MRS.SRABANI CHAKRABORTY
LECTURER-JCGP

Learning Objectives

At the end of this chapter, the readers will be able to:

- Classify cables and understand their construction
- Conceptualize cable rating and derating factor of cables
- Discuss the methods of laying cables

INTRODUCTION

Sometimes, electrical power is generated at remote places where the cost of production of power is less. The power generated is required to reach various consumers at different locations. Hence, there is a need to transmit and distribute power. This can be achieved either by overhead system or underground cables. Underground cables are generally used at places where overhead system is difficult to install. Hence, in heavily populated areas such as cities and towns, the cables are laid below the ground surface. The definition of the underground cable can thus be written as: *The underground cable consists of one or more conductors* (*according to the service*) *which are covered by proper insulation* (*depending on voltage level for which it is used*) *and finally it is protected by protecting covers.*

4.1 CLASSIFICATION OF CABLES

There are numerous methods by which cables can be classified. They are listed as follows:

(i) Types of insulating material used in cables.
(ii) The voltage level for which they are made.
(iii) According to number of cores used in the cable.
(iv) According to construction.
(v) According to the sheath used in the cable.
(vi) According to armouring.
(vii) According to application or say use.
(vii) According to location.

4.1.1 According to the Type of Insulating Material

This classification is based on the insulating material used in the cable.

(i) Impregnated paper insulated cable
(ii) Vulcanized India rubber (VIR) cable
(iii) Vulcanized bitumen insulated cable
(iv) Cross-linked polyethylene (XLPE) cable
(v) Polyvinyl chloride (PVC) cable
(vii) Varnished cambric insulated cable

4.1.2 According to the Voltage Level

Cables are also classified according to the voltage levels as follows:

(i) Low tension (LT) cables can be used up to 1000 V
(ii) High tension (HT) cables can be used up to 11000 V
(iii) Super tension (ST) cables can be used between 22000 (22 kV) to 66000 V (66 kV)
(iv) Extra high tension cables (EHT) can be used between 33 kV to 66 kV
(v) Extra super voltage cables can be used beyond 132 kV

4.1.3 According to the Number of Cores used in the Cable

Following is the classification of cables according to the number of cores used:

(i) Single core cable
(ii) Double core cable
(iii) Three-core cable
(iv) Three-and-a-half $\left(3\frac{1}{2}\right)$ core cable
(v) Four-core cable

4.1.4 According to the Construction of Cables

Following is the classification of cables according to construction of the cables:

(i) Low tension cable
(ii) Belted cable
(iii) Screened cable or H-type cable
(iv) Separate lead sheath (SL) cable
(v) HSL cable
(vi) Pressure cable
 (a) Oil-filled cable
 (b) Gas-filled cable

4.1.5 According to the Sheath used in the Cable

Following is the classification of cables according to the sheath used:

(i) Lead sheath cable
(ii) Lead alloy sheath cable
(iii) PVC sheath cable
(iv) Aluminium sheath cable

4.1.6 According to Armouring

This classification is based on armouring:

(i) Single-layer steel wire armouring cable
(ii) Double-layer steel wire armouring cable
(iii) Double-layer steel tape armouring cable

4.1.7 According to Application

Following is the classification of cables according to their applications:

(i) **Control cable:** It is used for transmission of control signal.
(ii) **Fire-proof cable:** It used at hazardous locations.
(iii) **Power cable:** It is used in transmission lines.
(iv) **Co-axial cable:** It is useful for high-frequency, low-voltage, and low-current telecommunication applications over a long distance.
(v) **Trailing cable:** It is used for supplying power to the moving equipment such as lifts, cranes, and trolleys, etc.

4.1.8 According to Location

Following is the classification of cables according to their location:

(i) Underground
(ii) Submarine
(iii) Aerial

However, it is noted that voltage-level classification method is generally used.

4.1.9 Comparison between Cables and Overhead Lines

We know that power is transmitted and distributed by two methods, either by overhead system or by underground system. Generally, high-voltage transmission is carried out by overhead system because of low cost while underground system is used for distribution of the power in highly populated areas such as cities and towns. Both the systems have their own advantages and disadvantages. So the selection of the system is difficult because in some particular cases, the cost is the main consideration and in other cases, losses and efficiency are more important. A comparison between underground system and overhead system is given as under for more clarification.

