Module 6

Underground Cables

Part I

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Topics to be covered

- Introduction
- Requirements for underground cables
- Advantages and disadvantages
- Comparison between underground cables and overhead lines
- Classification of cables
- Properties of insulating material

Underground Cables

- Essentially consists of one or more conductors covered with suitable insulation and surrounded by a protective layer.
- Favourable option for thickly populated areas or where installation of overhead lines is not possible.
- Usually employed for transmission of electric power at low or moderate voltages for short or moderate distances.

Requirements for underground cables

- Tinned stranded conductors
- Optimum size of conductor
- Physical and chemical stability
- Safe and reliable operation
- Sufficient mechanical protection

Advantages & Disadvantages

Advantages

– Better general appearance

– Less liable to damage through storms or lighting

– Low maintenance cost

– Less chances of faults

– Small voltage drops

Disadvantages

– Greater installation cost

– Insulation problems at high voltages

Comparison of underground cables and overhead lines

- In overhead lines inductance is dominant whereas in cables capacitance is dominant.
- Large charging current in high voltage cables limits length of cables.
- Copper is normally used conductor in cables, hence cost of conductor is more in cables in comparison to overhead lines.
- Cost of insulation –additional cost in cables.
- Erection cost is higher in overhead lines.

CLSSIFICATION OF CABLES

- Voltage levels
- Insulation
- Location
- Number of cores/conductors

Contd.

- According to voltage level
  - Low tension (L.T) ----- up to 1000V
  - High tension (H.T) ----- up to 11, 000V
  - Super tension (S.T) ---- from 22KV to 33KV
  - Extra high tension (E.H.T) cables --- from 33KV to 66KV
  - Extra super voltage cables ------beyond 132KV

Properties of Insulating Material

- High resistivity
- High dielectric strength
- Low thermal co-efficient
- Low water absorption
- Low permittivity
- Non – inflammable
- Chemical stability
- High mechanical strength
- Capability to with stand high rupturing voltage
- High tensile strength and plasticity

Construction of Cables

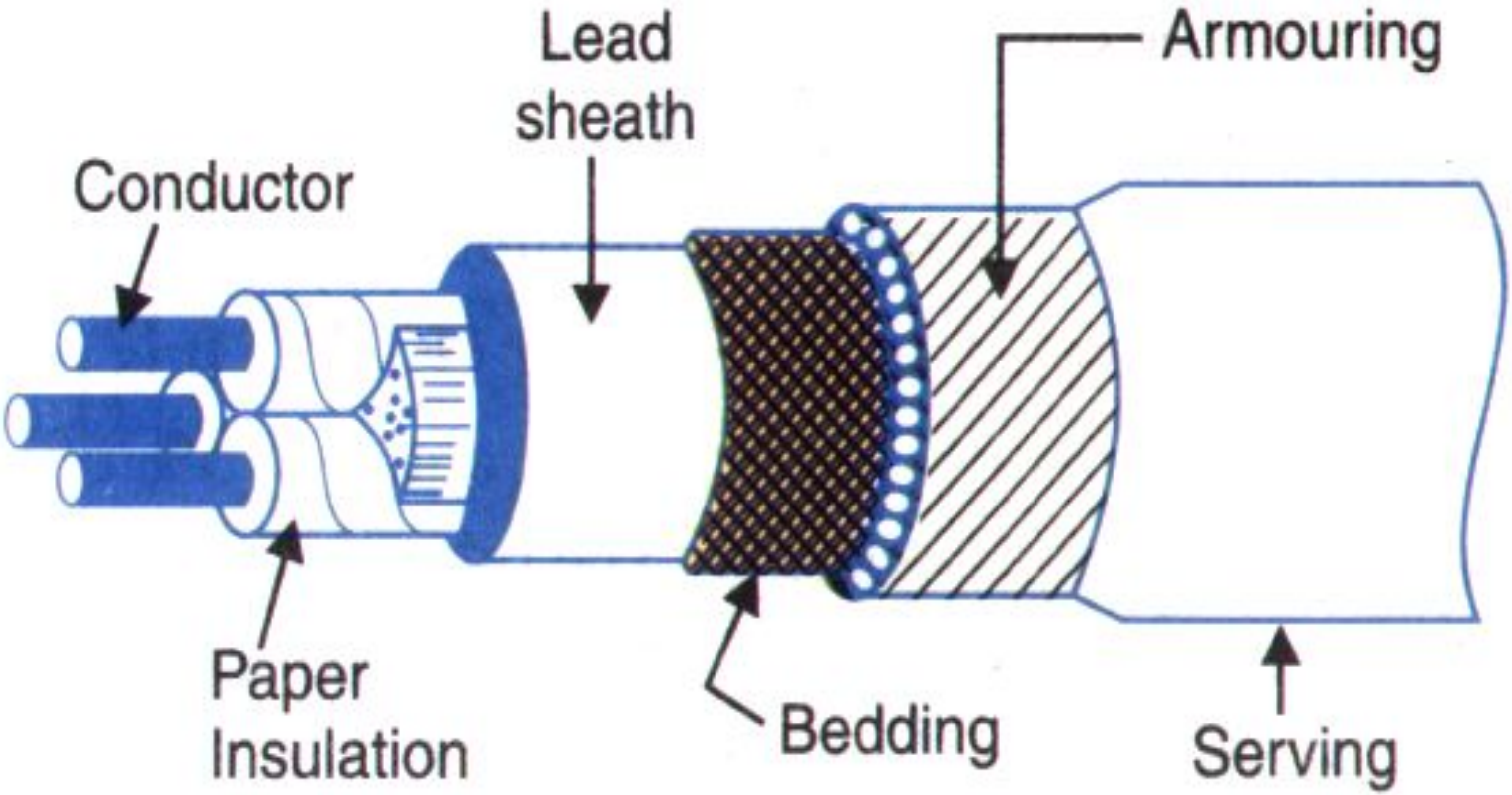


Figure 6.1: Construction of a cable

Construction of Cables

- **Core or Conductor**

  A cable may have one or more than one core depending upon the type of service.

- **Insulation**

  The core is provided with suitable thickness of insulation, depending upon the voltage to be withstood by the cable.

Construction of Cables

- **Metallic Sheath**

  A metallic sheath of lead or aluminum is provided over the insulation to protect it from moisture, gases or others damaging liquids and provides mechanical strength.

- **Bedding**

  Bedding is provided to protect the metallic sheath from corrosion and from mechanical damage due to armouring.

