12.7 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. 12.8 (*i*) shows a single line diagram of a radial system for d.c. distribution where a feeder *OC* supplies a distributor *AB* at point *A*. Obviously, the distributor is fed at one end only *i.e.*, point *A* is this case. Fig. 12.8 (*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.

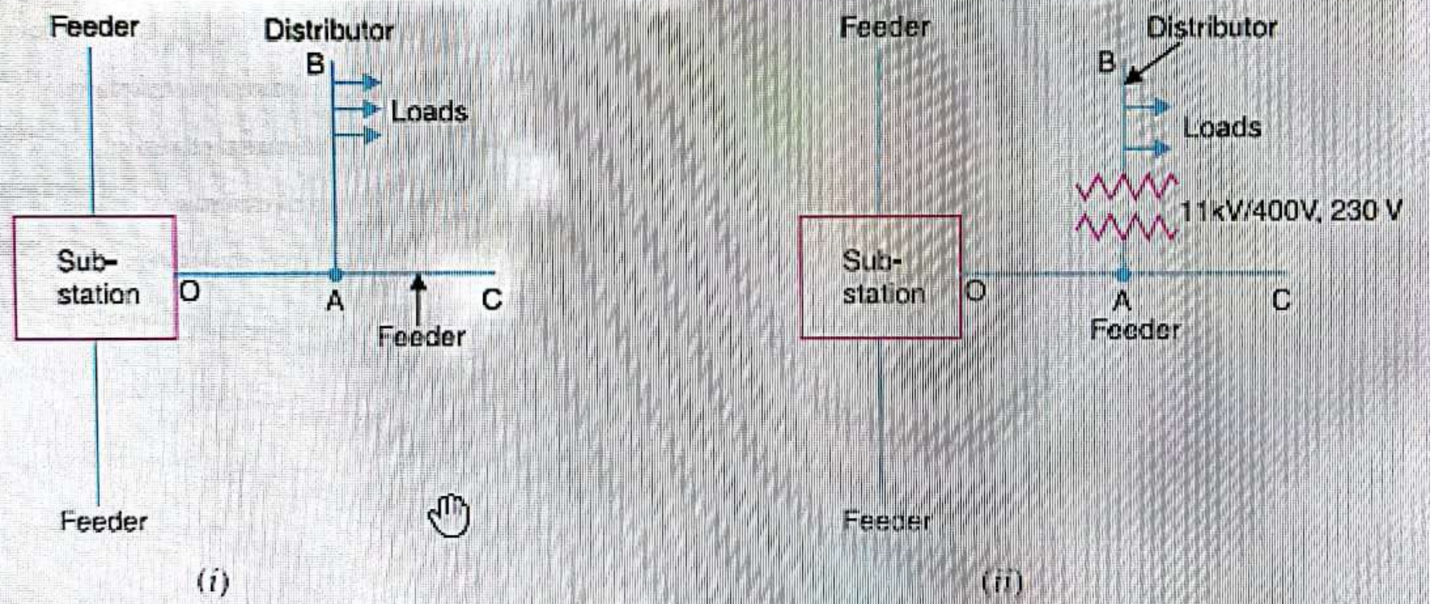


Fig. 12.8

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.

(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*.