Table 4.1 Comparison between Underground Cables and Overhead Lines

S. No.	Topic	Underground Cables	Overhead Lines
1	Damage because of lightning and storm	It is safe against storms and lighting. Hence it is more reliable system.	It is unsafe against storms and lighting. Hence is less reliable system.
2	Maintenance cost	Maintenance cost is low.	Maintenance cost is high.
3	Frequency of fault	Chances of fault are less because the cables are laid in the ground.	Chances of fault are more.
4	Voltage drop	Voltage drops are small because spacing between conductors is less and hence inductance is also less.	Voltage drops are high.
5	Appearance	It does not spoil the appearance. It is good looking.	Appearance is spoiled.
6	Location	It is generally used in populated areas where overhead line is not safe.	It can be used at any place.
7	Initial cost	Initial cost is high.	Initial cost is low.
8	Voltage level	It cannot be used over 66 kV because of insulation problem.	Insulation does not create any problems.
9	Flexibility	It is less flexible than overhead system.	More flexible than underground system because new conductor can be easily laid along with the existing conductors.
10	Public safety	The chances of the accidents are less because the cables are laid in the ground. Hence, it is safe.	More chances of accidents.
11	Value of charging current	Due to less spacing between the conductors, the capacitance is more and hence charging current is more.	The charging current is less.
12	Jointing	Jointing is very difficult in the cables. So tappings for load and service are not convenient.	Jointing is easy so that load tappings can be made easily.
13	Interference to other circuit	There is no interference effect to the communication circuits.	Communication circuit is interfered.
14	Size	Large sized conductors can be used in this system.	Small sized conductors are used in the overhead system.

4.2 CABLE CONSTRUCTION

The various parts of the cable are discussed here in detail. Figure 4.1 shows the construction of the three-conductor cable with its main parts.

4.2.1 Cores or Conductors

As mentioned earlier, according to the requirement and application the cable may consist of one, two, or three cores. For example, the cable shown in Fig. 4.1 is used for three-phase

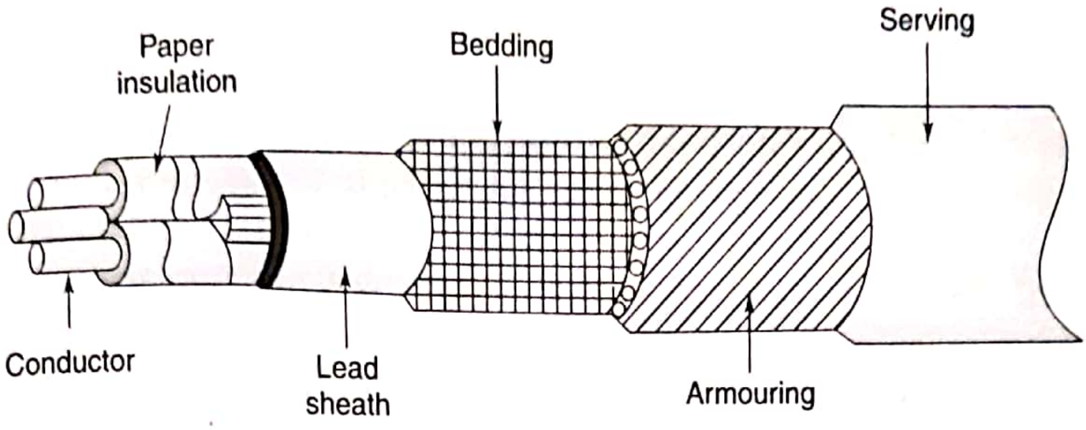

Fig. 4.1 Main Parts of the Cable

application. Generally, conductors are made of copper or aluminium. They are generally stranded to provide more flexibility.

4.2.2 Insulation

Insulation of proper thickness is provided on each core of the cable as shown in Fig. 4.1. The thickness of the insulation is determined by the voltage that needs to withstand the cable or voltage of the cable for which it is designed. Generally, impregnated paper, varnish cambric, or rubber mineral compounds are used for insulations.

4.2.3 Metallic Sheath

The underground cable is required to be protected from moisture, gases or other liquids of the soil and atmosphere. Therefore, metallic sheath of aluminium, or lead, or alloy is used over the insulation for the protection as shown in Fig. 4.1. A metal sheath is essential because no organic material is adequately moisture resistant. The main advantages of the lead sheath include easy-to-make, high-corrosion resistant, high flexibility, etc. Recently, aluminium is also used as sheath because of its low weight, low cost, easy to manufacture and higher mechanical strength compared to the lead alloy. Aluminium eliminates the use of armour usually required in lead sheath cables. Aluminium sheath can withstand the required gas pressure without reinforcement. Moreover, due to its greater conductivity, the aluminium sheath of low-voltage cables may be used as a neutral conductor. Hence, separate fourth neutral conductor is not required.

4.2.4 Bedding

A layer of bedding is provided over the metallic sheath to protect it from corrosion and mechanical injuries due to armouring. Generally, bedding consists of a paper tape which is compounded with fibrous materials such as jute or hessian tape. The compound used should be such that it does not react with the armouring material and lead sheath but at the same time it should be adhesive enough so that it sticks on, both to the lead sheath and armouring. Bedding is used in paper insulated lead-covered cables but not in polyvinyl chloride (PVC) cables.

