# ELEMENTS OF ELECTRICAL ENGINEERING

(22215)

## CHAPTER-3 Polyphase AC circuits - 10 M

CO3: Use three phase AC supply for industrial equipments and machines

By SAROJ DESAI

# Content

| | | |
|---|---|---|
| **Unit– III Polyphase AC Circuits** | 3a. Describe the salient features of the given type of AC power supply.<br>3b. Explain the concept of symmetrical system and phase sequence of the given AC supply.<br>3c. Distinguish the characteristics of the given type(s) of star (or delta) connections with sketches.<br>3d. Calculate the current and power of the given three phase | 3.1 3 phase system over 1 phase system<br>3.2 3-phase emf generation and its wave form<br>3.3 Phase sequence and balanced and unbalanced load<br>3.4 Phase and line current, phase and line voltage in star connected and delta connected balanced system<br>3.5 Current, power, power factor in a 3 phase balanced system.<br>3.6 Star and delta connections |

# PREREQUISITE: Generation of AC Wave

- **If a conductor is forcefully brought under a magnetic field, there will be an induced current in that conductor. The direction of this force can be found using Fleming’s Right Hand Rule.**
- **The magnitude of emf induced. is proportional to the component of the velocity in a direction perpendicular to the direction of the magnetic field and induced emf is given by**

  **e= BlvsinΘ volts**

- $$v = V_m \mathrm{Sin}\omega t\,.$$

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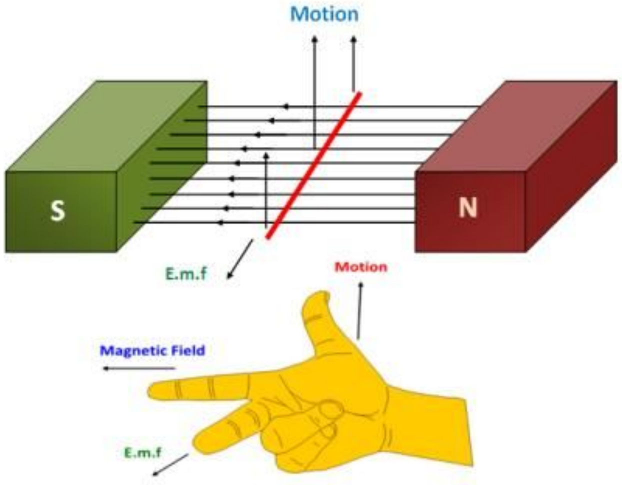
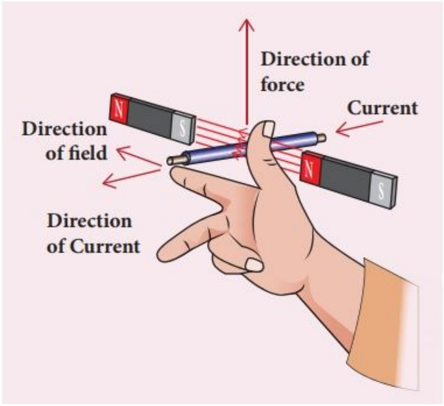
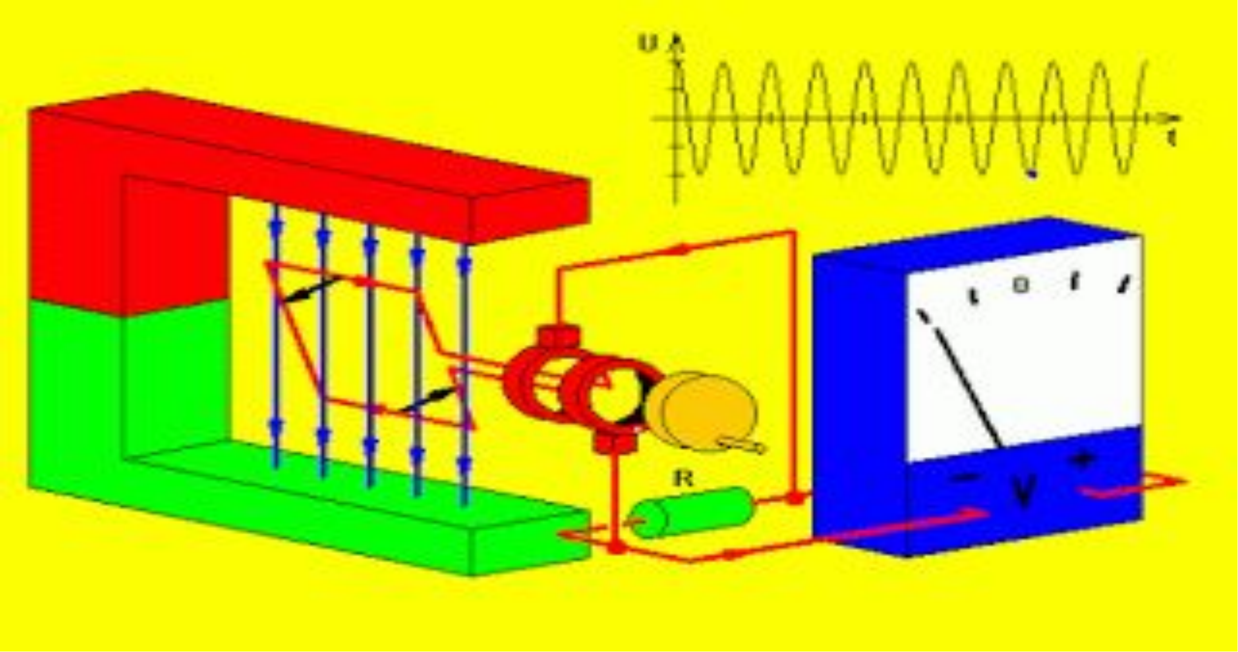


