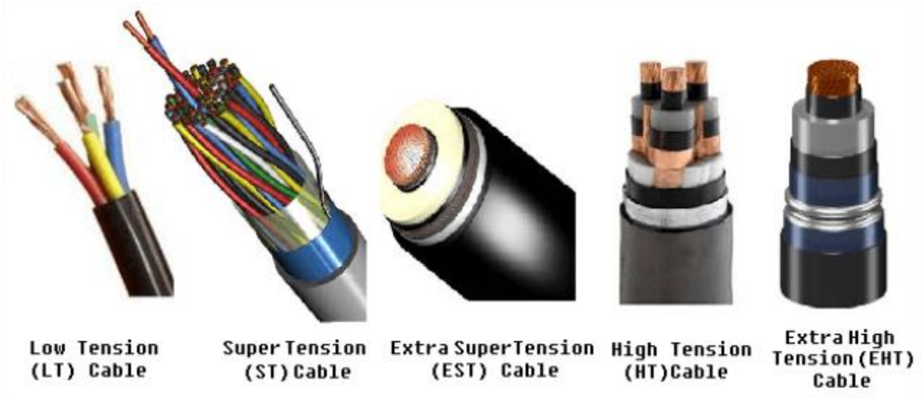


Fig 5-3 underground cables according to voltage rating

(B) Construction of cable

- Belted Cables : Maximum voltage of 11KV.
- Screened Cables : Maximum voltage of 66KV.
- Pressure Cables : Maximum voltage of more than 66KV.

4. Lying of underground cables

There are three main methods of lying underground cables:

1. Direct laying

- This method of laying underground cables is simple and cheap and is much favored in modern practice.
- In this method, a trench of about 1·5 meters deep and 45 cm wide is dug. The trench is covered with a layer of fine sand .
- the cable has been laid in the trench, it is covered with another layer of sand of about 10 cm thickness. The trench is then covered with bricks and other materials in order to protect the cable from mechanical injury.
- When more than one cable is to be laid in the same trench, a horizontal or vertical inter axial spacing of at least 30 cm s provided in order to reduce the effect of mutual heating and also to ensure that a fault occurring on one cable does not damage the adjacent cable.

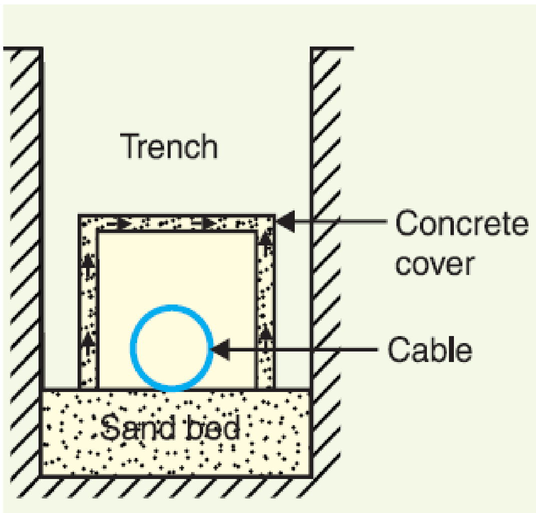


Fig. 5 – 4 Direct Lying of underground cables

2. *Draw in System*

- In this method, conduit or duct of glazed stone or cast iron or concrete are laid in the ground with manholes at suitable positions along the cable route.
- The cables are then pulled into position from manholes. Fig. 5-5 shows section through four-way underground duct line.
- This method is generally used for short length cable routes such as in workshops and road crossings .

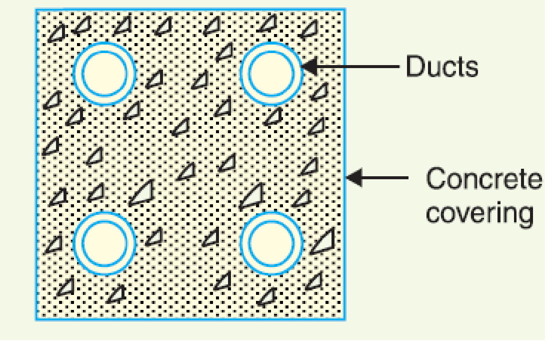


Fig 5 - 5 Draw in system

3. *Solid System*

- In this method of laying, the cable is laid in open pipes or troughs dug out in earth along the cable route. The troughing is of cast iron, stoneware, asphalt or treated wood.
- After the cable is laid in position, the troughing is filled with an asphaltic compound and covered over.
- Cables laid in this manner are usually plain lead covered because troughing affords good mechanical protection.
- This method is more expensive than direct laid system, but it provides good mechanical strength.