4.2.5 Armouring

To protect the cable from mechanical injuries while laying and handling, armouring is provided over the bedding. Armouring consists of one or two layers of galvanized steel wire or strip as shown in Fig. 4.1. In some cases, armouring is not provided.

4.2.6 Serving

To protect armouring from environmental conditions, a layer made of fibrous material such as jute, or same as bedding is used over the armouring. This layer is called as serving.

From the above discussion it is clear that bedding, armouring and serving are used in the cable to protect the conductor insulation and the metallic sheath from any mechanical injuries.

4.3 DIFFERENT TYPES OF CABLES

We have observed that cables are classified into different categories. Hence, different types of cables are available for various applications and conditions. These include cables for domestic purpose, LT applications, HT applications, control purpose, etc. It is not possible to discuss all cables used in the industry but some important cables are discussed as follows:

√4.3.1 Polyvinyl Chloride Cable (PVC)

The satisfactory operation of a cable depends on the insulation used in the cable. There are numerous insulations available in the form of rubber, impregnated paper, vulcanized Indian rubber (VIR), varnished cambric, polyvinyl chloride, etc. We need to understand that no single insulating material is completely perfect and provides complete insulation to the cable. Hence, the selection of the insulating material depends on the purpose of the application for which it is used.

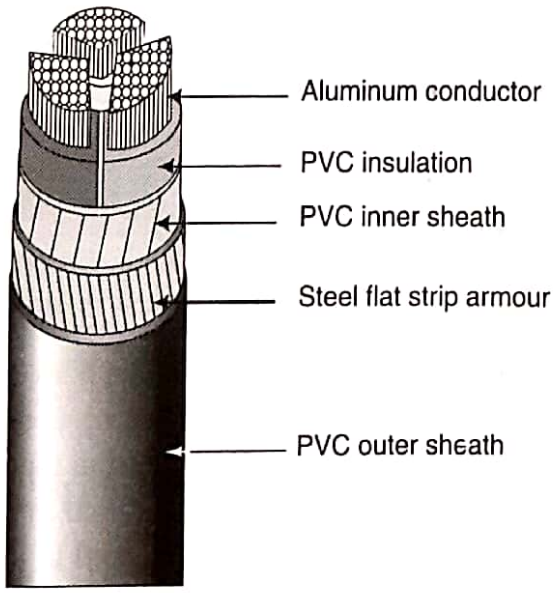

Fig. 4.2 PVC Cable for 1.1 kV

Polyvinyl chloride is obtained from the polymerization of acetylene. It is a synthetic compound available in the form of white odourless, tasteless, non-inflammable, and insoluble powder. To make this material as a cable insulator, it is mixed with some plasticizers. These plasticizers are liquid and have high boiling points. This plasticizer makes a gel which renders the material for a desired range of temperature. It is used over the conductor as an insulation cover. It has better dielectric strength, high insulating resistance and its maximum continuous temperature rating is 75°C. It is inert to oxygen, many alkalis and acids. Hence, it is mostly preferred over VIR in extreme condition such as cement or chemical factories. However, the mechanical property of this insulation is not as good as compared to the other material such as rubber and hence PVC cables are generally used for low and medium domestic lighting and power installations. The PVC cable for 1.1 kV is shown in Fig. 4.2.

4.3.2 Paper-Insulated Lead-Covered (PILC) Cable

This is also called paper insulated cable (PLC). The use of paper as an insulating material is one of the oldest methods and is still used in high-voltage cables. In this cable, the paper tape is lapped on the conductor until the required thickness is obtained. Then, it is impregnated with dielectric compounds such as oil resin or synthetic fluid. Rubber insulation is almost superseded by this insulation because this has an advantage of low cost, low capacitance, high dielectric strength and high insulation resistance. The only disadvantage is that the paper is hygroscopic and even if it is impregnated with suitable compounds, it still absorbs moisture resulting in insulation resistance. To prevent the water or moisture seeping into the paper insulation, a lead sheath is always applied over the paper insulation. The cross section of the PILC cable is shown in Fig. 4.3.

