Module 2 : AC Circuits 6 Hrs

Alternating voltages and currents, RMS, average, form factor, peak factor; Single phase RL, RC, RLC series and parallel circuits; **Power and power factor; Balanced three phase systems**

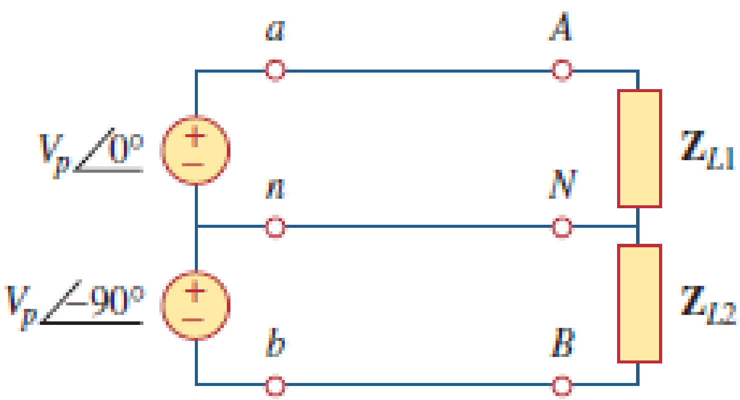
Course Outcome

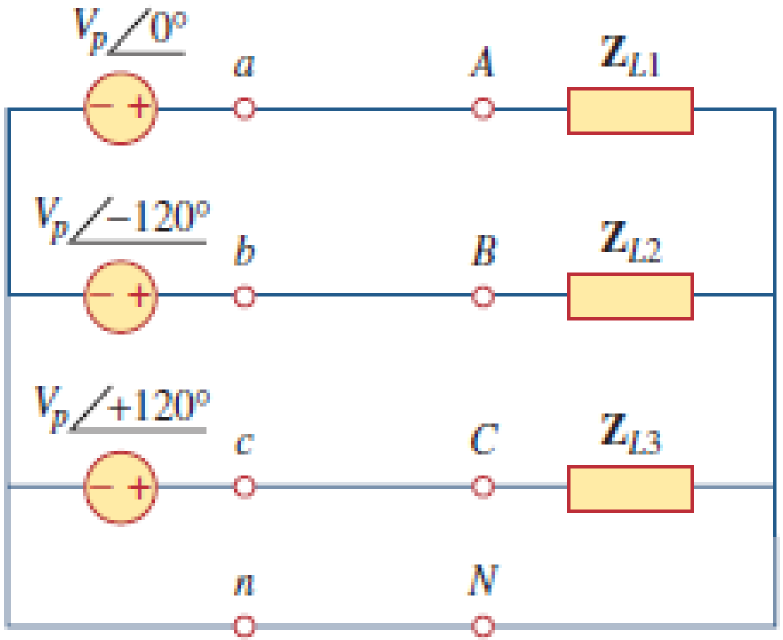
- Evaluate AC circuit parameters using laws

Poly-phase system

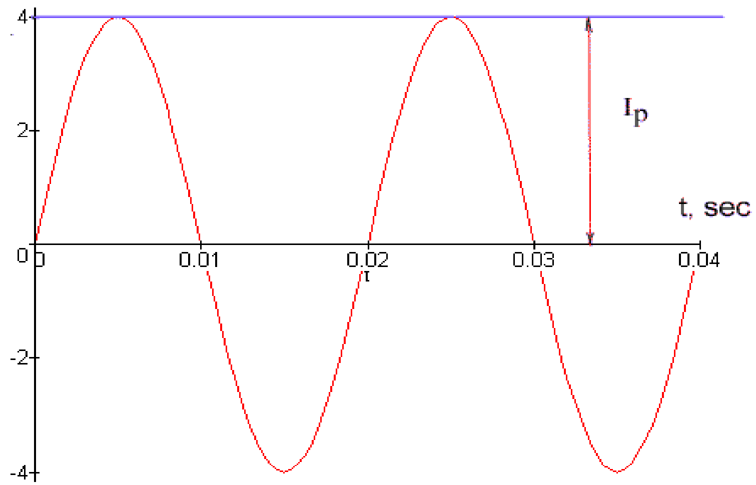
- Single phase - two wire system
- Poly phase - same frequency but different phases
- Two phase – same frequency and the phase angle difference between the phases are 90°
- Three phase -same frequency and the phase angle difference between the phases are 120°

