Basic Electrical Engg – EE102
(Lecture Notes – 3 Phase AC Circuits)
(PART-1)

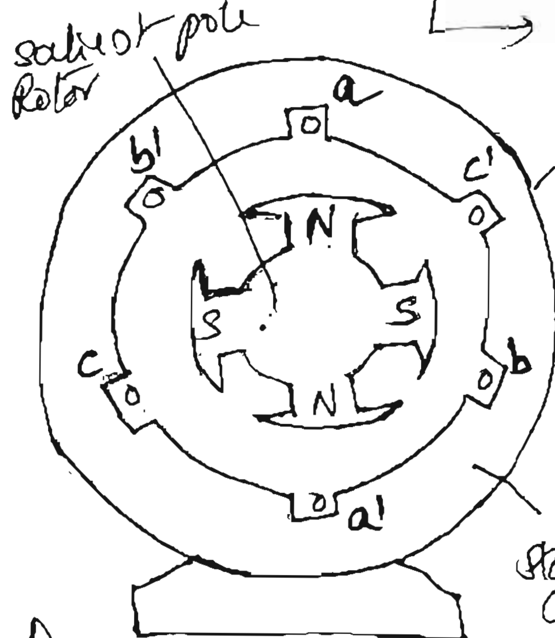
Topics Covered

- 3 Phase EMF Generation
- Delta and Star Connection
- Line and Phase Quantities
- Solution of 3 Phase Circuits
- Balanced Supply and Balanced Load
- Phasor Diagram
- 3 Phase Power Measurement by 2-Wattmeter Method

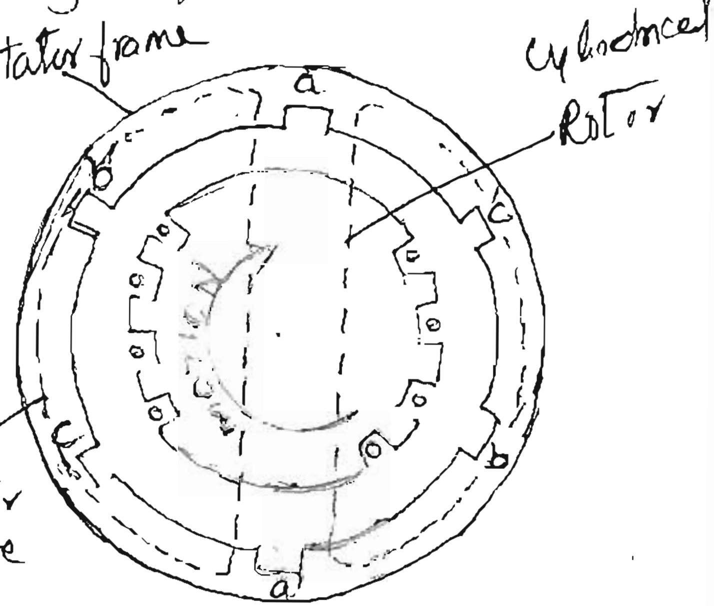
Three Phase Emf Generation – Three phase circuits

Synchronous generator – (Alternators)
- → Three phase power
- → Single phase power

- Stator
  - → stator frame
  - → stator core
  - → Stator winding
    - star connected
    - delta connected



Salient pole syn. generator



Cylindrical Rotor syn. generator.

- Rotor
  - → Salient pole type (low speed)
  - → cylindrical type (High speed)
  - Rotor core
  - Rotor windings