# DYNAMICALLY INDUCED EMF



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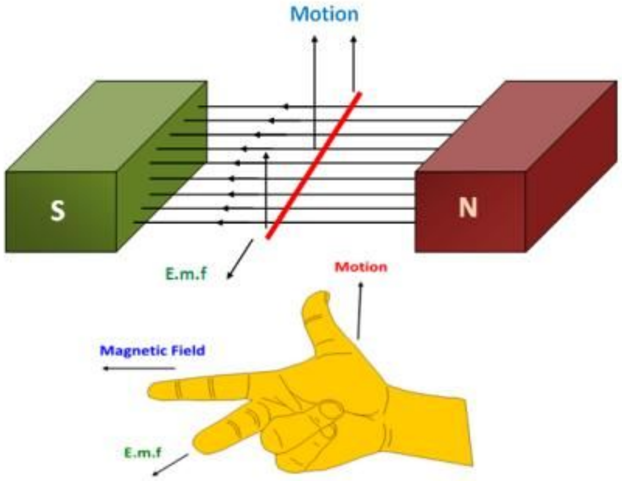
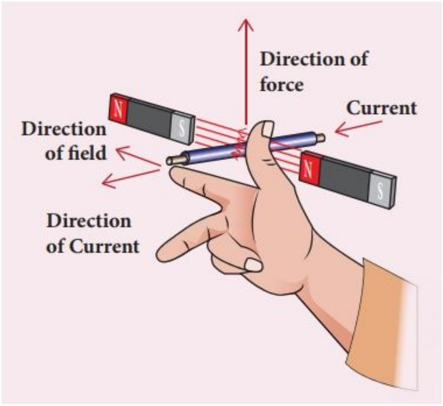
- **The magnitude of emf induced. is proportional to the component of the velocity in a direction perpendicular to the direction of the magnetic field and induced emf is given by**

