Electric Supply System

- *The conveyance of electric power from a power station to consumers' premises is known as* **electric supply system**.

- An electric supply system consists of three principal components *viz*., the **power station**, the **transmission lines** and the **distribution system**.

- Electric power is produced at the power stations which are located at favourable places, generally **quite away from the consumers.**

Electric Supply System

- It is then transmitted over large distances to load centres with the help of conductors known as **transmission lines**.
- Finally, it is distributed to a large number of small and big consumers through a **distribution network**.
- The electric supply system can be broadly classified into
  - d.c. or a.c. system
  - overhead or underground system.

Electric Supply System

- Now-adays, 3-phase, 3-wire a.c. system is universally adopted for generation and transmission of electric power as an economical proposition.
- However, distribution of electric power is done by 3-phase, 4-wire a.c. system.
- The underground system is more expensive than the overhead system.d.c. or a.c. system

Typical a.c. Power Supply Scheme

- The large network of conductors between the **power station** and the **consumers** can be broadly divided into two parts viz., **transmission system** and **distribution system**.
- Each part can be further sub-divided into two—**primary transmission** and **secondary transmission** and **primary distribution** and **secondary distribution**.
- Fig. 1. shows the layout of a typical a.c. power supply scheme by a single line diagram.

✓ Note: it is not necessary that all power schemes include all the stages shown in the figure.

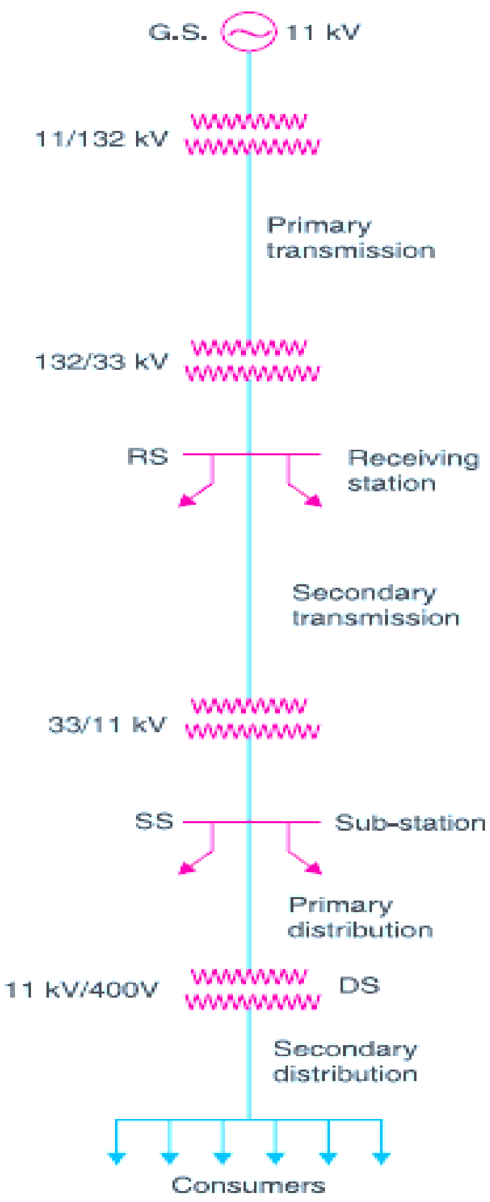
Typical a.c. Power Supply Scheme

Generating station :

- G.S. represents the generating station where electric power is produced by 3-phase alternators operating in parallel.
- The usual generation voltage is 11 kV
- For economy in the transmission of electric power, the generation voltage (*i.e.*, 11 kV) is stepped upto 132 kV (ormore)

Primary transmission.

- The electric power at 132 kV is transmitted by 3-phase, 3-wire overhead system to the Outskirts of the city.
- This forms the primary transmission.



Typical a.c. Power Supply Scheme

- *Secondary transmission.:*

- The primary transmission line terminates at the receiving station (RS) which usually lies at the outskirts of the city.
- At the receiving station, the voltage is reduced to 33kV by step-down transformers.
- From this station, electric power is transmitted at 33kV by 3-phase, 3-wire overhead system to various sub-stations (SS) located at the strategic points in the city.
- This forms the secondary transmission.

