# Basic Electrical and Electronics Engineering (BEEE102L)

## 3 phase systems

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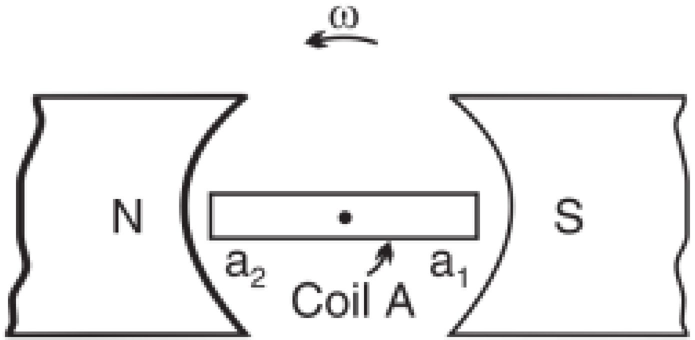
**LECTURE 2.10**

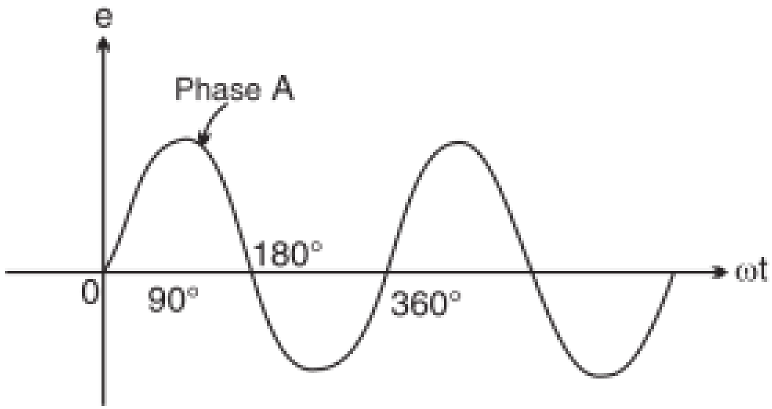
# TOPICS

- **Three Phase Systems**
- **Star & Delta Connections**
- Three Phase Power Measurement
- Electrical Safety
- Fuses and Earthing
- Residential Wiring

## Single Phase System

$$e_{a_1 a_2} = E_m \sin \omega t$$



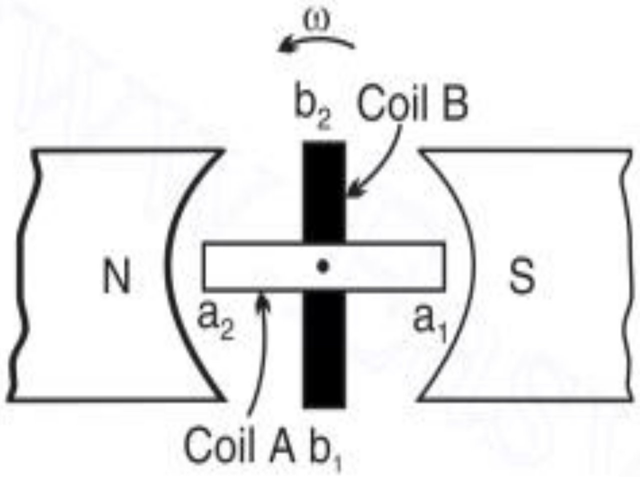



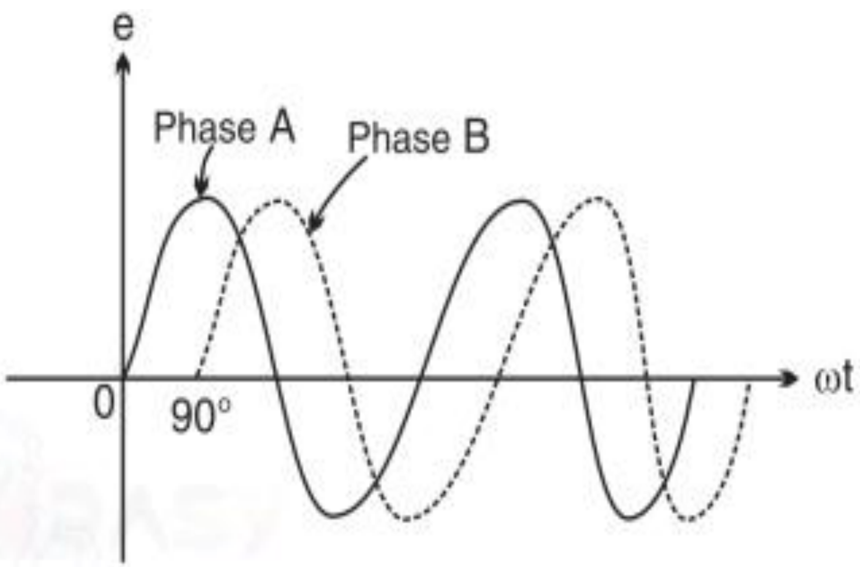

**Circuits or systems in which the ac sources operate at the same frequency but different phases are known as *polyphase***

## Two Phase System

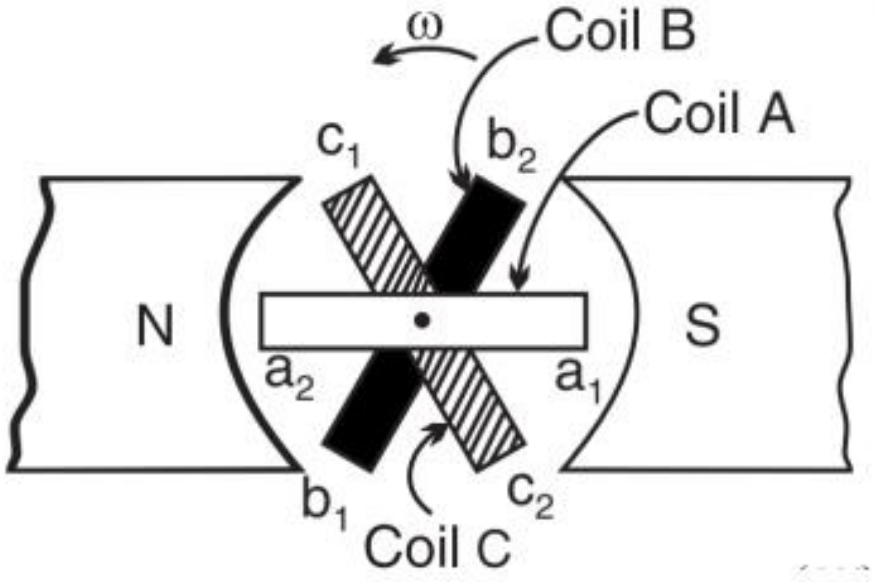
$$e_{a_1 a_2} = E_m \sin \omega t$$

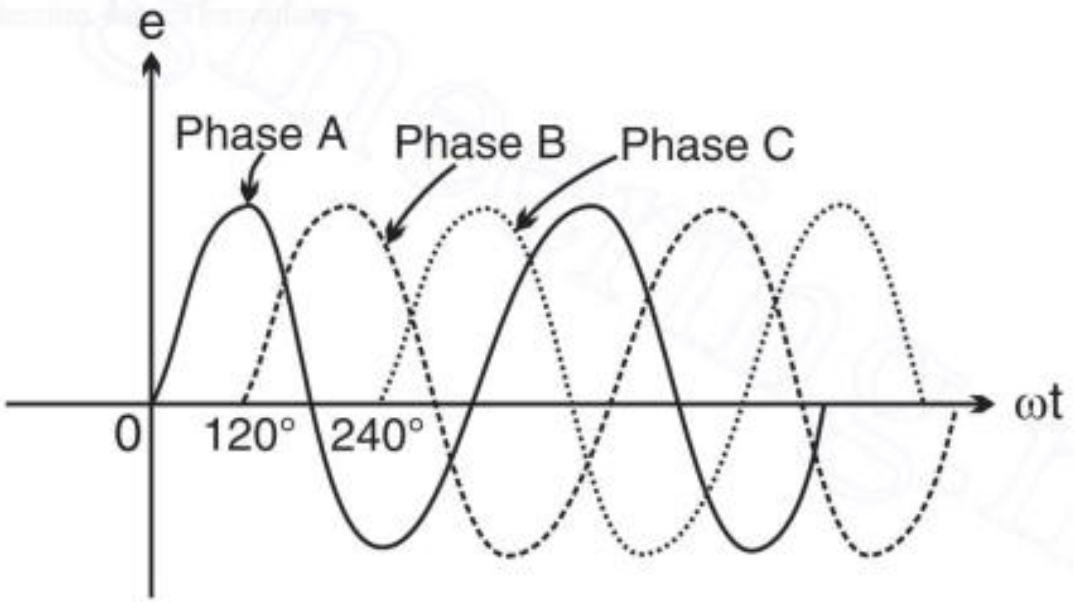
$$e_{b_1 b_2} = E_m \sin(\omega t - 90^\circ)$$



## Three Phase System




$$e_{a_1a_2} = E_m \sin \omega t \qquad e_{b_1b_2} = E_m \sin(\omega t - 120°) \qquad e_{c_1c_2} = E_m \sin(\omega t - 240°)$$

# Why Three Phase?

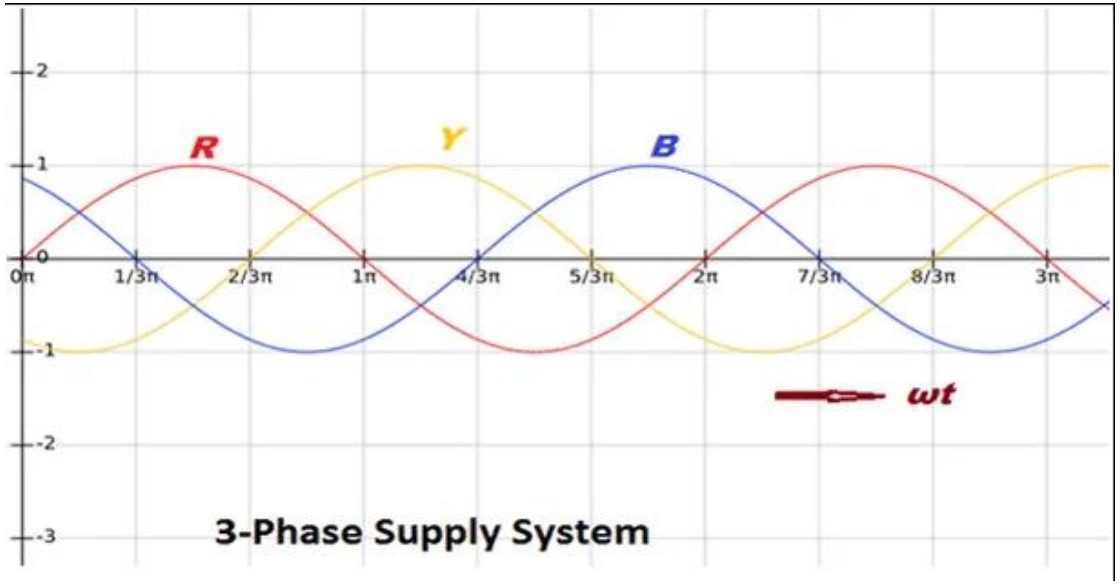
- **Constant power.** In a single-phase circuit, the instantaneous power varies sinusoidally from zero to a peak value at twice the supply frequency. However, in a balanced 3-phase system, the power supplied at all instants of time is constant.