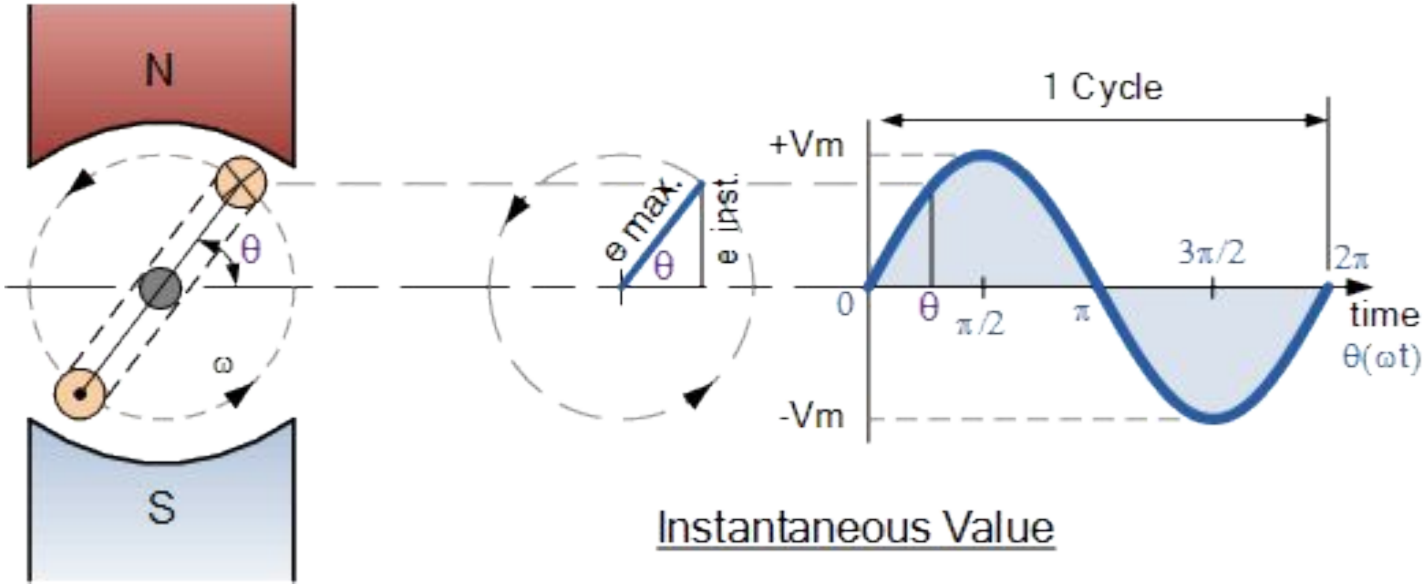
$$e = Blv\sin\Theta \text{ volts}$$

- $$v = V_m \text{Sin}\omega t\,.$$



# Single phase -AC generation



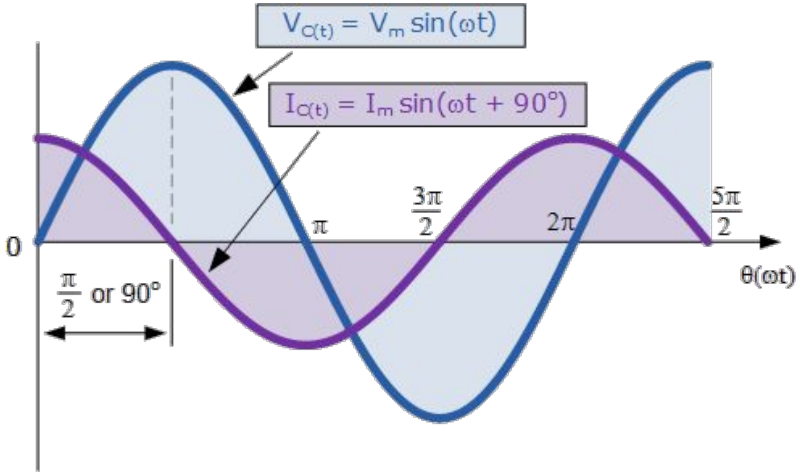
# PREREQUISITE: Phase of the AC signal

- Equation of AC voltage is

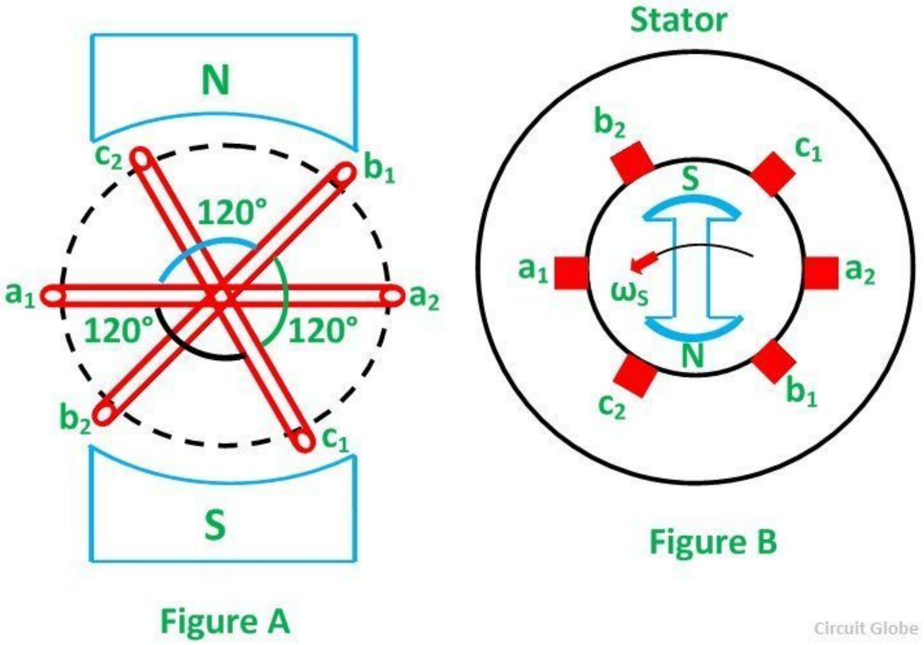
