

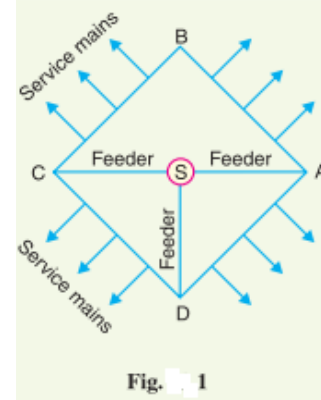
COMPONENTS OF DISTRIBUTION SYSTEM

Distribution System

That part of power system which distributes electric power for local use is known as **distribution system**.

In general, the distribution system is the electrical system between the sub-station fed by the transmission system and the consumers meters. It generally consists of feeders, distributors and the service mains. Fig.1 shows the single line diagram of a typical low tension distribution system.

- (i) **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.
- (ii) **Distributor** : A distributor is a conductor from which tappings are taken for supply to the consumers. In Fig.1, A B, 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 $\pm 6\%$ of rated value at the consumers' terminals.
- (iii) **Service mains** : A service mains is generally a small cable which connects the distributor to the consumers' terminals.



Classification of Distribution Systems

A distribution system may be classified according to ;

- (i) **Nature of current** : According to nature of current, distribution system may be classified as (a) d.c. distribution system (b) a.c. distribution system. Now-a-days, a.c. system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method.
- (ii) **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.
- (iii) **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. Each scheme has its own advantages and disadvantages.

A.C. Distribution

Now-a-days electrical energy is generated, transmitted and distributed in the form of alternating current. One important reason for the widespread use of alternating current in preference to direct current is the fact that alternating voltage can be conveniently changed in magnitude by means of a transformer. Transformer has made it possible to transmit a.c. power at high voltage and utilise it at a safe potential. High transmission and distribution voltages have greatly reduced the current in the conductors and the resulting line losses.

There is no definite line between transmission and distribution according to voltage or bulk capacity. However, in general, the a.c. distribution system is the electrical system between the stepdown substation fed by the transmission system and the consumers' meters. The a.c. distribution system is classified into

- (i) primary distribution system and
 - (ii) secondary distribution system.
- (i) **Primary distribution system**. It is that part of a.c. distribution system which operates at voltages somewhat higher than general utilisation 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.

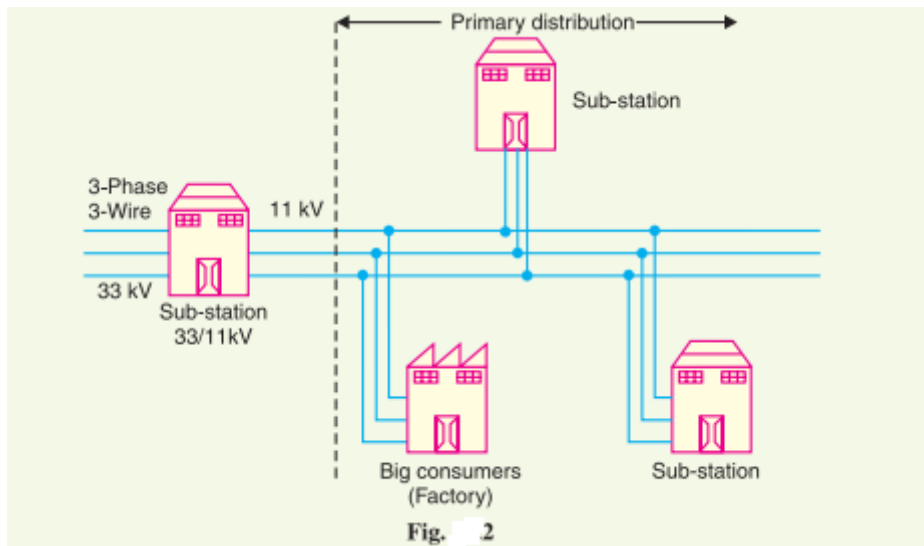


Fig.2 shows a typical primary distribution system. Electric power from the generating station is transmitted at high voltage to the substation located in or near the city. At this substation, voltage is stepped down to 11 kV with the help of step-down transformer. Power is supplied to various substations for distribution or to big consumers at this voltage. This forms the high voltage distribution or primary distribution.