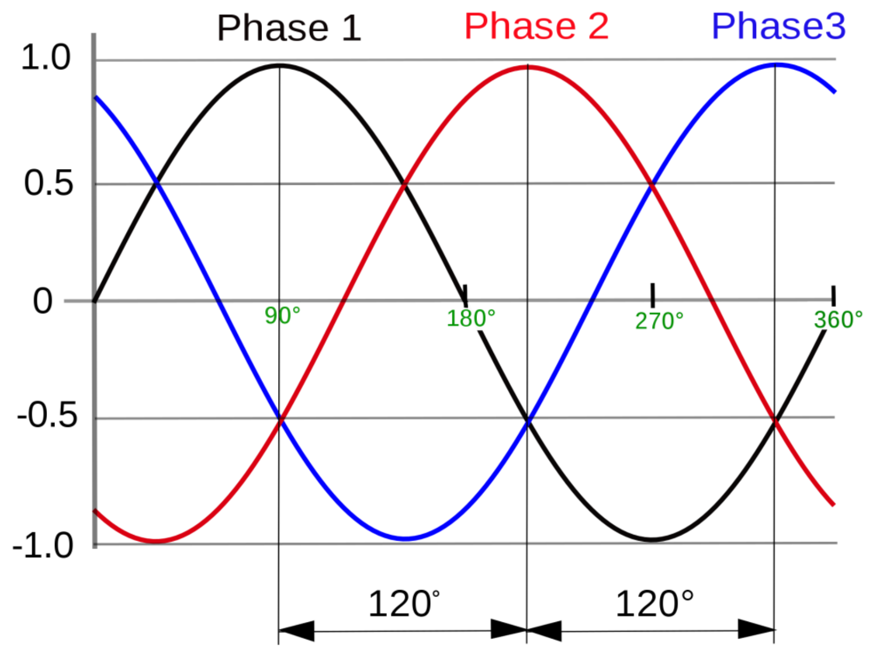
Different supply systems

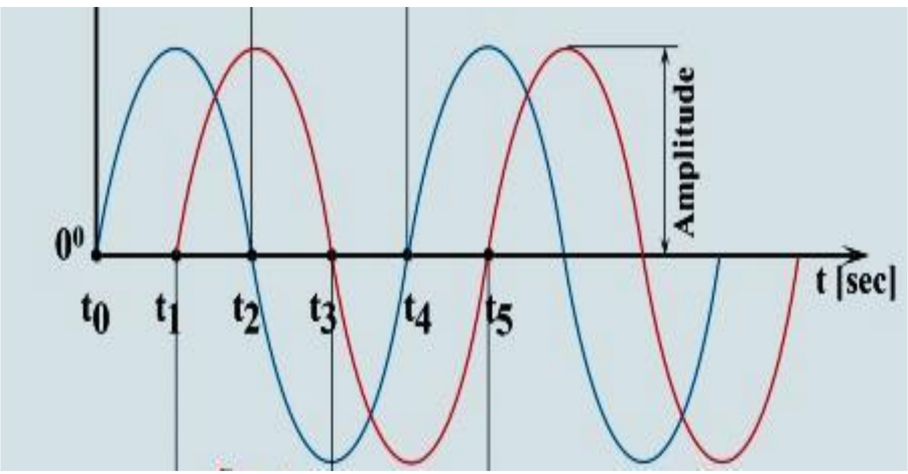


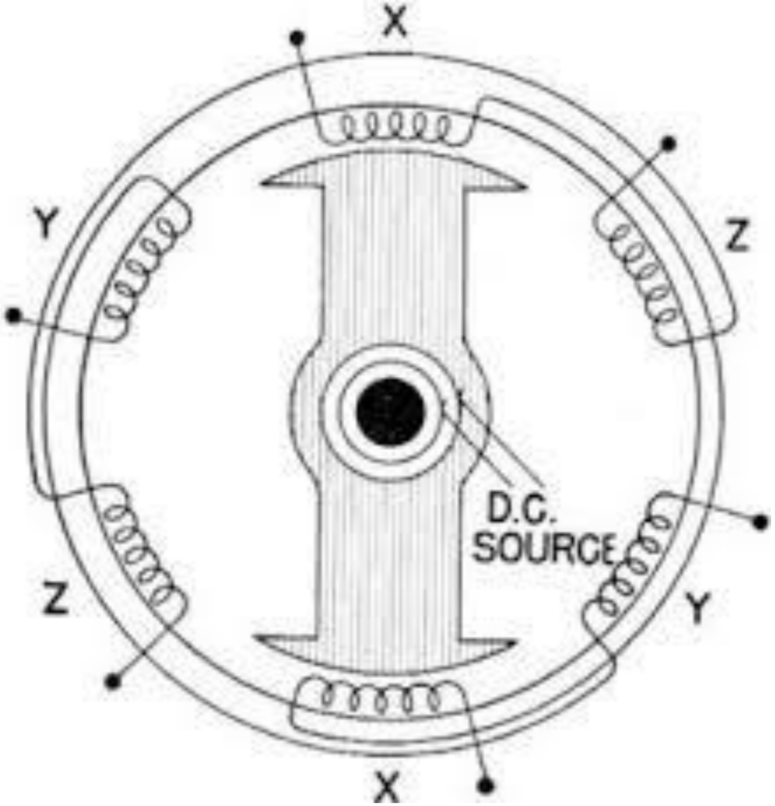


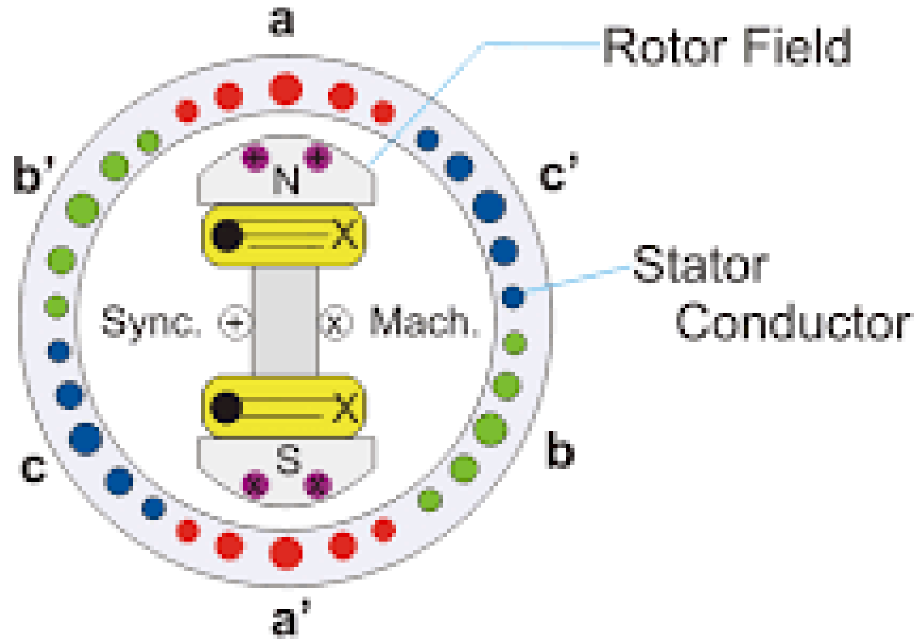
Different supply systems

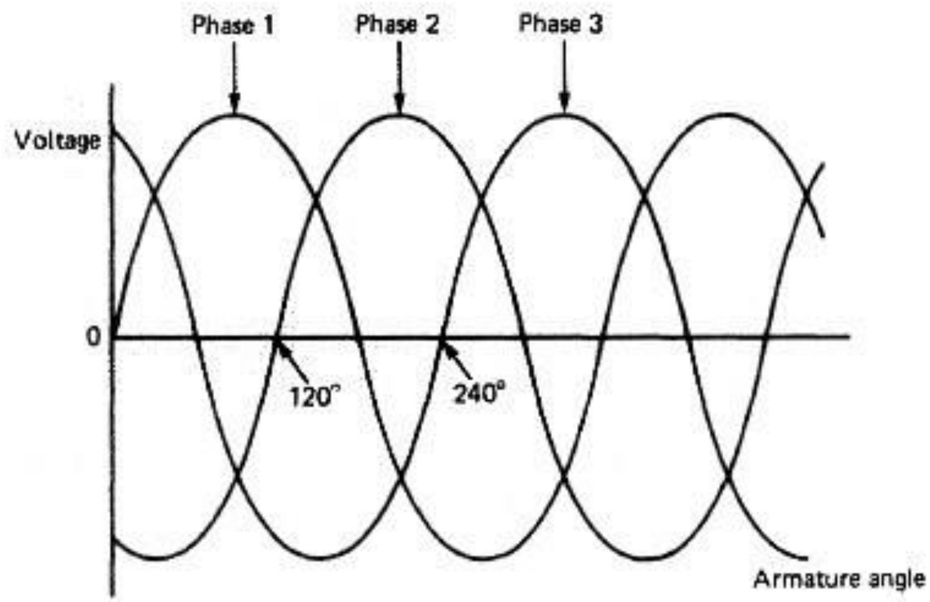







X
Y
Z
D.C.
SOURCE
Z
Y
X


a
Rotor Field
b'
c'
N
Stator
Conductor
Sync.
Mach.
S
c
b
a'


Phase 1
Phase 2
Phase 3
Voltage
0
120°
240°
Armature angle

Three Phase Systems

Advantages of three phase system

- Three phase power distribution requires lesser amount of copper or aluminium for transferring the same amount of power.
- 3 phase alternator or electrical machines occupy less space and less cost compared to single phase machine having same rating.
- Three phase system gives steady output.
- 3 phase motors will have uniform torque whereas single phase motors will have pulsating torque.