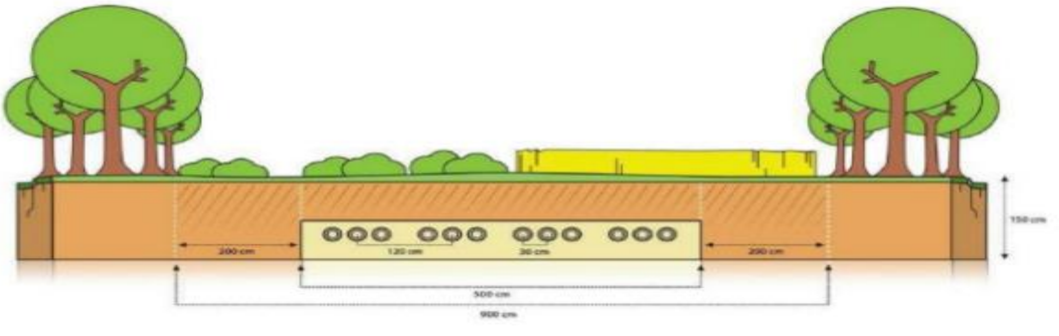


Fig 5 - 6 Solid system

A comparison between underground cables and overhead T.L

1. Construction

Underground cables are more expensive , Construction of the cables is more complicated compared to the overhead cables which are simple to construct, and do not require insulation and sheathing. The overhead cables have lesser requirements and cheaper to construct.

2. Size of Conductors

Underground cables have larger conductor sizes compared to overhead lines for the same amount of power. This is due to the fact that the overhead lines have a natural cooling and hence the ability to carry more power without heating up.

3. Voltage carrying capacity

The overhead lines are better suited to carry higher voltages compared to the underground cables, which are limited by the expensive construction and limited heat dissipation. For these reasons, the underground cables are mostly used for transmitting up to 33KV.

4. Fault detection and repair

It is easier to detect and repair faults in overhead cables. It is more complicated and takes more time to locate and repair the underground systems.

5. Public safety

Underground cables are safer to the public, animals and environment compared to the overhead lines i.e. there are no issues such as people getting in contact with fallen lines.

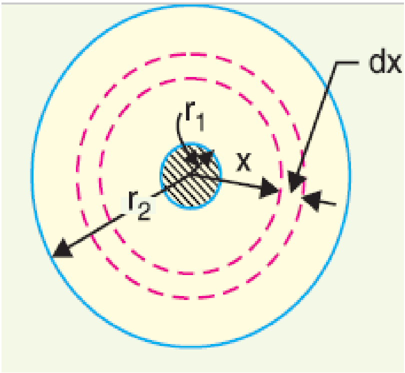
6. Interference

Overhead lines interfere with communication lines that are in close proximity, have corona discharge, radio and TV interference which does not happen with the underground lines.

7. Voltage drop

There is more voltage drop in the overheads due to the fact that their cables are of much smaller diameter than underground cables for the same power delivery.

Insulation Resistance of a Single-Core Cable



The cable conductor is provided with a suitable thickness of insulating material in order to prevent leakage current. The path for leakage current is radial through the insulation. The opposition offered by insulation to leakage current is known as insulation resistance of the cable. For satisfactory operation, the insulation resistance of the cable should be very high.

Fig 5 - 7 single core cable

Consider a single-core cable of conductor radius *r*1 and internal sheath

radius *r*2 as shown in Fig.5-7. Let *l* be the length of the cable and ρ be the resistivity of the insulation. Consider a very small layer of insulation of thickness *dx* at a radius *x*. The length through which leakage current tends to flow is *dx* and the area of X-section offered to this flow is 2π *x l*.

$$= \rho \frac{dx}{2\pi\, x\, l}$$

Insulation resistance of the whole cable is

$$R = \int_{r_1}^{r_2} \rho \frac{dx}{2\pi\, x\, l} = \frac{\rho}{2\pi l} \int_{r_1}^{r_2} \frac{1}{x} dx$$

$$\therefore \quad R = \frac{\rho}{2\pi\, l} \log_e \frac{r_2}{r_1}$$

This shows
that insulation resistance of a cable is inversely proportional to its length. In other words, if the cable length increases, its insulation resistance decreases and vice-versa.