- (ii) 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.

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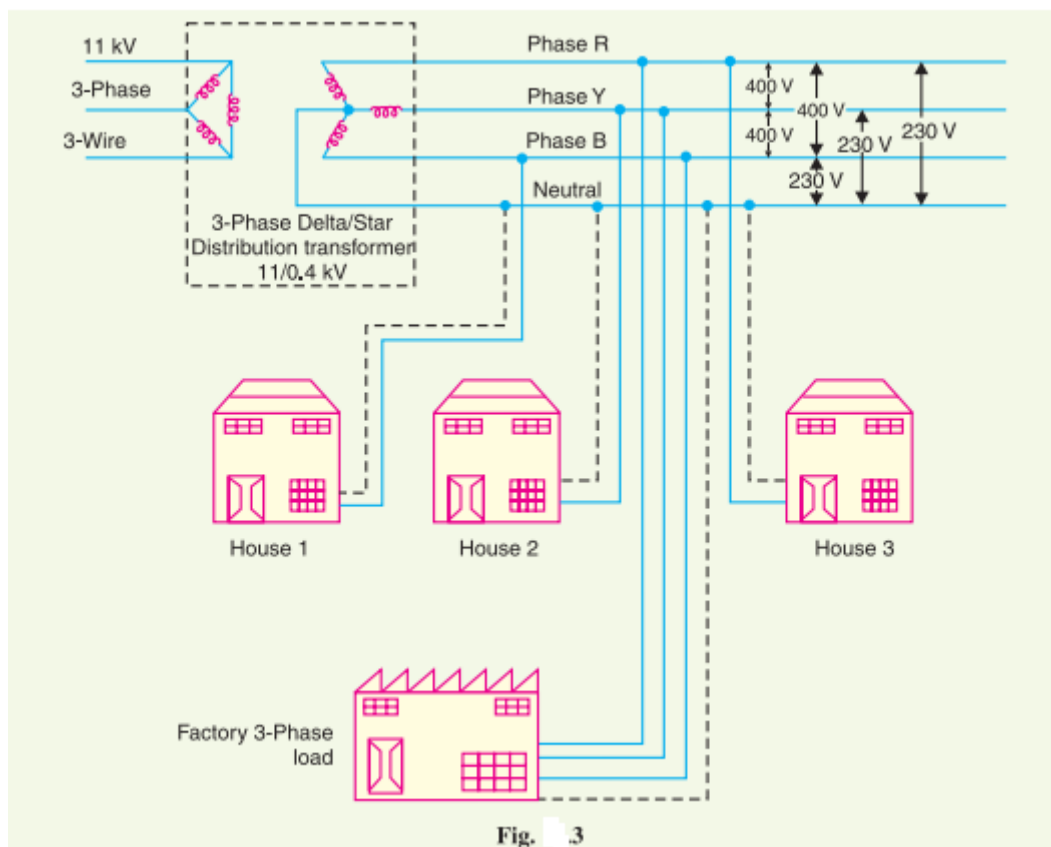


Fig.3 shows a typical secondary distribution system. The primary distribution circuit delivers power to various substations, called distribution substations. The substations are situated near the consumers' localities and contain stepdown transformers. At each distribution substation, the voltage is stepped down to 400 V and power is delivered by 3-phase,4-wire a.c. system. The voltage between any two phases is 400 V and between any phase and neutral is 230 V. 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

The distribution system can be overhead or underground. Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors. The underground system uses conduits, cables and manholes under the surface of streets and sidewalks. The choice between overhead and underground system depends upon a number of widely differing factors. Therefore, it is desirable to make a comparison between the two.

(i) Public safety : The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

(ii) Initial cost : The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipment. The initial cost of an underground system may be five to ten times than that of an overhead system.

(iii) Flexibility : The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc., are permanently placed once installed and the load expansion can only be met by laying new lines. However, on an overhead system, poles, wires, transformers etc., can be easily shifted to meet the changes in load conditions.

