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## Chapter7 Underground cables

***An underground cable** essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.*

Although several types of cables are available, the type of cable to be used will depend upon the working voltage and service requirements. In general, a cable must fulfil the following necessary requirements:

- The conductor used in cables should be tinned stranded copper or aluminium of high conductivity. Stranding is done so that conductor may become flexible and carry more current.
- The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits.
- The cable must have proper thickness of insulation in order to give high degree of safety and reliability at the voltage for which it is designed.
- The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it.
- The materials used in the manufacture of cables should be such that there is complete chemical and physical stability throughout.

## Construction of cables:

- ***Cores or Conductors.*** 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.
- ***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, gases and other damaging liquids (acids or alkalis) 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.
- ***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*.

## Insulating materials for cables:

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 *i.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

The principal insulating materials used in cables are rubber, vulcanised India rubber, impregnated paper, varnished cambric and polyvinyl chloride.

**Rubber.** Rubber may be obtained from milky sap of tropical trees or it may be produced from oil products. It has relative permittivity varying between 2 and 3, dielectric strength is about 30 kV/mm and resistivity of insulation is $10^{17}\Omega$ cm. Although pure rubber has reasonably high insulating properties, it suffers from some major drawbacks *viz.*, readily absorbs moisture, maximum safe temperature is low (about 38ºC), soft and liable to damage due to rough handling and ages when exposed to light. Therefore, pure rubber cannot be used as an insulating material.

**Vulcanised India Rubber (*V.I.R.*).** It is prepared by mixing pure rubber with mineral matter such as zine oxide, red lead etc., and 3 to 5% of sulphur. The compound so formed is rolled into thin sheets and cut into strips. The rubber compound is then applied to the conductor and is heated to a temperature of about 150ºC. The whole process is called *vulcanisation* and the product obtained is known as vulcanised India rubber.

Vulcanised India rubber has greater mechanical strength, durability and wear resistant property than pure rubber. Its main drawback is that sulphur reacts very quickly with copper and for this reason, cables using *VIR* insulation have tinned copper conductor. The *VIR* insulation is generally used for low and moderate voltage cables.

**Impregnated paper.** It consists of chemically pulped paper made from wood chippings and impregnated with some compound such as paraffinic or napthenic material. This type of insulation has almost superseded the rubber insulation. It is because it has the advantages of low cost, low capacitance, high dielectric strength and high insulation resistance. The only disadvantage is that paper is hygroscopic and even if it is impregnated with suitable compound, it absorbs moisture and thus lowers the insulation resistance of the cable. For this reason, paper insulated cables are always provided with some protective covering and are never left unsealed. If it is required to be left unused on the site during laying, its ends are temporarily covered with wax or tar.

**Varnished cambric.** It is a cotton cloth impregnated and coated with varnish. This type of insulation is also known as *empire tape*. The cambric is lapped on to the conductor in the form of a tape and its surfaces are coated with petroleum jelly compound to allow for the sliding of one turn over another as the cable is bent. As the varnished cambric is hygroscopic, therefore, such cables are always provided with metallic sheath. Its dielectric strength is about 4 kV/mm and permittivity is 2.5 to 3.8.

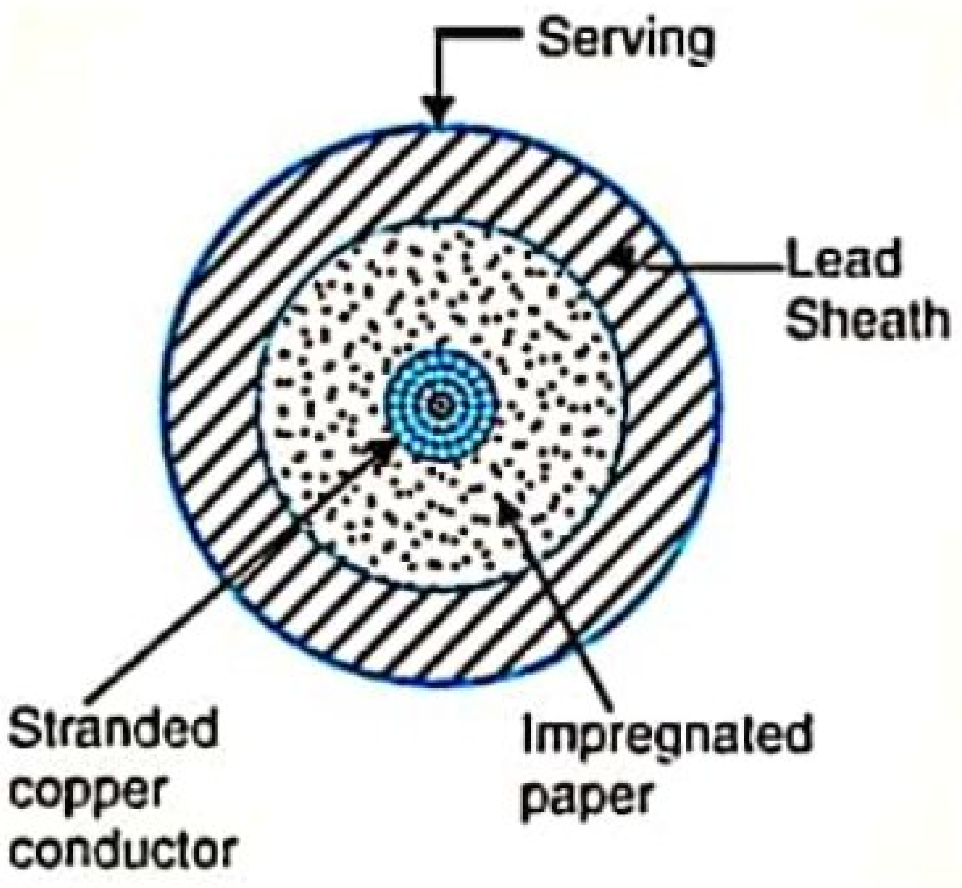
**Polyvinyl chloride (*PVC*).** This insulating material is a synthetic compound. It is obtained from the polymerisation of acetylene and is in the form of white powder. For obtaining this material as a cable insulation, it is compounded with certain materials known as plasticizers which are liquids with high boiling point. The plasticizer forms a gell and renders the material plastic over the desired range of temperature.

## Classification of cables:

Cables for underground service may be classified in two ways according to (*i*) the type of insulating material used in their manufacture (*ii*) the voltage for which they are manufactured. However, the latter method of classification is generally preferred, according to which cables can be divided into the following groups :

- Low-tension (L.T.) cables — upto 1000 V

- High-tension (H.T.) cables — upto 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



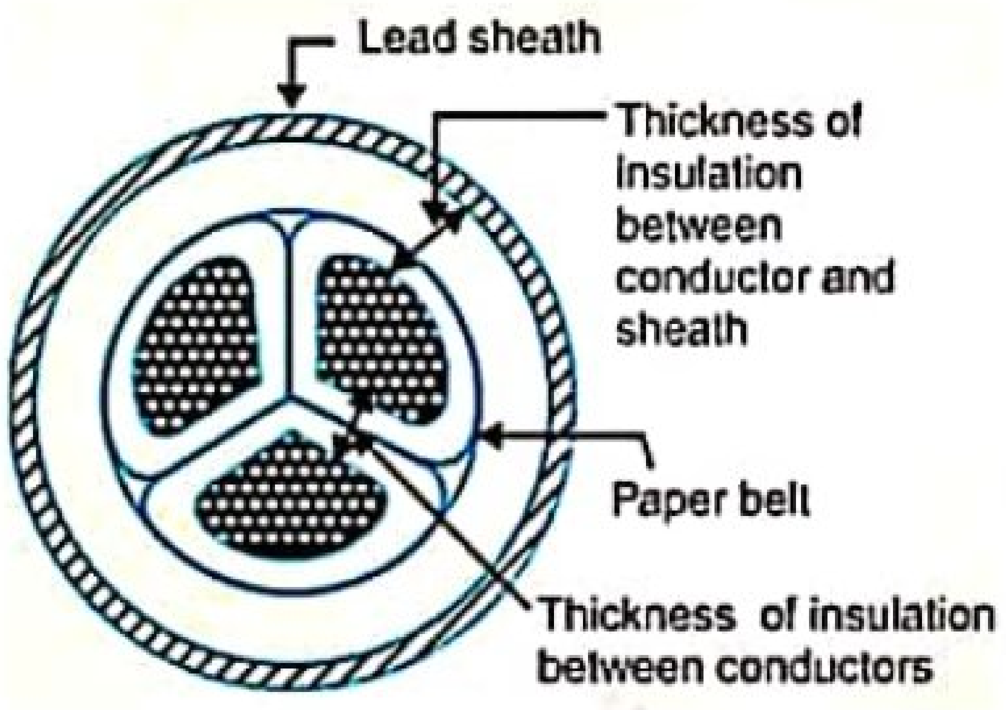
A cable may have one or more than one core depending upon the type of service for which it is intended. It may be (*i*) single-core (*ii*) two-core (*iii*) three-core (*iv*) four-core etc. For a 3-phase service, either 3-single-core cables or three-core cable can be used depending upon the operating voltage and load demand. The cable has ordinary construction be- cause the stresses developed in the cable for low voltages (upto 6600 V) are generally small. It consists of one circular core of tinned stranded copper (or aluminium) 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. Single-core cables are not usually armoured in order to avoid excessive sheath losses. The principal advantages of single-core cables are simple construction and availability of larger copper section.

## Cables for 3 phase service:

underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cable or three single core cables may be used. For voltages upto 66 kV, 3-core cable (*i.e.*, multi-core construction) is preferred due to economic reasons. However, for voltages beyond 66 kV, 3-core-cables become too large and unwieldy and, therefore, single-core cables are used. The following types of cables are generally used for 3-phase service :

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

**Belted cables.** These cables are used for voltages upto 11kV but in extraordinary cases, their use may be extended upto 22kV. 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 gap between the insulated cores is filled with fibrous insulating material (jute etc.) so as to give circular cross-section to the cable. The cores are generally stranded and may be of non- circular shape to make better use of available space. The belt is covered with lead sheath to protect the cable against ingress of moisture and mechanical injury. The lead sheath is covered with one or more layers of armouring with an outer serving.



**Screened cables.** These cables are meant for use upto 33 kV, but in particular cases their use may be extended to operating voltages upto 66 kV. Two principal types of screened cables are H- type cables and S.L. type cables.

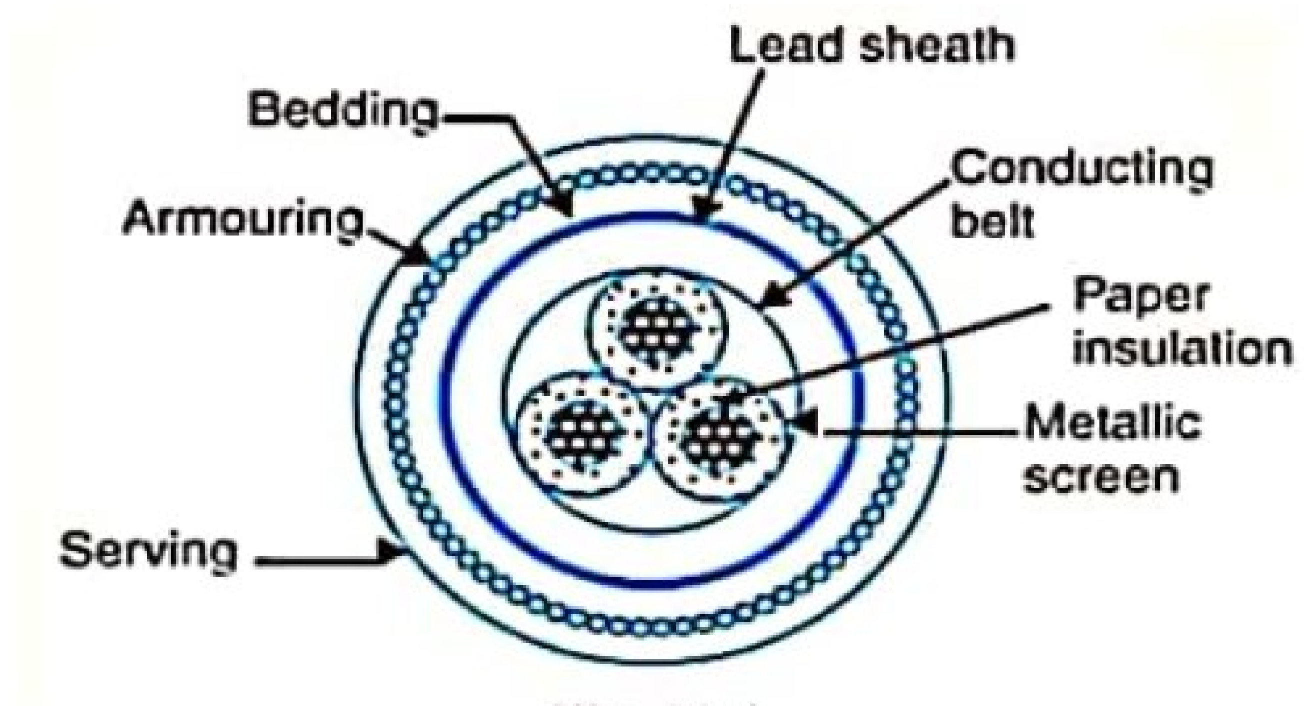


Fig. 11.4

**Pressure cables** For voltages beyond 66 kV, solid type cables are unreliable because there is a danger of breakdown of insulation due to the presence of voids. When the operating voltages are greater than 66 kV, *pressure cables* are used. In such cables, voids are eliminated by increasing the pressure of compound and for this reason they are called pressure cables. Two types of pressure cables *viz* oil-filled cables and gas pressure cables are commonly used.