Advantages of High Transmission Voltage

- **Increases transmission efficiency**

$$\text{Input power} = P + \text{Total losses}$$

$$= P + \frac{P^2 \rho l}{V^2 \cos^2 \phi \, a}$$

Assuming J to be the current density of the conductor, then,

$$a = I/J$$

$$\therefore \quad \text{Input power} = P + \frac{P^2 \rho \, l \, J}{V^2 \cos^2 \phi \, I} = P + \frac{P^2 \rho \, l \, J}{V^2 \cos^2 \phi} \times \frac{1}{I}$$

$$= P + \frac{P^2 \rho \, l \, J}{V^2 \cos^2 \phi} \times \frac{{}^{*}\sqrt{3}\, V \cos \phi}{P}$$

$$= P + \frac{\sqrt{3}\, P \, J \, \rho \, l}{V \cos \phi} = P\left[1 + \frac{\sqrt{3}\, J \rho \, l}{V \cos \phi}\right]$$

Advantages of High Transmission Voltage

- **Increases transmission efficiency**

$$\text{Transmission efficiency} = \frac{\text{Output power}}{\text{Input power}} = \frac{P}{P\left[1+\frac{\sqrt{3}\ J\rho l}{V\cos\phi}\right]} = \frac{1}{\left[1+\frac{\sqrt{3}\ J\rho l}{V\cos\phi}\right]}$$

$$= {}^{**}\left[1-\frac{\sqrt{3}\ J\rho l}{V\cos\phi}\right] \text{ approx.} \qquad \ldots(ii)$$

As J, ρ and l are constants, therefore, transmission efficiency increases when the line voltage is increased.

Advantages of High Transmission Voltage

- **Decreases percentage line drop**

$$\text{Line drop} = I\,R = I \times \frac{\rho\, l}{a}$$

$$= I \times \rho\, l \times J/I = \rho\, l\, J \qquad [\because\ a = I/J]$$

$$\%\text{age line drop} = \frac{J\,\rho\, l}{V} \times 100 \qquad ...(iii)$$

As J, ρ and l are constants, therefore, percentage line drop decreases when the transmission voltage increases.

Advantages of High Transmission Voltage

- **Limitations of high transmission voltage.**
  - From the above discussion, it might appear advisable to use the highest possible voltage for transmission of power in a bid to save conductor material.
  - However, it must be realised that high transmission voltage results in

(*i*) the increased cost of insulating the conductors

(*ii*) the increased cost of transformers, switchgear and other terminal apparatus.

  - Therefore, there is a limit to the higher transmission voltage which can be economically employed in a particular case.
  - This limit is reached when the saving in cost of conductor material due to higher voltage is offset by the increased cost of insulation, transformer, switchgear etc.
  - Hence, the choice of proper transmission voltage is essentially a question of economics.

Various Systems of Power Transmission

- For transmission of electric power, 3-phase, 3-wire a.c. system is universally adopted.
- However, other systems can also be used for transmission under special circumstances.
- The different possible systems of transmission are :

❑ D.C. system

(i) D.C. two-wire.

(ii) D.C. two-wire with mid-point earthed.

(iii) D.C. three-wire.

Various Systems of Power Transmission

- Single-phase A.C. system

(i) Single-phase two-wire.

(ii) Single-phase two-wire with mid-point earthed.

(iii) Single-phase three-wire.

- Two-phase A.C. system

(i) Two-phase four-wire.

(ii) Two-phase three wire.

- Three-phase A.C. system

(i) Three-phase three-wire.

(ii) Three-phase four-wire.

Various Systems of Power Transmission

- While comparing the amount of conductor material required in various systems, the proper comparison shall be on the basis of equal maximum stress on the dielectric.
- There are two cases :

(i) When transmission is by overhead system. In the overhead system, the maximum disruptive stress exists between the conductor and the earth.

Therefore, the comparison of the system in this case has to be made on the basis of maximum voltage between conductor and earth.

(ii) When transmission is by underground system.

In the underground system, the chief stress on the insulation is between conductors.

Therefore, the comparison of the systems in this case should be made on the basis of maximum potential difference between conductors.

Comparison of Conductor Material in Overhead System

- In comparing the relative amounts of conductor material necessary for different systems of transmission, similar conditions will be assumed in each case viz.,

(*i*) same power (*P watts*) transmitted by each system.