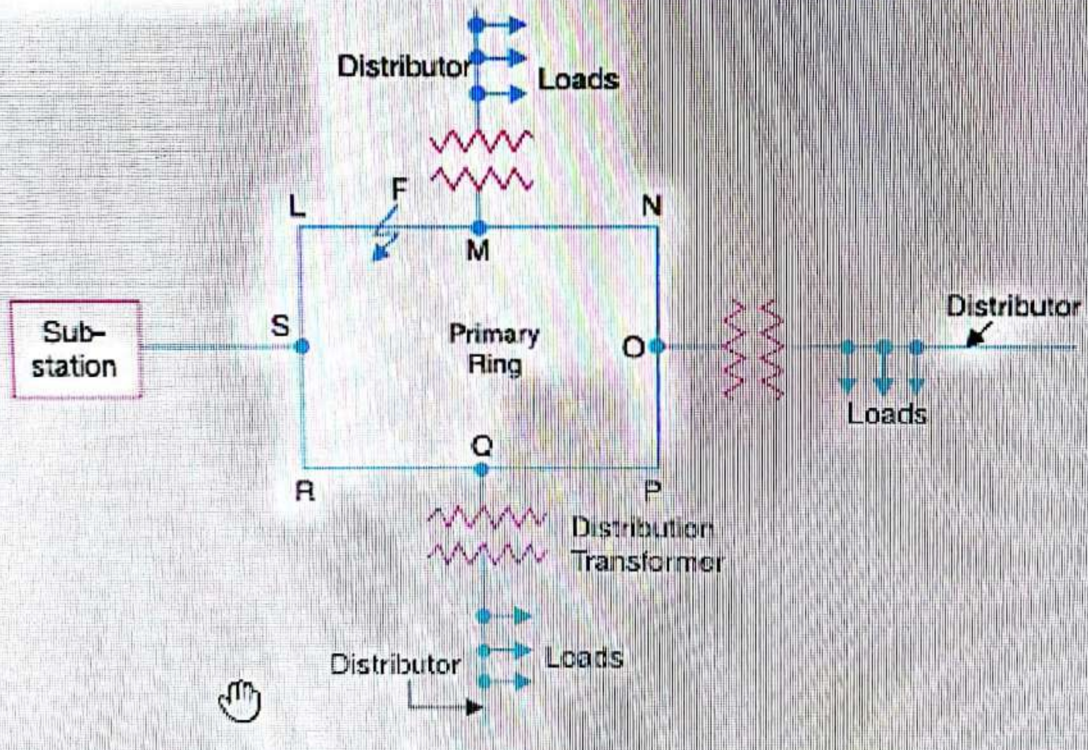
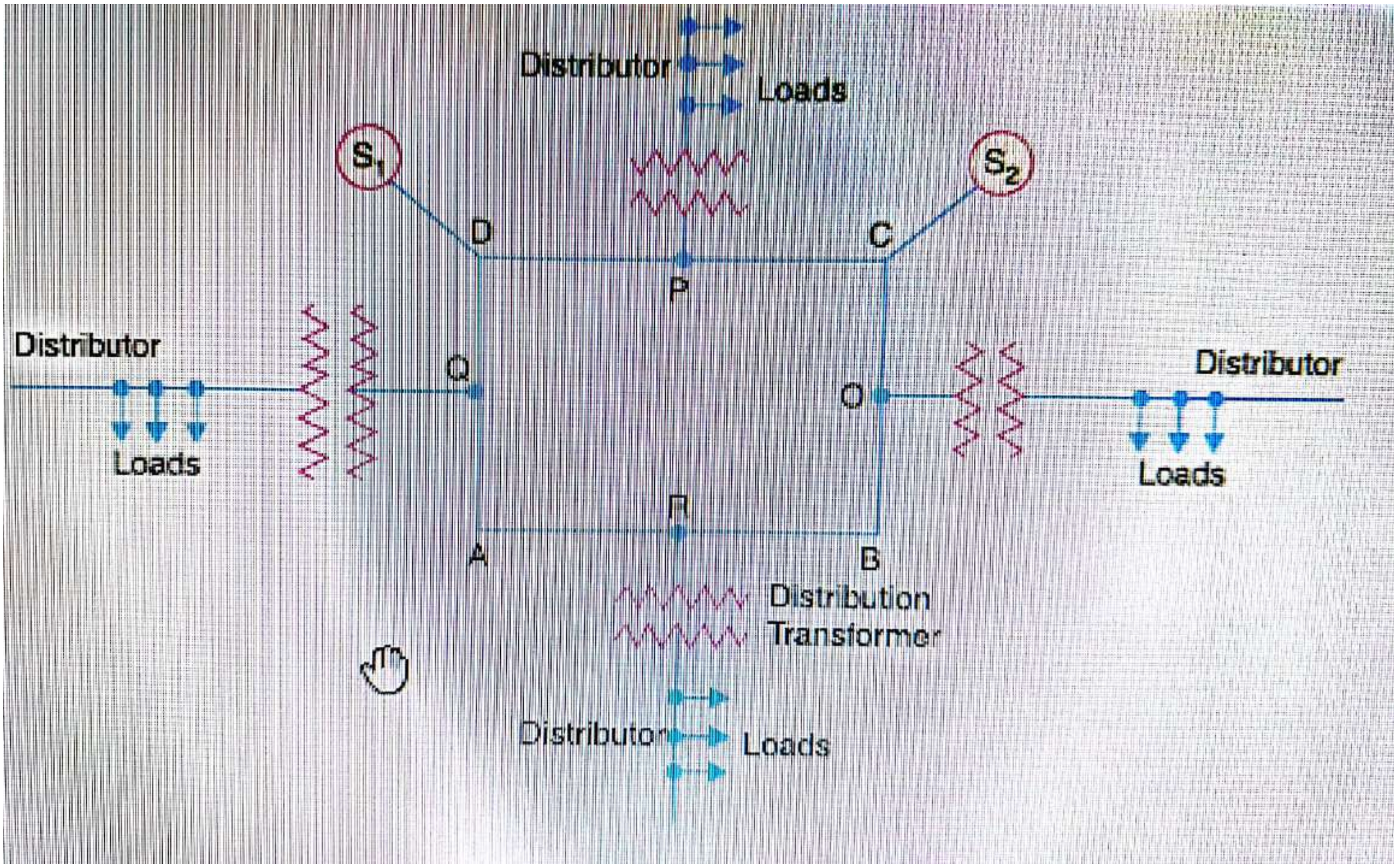


Fig. 12.9

(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. 12.10 shows the single line diagram of interconnected system where the closed feeder ring $ABCD$ is supplied by two substations S_1 and S_2 at points D and C respectively. Distributors are connected to



Distributor
Loads
S1
S2
D
C
P
Distributor
Q
O
Distributor
Loads
Loads
R
A
B
Distribution
Transformer
Distributor
Loads

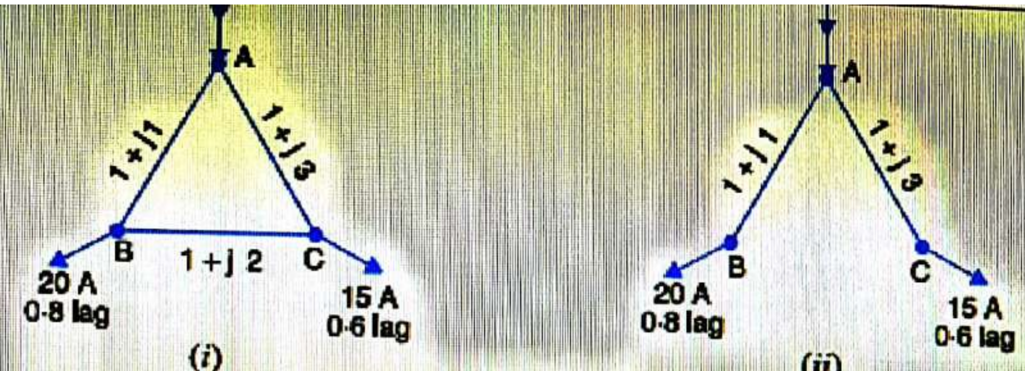


Fig. 14.7

Referring to Fig.14.7 *(ii)*, we have,

Current in section AB $= 20\,(0{\cdot}8 - j\,0.6) = 16 - j\,12$

Current in section AC $= 15\,(0{\cdot}6 - j\,0{\cdot}8) = 9 - j\,12$

Voltage drop in section AB $= (16 - j\,12)\,(1 + j1) = 28 + j\,4$

Voltage drop in section AC $= (9 - j\,12)\,(1 + j\,3) = 45 + j\,15$

Obviously, point B is at higher potential than point C. The p.d. between B and C is Thevenin's equivalent circuit e.m.f. E_0 *i.e.*

Thevenin's equivalent circuit e.m.f., E_0 = p.d. between B and C

$$= (45 + j\,15) - (28 + j\,4) = 17 + j\,11$$

Thevenin's equivalent impedance Z_o can be found by looking into the network from points B and C.

