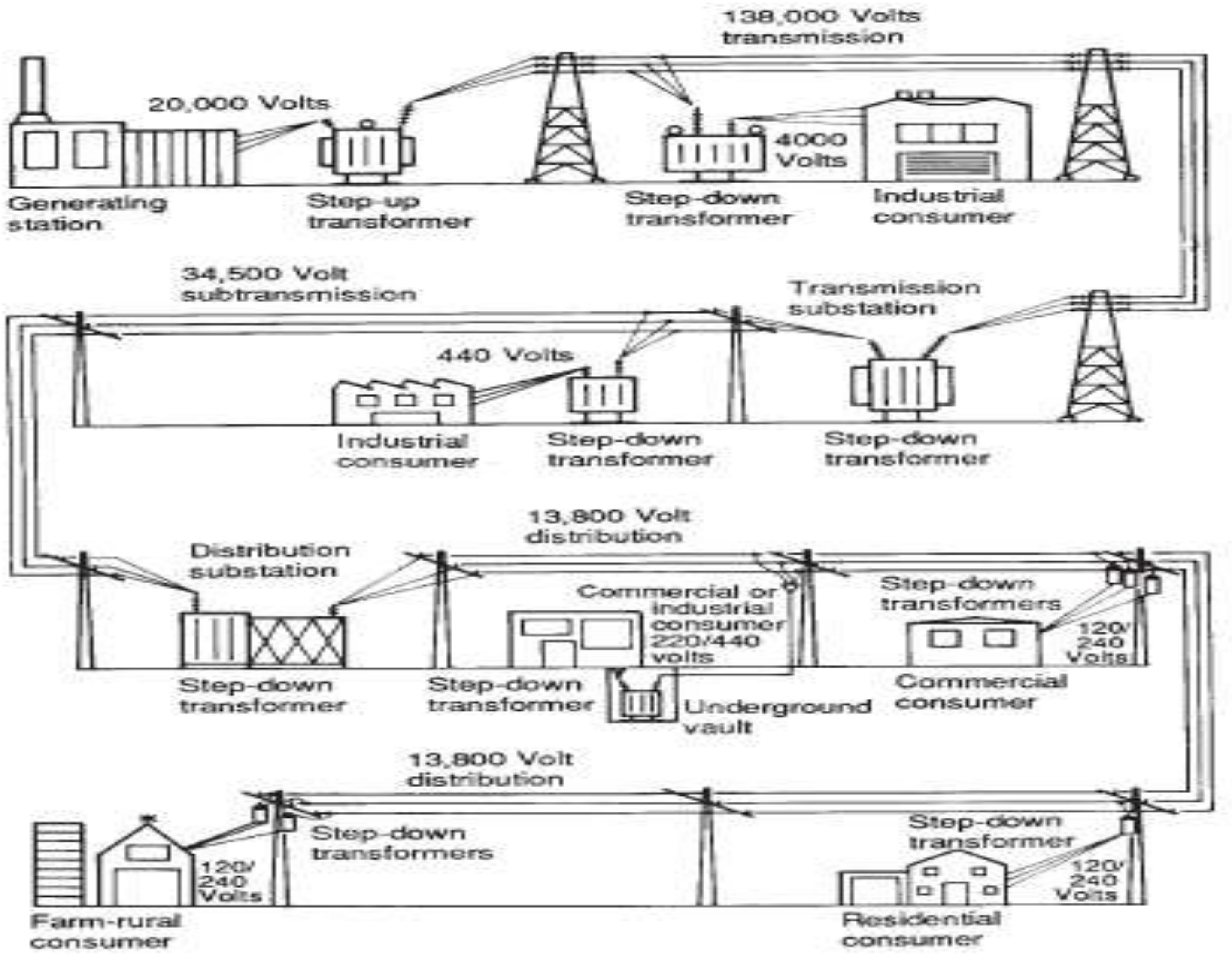
Electrical Distribution Systems

Advantages of Electricity

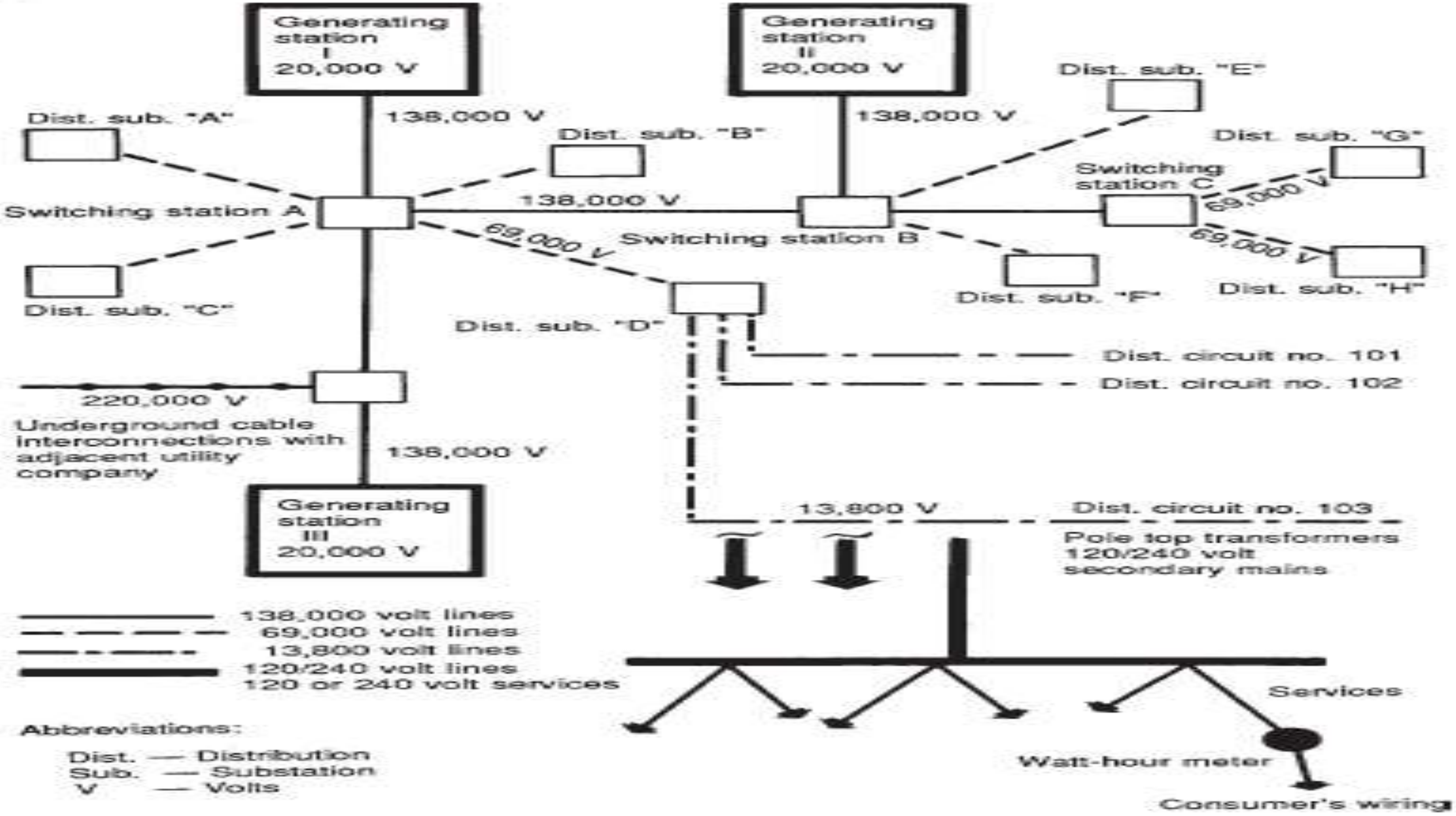
- Most convenient and useful form of energy.
- Present social infrastructure would not at all feasible without electricity.
- Transported instantly with a speed of light.
- The optimum utilization of electricity by society if effective distribution system is available.
- Consist of Generation, Transmission, sub-transmission and distribution.
- Generation and transmission is known as bulk power supply.
- Generation at 11 kV and transmission at 765 kV.