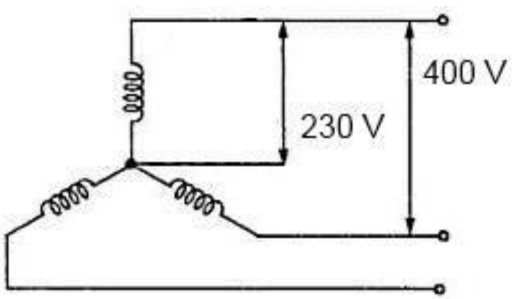
Three phase connections

Star (wye) connection (Y)

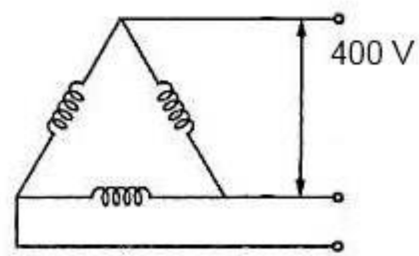
- Three similar ends of the three phase coils are joined together to form a common point called star point or neutral point.

Delta (mesh) connection (Δ)

- Dissimilar ends of the three phase coils are connected together to form a mesh. Wires are drawn from each junction for connecting load.

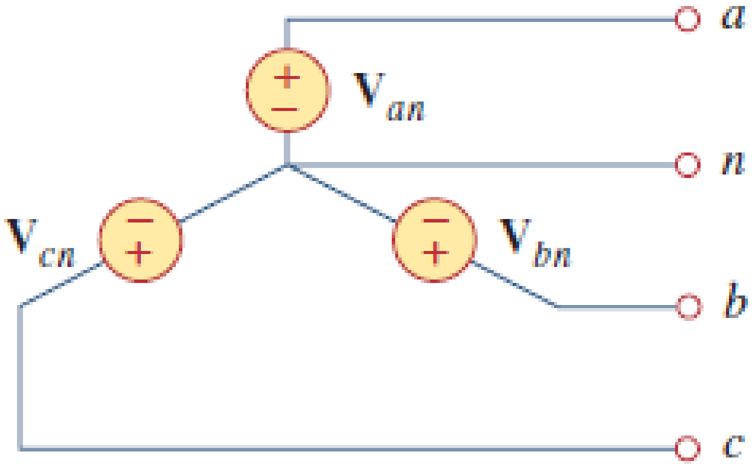


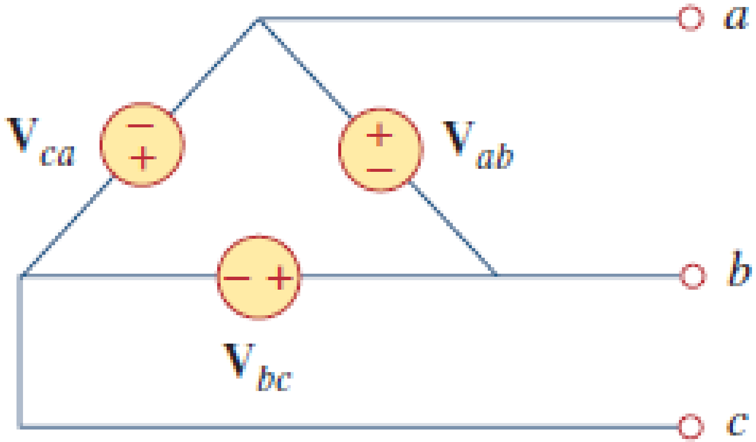