Obviously, $$Z_0 = (1 + j1) + (1 + j\,3) = 2 + j4$$

$\therefore$ $$\text{Current in } BC = \frac{E_0}{Z_0 + \text{Impedance of } BC}$$

$$= \frac{17 + j11}{(2 + j4) + (1 + j2)} = \frac{17 + j11}{3 + j6}$$

$$= 2{\cdot}6 - j\,1{\cdot}53 = 3\angle{-30{\cdot}48^\circ}\ \text{A}$$

$$\text{Current in } AB = (16 - j\,12) + (2{\cdot}6 - j\,1{\cdot}53)$$

$$
\begin{aligned}
&= 18{\cdot}6 - j\,13{\cdot}53 = 23\angle{-36{\cdot}03^\circ}\text{ A}\\
\text{Current in } AC &= (9 - j\,12) - (2{\cdot}6 - j\,1{\cdot}53)\\
&= 6{\cdot}4 - j\,10{\cdot}47 = 12{\cdot}27\angle{-58{\cdot}56^\circ}\text{ A}\\
\text{Current fed at } A &= (16 - j\,12) + (9 - j\,12)\\
&= 25 - j\,24 = 34{\cdot}65\angle{-43{\cdot}83^\circ}\text{ A}
\end{aligned}
$$

Lamp load alone. If there is lamp load alone, the line currents in phases *R*, *Y* and *B* are 70 *A*, 84 *A* and 33 *A* respectively. These currents will be 120° apart (assuming phase sequence *RYB*) as shown in Fig.14.16.

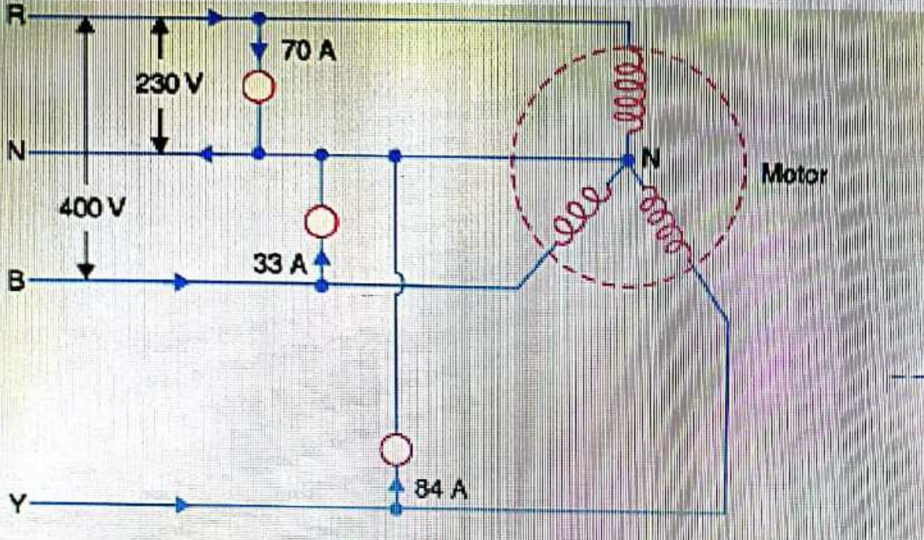


Fig. 14.15

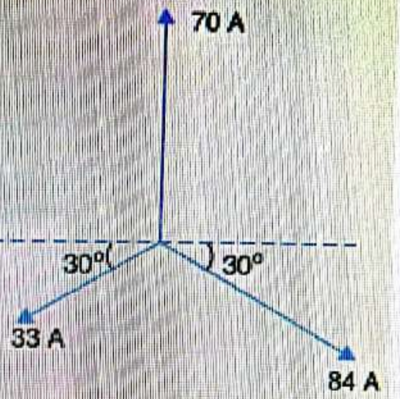


Fig. 14.16

Resultant *H*-component $= 84 \cos 30^\circ - 33 \cos 30^\circ = 44{\cdot}17$ A

Resultant V-component $= 70 - 33 \cos 60^\circ - 84 \cos 60^\circ = 11{\cdot}5$ A

$\therefore$ Neutral current, $I_N = \sqrt{(44{\cdot}17)^2 + (11{\cdot}5)^2} = 45{\cdot}64$ A

Both lamp load and motor load

When motor load is also connected along with lighting load, there will be no change in current in the neutral wire. It is because the motor load is balanced and hence no current will flow in the neutral wire due to this load.

$\therefore$ Neutral current, $I_N = 45{\cdot}64$ A ...*same as before*

The current in each line is the phasor sum of the line currents due to lamp load and motor load.

Active component of motor current $= 200 \times \cos \phi_m = 200 \times 0{\cdot}2 = 40$ A

Reactive component of motor current $= 200 \times \sin \phi_m = 200 \times 0{\cdot}98 = 196$ A

$$\therefore \quad I_R = \sqrt{(\text{sum of active comp.})^2 + (\text{reactive comp.})^2}$$

$$= \sqrt{(40 + 70)^2 + (196)^2} = 224{\cdot}8 \text{ A}$$

$$I_Y = \sqrt{(40 + 84)^2 + (196)^2} = 232 \text{ A}$$

$$I_B = \sqrt{(40+33)^2 + (196)^2} = \mathbf{209{\cdot}15\ A}$$

Power supplied

Power supplied to lamps $= 230\,(70 - 84 + 33) \times 1 = \mathbf{43010\ W}$ $\quad (\because \cos\phi_L = 1)$

Solution. This is a case of unbalanced load so that the line currents (and hence the phase currents) in the three lines will be different. The current in the *neutral wire will be equal to the phasor sum of three line currents as shown in Fig. 14.12.