Construction of Cables

- **Armouring**

 Its purpose is to protect the cable from mechanical injury while laying it or during the course of handling.

- **Serving**

 To protect armouring from atmospheric conditions, a layer of fibrous material is provided.

Underground Cables

Part II

Topics to be covered

- Insulating materials for cables
- Single core LT cable
- Cables for three phase

Insulating Materials for Cables

- **Rubber**

✔ It can be obtained from milky sap of tropical trees or from oil products.

✔ Dielectric strength = 30 KV/mm.

✔ Insulation resistivity =   ohm.cm

✔ Relative permittivity varying between 2 and 3.

✔ Drawbacks: hygroscopic. soft and liable to damage due to rough handling and ages when exposed to light.

✔ Maximum safe temperature is very low about 38 C

Insulating Materials for Cables

- **Vulcanized India Rubber**

✔It can be obtained from mixing pure rubber with mineral compounds i-e zinc oxide, red lead and sulphur and heated upto 150 C.

✔ It has greater mechanical strength, durability and wear resistant property.

✔ The sulphur reacts quickly with copper so tinned copper conductors are used.

✔ It is suitable for low and moderate voltage cables.

- **Varnished Cambric**

✔ This is simply the cotton cloth impregnated and coated with varnish.

✔ As the varnish cambric is also hygroscopic so need some protection.

✔ Its dielectric strength is about 40KV / mm and permittivity is 3 to 4.

✔ Terylene can be used in place of cambric which is mechanically stronger and non-hygroscopic.

Insulating Materials for Cables

- **Impregnated Paper**
  - ✔ This material has superseded the rubber, consists of chemically pulped paper impregnated with napthenic and paraffinic materials.
  - ✔ It has low cost, low capacitance, high dielectric strength and high insulation resistance.
  - ✔ The only disadvantage is the paper is hygroscopic, for this reason paper insulation is always provided protective covering.
- **Polyvinyl chloride (PVC)**
  - ✔ This material has good dielectric strength, high insulation resistance and high melting temperatures.
  - ✔ These have not so good mechanical properties as those of rubber.
  - ✔ It is inert to oxygen and almost inert to many alkalis and acids.

Single-core low Tension Cable

- Ordinary construction
- One circular core of tinned stranded conductor
- Insulated by layers of impregnated paper
- Surrounded by a lead sheath
- An overall serving of compounded fibrous material

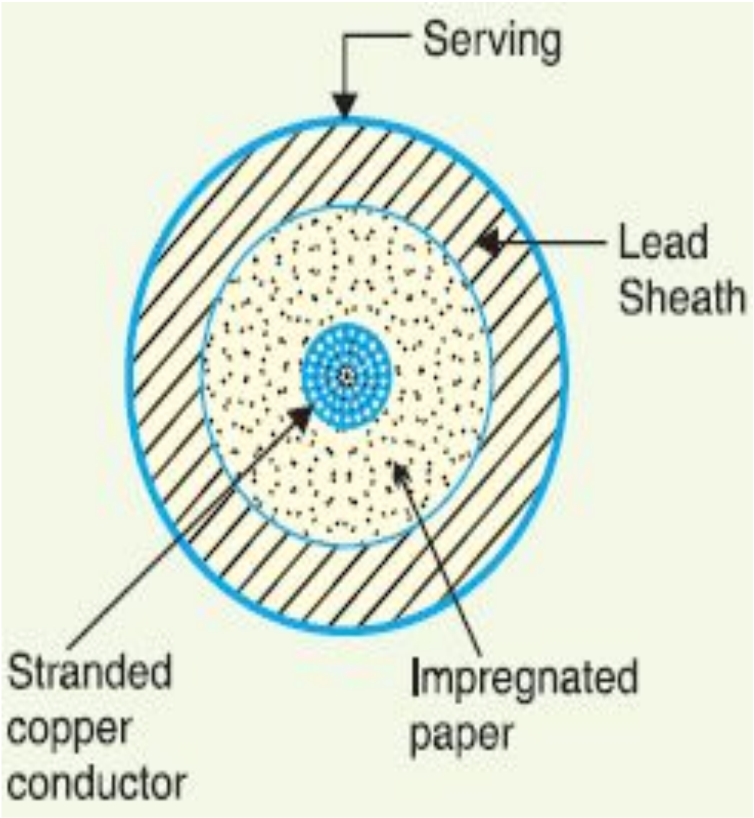


Figure 6.1:Single core LT cable

Cables for 3-Phase

- 1. Belted cables — upto 11 kV
- 2. Screened cables — from 22 kV to 66 kV
- 3. Pressure cables — beyond 66 kV

Belted Cables

The cores are insulated from each other by layers of impregnated paper.

Another layer of impregnated paper tape, called paper belt is wound round the grouped insulated cores.