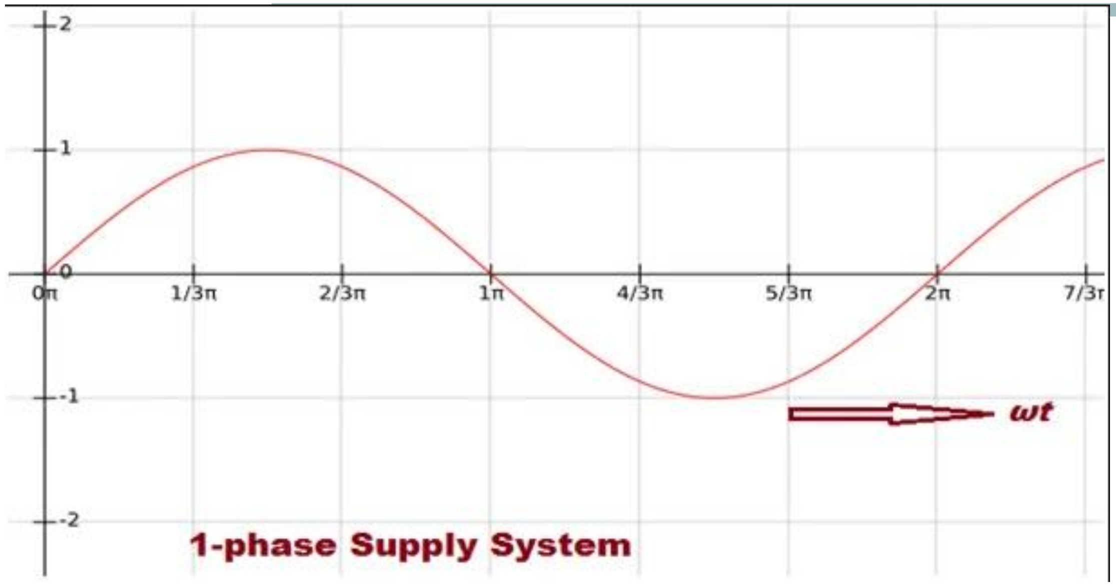
- **Greater output.** The output of a 3-phase machine is greater than that of a single-phase machine for a given volume and weight of the machine.

- **Cheaper.** The three-phase motors are much smaller and less expensive than single-phase motors because less material (copper, iron, insulation) is required.

- **Power transmission economics.** Transmission of electric power by 3-phase system is cheaper than that of single-phase system, even though three conductors are required instead of two.

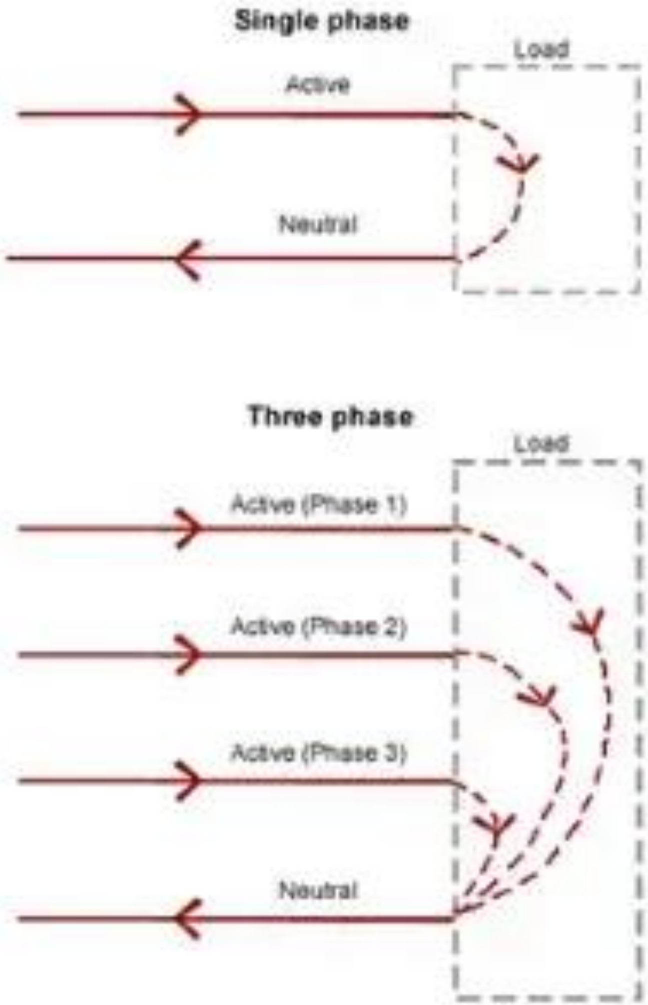
- **Rotating Magnetic Field** A 3-phase system can set-up a rotating uniform magnetic field in stationary windings. This cannot be done with a single-phase current.

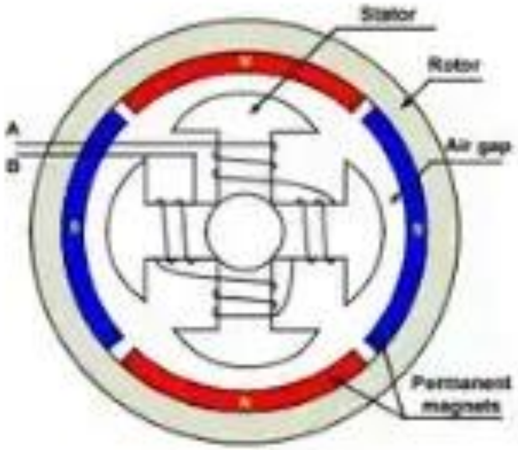


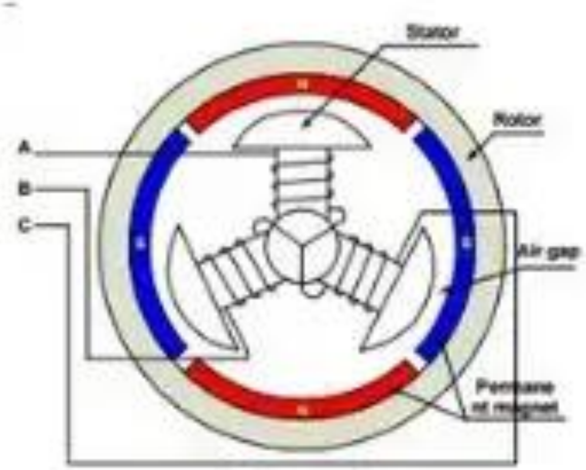

Presently 3-ø AC system is very popular and being used worldwide for power generation, power transmission, distribution and for electric motors.

# 3 Phase vs Single Phase Power Systems




Single-phase




Three-phase

# Advantages

Three phase system has the following advantages as compare to single phase system:

- Power to weight ratio of 3-ø alternator is high as compared to 1-ø alternator.
- Thus, for generation for same amount of Electric Power, the size of 3-ø alternator is small as compare to 1-ø alternator.
- Hence, the overall cost of alternator is reduced for generation of same amount of power.
- Moreover, due to reduction in weight, transportation and installation of alternator become convenient and less space is required to accommodate the alternator in power houses.
- A 3-phase system can be used to feed a 1-ø load, whereas vice-versa is not possible.

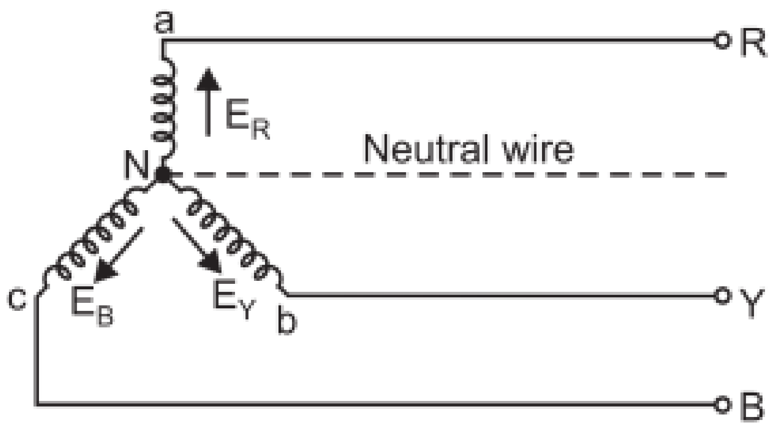
# Advantages

- For electric power transmission and distribution of same amount of power, the requirement of conductor material is less in 3-ø system as compare to 1-ø system.
- Hence, the 3-ø transmission and distribution system is economical as compare 1-ø system.
- 3-phase motor is having better power factor
- 3-phase induction motor is self-started as the magnetic flux produced by 3-phase supply is rotating in nature with a constant magnitude.
- Whereas 1-ø induction motor is not self-started as the magnetic flux produced by 1-ø supply is pulsating in nature.
- Hence, we have to make some arrangement to make the 1-ø induction motor self-started which further increases the cost of 1-ø induction motor.

## Three Phase Configurations

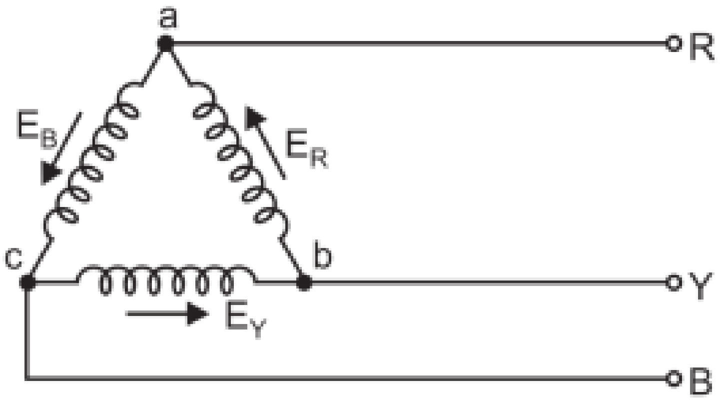
(i) Star or Wye (Y) connection
(ii) Delta (D) connection

**Y-connection**




If a neutral conductor exists, the system is called *3-phase, 4 wire system*. If there is no neutral conductor, it is called *3-phase, 3-wire system*.