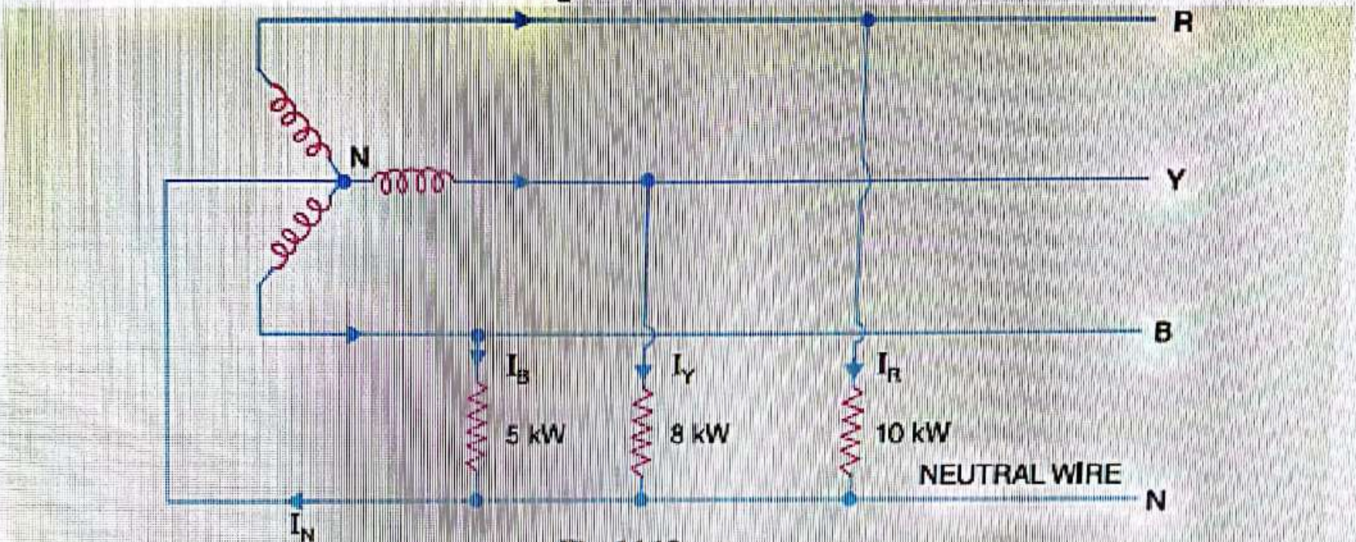


Fig. 14.12

(*i*) Phase voltage $= 400/\sqrt{3} = 231$ V

$I_R = 10 \times 10^3/231 = 43{\cdot}3$ A

$I_Y = 8 \times 10^3/231 = 34{\cdot}6$ A

$I_B = 5 \times 10^3/231 = 21{\cdot}65$ A

(*ii*) The three lines currents are represented by the respective phasors in Fig. 14.13. Note that the three line currents are of different magnitude but displaced 120° from one another. The current in the neutral wire will be the phasor sum of the three line currents.

Resolving the three currents along x-axis and y-axis, we have,

Resultant horizontal component $= I_Y \cos 30° - I_B \cos 30°$

$= 34{\cdot}6 \times 0{\cdot}866 - 21{\cdot}65 \times 0{\cdot}866 = 11{\cdot}22$ A

Resultant vertical component $= I_R - I_Y \cos 60° - I_B \cos 60°$

$= 43{\cdot}3 - 34{\cdot}6 \times 0{\cdot}5 - 21{\cdot}65 \times 0{\cdot}5 = 15{\cdot}2$ A

As shown in Fig. 14.14, current in neutral wire is

$$I_N = \sqrt{(11{\cdot}22)^2 + (15{\cdot}2)^2} = 18{\cdot}9 \text{ A}$$

UNSYMMETRICAL SPACING :- But TRANSPOSED.

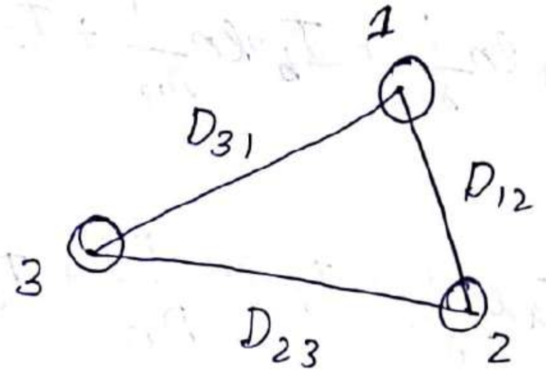
→ when 3-phase line Conductors are not equidistant from each other, the flux linkages and inductance of each phase are not the same.