(*ii*) the distance (*l metres*) over which power is transmitted remains the same.

(*iii*) the line losses (*W watts*) are the same in each case.

(*iv*) the maximum voltage between any conductor and earth (*Vm*) is the same in each case.

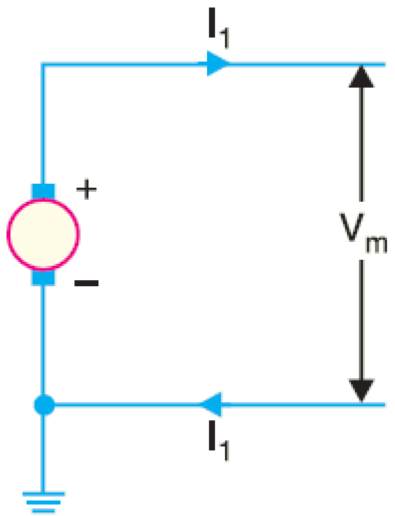
Comparison of Conductor Material in Overhead System

❑ Two-wire d.c. system with one conductor earthed

- In the 2-wire d.c. system, one is the outgoing or positive wire and the other is the return or negative wire as shown in Fig.
- The load is connected between the two wires.
- Max. voltage between conductors = V_m
- Power to be transmitted = P

➢ Load current, $I_1 = P/V_m$

- If R_1 is the resistance of each line conductor, then,
- $R_1 = \rho\, l/a_1$
- where a_1 is the area of X-section of the conductor



Comparison of Conductor Material in Overhead System

❑ Two-wire d.c. system with one conductor earthed

Line losses, $W = 2I_1^2 R_1 = 2\left(\frac{P}{V_m}\right)^2 \rho \frac{l}{a_1}$ $\quad\therefore\quad$ Area of X-section, $a_1 = \frac{2P^2\rho l}{W V_m^2}$

Volume of conductor material required

$$= 2a_1 l = 2\left(\frac{2P^2\rho l}{W V_m^2}\right) l = \frac{4P^2\rho l^2}{W V_m^2}$$

- ❖ It is a usual practice to make this system as the basis for comparison with other systems.
- ❖ Therefore, volume of conductor material required in this system shall be taken as the basic quantity *i.e.*

$$\frac{4P^2\rho l^2}{W V_m^2} = K\,(\text{say})$$

Comparison of Conductor Material in Overhead System

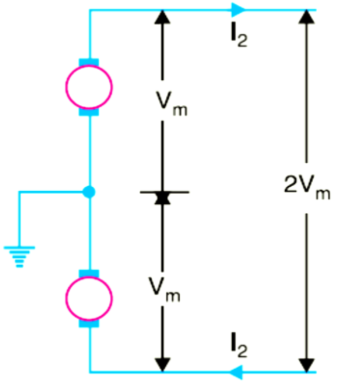
❑Two-wire d.c. system with mid-point earthed

❖ Fig. shows the two-wire d.c. system with mid-point earthed.

❖ The maximum voltage between any conductor and earth is V_m so that maximum voltage between conductors is $2V_m$.

❖ Load current, $I_2 = P/2V_m$

❖ Let a_2 be the area of X-section of the conductor.



$$\text{Line losses, } W = 2I_2^2 R_2 = 2\left(\frac{P}{2V_m}\right)^2 \times \frac{\rho l}{a_2}$$

$$[\because R_2 = \rho\, l/a_2]$$

$$\therefore \quad W = \frac{P^2 \rho\, l}{2a_2 V_m^2} \qquad \therefore \quad \text{Area of X-section, } a_2 = \frac{P^2 \rho\, l}{2W V_m^2}$$

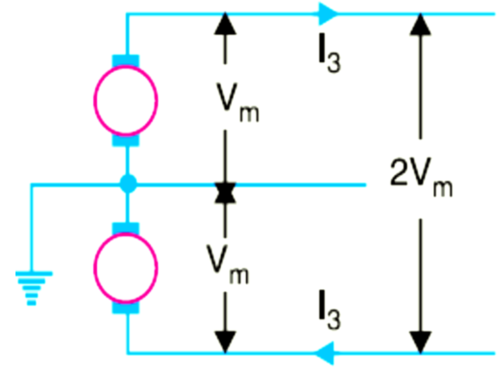
$\therefore$ Volume of conductor material required

$$= 2\, a_2 l = 2\left(\frac{P^2 \rho\, l}{2W V_m^2}\right) l = \frac{P^2 \rho\, l^2}{W V_m^2} = \frac{K}{4} \qquad \left[\because K = \frac{4P^2 \rho l^2}{W V_m^2}\right]$$

✓ Hence, the volume of conductor material required in this system is *one-fourth* of that required in a two-wire d.c. system with one conductor earthed.