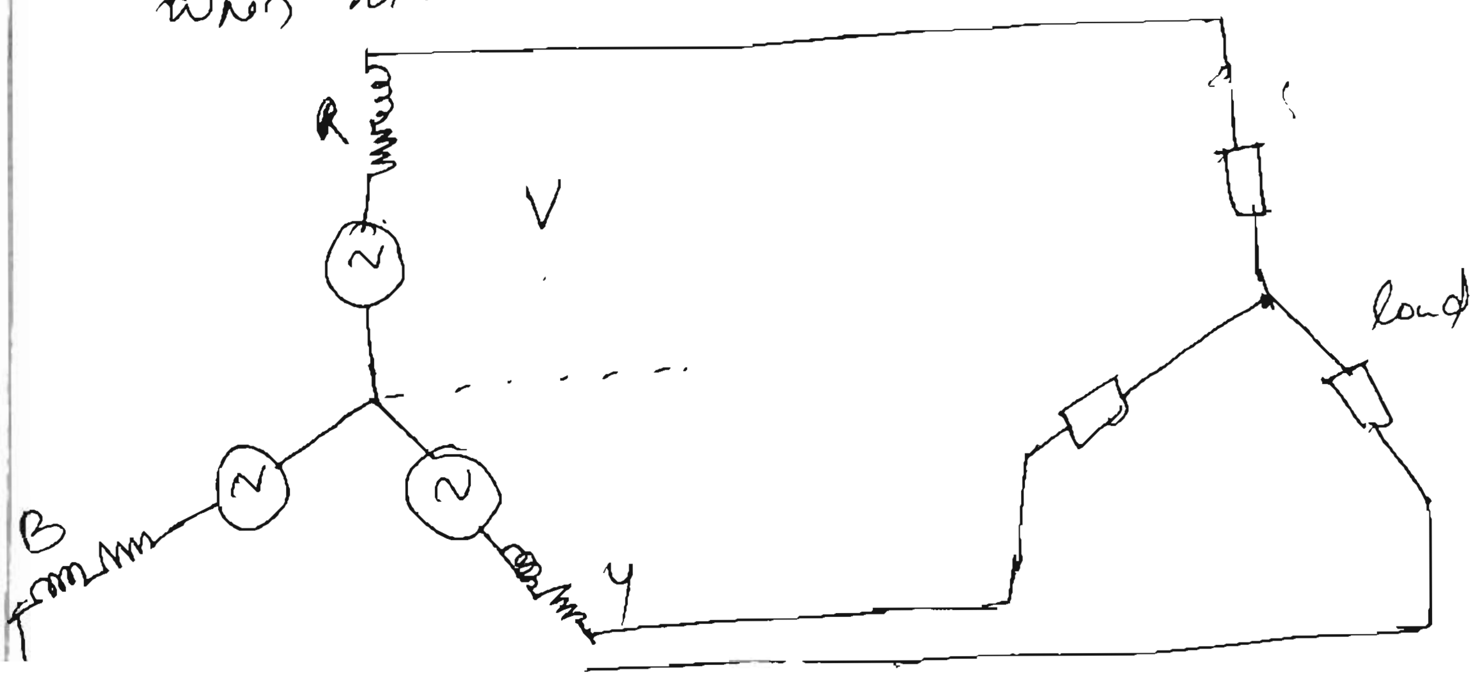
- slip rings, brushes
- Air gap.

Rotor → Prime mover → water turbine – low speed
→ Steam turbine → high speed
↓
At fixed speed N_s → Synchronous speed.

Rotor windings → dc excitation → field → Airgap.

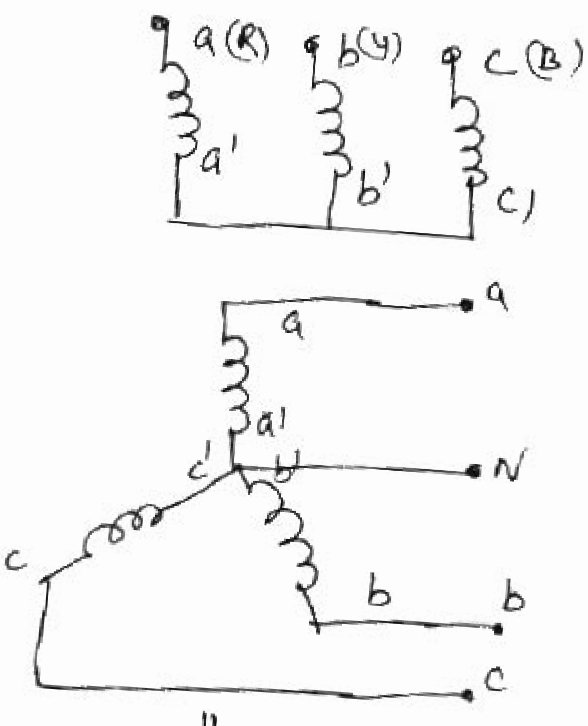
When rotor is stand still with field excitation → no emf in the Stator windings