Typical electrical supply from generator to customer

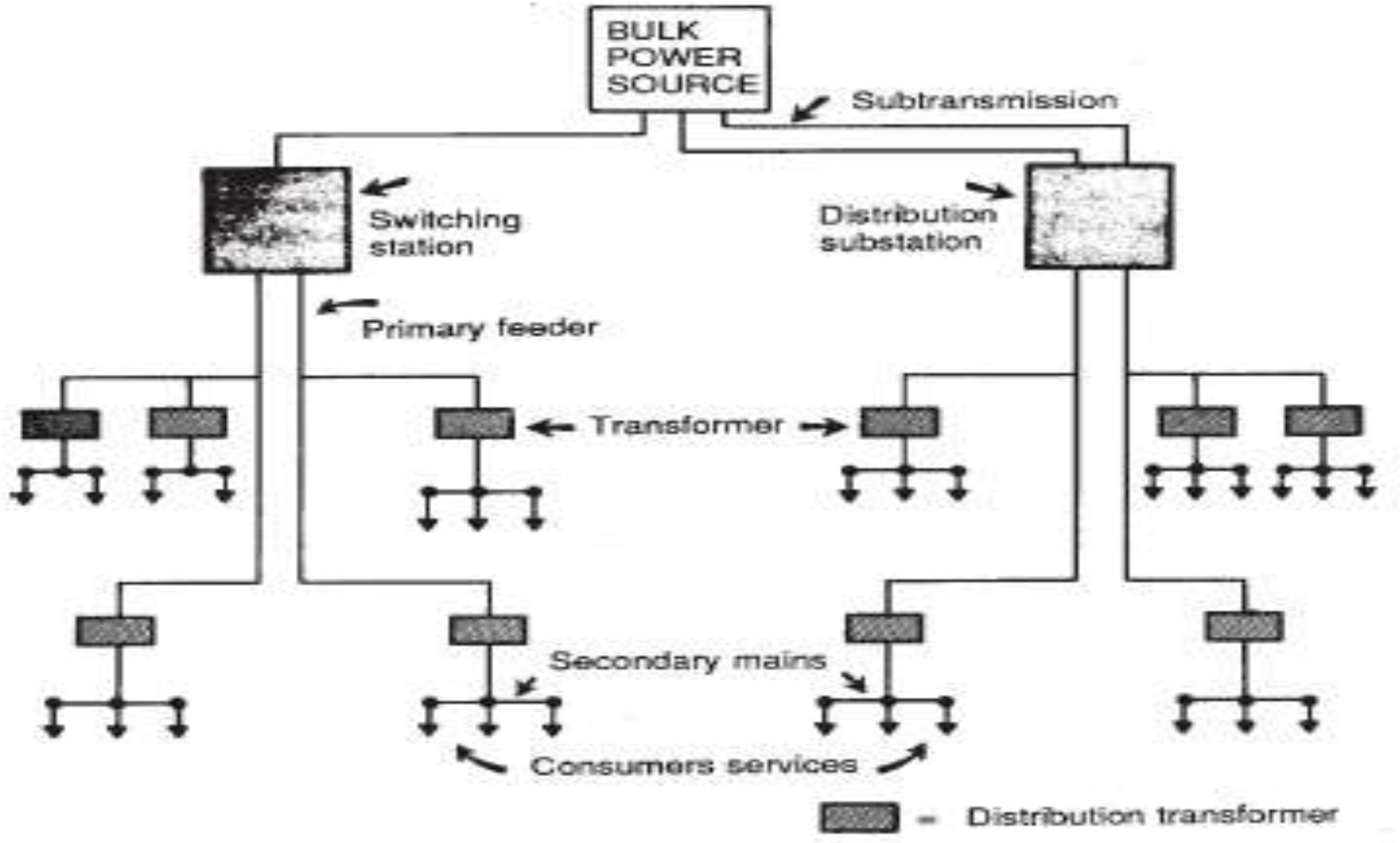


1. manufacture, production or generation, cogeneration – GENCO.
2. delivery or transmission and distribution – TRANSCO & DISCO.
3. consumption- Consumer.

Typical transmission and distribution system



Typical distribution system showing component parts



the generator produces 11 kV- 15 kV. This, however, is raised to 220 kV = 400 kVfor the long transmission journey. This power is conducted over 220 kV – 400 kV transmission lines to switching stations located in the important load area served.

When the power reaches the switching stations, it is stepped down to 132 kV – 66 kV for transmission in smaller quantities to the substations in the local load areas. (In some cases it might be stepped down to 33 kV for direct distribution to local areas.)

Each substation feeds its local load area by means of *primary distribution feeders, some operating at 33 kV* or higher.

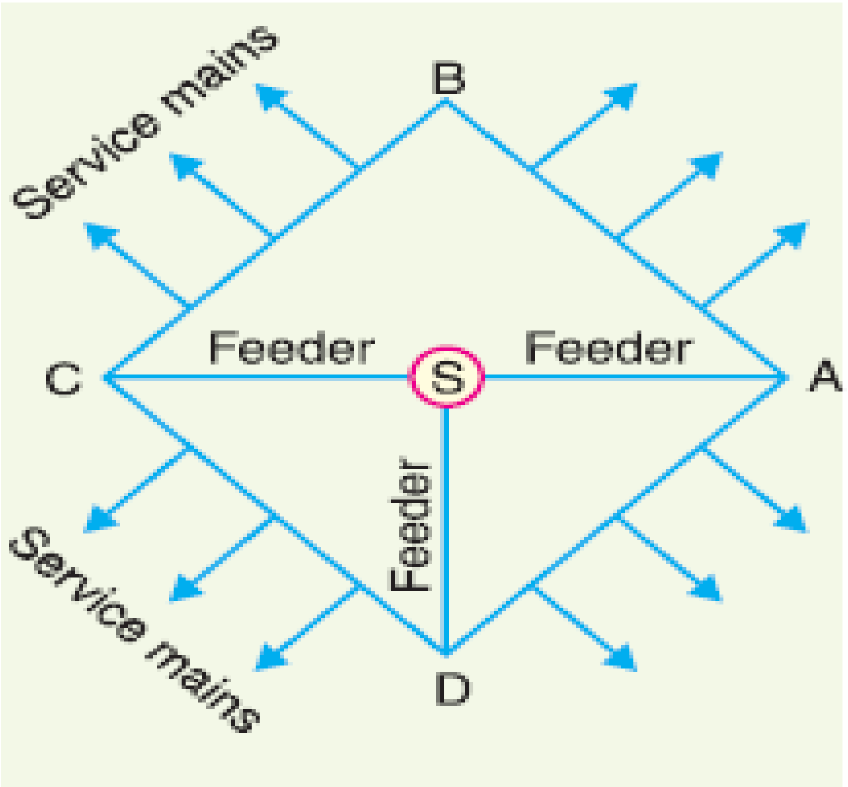
- Industrial and commercial customer with large power demands often receives services directly from the primary distribution system or sub-transmission system.
- Ordinarily, primary feeders are 1 km to 7.5 km in length; in rural sections where demands for electricity are relatively small and scattered, they are sometimes as long as 13 to 20 km.
- Distribution transformers connect to the primary distribution lines.
- Distribution transformers step down the primary voltage from 33 kV or 11 kV volts, as the case may be, to approximately 415/240 volts for distribution over secondary mains to the consumer’s service.

The lines which carry the energy at utilization voltage from the transformer to consumer’s services are called secondary distribution mains and may be found overhead or underground.

- Generation Voltage Level – 0.4/0.44, 6.6, 10.5, 11, 13.8, 15.75, 21 and 33 kV.
- Tie-line (Interconnecting line between two power system/areas) – 220, 400, 750, 765, 800 kV.
- HVDC – 500, 800, 1400 kV for stable power flow for 800-1400 km distance.
- High voltage subtransmission – 33, 66, 110, 132, 220 kV
- High voltage primary distribution – 3.3, 6.6, 11,22,33,66,132 kV.
- Low voltage secondary distribution – 415/240 V, 433/250 V

Distribution System

That part of power system which distributes electric power for local use is known as ***distribution*** **system.**
It generally consists of *feeders, distributors and the service mains.*



Feeders. A feeder is a conductor which connects the sub-station (or localised generating station) to the area where power is to be distributed. Generally, no tappings are taken from the feeder so that current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity.

Distributor. A distributor is a conductor from which tappings are taken for supply to the consumers. In Fig. *AB, BC, CD and DA are the distributors. The current through a distributor* is not constant because tappings are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is ± 6% of rated value at the consumers' terminals.

Service mains. A service mains is generally a small cable which connects the distributor to the consumers' terminals.

Classification of Distribution Systems

Nature of current. According to nature of current, (*a*) *D.C. distribution system* (*b*) *A.C. distribution system.*

A.C. system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method.

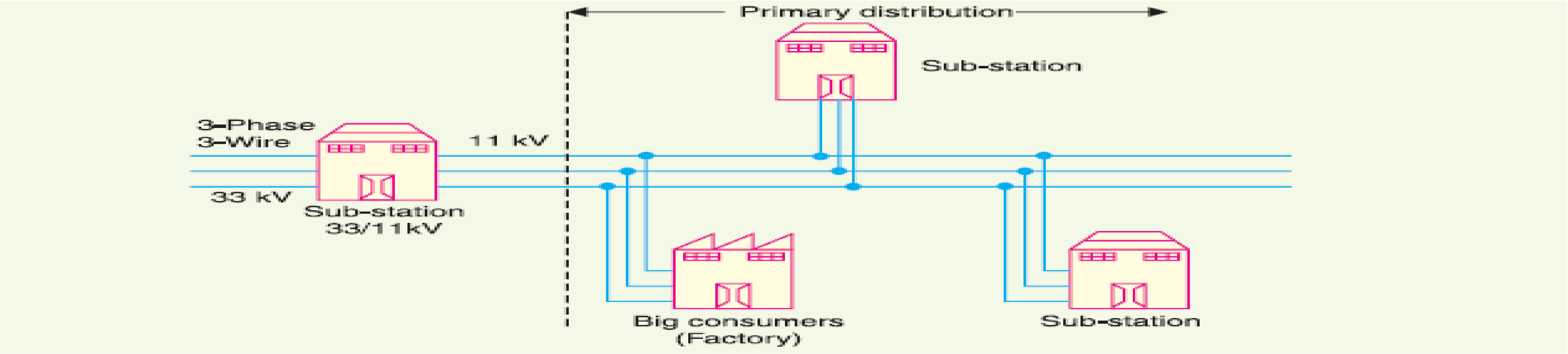
Type of construction. According to type of construction, distribution system may be classified as (*a*) *overhead system* (*b*) *underground system. The overhead system is generally* employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system. In general, the underground system is used at places where overhead construction is impracticable or prohibited by the local laws.