Comparison of Conductor Material in Overhead System

❑Three-wire d.c. system.



- ❖ In a 3-wire d.c. system, there are two outers and a middle or neutral wire which is earthed at the generator end as shown in Fig.
- ❖ If the load is balanced, the current in the neutral wire is zero.
- ❖ Assuming balanced loads,
- ❖ Load current, $I_3 = P/2Vm$
- ❖ Let a_3 be the area of X-section of each outer wire

$$\text{Line losses, } W = 2I_3^2 R_3 = 2\left(\frac{P}{2V_m}\right)^2 \times \rho \frac{l}{a_3} = \frac{P^2 \rho l}{2V_m^2 a_3}$$

$$\therefore \quad \text{Area of X-section, } a_3 = \frac{P^2 \rho l}{2WV_m^2}$$

❖ Assuming the area of X-section of neutral wire to be half that of the outer wire,
Volume of conductor material required

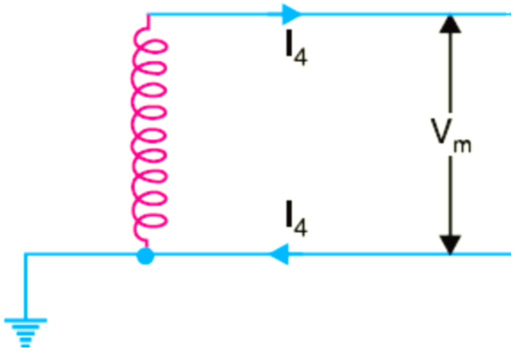
$$= 2 \cdot 5\, a_3 l = 2 \cdot 5 \left(\frac{P^2 \rho l}{2WV_m^2}\right) l = \frac{2 \cdot 5}{2}\left(\frac{P^2 \rho l^2}{WV_m^2}\right) = \frac{5}{16} K$$

$$\left[\because K = \frac{4P^2 \rho l^2}{WV_m^2}\right]$$

✓ Hence the volume of conductor material required in this system is 5/16th of what is required fora 2-wire d.c. system with one conductor earthed

Comparison of Conductor Material in Overhead System

❑Single phase 2-wire a.c. system with one conductor earthed



- ❖ Fig. shows a single phase 2-wire a.c. system with one conductor earthed.
- ❖ The maximum voltage between conductors is Vm so that r.m.s. value of voltage between them is Vm / 2 .
- ❖ Assuming the load power factor to be cos φ,

$$\text{Load current, } I_4 = \frac{P}{(V_m/\sqrt{2})\cos\phi} = \frac{\sqrt{2}\,P}{V_m\cos\phi}$$

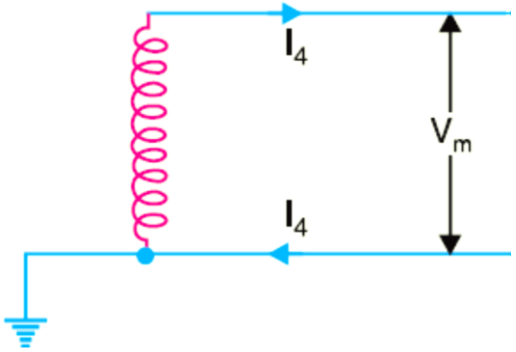
- ❖ Let a_4 be the area of X-section of the conductor.

$$\therefore \quad \text{Line losses, } W = 2\,I_4^2 R_4 = 2\left(\frac{\sqrt{2}\,P}{V_m\cos\phi}\right)^2 \times \frac{\rho\,l}{a_4} = \frac{4\,P^2\rho\,l}{\cos^2\phi\,V_m^2\,a_4}$$

$$\therefore \quad \text{Area of X-section, } a_4 = \frac{4\,P^2\rho\,l}{\cos^2\phi\,W V_m^2}$$