The belt is covered with lead sheath

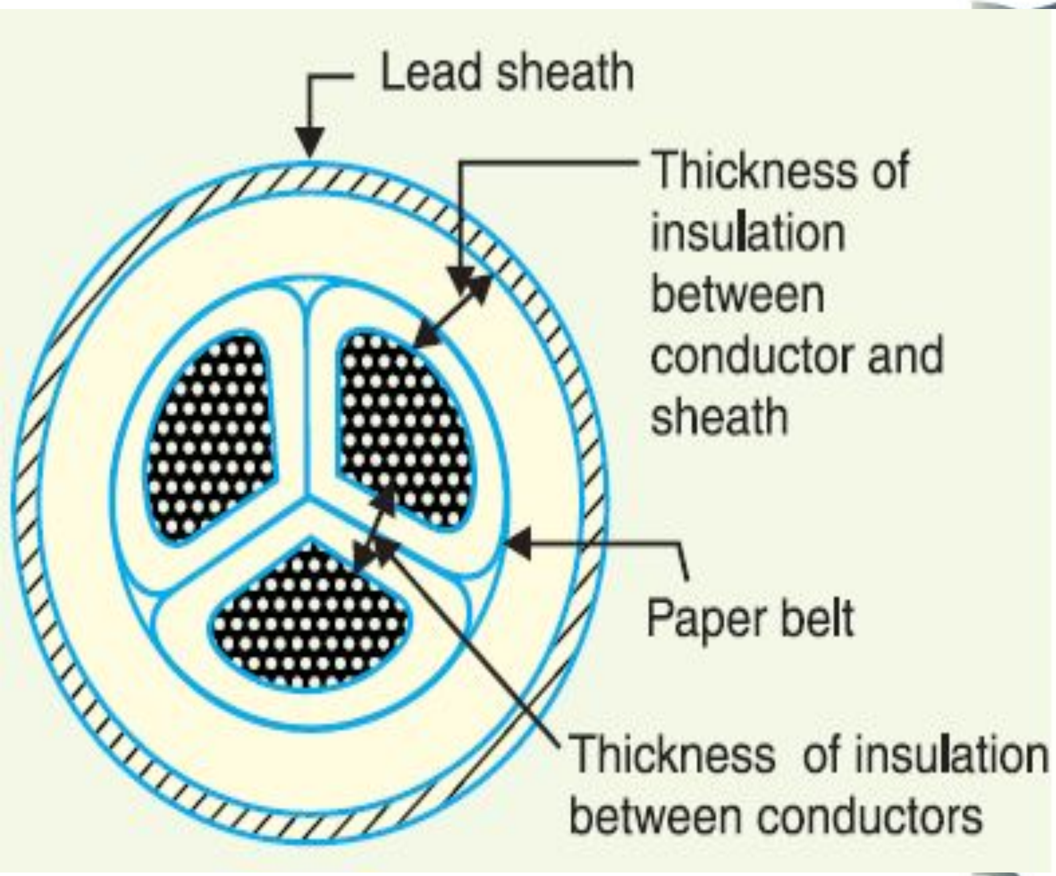


Figure 6.2: construction of Belted cable

Drawbacks of Belted Cables

- Suitable only for low and medium voltages
- Tangential stresses
- Local heating, resulting in the risk of breakdown of insulation at any moment.
- In order to overcome this difficulty, screened cables are used where leakage currents are conducted to earth through metallic screens.

Screened cables

Two principal types of screened cables are H-type cables and S.L. type cables.

(i) H-type cables.

The insulation on each core is covered with a metallic screen which usually consists of a perforated aluminium foil. The cores are laid in such a way that metallic screens make contact with one another.

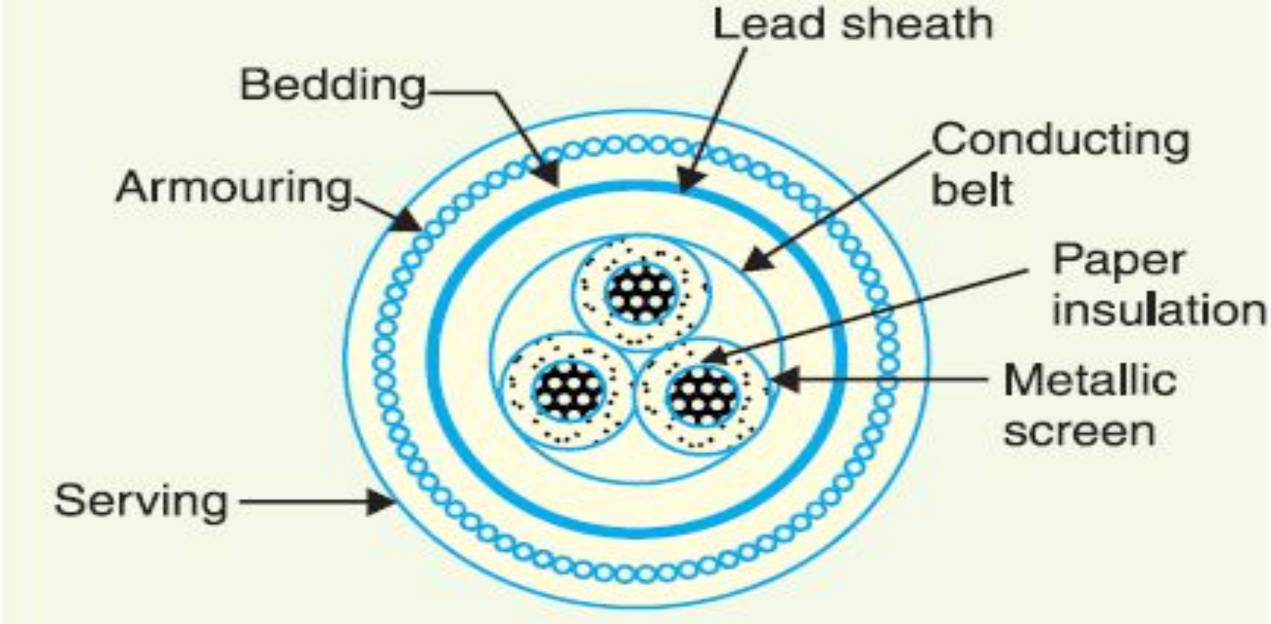


Figure 6.3 Construction of screened cable

H type Screened cables

- It is easy to see that each core screen is in electrical contact with the conducting belt and the lead sheath.
- Purely radial electric stresses and consequently dielectric losses are reduced.

Advantage

Metallic screens increase the heat dissipating power of the cable.

S.L. type cables

Advantages

- ❖ Minimize the possibility of core-to-core breakdown.
- ❖ Easy bending of cables

Disadvantage

- ❖ Greater care is required in manufacturing.