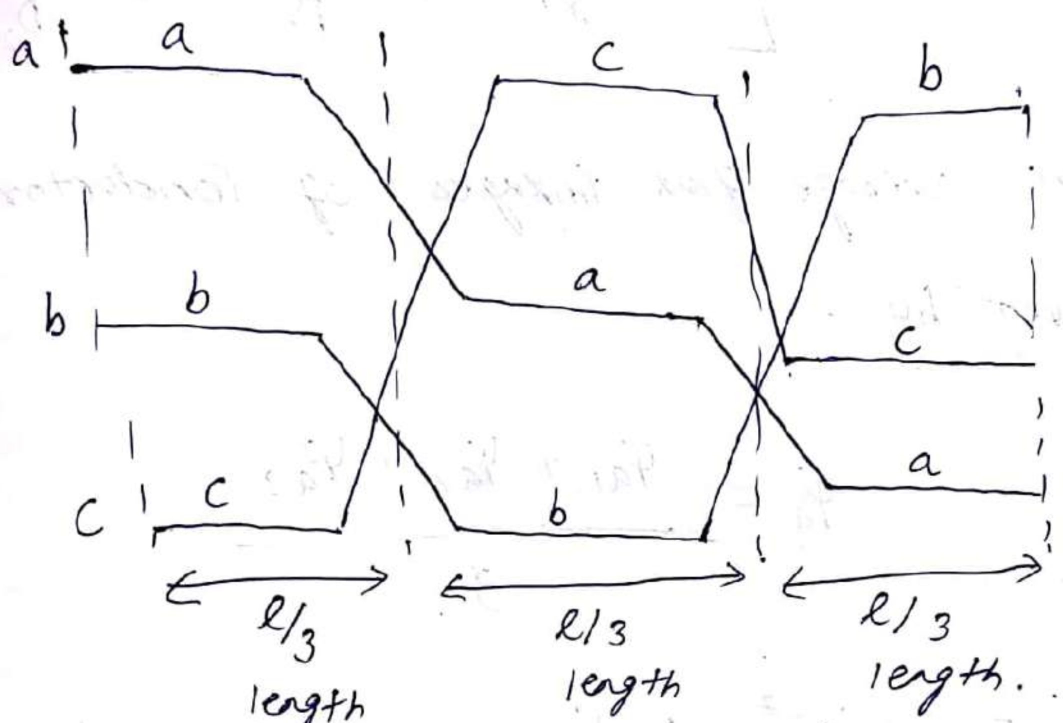
→ A different inductance in each phase results in enequal Voltage drops in the three phases.

→ ∴ the Voltage at the receiving end will not be the same for all phases.

→ Thus to make the Voltage drops equal, we generally interchange the positions of the Conductors at regular intervals along the line so that each Conductor occupies the original position of every other Conductor over an equal distance

→ This exchange of positions is known as "transposition".





→ For a transposed line a Conductor 'a' will occupy positions 1, 2 and 3 each for 1/3 of its length.

→ Similarly, Conductors b and C will occupy all these positions each for 1/3 of their lengths.

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$$\psi_{a1} = 2\times 10^{-7}\left[I_a \ln\frac{1}{r_1} + I_b \ln\frac{1}{D_{12}} + I_c \ln\frac{1}{D_{31}} \right]$$

$$\psi_{a2} = 2\times 10^{-7}\left[I_a \ln\frac{1}{r_1} + I_b \ln\frac{1}{D_{23}} + I_c \ln\frac{1}{D_{12}} \right]$$

$$\psi_{a3} = 2\times 10^{-7}\left[I_a \ln\frac{1}{r_1} + I_b \ln\frac{1}{D_{31}} + I_c \ln\frac{1}{D_{23}} \right]$$

Then average flux linkages of conductor a is given by

$$\psi_a = \frac{\psi_{a1} + \psi_{a2} + \psi_{a3}}{3}$$

$$\psi_a = 2\times 10^{-7} \times \frac{1}{3}\left[3 I_a \ln\frac{1}{r_1} + I_b \ln\frac{1}{D_{12} D_{23} D_{31}} + I_c \ln\frac{1}{D_{12} D_{23} D_{31}} \right]$$

$$\Rightarrow \psi_a = 2\times 10^{-7}\left[I_a \ln\frac{1}{r_1} + \frac{1}{3} I_b \ln\frac{1}{D_{12} D_{23} D_{31}} + \frac{1}{3} I_c \ln\frac{1}{D_{12} D_{23} D_{31}} \right]$$

$$\Rightarrow \psi_a = 2\times 10^{-7}\left[I_a \ln\frac{1}{r_1} + I_b \ln\frac{1}{\sqrt[3]{D_{12} D_{23} D_{31}}} + I_c \ln\frac{1}{\sqrt[3]{D_{12} D_{23} D_{31}}} \right]$$

$$\Rightarrow \psi_a = 2\times10^{-7}\left[I_a \ln\frac{1}{r'} + (I_c+I_b)\times\frac{1}{\sqrt[3]{D_{12}D_{23}D_{31}}}\right]$$

$$\therefore \boxed{I_c + I_b = -I_a.}$$

$$\Rightarrow \psi_a = 2\times10^{-7}\left[I_a \ln\frac{\sqrt[3]{D_{12}D_{23}D_{31}}}{r'}\right]$$

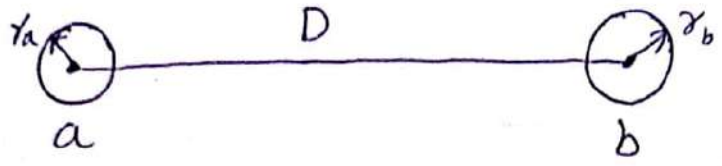
wb-T/Meter

$$\Rightarrow \boxed{L_a = \frac{\psi_a}{I_a} = 2\times10^{-7}\ln\frac{\sqrt[3]{D_{12}D_{23}D_{31}}}{r'} \text{ H/m.}}$$

Consider $\sqrt[3]{D_{12}D_{23}D_{31}} = D_{eq}$.

$$\boxed{L_a = 2\times10^{-7}\ln\left(\frac{D_{eq}}{r'}\right) \text{ H/m.}} = L_b = L_c.$$

CAPACITANCE OF A TWO WIRE LINE:-



Consider two Conductors a & b of infinite length parallel to each other.

Radii of both the Conductors are r_a & r_b, distance between the centers of the Conductors is 'D'.