  $v = V_m \sin\omega t$

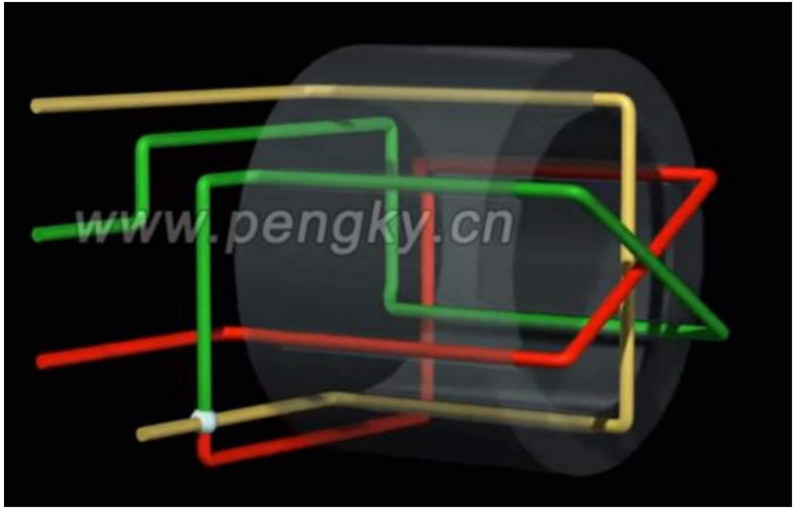
  $i = I_m \sin(\omega t + 90°)$

Thus phase of voltage is 0° and phase of current is 90°



# Three phase -AC generation

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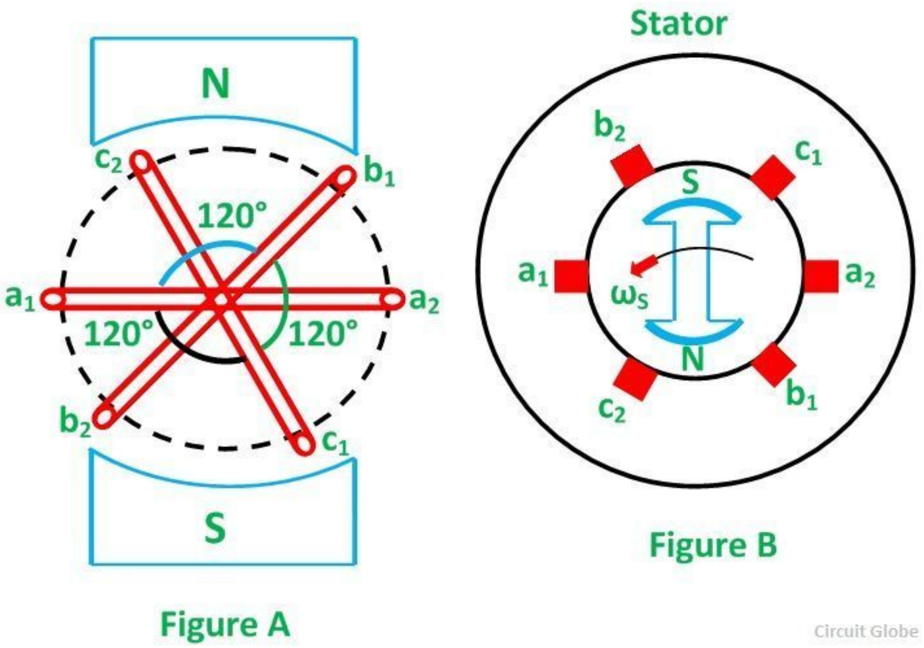
# Three phase -AC generation