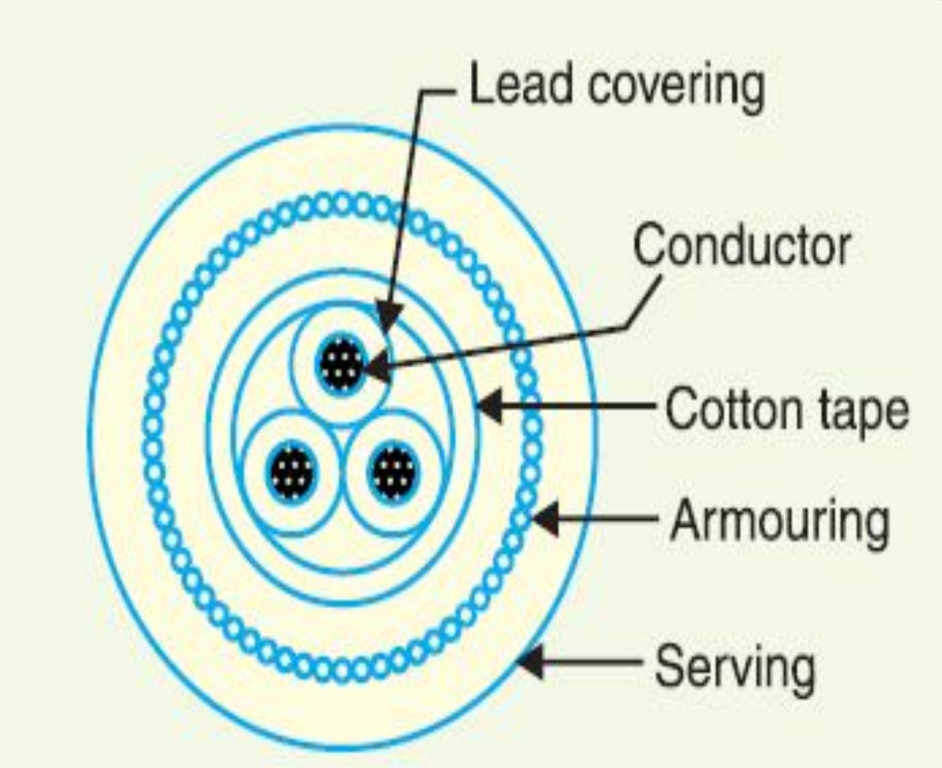


Figure 6.4: Construction of S.L. cable

Underground Cables

Part III

Limitations of solid type cables

Solid insulation is used and no gas or oil circulates in the cable sheath. The voltage limit for solid type cables is 66 kV due to the following reasons :

(a) Conductor temperature increases and the cable compound expands

(b) When the load on the cable decreases, the conductor cools and a partial vacuum is formed within the cable sheath.

(c) Under operating conditions, the voids are formed as a result of the differential expansion and contraction of the sheath and impregnated compound.

Pressure Cables

- When the operating voltages are greater than 66 kV and up to 230 kV
- Voids are eliminated by increasing the pressure of compound

Oil-filled cables

- In such types of cables, channels or ducts are provided in the cable for oil circulation.
- The pressure of oil is kept constant by means of external reservoirs.
- Oil under pressure compresses the layers of paper insulation and fills any voids that may have formed between the layers.

Oil-filled Cables

- The oil channel is formed at the centre by stranding the conductor wire around a hollow cylindrical steel spiral tape.
- The oil under pressure is supplied to the channel by means of external reservoir.
- Disadvantage: The channel is at the middle of the cable and is at full voltage w.r.t. earth, so that a very complicated system of joints is necessary.

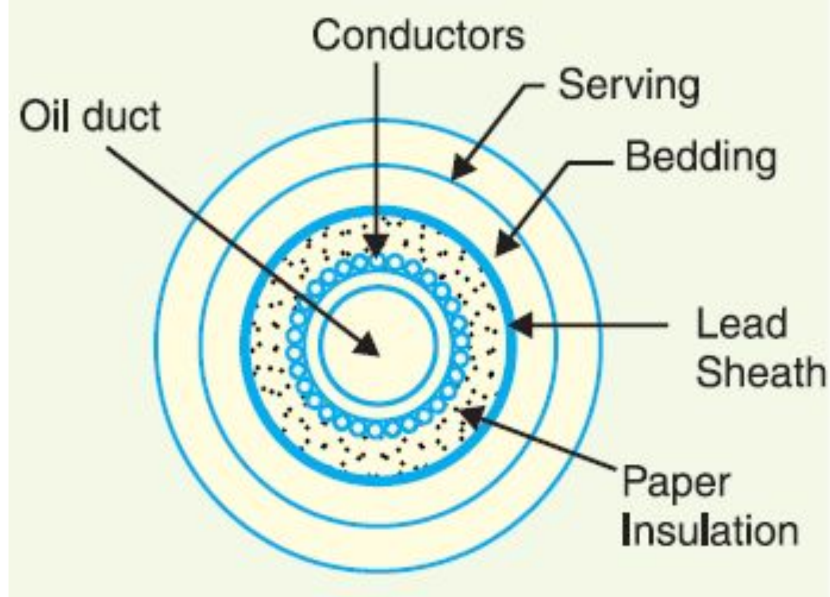


Fig. Single-core conductor channel, oil-filled cable

Single core sheath channel Oil-filled Cables

Figure 6.6 shows the constructional details of a single core sheath channel oil-filled cable.

In this type of cable, the conductor is solid similar to that of solid cable and is paper insulated.

However, oil ducts are provided in the metallic sheath as shown.

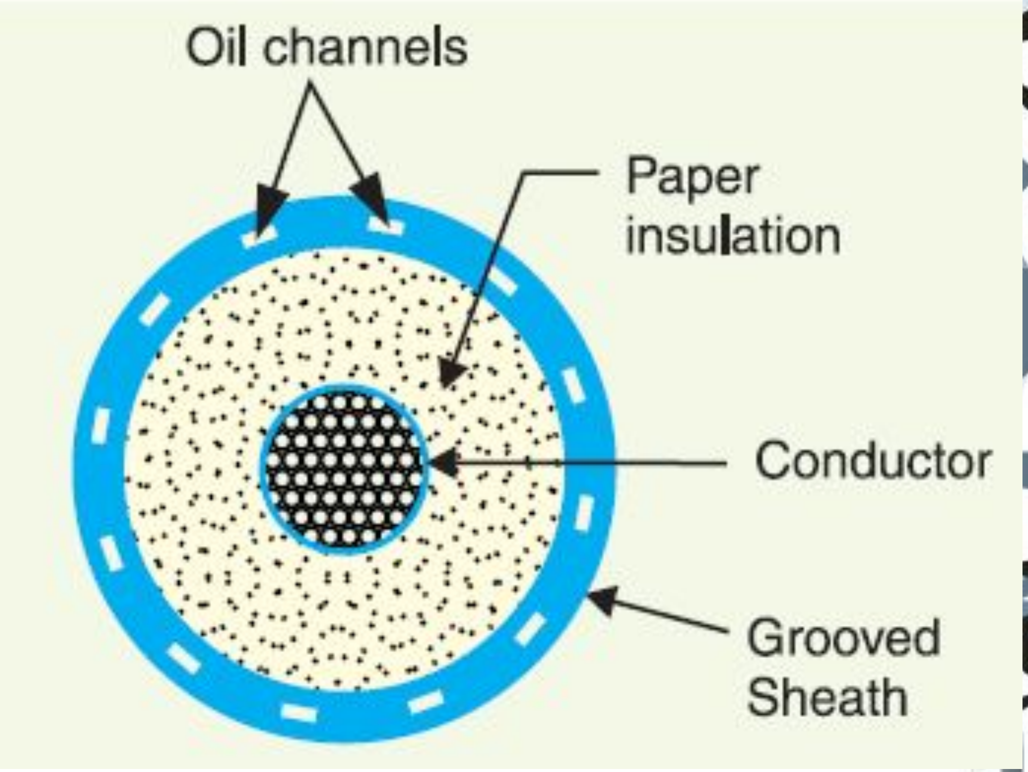


Figure 6.6: Single core sheath channel

3-core Oil-filler Cables

- The oil ducts are located in the filler spaces.
- These channels are composed of perforated metal-ribbon tubing and are at earth potential.