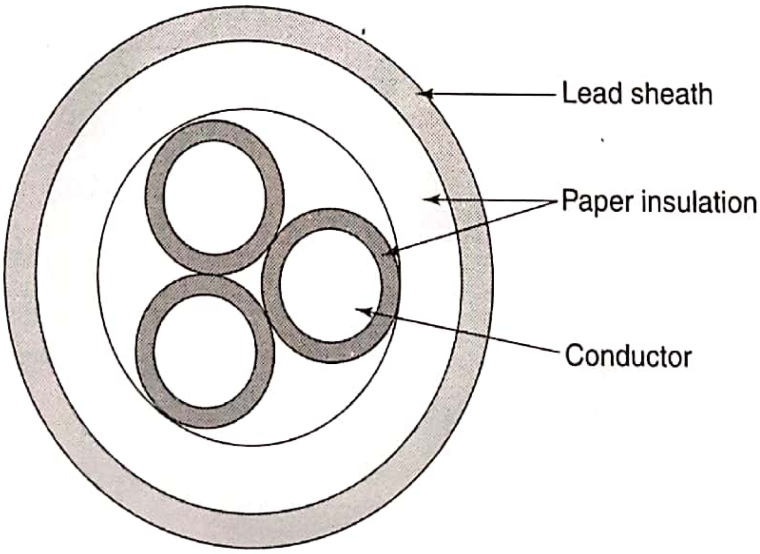

Fig. 4.3 Cross-Sectional View of PILC Cable

Paper-insulated lead-covered cable is used because of its tendency to absorb moisture in applications where the cable route consists of fewer joints as large number of joints increase the installation cost which does not permit the paper insulated cables. They are widely used for distribution of power at low voltages in highly populated areas where the joints are used only at the terminal equipment. However, for small installations where the length is small and more joints are used, VIR cables are cheaper and more durable.

The main advantages of the cable are as follows:

(i) It is low cost.

(ii) It has more dielectric strength (about 20 kV/mm)

(iii) The thermal resistivity is low.

(iv) The permissible continuous temperature range is of 80°C.

4.3.3 Fire-Retardant Low-Smoke (FRLS) Cable

Conventional power cables with PVC insulation are house-wiring cables, which are suitable for normal working conditions but hazardous in high temperature environment specially when exposed to fire from an external source. When fire breaks out in a building, the cable is burned. It produces black, toxic smoke which is dangerous for human life. Hence, special cables (FRLS) are developed which are safe in such fire accidents. In this cable, bared or annealed copper conductor is used and it is insulated by special grade PVC compound (FRLS). This cable is ideal for domestic wiring and it is also used in UPS, batteries, invertors, and control panels, etc. They are generally used in power plants, steel plants, fertilizers and petro chemical plants, high-rise buildings, cinema theatres, hotels, and hospitals. In such locations, the cables are laid together in small space and are installed in ducts or racks. The cross-sectional view of FRLS cable is shown in Fig. 4.4.

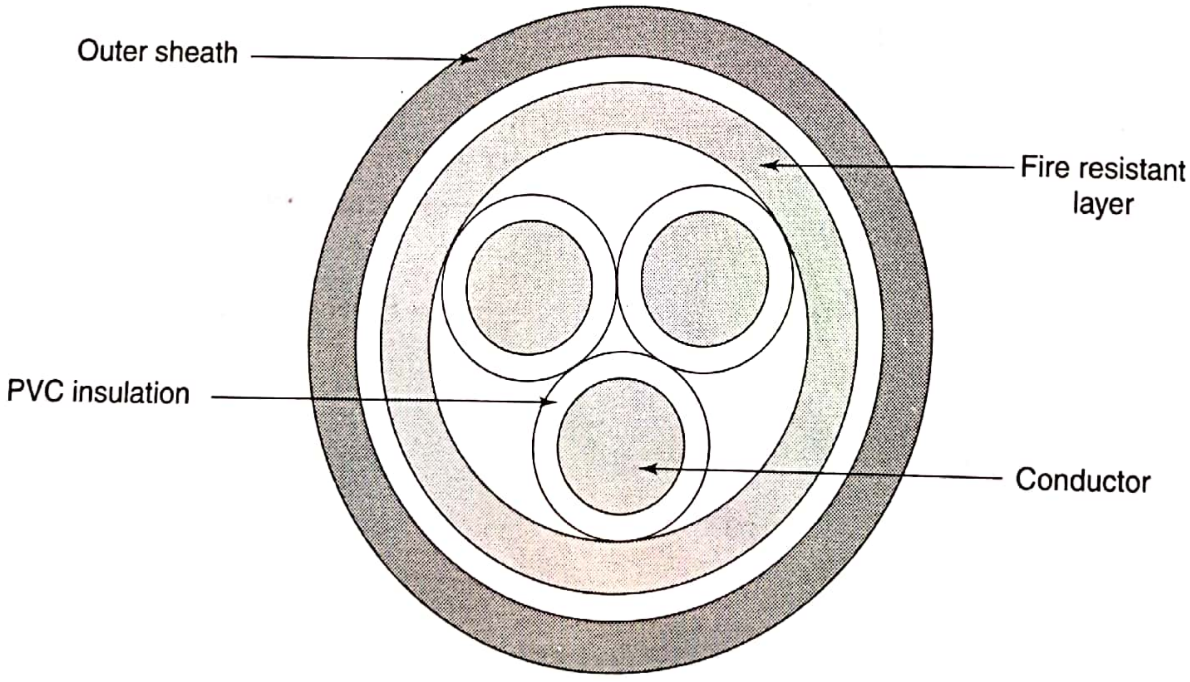

Fig. 4.4 Fire-Retardant Low-Smoke (FRLS) Cable

The main advantages of the cable are as follows:

(i) It has excellent fire resistant property.