Star Connection



Delta Connection

Three phase voltage sources



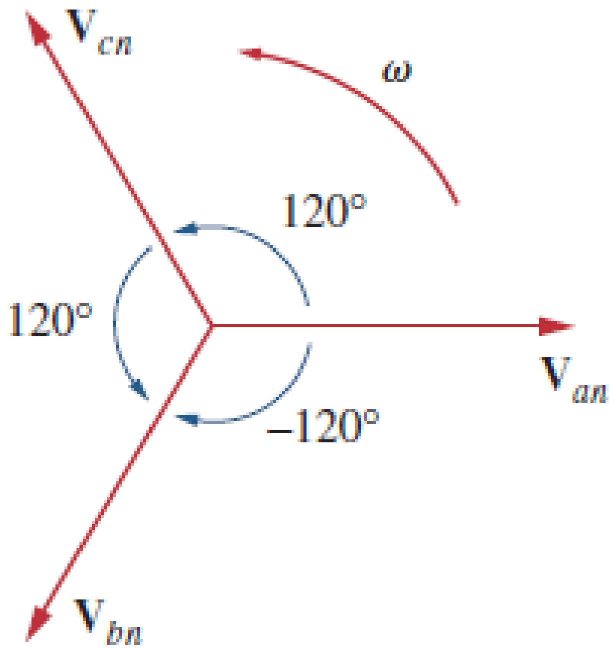


Balanced system

$$\mathbf{V}_{an} + \mathbf{V}_{bn} + \mathbf{V}_{cn} = 0$$

$$|\mathbf{V}_{an}| = |\mathbf{V}_{bn}| = |\mathbf{V}_{cn}|$$

Positive phase sequence

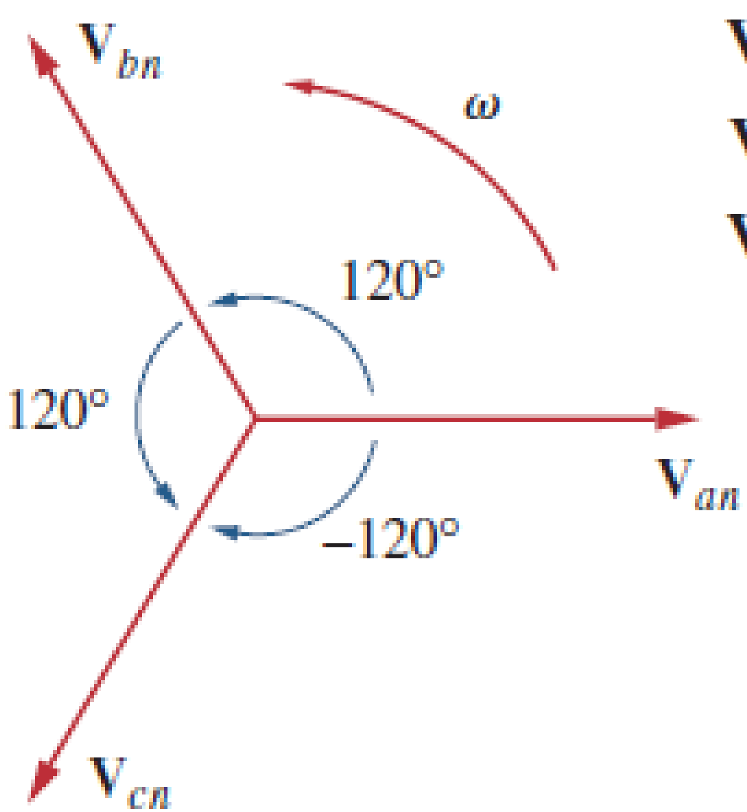


$$\mathbf{V}_{an} = V_p\angle 0^\circ$$

$$\mathbf{V}_{bn} = V_p\angle -120^\circ$$

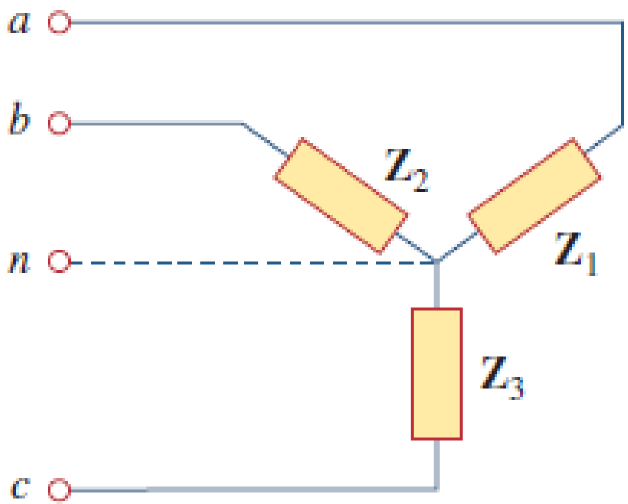
$$\mathbf{V}_{cn} = V_p\angle -240^\circ = V_p\angle +120^\circ$$