Charge / unit length on both conductors is q_a & q_b C/m.

Now Voltage difference b/w Conductors -

$$V_{ab} \text{ due to } q_a = \frac{q_a}{2\pi\varepsilon} \ln\left[\frac{D}{r_a}\right]$$

$$V_{ab} \text{ due to } q_b = \frac{q_b}{2\pi\varepsilon} \ln\left[\frac{r_b}{D}\right]$$

Total voltage difference due to both q_a and q_b

$$V_{ab} = \frac{1}{2\pi\varepsilon}\left[q_a \ln\left[\frac{D}{r_a}\right] + q_b \ln\left[\frac{r_b}{D}\right]\right] \quad -(1)$$

As the system is a single phase, 2w system

$$q_b = -q_a.$$

Substituting in (1) we get.

$$V_{ab} = \frac{q_a}{2\pi\varepsilon}\left[\ln\frac{D}{r_a} - \ln\frac{r_b}{D}\right]$$

$$\Rightarrow V_{ab} = \frac{q_a}{2\pi\varepsilon}\ln\left(\frac{D^2}{r_a r_b}\right)$$

$$\Rightarrow V_{ab} = \frac{2q_a}{2\pi\varepsilon}\ln\frac{D}{\sqrt{r_a r_b}}$$

$$\Rightarrow V_{ab} = \frac{q_a}{\pi\varepsilon}\ln\frac{D}{\sqrt{r_a r_b}}.$$

assuming identical Conductors, we get.

$$r_a = r_b = r$$

$$\Rightarrow V_{ab} = \frac{q_a}{\pi\varepsilon}\ln\left(\frac{D}{r}\right)$$

we know,

$$C = \frac{q}{V}$$

$$\Rightarrow C_{ab} = \frac{\pi\varepsilon}{\ln\left(\frac{D}{r}\right)}$$

$$\varepsilon = \varepsilon_r \times \varepsilon_0$$

$\varepsilon_r \rightarrow 1$ (assume)

$$\Rightarrow \varepsilon = \varepsilon_0 = \frac{1}{4\pi \times 9 \times 10^9}$$

$$\Rightarrow C_{ab} = \frac{\pi \times \frac{1}{4\pi \times 9 \times 10^9}}{\ln \frac{D}{r}}$$

$$\Rightarrow C_{ab} = \frac{1}{36 \times 10^9 \ln\left(\frac{D}{r}\right)} \text{ F/m.}$$

$$\Rightarrow \boxed{C_{ab} = \frac{1}{36 \ln\left(\frac{D}{r}\right)} \mu\text{F/km.}}$$

Capacitance between phase to neutral is twice the line to line capacitance, hence we can write

$$\boxed{C_{an} = C_{bn} = \frac{1}{18 \ln\left(D/r\right)} \mu\text{F/km.}}$$

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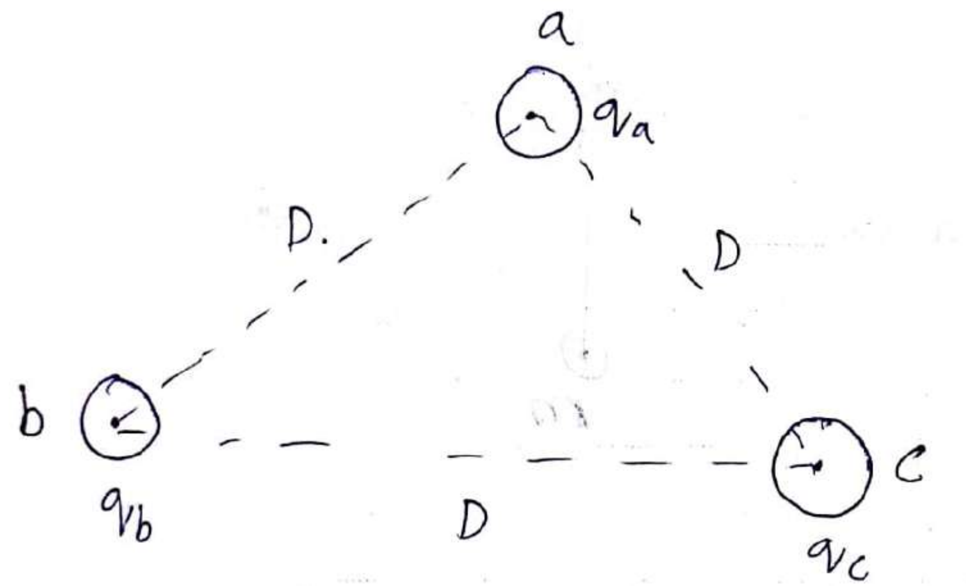
CAPACITANCE OF 3ϕ, 3wire LINE :-

Equilateral Spacing :-



Conductors are as if at Corners of triangle. Conductors are a, b, c with Charge / unit length as q_a, q_b and q_c

$$V_{ab} = \frac{1}{2\pi\varepsilon}\left\{ q_a \ln\frac{D}{r} + q_b \ln\frac{r}{D} + \underbrace{q_c \ln\frac{D}{D}}_{0} \right\}$$

$$V_{ac} = \frac{1}{2\pi\varepsilon}\left\{ q_a \ln\frac{D}{r} + \underbrace{q_b \ln\left(\frac{D}{D}\right)}_{0} + q_c \ln\left(\frac{r}{D}\right) \right\}$$

$$V_{ab} + V_{ac} = \frac{1}{2\pi\varepsilon}\left\{ 2q_a \ln\left(\frac{D}{r}\right) + (q_b+q_c)\ln\left(\frac{r}{D}\right) \right\}$$