(ii) It is self extinguishing.

(iii) It produces very less toxic fumes during fire.

(iv) It has less amount of noncorrosive material.

4.3.4 Cross-Linked Polythene (XLPE) CABLE

When low density polythene is vulcanized under controlled conditions, a product with cross-linked carbon atoms is produced. It is called as cross-linked polythene (XLPE). This material has a high melting point, smaller weight, small dimensions, low dielectric constant and good mechanical strength. This cable has high maximum continuous rating of 90°C with dielectric strength of about 20 kV/mm. This cable can be buried directly under the ground. This cable is most suitable for all voltages above 3.3 kV. These cables are also used in HVDC system. The XLPE cable is shown in Fig. 4.5.

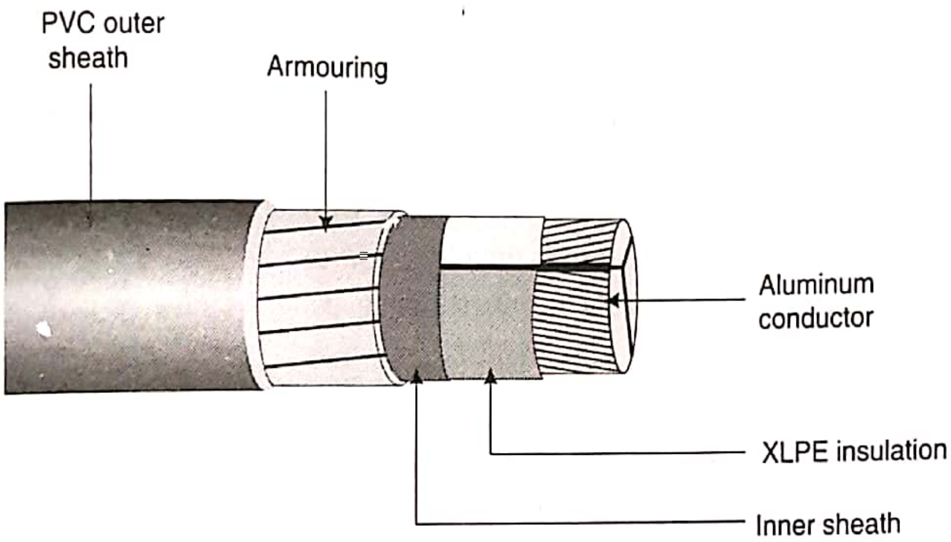

Fig. 4.5 Cross-Linked Polythene (XLPE) Cable

The main advantages of XPLE cable are as follows:

(i) It has light weight.
(ii) It has high melting point.
(iii) They are mechanically strong.
(iv) They are non-inflammable.
(v) They have more flexibility when compared to other cables.
(vi) The permissible continuous temperature range is of 90°C.
(vii) It has good thermal properties.
(viii) These cables are not affected by partial discharge in the presence of moisture.

After development of the XLPE cables, the complex oil-filled and gas-pressure cables have become outdated for the voltage range of 66 to 400 kV.

4.3.5 Gas-Filled (SF6) Cable

The main drawback of the solid impregnated cable is that it cannot maintain the dielectric pressure. Hence, it is only used up to 66 kV. If we load the impregnated paper cable above 66 kV, impregnated compound expands more than the paper. After removing the load, it cools down and the compound contracts but does not get back to the original position. Hence, cavities or voids are formed in the dielectric. Ionization of the gas in these voids may spoil the insulation and cable may be break at low temperatures. It is necessary to prevent the voids or maintain the dielectric pressure. This can be done by the following two methods:

(i) By using the low viscosity oil which is filled in the space in impregnated paper. Such types of cables are called as oil-filled cables.

(ii) By using high pressure gas to suppress the ionization. Such types of cables are called as gas-pressure cable.

The gas-pressure cable is also divided into two types:

(a) External gas-pressure cable (compression cable)

(b) Internal gas-pressure cable

SF_6-type cable comes under internal gas-pressure cable. In this cable, sulphur hexafluoride (SF_6) gas is filled in the spaces in impregnated paper insulation to suppress the ionization. The conductors are made of hollow aluminium tubes which are separated by spacers. EHV/UHV lines with SF_6 are widely used for voltages more than 132 kV to 1200 kV. This cable is most suitable for short distances, crossing the river and highways. The cable is shown in Fig. 4.6.