Comparison of Conductor Material in Overhead System

❑Single phase 2-wire a.c. system with one conductor earthed



- Volume of conductor material required

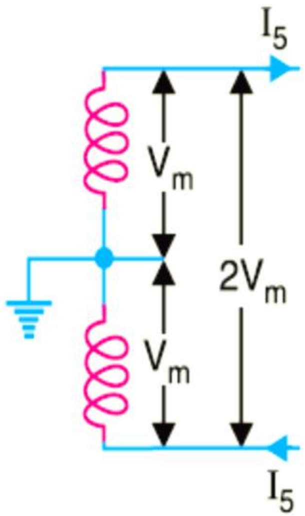
$$= 2 a_4 l = 2\left(\frac{4 P^2 \rho l}{V_m^2 W \cos^2 \phi}\right) l$$

$$= \frac{2}{\cos^2 \phi} \times \frac{4 P^2 \rho l^2}{W V_m^2} = \frac{2 K}{\cos^2 \phi} \qquad \left[\because K = \frac{4 P^2 \rho l^2}{W V_m^2}\right]$$

- Hence, the volume of conductor material required in this system is $2/\cos^2 \varphi$ times that of 2-wire d.c. system with the one conductor earthed.

Comparison of Conductor Material in Overhead System

❑Single phase 2-wire system with mid-point earthed



- Fig. shows a single phase a.c. system with mid-point earthed.
- The two wires possess equal and opposite voltages to earth (i.e., Vm).
- Therefore, the maximum voltage between the two wires is 2Vm.
- The r.m.s. value of voltage between conductors is = 2Vm/√2 = √2Vm .
- Assuming the power factor of the load to be cos φ,

$$\text{Load current, } I_5 = \frac{P}{\sqrt{2}\, V_m \cos\phi}$$

- Let a_5 be the area of X-section of the conductor.

$$\text{Line losses, } W = 2 I_5^2 R_5 = 2\left(\frac{P}{\sqrt{2}\, V_m \cos\phi}\right)^2 R_5$$

$$\therefore \quad W = \frac{P^2 \rho\, l}{a_5 V_m^2 \cos^2\phi}$$

$$\therefore \quad \text{Area of X-section, } a_5 = \frac{P^2 \rho\, l}{W V_m^2 \cos^2\phi}$$

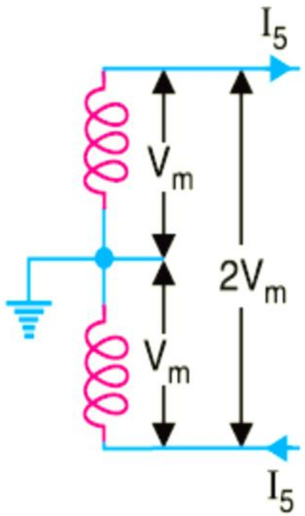
Comparison of Conductor Material in Overhead System

❑Single phase 2-wire system with mid-point earthed

❖ Volume of conductor material required

$$= 2 a_5 l = 2\left(\frac{P^2 \rho l}{W V_m^2 \cos^2 \phi}\right) l = \frac{2 P^2 \rho l^2}{W V_m^2 \cos^2 \phi} = \frac{2}{\cos^2 \phi} \times \frac{P^2 \rho l^2}{W V_m^2}$$

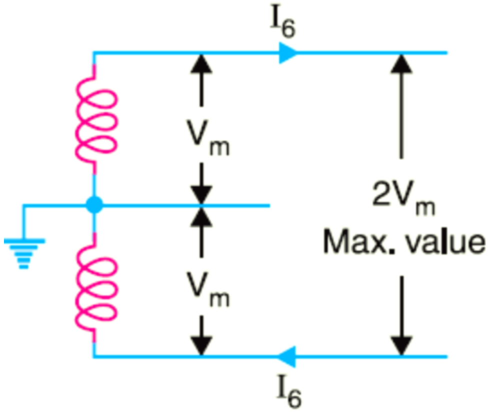
$$= \frac{K}{2 \cos^2 \phi} \qquad \left[\because K = \frac{4 P^2 \rho l^2}{W V_m^2}\right]$$



➢ Hence the volume of conductor material required in this system is 1/2 $\cos^2 \varphi$ times that of 2-wire d.c. system with one conductor earthed.