When rotor is driven and field excitation on → emf is induced in the Stator windings



In a 3 phase system, three voltages are generated by the 3 phase windings of a three phase syn. generator, the three windings may be connected in Star or Delta

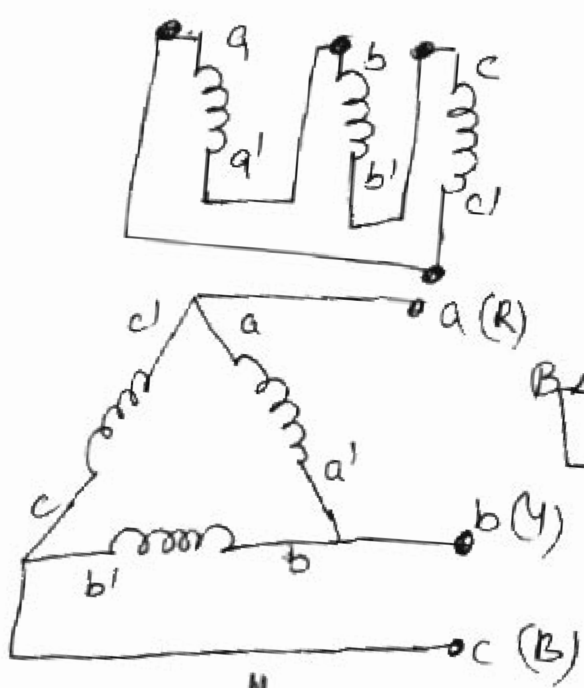
Star



⇓

3 wire system | 4 wire wire (Neutral)

Delta



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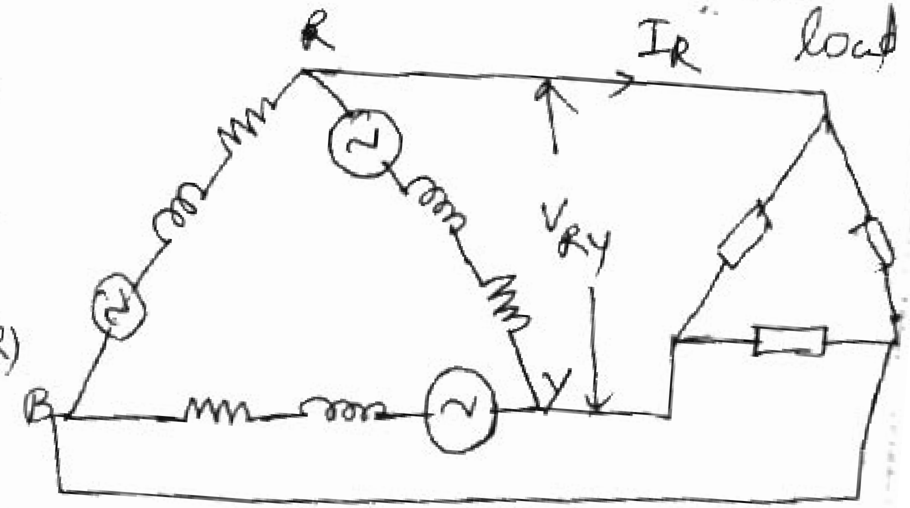
Three wire system



Advantages of Three phase system

PS → (a) Generation, (b) Transmission, (c) Distribution

Generation ⇓ 11 kV/33

Transmission 400kV/765kV

Distribution 33kV/11kV

(d) Utilization → Three phase (400V, 50Hz)

→ Single phase (230V, 50Hz)

- Three phase Transmission line cheaper → same P, V.

→ Three phase IM → more efficient.

→ " " better pf than 1 phase IM

→ " " provides uniform torque.