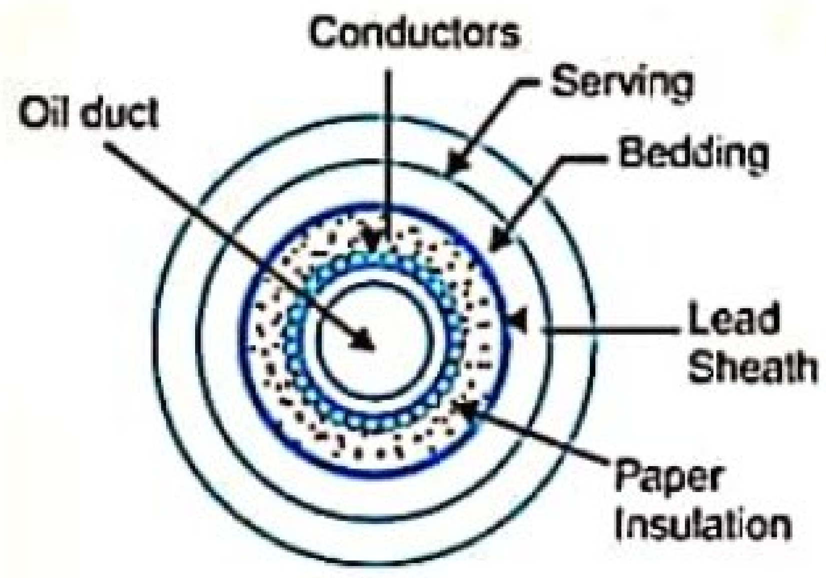
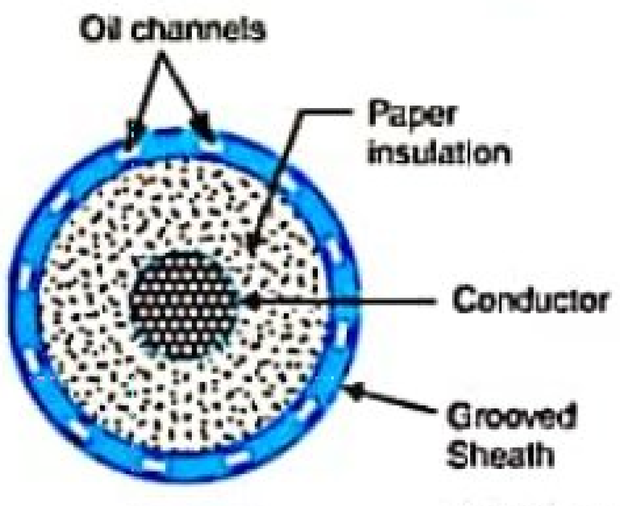


Fig. 11.6 Single-core conductor channel, oil-filled cable



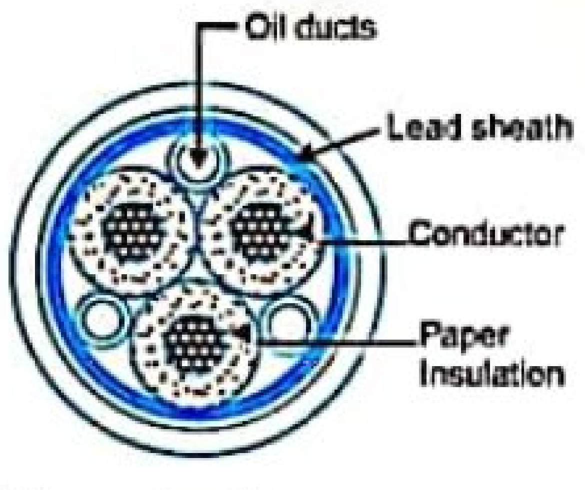


Fig. 11.7 *Oil-filled cables* Fig. 11.8

## Laying of underground cable:

The reliability of underground cable network depends to a considerable extent upon the proper laying and attachment of fittings *i.e.*, cable end boxes, joints, branch connectors etc. There are three main methods of laying underground cables *viz.*, direct laying, draw-in system and the solid system.

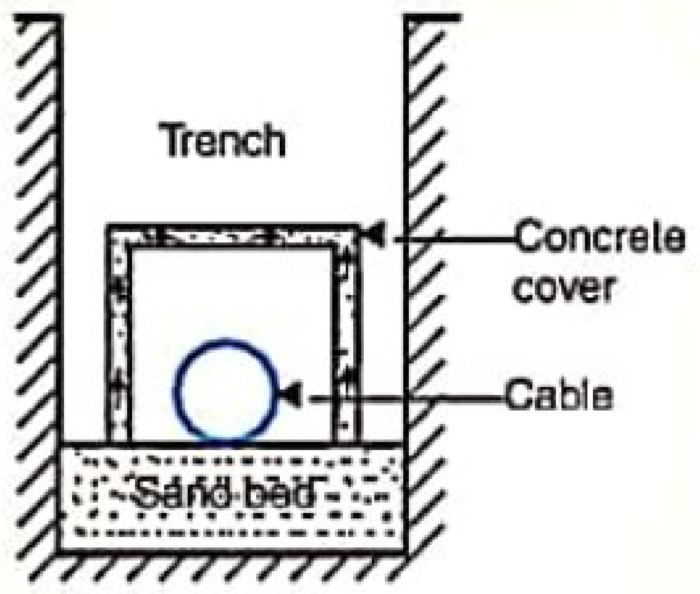


Fig. 11.10

**Direct laying.** This method of laying underground cables is simple and cheap and is much favoured in modern practice. In this method, a trench of about 1·5 metres deep and 45 cm wide is dug. The trench is covered with a layer of fine sand (of about 10 cm thickness) and the cable is laid over this sand bed. The sand prevents the entry of moisture from the ground and thus protects the cable from decay. After 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 is 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. Cables to be laid in this way must have serving of bituminised paper and hessian tape so as to provide protection against corrosion and electorlysis.

*Advantages*

- It is a simple and less costly method.
- It gives the best conditions for dissipating the heat generated in the cables.
- It is a clean and safe method as the cable is invisible and free from external disturbances.

*Disadvantages*

- The extension of load is possible only by a completely new excavation which may cost as much as the original work.
- The alterations in the cable netwok cannot be made easily.
- The maintenance cost is very high.
- Localisation of fault is difficult.
- It cannot be used in congested areas where excavation is expensive and inconvenient.

**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. 11.11 shows section through four-way underground duct line. Three of the ducts carry transmission cables and the fourth duct carries relay protection connection, pilot wires. Care must be taken that where the duct line changes direction ; depths, dips and offsets be made with a very long radius or it will be difficult to pull a large cable between the manholes. The distance between the manholes should not be too long so as to simplify the pulling in of the cables. The cables to be laid in this way need not be armoured but must be provided with serving of hessian and jute in order to protect them when being pulled into the ducts.

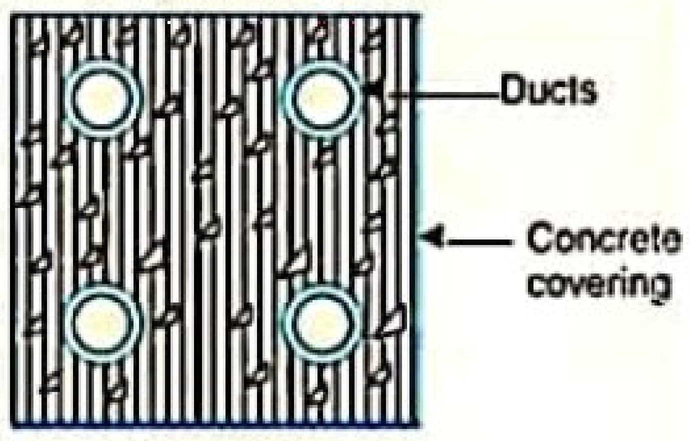


Fig. 11.11

*Advantages*

- Repairs, alterations or additions to the cable network can be made without opening the ground.
- As the cables are not armoured, therefore, joints become simpler and maintenance cost is reduced considerably.
- There are very less chances of fault occurrence due to strong mechanical protection pro- vided by the system.

*Disadvantages*

- The initial cost is very high.
- The current carrying capacity of the cables is reduced due to the close grouping of cables and unfavourable conditions for dissipation of heat.

**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 a bituminous or asphaltic compound and covered over. Cables laid in this manner are usually plain lead covered because troughing affords good mechanical protection.

*Disadvantages*

- It is more expensive than direct laid system.
- It requires skilled labour and favourable weather conditions.
- Due to poor heat dissipation facilities, the current carrying capacity of the cable is reduced

## Types of cable faults:

Cables are generally laid directly 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 :

(i) Open-circuit fault
(ii) Short-circuit fault
(iii) Earth fault.

*Open-circuit fault*. 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 a megger. For this purpose, the three conductors of the 3-core cable at the far end are shorted and earthed. Then resistance be- tween each conductor and earth is measured by a megger. The megger 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 fault.* 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 step is repeated for other conductors taking two at a time.

*Earth fault.* 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 in underground cables:

(i) Murray loop test
(ii) Varley loop test

### Murray Loo p Test

The Murray loop test is the most common and accurate method of locating earth fault or short-circuit fault in underground cables.

(i) **Earth fault :** Fig. 11.22 shows the circuit diagram for locating the earth fault by Murray loop test. Here *AB* is the sound cable and *CD* is the faulty cable; the earth fault occuring at point *F*. The far end *D* of the faulty cable is joined to the far end *B* of the sound cable through a low resistance

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link. Two variable resistances $P$ and $Q$ are joined to ends $A$ and $C$ (See Fig. 11.22) respectively and serve as the ratio arms of the Wheatstone bridge.

Let $R$ = resistance of the conductor loop upto the fault from the test end

$X$ = resistance of the other length of the loop

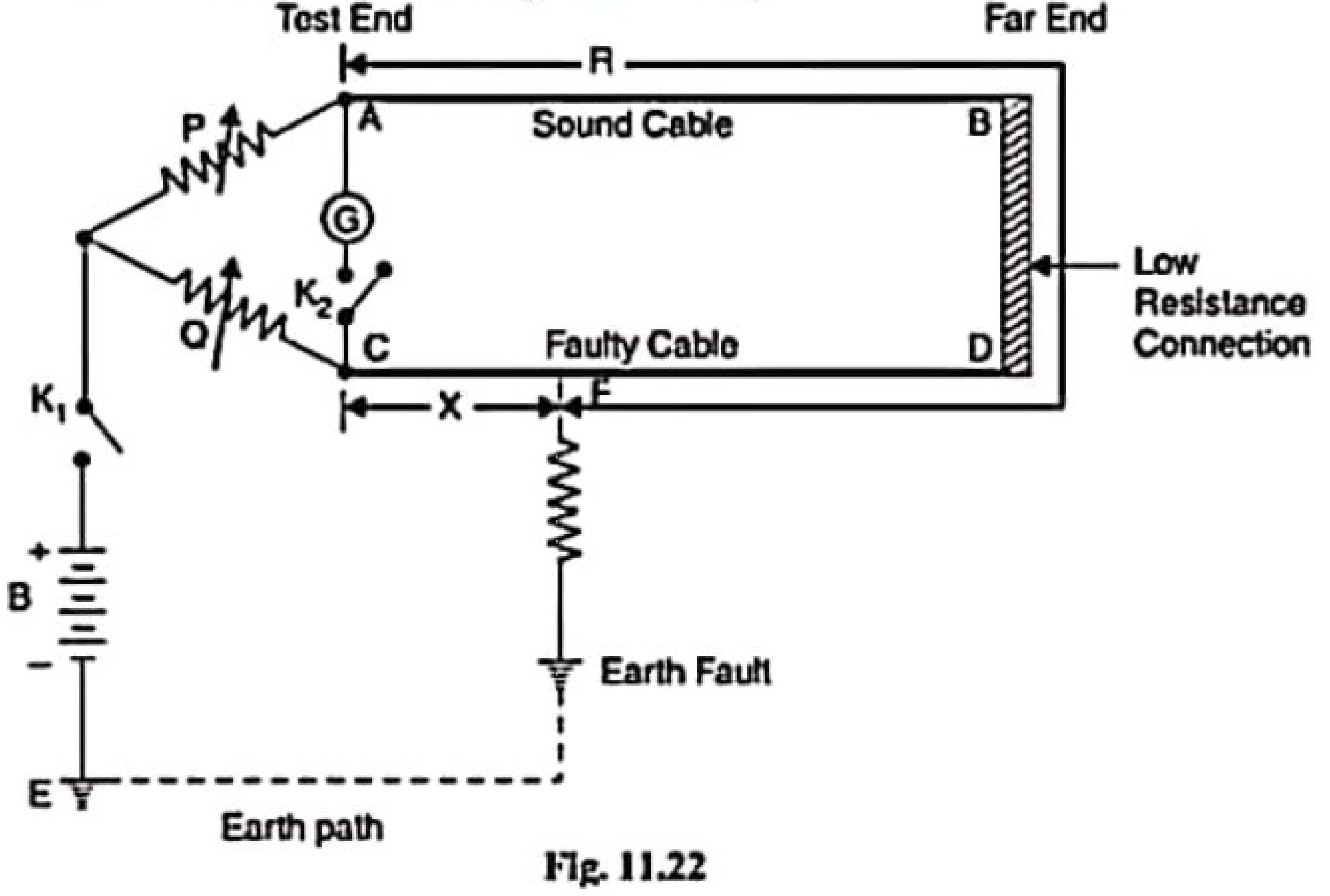

Fig. 11.22

Note that $P$, $Q$, $R$ and $X$ are the four arms of the Wheatstone bridge. The resistances $P$ and $Q$ are varied till the galvanometer indicates zero deflection.

In the balanced position of the bridge, we have,

$$\frac{P}{Q} = \frac{R}{X}$$

or
$$\frac{P}{Q}+1 = \frac{R}{X}+1$$

or
$$\frac{P+Q}{Q} = \frac{R+X}{X}$$

If $r$ is the resistance of each cable, then $R+X=2r$.

$$\therefore \quad \frac{P+Q}{Q} = \frac{2r}{X}$$

or
$$X = \frac{Q}{P+Q}\times 2r$$

If $l$ is the length of each cable in metres, then resistance per metre length of cable $= \frac{r}{l}$.

$\therefore$ Distance of fault point from test end is

$$d = \frac{X}{r/l} = \frac{Q}{P+Q}\times 2r \times \frac{l}{r} = \frac{Q}{P+Q}\times 2l$$

or
$$d = \frac{Q}{P+Q}\times (\text{loop length}) \ {}^{*}\text{metres}$$

Thus the position of the fault is located. Note that resistance of the fault is in the battery circuit and not in the bridge circuit. Therefore, fault resistance does not affect the balancing of the bridge. However, if the fault resistance is high, the sensitivity of the bridge is reduced.

**(*ii*) Short-circuit fault :** Fig. 11.23 shows the circuit diagram for locating the short-circuit fault by Murray loop test. Again $P$, $Q$, $R$ and $X$ are the four arms of the bridge. Note that fault resistance is in the battery circuit and not in the bridge circuit. The bridge in balanced by adjusting the resistances $P$ and $Q$. In the balanced position of the bridge :

$$\frac{P}{Q} = \frac{R}{X}$$

or
$$\frac{P+Q}{Q} = \frac{R+X}{X} = \frac{2r}{X}$$

∴
$$X = \frac{Q}{P+Q} \times 2r$$

or
$$X = \frac{Q}{P+Q} \times (\text{loop length}) \text{ metres}$$

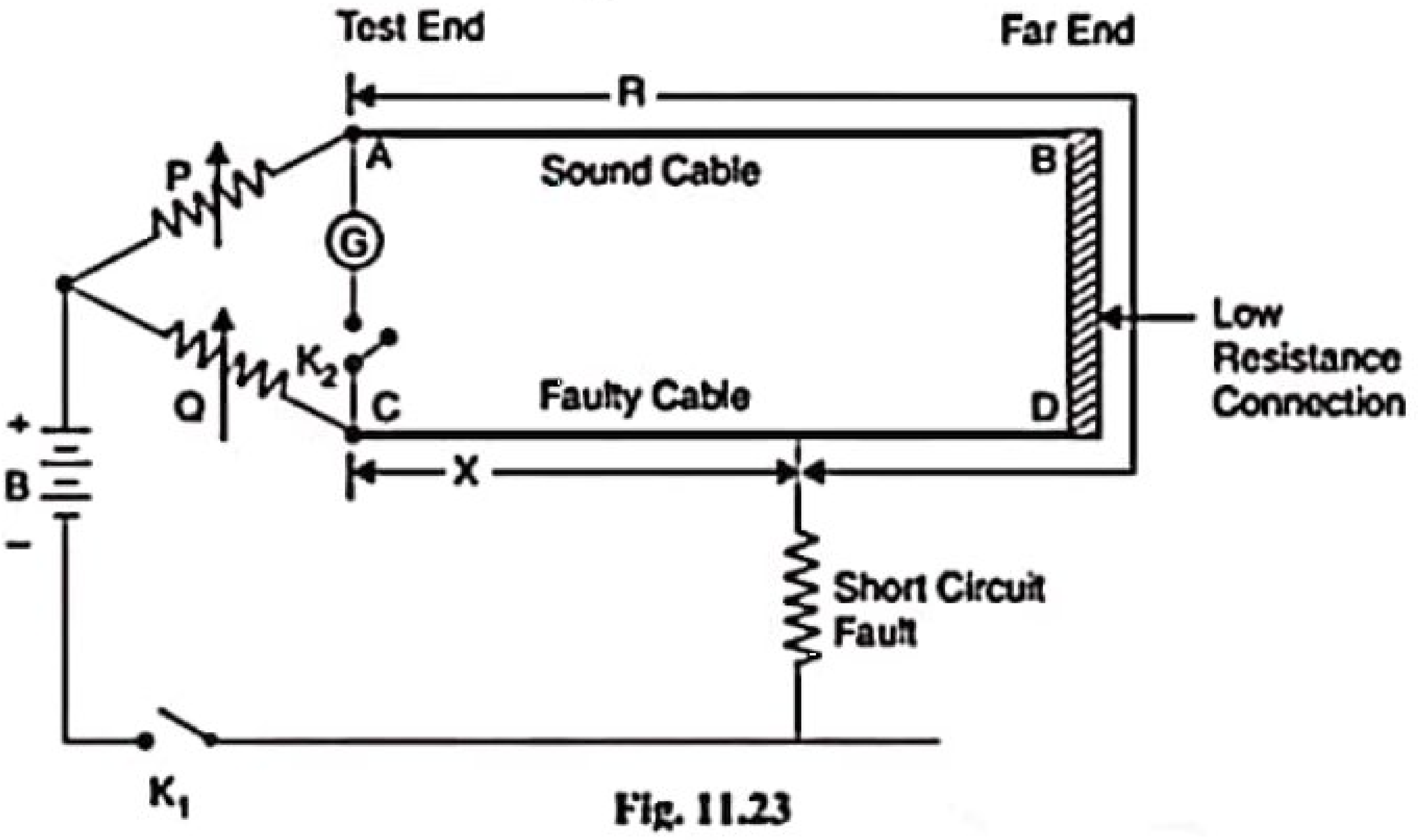

Fig. 11.23

Thus the position of the fault is located.