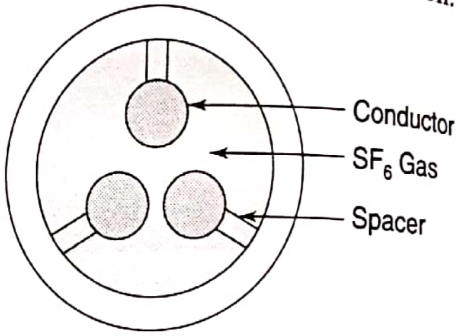

Fig. 4.6 SF_6 Cable

The advantages of the cable are given as follows:

(i) The oil pressurization plant is not required.

(ii) It can carry more current.

(iii) It has low capacitance and low dielectric losses.

(iv) The termination of this cable is simple and cheaper as compared to that of the oil-filled cables.

(v) The manufacturing is simple.

(vi) SF_6 gas is not toxic, and is chemically stable and non-inflammable.

4.4 CABLE RATING

The following are the main ratings of the cable:

(i) **Current Rating:** It is the value of the maximum current that can be passed through the cable safely without damaging it. This current rating determines the upper limit of the power transfer through the cable and hence it is very important. The cable rating is further classified as follows:

(i) Normal continuous rating

(ii) Over current rating

(iii) Short circuit current ratting

Various factors which determine the current rating of the cable are as follows:

(i) Minimum conductor operating temperature

(ii) Heat dissipating property of the cable

(iii) Atmospheric condition in which the cable is used

(iv) Thermal resistance of the cable

(v) Cross-sectional area of the conductor
(vi) Allowable voltage drop
(vii) Methods of cable laying
(viii) Depth of the cable at which it is laid in the ground
(ix) Distance between the two cables

(ii) **Voltage Rating:** It is the maximum value of voltage that can be withstood by the cable without damaging its insulation. This voltage level is important because it decides the dielectric losses in the cable and depends only on the voltage.

(iii) **Thermal Rating:** The range of temperature in which the cable can work safely without thermal breakdown is called as thermal rating of the cable. Thermal rating depends on the following factor:

(i) Various power losses occur in the cable such as copper losses, dielectric losses, sheath losses, and inter sheath losses. Due to these losses, heat is generated in the cable which determines the thermal rating of the cable.

(ii) Heat dissipation rate of the surrounding medium because heat is not preferable for the cable.

(iii) Frequent change in load.

Here, it is to be noted that if the cable temperature exceeds the permissible value, cable may break or get permanently damaged.

4.4.1 Derating Factor of Cable

The current-carrying capacity of the cable depends on many factors as already discussed earlier. But when the installation of the cable system is different from the normal, we have to consider the derating factor of the cable and according to this, the actual current-carrying capacity of the conductor is obtained.

While calculating derating factor of cable, many other factors are considered such as ambient temperature, method of cable laying, single-cable laying or grouping of cables, etc. The cable manufacturing firm gives the derating factor for a particular range of cable installation system. By using these values actual current-capacity of the cable is calculated as follows:

$$I_{\text{actual}} = I_{\text{base}} \times K_d$$

where I_{actual} is the derated current capacity of the conductor in A,
I_{base} is the base current-carrying capacity in A,
K_d is the product of the all derating factors given by the manufacturer.

Example 4.1 Suppose a conductor has base current-carrying capacity of 45 A, ambient derating factor of 0.90 and grouping derating factor of 0.75 then,

$$K_d = 0.90 \times 0.75 = 0.675$$

$$\therefore \quad I_{\text{actual}} = I_{\text{base}} \times K_d = 0.675 \times 45 = 30.37 \text{ A}$$

Hence, instead of 45 A, we can draw only 30.37 A current after derating the cable.

4.5 METHODS OF CABLE LAYING

The methods of cable laying generally depend on the local conditions. It is important because, as said earlier, it decides the current rating of the cable. The general methods of cable laying are discussed here. Here, it is to be noted that for special locations, such as road crossing, railway crossing, water main crossing, communication line crossing, in tunnels, on bridges, etc., special care has to be taken.

4.5.1 Direct Laying Method

Direct laying method is one of the simplest and cheapest methods of laying cable. In this method, a trench is made in the ground which may vary in length from 0.5 m to 1.2 m. The bottom of the trench is leveled and sharp edges are removed. Then a layer of 10 cm of sand is laid at the bottom of the trench. Over this sand layer, the cable is laid and again a layer of 10 cm of sand is made to cover the cable. To prevent the mechanical damage, bricks or reinforced concrete slab is provided. This also gives a warning while excavating in the future. At the end, this trench is filled with soil. This method is shown in the Fig. 4.7.