Example 11.1. *A single-core cable has a conductor diameter of 1cm and insulation thickness of 0·4 cm. If the specific resistance of insulation is 5 × 10^{14} Ω-cm, calculate the insulation resistance for a 2 km length of the cable.*

Solution

Conductor radius, $r_1 = 1/2 = 0{\cdot}5$ cm

Length of cable, $l = 2$ km $= 2000$ m

Resistivity of insulation, $\rho = 5 \times 10^{14}\ \Omega\text{-cm} = 5 \times 10^{12}\ \Omega\text{-m}$

Internal sheath radius, $r_2 = 0{\cdot}5 + 0{\cdot}4 = 0{\cdot}9$ cm

∴ Insulation resistance of cable is

$$R = \frac{\rho}{2\pi l} \log_e \frac{r_2}{r_1} = \frac{5 \times 10^{12}}{2\pi \times 2000} \log_e \frac{0 \cdot 9}{0 \cdot 5}$$

$$= 0{\cdot}234 \times 10^{9}\ \Omega = \mathbf{234\ M\ \Omega}$$

Capacitance of a Single-Core Cable

A single-core cable can be considered to be equivalent to two long co-axial cylinders. The conductor (or core) of the cable is the inner cylinder while the outer cylinder is represented by lead sheath which is at earth potential.

Consider a single core cable with conductor diameter *d* and inner sheath diameter *D* (Fig. 5-8). Let the charge per meter axial length of the cable be *Q* coulombs and ε be the permittivity of the insulation material between core and lead sheath. Obviously $\varepsilon = \varepsilon_0 \varepsilon_r$ where ε_r is the relative permittivity of the insulation. Where $\varepsilon_0 = 8.84x10^{-12}\ F/m$

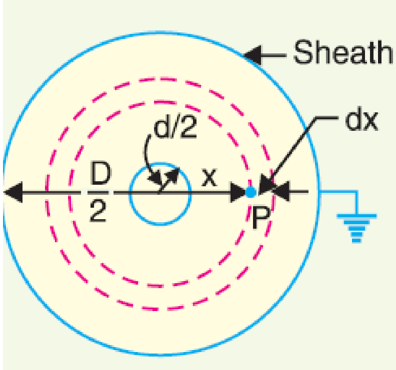


Fig. 5 -8

Consider a cylinder of radius *x* meters and axial length 1 meter. The surface area of this cylinder is $= 2\pi x \times 1 = 2\pi x\ m^2$

∴ Electric flux density at any point *P* on the considered cylinder is

$$D_x = \frac{Q}{2\pi x}\ \text{C/m}^2$$

$$\text{Electric intensity at point } P,\ E_x = \frac{D_x}{\varepsilon} = \frac{Q}{2\pi x \varepsilon} = \frac{Q}{2\pi x \varepsilon_0 \varepsilon_r}\ \text{volts/m}$$

The work done in moving a unit positive charge from point *P* through a distance *dx* in the direction of electric field is $E_x\,dx$. Hence, the work done in moving a unit positive charge from conductor to sheath, which is the potential difference *V* between conductor and sheath, is given by :

$$V = \int_{d/2}^{D/2} E_x\,dx = \int_{d/2}^{D/2} \frac{Q}{2\pi x \varepsilon_0 \varepsilon_r}\,dx = \frac{Q}{2\pi \varepsilon_0 \varepsilon_r} \log_e \frac{D}{d}$$

Capacitance of the cable is

$$C = \frac{Q}{V} = \frac{Q}{\frac{Q}{2\pi \varepsilon_0 \varepsilon_r} \log_e \frac{D}{d}}\ \text{F/m}$$

$$= \frac{2\pi \varepsilon_o \varepsilon_r}{\log_e (D/d)}\ \text{F/m}$$

$$= \frac{2\pi \times 8{\cdot}854 \times 10^{-12} \times \varepsilon_r}{2{\cdot}303 \log_{10} (D/d)}\ \text{F/m}$$

$$= \frac{\varepsilon_r}{41{\cdot}4 \log_{10} (D/d)} \times 10^{-9}\ \text{F/m}$$

If the cable has a length of *l* metres, then capacitance of the cable is

$$C = \frac{\varepsilon_r\, l}{41{\cdot}4 \log_{10} \frac{D}{d}} \times 10^{-9}\ \text{F}$$

Example 11.4. *A single core cable has a conductor diameter of 1 cm and internal sheath diameter of 1·8 cm. If impregnated paper of relative permittivity 4 is used as the insulation, calculate the capacitance for 1 km length of the cable.*

Solution.