## Varley Loop Test

The Varley loop test is also used to locate earth fault or short-circuit fault in underground cables. This test also employs Wheatstone bridge principle. It differs from Murray loop test in that here the ratio arms $P$ and $Q$ are fixed resistances. Balance is obtained by adjusting the variable resistance $S$

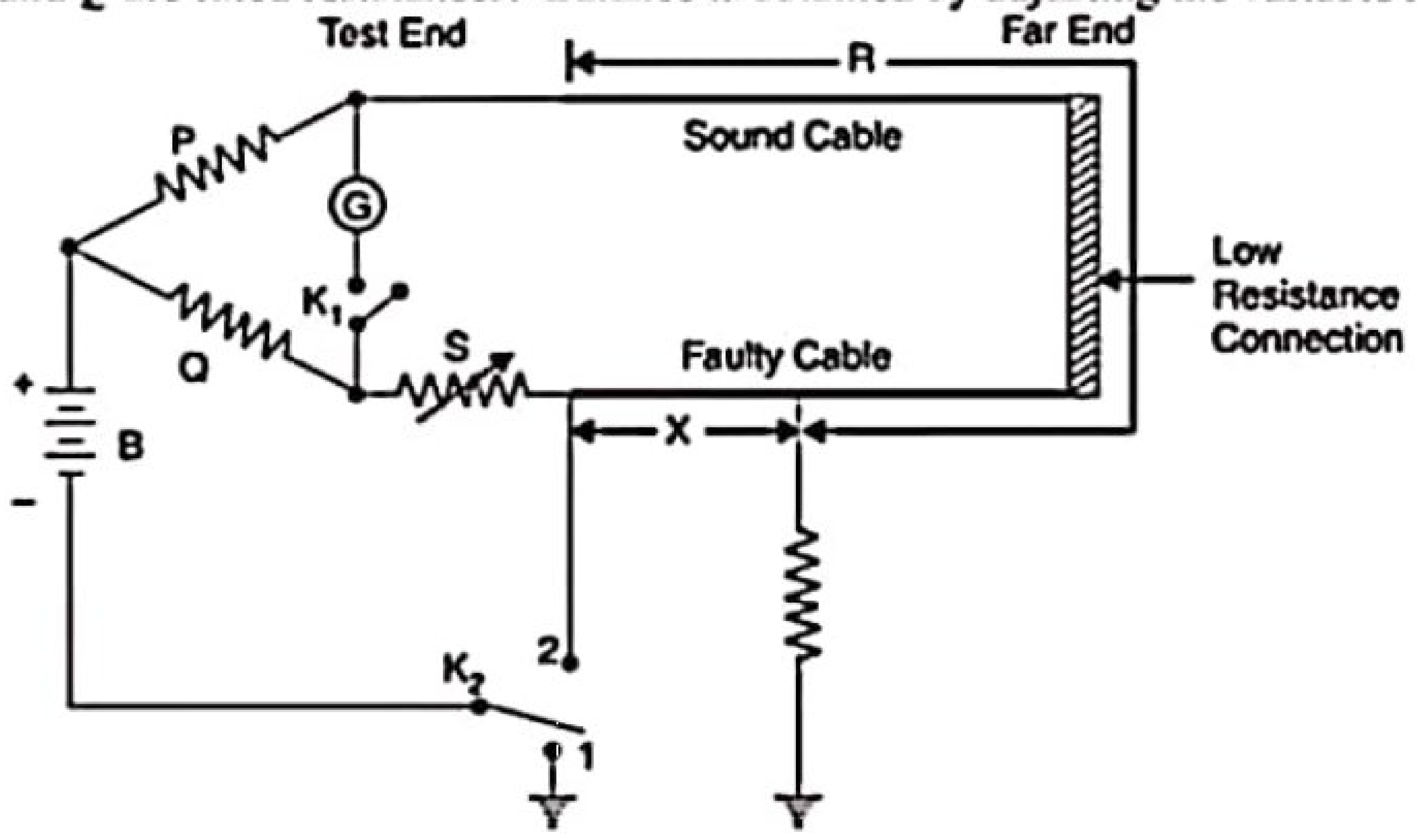

Fig. 11.24 Varley Loop Test (Earth Fault)

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connected to the test end of the faulty cable. The connection diagrams for locating the earth fault and short-circuit fault by Varley loop test are shown in Figs. 11.24 and 11.25 respectively.

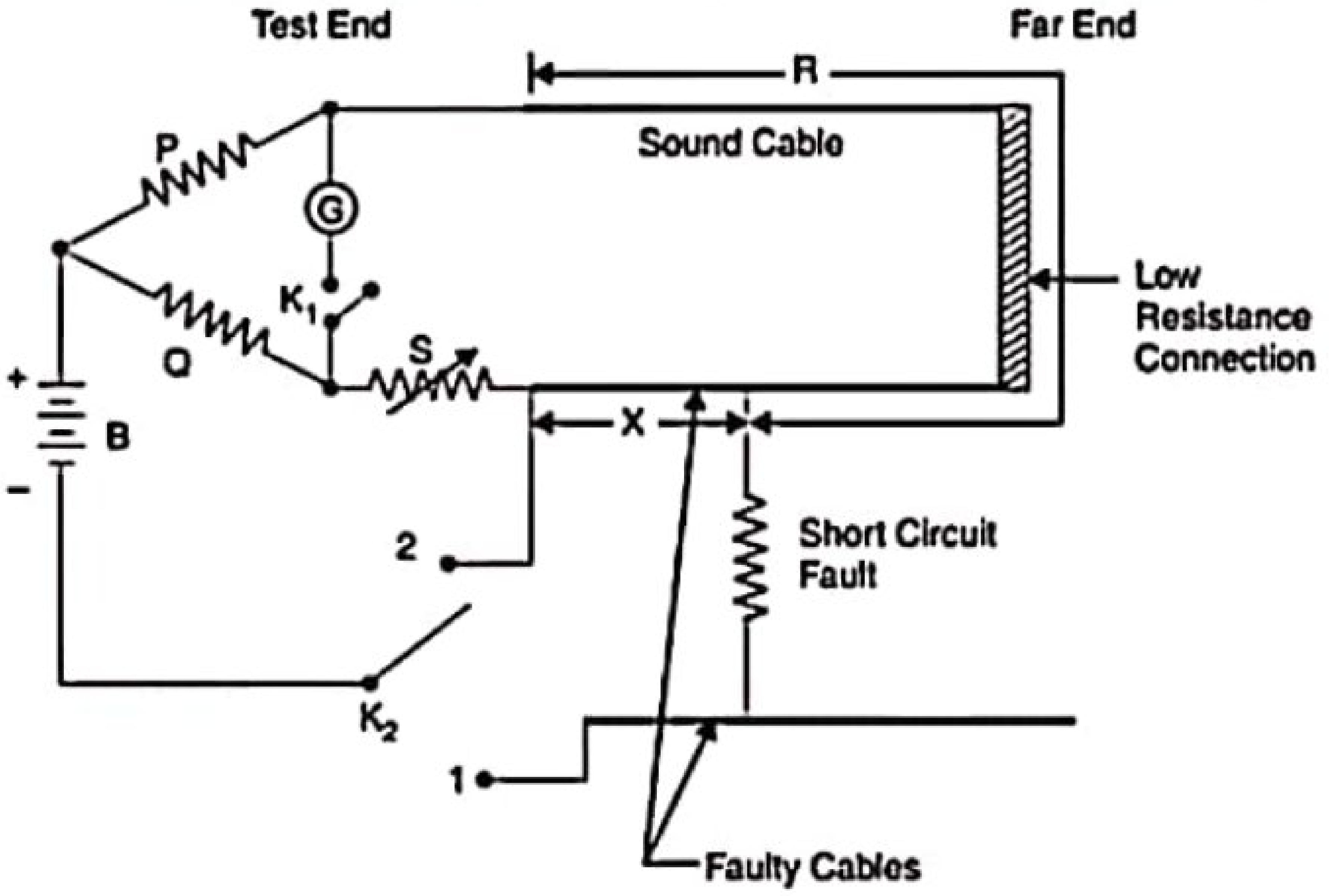

Fig. 11.25 Varley Loop Test (Short Circuit Test)

For earth fault or short-circuit fault, the key $K_2$ is first thrown to position 1. The variable resistance $S$ is varied till the bridge is balanced for resistance value of $S_1$. Then,

$$\frac{P}{Q} = \frac{R}{X+S_1}$$

or
$$\frac{P+Q}{Q} = \frac{R+X+S_1}{X+S_1}$$

or
$$X = \frac{Q(R+X)-PS_1}{P+Q} \quad \text{...}(i)$$

Now key $K_2$ is thrown to position 2 (for earth fault or short-circuit fault) and bridge is balanced with new value of resistance $S_2$. Then,

$$\frac{P}{Q} = \frac{R+X}{S_2}$$

or
$$(R+X)Q = PS_2 \quad \text{...}(ii)$$

From eqs. (*i*) and (*ii*), we get,

$$X = \frac{P(S_2-S_1)}{P+Q}$$

Since the values of $P$, $Q$, $S_1$ and $S_2$ are known, the value of $X$ can be determined.

$$\text{Loop resistance} = R+X = \frac{P}{Q}S_2$$

If $r$ is the resistance of the cable per metre length, then,

Distance of fault from the test end is

$$d = \frac{X}{r} \text{ metres}$$

## Chapter8 Economic Aspects

*The cosine of angle between voltage and current in an a.c. circuit is known as* **power factor.**

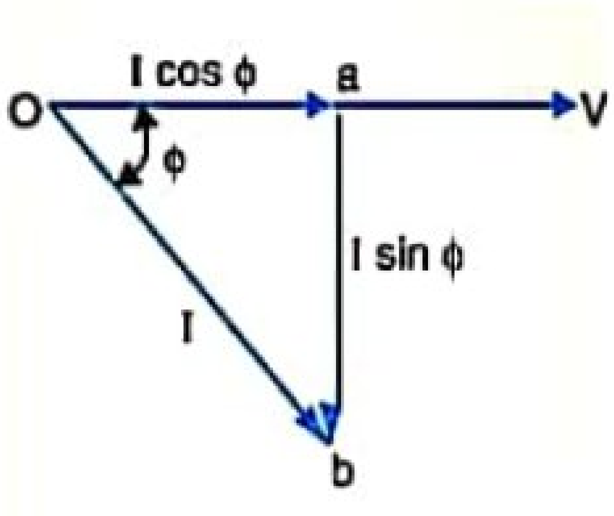

Fig. 6.1

Power factor= R/Z

Power factor= Active power / apparent power

## Disadvantages of low power factor:

Lower the power factor, higher is the load current and *vice-versa*. A power factor less than unity results in the following disadvantages :

1. kVA rating of the equipment is inversely proportional to power factor. The smaller the power factor, the larger is the kVA rating. Therefore, at low power factor, the kVA rating of the equipment has to be made more, making the equipment larger and expensive.
2. the conductor will have to carry more current at low power factor. This necessitates large conductor size.

3. Large copper losses. The large current at low power factor causes more $I^2R$ losses in all the elements of the supply system. This results in poor efficiency.

4. Poor voltage regulation. The large current at low lagging power factor causes greater voltage drops in alternators, transformers, transmission lines and distributors. This results in the decreased voltage available at the supply end, thus impairing the performance of utilisation devices.

5. Reduced handling capacity of system. The lagging power factor reduces the handling capacity of all the elements of the system. It is because the reactive component of current prevents the full utilisation of installed capacity.

## Causes of low power factor:

(i) Most of the a.c. motors are of induction type (1ϕ and 3ϕ induction motors) which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0·2 to 0·3) and rises to 0·8 or 0·9 at full load.

(ii) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.

(iii) The load on the power system is varying ; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetisation current. This results in the decreased power factor.

## Power factor improvement:

The low power factor is mainly due to the fact that most of the power loads are inductive and, therefore, take lagging currents. In order to improve the power factor, some device taking leading power should be connected in parallel with the load. One of such devices can be a capacitor. The capacitor draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the power factor of the load.