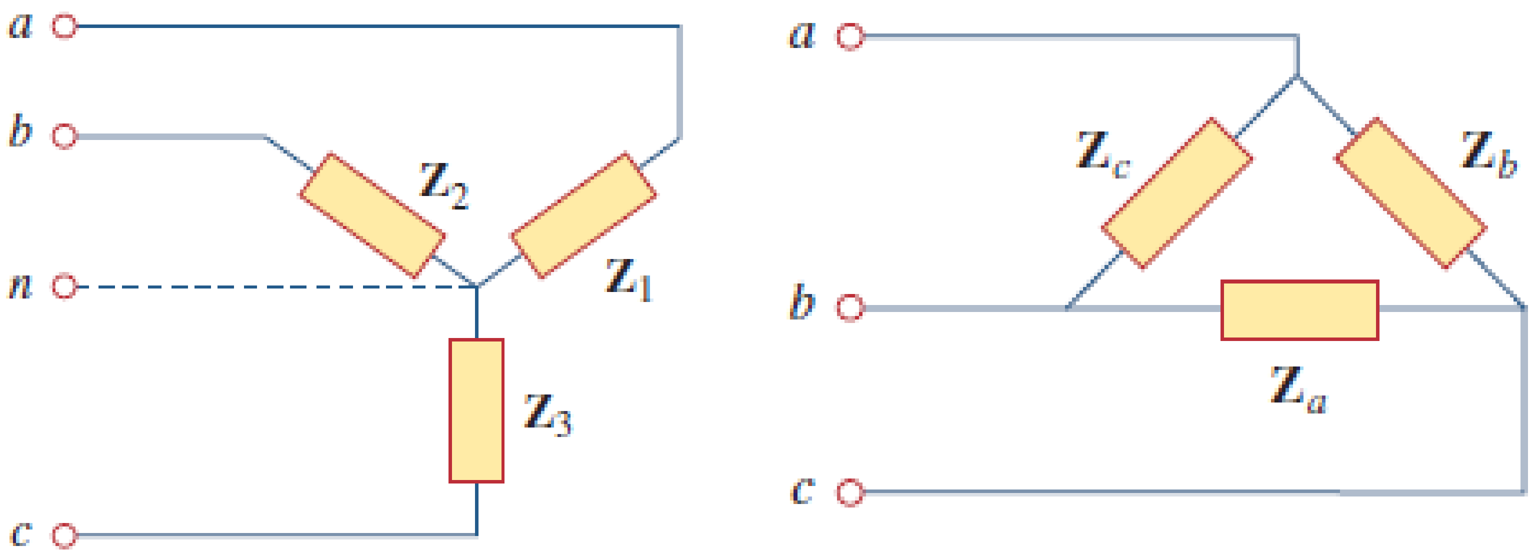
**D -connection**




*In a D-connection, no neutral point exists and only 3-phase, 3-wire system can be formed.*

# Star & Delta Connections

The **phase sequence** is the time order in which the voltages pass through their respective maximum values.

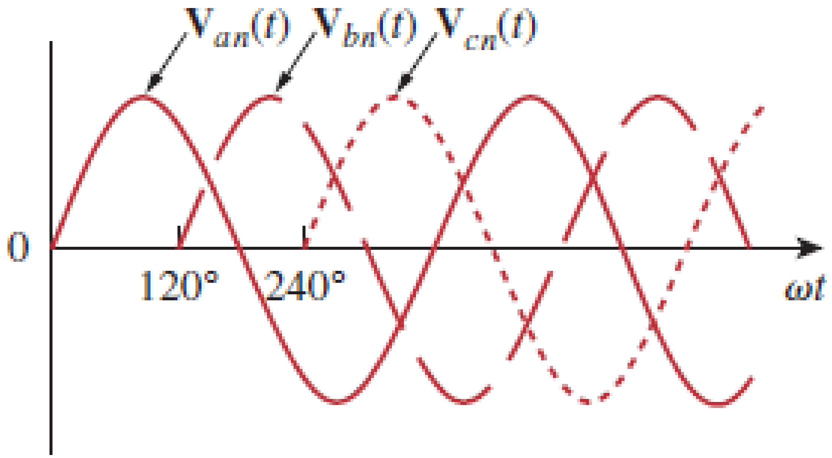


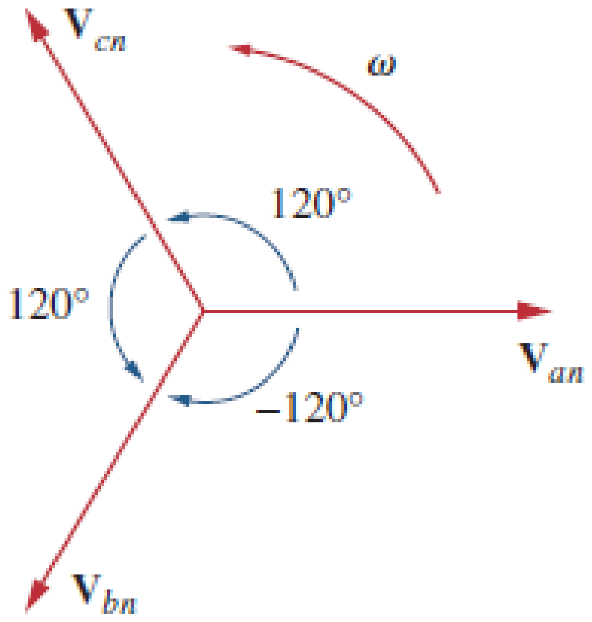

$$\mathbf{Z}_1 = \mathbf{Z}_2 = \mathbf{Z}_3 = \mathbf{Z}_Y$$

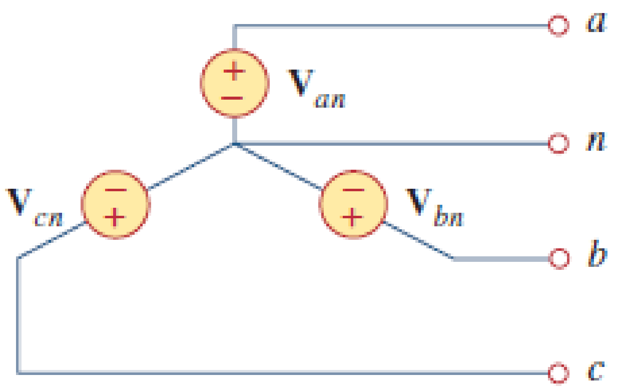
$$\mathbf{Z}_a = \mathbf{Z}_b = \mathbf{Z}_c = \mathbf{Z}_\Delta$$

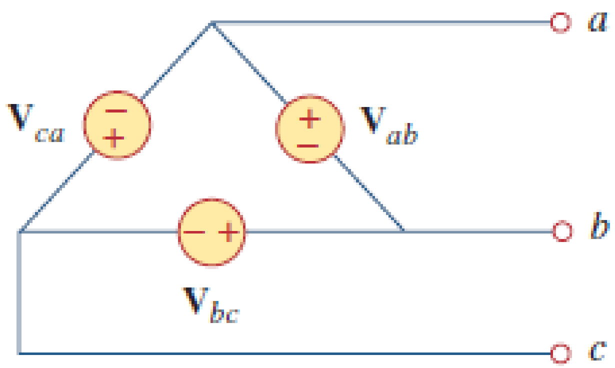
A **balanced load** is one in which the phase impedances are equal in magnitude and in phase.

# Three Phase System




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

**Balanced phase voltages** are equal in magnitude and are out of phase with each other by 120°.

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

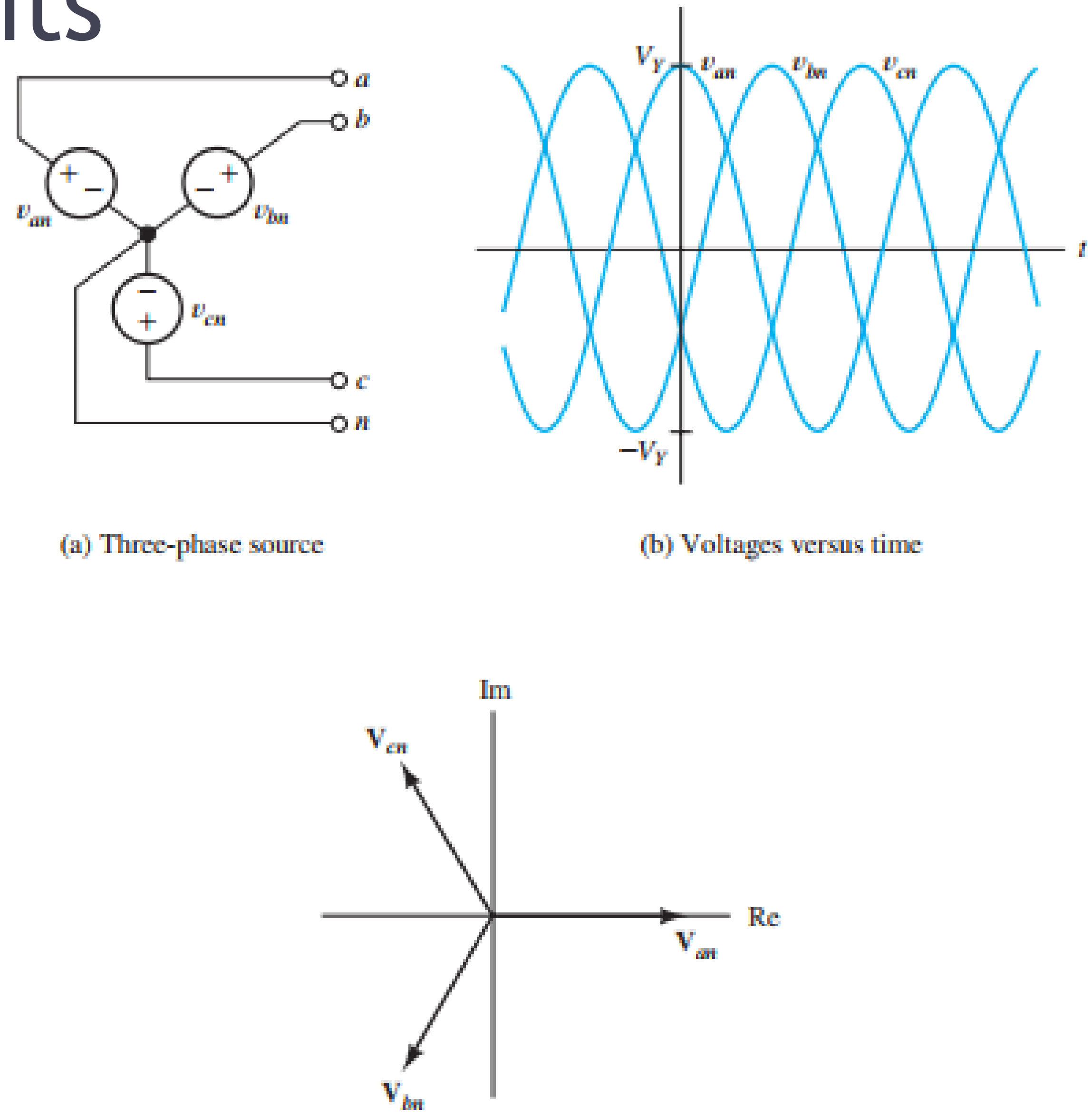
# Balanced three-PHASE Circuits

- We consider the most common case: three equal-amplitude ac voltages having phases that are 120° apart.
- This is known as a balanced three-phase source.
- The source shown in Figure is said to be **wye connected (Y connected).**
- The three voltages shown in Figure