- The system which has three phases, i.e., the current will pass through the three wires, and there will be one neutral wire for passing the fault current to the earth is known as the three phase system
- The system which uses three wires for generation, transmission and distribution is known as the three phase system.

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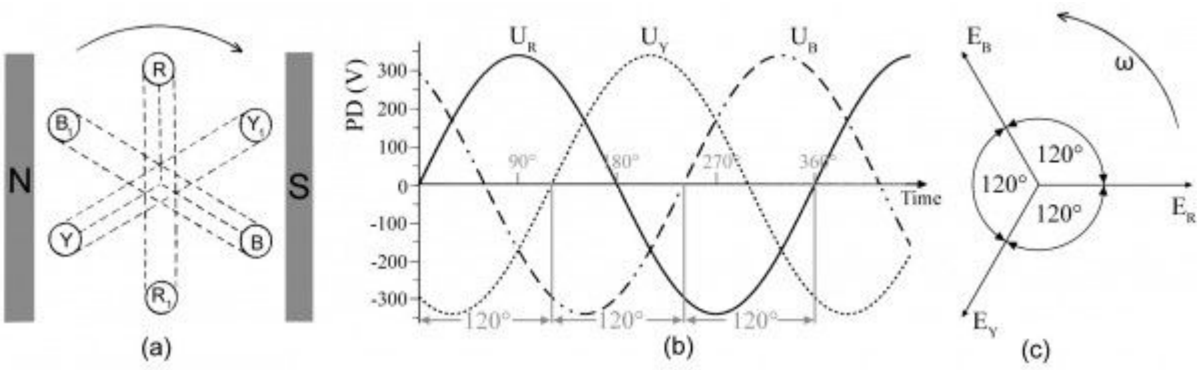
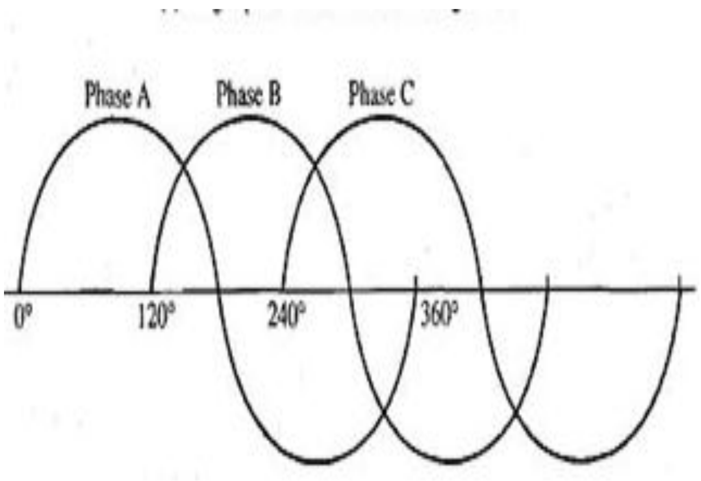
# Three phase -AC generation




- Phase Sequence : The order in which the voltages in three phase reach their maximum positive values is called phase sequence.
- Phase sequence is R-Y-B
- Balanced Load- in three phase system irrespective of star or delta connection , if all phases impedances are exactly identical with respect to magnitude and their nature , it is called balanced load.