$$\text{Capacitance of cable,} \quad C = \frac{\varepsilon_r\, l}{41{\cdot}4 \log_{10} (D/d)} \times 10^{-9}\ \text{F}$$

$$D = 1{\cdot}8\ \text{cm}; \qquad d = 1\ \text{cm}$$

Substituting these values in the above expression, we get,

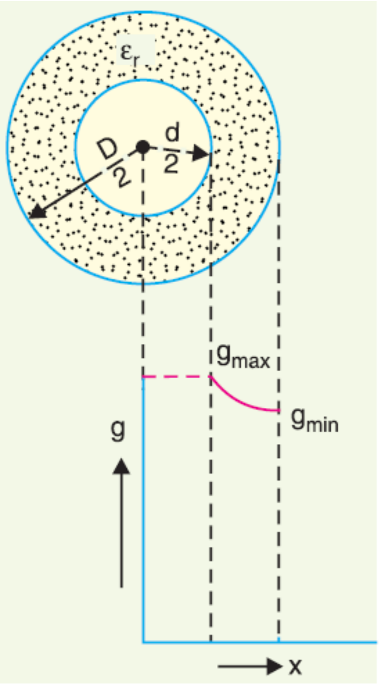
$$C = \frac{4 \times 1000}{41{\cdot}4 \log_{10} (1{\cdot}8/1)} \times 10^{-9}\ \text{F} = 0{\cdot}378 \times 10^{-6}\ \text{F} = \mathbf{0{\cdot}378\ \mu F}$$

Dielectric Stress in a Single-Core Cable

Under operating conditions, the insulation of a cable is subjected to electrostatic forces. **This is known as dielectric stress**.

Dielectric stress≡ potential gradient, g_x ≡ electric intensity, E_x at same point of cable.

Consider a single core cable with core diameter *d* and internal sheath diameter *D*. the electric intensity at a point *x* meters from the center of the cable is



$$E_x = \frac{Q}{2\pi\varepsilon_o\varepsilon_r x} \text{ volts/m}$$

By definition, electric intensity is equal to potential gradient. Therefore, potential gradient *g* at a point *x* meters from the center of cable is

$$g = E_x$$

$$g = \frac{Q}{2\pi\varepsilon_o\varepsilon_r x} \text{ volts/m} \qquad ...(i)$$

potential difference *V* between conductor and sheath is

$$V = \frac{Q}{2\pi\varepsilon_o\varepsilon_r}\log_e\frac{D}{d} \text{ volts}$$

$$Q = \frac{2\pi\varepsilon_o\varepsilon_r V}{\log_e\frac{D}{d}}$$

Substituting the value of *Q* from exp. (*ii*) in exp. (*i*), we get,

$$g = \frac{\frac{2\pi\varepsilon_o\varepsilon_r V}{\log_e D/d}}{2\pi\varepsilon_o\varepsilon_r x} = \frac{V}{x\log_e\frac{D}{d}} \text{ volts/m}$$

∴ Maximum potential gradient is

$$g_{max} = \frac{2V}{d\log_e\frac{D}{d}} \text{ volts/m} \qquad \text{[Putting } x = d/2 \text{ in exp. } (iii)]$$

Minimum potential gradient is

$$g_{min} = \frac{2V}{D\log_e\frac{D}{d}} \text{ volts/m} \qquad \text{[Putting } x = D/2 \text{ in exp. } (iii)]$$

$$\therefore \quad \frac{g_{max}}{g_{min}} = \frac{\dfrac{2V}{d \log_e D/d}}{\dfrac{2V}{D \log_e D/d}} = \frac{D}{d}$$

The variation of stress in the dielectric is shown in fig 5-8 above. It is clear that electric stress is maximum at the conductor surface and its value goes on decreasing as we move away from the conductor. It may be noted that maximum stress is an important consideration in the design of a cable.

Example 11.7. *A 33 kV single core cable has a conductor diameter of 1 cm and a sheath of inside diameter 4 cm. Find the maximum and minimum stress in the insulation.*

Solution.

The maximum stress occurs at the conductor surface and its value is given by;

$$g_{max} = \frac{2V}{d \log_e \frac{D}{d}}$$

Here, $V = 33$ kV (r.m.s) ; $d = 1$ cm ; $D = 4$ cm

Substituting the values in the above expression, we get,

$$g_{max} = \frac{2 \times 33}{1 \times \log_e 4} \text{ kV } \dagger\text{/cm} = \mathbf{47{\cdot}61 \text{ kV/cm}} \; r.ms.$$

The minimum stress occurs at the sheath and its value is give by ;

$$g_{min} = \frac{2V}{D \log_e \frac{D}{d}} = \frac{2 \times 33}{4 \times \log_e 4} \text{ kV/cm} = \mathbf{11{\cdot}9 \text{ kV/cm}} \; r.m.s$$

Alternatively ;

$$g_{min} = g_{max} \times \frac{d}{D} = 47{\cdot}61 \times 1/4 = \mathbf{11{\cdot}9 \text{ kV/cm}} \; r.m.s.$$