$$v_{an}(t) = V_Y \cos(\omega t)$$

$$v_{bn}(t) = V_Y \cos(\omega t - 120°)$$

$$v_{cn}(t) = V_Y \cos(\omega t + 120°)$$

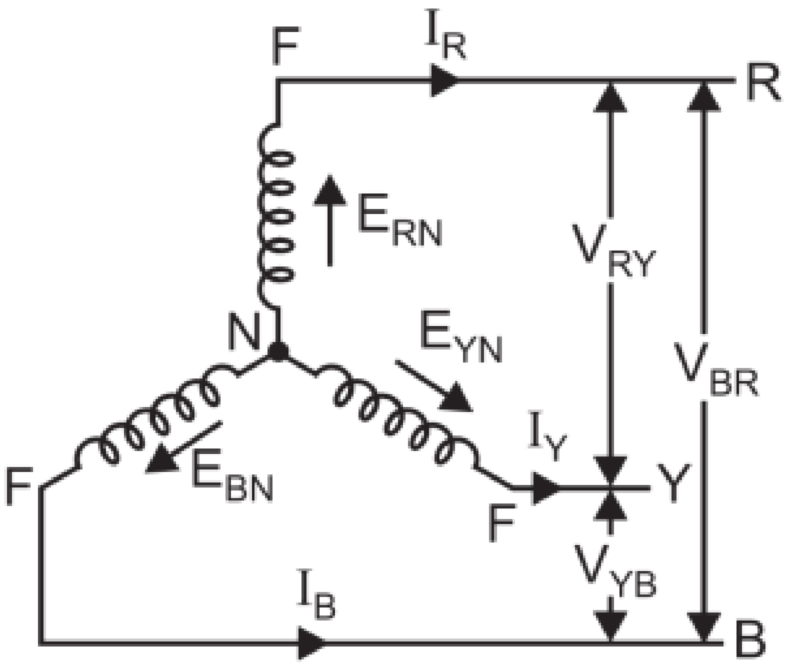



(a) Three-phase source

(b) Voltages versus time

(c) Phasor diagram

## Star or Wye Connected System




The voltages $E_{RN}$, $E_{YN}$, and $E_{BN}$ are respectively between lines *R*, *Y*, and *B*, and the neutral line *N*. These voltages are called *phase voltages*. If the voltage sources have the same amplitude and frequency *ω* and are out of phase with each other by 120º, the voltages are said to be *balanced*.

**Phase Voltage**

$$\boldsymbol{E_{RN}} = V_{Ph}\angle 0^\circ \qquad \boldsymbol{E_{YN}} = V_{Ph}\angle -120^\circ$$

$$\boldsymbol{E_{BN}} = V_{Ph}\angle -240^\circ$$

*When voltages are balanced* $\quad E_{RN} + E_{YN} + E_{BN} = 0$

$$|E_{RN}| = |E_{YN}| = |E_{BN}| = V_{Ph}$$

**Line Voltage**

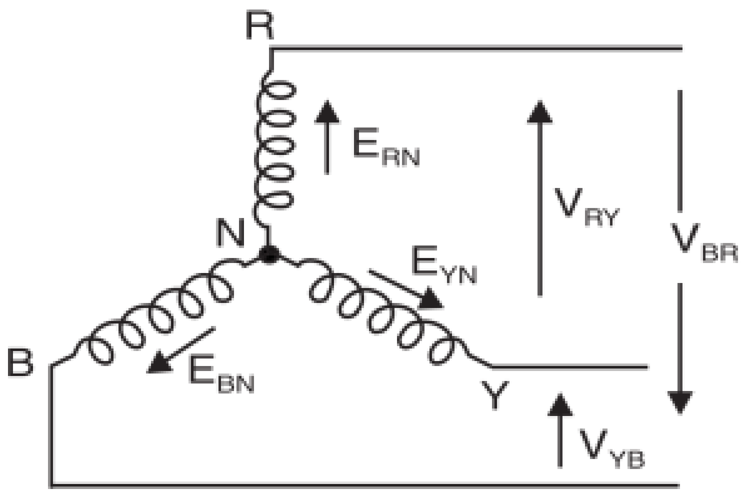
$$\boldsymbol{V_{RY}} = V_L\angle 0^\circ \qquad \boldsymbol{V_{YB}} = V_L\angle -120^\circ$$

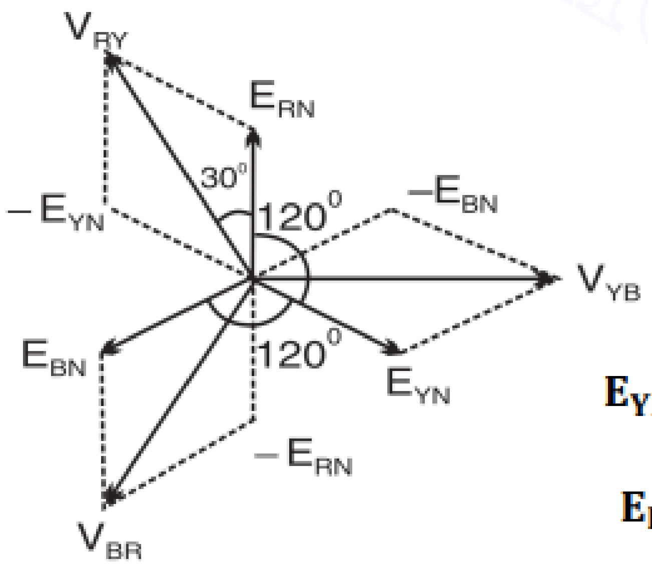
$$\boldsymbol{V_{BR}} = V_L\angle -240^\circ$$

Line voltage = $\sqrt{3}\times$ Phase voltage $\quad V_L = \sqrt{3}V_{Ph}$

Line current = Phase current $\quad I_L = I_{Ph}$

# Star or Wye Connected System




$$V_{RY} = E_{RN} + E_{NY} = E_{RN} - E_{YN}$$

$$V_{RY} = 2V_{Ph}\cos(60°/2) = 2V_{Ph}\cos 30° = \sqrt{3}V_{Ph}$$

$$V_{YB} = E_{YN} - E_{BN} = \sqrt{3}V_{Ph}$$

$$V_{BR} = E_{BN} - E_{RN} = \sqrt{3}V_{Ph}$$

$$\mathbf{E_{RN}} = V_{Ph}\angle 0° = V_{Ph}(1 + j0)$$

$$\mathbf{E_{YN}} = V_{Ph}\angle -120° = V_{Ph}(-0.5 - j0.866)$$

$$\mathbf{E_{BN}} = V_{Ph}\angle -240° = V_{Ph}(-0.5 + j0.866)$$

$$\mathbf{V_{RY}} = \mathbf{E_{RN}} - \mathbf{E_{YN}} = V_{Ph}(1 + j0) - V_{Ph}(-0.5 - j0.866)$$

line voltage leads phase voltage by 30°

$$\mathbf{V_{RY}} = V_{Ph}(1.5 + j0.866) = \sqrt{3}V_{Ph}\angle 30°$$

$$V_L = \sqrt{3}V_P\angle 30°$$

$$I_P = I_L$$

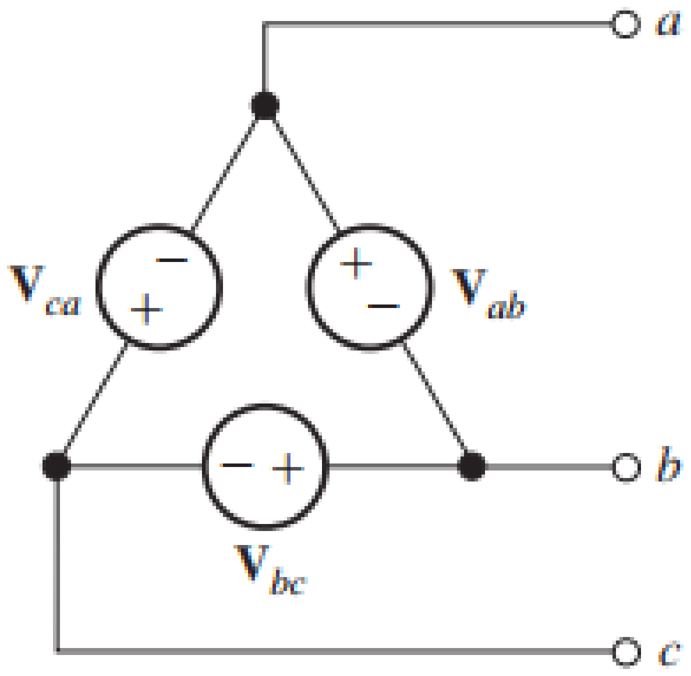
$$V_{RY} = V_{ph}\angle 0° - V_{ph}\angle -120°$$

$$V_{RY} = V_{ph}((\cos 0° + j\sin 0°) - (\cos(-120°) + j\sin(-120°)))$$

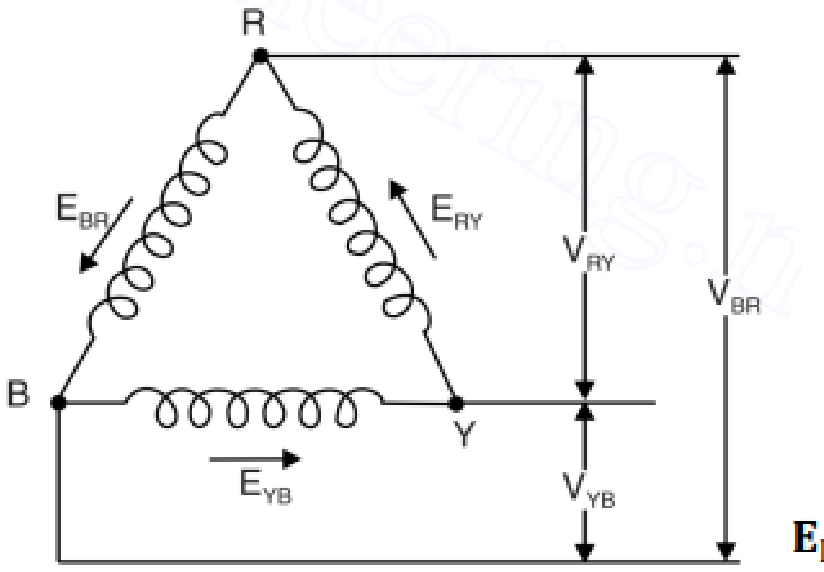
$$V_{RY} = V_L = V_{ph}(\frac{3}{2} + \frac{\sqrt{3}}{2}j)$$

# Delta-Connected Sources

- A set of balanced three-phase voltage sources can be connected in the form of a delta, as shown in Figure



## Delta Connected System




*When voltages are balanced*

$$\mathbf{E_{RY}} = V_{Ph}\angle 0^\circ = V_{Ph}(1 + j0)$$

$$\mathbf{E_{YB}} = V_{Ph}\angle -120^\circ = V_{Ph}(-0.5 - j0.866)$$

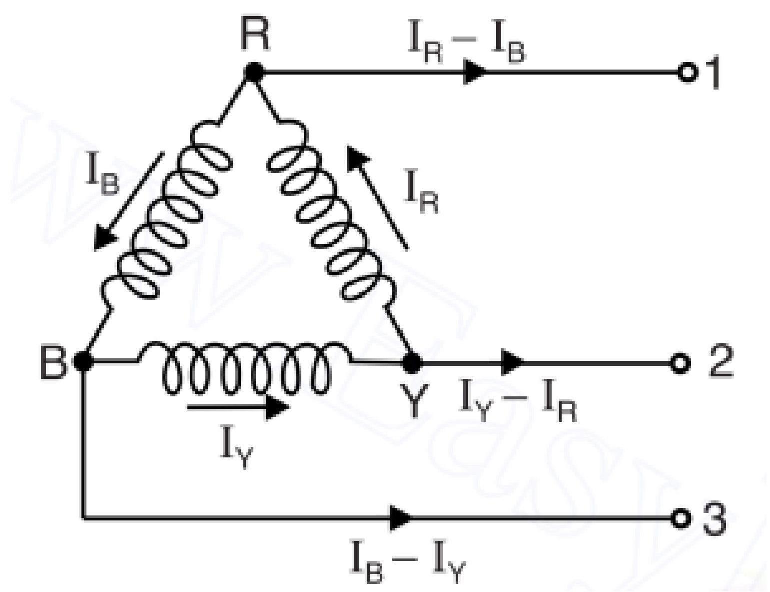
$$\mathbf{E_{BR}} = V_{Ph}\angle -240^\circ = V_{Ph}(-0.5 + j0.866)$$