Scheme of connection. According to scheme of connection, the distribution system may be classified as;

(*a*) *radial* system (*b*) *ring main system* (*c*) *inter-connected system.*

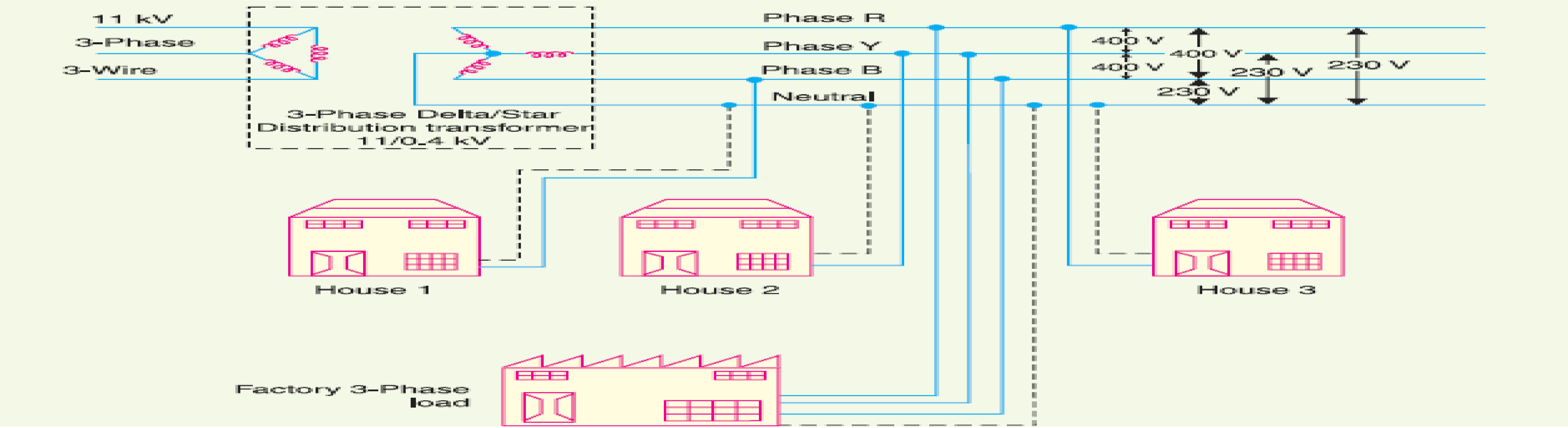
A.C. Distribution

Primary distribution system. It is that part of A.C. distribution system which operates at voltages somewhat higher than general utilization and handles large blocks of electrical energy than the average low-voltage consumer uses. The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the substation required to be fed. The most commonly used primary distribution voltages are 11 kV, 6·6 kV and 3·3 kV. Due to economic considerations, primary distribution is carried out by 3- phase, 3-wire system.



Electric power from the generating station is transmitted at high voltage to the substation located in or near the city. At this substation, voltage is stepped down to 11 kV with the help of step-down transformer. Power is supplied to various substations for distribution or to big consumers at this voltage. This forms the high voltage distribution or primary distribution.

A.C. Distribution



Secondary distribution system. It is that part of a.c. distribution system which includes the range of voltages at which the ultimate consumer utilises the electrical energy delivered to him. The secondary distribution employs 400/230 V, 3-phase, 4-wire system. The single phase domestic loads are connected between any one phase and the neutral, whereas 3-phase 400 V motor loads are connected across 3- phase lines directly.

Overhead Versus Underground System

- *Public safety* : The underground system is more safe there are little chances of any hazard.

- *Initial cost* : underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipment. May be five to ten times than that of an overhead system.

- *Flexibility* : overhead system is much more flexible than the underground system. In underground cables manholes, duct lines etc., are permanently placed. On an overhead system, poles, wires, transformers etc., can be easily shifted to meet the changes in load conditions .

- *Faults* : faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

- *Appearance* : appearance of an underground system is better as all the distribution lines are invisible.

- *Fault location and repairs* : On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can be easily made. Little chances of faults in an underground system. However, if a fault does occur, it is difficult to locate and repair on this system.

Overhead Versus Underground System

➢ *Useful life* : An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years.

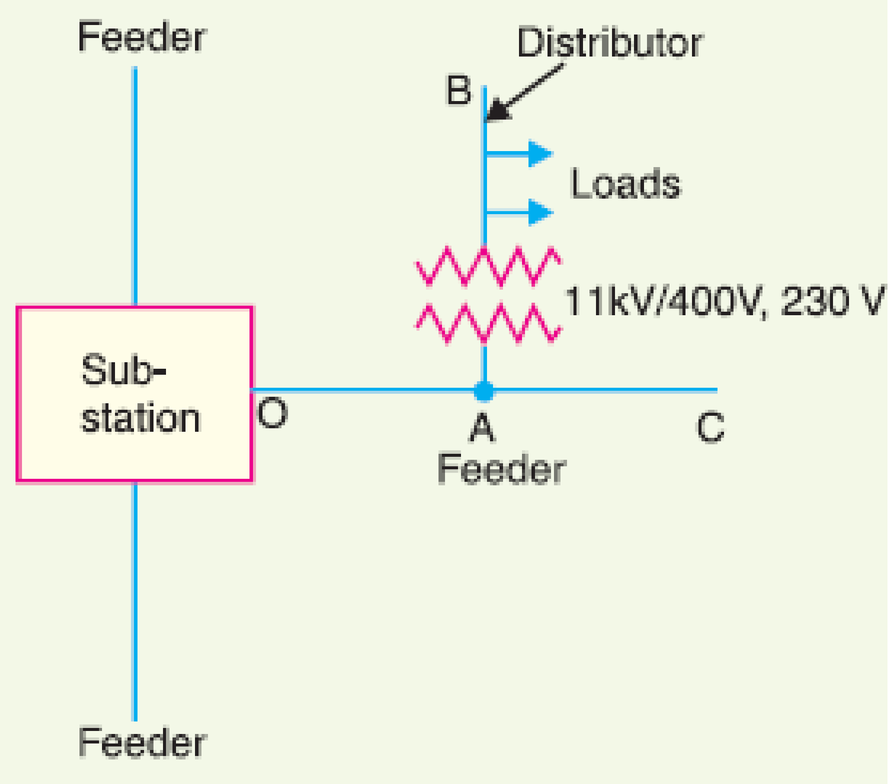
➢ *Maintenance cost* : maintenance cost of underground system is very low as compared with that of overhead system.

➢ *Current carrying capacity and voltage drop* : An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductors.

➢ *Interference with communication circuits* : An overhead system causes electromagnetic interference with the telephone lines. No such interference with the underground system.

Connection Schemes of Distribution System

Radial System. In this system, separate feeders radiate from a single substation and feed the distributors at one end only. The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.



it suffers from the following drawbacks :

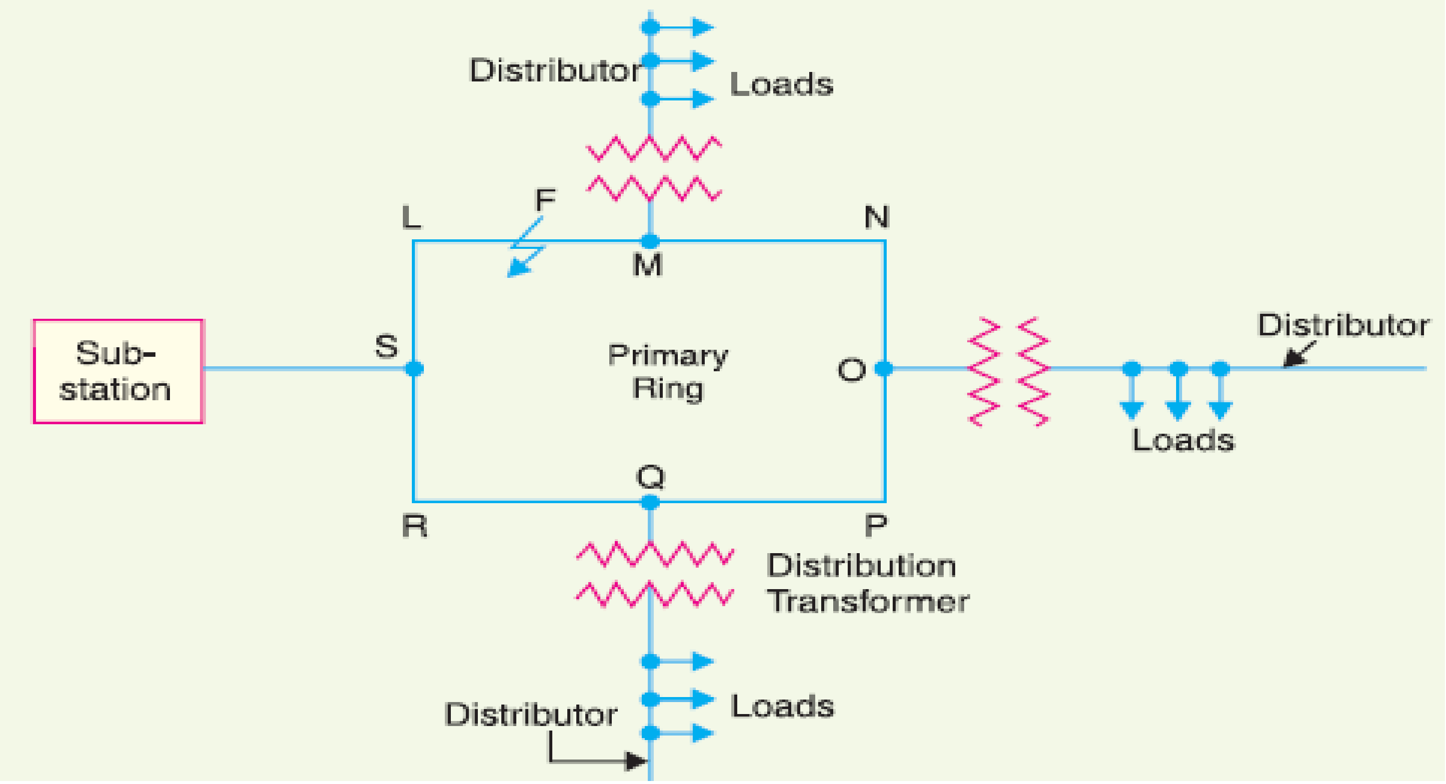
(a) *The end of the distributor nearest to the feeding point will be heavily loaded.*

(b) *The consumers are dependent on a single feeder and single distributor. Therefore, any fault* on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.

(c) *The consumers at the distant end of the distributor would be subjected to serious voltage* fluctuations when the load on the distributor changes. Due to these limitations, this system is used for short distances only.

Connection Schemes of Distribution System

Ring main system. In this system, the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation.