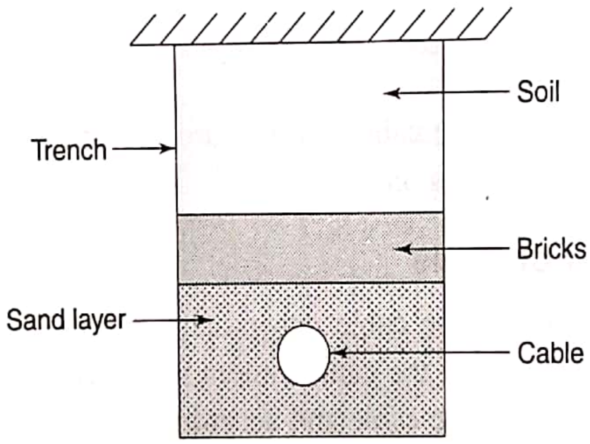

Fig. 4.7 Direct Laying Method

Advantages:

- This is a very cheap and simple method.
- It gives the best cooling for heat dissipation of the cable.
- It is not affected by the vibration that is produced by traffic.

Disadvantages:

- It is more difficult to locate the fault.
- It has a high maintenance cost.
- For future expansion, cable network cannot be changed easily.
- It has a high installation cost.
- The load can be increased only by laying new cables in the trench.

4.5.2 Draw-in System

Draw-in system is most suitable method for laying in cables in populated areas such as cities, towns, etc. In this system, ducts or pipes of steel, iron or cement concrete are laid in the ground. A provision is made for manholes at suitable locations. Then the cables are laid in ducts through the manholes. In this case, the cable does not require armouring because of the use of pipes or ducts. This system is shown in Fig. 4.8.

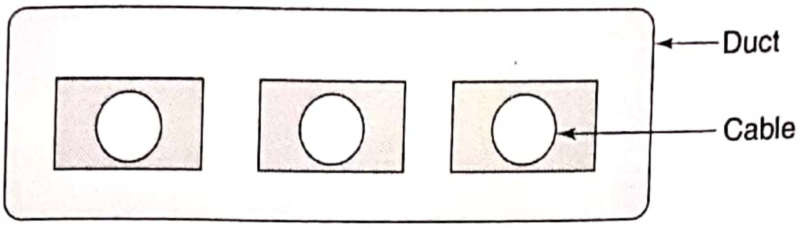

Fig. 4.8 Draw-in system

Advantages:

- Ducts provide very strong mechanical protection. Hence, less chances of faults.
- It is very easy to repair or maintain because cable can be easily drawn out from the manholes.
- The load can be increased easily without digging the trench. Hence, installation cost is low for new loads.
- Cable jointing is easy because of the absence of armouring.

Disadvantages:

- Installation of the ducts or pipes increases the initial cost.
- Due to cable grouping, the current capacity of the cable is reduced.

4.5.3 Solid System

In solid system method, first trough or pipe of wood, earthenware, cast iron or asphalt are used. Generally, asphalt troughs or open pipes are used because of easy laying. The cables are laid in these pipes and pipes are filled with bituminous and asphaltic compounds. After filling, a cover of bricks, tiles or wood is provided to give good mechanical protection. In this method, lead-covered cables are mainly used. This is shown in Fig. 4.9.

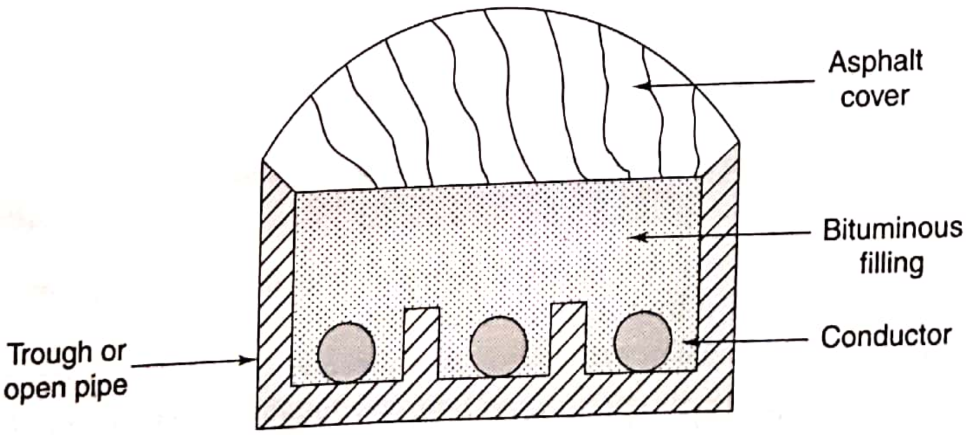

Fig. 4.9 Solid System

Advantages:

- It provides good mechanical support.
- There are very few chances of fault due to strong mechanical protection.
- The performance of cable is not affected by the surrounding soil.