# Three phase -AC generation




$v_{Ai} = V_{Amax} \sin\omega t$

$v_{Bi} = V_{Bmax} \sin(\omega t\text{-}120)$

$v_{Ci} = V_{Cmax} \sin(\omega t\text{-}240)$

**Balanced system: A three phase system is said to be balanced when**

i. The e.m.f for three phases are equal and phase displaced by $120^0$ electrical degrees

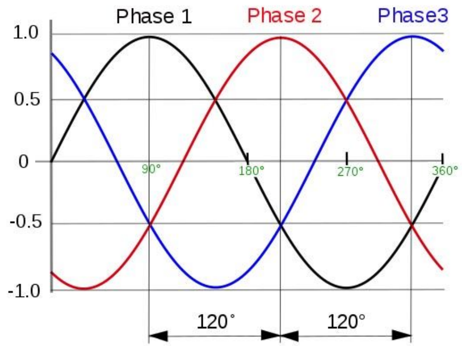
ii. All phases impedances are exactly identical with respect to magnitude and their nature

iii .The resulting current is all phases are equal and have same phase angles

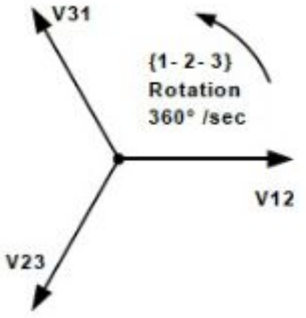
iv. Equal power and reactive power flow in each phase.

# Three phase -AC generation - terminology

The three-phase loads may be balanced or unbalanced as discussed above.




Balance Load: If the three loads Z1, Z2 and Z3 have the same magnitude and phase angle, then the 3 phase load is said to be a balanced load. Under such connections, all the phase or line currents and all the phase or line voltages are equal in magnitude.




Phase Sequence: In a three-phase system, the order in which the voltages attain their maximum positive value is called Phase Sequence. There are three voltages or EMFs in the three-phase system with the same magnitude, but the frequency is displaced by an angle of 120 deg electrically.

# Advantages of Three phase system over single phase system

## 3ϕ system

1. Three phase system is much cheaper than single phase with respect to power generation,transmission and distribution.
2. Three phase system is compact and comparatively smaller
3. Power generation cost is less as compare to single phase system
4. Copper loss and eddy current losses are less

Figure (B)

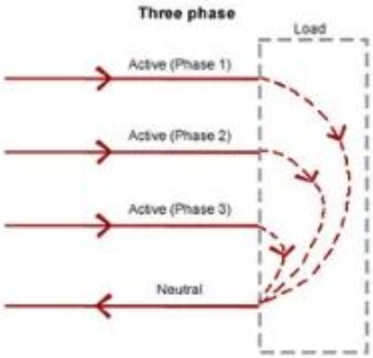
## 1ϕ system

1. single phase system is much costlier than Three phase with respect to power generation,transmission and distribution.
2. Single phase system is comparatively bulky.
3. Power generation cost is less as compare to single phase system
4. Copper loss and eddy current losses are less

Figure (A)

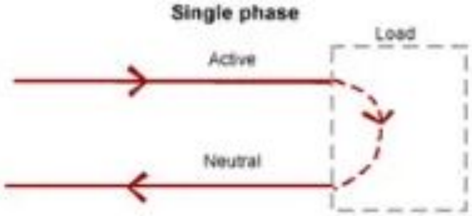
# Advantages of Three phase system over single phase system

**3ϕ system**




**1ϕ system**

1.