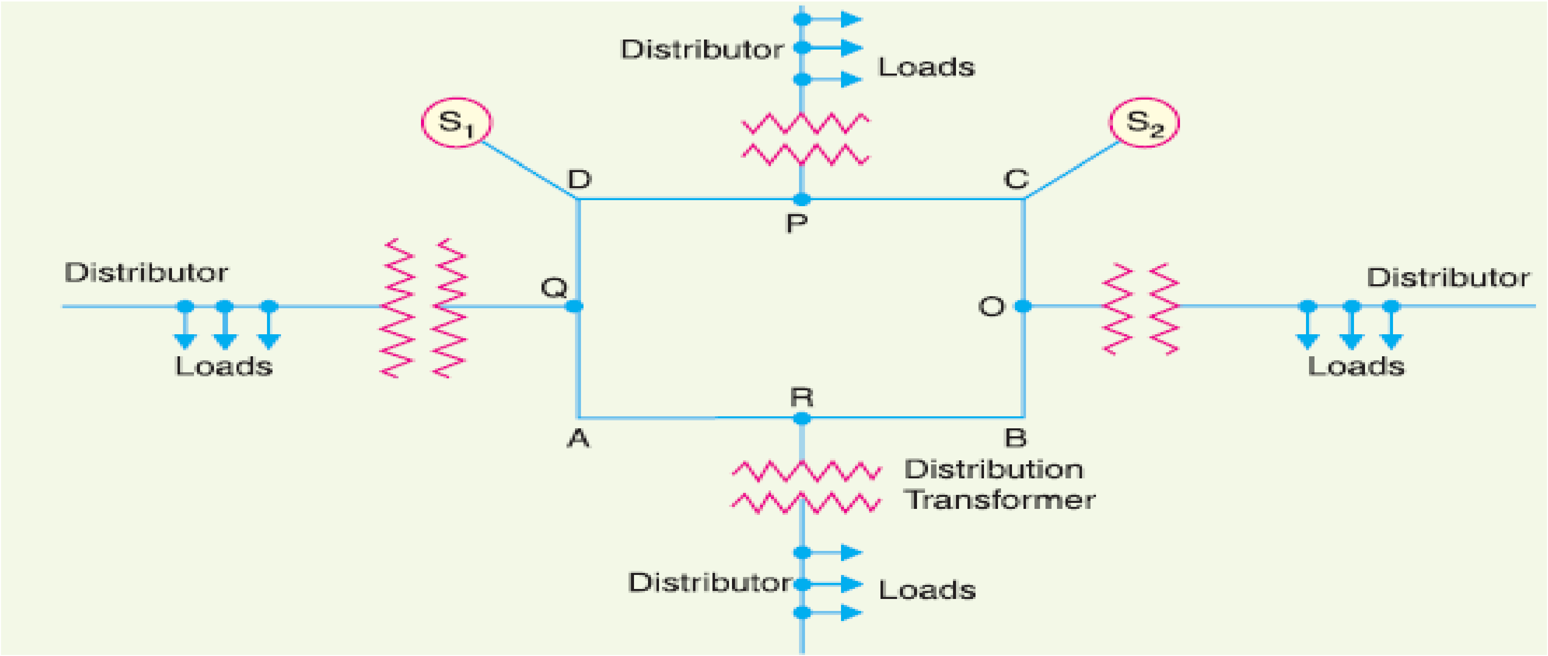
The ring main system has the following advantages :

(*a*) *There are less voltage fluctuations at consumer's terminals.*

(*b*) *The system is very reliable as each distributor is fed via two feeders. In the event of fault* on any section of the feeder, the continuity of supply is maintained.

Connection Schemes of Distribution System

Interconnected system. When the feeder ring is energized by two or more than two generating stations or substations, it is called inter-connected system.



The interconnected system has the following advantages :

(*a) It increases the service reliability.*

(b) Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.

Fig. shows the single line diagram of interconnected system where the closed feeder ring *ABCD is supplied by* two substations *S1 and S2 at points D and C respectively. Distributors are connected to* points *O, P, Q and R of the feeder ring through distribution transformers.*

Requirements of a Distribution System:

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a good distribution system are :

proper voltage, availability of power on demand and reliability.

(i) Proper voltage.

- One important requirement of a distribution system is that voltage variations at consumer's terminals should be as low as possible.

- The changes in voltage are generally caused due to the variation of load on the system. Low voltage causes loss of revenue, inefficient lighting and possible burning out of motors.

- High voltage causes lamps to burn out permanently and may cause failure of other appliances. Therefore, a good distribution system should ensure that the voltage variations at consumers terminals are within permissible limits.

- The statutory limit of voltage variations is ± 6% of the rated value at the consumer's terminals. Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V.

(ii) Availability of power on demand.

- Power must be available to the consumers in any amount that they may require from time to time. For example, motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company.
- As electrical energy cannot be stored, therefore, the distribution system must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

(iii) Reliability.

Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately, electric power, like everything else that is man-made, can never be absolutely reliable. However, the reliability can be improved to a considerable extent by *(a) interconnected system (b) reliable automatic control system (c) providing additional* reserve facilities.

D.C. Distribution

In the beginning of the electrical age, electricity was generated as a direct current and voltages were low. The resistance losses in the lines made it impracticable to transmit and distribute power for more than a few localities of the city. With the development of the transformer, A.C. has taken over the load formerly supplied by D.C.

Now-a-days, electrical energy is generated, transmitted and distributed in the form of A.C. as an economical proposition. The transformer permits the transmission and distribution of A.C. power at high voltages. This has greatly reduced the current in the conductors (and hence their sizes) and the resulting line losses.

However, for certain applications, D.C. supply is absolutely necessary. For example, D.C. supply is required for the operation of variable speed machinery (*e.g. D.C. motors), electrochemical* work and electric traction. For this purpose, A.C. power is converted into D.C. power at the sub-station by using converting machinery *e.g. mercury are rectifiers, rotary converters and* motor-generator sets. The D.C. supply from the sub-station is conveyed to the required places for distribution. In this topic, we shall confine our attention to the various aspects of D.C. distribution.

Types of D.C. Distributors

The most general method of classifying D. C. distributors is the way they are fed by the feeders. On this basis D. C. distributors are classified as:

(i) Distributor fed at one end

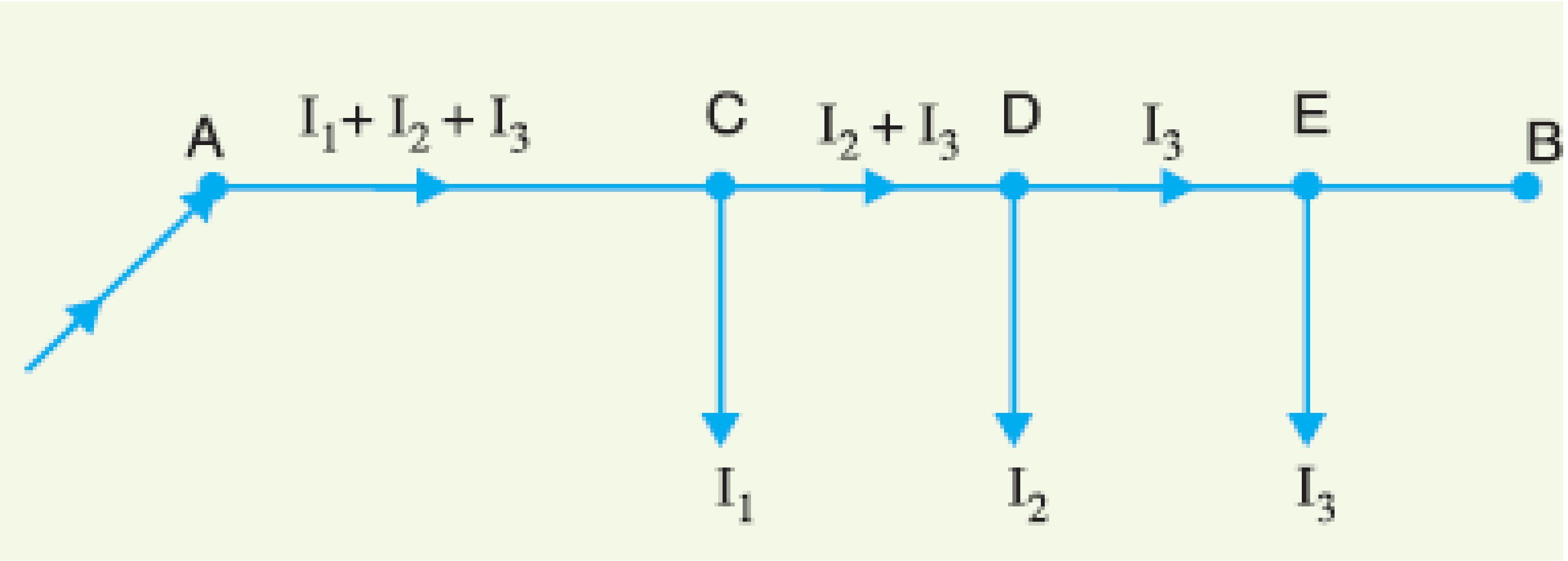
(ii) Distributor fed at both ends

(iii) Distributor fed at the centre

(iv) Ring distributor.

(i) Distributor fed at one end.