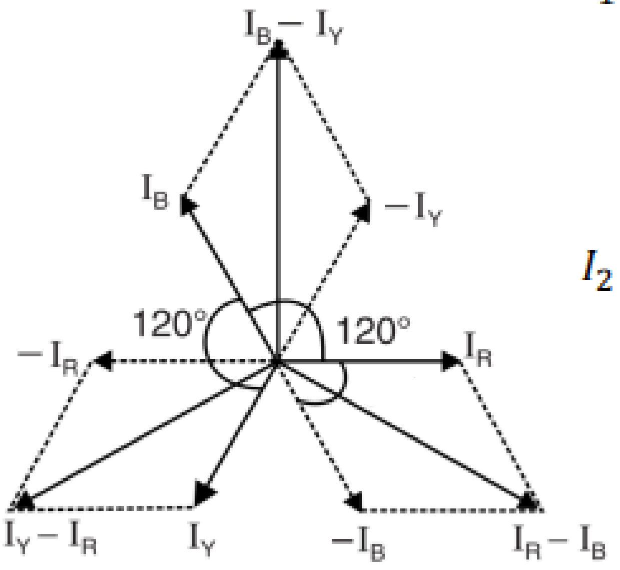
$$\mathbf{E_{RY}} + \mathbf{E_{YB}} + \mathbf{E_{BR}} = V_{Ph}(1 + j0) + V_{Ph}(-0.5 - j0.866) + V_{Ph}(-0.5 + j0.866) = 0$$

Line voltage = Phase voltage $\quad V_L = V_{Ph}$

Line current = $\sqrt{3}\times$ Phase current $\quad I_L = \sqrt{3}\, I_{Ph}$

## Delta Connected System




$$I_1 = I_R - I_B \qquad I_2 = I_Y - I_R \qquad I_3 = I_B - I_Y$$

$$I_1 = 2I_{Ph}\cos(60°/2) = 2I_{Ph}\cos 30° = \sqrt{3}I_{Ph}$$

$$I_2 = I_Y - I_R = \sqrt{3}I_{Ph} \qquad I_3 = I_B - I_Y = \sqrt{3}I_{Ph}$$

$$\mathbf{I_R} = I_{Ph}\angle 0° = I_{Ph}(1 + j0)$$

$$\mathbf{I_Y} = I_{Ph}\angle -120° = I_{Ph}(-0.5 - j0.866)$$

$$\mathbf{I_B} = I_{Ph}\angle -240° = I_{Ph}(-0.5 + j0.866)$$

line Current lags phase current by 30°

$$\mathbf{I_1} = \mathbf{I_R} - \mathbf{I_B} = I_{Ph}(1 + j0) - I_{Ph}(-0.5 + j0.866)$$

$$\boldsymbol{I_L = \sqrt{3}I_P\angle -30°}$$

$$\boldsymbol{V_P = V_L}$$

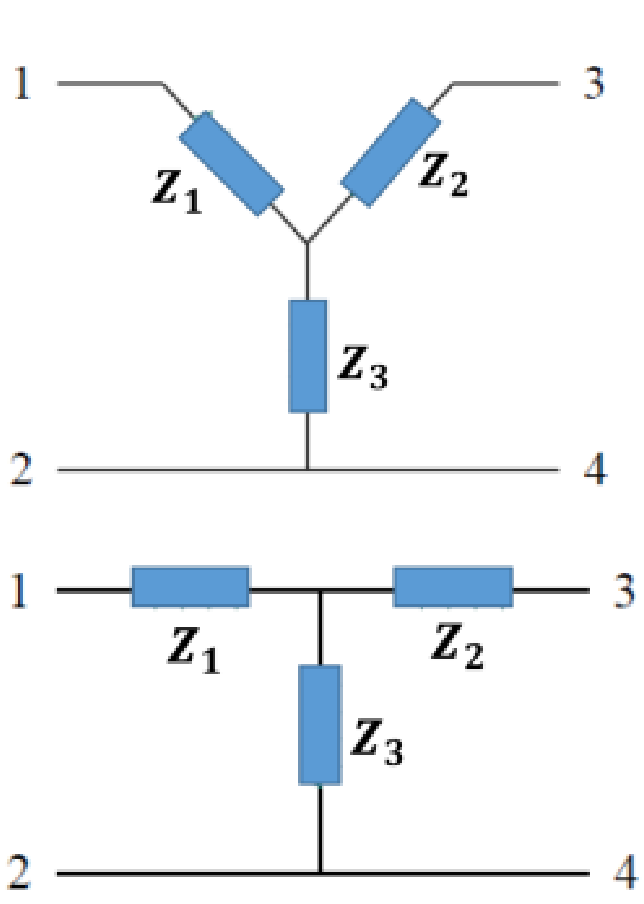
$$\boldsymbol{I_1 = I_{ph}\angle 0° - I_{ph}\angle -240°}$$

$$\boldsymbol{I_1 = I_{ph}((\cos 0° + j\sin 0°) - (\cos(-240°) + j\sin(-240°)))}$$

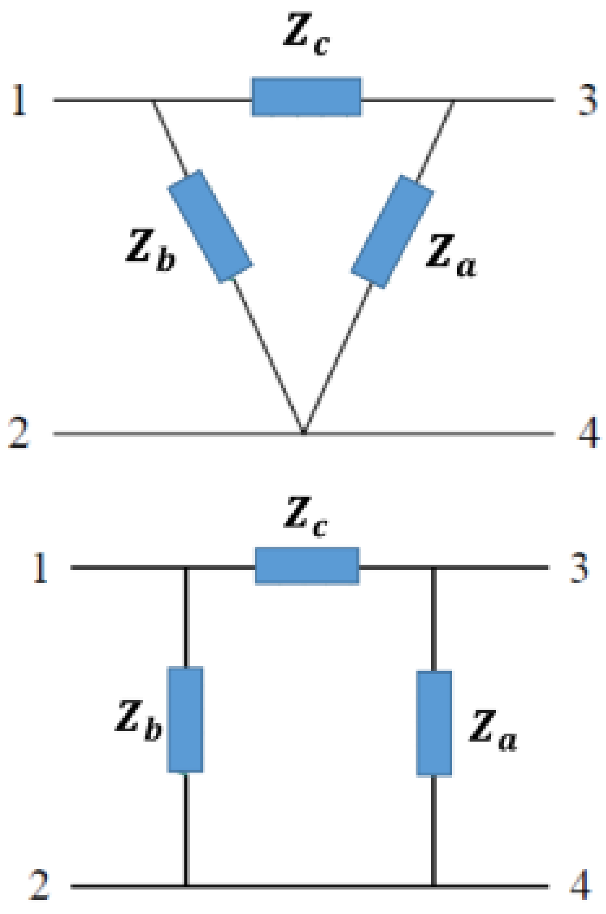
$$\boldsymbol{I_1 = I_{ph}(\frac{3}{2} - \frac{\sqrt{3}}{2}j)}$$

# Three Phase Load

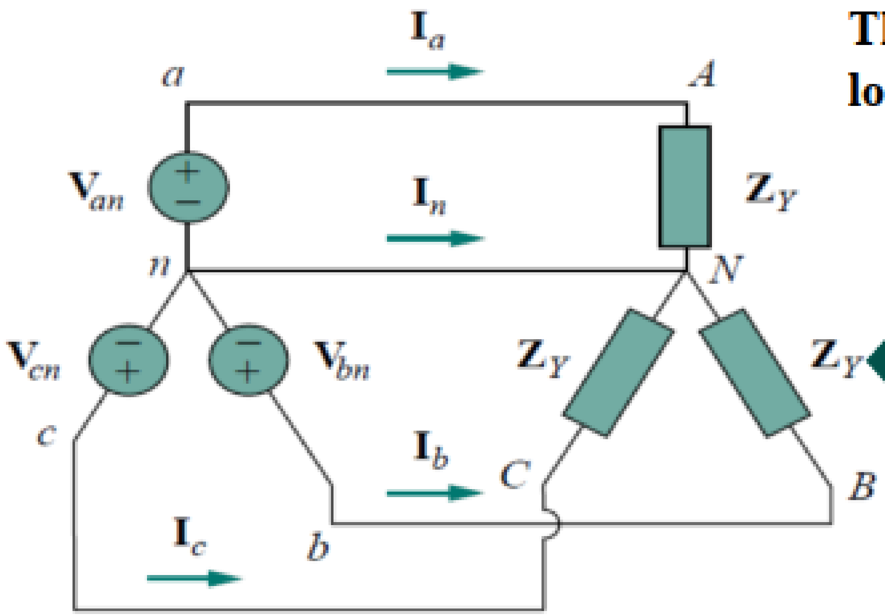
**Star or Y-connected Load**




**Δ-connected Load**

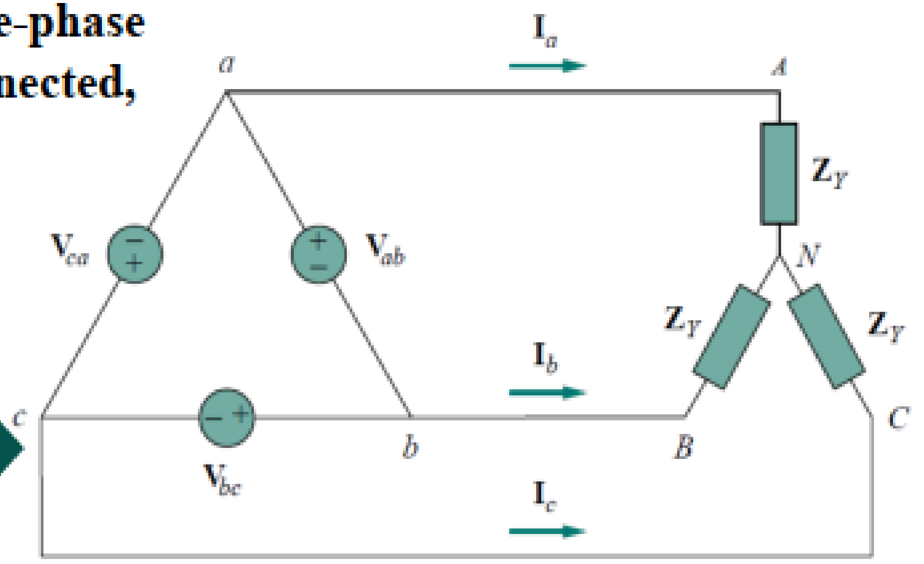


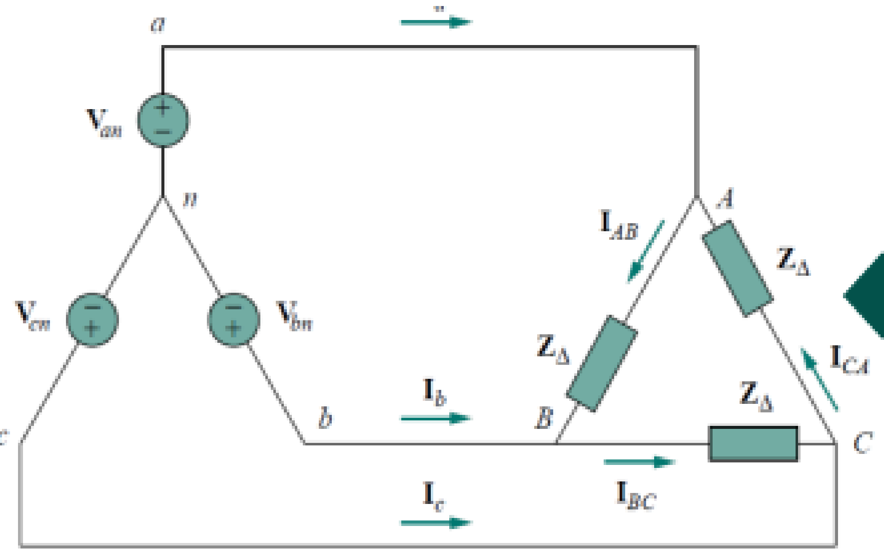
Three-phase source and the three-phase load can be either wye- or delta-connected,