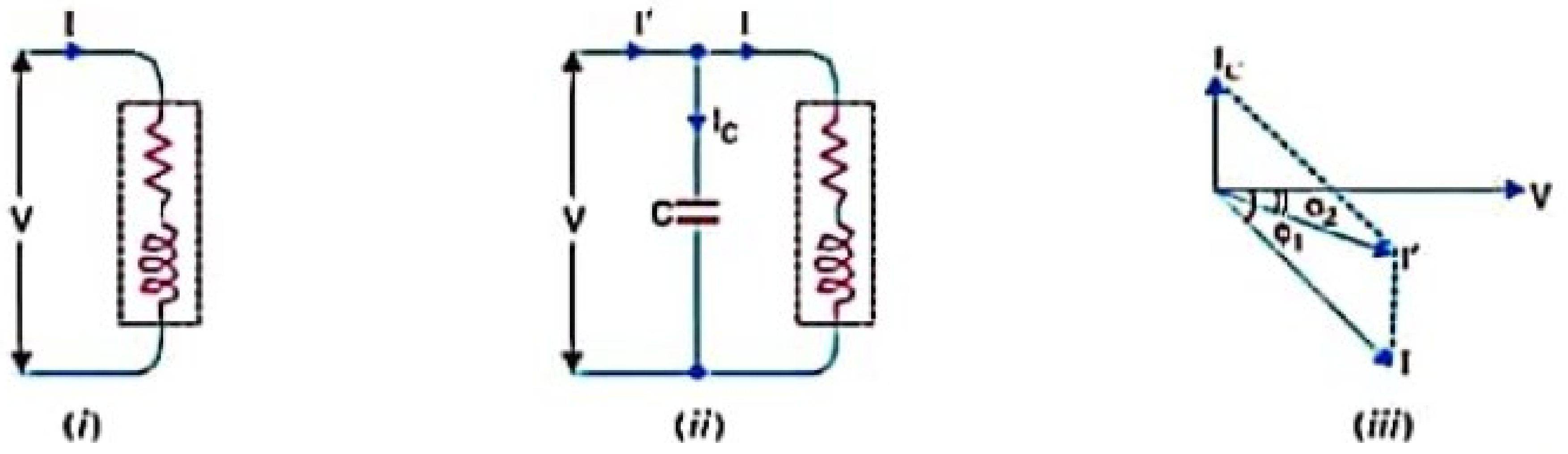

Fig. 6.3

## Power Factor Improvement Equipment:

Normally, the power factor of the whole load on a large generating station is in the region of 0·8 to 0·9. However, sometimes it is lower and in such cases it is generally desirable to take special steps to improve the power factor. This can be achieved by the following equipment :

1. Static capacitors.2. Synchronous condenser.3. Phase advancers.

**Static capacitor.** The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor. The capacitor (generally known as static capacitor) draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the power factor of the load. For three-phase loads, the capacitors can be connected in delta or star.

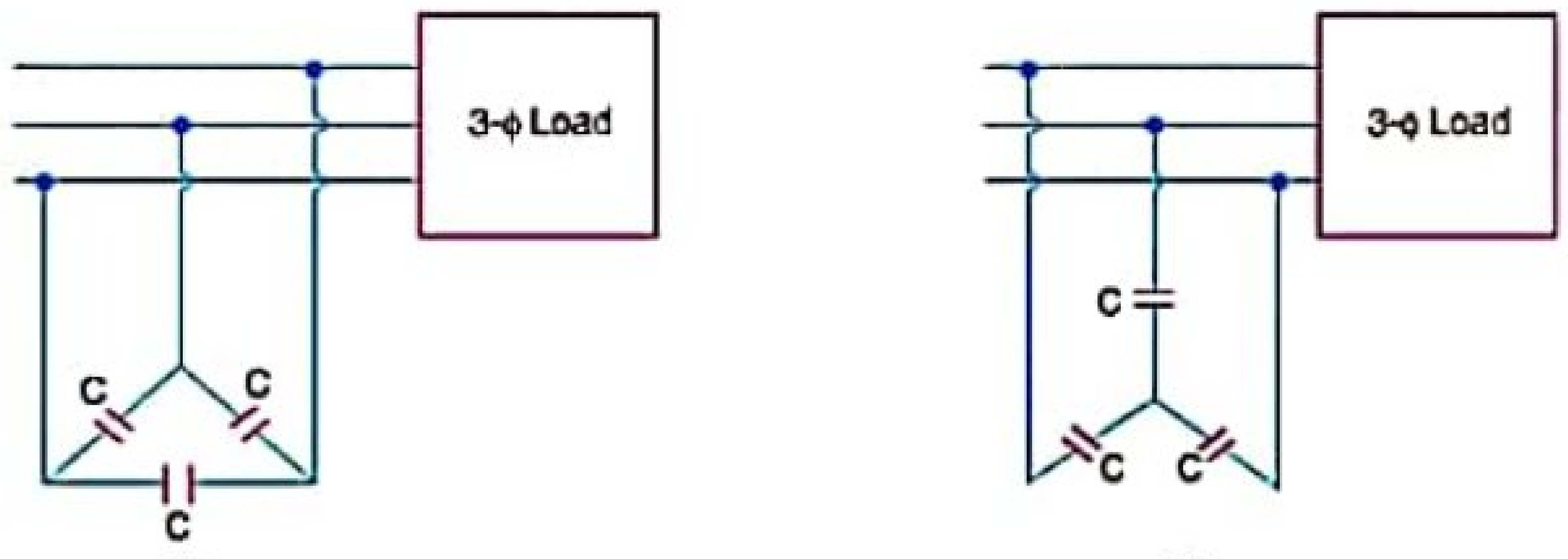

Fig. 6.4

Advantages

- They have low losses.
- They require little maintenance as there are no rotating parts.
- They can be easily installed as they are light and require no foundation.

- They can work under ordinary atmospheric conditions.

### Disadvantages

- They have short service life ranging from 8 to 10 years.
- They are easily damaged if the voltage exceeds the rated value.
- Once the capacitors are damaged, their repair is uneconomical.

**Synchronous condenser.** A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as *synchronous condenser.* When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralises the lagging reactive component of the load. Thus the power factor is improved.

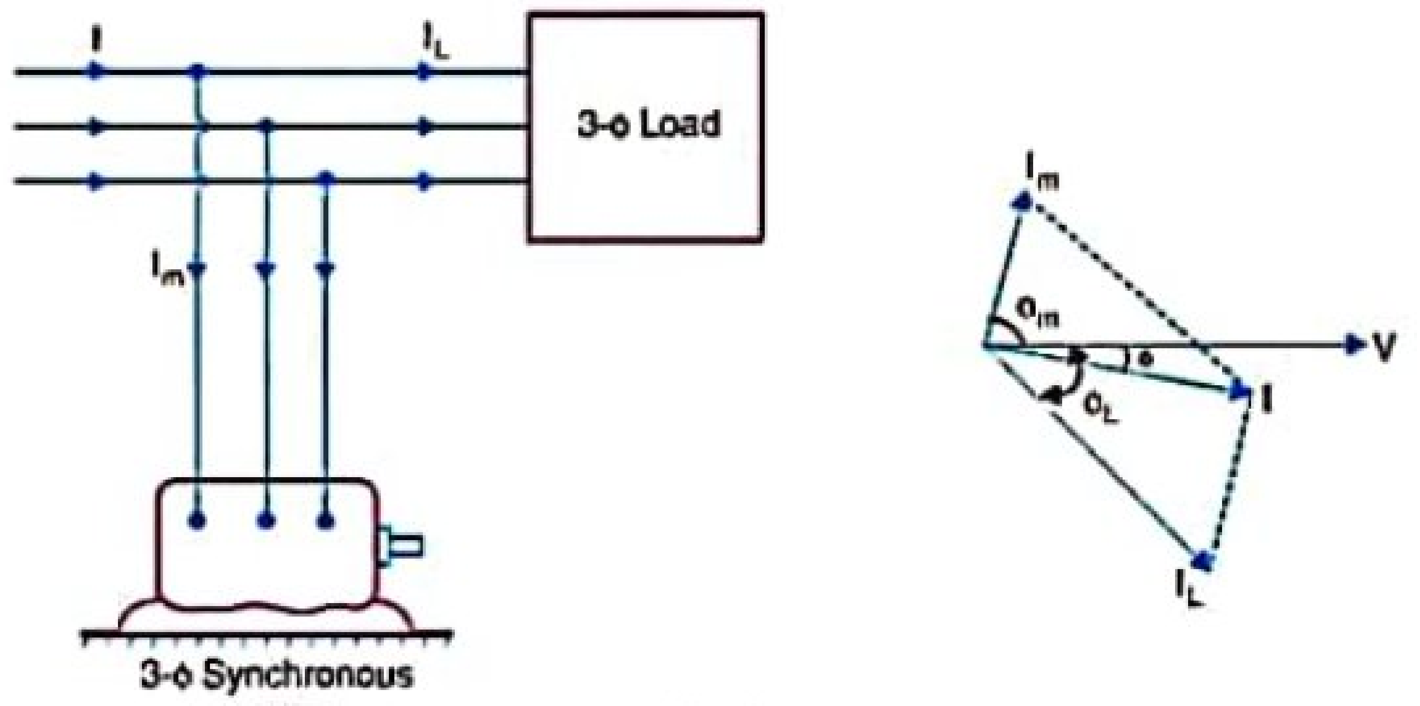

Fig. 6.5

### Advantages

- By varying the field excitation, the magnitude of current drawn by the motor can be changed by any amount. This helps in achieving stepless † control of power factor.
- The motor windings have high thermal stability to short circuit currents.
- The faults can be removed easily.

### Disadvantages

- There are considerable losses in the motor.
- The maintenance cost is high.
- It produces noise.
- Except in sizes above 500 kVA, the cost is greater than that of static capacitors of the same rating.
- As a synchronous motor has no self-starting torque, therefore, an auxiliary equipment has to be provided for this purpose.

**Phase advancers.** Phase advancers are used to improve the power factor of induction motors. The low power factor of an induction motor is due to the fact that its stator winding draws exciting current which lags behind the supply voltage by 90°. If the exciting ampere turns can be provided from some other a.c. source, then the stator winding will be relieved of exciting current and the power factor of the motor can be improved. This job is accomplished by the phase advancer which is simply an a.c. exciter. The phase advancer is mounted on the same shaft as the main motor and is connected in the rotor circuit of the motor. It provides exciting ampere turns to the rotor circuit at slip frequency. By providing more ampere turns than required, the induction motor can be made to operate on leading power factor like an over-excited synchronous motor.

Phase advancers have two principal advantages. Firstly, as the exciting ampere turns are supplied at slip frequency, therefore, lagging kVAR drawn by the motor are considerably reduced. Secondly, phase advancer can be conveniently used where the use of synchronous motors is unadmissible. However, the major disadvantage of phase advancers is that they are not economical for motors below 200 H.P.

## Load Curves

*The curve showing the variation of load on the power station with respect to (w.r.t) time is known as a* **load curve.**

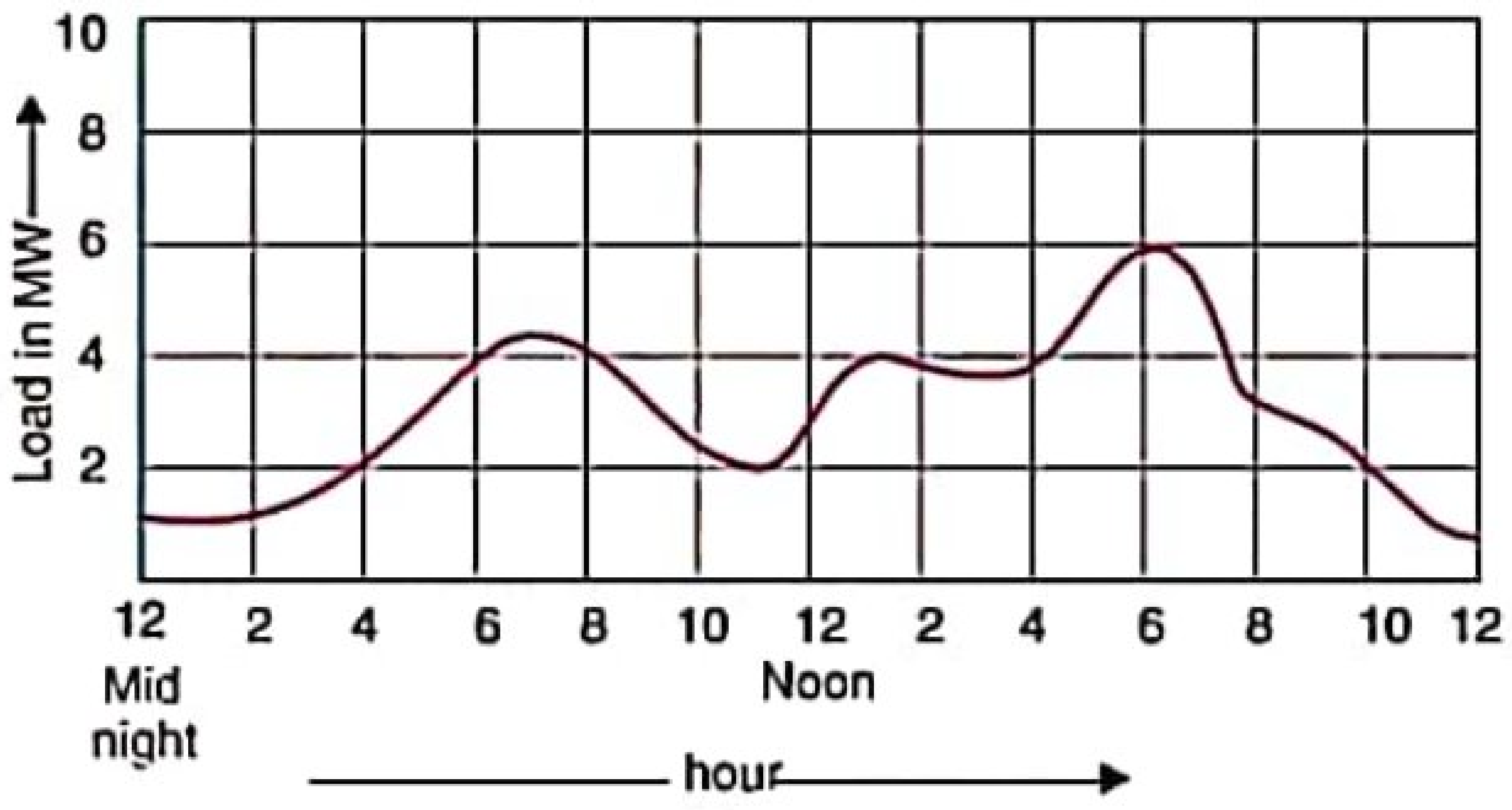

Fig. 3.2

- The daily load curve shows the variations of load on the power station during different hours of the day.
- The area under the daily load curve gives the number of units generated in the day. Units generated/day = Area (in kWh) under daily load curve.
- The highest point on the daily load curve represents the maximum demand on the station on that day.
- The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

$$\text{Average load} = \frac{\text{Area (in kWh) under daily load curve}}{\text{24 hours}}$$

The ratio of the area under the load curve to the total area of rectangle in which it is contained gives the load factor.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{\text{Average load} \times 24}{\text{Max. demand} \times 24}$$

$$= \frac{\text{Area (in kWh) under daily load curve}}{\text{Total area of rectangle in which the load curve is contained}}$$

## Demand factor.

It is the ratio of maximum demand on the power station to its connected load i.e.

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

The value of demand factor is usually less than 1. It is expected because maximum demand on the power station is generally less than the connected load. If the maximum demand on the power station is 80 MW and the connected load is 100 MW, then demand factor = 80/100 = 0·8. The knowledge of demand factor is vital in determining the capacity of the plant equipment.

## Maximum demand

It is the greatest demand of load on the power station during a given period.
The load on the power station varies from time to time. The maximum of all the demands that have occurred during a given period (day) is the maximum demand. Thus referring back to the load curve the maximum demand on the power station during the day is 6 MW and it occurs at 6 P.M. Maximum demand is generally less than the connected load because all the consumer do not switch on their connected load to the system at a time. The knowledge of maximum demand is very important as it helps in determining the installed capacity of the station. The station must be capable of meeting the maximum demand.