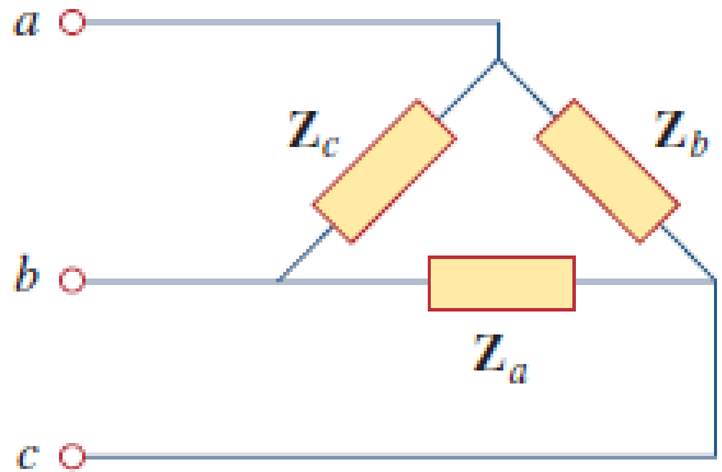
Negative phase sequence



$$\mathbf{V}_{an} = V_p\angle 0^\circ$$
$$\mathbf{V}_{cn} = V_p\angle -120^\circ$$
$$\mathbf{V}_{bn} = V_p\angle -240^\circ = V_p\angle +120^\circ$$

Three phase load configurations





For a balanced star connected load

$$\mathbf{Z}_1 = \mathbf{Z}_2 = \mathbf{Z}_3 = \mathbf{Z}_Y$$

For a balanced delta connected load

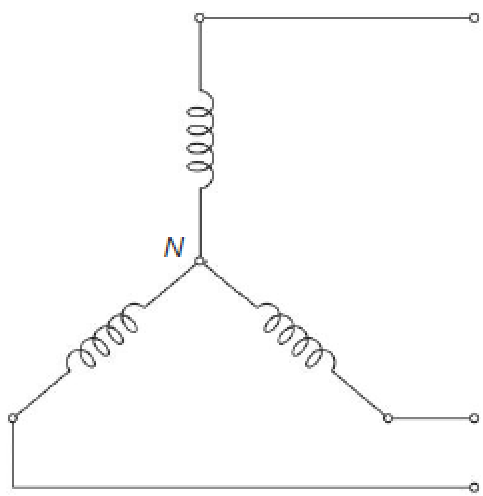
$$\mathbf{Z}_a = \mathbf{Z}_b = \mathbf{Z}_c = \mathbf{Z}_\Delta$$

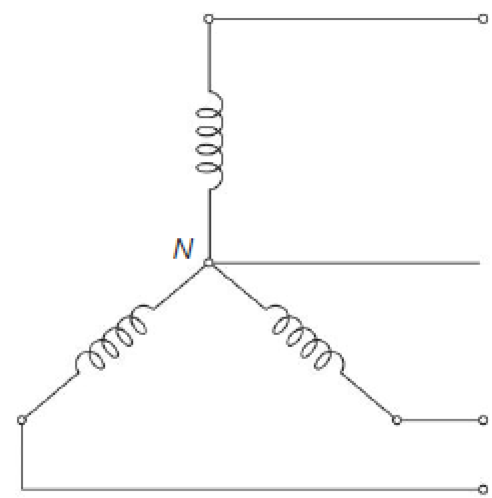
Identify the type of 3-phase connection

Identify the type of 3-phase connection

Balanced three phase systems
Star (wye) connection (Y)

- Three wire system
- Four wire system
- The phase angle difference between each phase is 120°
- All the three phase voltages have the same amplitude, same period and frequency.