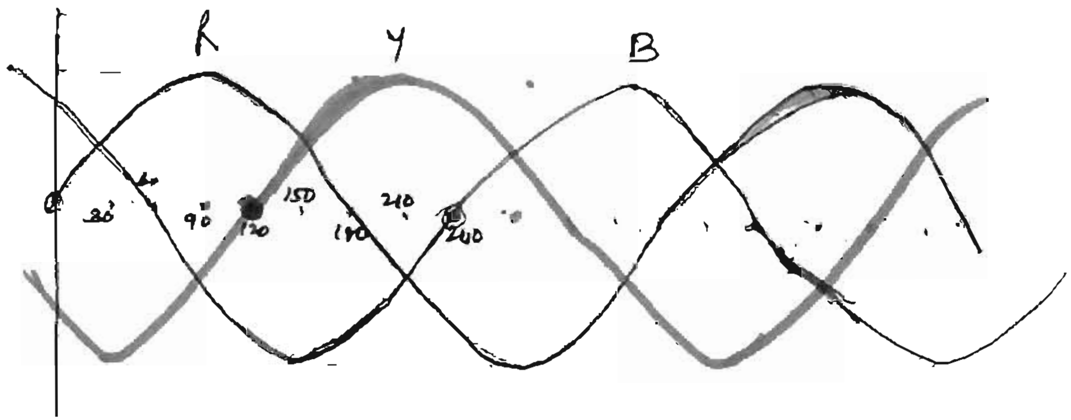
→ Three phase IM → self starting

1 phase IM → Auxilliary winding for starting

→ Three phase system has better Voltage Regulation.

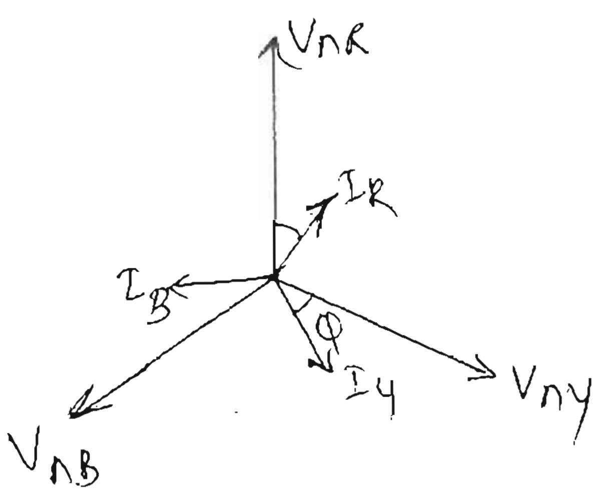
→ For a given size and frame, the power generated by a 3 phase alternator is high

Three phase voltages, currents and power

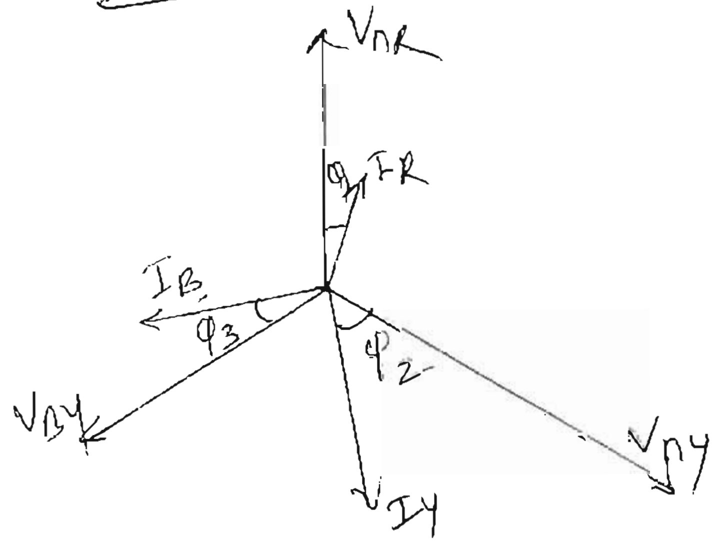


When loads connected to the three phase are equal the currents in the three phases are equal in magnitude and displaced in phase by 120°.