Y - Y Connection

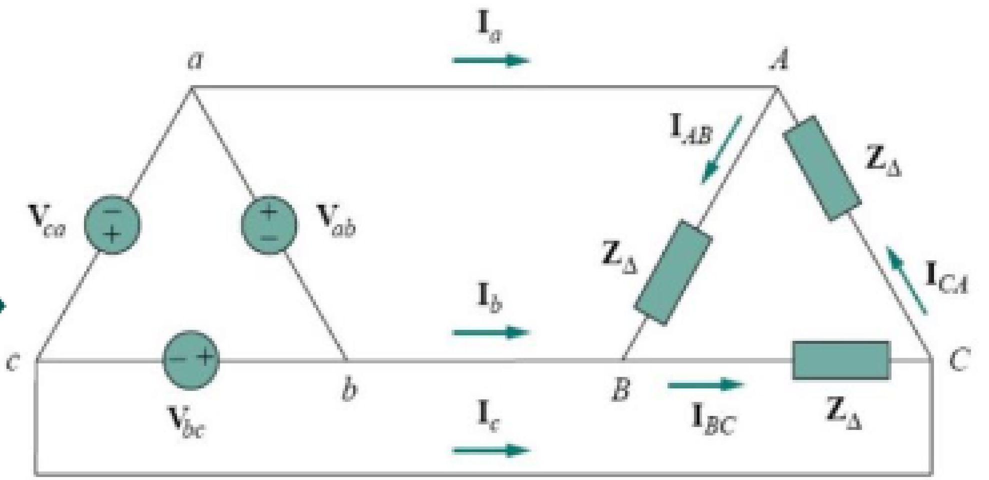
Δ - Y Connection



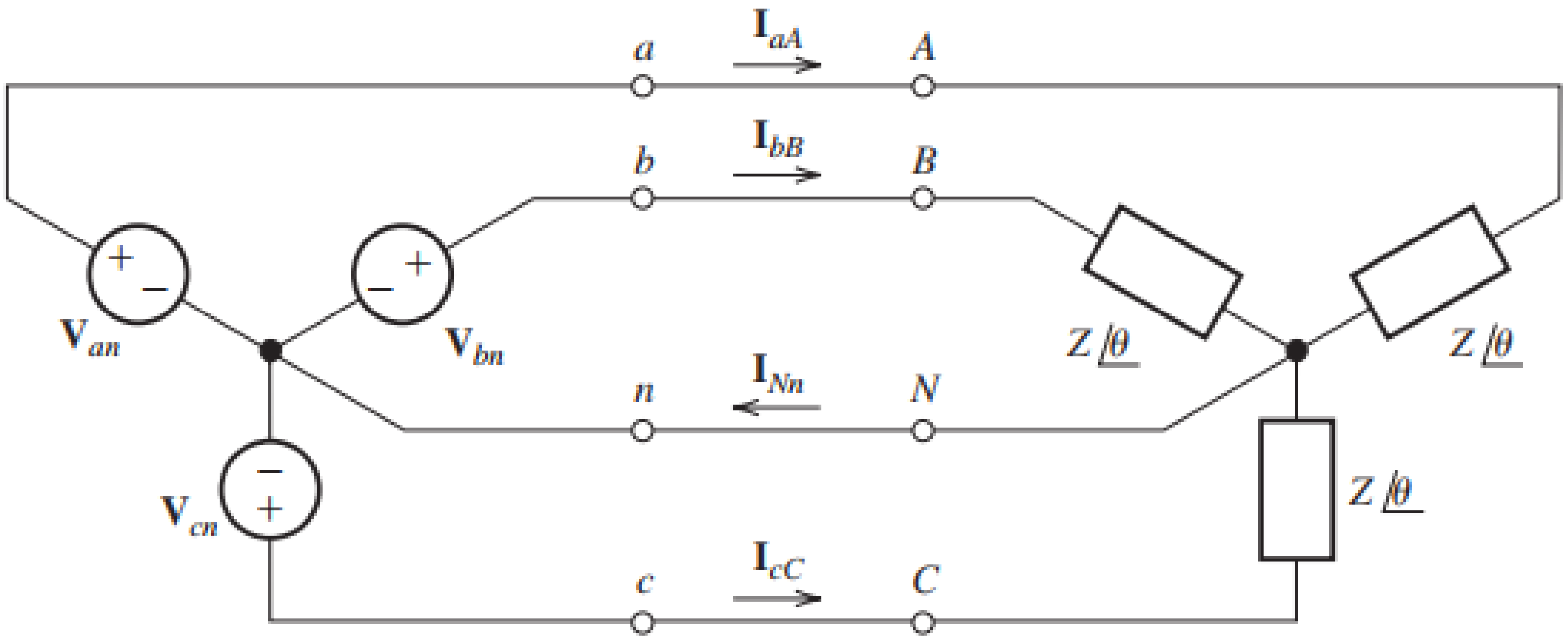

Y - Δ Connection

Δ - Δ Connection



# Wye - Wye Connection

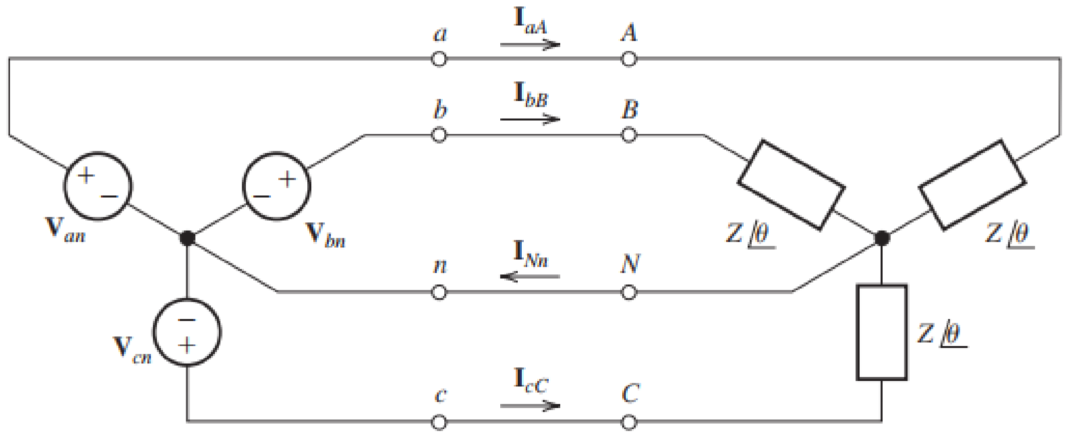
- Consider the three-phase source connected to a balanced three-phase load shown in Figure.



# Wye - Wye Connection

- The wires a-A, b-B, and c-C are called lines, and the wire n–N is called the neutral.
- This configuration is called a wye–wye (Y–Y) or star-star connection with neutral.
- By the term balanced load, means that the three load impedances are equal.
- phase A of the source is $v_{an}(t)$, and phase A of the load is the impedance connected between A and N.
- $V_Y$ is the line-to-neutral voltage of the wye-connected source.
- $I_{aA}$, $I_{bB}$, and $I_{cC}$ are called line currents.

**line-to-neutral voltage is phase voltage**



# Wye - Wye Connection

- The current in phase A of the load is given by

$$I_{aA} = \frac{\mathbf{V}_{an}}{Z\angle\theta} = \frac{V_Y\angle 0^\circ}{Z\angle\theta} = I_L\angle -\theta$$

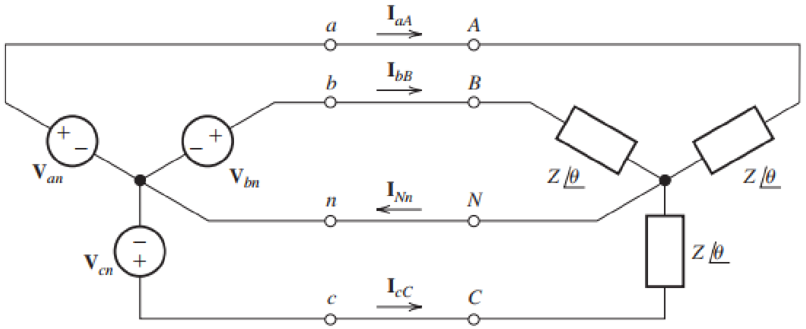
- Where $I_L = V_Y/Z$
- Because the load impedances are equal, all of the line currents are the having the same magnitude, except for phase.
- Thus, the currents are given by

$$i_{aA}(t) = I_L \cos(\omega t - \theta)$$

$$i_{bB}(t) = I_L \cos(\omega t - 120^\circ - \theta)$$

$$i_{cC}(t) = I_L \cos(\omega t + 120^\circ - \theta)$$

# Wye - Wye Connection




- The neutral current in Figure is given by
- In terms of phasors, this is

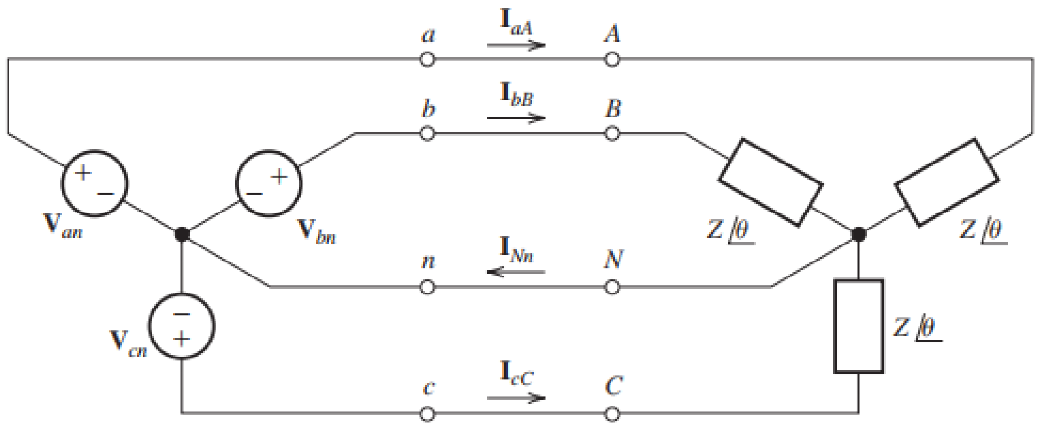
$$i_{Nn}(t) = i_{aA}(t) + i_{bB}(t) + i_{cC}(t)$$

$$\begin{aligned}
\mathbf{I}_{Nn} &= \mathbf{I}_{aA} + \mathbf{I}_{bB} + \mathbf{I}_{cC} \\
&= I_L \angle -\theta + I_L \angle -120^\circ - \theta + I_L \angle 120^\circ - \theta \\
&= I_L \angle -\theta \times (1 + 1 \angle -120^\circ + 1 \angle 120^\circ) \\
&= I_L \angle -\theta \times (1 - 0.5 - j0.866 - 0.5 + j0.866) \\
&= 0
\end{aligned}$$

- Thus, the neutral current is zero in a balanced three-phase system.