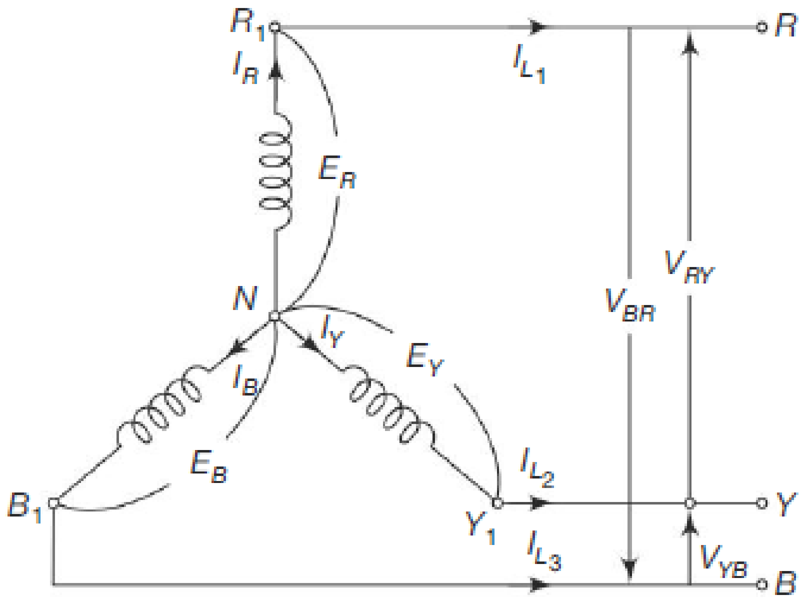
Voltage and current relationship

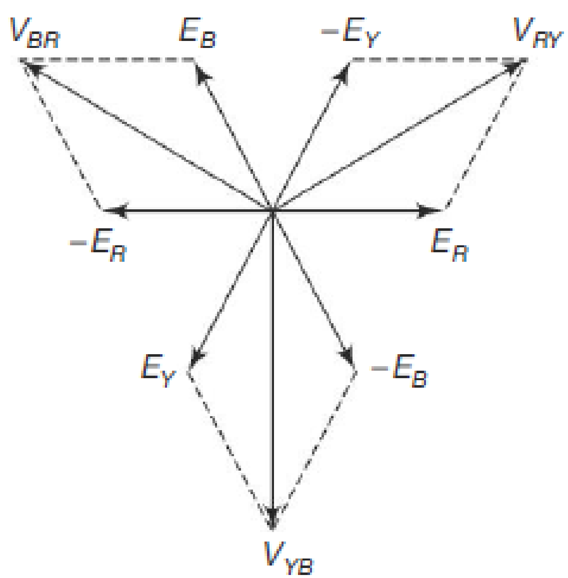
E_R, E_Y, E_B	:	Phase voltages of R, Y and B phases
I_R, I_Y, I_B	:	Phase currents
V_{RY}, V_{YB}, V_{BR}	:	Line voltages
I_{L1}, I_{L2}, I_{L3}	:	Line currents

In a balanced system,

$$E_R = E_Y = E_B = E_P \qquad V_{RY} = V_{YB} = V_{BR} = V_L$$

$$I_R = I_Y = I_B = I_P \qquad I_{L1} = I_{L2} = I_{L3} = I_L$$





Current Relationship Applying Kirchhoff's current law at nodes R_1, Y_1, B_1 we get $I_R = I_{L1}$; $I_Y = I_{L2}$; $I_B = I_{L3}$.

This means that in a balanced star connected system, phase current equals the line current

$$I_P = I_L.$$

Voltage Relationship Let us apply Kirchhoff's voltage law to the loop consisting of voltages E_R, V_{RY} and E_Y. We have

$$\overline{E}_R - \overline{E}_Y = \overline{V}_{RY}$$

Using law of parallelogram,

$$|\overline{V}_{RY}| = V_{RY} = \sqrt{E_R^2 + E_Y^2 + 2\,E_R\,E_Y \cos 60°}$$

$$= \sqrt{E_P^2 + E_P^2 + 2\,E_P\,E_P\,(\%0)} = E_P\sqrt{3}$$

Similarly,

$$\overline{E}_Y - \overline{E}_B = \overline{V}_{YB} \quad \text{and} \quad \overline{E}_B - \overline{E}_R = \overline{V}_{BR}$$

$\therefore$ $$\overline{V}_{YB} = E_P\sqrt{3} \text{ and } \quad V_{BR} = E_P\sqrt{3}$$

Thus, $$V_L = \sqrt{3}\,E_P$$

Line voltage = $\sqrt{3}$ phase voltage

Power Relationship Let $\cos\phi$ be the power factor of the system.

$$\text{Power consumed in one phase} = E_P I_P \cos\phi$$

$$\begin{aligned}\text{Power consumed in three phases} &= 3E_P I_P \cos\phi \\ &= 3\frac{V_L}{\sqrt{3}} I_L \cos\phi \\ &= \sqrt{3}\, V_L I_L \cos\phi \text{ watts}\end{aligned}$$

$$\text{Reactive power in one phase} = E_P I_P \sin\phi$$

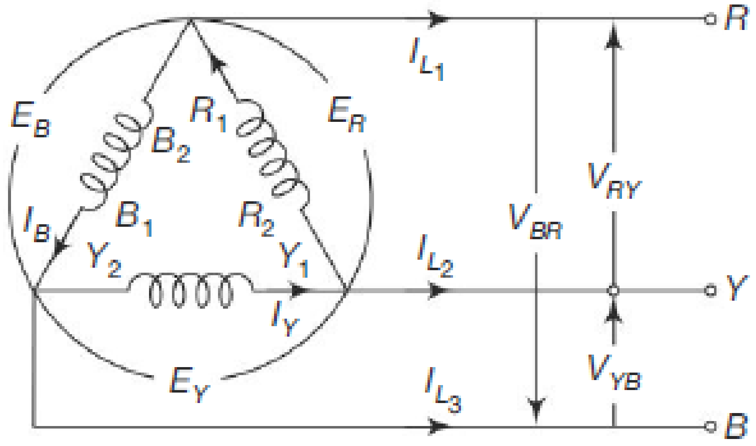
$$\begin{aligned}\text{Total reactive power} &= 3E_P I_P \sin\phi \\ &= \sqrt{3}\, V_L I_L \sin\phi \text{ VAR}\end{aligned}$$