Balanced system



Unbalanced system



Balanced system

$V_{nR} = V\angle 0 = V_m \sin \omega t$

$V_{ny} = V\angle -120 = V_m \sin(\omega t - 120)$

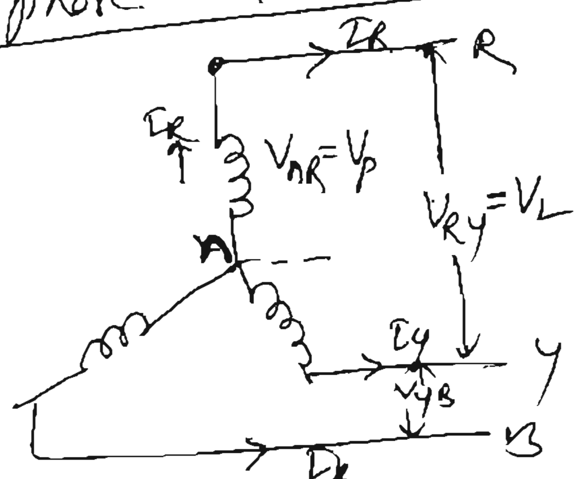
$V_{nB} = V\angle -240 = V_m \sin(\omega t - 240) = V_m \sin(\omega t + 120)$

Power.

$P \Rightarrow$ 3 phase load $\rightarrow$ sum of P of each phase.