(iv) Faults : The chances of faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

(v) Appearance : The general appearance of an underground system is better as all the distribution lines are invisible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.

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

(vii) 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.

(viii) Useful life : The useful life of underground system is much longer than that of an overhead system. 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.

(ix) Maintenance cost : The maintenance cost of underground system is very low as compared with that of overhead system because of less chances of faults and service interruptions from wind, ice, lightning as well as from traffic hazards.

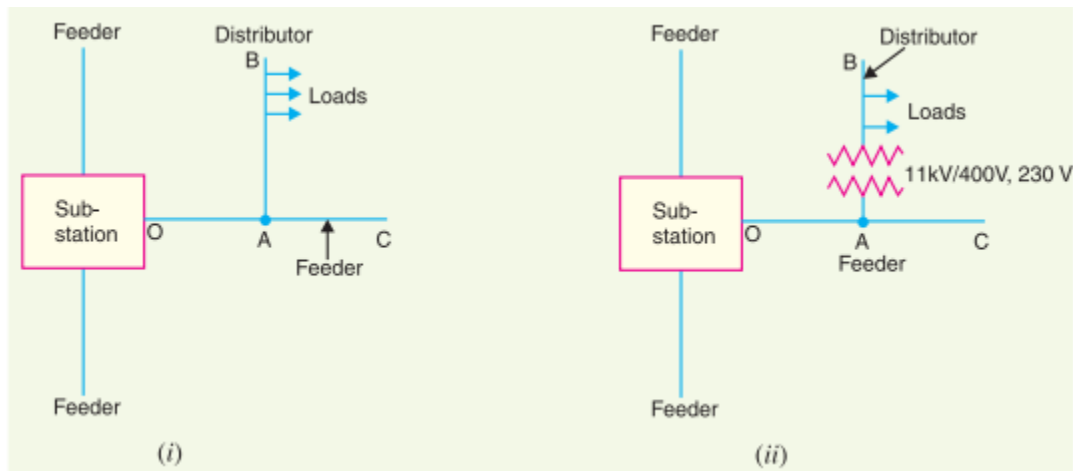
(x) Interference with communication circuits : An overhead system causes electromagnetic interference with the telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground system.

It is clear from the above comparison that each system has its own advantages and disadvantages. However, comparative economics (i.e., annual cost of operation) is the most powerful factor influencing the choice between underground and overhead system. The greater capital cost of underground system prohibits its use for distribution. But sometimes non-economic factors (e.g., general appearance, public safety etc.) exert considerable influence on choosing underground system. In general, overhead system is adopted for distribution and the use of underground system is made only where overhead construction is impracticable or prohibited by local laws.

Connection Schemes of Distribution System

All distribution of electrical energy is done by constant voltage system. In practice, the following distribution circuits are generally used :

(i) **Radial System :** In this system, separate feeders radiate from a single substation and feed the distributors at one end only. Fig. (i) shows a single line diagram of a radial system for d.c. distribution where a feeder OC supplies a distributor A B at point A. Obviously, the distributor is fed at one end only i.e., point A is this case. Fig. (ii) shows a single line diagram of radial system for a.c. distribution. The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.