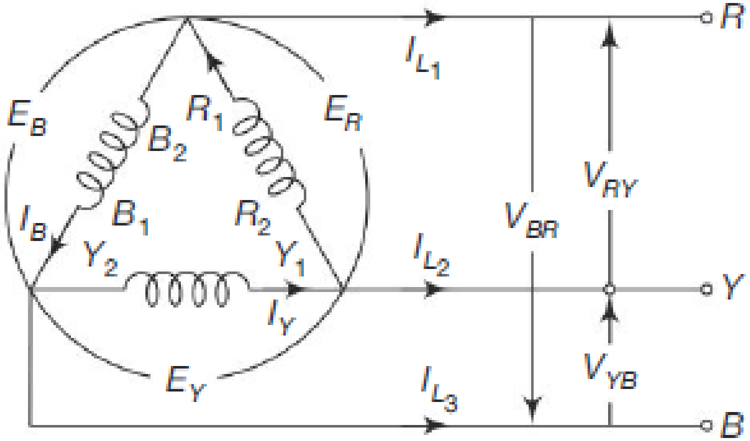
$$\text{Apparent power per phase} = 3\, E_P I_P$$

$$\text{Total apparent power} = 3E_P I_P = \sqrt{3}\, V_L I_L \text{ volt amp}$$

Balanced three phase systems
Delta (mesh) connection (Δ)

- Three wire system
- The phase angle difference between each phase is 120°
- All the three phase voltages have the same amplitude, same period and frequency.



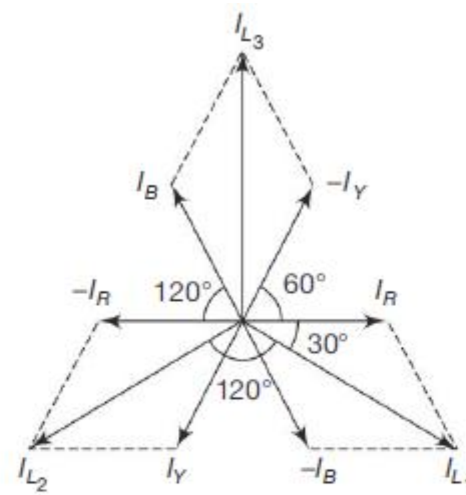


$E_R = E_Y = E_B = E_P$, phase voltage

$I_R = I_Y = I_B = I_P$, phase current

$V_{RY} = V_{YB} = V_{BR} = V_L$, line voltage

$I_{L1} = I_{L2} = I_{L3} = I_L$, line current



Voltage Relationship Applying Kirchhoff's voltage law to the loop consisting of E_R and V_{RY}, we have $E_R = V_{RY}$.

Similarly, $E_Y = V_{YB}$ and $E_B = V_{BR}$,

Thus $E_P = V_L$.

Phase Voltage = Line Voltage

Current Relationship Applying Kirchhoff's current law at the junction of R_1 and B_2, we have $\bar{I}_R - \bar{I}_B = \bar{I}_L 1$.

Referring to the phasor diagram and applying the law of parallelogram, we have

$$I_L I = \sqrt{I_R^2 + I_B^2 + 2 I_R I_B \cos 60^\circ}$$

$$= \sqrt{I_P^2 I_P^2 + 2 I_P I_P (\%0)}$$

$$= I_P \sqrt{3}$$

Similarly, we have

$$\bar{I}_Y - \bar{I}_R = \bar{I}_L 2 \quad \text{and} \quad \bar{I}_B - \bar{I}_Y = \bar{I}_L 3$$

Hence, $I_L 2 = I_P \sqrt{3}$ and $I_L^3 = I_P \sqrt{3}$

Thus, line current = $\sqrt{3}$ phase current

$$I_L = \sqrt{3}\, I_P$$

Power Relationship Let $\cos\phi$ be the power factor of the system.

$$\text{Power per phase} = E_P I_P \cos\phi$$

$$\text{Total power for all the three phases} = 3\,E_P I_P \cos\phi$$

$$= 3\,V_L \frac{I_L}{\sqrt{3}} \cos\phi$$

$$= \sqrt{3}\,V_L I_L \cos\phi \text{ watts}$$

$$\text{Reactive power in one phase} = E_P I_P \sin\phi$$

$$\text{Total reactive power} = 3\,E_P I_P \sin\phi$$

$$= \sqrt{3}\,V_L I_L \sin\phi \text{ VAR}$$

$$\text{Apparent power per phase} = E_P I_P$$

$$\text{Total apparent power} = 3\,E_P I_P = \sqrt{3}\,V_L I_L \text{ volt amp}$$