$$P = \underline{3 V_p I_p \cos\phi}$$

Line and phase voltages and currents in 3 phase star connection



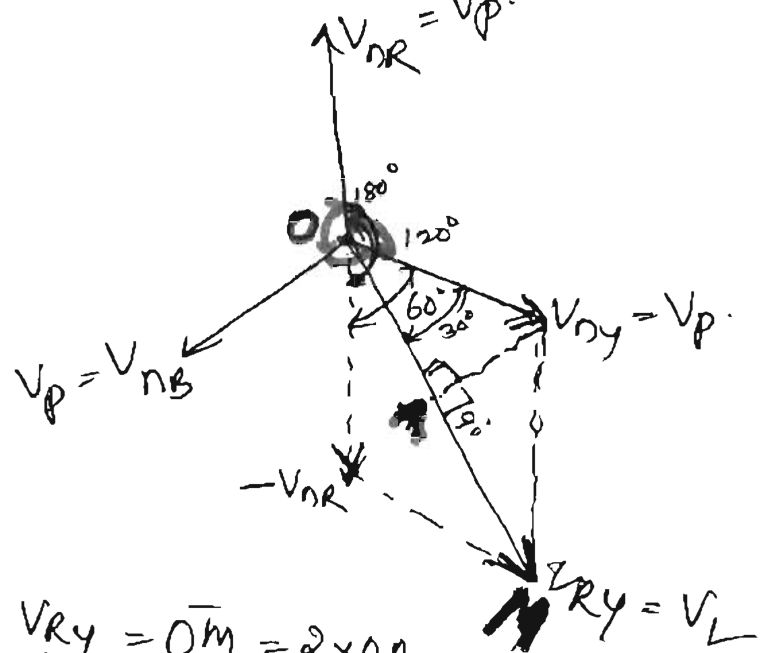
$V_p = V_{nR} = V_{ny} = V_{nB}.$

$V_L = V_{Ry} = V_{yB} = V_{BR}$

$I_R = I_y = I_B = I_p = I_L$

KVL $\rightarrow$ RnY

$V_{Ry} = V_{Rn} + V_{ny} = -V_{nR} + V_{ny}$



$V_{Ry} = \overline{OM} = 2 \times OA$

$V_L = 2 \times V_{ny} \cos 30^\circ = 2 \times V_p \times \frac{\sqrt{3}}{2}$

$$\boxed{V_L = \sqrt{3} V_p}$$

$$\boxed{I_L = I_p}$$

OR

$$V_{RY} = V_L = -V_{nR} + V_{ny}$$

$$= -V_p\angle 0 + V_p\angle{-120}$$

$$= -V_p + V_p(\cos 120 - j\sin 120)$$

$$= -V_p + V_p\left(-\frac{1}{2} - j\frac{\sqrt{3}}{2}\right)$$

$$= V_p\left(-\frac{3}{2} - j\frac{\sqrt{3}}{2}\right)$$

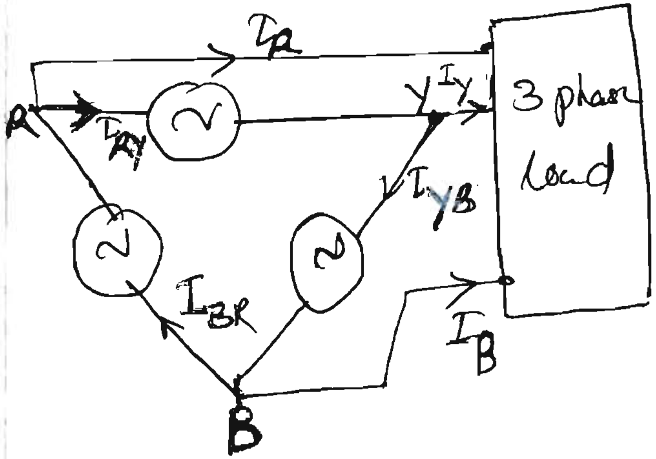
$$= \sqrt{3}V_p\left(-\frac{\sqrt{3}}{2} - j\frac{1}{2}\right)$$

$$V_L = \sqrt{3}V_p\angle{-150}$$

As $\angle{-150} = \cos(-150) + j\sin(-150)$

$$\boxed{\begin{aligned} V_L &= \sqrt{3}V_p \\ I_L &= I_p \end{aligned}}$$ star

Line and phase voltages and currents in 3 phase delta connection



$$I_{RY} = I_p\angle 0.$$

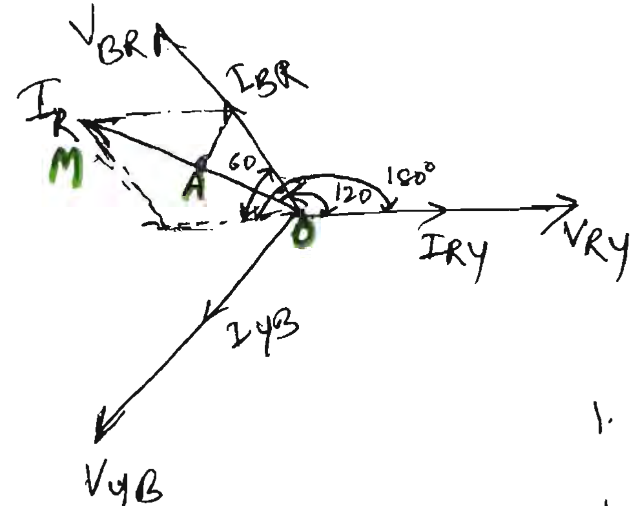
$$I_{YB} = I_p\angle{-120}.$$

$$I_{BR} = I_p\angle 120.$$

$$I_R = I_{BR} - I_{RY} = I_p\angle 120 - I_p\angle 0$$

$$= I_p\left(-\frac{3}{2} + j\frac{\sqrt{3}}{2}\right) = \sqrt{3}I_p\angle 150$$

$$\therefore \boxed{\begin{aligned} V_L &= V_p \\ I_L &= \sqrt{3}I_p \end{aligned}}$$ delta