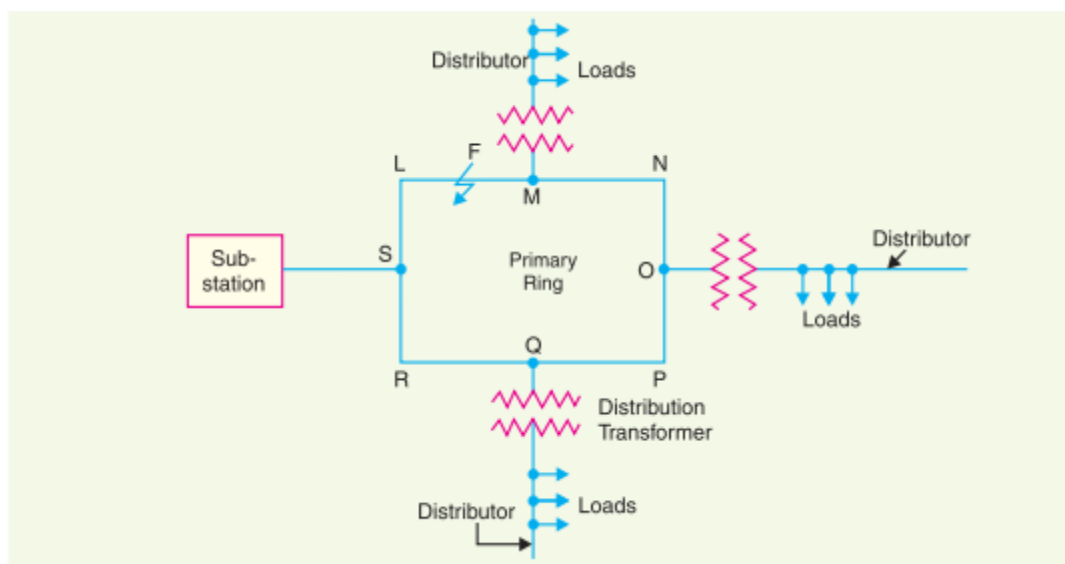


This is the simplest distribution circuit and has the lowest initial cost. However, it suffers from the following drawbacks :

- (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.

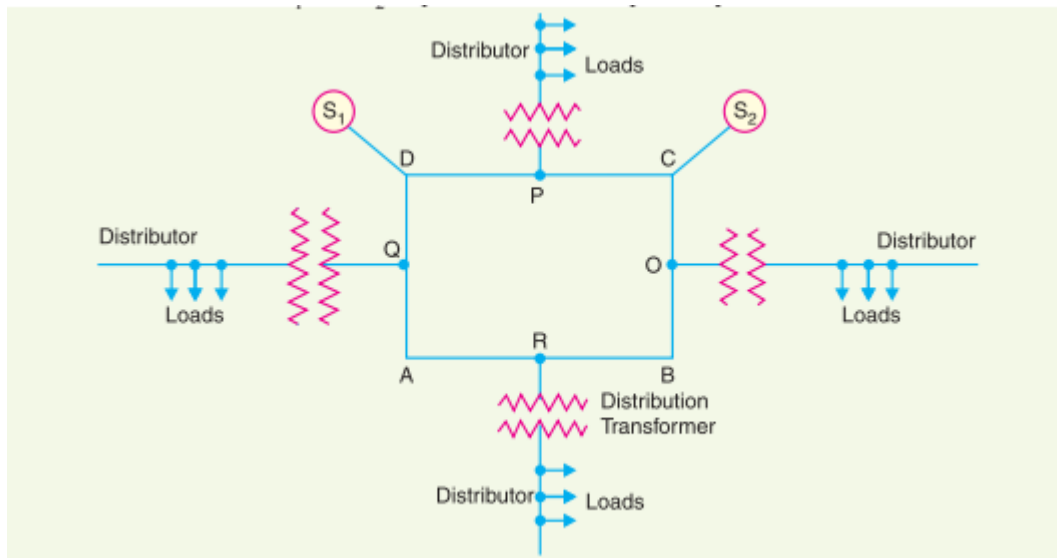
(ii) **Ring main system :** In this system, the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. Fig. below shows the single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS. The distributors are tapped from different points M, O and Q of the feeder through distribution transformers.



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. For example, suppose that fault occurs at any point F of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers via the feeder SRQPONM.

(iii) **Interconnected system** : When the feeder ring is energised by two or more than two generating stations or substations, it is called inter-connected system. Fig. below 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.



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.

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 :

(i) Proper voltage, (ii) Availability of power on demand and (iii) 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 $\pm 6\%$ 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.

Design Considerations in Distribution System

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. For this purpose, design of feeders and distributors requires careful consideration.

(i) Feeders : A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant. It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the substation.

(ii) Distributors : A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer's terminals ($\pm 6\%$ of rated value). The size and length of the distributor should be such that voltage at the consumer's terminals is within the permissible limits.