# Line-to-Line Voltages

- The voltages between terminals a, b, or c and the neutral point n are called line-to-neutral voltages **/ phase voltages**.
- On the other hand, voltages between a and b, b and c, or a and c are called line-to-line voltages or, more simply, **line voltages.**
- Thus $V_{an}$, $V_{bn}$, and $V_{cn}$ are line-to-neutral voltages (phase voltages, whereas $V_{ab}$, $V_{bc}$, and $V_{ca}$ are line-to-line voltages **Line voltages**.
- Let us consider the relationships between line-to-line voltages and line-to-neutral voltages.



# Line-to-Line Voltages

- We can obtain the following relationship by applying KVL to Figure:

$$\mathbf{V}_{ab} = \mathbf{V}_{an} - \mathbf{V}_{bn}$$

$$\mathbf{V}_{ab} = V_Y \angle 0^\circ - V_Y \angle -120^\circ$$

$$\mathbf{V}_{ab} = \sqrt{3} V_Y \angle 30^\circ$$

$$V_L = \sqrt{3} V_Y$$

- We denote the magnitude of the line-to-line voltage as $V_L$.

# Line-to-Line Voltages

- Thus, the relationship between the line-to-line voltage $V_{ab}$ and the line-to-neutral voltage $V_{an}$ is

$$\mathbf{V}_{ab} = \mathbf{V}_{an} \times \sqrt{3}\,\angle 30^\circ$$

Similarly, it can be shown that

$$\mathbf{V}_{bc} = \mathbf{V}_{bn} \times \sqrt{3}\,\angle 30^\circ$$

and

$$\mathbf{V}_{ca} = \mathbf{V}_{cn} \times \sqrt{3}\,\angle 30^\circ$$

# Example:
# Analysis of a Wye-Wye System

- A balanced positive-sequence wye-connected 60-Hz three-phase source has line-to neutral voltages of $V_Y = 1000$ V.
- This source is connected to a balanced wye-connected load.
- Each phase of the load consists of a 0.1H inductance in series with a 50Ω resistance.
- Find the line currents, the line-to-line voltages, the power, and the reactive power delivered to the load.

## Three Phase Power

Total Power, $P = 3 \times \text{Power in each phase}$

### Y-System

$$P = 3 \times V_{Ph} I_{Ph} \cos\phi$$

$$V_{Ph} = \frac{V_L}{\sqrt{3}} \qquad I_{Ph} = I_L$$

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

Real Power $P = \sqrt{3} V_L I_L \cos\phi$

Reactive Power, $Q = \sqrt{3} V_L I_L \sin\phi$

Apparent Power, $S = \sqrt{3} V_L I_L = \sqrt{P^2 + Q^2}$

Power Factor $= \cos\phi = \frac{P}{S}$

For balanced condition $\mathbf{I_N} = \mathbf{I_R} + \mathbf{I_Y} + \mathbf{I_B} = 0$

### Δ-System

$$P = 3 \times V_{Ph} I_{Ph} \cos\phi$$

$$V_{Ph} = V_L \qquad I_{Ph} = \frac{I_L}{\sqrt{3}}$$

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

Real Power $P = \sqrt{3} V_L I_L \cos\phi$

Reactive Power, $Q = \sqrt{3} V_L I_L \sin\phi$

Apparent Power, $S = \sqrt{3} V_L I_L = \sqrt{P^2 + Q^2}$

Power Factor $= \cos\phi = \frac{P}{S}$

- Y Connection

Three similar coils each of resistance of 20 Ω and inductance of 0.17 H are connected across a 3 phase, 440 V, 50 Hz supply. Find the line and phase values of the current, real power and apparent power when they are connected in (a) Star and (b) Delta

$$Z_{Ph} = 20 + j53.38\,\Omega$$

STAR

$$V_L = 440 \angle 0^\circ \text{ V}$$

$$V_{Ph} = \frac{440}{\sqrt{3}} \angle -30 = 254.04 \angle -30^\circ \text{ V}$$

$$I_L = I_{Ph} = \frac{V_{Ph}}{Z_{Ph}} = \frac{254.04 \angle -30^\circ}{20 + j53.38}$$

$$I_{L_1} = I_{Ph_1} = 4.45 \angle -99.46 \text{ A}$$

$$I_{L_2} = I_{Ph_2} = 4.45 \angle -219.46^\circ \text{ A}$$

$$I_{L_3} = I_{Ph_3} = 4.45 \angle 30.54^\circ \text{ A}$$

DELTA

$$V_L = V_{Ph} = 440 \angle 0^\circ \text{ V}$$

$$I_{Ph_1} = \frac{440 \angle 0^\circ}{20 + j53.38} = 7.72 \angle -69.4$$

$$I_{Ph_2} = 7.72 \angle -189.44^\circ \text{ A}$$

$$I_{Ph_3} = 7.72 \angle 50.44^\circ \text{ A}$$

$$I_{L_1} = 4.45 \angle -39.44^\circ \text{ A}$$

$$I_{L_2} = 4.45 \angle -159.44^\circ \text{ A}$$

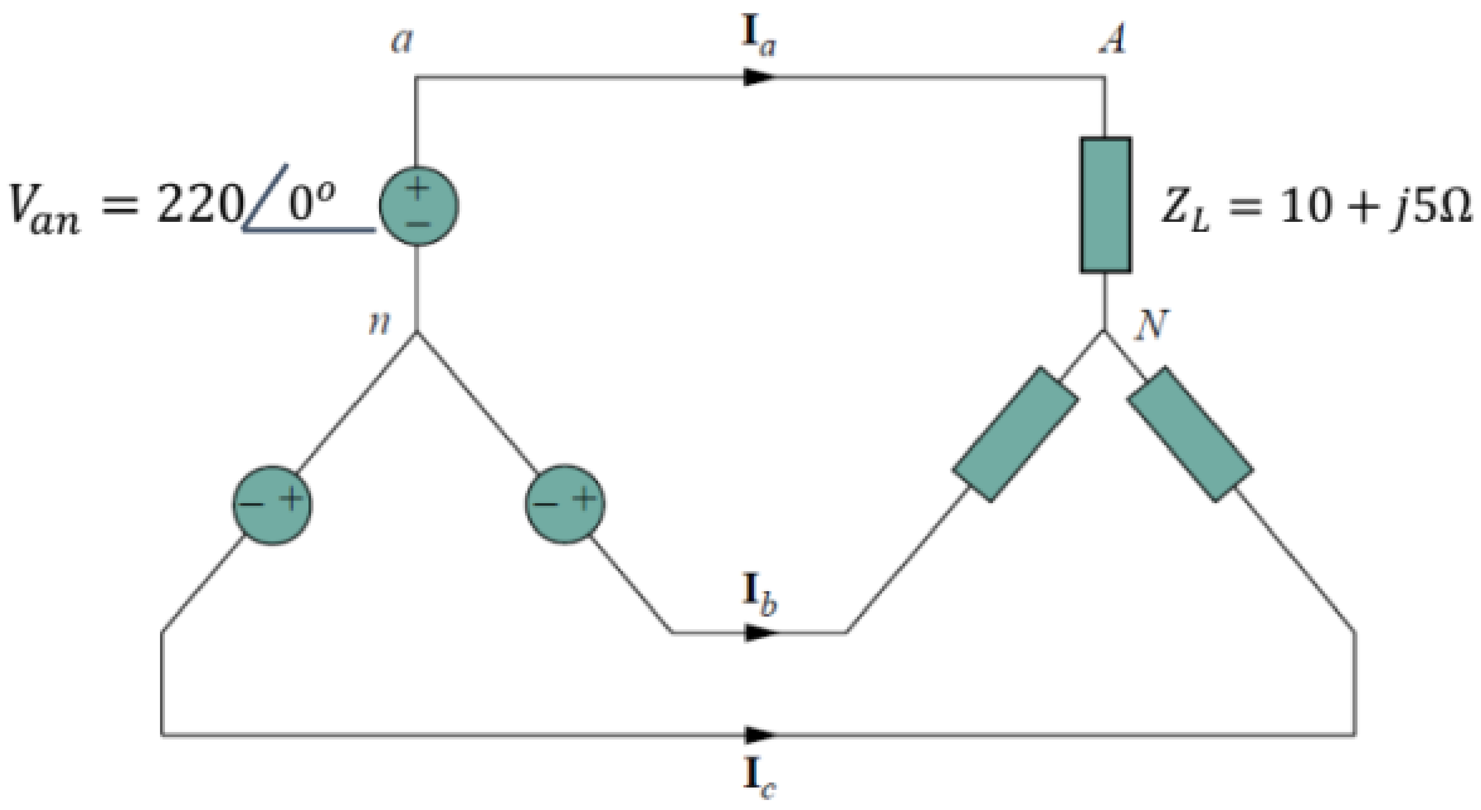
$$I_{L_3} = 4.45 \angle 81.44^\circ \text{ A}$$

A Y-connected balanced 3-phase generator load with the phase voltage of 220 V is connected to a balanced Y-connected load with an impedance per phase of 10+j5 Ω. Calculate the (i) line voltages, (ii) phase currents, (iii) line currents and (iv) complex power at the source and load.

**One line voltage of a balanced Y-connected source is $180\angle -20^{o}$ . If the source is connected to a balanced Δ-connected load of $20\angle 40^{o}$ . Calculate the (i) phase voltages, (ii) phase currents, (ii) line currents and (iii) complex power at the source and load.**

**A balanced Y-connected load with a phase resistance of 40Ω and a reactance of 25Ω is supplied by a balanced Δ-connected source with a line voltage of 210 V. Calculate the (i) phase voltages, (ii) phase currents, (ii) line currents and (iii) complex power at the source and load.**

- A Y-connected balanced 3-phase generator load with the phase voltage of 220 V is connected to a balanced Y-connected load with an impedance per phase of 10+j5 Ω. Calculate the (i) line voltages, (ii) phase currents, (iii) line currents and (iv) complex power at the source and load.