Balanced System

$$q_a + q_b + q_c = 0$$

$$\Rightarrow \quad q_b + q_c = -q_a.$$

$$\Rightarrow \quad V_{ab} + V_{ac} = \frac{q_a}{2\pi\varepsilon}\left\{2\ln\left(\frac{D}{r}\right) - \ln\left(\frac{r}{D}\right)\right\}.$$

$$= \frac{q_a}{2\pi\varepsilon}\left\{2\ln\left(\frac{D}{r}\right) + \ln\left(\frac{D}{r}\right)\right\}.$$

$$= \frac{3q_a}{2\pi\varepsilon}\ln\left(\frac{D}{r}\right). \quad \text{--- } (1)$$

$V_{an} = V\angle 0$, $\quad V_{bn} = V\angle 120^\circ$, $\quad V_{cn} = V\angle -120$

$$V_{ab} = V_{an} - V_{bn} = V\angle 0^\circ - V\angle 120^\circ$$

$$= V\left[1\angle 0^\circ - 1\angle 120^\circ\right]$$

$$= \sqrt{3}\,V\angle -30^\circ$$

$$V_{ac} = V_{an} - V_{cn} = V\left[1\angle 0^\circ - 1\angle -120\right]$$

$$= \sqrt{3}\,V\angle 30^\circ$$

$$V_{ab} + V_{ac} = \sqrt{3}\,V\left[1\angle 30^\circ + 1\angle -30^\circ\right]$$

$\Rightarrow V_{ab} + V_{ac} = 3V_{an}$ —— (2)

equating (1) and (2) we get,

$$3V_{an} = \frac{3q_a}{2\pi\varepsilon} \ln\left(\frac{D}{r}\right)$$

$$\Rightarrow V_{an} = \frac{q_a}{2\pi\varepsilon} \ln\left(\frac{D}{r}\right).$$

$$C_{an} = \frac{q_a}{V_{an}} = \frac{2\pi\varepsilon}{\ln\left(\frac{D}{r}\right)} \; F/m.$$

$$\varepsilon = \underbrace{\varepsilon_r}_{1 \text{ (assume)}} \times \varepsilon_0$$

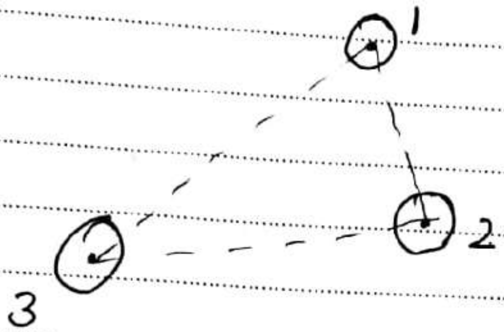
$$\Rightarrow \varepsilon = \varepsilon_0 = \frac{1}{4\pi \times 9 \times 10^9}$$

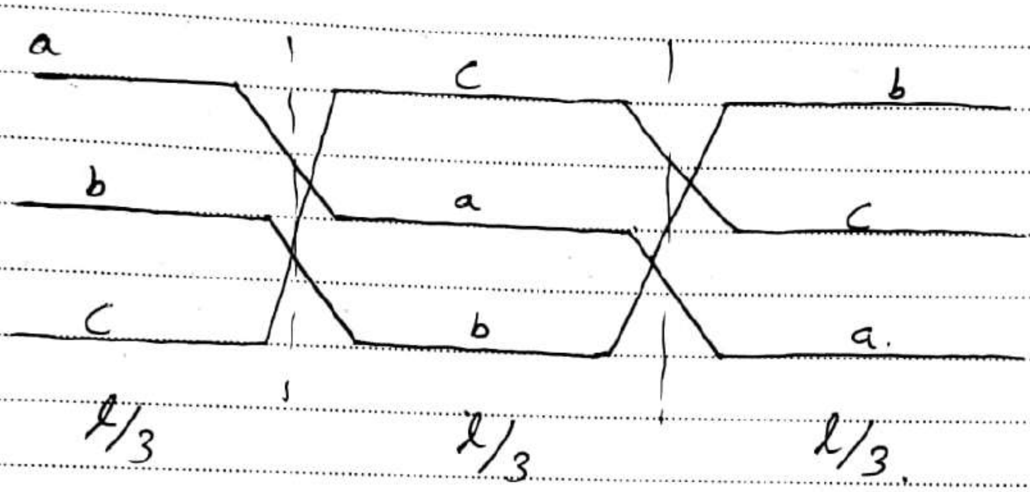
$$C_{an} = \frac{2\pi \times \frac{1}{4\pi \times 9 \times 10^9}}{\ln\left(\frac{D}{r}\right)}.$$

$$\Rightarrow C_{an} = \frac{1}{18 \ln\left(\frac{D}{r}\right) \times 10^9} \; F/m.$$

$$\Rightarrow \boxed{C_{an} = \frac{1}{18 \ln\left(\frac{D}{r}\right)} \; \mu F/km}$$

UNSYMMETRICAL BUT TRANSPOSED :-





Voltage difference between Conductors a & b in 1st section of transposition

$$V_{ab1} = \frac{1}{2\pi\varepsilon}\left\{ q_a \ln\frac{D_{12}}{r} + q_b \ln\frac{r}{D_{21}} + q_c \ln\frac{D_{32}}{D_{31}} \right\}.$$

$$V_{ab2} = \frac{1}{2\pi\varepsilon}\left\{ q_a \ln\frac{D_{23}}{r} + q_b \ln\frac{r}{D_{32}} + q_c \ln\frac{D_{13}}{D_{12}} \right\}$$

$$V_{ab3} = \frac{1}{2\pi\varepsilon}\left\{ q_a \ln\frac{D_{31}}{r} + q_b \ln\frac{r}{D_{13}} + q_c \ln\frac{D_{21}}{D_{23}} \right\}$$