## Load factor

*The ratio of average load to the maximum demand during a given period is known as* **load factor** *i.e.,*

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}}$$

If the plant is in operation for T hours,

$$\text{Load factor} = \frac{\text{Average load} \times T}{\text{Max. demand} \times T} = \frac{\text{Units generated in T hours}}{\text{Max. demand} \times \text{T hours}}$$

The load factor may be daily load factor, monthly load factor or annual load factor if the time period considered is a day or month or year. Load factor is always less than 1 because average load is smaller than the maximum demand.

## Diversity factor.

The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor i.e.

$$\text{Diversity factor} = \frac{\text{Sum of individual max. demands}}{\text{Max. demand on power station}}$$

## Plant capacity factor

*It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period i.e.,*

$$\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}}$$

$$= \frac{\text{Average demand} \times T^{**}}{\text{Plant capacity} \times T}$$

$$= \frac{\text{Average demand}}{\text{Plant capacity}}$$

## Connected load

*It is the sum of continuous ratings of all the equipments connected to supply system.*

A power station supplies load to thousands of consumers. Each consumer has certain equipment installed in his premises. The sum of the continuous ratings of all the equipments in the consumer's premises is the "connected load" of the consumer. For instance, if a consumer has connections of five 100-watt lamps and a power point of 500 watts, then connected load of the consumer is 5 × 100 + 500= 1000 watts. The sum of the connected loads of all the consumers is the connected load to the power station.

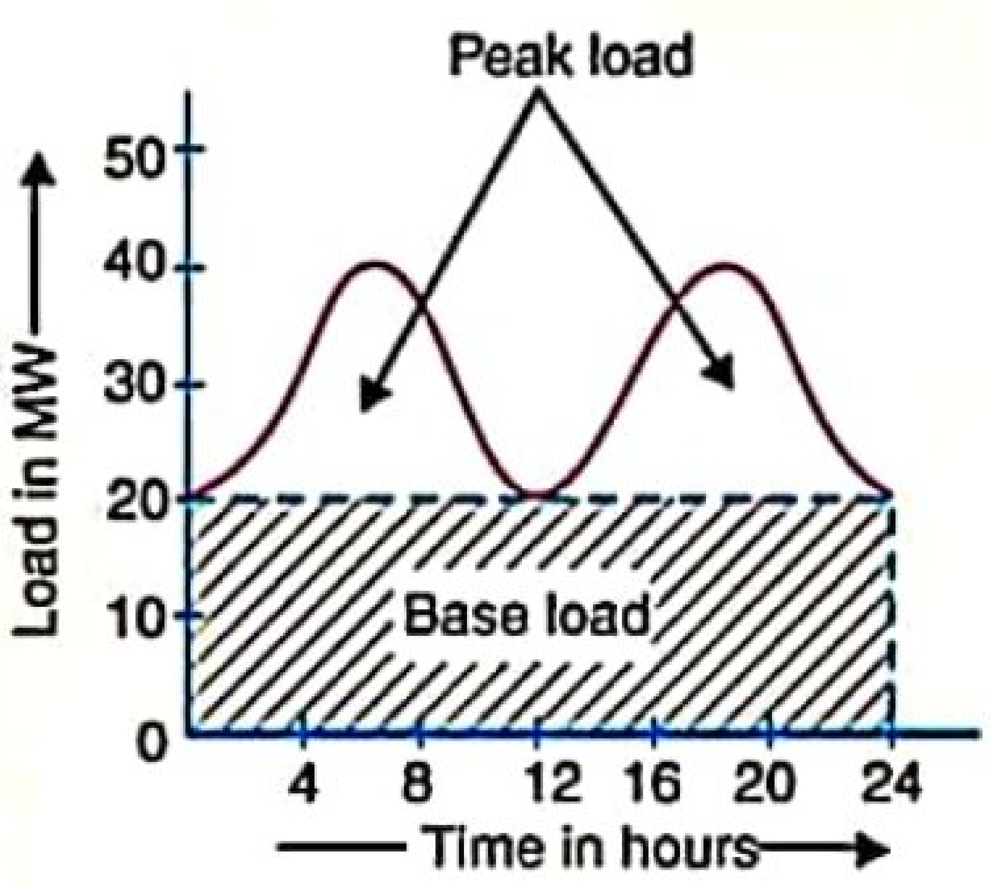

Fig. 3.13

## Base Load and Peak Load on Power Station

The changing load on the power station makes its load curve of variable nature. load on the power station varies from time to time. However, load on the power station can be considered in two parts, namely;

(i) Base load
(ii) Peak load

**Base load.** *The unvarying load which occurs almost the whole day on the station is known as* **base load.**

**Peak load.** *The various peak demands of load over and above the base load of the station is known as* **peak load.**

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## Problems:

**Example** *The maximum demand on a power station is 100 MW. If the annual load factor is 40%, calculate the total energy generated in a year.*

**Solution.**

$$
\begin{aligned}
\text{Energy generated/year} &= \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year} \\
&= (100 \times 10^3) \times (0{\cdot}4) \times (24 \times 365)\ \text{kWh} \\
&= 3504 \times 10^5\ \text{kWh}
\end{aligned}
$$

**Example** *A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being 61·5 × 10⁶ per annum. Calculate (i) the demand factor and (ii) load factor.*

**Solution.**

(*i*) $$\text{Demand factor} = \frac{\text{Max. demand}}{\text{Connected load}} = \frac{20}{43} = 0{\cdot}465$$

(*ii*) $$\text{Average demand} = \frac{\text{Units generated / annum}}{\text{Hours in a year}} = \frac{61{\cdot}5 \times 10^6}{8760} = 7020\ \text{kW}$$

$$\therefore \quad \text{Load factor} = \frac{\text{Average demand}}{\text{Max. demand}} = \frac{7020}{20 \times 10^3} = 0{\cdot}351 \text{ or } 35{\cdot}1\%$$

**Example** *A 100 MW power station delivers 100 MW for 2 hours, 50 MW for 6 hours and is shut down for the rest of each day. It is also shut down for maintenance for 45 days each year. Calculate its annual load factor.*

**Solution.**

Energy supplied for each working day

$$
\begin{aligned}
&= (100 \times 2) + (50 \times 6) = 500\ \text{MWh} \\
\text{Station operates for} &= 365 - 45 = 320 \text{ days in a year} \\
\therefore \quad \text{Energy supplied/year} &= 500 \times 320 = 160{,}000\ \text{MWh} \\
\text{Annual load factor} &= \frac{\text{MWh supplied per annum}}{\text{Max. demand in MW} \times \text{Working hours}} \times 100 \\
&= \frac{160{,}000}{(100) \times (320 \times 24)} \times 100 = 20{\cdot}8\%
\end{aligned}
$$

**Example** *A generating station has a maximum demand of 25MW, a load factor of 60%, a plant capacity factor of 50% and a plant use factor of 72%. Find (i) the reserve capacity of the plant (ii) the daily energy produced and (iii) maximum energy that could be produced daily if the plant while running as per schedule, were fully loaded.*

**Solution.**

(*i*) $$\text{Load factor} = \frac{\text{Average demand}}{\text{Maximum demand}}$$

*or* $$0{\cdot}60 = \frac{\text{Average demand}}{25}$$

$$\therefore \quad \text{Average demand} = 25 \times 0{\cdot}60 = 15\ \text{MW}$$

$$\text{Plant capacity factor} = \frac{\text{Average demand}}{\text{Plant capacity}}$$

$$\therefore \quad \text{Plant capacity} = \frac{\text{Average demand}}{\text{Plant capacity factor}} = \frac{15}{0{\cdot}5} = 30\ \text{MW}$$

$$\therefore \text{ Reserve capacity of plant} = \text{Plant capacity} - \text{maximum demand}$$
$$= 30 - 25 = 5 \text{ MW}$$

(*ii*) $$\text{Daily energy produced} = \text{Average demand} \times 24$$
$$= 15 \times 24 = 360 \text{ MWh}$$

(*iii*) Maximum energy that could be produced

$$= \frac{\text{Actual energy produced in a day}}{\text{Plant use factor}}$$
$$= \frac{360}{0 \cdot 72} = 500 \text{ MWh/day}$$

**Example** *A diesel station supplies the following loads to various consumers :*

*Industrial consumer = 1500 kW ; Commercial establishment = 750 kW*

*Domestic power = 100 kW; Domestic light = 450 kW*

*If the maximum demand on the station is 2500 kW and the number of kWh generated per year is* $45 \times 10^5$*, determine* (*i*) *the diversity factor and* (*ii*) *annual load factor.*

**Solution.**

(*i*) $$\text{Diversity factor} = \frac{1500 + 750 + 100 + 450}{2500} = 1 \cdot 12$$

(*ii*) $$\text{Average demand} = \frac{\text{kWh generated / annum}}{\text{Hours in a year}} = 45 \times 10^5/8760 = 513 \cdot 7 \text{ kW}$$

$$\therefore \text{ Load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{513 \cdot 7}{2500} = 0 \cdot 205 = 20 \cdot 5\%$$

**Example** *A power station has a maximum demand of 15000 kW. The annual load factor is 50% and plant capacity factor is 40%. Determine the reserve capacity of the plant.*

**Solution.**

$$\text{Energy generated/annum} = \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year}$$
$$= (15000) \times (0 \cdot 5) \times (8760) \text{ kWh}$$
$$= 65 \cdot 7 \times 10^6 \text{ kWh}$$

$$\text{Plant capacity factor} = \frac{\text{Units generated / annum}}{\text{Plant capacity} \times \text{Hours in a year}}$$

$$\therefore \text{ Plant capacity} = \frac{65 \cdot 7 \times 10^6}{0 \cdot 4 \times 8760} = 18{,}750 \text{ kW}$$

$$\text{Reserve capacity} = \text{Plant capacity} - \text{Max. demand}$$
$$= 18{,}750 - 15000 = 3750 \text{ kW}$$

## Chapter9 Types of tariff

**Tariff :** *The rate at which electrical energy is supplied to a consumer is known as* **tariff.**

*Objectives of tariff.* Like other commodities, electrical energy is also sold at such a rate so that it not only returns the cost but also earns reasonable profit. Therefore, a tariff should include the following items:

- Recovery of cost of producing electrical energy at the power station.
- Recovery of cost on the capital investment in transmission and distribution systems.
- Recovery of cost of operation and maintenance of supply of electrical energy *e.g.*, metering equipment, billing etc.
- A suitable profit on the capital investment.

**Flat rate tariff.** *When different types of consumers are charged at different uniform per unit rates, it is called a* **flat rate tariff.**

In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate. For instance, the flat rate per kWh for lighting load may be 60 paise, whereas it may be slightly less† (say 55 paise per kWh) for power load. The different classes of consumers are made taking into account their diversity and load factors. The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculations.

Disadvantages

Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.

A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

**Two-part tariff.** *When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a* **two-part tariff.**

In two-part tariff, the total charge to be made from the consumer is split into two components *viz.*, fixed charges and running charges. The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer. Thus, the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed *i.e.*,

Total charges = Rs ($b \times$ kW + $c \times$ kWh)
where, $b$ = charge per kW of maximum demand
$c$ = charge per kWh of energy consumed

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

Advantages

- It is easily understood by the consumers.
- It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

Disadvantages

- The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.

- There is always error in assessing the maximum demand of the consumer.

**Block rate tariff.** *When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a* **block rate tariff.**

In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. The price per unit in the first block is the highest** and it is progressively reduced for the succeeding blocks of energy. For example, the first 30 units may be charged at the rate of 60 paise per unit ; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

- The advantage of such a tariff is that the consumer gets an incentive to consume more electrical energy. This increases the load factor of the system and hence the cost of generation is reduced. However, its principal defect is that it lacks a measure of the consumer's demand. This type of tariff is being used for majority of residential and small commercial consumers.

## Problems:

**Example** *A consumer has a maximum demand of 200 kW at 40% load factor. If the tariff is Rs. 100 per kW of maximum demand plus 10 paise per kWh, find the overall cost per kWh.*

**Solution.**

$$\begin{aligned}\text{Units consumed/year} &= \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year}\\ &= (200) \times (0{\cdot}4) \times 8760 = 7{,}00{,}800\ \text{kWh}\\ \text{Annual charges} &= \text{Annual M.D. charges} + \text{Annual energy charges}\\ &= \text{Rs}\,(100 \times 200 + 0{\cdot}1 \times 7{,}00{,}800)\\ &= \text{Rs}\ 90{,}080\end{aligned}$$

$$\therefore \qquad \text{Overall cost/kWh} = \text{Rs}\ \frac{90{,}080}{7{,}00{,}800} = \text{Re}\ 0{\cdot}1285 = 12{\cdot}85\ \text{paise}$$

**Example** *The maximum demand of a consumer is 20 A at 220 V and his total energy consumption is 8760 kWh. If the energy is charged at the rate of 20 paise per unit for 500 hours use of the maximum demand per annum plus 10 paise per unit for additional units, calculate :* **(*i*)** *annual bill* **(*ii*)** *equivalent flat rate.*

**Solution.**

Assume the load factor and power factor to be unity.

$$\therefore \qquad \text{Maximum demand} = \frac{220 \times 20 \times 1}{1000} = 4{\cdot}4\ \text{kW}$$

$$\begin{aligned}(i)\ \ \text{Units consumed in 500 hrs} &= 4{\cdot}4 \times 500 = 2200\ \text{kWh}\\ \text{Charges for 2200 kWh} &= \text{Rs}\ 0{\cdot}2 \times 2200 = \text{Rs}\ 440\\ \text{Remaining units} &= 8760 - 2200 = 6560\ \text{kWh}\end{aligned}$$

$$\text{Charges for 6560 kWh} = \text{Rs } 0{\cdot}1\times 6560 = \text{Rs } 656$$

$$\therefore \quad \text{Total annual bill} = \text{Rs } (440+656) = \text{Rs. } 1096$$

(*ii*) $$\text{Equivalent flat rate} = \text{Rs } \frac{1096}{8760} = \text{Re } 0{\cdot}125 = 12{\cdot}5 \text{ paise}$$

**Example** *The following two tariffs are offered :*

*(a) Rs 100 plus 15 paise per unit ;*

*(b) A flat rate of 30 paise per unit ;*

*At what consumption is first tariff economical ?*

**Solution.**

Let $x$ be the number of units at which charges due to both tariffs become equal. Then,

$$100 + 0{\cdot}15x = 0{\cdot}3x$$

or $$0{\cdot}15x = 100$$

$$\therefore \quad x = 100/0{\cdot}15 = 666{\cdot}67 \text{ units}$$

Therefore, tariff (*a*) is economical if consumption is more than 666·67 units.

