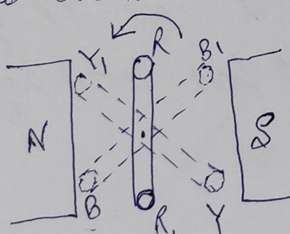
Three phase system

Application of alternating current was limited to heating & lightening lamps in early days. Years later A.C. motors were developed that was operated on A.C. and its performance was analysed. In A.C. motors, Induction motor was not self starting and required two windings. This developed the need for requirement of more than one phase system. Moreover the power generation and its transmission over long distances demanded higher voltage levels and justified the use of 3 phase a.c..

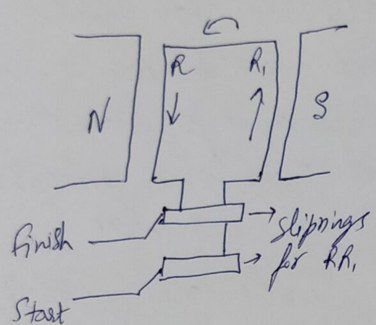
Generation of 3 phase emfs

Suppose there are three coils namely RR_1, YY_1, BB_1 rotating anticlockwise at a uniform speed in magnetic field due to Poles N.S.



This arrangement is similar to single phase emf generation where only one coil was present. Here we have three coils placed at 120° to each other.

Generation of 3 phase voltage is based on Faraday's law of electromagnetic Induction. When the loop RR_1 has moved through 90° to the position as shown, the generated emf in the Coil is at its maximum value and its direction round the loop is from 'start' to ~~start~~ 'finish' as shown.



Similarly the loop YY_1 has emf generated on the same lines as the loops are rotating in same manner, has exactly same amplitude as that generated in RR_1 but lags by 120°. In the same manner, the coil BB_1 has same amplitude of emf generation but it lags YY_1 by 120°. Thus from RR_1 phase it has total lags of 240°.

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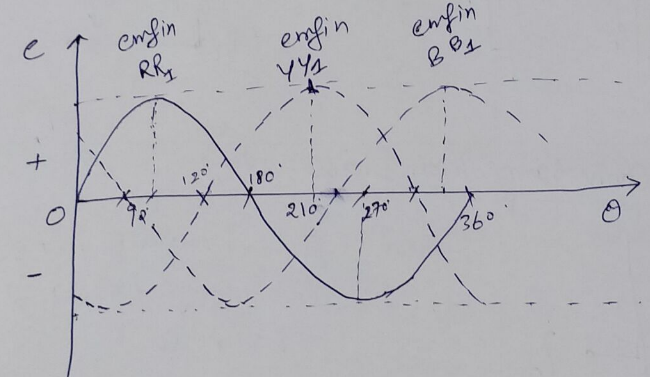
If the Instantaneous value of emf generated in phase RR_1 is represented by

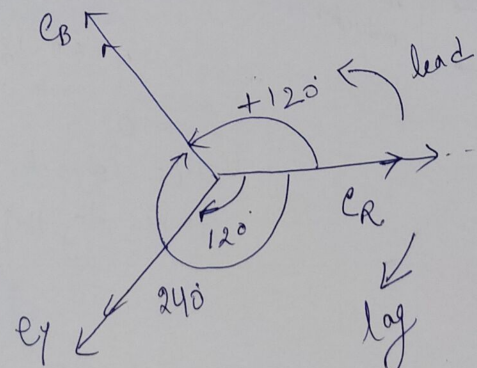
$e_R = E_m \sin\theta$, then instantaneous value in YY_1 is represented by

$$e_Y = E_m \sin(\theta - 120°)$$

and in BB_1 is

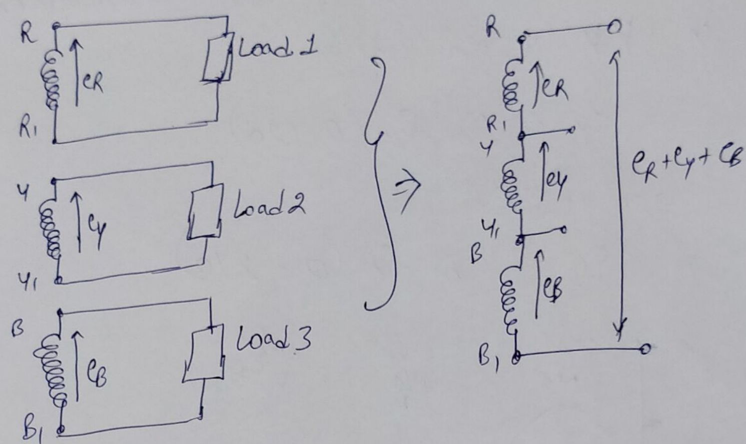
$$e_B = E_m \sin(\theta - 240°)$$



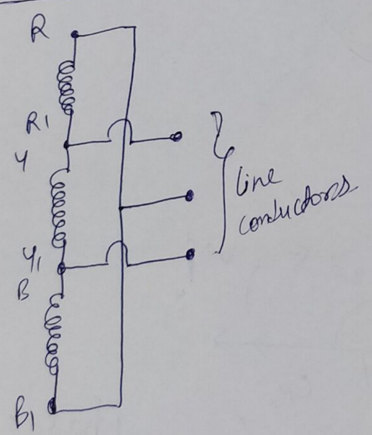


Phasor Diagram.