Comparison of Conductor Material in Overhead System

❑Single phase, 3-wire system



- The single phase 3-wire system is identical in principle with 3-wire d.c. system.
- The system consists of two outers and neutral wire taken from the mid-point of the phase winding as shown in Fig.
- If the load is balanced, the current through the neutral wire is zero.
- Assuming balanced load,
- Max. voltage between conductors = 2 Vm
- R.M.S.value of voltage between conductors = 2Vm/√2 = √2Vm
- If the p.f of the load is cos φ, then,

$$\text{Load current, } I_6 = \frac{P}{\sqrt{2}\, V_m \cos\phi}$$

➢ Let a_6 be the area of X-section of each outer conductor

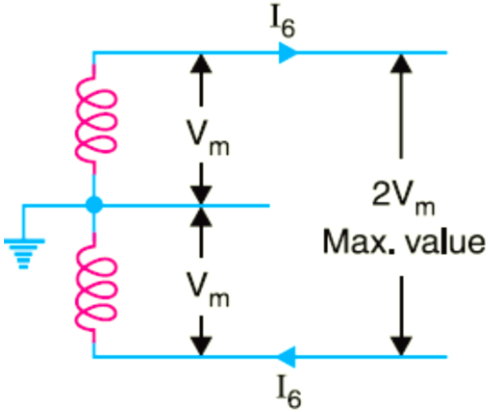
$$\text{Line losses, } W = 2 I_6^2 R_6 = 2\left(\frac{P}{\sqrt{2}\, V_m \cos\phi}\right)^2 \times \frac{\rho\, l}{a_6} = \frac{P^2 \rho\, l}{a_6 V_m^2 \cos^2\phi}$$

$$\therefore \quad \text{Area of X-section, } a_6 = \frac{P^2 \rho\, l}{W V_m^2 \cos^2\phi}$$

Comparison of Conductor Material in Overhead System

❑Single phase, 3-wire system

- ❖ Assuming the area of X-section of neutral wire to be half that of the outer wire,
- ❖ Volume of conductor material required



$$= 2{\cdot}5\, a_6\, l = 2{\cdot}5\left(\frac{P^2 \rho\, l}{W\, V_m^2 \cos^2\phi}\right) l = \frac{2\cdot 5\, P^2 \rho\, l^2}{W\, V_m^2 \cos^2\phi} \quad = \frac{2\cdot 5}{\cos^2\phi} \times \frac{P^2 \rho\, l^2}{W\, V_m^2}$$

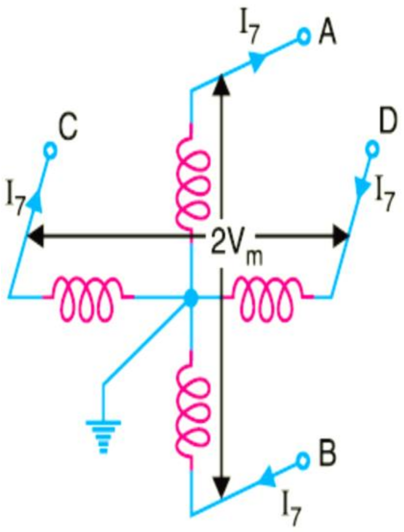
$$= \frac{5K}{8 \cos^2\phi}$$

$$\left[\because K = \frac{4P^2 \rho\, l^2}{W\, V_m^2}\right]$$

- ➢ Hence, the volume of conductor material required in this system is 5/8 $\cos^2 \varphi$ times that required in a 2-wire d.c. system with one conductor earthed.