**Example** *. A supply is offered on the basis of fixed charges of Rs 30 per annum plus 3 paise per unit or alternatively, at the rate of 6 paise per unit for the first 400 units per annum and 5 paise per unit for all the additional units. Find the number of units taken per annum for which the cost under the two tariffs becomes the same.*

**Solution.** Let $x$ (> 400) be the number of units taken per annum for which the annual charges due to both tariffs become equal.

$$\text{Annual charges due to first tariff} = \text{Rs } (30 + 0{\cdot}03x)$$

$$\text{Annual charges due to second tariff} = \text{Rs } [(0{\cdot}06\times 400) + (x-400)\times 0{\cdot}05]$$

$$= \text{Rs } (4 + 0{\cdot}05x)$$

As the charges in both cases are equal,

$$\therefore \quad 30 + 0{\cdot}03x = 4 + 0{\cdot}05x$$

or $$x = \frac{30-4}{0{\cdot}05-0{\cdot}03} = 1300 \text{ kWh}$$

**Example** *An electric supply company having a maximum load of 50 MW generates $18\times 10^7$ units per annum and the supply consumers have an aggregate demand of 75 MW. The annual expenses including capital charges are :*

*For fuel = Rs 90 lakhs*

*Fixed charges concerning generation = Rs 28 lakhs*

*Fixed charges concerning transmission and distribution = Rs 32 lakhs*

*Assuming 90% of the fuel cost is essential to running charges and the loss in transmission and distribution as 15% of kWh generated, deduce a two part tariff to find the actual cost of supply to the consumers.*

**Solution.**

**Annual fixed charges**

$$\text{For generation} = \text{Rs } 28\times 10^5$$

$$\text{For transmission and distribution} = \text{Rs } 32\times 10^5$$

$$\text{For fuel (10\% only)} = \text{Rs } 0{\cdot}1\times 90\times 10^5 = \text{Rs } 9\times 10^5$$

$$\text{Total annual fixed charge} = \text{Rs } (28+32+9)\times 10^5 = \text{Rs } 69\times 10^5$$

This cost has to be spread over the aggregate maximum demand of all the consumers *i.e.*, 75 MW.

$\therefore$ Cost per kW of maximum demand $= \text{Rs}\dfrac{69\times10^5}{75\times10^3} = \text{Rs. } 92$

**Annual running charges.**

Cost of fuel (90%) $= \text{Rs } 0{\cdot}9\times90\times10^5 = \text{Rs } 81\times10^5$

Units delivered to consumers $=$ 85% of units generated

$= 0{\cdot}85\times18\times10^7 = 15{\cdot}3\times10^7$ kWh

This cost is to be spread over the units delivered to the consumers.

$\therefore$ Cost/kWh $= \text{Rs}\dfrac{81\times10^5}{15{\cdot}3\times10^7} = \text{Re } 0{\cdot}053 = 5.3$ paise

$\therefore$ Tariff is Rs 92 per kW of maximum demand plus 5·3 paise per kWh.

**Example** *A generating station has a maximum demand of 75 MW and a yearly load factor of 40%. Generating costs inclusive of station capital costs are Rs. 60 per annum per kW demand plus 4 paise per kWh transmitted. The annual capital charges for transmission system are Rs 20,00,000 and for distribution system Rs 15,00,000 ; the respective diversity factors being 1·2 and 1·25. The efficiency of transmission system is 90% and that of the distribution system inclusive of substation losses is 85%. Find the yearly cost per kW demand and cost per kWh supplied :*

(*i*) *at the substation* (*ii*) *at the consumers premises.*

**Solution.**

Maximum demand $= 75 \text{ MW} = 75{,}000$ kW

Annual load factor $= 40\% = 0{\cdot}4$

(*i*) **Cost at substation.** The cost per kW of maximum demand is to be determined from the total annual fixed charges associated with the supply of energy at the substation. The cost per kWh shall be determined from the running charges.

(*a*) **Annual fixed charges**

Generation cost $= \text{Rs } 60\times75\times10^3 = \text{Rs } 4{\cdot}5\times10^6$

Transmission cost $= \text{Rs } 2\times10^6$

Total annual fixed charges at the substation

$= \text{Rs } (4{\cdot}5+2)\times10^6 = \text{Rs } 6{\cdot}5\times10^6$

Aggregate of all maximum demands by the various substations

$=$ Max. demand on generating station $\times$ Diversity factor

$= (75\times10^3)\times1{\cdot}2 = 90\times10^3$ kW

The total annual fixed charges have to be spread over the aggregate maximum demands by various substations *i.e.*, $90\times10^3$ kW.

Annual cost per kW of maximum demand

$= \text{Rs}\dfrac{6{\cdot}5\times10^6}{90\times10^3} = \text{Rs. } 72.22$

(*b*) **Running Charges.** It is given that cost of 1 kWh transmitted to substation is 4 paise. As the transmission efficiency is 90%, therefore, for every kWh transmitted, 0·9 kWh reaches the substation.

$\therefore$ Cost/kWh at substation $= 4/0{\cdot}9 = 4{\cdot}45$ paise

Hence at sub-station, the cost is Rs 72·22 per annum per kW maximum demand plus 4·45 paise per kWh.

*(ii)* **Cost at consumer's premises.** The total annual fixed charges at consumer's premises is the sum of annual fixed charges at substation (*i.e.* Rs $6{\cdot}5\times10^6$) and annual fixed charge for distribution (*i.e.*, Rs $1{\cdot}5\times10^6$).

∴ Total annual fixed charges at consumer's premises

$$= \text{Rs}\,(6{\cdot}5+1{\cdot}5)\times10^6=\text{Rs}\,8\times10^6$$

Aggregate of maximum demands of all consumers

$$= \text{Max. demand on Substation}\times\text{Diversity factor}$$

$$= (90\times10^3)\times1{\cdot}25=112{\cdot}5\times10^3\ \text{kW}$$

∴ Annual cost per kW of maximum demand

$$= \text{Rs}\,\frac{8\times10^6}{112{\cdot}5\times10^3}=\text{Rs. }71.11$$

As the distribution efficiency is 85%, therefore, for each kWh delivered from substation, only 0·85 kWh reaches the consumer's premises.

∴ Cost per kWh at consumer's premises

$$= \frac{\text{Cost per kWh at substation}}{0{\cdot}85}=\frac{4{\cdot}45}{0{\cdot}85}=:5.23\ \text{paise}$$

Hence at consumer's premises, the cost is Rs. 71·11 per annum per kW maximum demand plus 5·23 paise per kWh.

# Chapter10 substation

## Substation:

*The assembly of apparatus used to change some characteristic (e.g. voltage, a.c. to d.c., frequency, p.f. etc.) of electric supply is called a* **sub-station.**

Sub-stations are important part of power system. The continuity of supply depends to a considerable extent upon the successful operation of substations. It is, therefore, essential to exercise utmost care while designing and building a sub-station. The following are the important points which must be kept in view while laying out a substation :

- It should be located at a proper site. As far as possible, it should be located at the centre of gravity of load.
- It should provide safe and reliable arrangement. For safety, consideration must be given to the maintenance of regulation clearances, facilities for carrying out repairs and maintenance, abnormal occurrences such as possibility of explosion or fire etc. For reliability, consideration must be given for good design and construction, the provision of suitable protective gear *etc.*
- It should be easily operated and maintained.
- It should involve minimum capital cost

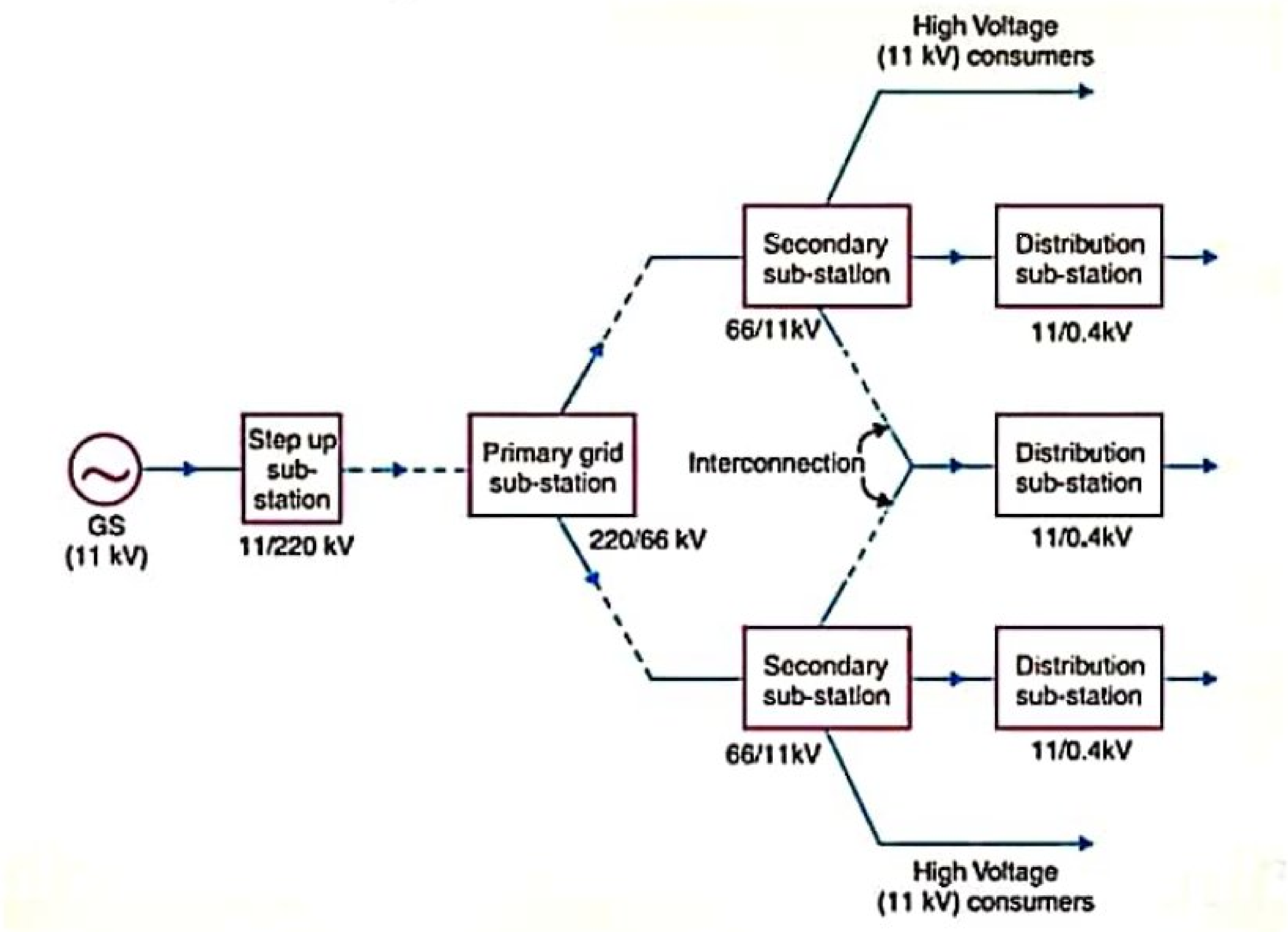
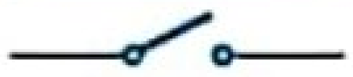
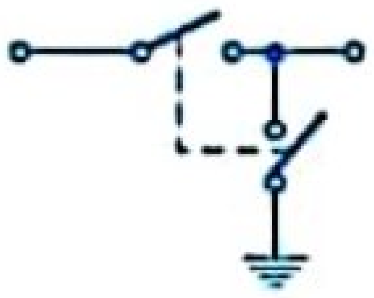
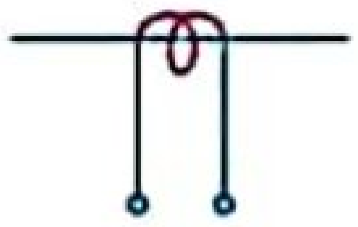
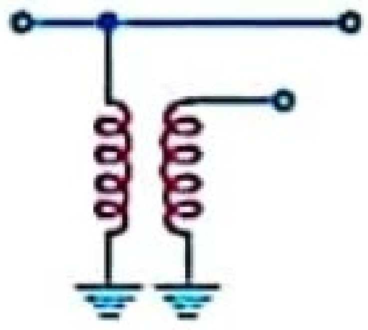
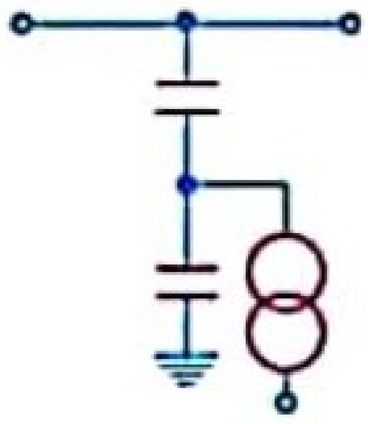
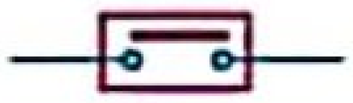
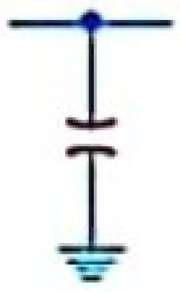
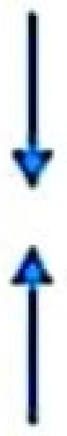
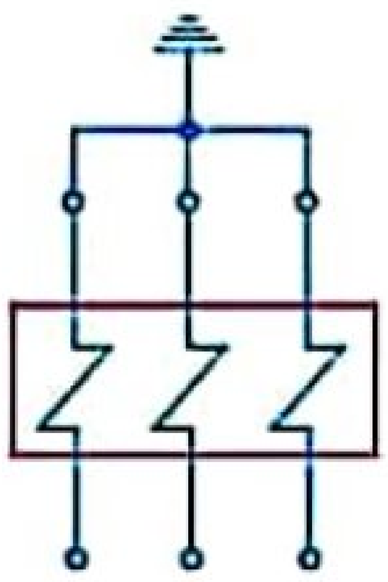
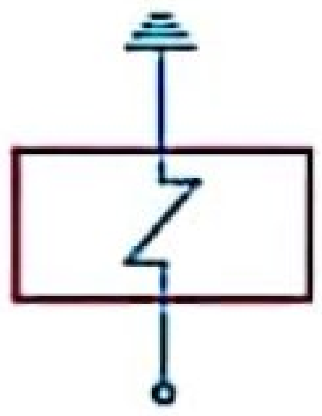


Fig. 25.1

## Symbols for equipment in substation:

| S.No. | Circuit element | Symbol |
|---|---|---|
| 1 | Bus-bar |  |
| 2 | Single-break isolating switch |  |
| 3 | Double-break isolating switch |  |
| 4 | On load isolating switch |  |
| 5 | Isolating switch with earth Blade |  |
| 6 | Current transformer |  |
| 7 | Potential transformer |  |
| 8 | Capacitive voltage transformer |  |
| 9 | Oil circuit breaker |  |
| 10 | Air circuit breaker with overcurrent tripping device |  |
| 11 | Air blast circuit breaker |  |
| 12 | Lightning arrester (active gap) |  |
| 13 | Lightning arrester (valve type) |  |

| S.No. | Circuit element | Symbol |
|---|---|---|
| 14 | Arcing horn |  |
| 15 | 3-ϕ Power transformer |  |
| 16 | Overcurrent relay |  |
| 17 | Earth fault relay |  |