In this type of feeding, the distributor is connected to the supply at one end and loads are taken at different points along the length of the distributor. Fig. shows the single line diagram of a D.C. distributor *AB fed at* the end *A (also known as singly fed distributor) and loads I1, I2 and I3 tapped off at points C, D and E respectively.*



The following points are worth noting in a singly fed distributor :

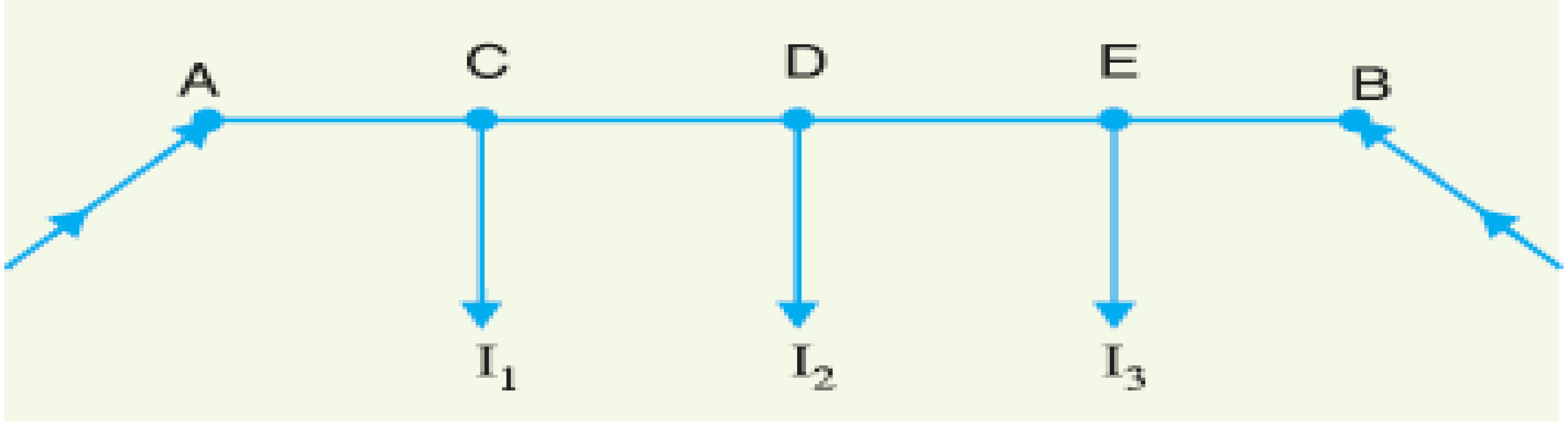
(a) *The current in the various sections of the distributor away from feeding point goes on* decreasing. Thus current in section *AC is more than the current in section CD and current in section CD is more than the current in section DE.*

(b) *The voltage across the loads away from the feeding point goes on decreasing. Thus in Fig.* the minimum voltage occurs at the load point *E.*

(c) *In case a fault occurs on any section of the distributor, the whole distributor will have to be* disconnected from the supply mains. Therefore, continuity of supply is interrupted.

(ii) Distributor fed at both ends.

In this type of feeding, the distributor is connected to the supply mains at both ends and loads are tapped off at different points along the length of the distributor. The voltage at the feeding points may or may not be equal. Fig. shows a distributor *AB* fed at the ends *A and B and loads of I1*, *I2* and *I3 tapped off at points C, D and E* respectively. Here, the load voltage goes on decreasing as we move away from one feeding point *say A*, *reaches minimum value and* then again starts rising and reaches maximum value when we reach the other feeding point *B. The minimum voltage occurs at some load point and is never fixed. It is shifted with the* variation of load on different sections of the distributor.



Advantages

(a) If a fault occurs on any feeding point of the distributor, the continuity of supply is maintained from the other feeding point.

(b) In case of fault on any section of the distributor, the continuity of supply is maintained from the other feeding point.

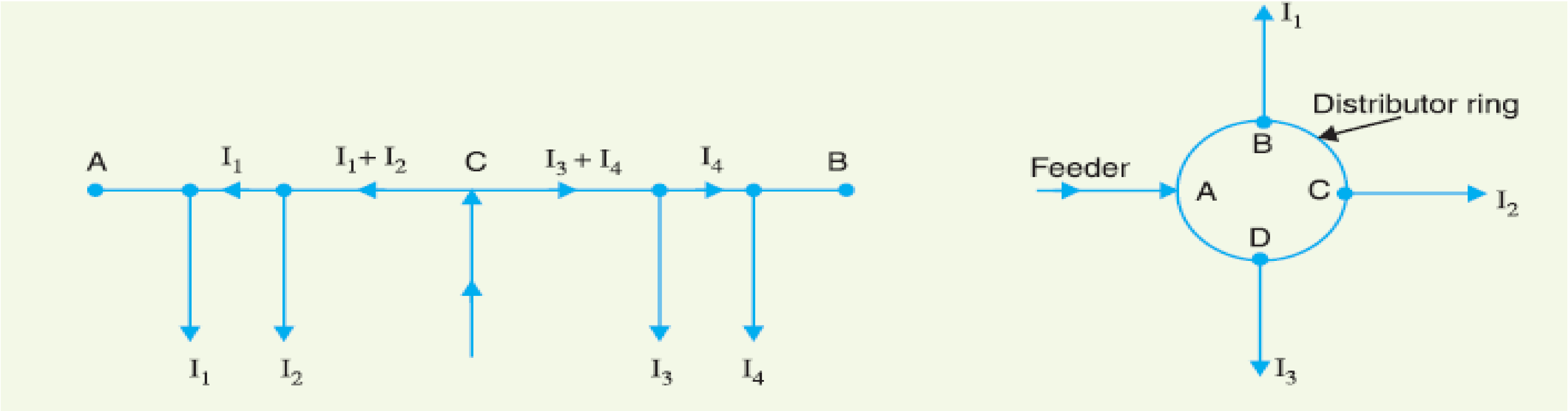
(c) The area of X-section required for a doubly fed distributor is much less than that of a singly fed distributor.

(iii) Distributor fed at the centre.

In this type of feeding, the centre of the distributor is connected to the supply mains as shown in Fig. It is equivalent to two singly fed distributors, each distributor having a common feeding point and length equal to half of the total length.

(iv) Ring mains.

In this type, the distributor is in the form of a closed ring as shown in Fig. It is equivalent to a straight distributor fed at both ends with equal voltages, the two ends being brought together to form a closed ring. The distributor ring may be fed at one or more than one point.



Mechanical Design of Overhead Lines

- Electric power can be transmitted or distributed either by means of underground cables or by overhead lines. The underground*cables are rarely used for power transmission due to two main reasons. Firstly, power is generally transmitted over long distances to load centers. Obviously, the installation costs for underground transmission will be very heavy.

- Secondly, electric power has to be transmitted at high voltages for economic reasons. It is very difficult to provide proper insulation to the cables to withstand such higher pressures. Therefore, as a rule, power transmission over long distances is carried out by using overhead lines. With the growth in power demand and consequent rise in voltage levels, power transmission by overhead lines has assumed considerable importance.

An overhead line is subjected to uncertain weather conditions and other external interferences. This calls for the use of proper mechanical factors of safety in order to ensure the continuity of operation in the line. In general, the strength of the line should be such so as to provide against the worst probable weather conditions. In this chapter, we shall focus our attention on the various aspects of mechanical design of overhead lines.

Main Components of Overhead Lines:

An overhead line may be used to transmit or distribute electric power. The successful operation of an overhead line depends to a great extent upon the mechanical design of the line. While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to provide against the most probable weather conditions. In general, the main components of an overhead line are:

(i) Conductors which carry electric power from the sending end station to the receiving end station.

(ii) Supports which may be poles or towers and keep the conductors at a suitable level above the ground.

(iii) Insulators which are attached to supports and insulate the conductors from the ground.

(iv) Cross arms which provide support to the insulators.

(v) Miscellaneous items such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

Conductor Materials:

The conductor is one of the important items as most of the capital outlay is invested for it. Therefore, proper choice of material and size of the conductor is of considerable importance. The conductor material used for transmission and distribution of electric power should have the following properties :

(i) high electrical conductivity.

(ii) high tensile strength in order to withstand mechanical stresses.

(iii) low cost so that it can be used for long distances.

(iv) low specific gravity so that weight per unit volume is small.

All above requirements are not found in a single material. Therefore, while selecting a conductor material for a particular case, a compromise is made between the cost and the required electrical and mechanical properties.

Commonly used conductor materials. The most commonly used conductor materials for overhead lines are *copper, aluminium, steel-cored aluminium, galvanised steel and cadmium copper.*

The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and the local conditions.

Line Supports:

The supporting structures for overhead line conductors are various types of poles and towers called line supports. In general, the line supports should have the following properties :

(i) High mechanical strength to withstand the weight of conductors and wind loads etc.

(ii) Light in weight without the loss of mechanical strength.

(iii) Cheap in cost and economical to maintain.

(iv) Longer life.

(v) Easy accessibility of conductors for maintenance.