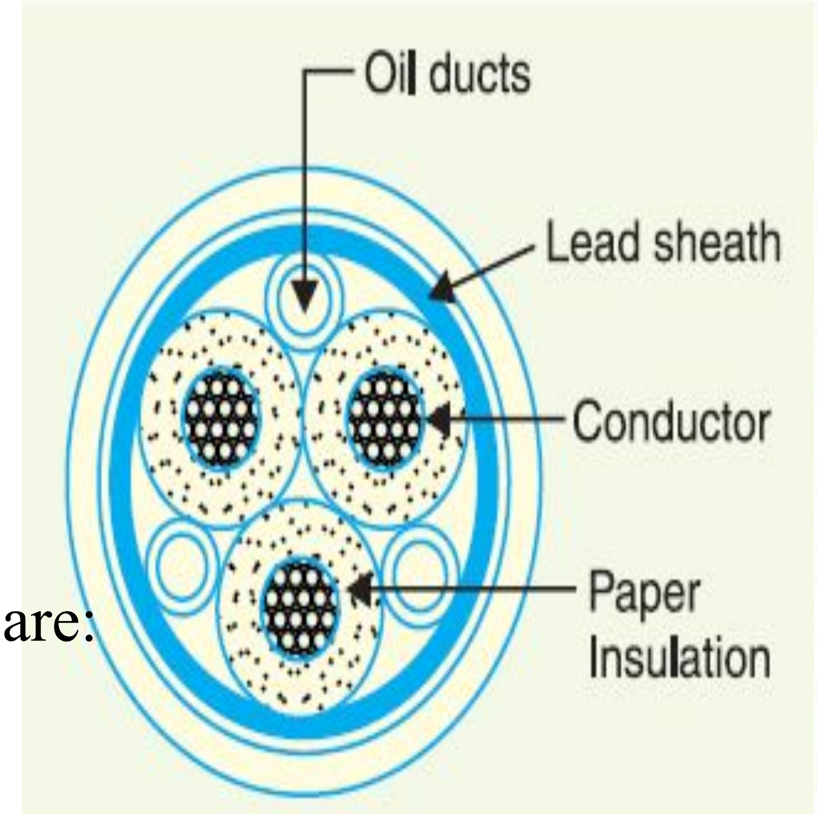


Figure 6.7: 3-core oil filler cable

The advantages of oil-filled cables are:

❖ No voids

❖ No ionization

❖ Allowable temperature range

❖ Increased dielectric strength

❖ Disadvantages: High initial cost and complicated system of laying.

Gas-filled Cables

- ❖ The cable is laid in a gas-tight steel pipe.
- ❖The pipe is filled with dry nitrogen gas at 12 to 15 atmospheres.
- ❖ The gas pressure produces radial compression and closes the voids that may have formed between the layers of paper insulation.

Advantages

- ❖Such cables can carry more load current and operate at higher voltages than a normal cable.
- ❖ Moreover, maintenance cost is small and the nitrogen gas helps in quenching any flame.

Disadvantage: The overall cost is very high.

Underground Cables

Part IV

Introduction to XLPE cables

- Cross linking is the effect produced in the vulcanization of rubber
- XLPE stands for cross linked polyethylene
- Small amounts of chemical additives to the polymer enable the molecular chains to be cross-linked into a lattice formation by appropriate treatment.
- Three processes for conversion of PE into XLPE-Electron irradiation, chemical cross linking and organic Sioplas methdod.

Introduction to XLPE cables

- **XLPE Cables (Cross Linked Poly-ethylene)**
  - ✔ This material has temperature range beyond 250 – 300 C
  - ✔ This material gives good insulating properties
  - ✔ It is light in weight, small overall dimensions, low dielectric constant and high mechanical strength, low water absorption.
  - ✔ These cables permit conductor temperature of 90 C and 250 C under normal and short circuit conditions.
  - ✔ These cables are suitable up to high .