## Key diagram of 66/11 KV substation:

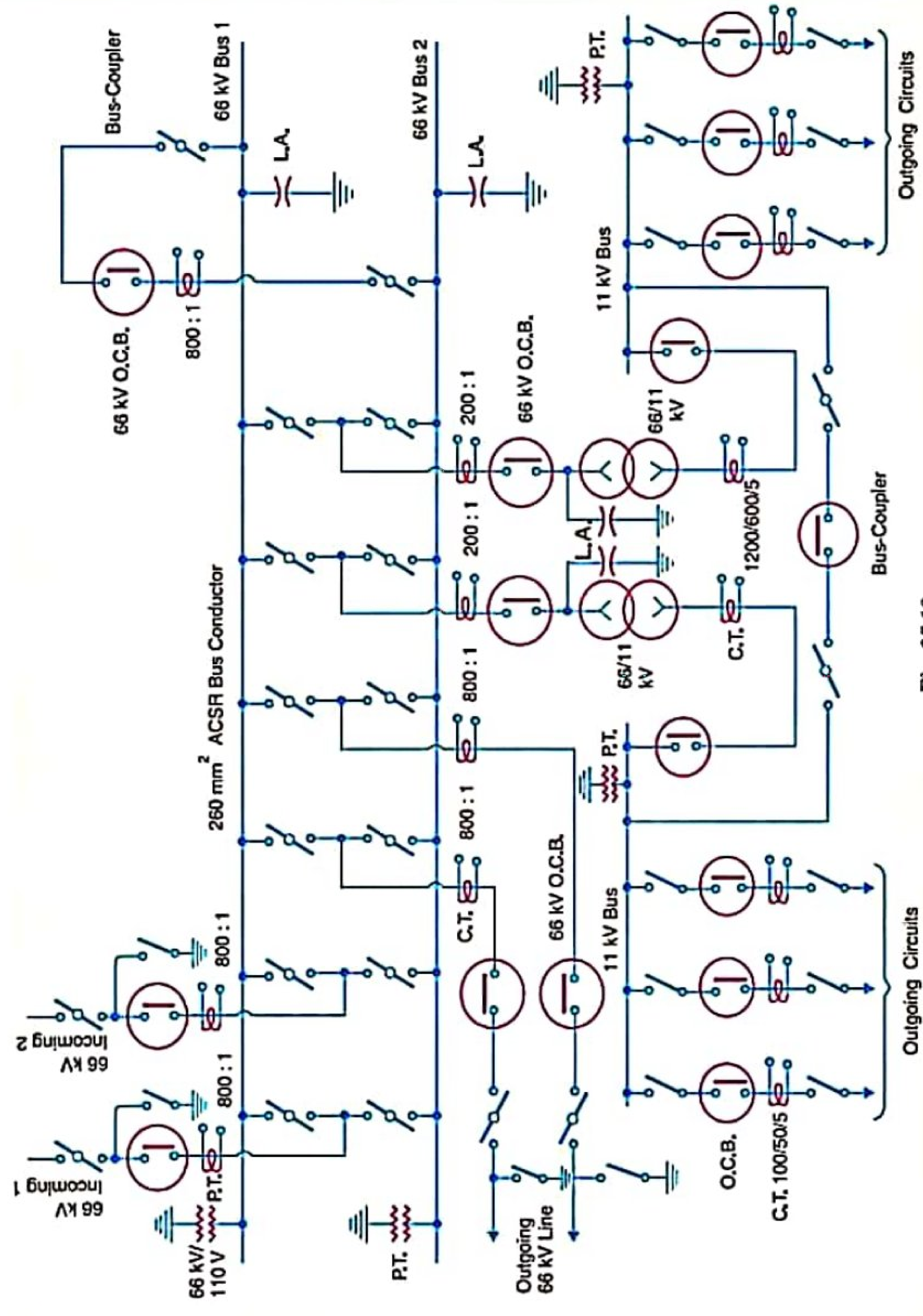


Fig. 25.10

- There are two 66 kV incoming lines marked 'incoming 1' and 'incoming 2' connected to the bus-bars. Such an arrangement of two incoming lines is called a double circuit. Each incoming line is capable of supplying the rated sub-station load. Both these lines can be loaded simultaneously to share the sub-station load or any one line can be called upon to meet the entire load. The double circuit arrangement increases the reliability of the system. In case there is a breakdown of one incoming line, the continuity of supply can be maintained by the other line.
- The sub-station has duplicate bus-bar system; one 'main bus-bar' and the other spare bus- bar. The incoming lines can be connected to either bus-bar with the help of a bus-coupler which consists of a circuit breaker and isolators. The advantage of double bus-bar system is that if repair is to be carried on one bus-bar, the supply need not be interrupted as the entire load can be transferred to the other bus.
- There is an arrangement in the sub-station by which the same 66 kV double circuit supply is going out *i.e.* 66 kV double circuit supply is passing through the sub-station. The outgoing 66 kV double circuit line can be made to act as incoming line.
- There is also an arrangement to step down the incoming 66 kV supply to 11 kV by two units of 3-phase transformers; each transformer supplying to a separate bus-bar. Generally, one transformer supplies the entire sub-station load while the other transformer acts as a standby unit. If need arises, both the transformers can be called upon to share the sub-station load. The 11 kV outgoing lines feed to the distribution sub-stations located near consumers localities.
- Both incoming and outgoing lines are connected through circuit breakers having isolators on their either end. Whenever repair is to be carried over the line towers, the line is first switched off and then earthed.
- The potential transformers (P.T.) and current transformers (C.T.) and suitably located for supply to metering and indicating instruments and relay circuits (not shown in the figure). The P.T. is connected right on the point where the line is terminated. The CTs are connected at the terminals of each circuit breaker.
- The lightning arresters are connected near the transformer terminals (on H.T. side) to protect them from lightning strokes.
- There are other auxiliary components in the sub-station such as capacitor bank for power factor improvement, earth connections, local supply connections, d.c. supply connections etc. However, these have been omitted in the key diagram for the sake of simplicity.

## Key diagram of 11KV/400V substation:

- The 3-phase, 3-wire 11 kV line is tapped and brought to the gang operating switch installed near the sub-station. The G.O. switch consists of isolators connected in each phase of the 3- phase line.
- From the G.O. switch, the 11 kV line is brought to the indoor sub-station as underground cable. It is fed to the H.T. side of the transformer (11 kV/400 V) *via* the 11 kV O.C.B. The transformer steps down the voltage to 400 V, 3-phase, 4-wire.
- The secondary of transformer supplies to the bus-bars *via* the main O.C.B. From the bus- bars, 400 V, 3-phase, 4-wire supply is given to the various consumers *via* 400 V O.C.B. The voltage between any two phases is 400 V and between any phase and neutral it is 230 V. The single phase residential load is connected between any one phase and neutral whereas 3- phase, 400 V motor load is connected across 3-phase lines directly.
- The CTs are located at suitable places in the sub-station circuit and supply for the metering and indicating instruments and relay circuits.

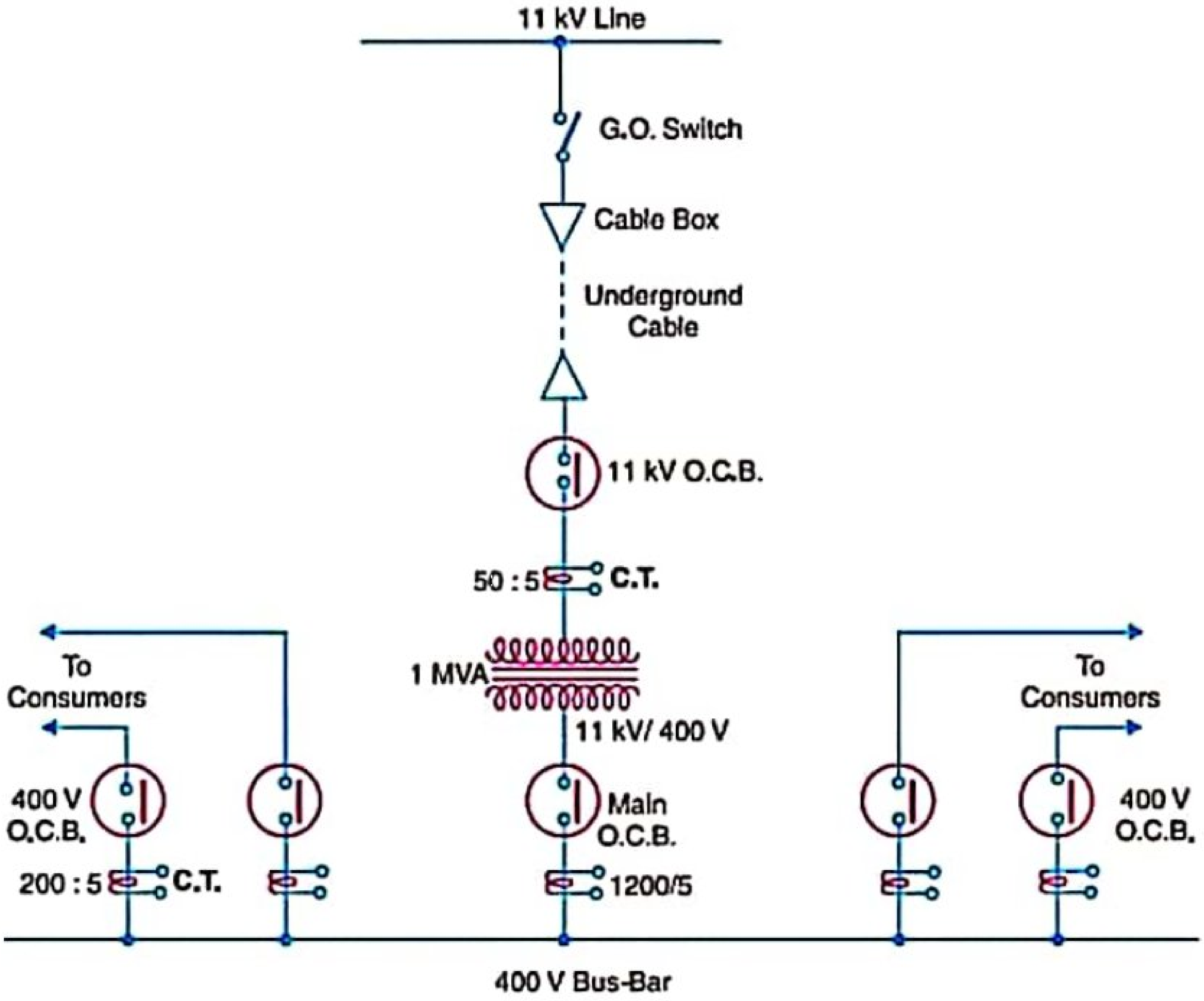


Fig. 25.11

## Earthing or Grounding:

*The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system (e.g. neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called* **grounding or earthing.**

If grounding is done systematically in the line of the power system, we can effectively prevent accidents and damage to the equipment of the power system and at the same time continuity of supply can be maintained. Grounding or earthing may be classified as : **(*i*)** Equipment grounding **(*ii*)** System grounding.

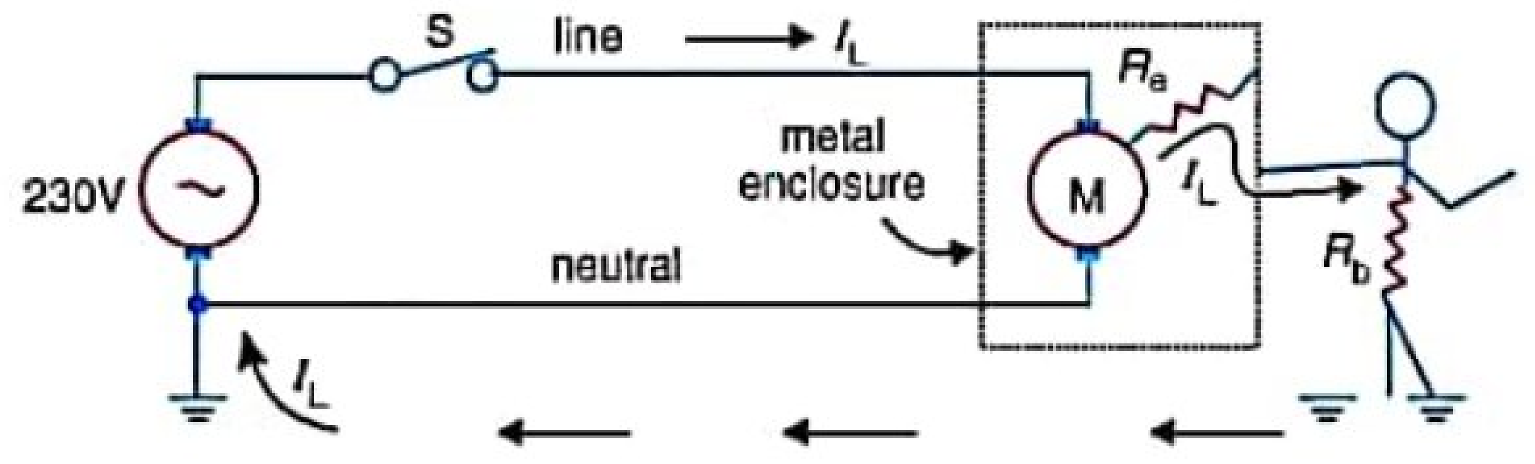
Equipment grounding deals with earthing the non-current-carrying metal parts of the electrical equipment. On the other hand, system grounding means earthing some part of the electrical system *e.g.* earthing of neutral point of star-connected system in generating stations and sub-stations.

## Equipment grounding:

*The process of connecting non-current-carrying metal parts (i.e. metallic enclosure) of the electrical equipment to earth (i.e. soil) in such a way that in case of insulation failure, the enclosure effectively remains at earth potential is called* **equipment grounding.**

We are frequently in touch with electrical equipment of all kinds, ranging from domestic appliances and hand-held tools to industrial motors. We shall illustrate the need of effective equipment grounding by considering a single-phase circuit composed of a 230 V source connected to a motor M as shown in Fig. 26.1. Note that neutral is solidly grounded at the service entrance. In the interest of easy understanding, we shall divide the discussion into three heads *viz.* (*i*) Ungrounded enclosure (ii) enclosure connected to neutral wire (*iii*) ground wire connected to enclosure.

- **Ungrounded enclosure.** Fig. 26.1 shows the case of ungrounded metal enclosure. If a person touches the metal enclosure, nothing will happen if the equipment is functioning correctly. But if the winding insulation becomes faulty, the resistance $R_e$ between the motor and enclosure drops to a low value (a few hundred ohms or less). A person having a body resistance $R_b$ would complete the current path as shown in Fig. 26.1.



If $R_e$ is small (as is usually the case when insulation failure of winding occurs), the leakage current $I_L$ through the person's body could be dangerously high. As a result, the person would get severe *electric shock which may be fatal. Therefore, this system is unsafe.

- **Enclosure connected to neutral wire.** It may appear that the above problem can be solved by connecting the enclosure to the grounded neutral. Now the leakage current $I_L$ flows from the motor, through the enclosure and straight back to the neutral wire . Therefore, the enclosure remains at earth potential. Consequently, the operator would not experience any electric shock.

The trouble with this method is that the neutral wire may become open either accidentally or due to a faulty installation. For example, if the switch is inadvertently in series with the neutral rather than the live wire the motor can still be turned on and off. However, if someone touched the enclosure while the motor is *off,* he would receive a severe electric shock. It is because when the motor is off, the potential of the enclosure rises to that of the live conductor.