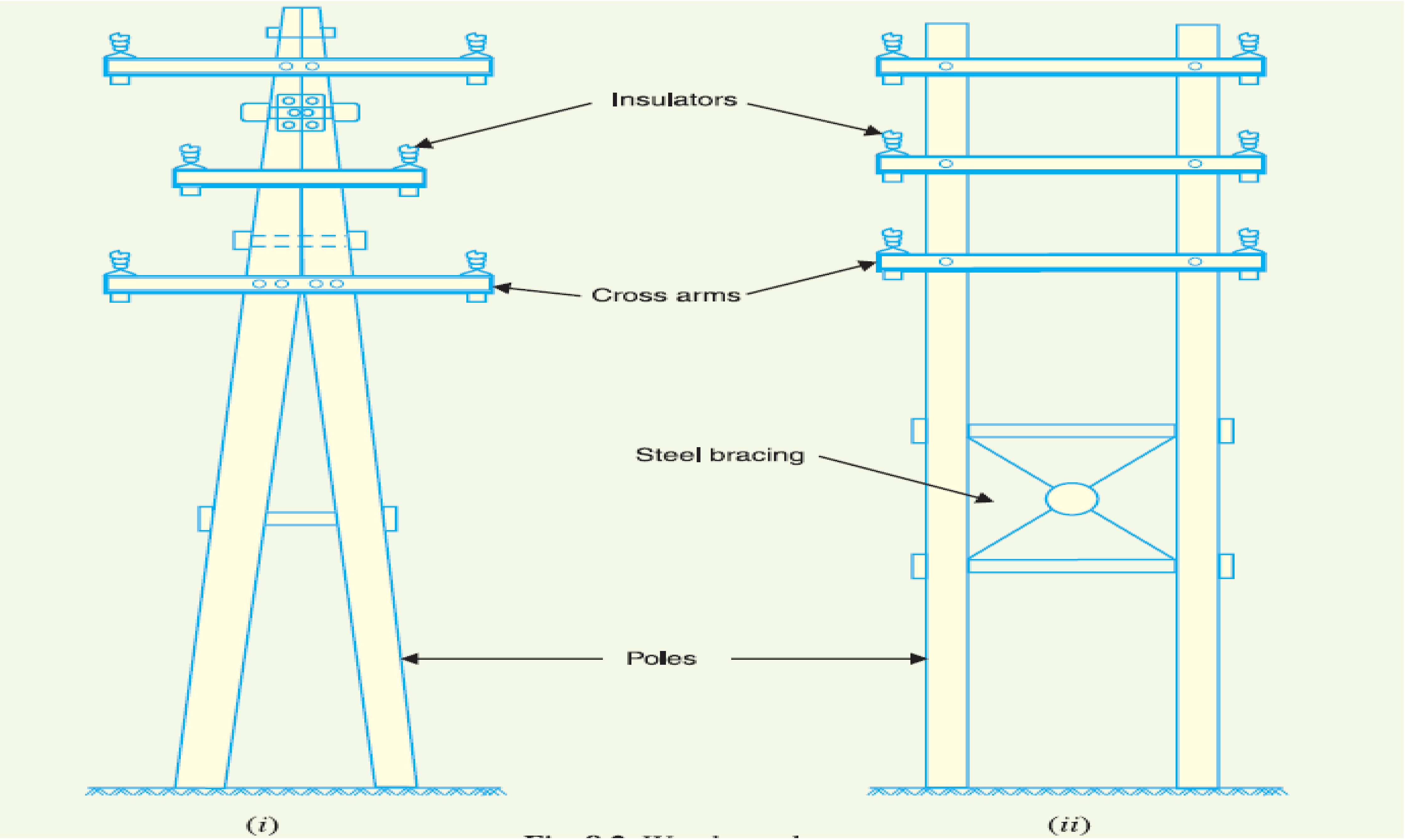
The line supports used for transmission and distribution of electric power are of various types including wooden poles, steel poles, R.C.C. poles and lattice steel towers. The choice of supporting structure for a particular case depends upon the line span, X-sectional area, line voltage, cost and local conditions.

1. Wooden poles.

These are made of seasoned wood (sal or chir) and are suitable for lines of moderate X-sectional area and of relatively shorter spans, say up to 50 meters. Such supports are cheap, easily available, provide insulating properties and, therefore, are widely used for distribution purposes in rural areas as an economical proposition. The wooden poles generally tend to rot below the ground level, causing foundation failure. In order to prevent this, the portion of the pole below the ground level is impregnated with preservative compounds like creosote oil. Double pole structures of the 'A' or 'H' type are often used to obtain a higher transverse strength than could be economically provided by means of single poles.

The main objections to wooden supports are :

(i) tendency to rot below the ground level
(ii) comparatively smaller life (20-25 years)
(iii) cannot be used for voltages higher than 20 kV
(iv) less mechanical strength and (v) require periodical inspection.


Insulators
Cross arms
Steel bracing
Poles
(i)
(ii)

2. Steel poles.

The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles are generally used for distribution purposes in the cities. This type of supports need to be galvanized or painted in order to prolong its life. The steel poles are of three types *viz.*,

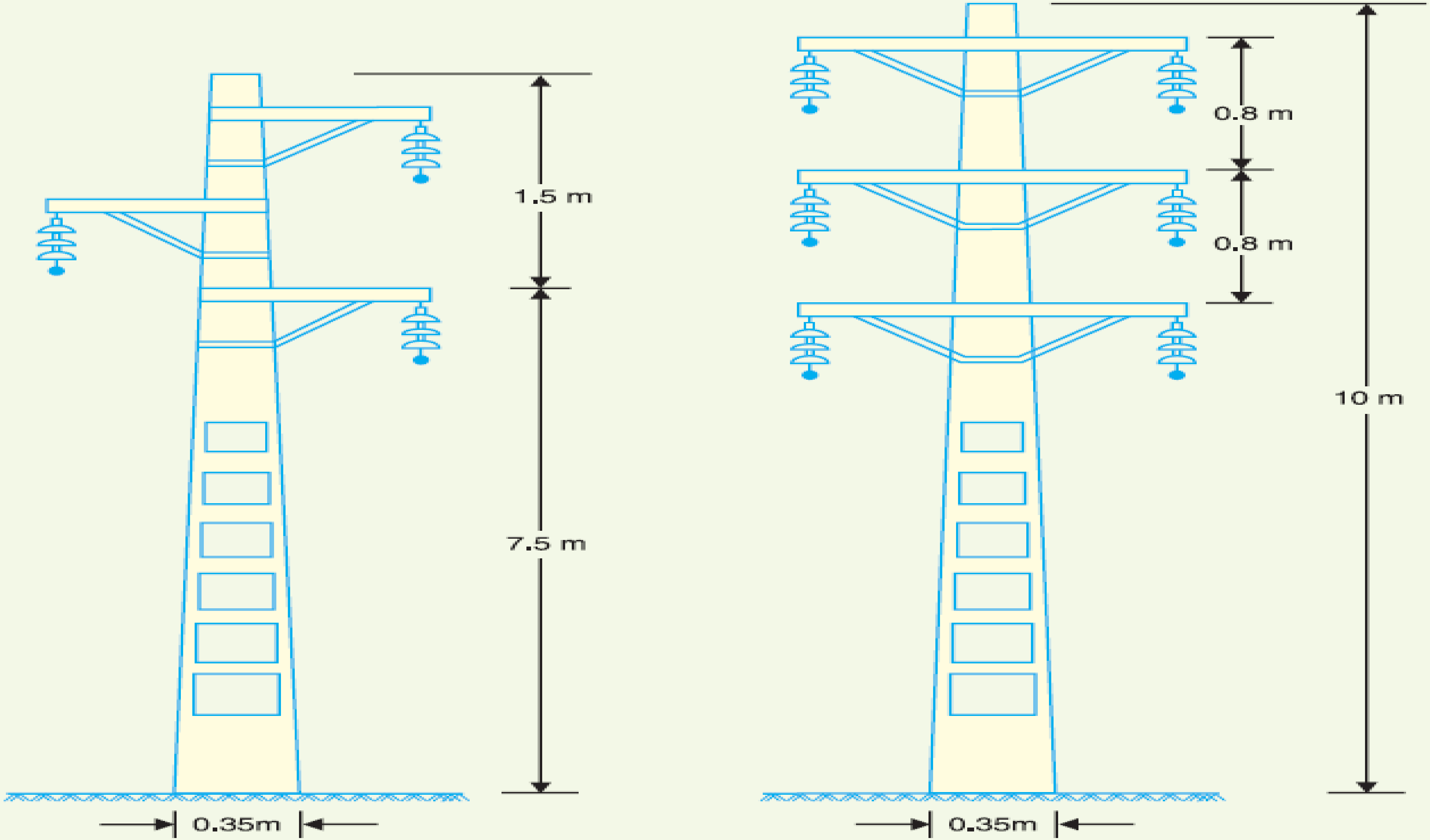
(i) rail poles (ii) tubular poles and

(iii) rolled steel joints.

3. RCC poles.

The reinforced concrete poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Moreover, they give good outlook, require little maintenance and have good insulating properties. Figure shows R.C.C. poles for single and double circuit. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports.

The main difficulty with the use of these poles is the high cost of transport owing to their heavy weight. Therefore, such poles are often manufactured at the site in order to avoid heavy cost of transportation.



(i) (ii)

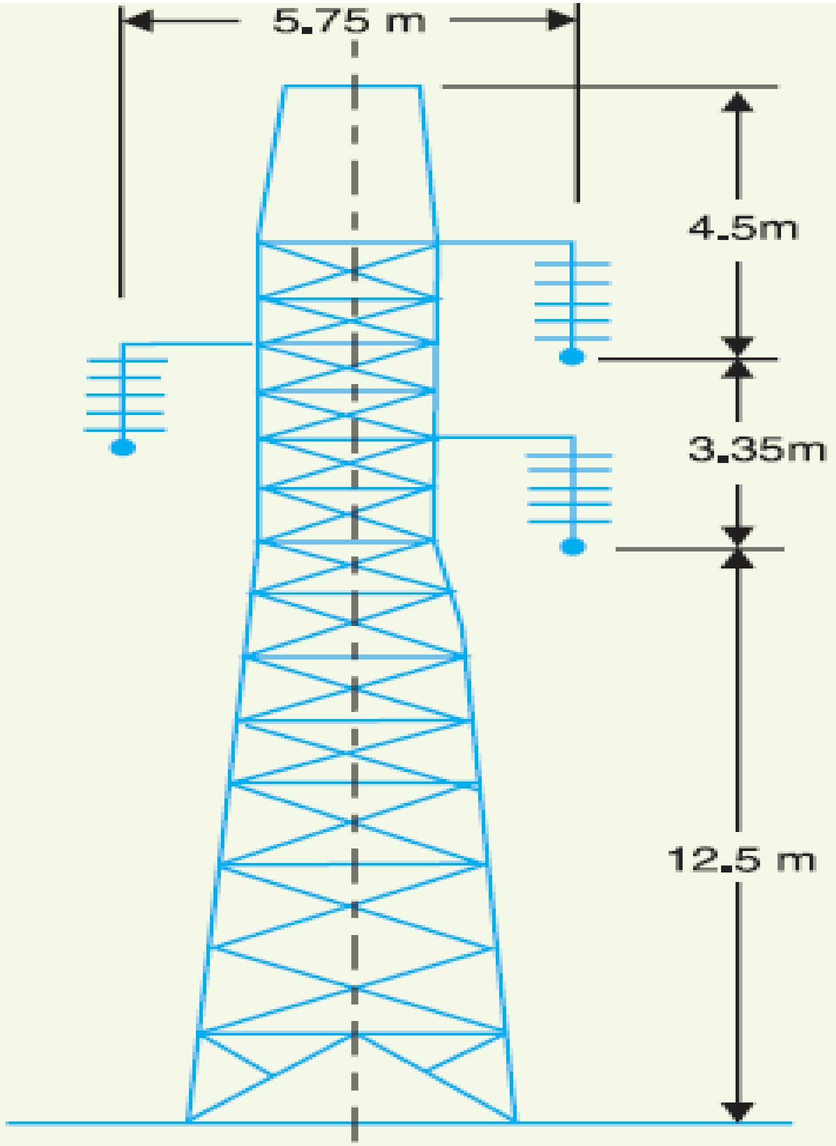
4. Steel towers.