Constructional details of XLPE cable

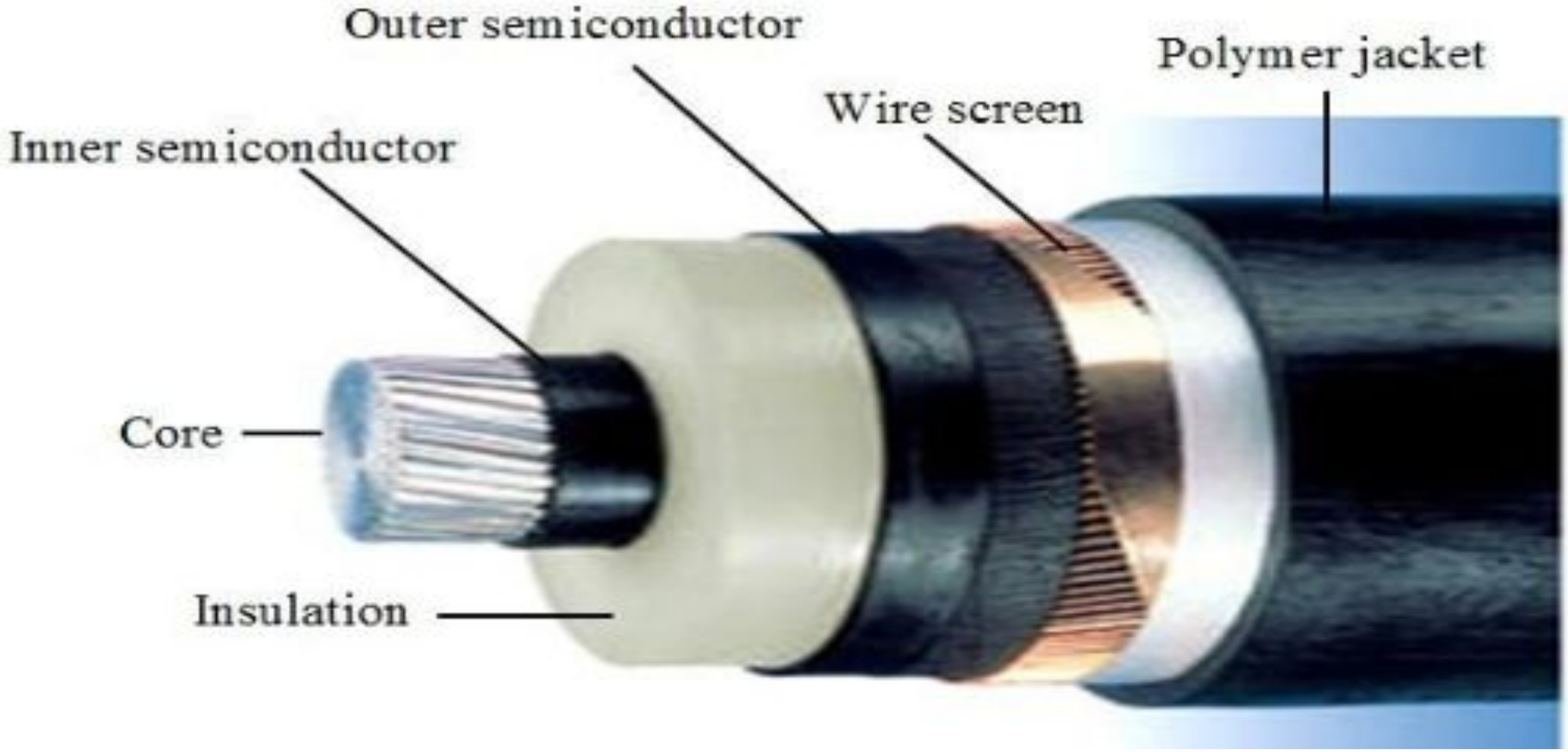


Figure 6.8: Labelled diagram of XLPE Cable

Underground Cables

Part V

Thermal resistance

- Thermal resistance is defined as ratio of temperature difference to heat flowing in unit time

Thermal resistance of dielectric of single core cable

Laying of Underground Cables

Before laying cable under the ground, its route should be surveyed & selected. The position of water mains or drains etc. Should be ascertained. Cables which are to be buried under ground must possess following properties:

A) moisture of soil should not enter the core of cable.

B) it must possess high insulation resistance.

C) it should not be costly.

D)it should be sufficiently flexible.

E) it should not be bulky.

F) it should be able to withstand heat produced due to flow of current.

G) it should not be capable of being damaged while laying in the ground.

Laying of Underground Cables

- The reliability of underground cable network depends to a considerable extent upon proper laying.
- There are three main methods of Laying underground cables

a. Direct Laying

b. Draw in system

c. Solid system

Direct Laying

- This method is cheap and simple and is most likely to be used in practice.
- A trench of about 1.5 meters deep is dug.
- A cable is been laid inside the trench and is covered with concrete material or bricks in order to protect it from mechanical injury.
- This gives the best heat dissipating conditions beneath the earth.
- It is clean and safe method.

Disadvantages of Direct Laying

- Localization of fault is difficult
- It can be costlier in congested areas where excavation is expensive and inconvenient.
- The maintenance cost is high

Draw in System

- In this conduit or duct of concrete is laid in ground with main holes at suitable positions along the cable route.
- The cables are then pulled into positions from main holes.

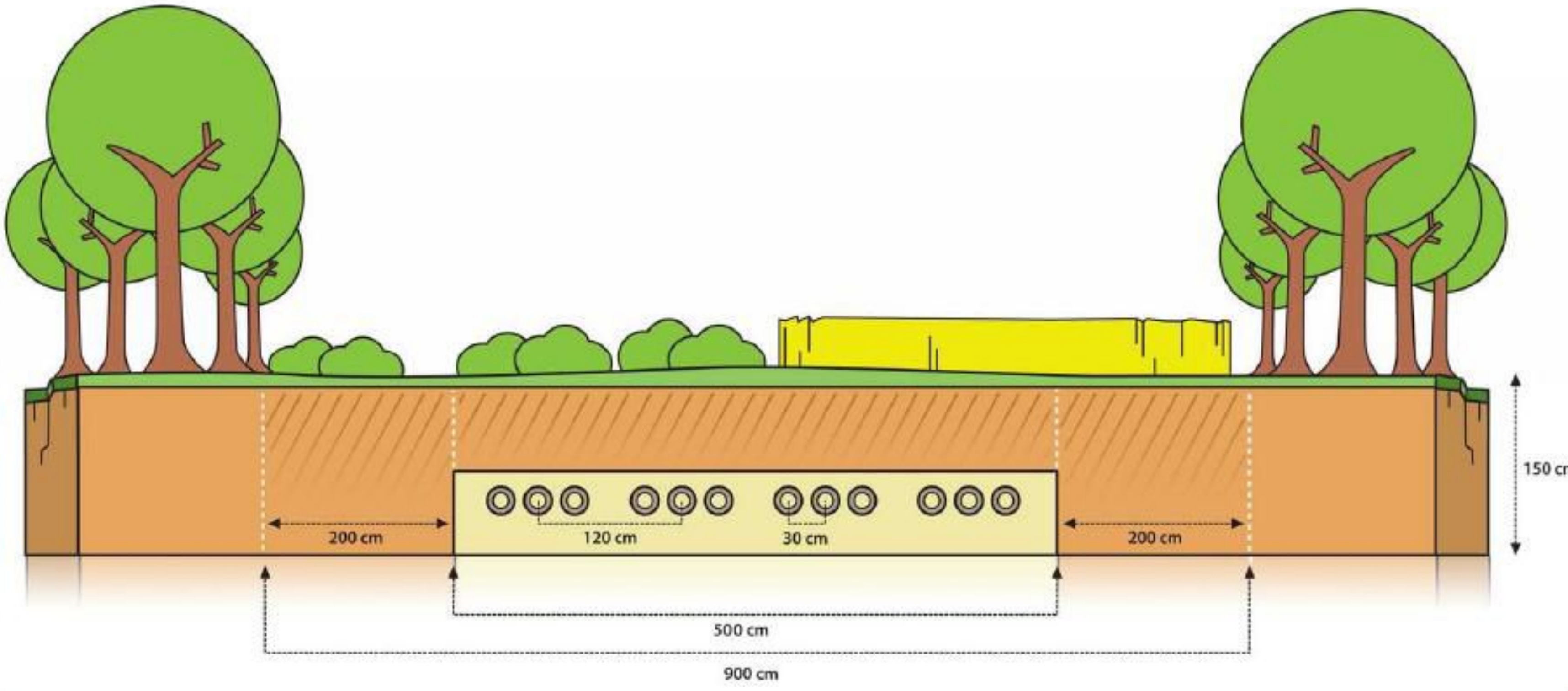
Draw in System

- It is very high initial cost
- Heat dissipation conditions are not good
- This method is suitable for congested areas where excavation is expensive and inconvenient
- This is generally used for short lengths cable route such as in workshops, road crossings where frequent digging is costlier and impossible