Delta Connection and star connection of three phase winding, their line to phase quantity relation.



→ Delta Connection of three phase winding.



As instantaneous value of total emf from B_1 to R is

$$e_R + e_Y + e_B$$

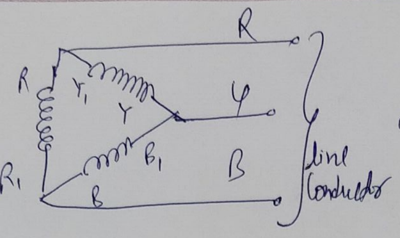
$$= E_m\{\sin\theta + \sin(\theta - 120) + \sin(\theta - 240)\}$$

$$= E_m(\sin\theta - \tfrac{1}{2}\sin\theta - 0.866\cos\theta - \tfrac{1}{2}\sin\theta + 0.866\cos\theta)$$

$$= 0$$

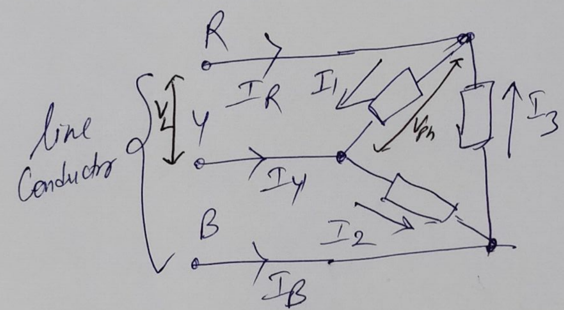
Hence conductor R & B_1 are joined together

③

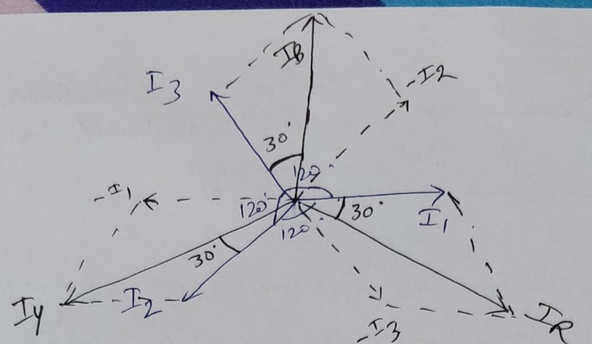


Conventional representation of a delta or mesh connected winding.

Consider Delta connected generator with winding connections as given above, has three line conductors and this is connected to load. Now the load can be in star or Delta form. let us consider Delta connected load.



Here we have three phase load which is combination of three single phase load and it is connected in Delta form. The current in the line conductor is line current I_R, I_Y and I_B. The current in the loads as depicted by I_1, I_2 and I_3 are rms value of phase current. Since the load is balanced, these currents are equal in magnitude and differ by 120°



As $I_R + I_3 = I_1$

$\Rightarrow I_R = I_1 - I_3$.

Similarly

$I_Y + I_1 = I_2$

$I_Y = I_2 - I_1$

and also $I_B = I_3 - I_2$.