In practice, wooden, steel and reinforced concrete poles are used for distribution purposes at low voltages, say up to 11 kV. However, for long distance transmission at higher voltage, steel towers are invariably employed. Steel towers have greater mechanical strength, longer life, can withstand most severe climatic conditions and permit the use of longer spans.

The risk of interrupted service due to broken or punctured insulation is considerably reduced owing to longer spans.

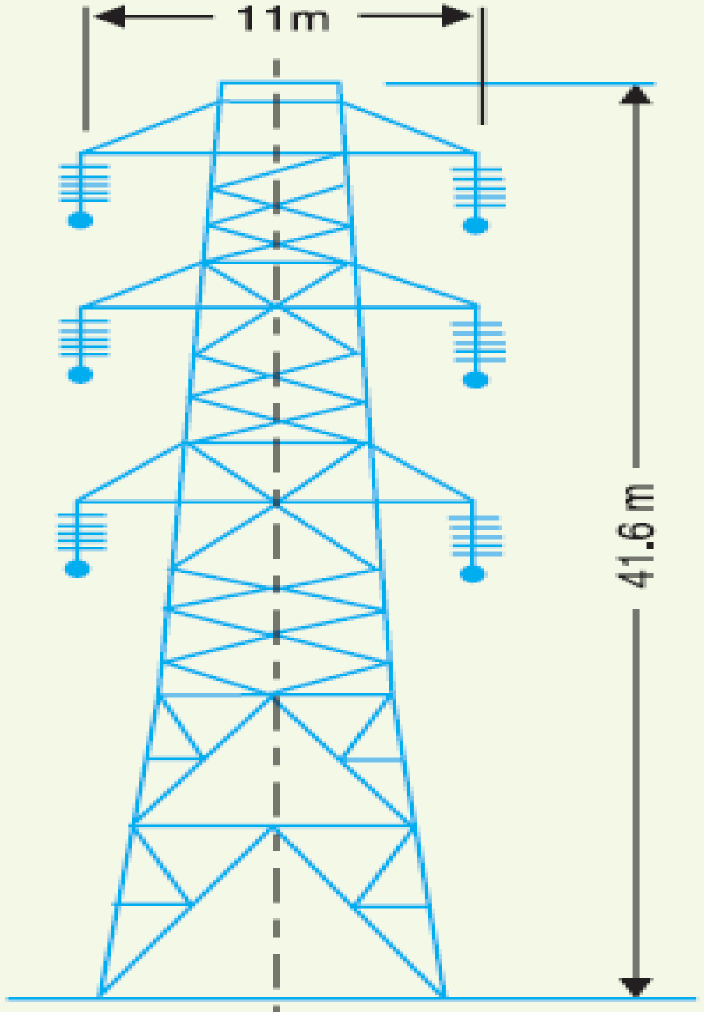
Tower footings are usually grounded by driving rods into the earth. This minimizes the lightning troubles as each tower acts as a lightning conductor.

Figure (i) *shows a single circuit tower. However, at a moderate additional cost, double circuit* tower can be provided as shown in Figure *(ii). The double circuit has the advantage that it ensures* continuity of supply. It case there is breakdown of one circuit, the continuity of supply can be maintained by the other circuit.



110 kV, Span 320 m

(*i*)



220 kV, Span 320 m

(*ii*)

Insulators:

The overhead line conductors should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports *i.e., line conductors must be properly insulated* from supports. This is achieved by securing line conductors to supports with the help of *insulators*.

The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth. In general, the insulators should have the following desirable properties

(i) High mechanical strength in order to withstand conductor load, wind load etc.

(ii) High electrical resistance of insulator material in order to avoid leakage currents to earth.

(iii) High relative permittivity of insulator material in order that dielectric strength is high.

***(iv) The insulator material should be non-porous, free from impurities and cracks otherwise the* permittivity will be lowered.**

(v) High ratio of puncture strength to flashover.

The most commonly used material for insulators of overhead line is *porcelain but glass, steatite* and special composition materials are also used to a limited extent. It is stronger mechanically than glass, gives less trouble from leakage and is less effected by changes of temperature.

Types of Insulator:

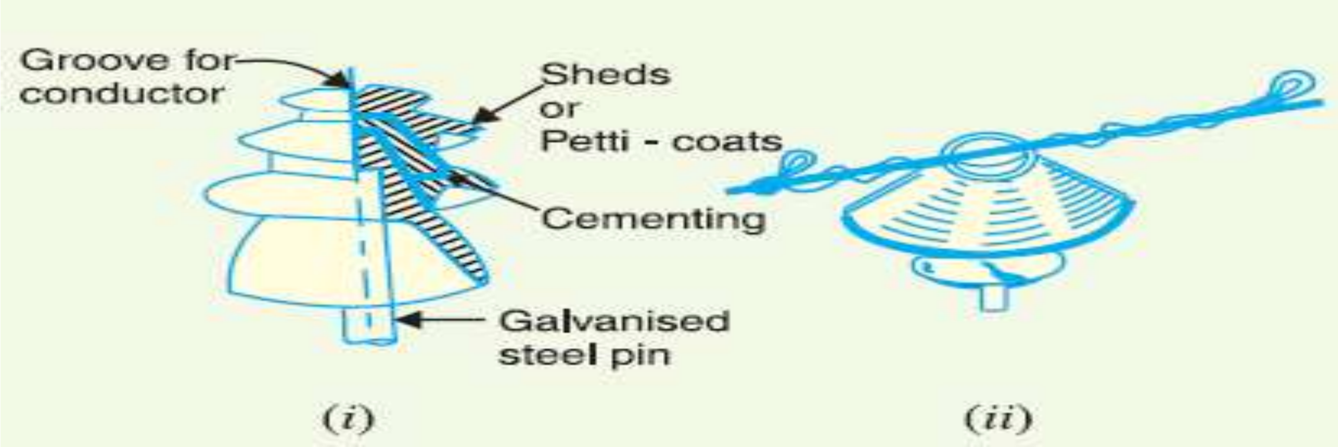
i) Pin type Insulator

ii) Suspension type Insulator

iii) Strain type Insulator

iv) Shackle type Insulator

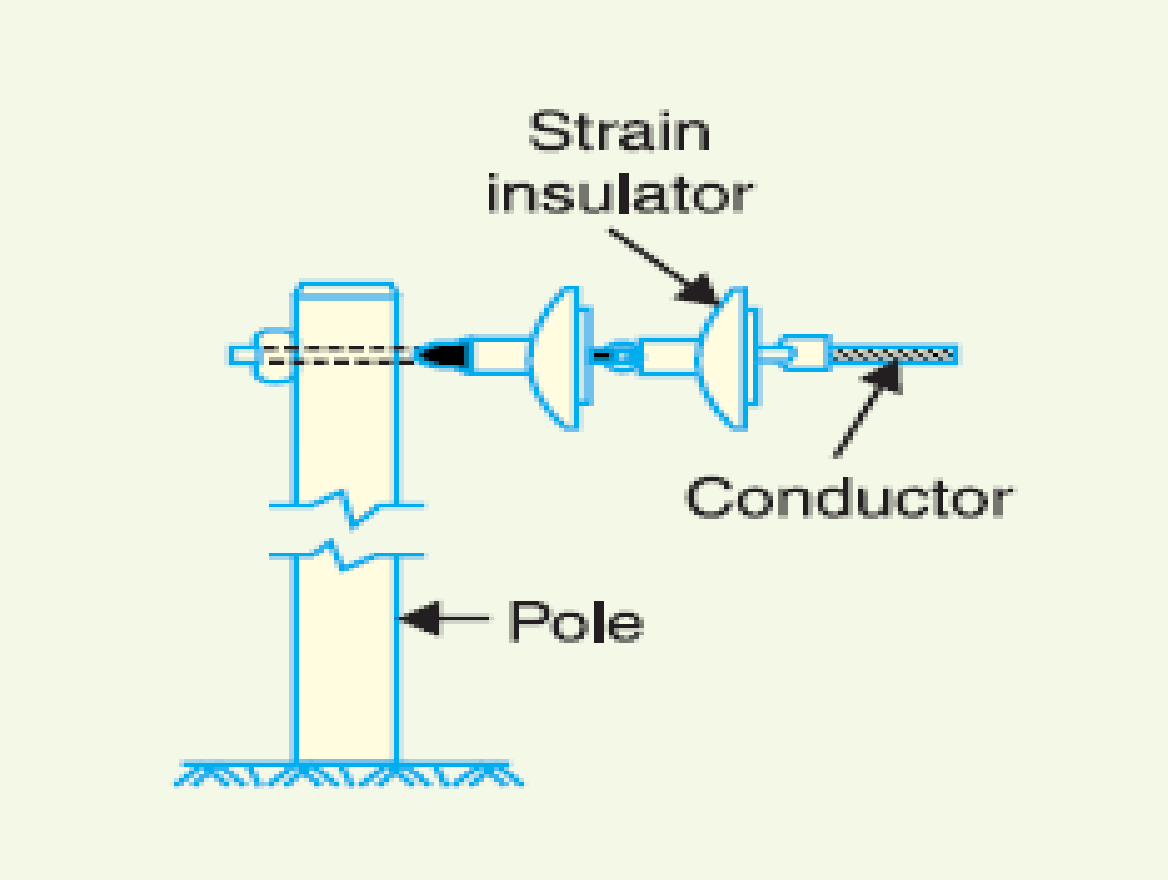
Types of Insulator:



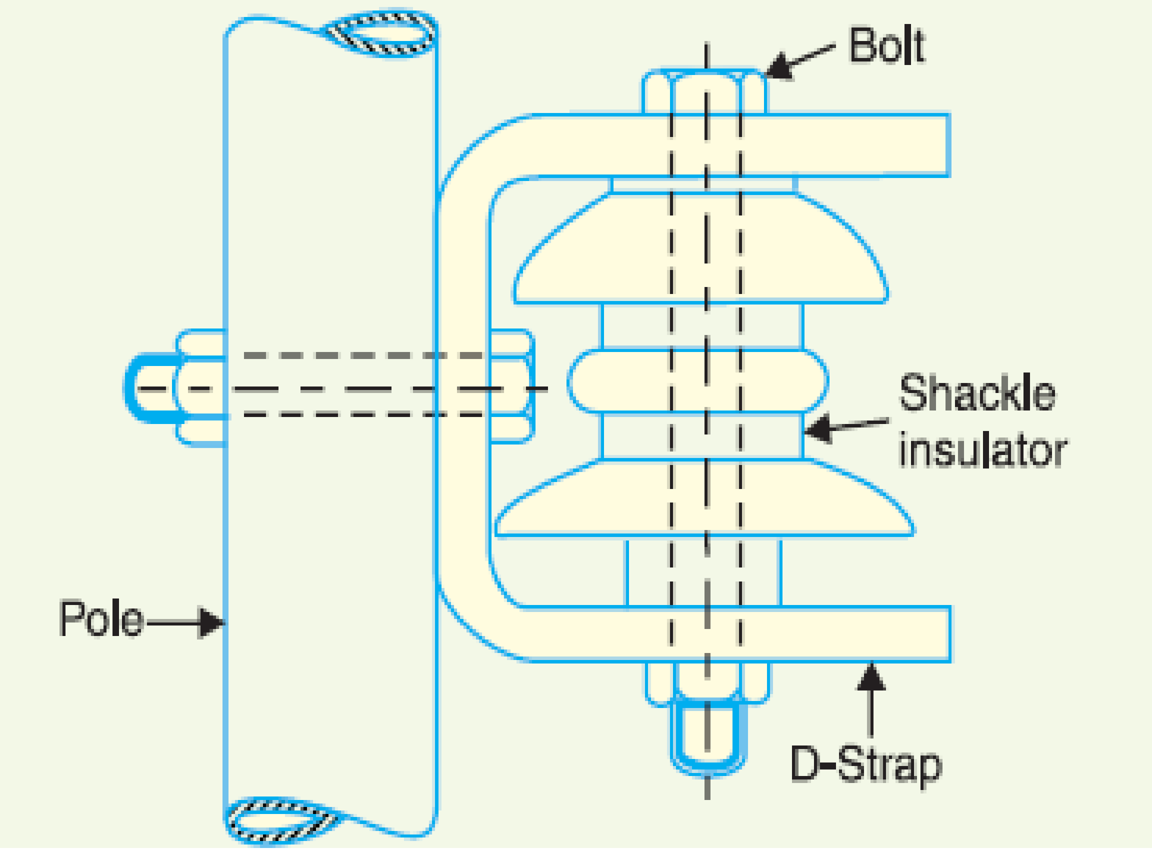
Pin Type Insulator

Pin type insulator

Suspension insulator



Strain Type Insulator



Shackle Type Insulator

Suspension type insulators:

The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33 kV. For high voltages (>33 kV), it is a usual practice to use suspension type insulators shown in Fig. They consist of a number of porcelain discs connected in series by metal links in the form of a string.

The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower. Each unit or disc is designed for low voltage, say 11 kV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66 kV, then six discs in series will be provided on the string.

Advantages:

(i) Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.

(ii) Each unit or disc of suspension type insulator is designed for low voltage, usually 11 kV. Depending upon the working voltage, the desired number of discs can be connected in series.

(iii) If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

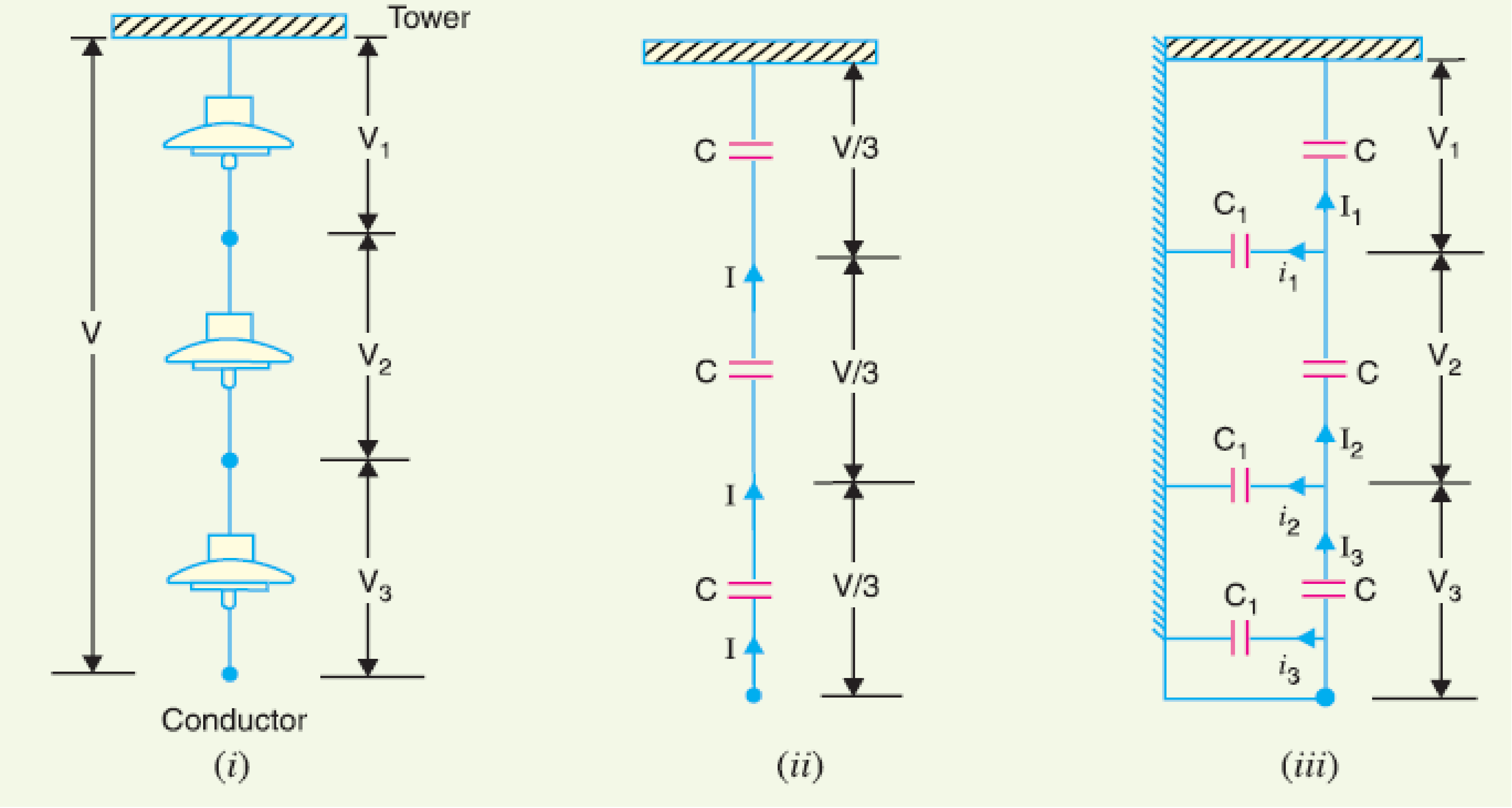
(iv) The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

(v) In case of increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

(vi) The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

Potential Distribution over Suspension Insulator String

- A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links. Fig. (i) shows 3-disc string of suspension insulators. The porcelain portion of each disc is in between two metal links.
- Therefore, each disc forms a capacitor C as shown in Fig. (ii). This is known as mutual capacitance or self-capacitance. If there were mutual capacitance alone, then charging current would have been the same through all the discs and consequently voltage across each unit would have been the same i.e., V/3 as shown in Fig.(ii).
- However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1. Due to shunt capacitance, charging current is not the same through all the discs of the string [See(iii)].
- Therefore, voltage across each disc will be different. Obviously, the disc nearest to the line conductor will have the maximum* voltage. Thus referring to Fig. (iii), V3 will be much more than V2 or V1.
- * Because charging current through the string has the maximum value at the disc nearest to the conductor.



Tower
V
V1
V2
V3
Conductor
(i)
C
V/3
I
(ii)
C
C1
I1
i1
I2
i2
I3
i3
(iii)

The following points may be noted regarding the potential distribution over a string of suspension insulators :

(i) The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance.

(ii) The disc nearest to the conductor has maximum voltage across it. As we move towards the cross-arm, the voltage across each disc goes on decreasing.

(iii) The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured. Therefore, means must be provided to equalize the potential across each unit.

(iv) If the voltage impressed across the string were D. C. , then voltage across each unit would be the same. It is because insulator capacitances are ineffective for D. C.

String Efficiency:

As stated above, the voltage applied across the string of suspension insulators is not uniformly distributed across various units or discs. The disc nearest to the conductor has much higher potential than the other discs. This unequal potential distribution is undesirable and is usually expressed in terms of string efficiency.

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as ***string efficiency i.e.,***

String efficiency = Voltage across the string/ *n x* Voltage across *disc nearest to conductor*

where *n = number of discs in the string.*

String efficiency is an important consideration since it decides the potential distribution along the string. The greater the string efficiency, the more uniform is the voltage distribution. Thus 100% string efficiency is an ideal case for which the voltage across each disc will be exactly the same. Although it is impossible to achieve 100% string efficiency, yet efforts should be made to improve it as close to this value as possible.