KCL at node R

$$I_R = I_{BR} - I_{RY}$$

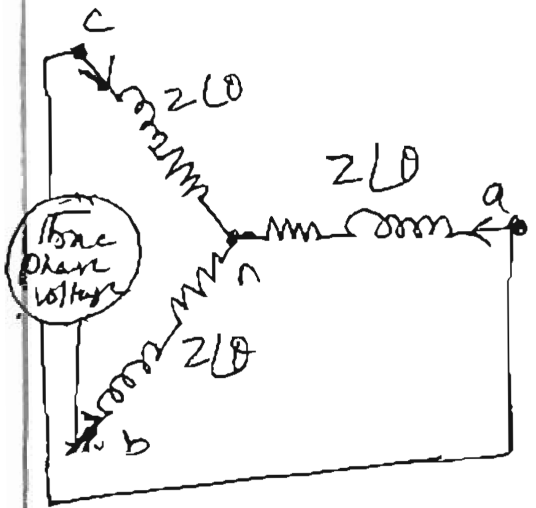
$$\therefore I_R = OM = 2 \times OA$$

$$= 2 \times I_{BR}\cos 30$$

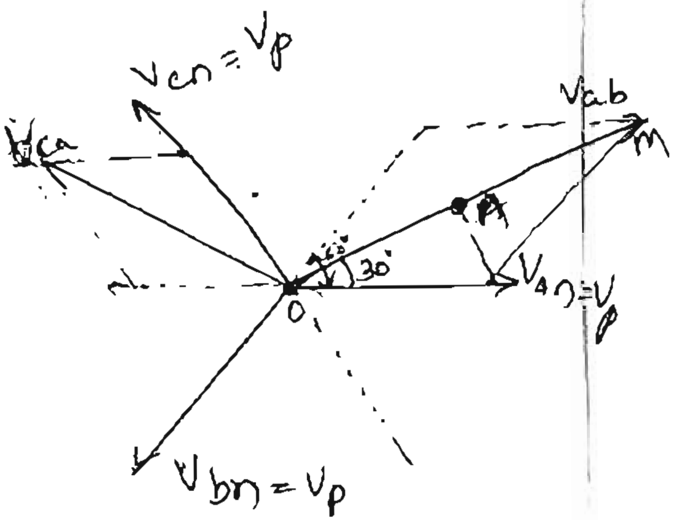
$$I_R = I_L = 2 \times I_p\frac{\sqrt{3}}{2}$$

$$= \sqrt{3}I_p$$

Balanced Three phase Star Connected load



Balanced



$$V_{ab} = V_L = V_{an} + V_{nb} = \overline{OM} = 2 \times OA$$
$$= 2 \times V_{an} \cos 30$$

$$\underline{V_L = \sqrt{3}\, V_p}$$

OR $V_{ab} = V_p\angle 0 - V_p\angle -120$

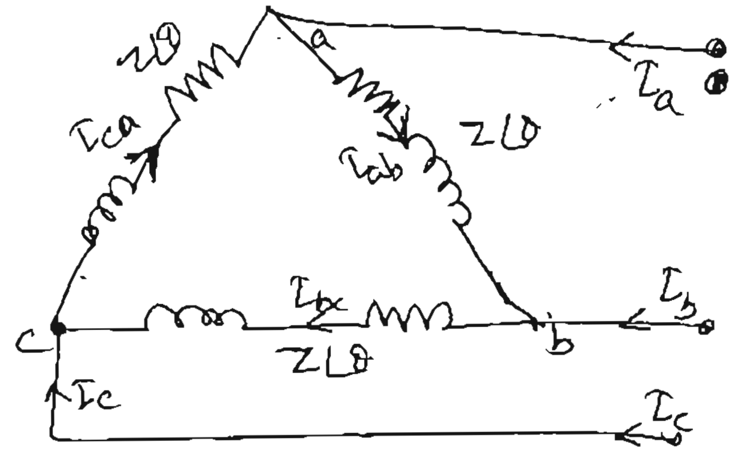
$$= V_p - V_p\left(-\tfrac{1}{2} - j\tfrac{\sqrt{3}}{2}\right)$$
$$= V_p\left(\tfrac{3}{2} + j\tfrac{\sqrt{3}}{2}\right) = \sqrt{3}\, V_p\left[\tfrac{\sqrt{3}}{2} + j\tfrac{1}{2}\right]$$