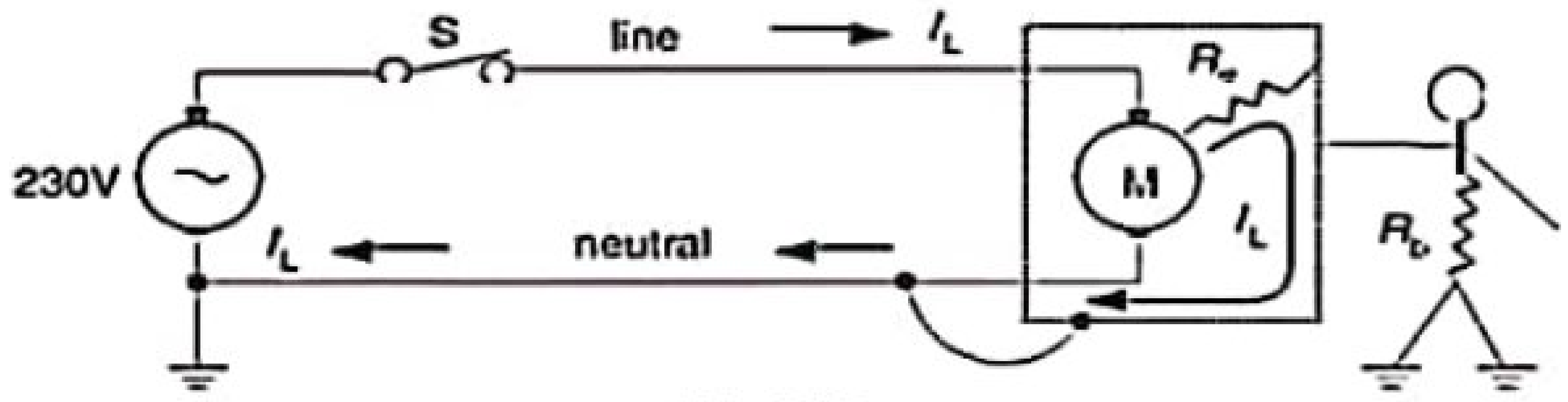


Fig. 26.2

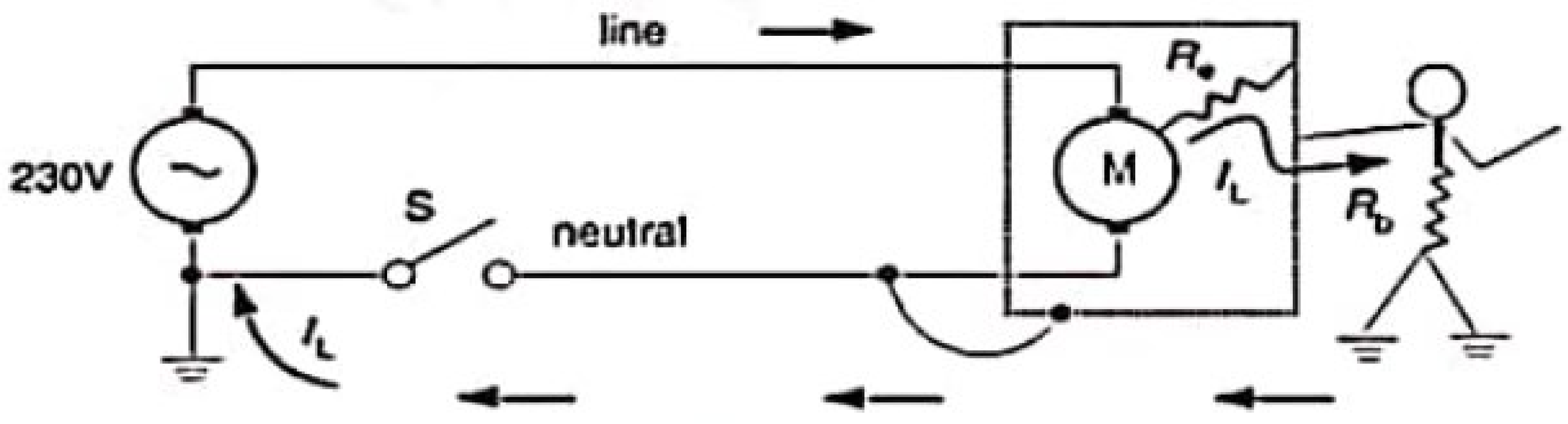


Fig. 26.3

- **Ground wire connected to enclosure.** To get rid of this problem, we install a third wire, called *ground wire*, between the enclosure and the system ground as shown in Fig. 26.4. The ground wire may be bare or insulated. If it is insulated, it is coloured green. Electrical outlets have three contacts — one for live wire, one for neutral wire and one for ground wire.

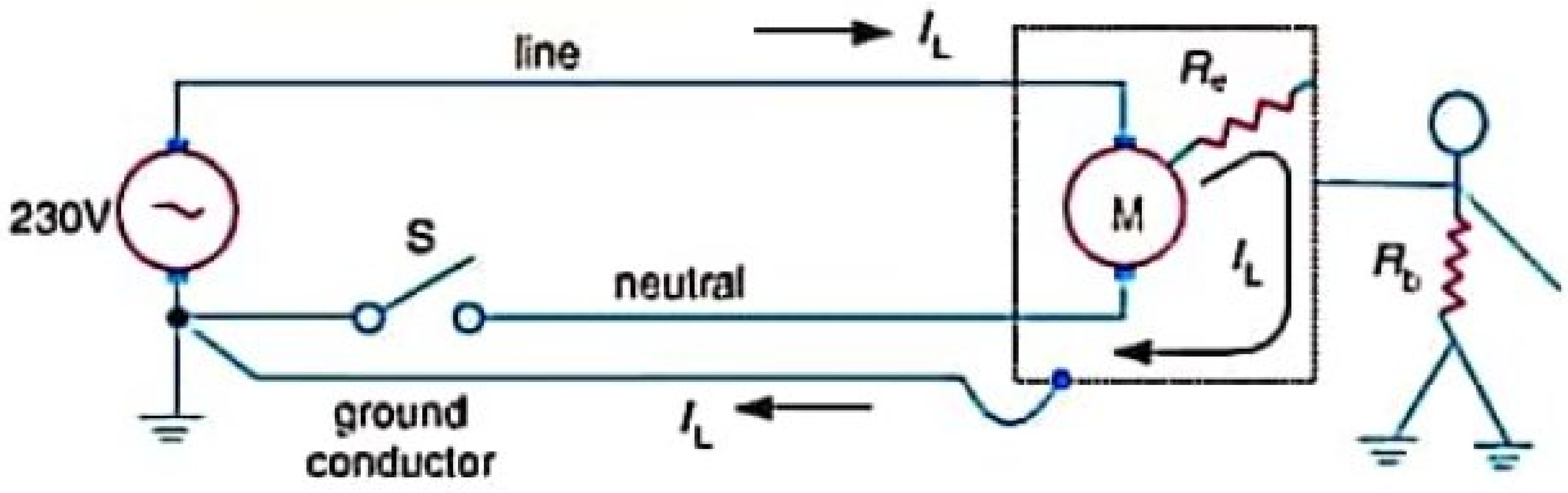


Fig. 26.4

## System Grounding:

***The process of connecting some electrical part of the power system (e.g. neutral point of a star-connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called* system grounding.**

- the primary winding of a distribution transformer connected between the line and neutral of a 11 kV line. If the secondary conductors are *ungrounded*, it would appear that a person could touch either secondary conductor without harm because there is no ground return. However, this is not true. Referring to Fig. 26.5, there is capacitance $C_1$ between primary and secondary and capacitance $C_2$ between secondary and ground. This capacitance coupling can produce a high voltage between the secondary lines and the ground. Depending upon the relative magnitudes of $C_1$ and $C_2$, it may be as high as 20% to 40% of the primary voltage. If a person touches either one of the secondary wires, the resulting capacitive current $I_C$ flowing through the body could be dangerous even in case of small transformers. For example, if $I_C$ is only 20 mA, the person may get a fatal electric shock. If one of the secondary conductors is grounded, the capacitive coupling almost reduces to zero and so is the capacitive current $I_C$. As a result, the person will experience no electric shock. This explains the importance of system grounding.

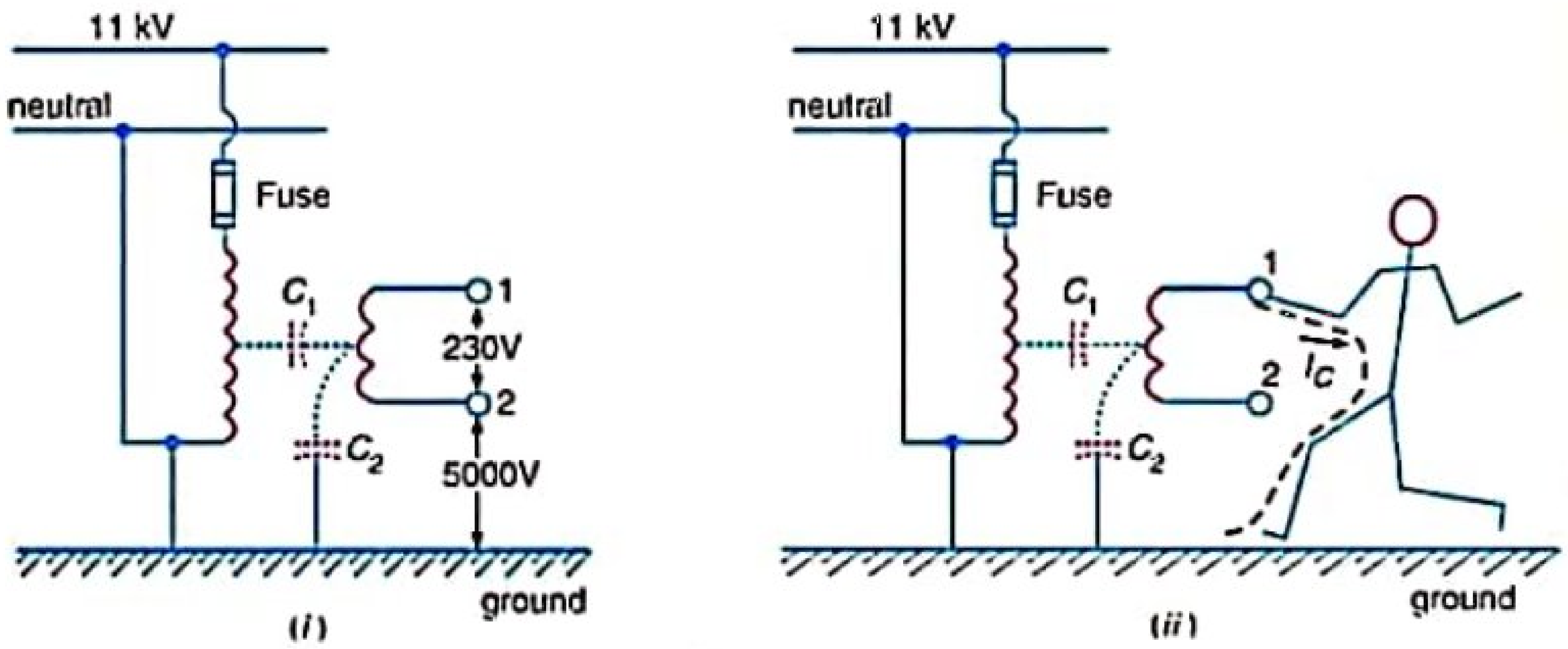
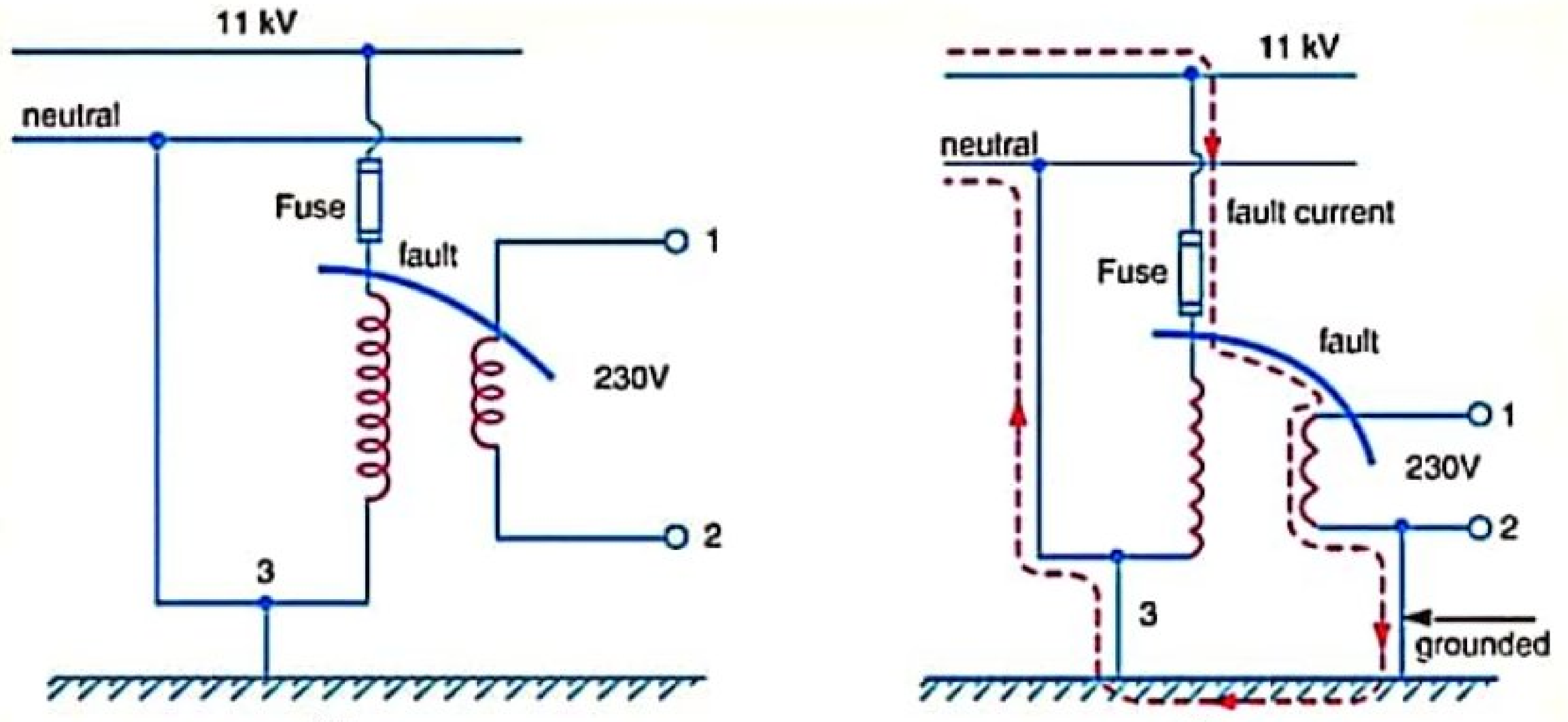


**Fig. 26.5**

- Let the primary winding of a distribution transformer connected between the line and neutral of a 11 kV line. The secondary conductors are ungrounded. Suppose that the high voltage line (11 kV in this case) touches the 230 V conductor. This could be caused by an internal fault in the transformer or by a branch or tree falling across the 11 kV and 230 V lines. Under these circumstances, a very high voltage is imposed between the secondary conductors and ground. This would immediately puncture the 230 V insulation, causing a massive flashover. This flashover could occur anywhere on the secondary network, possibly inside a home or factory. Therefore, ungrounded secondary in this case is a potential fire hazard and may produce grave accidents under abnormal conditions If one of the secondary lines is grounded, the accidental contact between a 11 kV conductor and a 230 V conductor produces a dead short. The short-circuit current (*i.e.* fault current) follows the dotted path. This large current will blow the fuse on the 11 kV side, thus disconnecting the transformer and secondary distribution system from the 11 kV line. This explains the importance of system grounding in the line of the power system.


11 kV
neutral
Fuse
fault
1
230V
2
3
11 kV
neutral
fault current
Fuse
fault
1
230V
2
3
grounded

(i) (ii)

Fig. 26.6