A.C. Distribution Calculations

A.C. distribution calculations differ from those of d.c. distribution in the following respects :

(i) In case of d.c. system, the voltage drop is due to resistance alone. However, in a.c. system, the voltage drops are due to the combined effects of resistance, inductance and capacitance.

(ii) In a d.c. system, additions and subtractions of currents or voltages are done arithmetically but in case of a.c. system, these operations are done vectorially.

(iii) In an a.c. system, power factor (p.f.) has to be taken into account. Loads tapped off from the distributor are generally at different power factors. There are two ways of referring power factor viz

(a) It may be referred to supply or receiving end voltage which is regarded as the reference vector.

(b) It may be referred to the voltage at the load point itself.

There are several ways of solving a.c. distribution problems. However, symbolic notation method has been found to be most convenient for this purpose. In this method, voltages, currents and impedances are expressed in complex notation and the calculations are made exactly as in d.c. distribution.

Methods of Solving A.C. Distribution Problems

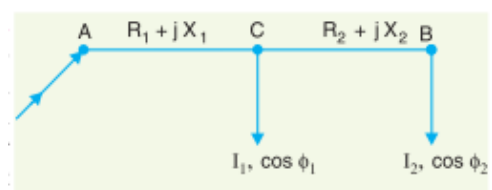
In a.c. distribution calculations, power factors of various load currents have to be considered since currents in different sections of the distributor will be the vector sum of load currents and not the arithmetic sum. The power factors of load currents may be given

(i) w.r.t. receiving or sending end voltage or

(ii) w.r.t. to load voltage itself. Each case shall be discussed separately.

(i) Power factors referred to receiving end voltage

Consider an a.c. distributor A B with concentrated loads of I_1 and I_2 tapped off at points C and B as shown in the Fig. Taking the receiving end voltage V_B as the reference vector, let lagging power factors at C and B be $\cos \phi_1$ and $\cos \phi_2$ w.r.t. V_B . Let R_1 , X_1 and R_2 , X_2 be the resistance and reactance of sections AC and CB of the distributor.



Impedance of section AC,	$\vec{Z}_{AC} = R_1 + j X_1$
Impedance of section CB,	$\vec{Z}_{CB} = R_2 + j X_2$
Load current at point C,	$\vec{I}_1 = I_1 (\cos \phi_1 - j \sin \phi_1)$
Load current at point B,	$\vec{I}_2 = I_2 (\cos \phi_2 - j \sin \phi_2)$
Current in section CB,	$\vec{I}_{CB} = \vec{I}_2 = I_2 (\cos \phi_2 - j \sin \phi_2)$
Current in section AC,	$\vec{I}_{AC} = \vec{I}_1 + \vec{I}_2$ $= I_1 (\cos \phi_1 - j \sin \phi_1) + I_2 (\cos \phi_2 - j \sin \phi_2)$
Voltage drop in section CB,	$\vec{V}_{CB} = \vec{I}_{CB} \vec{Z}_{CB} = I_2 (\cos \phi_2 - j \sin \phi_2) (R_2 + j X_2)$
Voltage drop in section AC,	$\vec{V}_{AC} = \vec{I}_{AC} \vec{Z}_{AC} = (I_1 + I_2) \vec{Z}_{AC}$

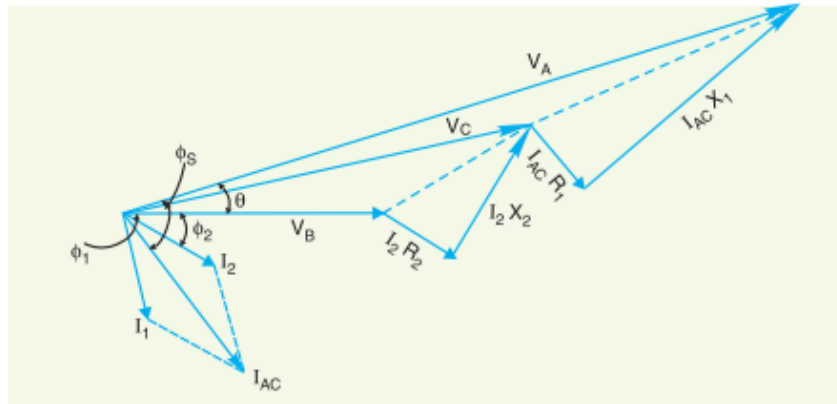
$$= [I_1(\cos \phi_1 - j \sin \phi_1) + I_2(\cos \phi_2 - j \sin \phi_2)] [R_1 + jX_1]$$