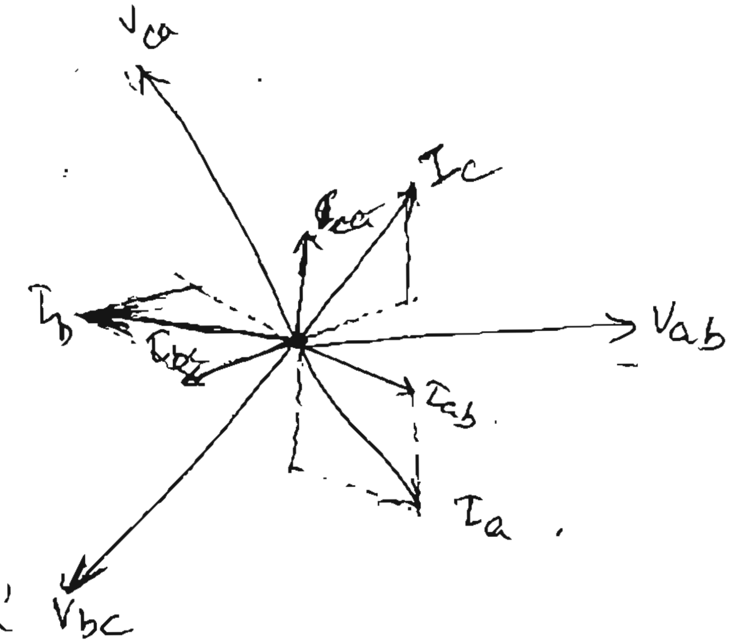
$V_{ab} = V_L = \sqrt{3}\, V_p \angle 30^\circ$

V_L leads V_p by 30°

$$\boxed{\begin{aligned} V_L &= \sqrt{3}\, V_p \\ I_L &= I_p \end{aligned}}$$

Balanced Delta Connected load





KCL nodal

$I_a = I_{ab} - I_{ca}$

$I_b = I_{bc} - I_{ab}$

$I_c = I_{ca} - I_{bc}$

Delta connected load (Continued)

$$I_{ab} = \frac{V_{ab}}{Z\angle\theta} = \frac{V_L\angle 0}{Z\angle\theta} = \frac{V_L}{Z}\angle{-\theta}$$

$$I_{bc} = \frac{V_{bc}}{Z\angle\theta} = \frac{V_L\angle{-120}}{Z\angle\theta} = \frac{V_L}{Z}\angle{-(120+\theta)}$$

$$I_{ca} = \frac{V_{ca}}{Z\angle\theta} = \frac{V_L\angle 120}{Z\angle\theta} = \frac{V_L}{Z}\angle(120-\theta)$$

Star connected load

$$I_a = \frac{V_{an}}{Z\angle\theta} = \frac{V_p\angle 0}{Z\angle\theta} = \frac{V_p}{Z}\angle{-\theta}$$

$$I_b = \frac{V_{bn}}{Z\angle\theta} = \frac{V_p\angle{-120}}{Z\angle\theta} = \frac{V_p}{Z}\angle{-(120+\theta)}$$

$$I_c = \frac{V_{cn}}{Z\angle\theta} = \frac{V_p\angle 120}{Z\angle\theta} = \frac{V_p}{Z}\angle 120-\theta$$

Power in Three phase Balanced system

Active Power in each phase $P_a = P_b = P_c = V_p I_p \cos\theta$.

Total power $P = P_a + P_b + P_c = \underline{3 V_p I_p \cos\theta}$

For star connection

$V_L = \sqrt{3}\, V_p$; $I_L = I_p$.

$\therefore P = \boxed{3 V_p I_p \cos\theta}$.

$P = 3\frac{V_L}{\sqrt{3}} I_L \cos\theta = \boxed{\sqrt{3} V_L I_L \cos\theta}$.

For Delta connection

$V_L = V_p$

$I_L = \sqrt{3} I_p$.

$P = \boxed{3 V_p I_p \cos\theta}$

$P = 3 V_L \frac{I_L}{\sqrt{3}} \cos\theta$

$= \boxed{\sqrt{3} V_L I_L \cos\theta}$

Active, Reactive and Apparent Power

$$P = 3V_p I_p \cos\theta = \sqrt{3} V_L I_L \cos\theta .$$

Apparent Power $S = 3V_p I_p = \sqrt{3} V_L I_L$

Reactive Power $Q = 3V_p I_p \sin\theta = \sqrt{3} V_L I_L \sin\theta$

Phase sequence.

ABC (RYB) → 'B' phase voltage lags 'A' phase voltage by 120° and 'C' phase voltage lags 'A' phase voltage by 240°.

ACB (RBY) → C, B lags 'a' by 120° & 240° resply.

Reversal of phase sequence → reverses the dirn of rotation of 3φ motor