**At Source (Y)**

**Given**

$$V_P = 220\angle 0^o \text{ V}$$

**Relationship between phase and line, voltage and current in Y connection**

$$\boxed{\begin{aligned} V_L &= \sqrt{3}V_P\angle 30^o \\ I_L &= I_P \end{aligned}}$$

**(i) line voltage**

$$V_L = \sqrt{3}(220)\angle 0^o \angle 30^o$$

$$V_L = 381.05\angle 30^o \text{ V}$$

**At Load (Y)**

**Given**

$$Z = 10 + j5\,\Omega$$

**Relationship between phase and line, voltage and current in Y connection**

$$\boxed{\begin{aligned} V_L &= \sqrt{3}V_P\angle 30^o \\ I_L &= I_P \end{aligned}}$$

**(i) line voltage**

**Line voltage of load is equal to line voltage of the source**

$V_{AB} = V_{ab}$ $\quad V_L = 381.05\lfloor 30^o$ V

**(ii) Phase current**

$$I_P = \frac{V_P}{Z_L} = \frac{220}{10 + j5\Omega} = \frac{220}{11.18\lfloor 26.56}$$

$$= 19.678\lfloor -26.56 \text{ A}$$

At Source (Y)

**(iii) line current**

**Line current of source is equal to line current of the load**

$$I_L = 19.678\lfloor -26.56 \text{ A}$$

**(ii) Phase current**

$$I_L = I_P = 19.678\lfloor -26.56 \text{ A}$$

**(iii) Complex power**

$$S = -(P + jQ)$$

$$S = -(3V_P I_P \cos(\theta_V - \theta_i) + j3V_P I_P \sin(\theta_V - \theta_i))$$

$$= -\big(3(220)(19.678)\cos(0^o + 26.56^o) +$$
$$j3(220)(19.678)\sin(0^o + 26.56^o)\big)$$

$$S = -(11616.86 + j5807.15) \text{ VA}$$

**Source power should be negative**

At Load (Y)

**(iii) line current**

$$I_L = I_P = 19.678\lfloor -26.56 \text{ A}$$

**(iii) Complex power**

$$S = P + jQ$$

$$S = 3V_P I_P \cos(\theta_V - \theta_i) + j3V_P I_P \sin(\theta_V - \theta_i)$$

$$= 3(220)(19.678)\cos(0^o + 26.56^o) +$$
$$j3(220)(19.678)\sin(0^o + 26.56^o)$$

$$S = 11616.86 + j5807.15 \text{ VA}$$

**Load power should be positive**

Calculate the line currents for the circuit given in Fig. 1. Hence, calculate the average power across the load in each phase.

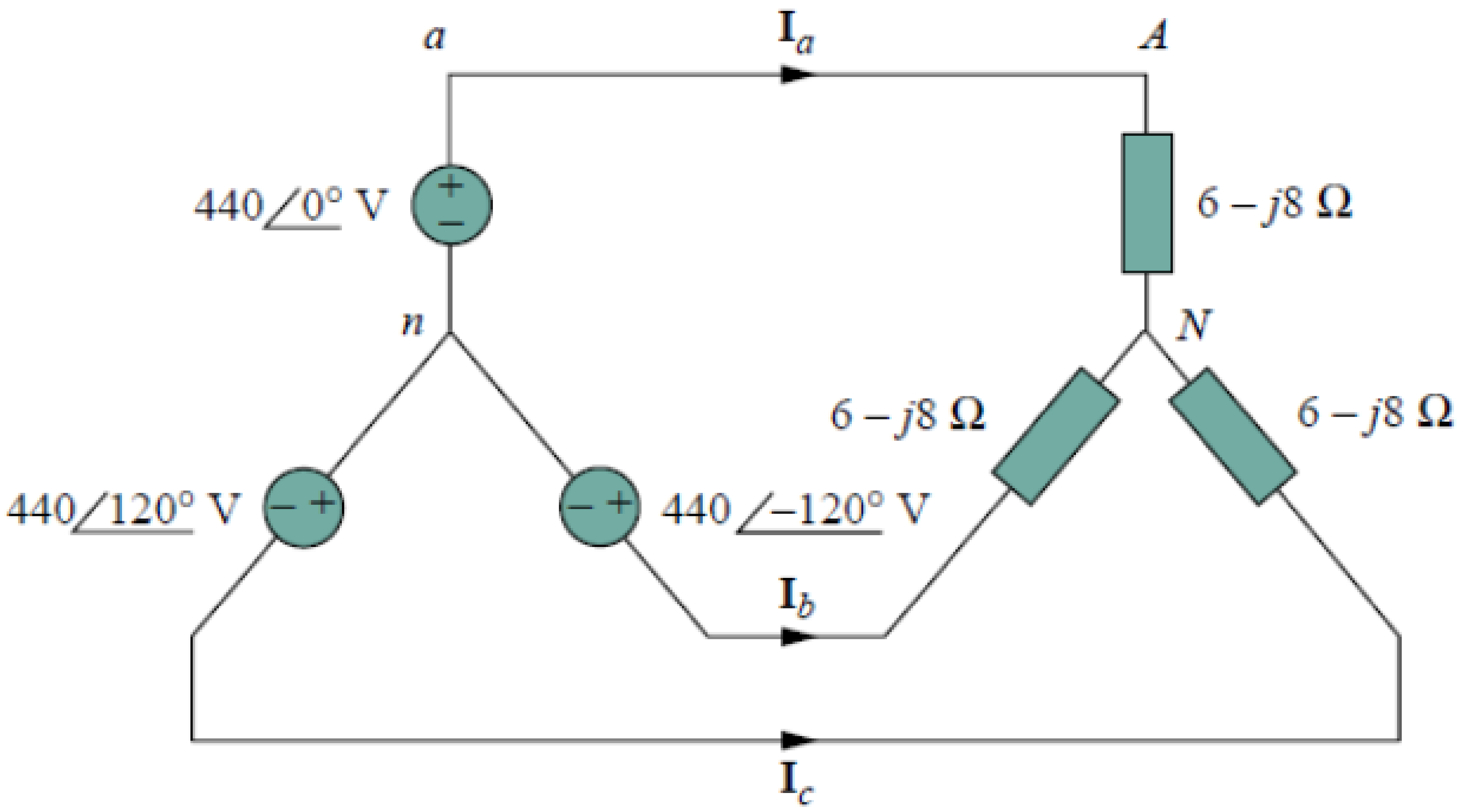



**Fig. 1**

This is a balanced Y-Y system.


Using the per-phase circuit shown above,

$$\mathbf{I}_a = \frac{440\angle 0°}{6 - j8} = \underline{44\angle 53.13°\ \mathrm{A}}$$

$$\mathbf{I}_b = \mathbf{I}_a\angle -120° = \underline{44\angle -66.87°\ \mathrm{A}}$$

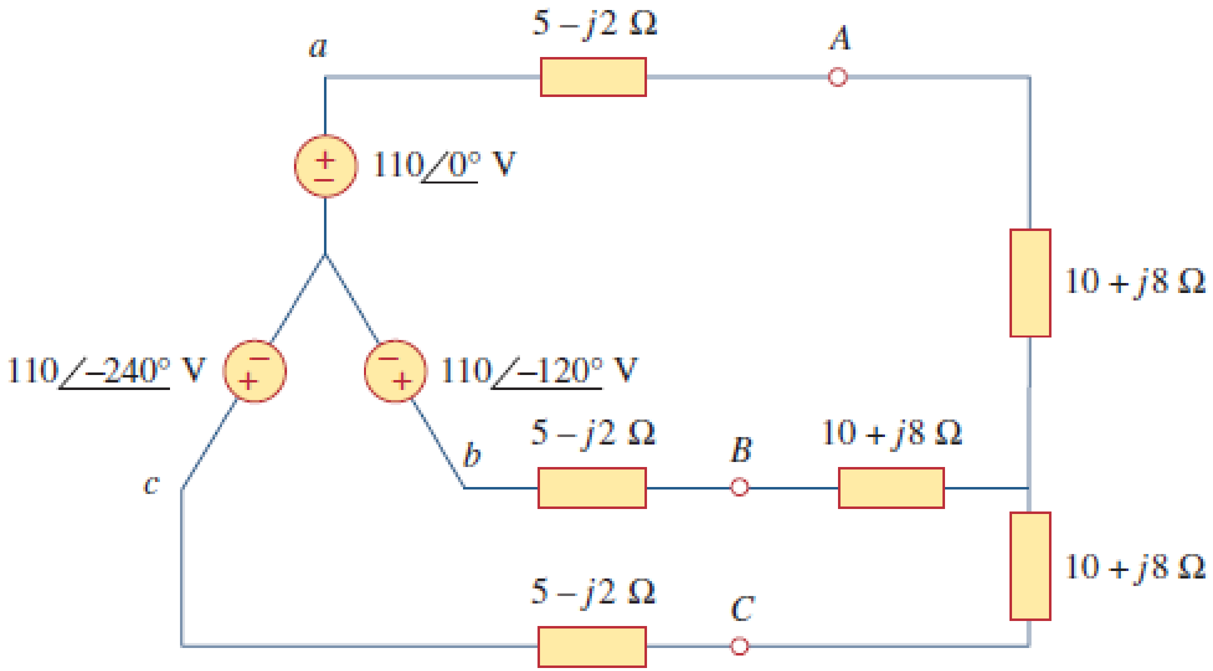
$$\mathbf{I}_c = \mathbf{I}_a\angle 120° = \underline{44\angle 173.13°\ \mathrm{A}}$$

Average power calculations:

Pa = Pb = Pc = 11.616kW

Pavg = 11.616kW X 3 = 34.85kW

# EXAMPLE




$$\mathbf{I}_a = \frac{\mathbf{V}_{an}}{\mathbf{Z}_Y}$$

where $\mathbf{Z}_Y = (5 - j2) + (10 + j8) = 15 + j6 = 16.155\angle 21.8^\circ$. Hence,

$$\mathbf{I}_a = \frac{110\angle 0^\circ}{16.155\angle 21.8^\circ} = 6.81\angle -21.8^\circ \text{ A}$$

A balanced delta-connected load has a phase current $I_{AC} = 10\angle 30°$ A.
(a) Determine the three line currents assuming that the circuit operates in the positive phase sequence.
(b) Calculate the load impedance if the line voltage is $V_{AB} = 110\angle 0°$ V

(a) $\mathbf{I}_{CA} = -\mathbf{I}_{AC} = 10\angle(-30° + 180°) = 10\angle 150°$

This implies that

$$\mathbf{I}_{AB} = 10\angle 30°$$

$$\mathbf{I}_{BC} = 10\angle -90°$$

$$\mathbf{I}_a = \mathbf{I}_{AB}\sqrt{3}\angle -30° = \underline{\mathbf{17.32\angle 0°\ A}}$$

$$\mathbf{I}_b = \underline{\mathbf{17.32\angle -120°\ A}}$$

$$\mathbf{I}_c = \underline{\mathbf{17.32\angle 120°\ A}}$$

(b) $\mathbf{Z}_\Delta = \dfrac{\mathbf{V}_{AB}}{\mathbf{I}_{AB}} = \dfrac{110\angle 0°}{10\angle 30°} = \underline{\mathbf{11\angle -30°\ \Omega}}$