Comparison of Conductor Material in Overhead System

❑Two phase, 4-wire a.c. system

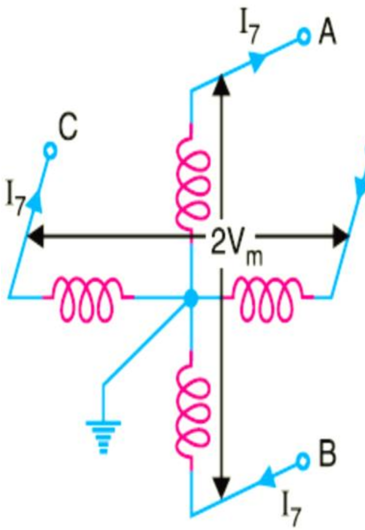


- As shown in Fig., the four wires are taken from the ends of the two-phase windings and the mid-points of the two windings are connected together.
- This system can be considered as two independent single-phase systems, each transmitting one half of the total power.
- Max. voltage between outers A and B = $2V_m$
- R.M.S. value of voltage = $2V_m/\sqrt{2} = \sqrt{2}V_m$
- Power supplied per phase (i.e., by outers A and B) = P/2
- Assuming p.f. of the load to be cos φ,

$$\text{Load current, } I_7 = \frac{P/2}{\sqrt{2}\,V_m \cos\phi} = \frac{P}{2\sqrt{2}\,V_m \cos\phi}$$

Comparison of Conductor Material in Overhead System

❑Two phase, 4-wire a.c. system



- Let a_7 be the area of X-section of one conductor

$$\text{Line losses, } W = 4 I_7^2 R_7 = 4\left(\frac{P}{2\sqrt{2}\, V_m \cos\phi}\right)^2 \times \frac{\rho\, l}{a_7}$$

$$\therefore \quad W = \frac{P^2 \rho\, l}{2 a_7 V_m^2 \cos^2\phi}$$

$$\therefore \quad \text{Area of X-section, } a_7 = \frac{P^2 \rho\, l}{2\, W\, V_m^2 \cos^2\phi}$$

- Volume of conductor material required = 4 $a_7 l$

$$= 4\left(\frac{P^2 \rho\, l}{2\, W\, V_m^2 \cos^2\phi}\right) l = \frac{4 P^2 \rho\, l^2}{2\, W\, V_m^2 \cos^2\phi} = \frac{1}{2\cos^2\phi} \times \frac{4P^2 \rho\, l^2}{W\, V_m^2} = \frac{K}{2\cos^2\phi}$$

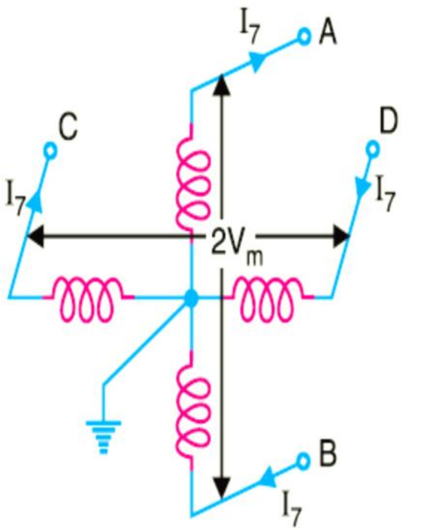
$$\left[\because K = \frac{4P^2 \rho\, l^2}{W\, V_m^2}\right]$$

- Hence, the volume of conductor material required for this system is 1/2 $\cos^2\varphi$ times that of 2- wire d.c. system with one conductor earthed.

Comparison of Conductor Material in Overhead System

❑Two phase, 4-wire a.c. system

❖ Let a_7 be the area of X-section of one conductor



$$\text{Line losses, } W = 4 I_7^2 R_7 = 4\left(\frac{P}{2\sqrt{2}\, V_m \cos\phi}\right)^2 \times \frac{\rho l}{a_7}$$

$$\therefore \qquad W = \frac{P^2 \rho l}{2 a_7 V_m^2 \cos^2\phi}$$

$$\therefore \qquad \text{Area of X-section, } a_7 = \frac{P^2 \rho l}{2 W V_m^2 \cos^2\phi}$$

➢ Volume of conductor material required = 4 $a_7 l$

$$= 4\left(\frac{P^2 \rho l}{2 W V_m^2 \cos^2\phi}\right) l = \frac{4 P^2 \rho l^2}{2 W V_m^2 \cos^2\phi} = \frac{1}{2\cos^2\phi} \times \frac{4P^2 \rho l^2}{W V_m^2} = \frac{K}{2\cos^2\phi}$$

$$\left[\because K = \frac{4P^2 \rho l^2}{W V_m^2}\right]$$

➢ Hence, the volume of conductor material required for this system is 1/2 $\cos^2\varphi$ times that of 2- wire d.c. system with one conductor earthed.