Avg Voltage diff in a & b

$$V_{ab} = \frac{V_{ab1} + V_{ab2} + V_{ab3}}{3}.$$

$$\Rightarrow V_{ab} = \frac{1}{3\times 2\pi\varepsilon}\left\{ q_a\left[\ln\left(\frac{D_{12}D_{23}D_{31}}{r^3}\right)\right] + q_b\left[\ln\left(\frac{r^3}{D_{21}D_{32}D_{13}}\right)\right] + \underbrace{q_c\left[\ln\left(\frac{D_{32}D_{31}D_{21}}{D_{31}D_{12}D_{23}}\right)\right]}_{0} \right\}$$

$$\Rightarrow V_{ab} = \frac{1}{6\pi\varepsilon}\left\{ q_a \ln\left(\frac{D_{12}D_{23}D_{31}}{r^3}\right) + q_b \ln\left(\frac{r^3}{D_{21}D_{32}D_{13}}\right)\right\}$$

$$V_{ac} = \frac{1}{6\pi\varepsilon}\left\{ q_a \ln\left(\frac{D_{12}D_{23}D_{31}}{r^3}\right) + q_c \ln\left(\frac{r^3}{D_{12}D_{23}D_{31}}\right)\right\}$$

$$V_{ab} + V_{ac} = \frac{1}{6\pi\varepsilon}\left\{ 2q_a \ln\left(\frac{D_{12}D_{23}D_{31}}{r^3}\right) + (q_b + q_c)\ln\left(\frac{r^3}{D_{12}D_{23}D_{31}}\right)\right\}$$

$$q_b + q_c = -q_a$$

$$\Rightarrow V_{ab} + V_{ca} = \frac{1}{6\pi\varepsilon}\left\{ 2q_a \ln\left(\frac{D_{12}D_{23}D_{31}}{r^3}\right) + q_a \ln\left(\frac{D_{12}D_{23}D_{31}}{r^3}\right)\right\}$$

$$\Rightarrow 3V_{an} = \frac{1}{6\pi\varepsilon} \times \cancel{3} \times q_a \times \ln\left(\frac{D_{12}D_{23}D_{31}}{r^3}\right).$$

$$\Rightarrow V_{an} = \frac{1}{6\pi\varepsilon} \times q_a \times \ln\left(\frac{D_{12}D_{23}D_{31}}{r^3}\right).$$

$$\Rightarrow V_{an} = \frac{q_a}{2\pi\varepsilon} \ln\left(\frac{\sqrt[3]{D_{12}D_{23}D_{31}}}{r}\right)$$

$$\boxed{C_{an} = \frac{q_a}{V_{an}} = \frac{2\pi\varepsilon}{\ln\left(\frac{D_{eq}}{r}\right)} \text{ F/m.}}$$

$$\Rightarrow \boxed{C_{an} = \frac{1}{18 \ln\left(\frac{D_{eq}}{r}\right)} \ \mu\text{F/km.}}$$

$$\therefore \boxed{C_{ph} = C_{bn} = C_{cn} = C_{an}.}$$

Solution. Fig. 9.14. shows the arrangement of double circuit single phase line. Conductors a, a' form one connection and conductors b, b' form the return connnection. The conductor radius, $r = 1/2 = 0{\cdot}5$ cm.

G.M.R. of conductor $= 0{\cdot}7788\, r = 0{\cdot}7788 \times 0{\cdot}5 = 0{\cdot}389$ cm

Self G.M.D. of aa' combination is

$$D_s = \sqrt[4]{D_{aa} \times D_{aa'} \times D_{a'a'} \times D_{a'a}}$$

$$= \sqrt[4]{(0{\cdot}389 \times 100)^2} = 6{\cdot}23 \text{ cm}$$

Mutual G.M.D. between a and b is

$$D_m = \sqrt[4]{D_{ab} \times D_{ab'} \times D_{a'b} \times D_{a'b'}}$$

$$= \sqrt[4]{(25 \times 103 \times 103 \times 25)} = 50{\cdot}74 \text{ cm}$$

$$[\because D_{ab'} = D_{a'b} = \sqrt{25^2 + 100^2} = 103 \text{ cm}]$$

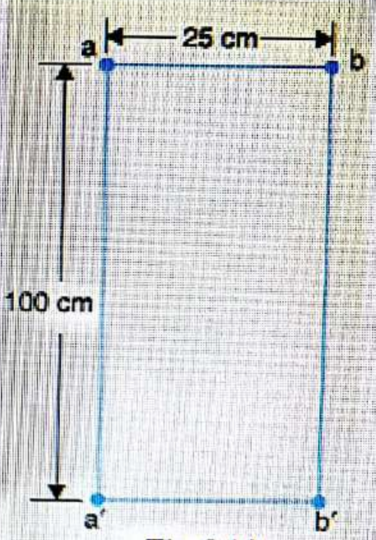


Fig. 9.14

Inductance per conductor per metre

$$= 2 \times 10^{-7} \log_e D_m/D_s = 2 \times 10^{-7} \log_e 50{\cdot}74/6{\cdot}23 \text{ H}$$

$$= 0{\cdot}42 \times 10^{-6} \text{ H}$$

$\therefore$ Loop inductance per km of the line

$$= 2 \times 0{\cdot}42 \times 10^{-6} \times 1000 \text{ H} = \mathbf{0{\cdot}84 \text{ mH}}$$

Solution.

Conductor radius, $r = 1\cdot25/2 = 0\cdot625$ cm

Spacing of conductors, $d = 2$ m $= 200$ cm

Capacitance of each line conductor

$$= \frac{2\pi\varepsilon_0}{\log_e d/r}\ \text{F/m} = \frac{2\pi \times 8\cdot854 \times 10^{-12}}{\log_e 200/0\cdot625}\ \text{F/m}$$

$$= 0\cdot0096 \times 10^{-9}\ \text{F/m} = 0\cdot0096 \times 10^{-6}\ \text{F/km} = \mathbf{0\cdot0096\ \mu F/km}$$