As $I_R = 2 I_1 \cos 30°$

Since magnitude of I_1, I_2 and I_3 are equal as in balanced load,

$\Rightarrow I_R = \sqrt{3} I_1$

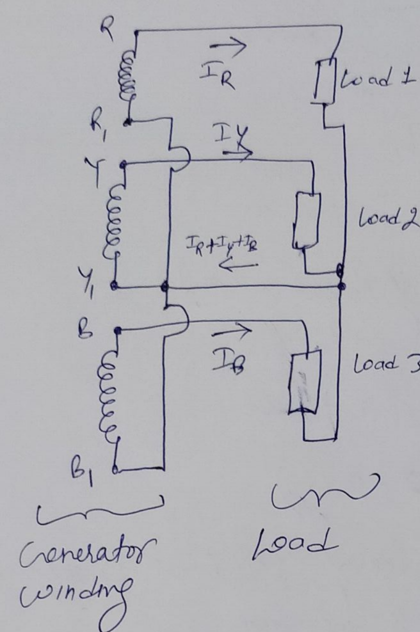
or $\boxed{I_L = \sqrt{3} I_{ph}}$

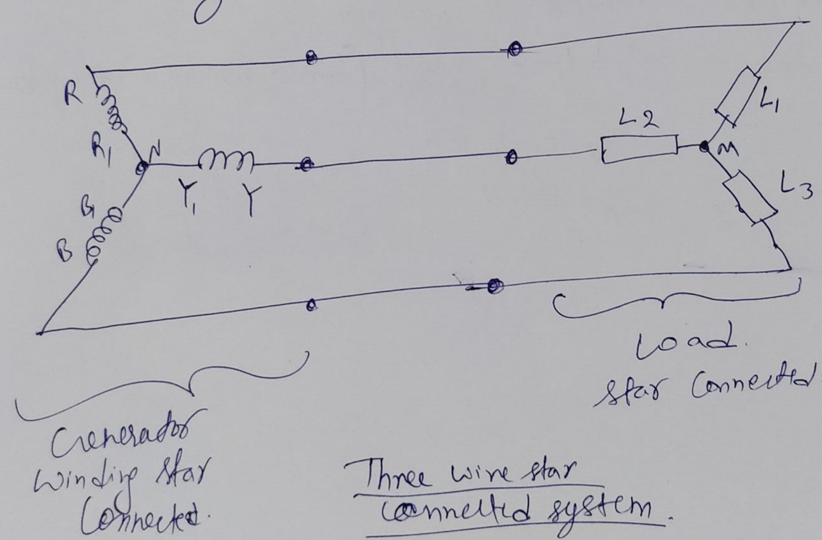
Line current is $\sqrt{3}$ times the phase current.

It is seen from Delta Connection of load that the line and phase voltages are same i.e.

$\boxed{V_L = V_{ph}}$

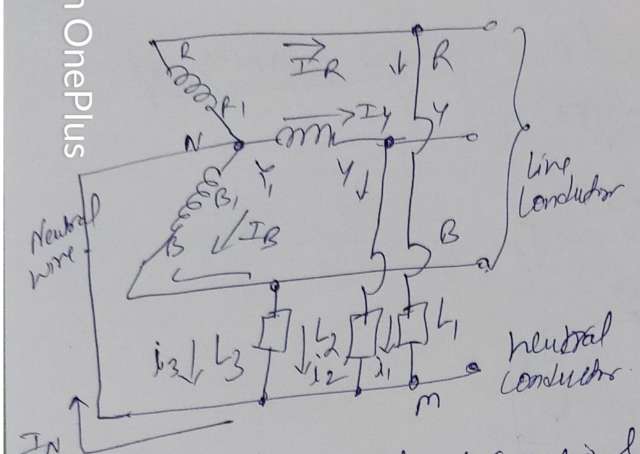
Star Connection and line to phase quantity of three phase windings-





Three wire star connected system.

Four wire star connected system.



let instantaneous value of current in load 1 is $i_1 = I_m \sin\theta$, then

$$i_2 = I_m \sin(\theta - 120^\circ)$$

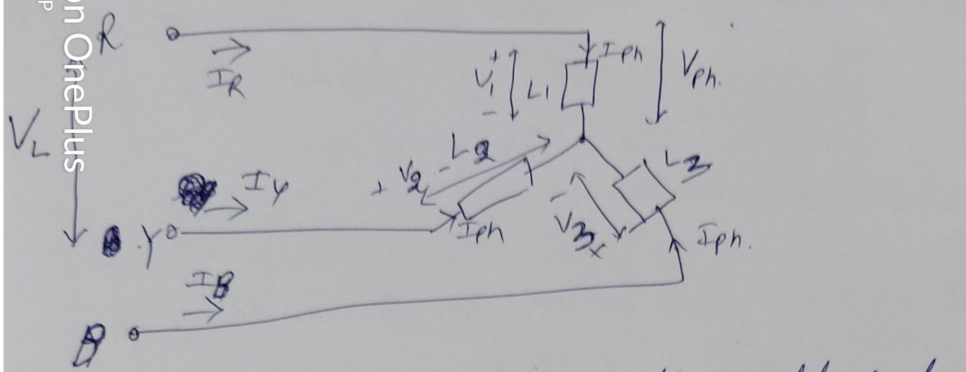
$$i_3 = I_m \sin(\theta - 240^\circ)$$

The instantaneous value of resultant current in neutral conductor is given by

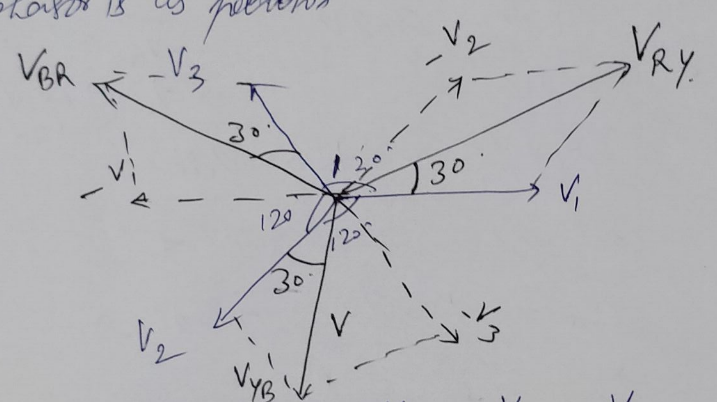
$$I_N = i_1 + i_2 + i_3 = I_m \{\sin\theta + \sin(\theta - 120^\circ) + \sin(\theta - 240^\circ)\}$$