Solid System

- In this system the cable is laid in open pipes or troughs dug out in earth along the cable route.
- The troughing is of cast iron or treated wood
- Troughing is filled with a bituminous after cables is laid.
- It provides good mechanical strength
- It has poor heat dissipation conditions
- It requires skilled labour and favorable weather conditions
- It is very much expensive system

Solid System



TYPES OF CABLE FAULTS

Cables are generally laid in the ground or in ducts in the underground distribution system. For this reason, there are little chances of faults in underground cables. However, if a fault does occur it is difficult to locate and repair the fault because conductors are not visible. Nevertheless, the following are the faults most likely to occur in underground cables

1) open circuit fault

2) short circuit fault

3)earth fault

Open Circuit Faults

- When there is a break in the conductor of a cable, it is called open circuit fault.
- The open circuit fault can be checked by megger. For this purpose, the three conductors of the 3-core cable at the far end are shorted and earthed.
- The resistance between each conductor and earth is measured by a megger and it will indicate zero resistance in the circuit of the conductor that is not broken.
- However, if the conductor is broken, the megger will indicate infinite resistance in its circuit

Short Circuit Faults

- When two conductors of a multi-core cable come in electrical contact with each other due to insulation failure, it is called a short circuit fault.
- Again, we can seek the help of a megger to check this fault.
- For this purpose the two terminals of the megger are connected to any two conductors.
- If the megger gives zero reading, it indicates short circuit fault between these conductors.
- The same steps is repeated for other conductors taking two a time.

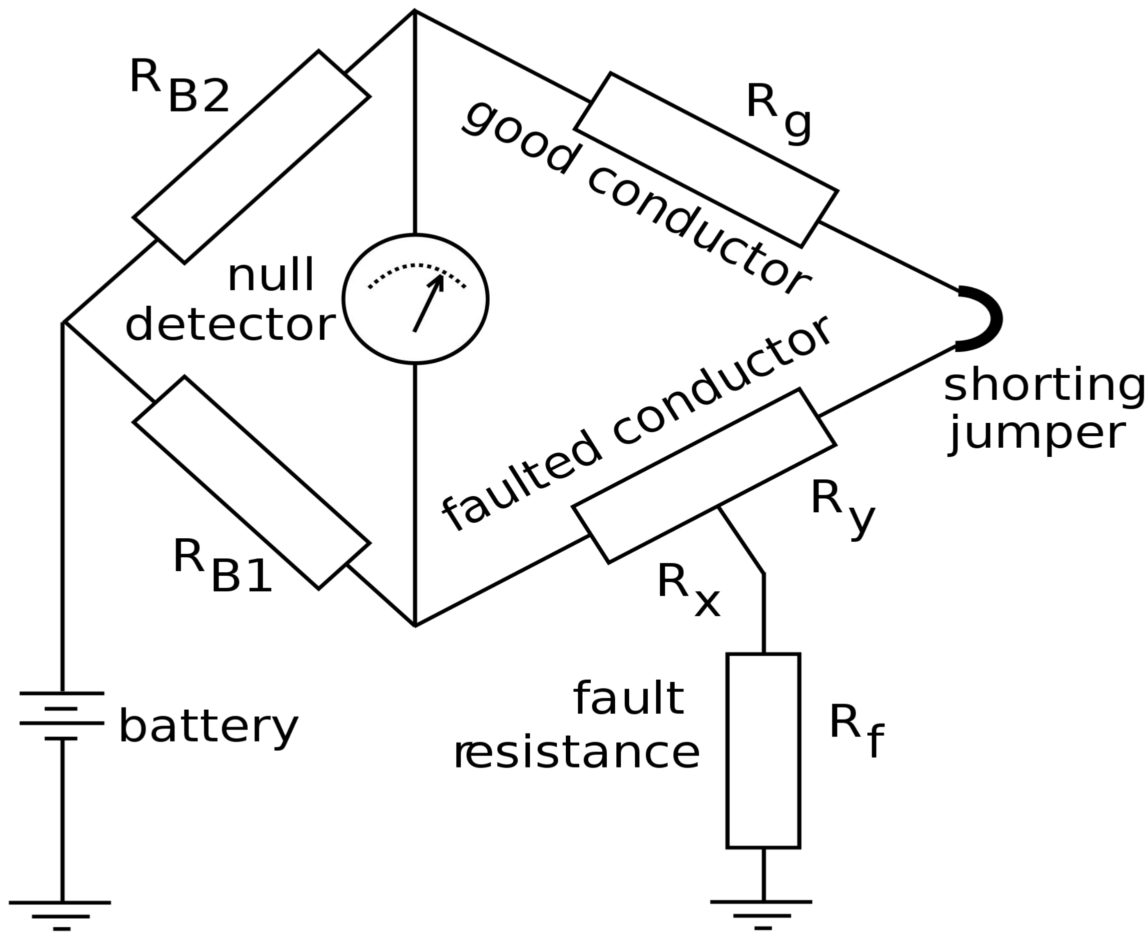
Earth Faults

- When the conductor of a cable comes in contact with earth, it is called earth fault or ground fault.
- To identify this fault, one terminal of the megger is connected to the conductor and the other terminal connected to earth.
- If the megger indicates zero reading, it means the conductor is earthed. The same procedure is repeated for other conductors of the cable.

Loop tests for location of faults

- Murray loop test
- Varley loop test

Murray loop test



Varley loop Test

- This test uses fixed resistors for RB1 and RB2, and inserts a variable resistor in the faulted leg.
- If the fault resistance is high, the sensitivity of the Murray bridge is reduced and the Varley loop may be more suitable.

Underground Cables

Part V

Thermal characteristics of cable

- Ohmic losses in the core
- Dielectric loss
- Sheath loss

Ohmic losses

Steps to determine hot resistance of conductor

- Determine resistance at operating temperature taking room temperature of conductor as reference.