Disadvantages:

- It has high initial cost.
- The heat dissipation is poor.
- It requires longer time for laying the cables.
- The current capacity of the cable is reduced.
- It has high maintenance and repairing cost.
- The future expansion of cables is difficult.

4.5.4 Cable Laying by Racking on Wall or Overhead Structure

In this method, 'J' type hooks made of iron are grouted in the wall as shown in Fig. 4.10. The cables are laid on these hooks. The hooks support the cables. The distance between the support and the wall is decided by the number of cables laid and weight of the cables. If more than one cable is required to be supported, separate hooks are used. When the wall direction is changed, 'J' hook should be fixed near the turning on both sides.

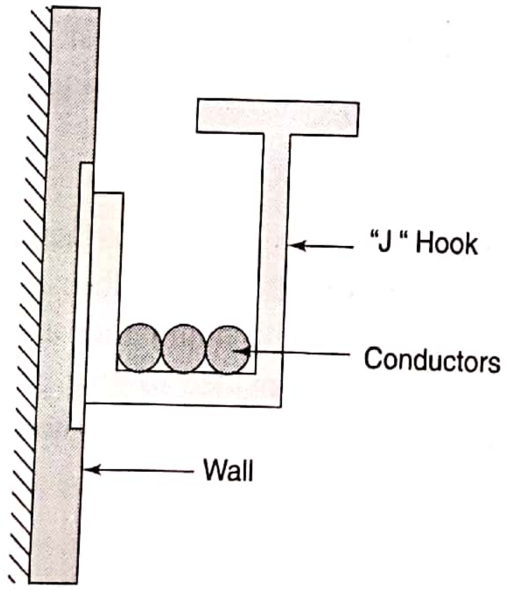

Fig. 4.10 Cable Laying by Racking on Wall

Advantages:

- It is easy to install and has a low maintenance cost.
- It has low initial cost.
- The future expansion of cables is possible.
- It is easy to locate faults.
- The performance of the cable is not affected by the surrounding soil.

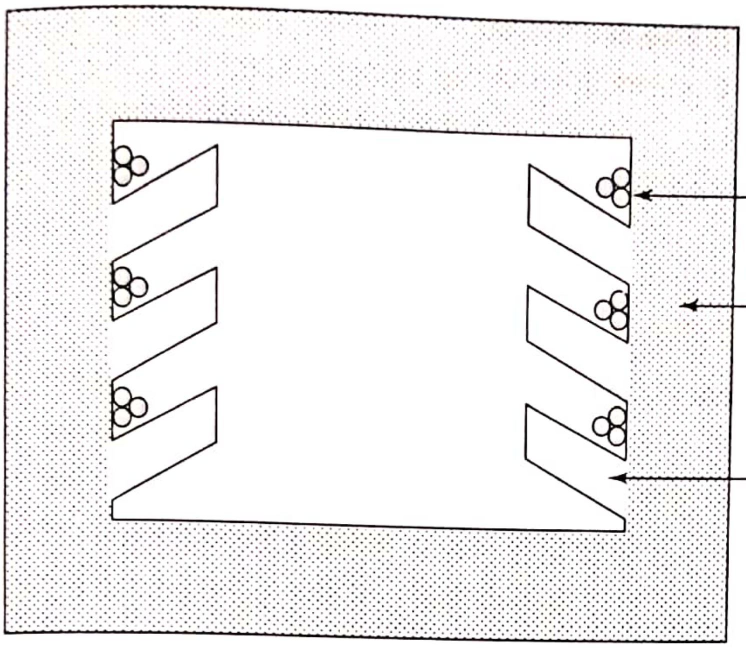

Fig. 4.11 Cable Laying by Racking in Tunnel

Disadvantages:

- It requires special type of 'J' hooks.
- There is increased possibility of fire.
- As the temperature is increased, the current capacity of the cable is decreased.

4.5.5 Cable Laying by Racking in Tunnel

In this method, first of all a tunnel is made in the foundation of the building, factory, substation, or power station, etc. Then various cables are racked in the tunnel as shown in Fig. 4.11. Here, air ventilation is not present and hence the temperature of the cable and tunnel may increase.

Advantages:

- In this case, a separate rack is not required.
- It provides fire protection.

Disadvantages:

- The method is costly because it requires tunnel construction.
- Due to the absence of air ventilation, temperature of the cable and tunnel is more.