$$I_N = I_m \times 0$$

$$I_N = 0$$



Let the phase voltages in different phases be V_1, V_2 and V_3. Since balanced load is there, the phasor is as follows



As $V_{RY} = V_L = V_{RN} - V_{YN}$

Since $V_{RN} = V_1$ & $V_{YN} = V_2$

As $V_{RY} = V_L = 2V_1 \cos 30°$

Since magnitude of V_1, V_2 and V_3 are equal in balanced load,

$V_{RY} = \sqrt{3}\, V_1$ or $\boxed{V_L = \sqrt{3}\, V_{ph}}$

It is seen from star connection of load that the line and phase currents are same i.e.,

$$\boxed{I_L = I_{ph}}$$

Ex In a three phase balanced star connected load, supply voltage is 208 V. Each load has a resistance of 35 Ω. Determine the power factor, total power and phase & line currents of the system.

Sol ⇒ Supply voltage = 208 V

$V_L = 208\,V$

$V_{ph} = 208/\sqrt{3} = 120$ Volt

$\vec{V_a} = 120 \angle 0^\circ$

$\vec{V_b} = 120 \angle -120^\circ$

$\vec{V_c} = 120 \angle -240^\circ$

Current in each phase is calculated as

$$\vec{I_a} = \frac{120 \angle 0^\circ}{35} = 3.428 \angle 0^\circ$$

$$\vec{I_b} = \frac{120 \angle -120^\circ}{35} = 3.428 \angle -120^\circ$$

$$\vec{I_c} = \frac{120 \angle -240^\circ}{35} = 3.428 \angle -240^\circ$$

Load is resistive hence resistive power is $I^2 R$.

⇒ Total power = $3 I^2 R = 3 \times (3.428)^2 \times 35$

$= 3 \cancel{\times}\, 411.3$ watts

Also $I_L = I_{ph}$ since it is star connection.

P.F. is unity since resistive load.

(8)

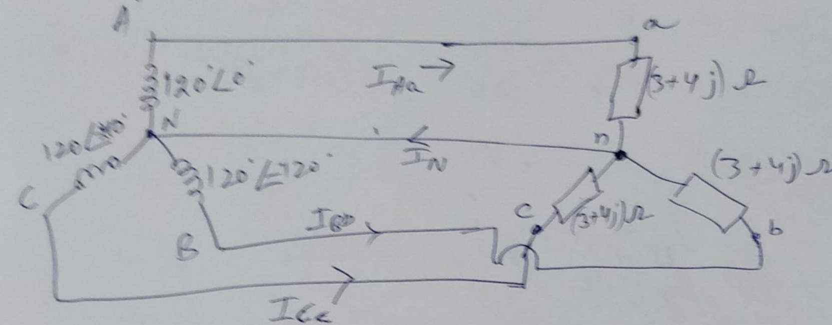
3) The phase sequence of the star connected generator in figure is ABC.

(a) find the phase angles θ_2 and θ_3

(b) find the magnitude of line voltages

(c) find the line currents

(d) verify that, since the load is balanced, $I_N = 0$.



Sol^n (a) $\theta_2 = -120°$, $\theta_3 = -240°$

(b) $E_L = \sqrt{3}\, E_{ph} = 120° \angle 0° \times \sqrt{3} = 208\,V$.

(c) $V_{an} = 120\angle 0°$

$V_{bn} = 120\angle -120°$

$V_{cn} = 120\angle -240°$

$I_{an} = I_{ph} = \dfrac{V_{an}}{Z_{an}} = \dfrac{120\angle 0°}{3+4j} = \dfrac{120\angle 0°}{5\angle 53.13°}$

$I_{an} = 24\angle -53.13$

$I_{bn} = \dfrac{120\angle -120°}{5\angle 53.13} = 24\angle -173.13°$

$$I_{cn} = \frac{120 \angle -240^\circ}{5 \angle 53.13^\circ} = 24 \angle 66.87^\circ$$

NOW

$$I_N = I_{Aa} + I_{Bb} + I_{Cc}$$

$$= 24 \angle -53.13^\circ + 24 \angle 173.13 + 24 \angle 66.87^\circ$$

$$I_N = 0$$