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- Effective resistance of conductor by taking into account the skin effect.
- Increase in resistance due to stranding of conductor
- By taking into account the three steps, effective resistance is calculated.

Dielectric loss

- The cable is a like a capacitor with the core and sheath forming the two plates of capacitor separated by dielectric material.
- Equivalent circuit and phasor diagram for the same is drawn in figure 6.9.
- The equivalent circuit for the system is represented by a parallel combination of leakage resistance R and capacitance C as shown in figure 6.9.

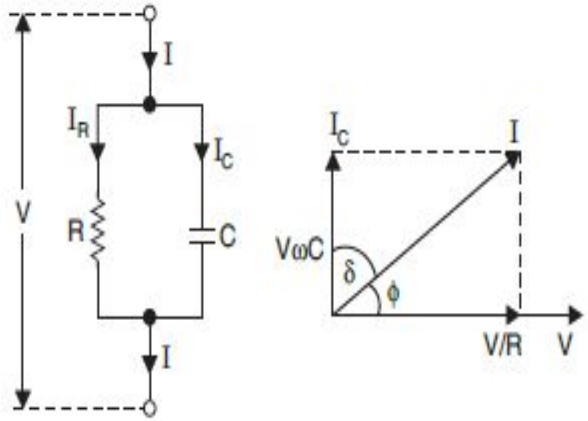
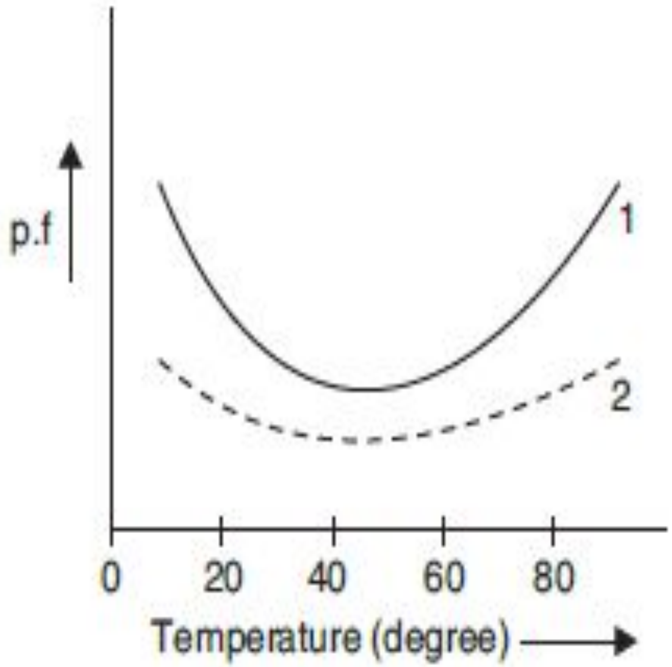


Figure 6.9 : (a) Equivalent circuit of cable (b) phasor diagram for equivalent circuit

Variation of power factor of dielectric



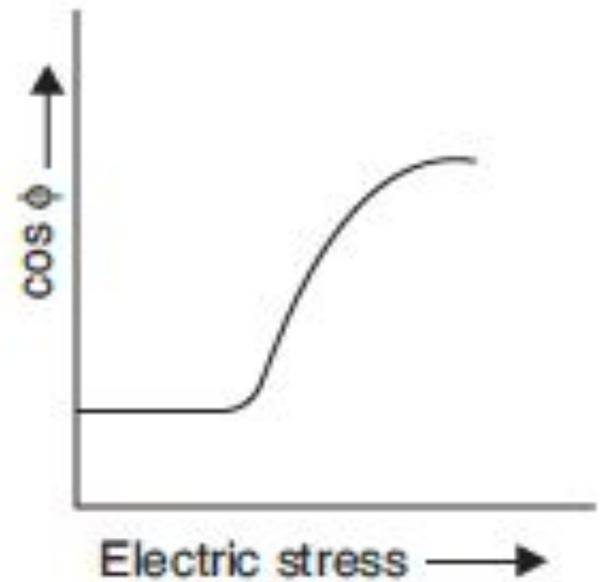


Figure 6.10 (a) Variation of power factor with temperature (b) variation of power factor With electric stress

Sheath loss

Sheath currents are categorized as

- Sheath eddy currents which flow entirely in the sheath of same cable
- Sheath short circuit currents which flow from one sheath of one cable to sheath of other cable.

Underground Cables

Part VI

Parameters of Underground Cables

- Insulation resistance
- Capacitance
- Electric stresses
- Dielectric loss(already explained in UG cables_Part V)

Insulation resistance

- Resistance offered by the insulating material to the flow of leakage current which flows radially from conductor to sheath through dielectric.

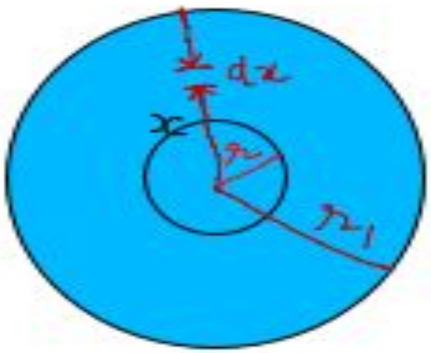


Figure 6.10 Single core cable

Underground Cables

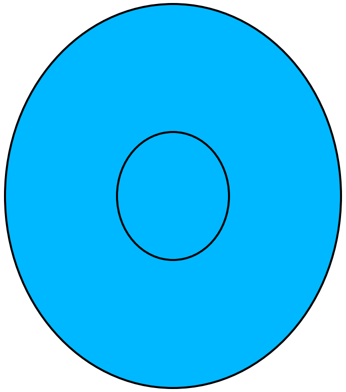
Part VII

Current rating of cables

- Maximum possible temperature rise of insulation
- Method of heat dissipation through the cable
- The installation conditions
- Heat flow in a cable is similar to leakage current flow (an analogy between electric field and thermal field exists).
- So, thermal form of Ohm's law is applicable to determine resistance which is known as thermal resistance.

Thermal resistance

- Thermal resistance is defined as ratio of temperature difference to heat flowing in unit time



- The heat generated can be expressed as a function of current in the cable.
- If the total thermal resistance of the heat path(cable insulation, protective covering and soil) can be calculated, the maximum current rating can be determined.

Permissible current loading