Sending end voltage,

$$\vec{V}_A = \vec{V}_B + \vec{V}_{CB} + \vec{V}_{AC}$$

Sending end current,

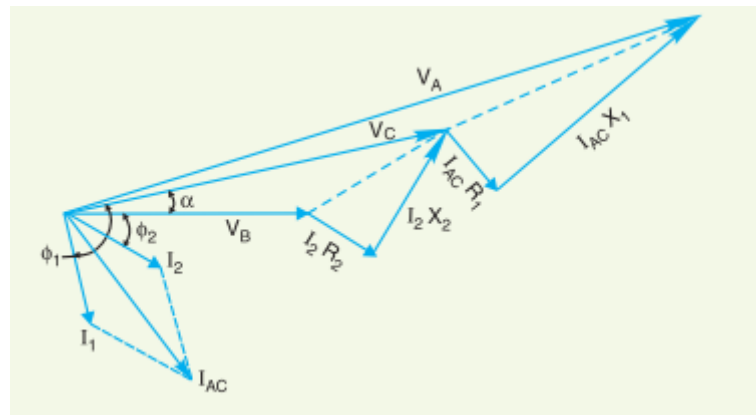
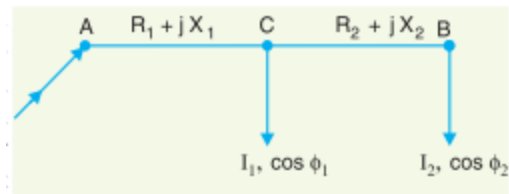
$$\vec{I}_A = \vec{I}_1 + \vec{I}_2$$



The vector diagram of the a.c. distributor under these conditions is shown in above Fig. Here, the receiving end voltage V_B is taken as the reference vector. As power factors of loads are given w.r.t. V_B , therefore, I_1 and I_2 lag behind V_B by ϕ_1 and ϕ_2 respectively.

(ii) Power factors referred to respective load voltages :

Suppose the power factors of loads in the Fig. are referred to their respective load voltages. Then ϕ_1 is the phase angle between V_C and I_1 and ϕ_2 is the phase angle between V_B and I_2 . The vector diagram under these conditions is shown in Fig. below.



Voltage drop in section CB,

$$\vec{V}_{CB} = I_2 Z_{CB} = I_2 (\cos \phi_2 - j \sin \phi_2) (R_2 + j X_2)$$

Voltage at point C,

$$\vec{V}_C = \vec{V}_B + \text{Drop in section CB} = V_C \angle \alpha \text{ (say)}$$

Now

$$I_1 = I_1 \angle -\phi_1 \text{ w.r.t. voltage } V_C$$

\therefore

$$I_1 = I_1 \angle -(\phi_1 - \alpha) \text{ w.r.t. voltage } V_B$$

i.e.

$$I_1 = I_1 [\cos(\phi_1 - \alpha) - j \sin(\phi_1 - \alpha)]$$

Now

$$\begin{aligned} \vec{I}_{AC} &= \vec{I}_1 + \vec{I}_2 \\ &= I_1 [\cos(\phi_1 - \alpha) - j \sin(\phi_1 - \alpha)] + I_2 (\cos \phi_2 - j \sin \phi_2) \end{aligned}$$

Voltage drop in section AC,

$$\vec{V}_{AC} = \vec{I}_{AC} Z_{AC} = (I_1 + I_2) Z_{AC}$$

\therefore Voltage at point A,

$$\vec{V}_A = \vec{V}_B + \text{Drop in CB} + \text{Drop in AC}$$