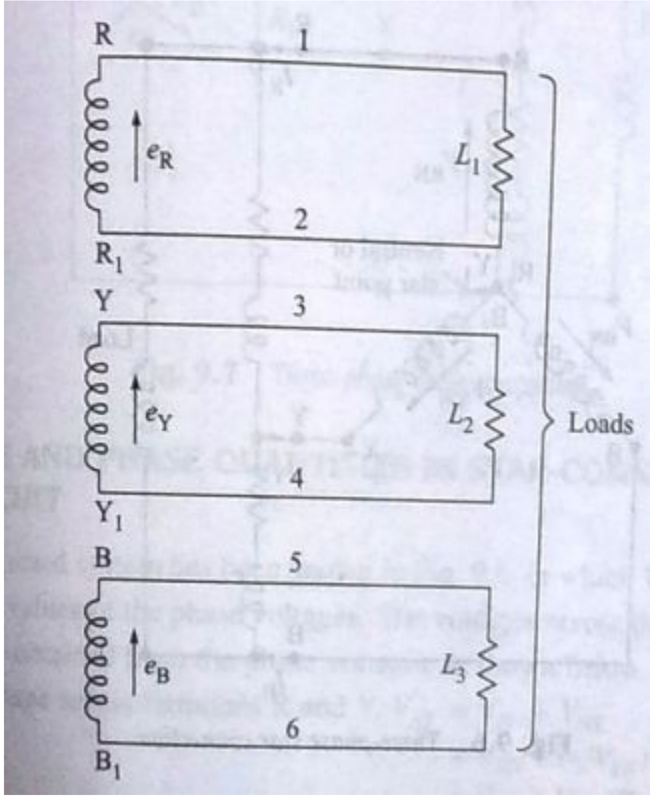
# Connection of **3ϕ system**

The three phases are connected to different load as shown in figure.

In this case it requires 6 WIRES to connect 3 loads.

To reduce the conductors so as to reduce copper usage, there are 2 types of connections specially used

1. STAR (Y) Connection
2. DELTA(**Δ**) Connection



# Connection of **3ϕ system**

**Line Voltage:** In a three-phase power system, The potential difference between the two phases is called line voltage (typically phase to phase). It is denoted by $V_L$. The voltage between R to Y or Y to B or B to R.

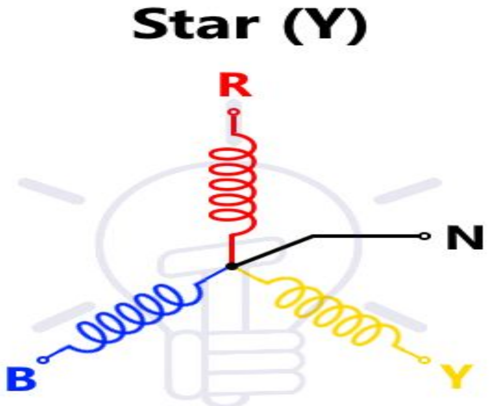
**Phase voltage :** In three phase system, the potential difference across the conductor is called phase voltage. It is denoted by $V_{ph}$ volts

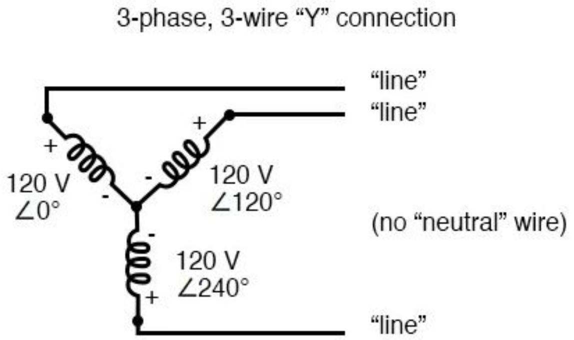
**Line current:** In a three-phase power system, The supply current measure between the two phases is called line current. It is denoted by $I_L$ volts

**Phase current:** Phase current is the measure of the current through phase of the three phase system. It is denoted by $I_{ph}$.

# Connection of **3ϕ system-** STAR (Y) Connection

1. In STAR Connection, the starting or finishing ends (similar ends) of three coils are connected together to form the neutral point. A common wire is taken out from the neutral point which is called Neutral.



# Connection of **3ϕ system-** STAR (Y) Connection

**Line Voltage:** $E_L = V_{RY} = V_{YB} = V_{BR}$

**Phase voltage :** $E_{ph} = V_{RN} = V_{YN} = V_{BN}$

**Line current :** $I_L = I_R = I_Y = I_B$

**Phase current** $I_{ph} = I_r = I_y = I_b$

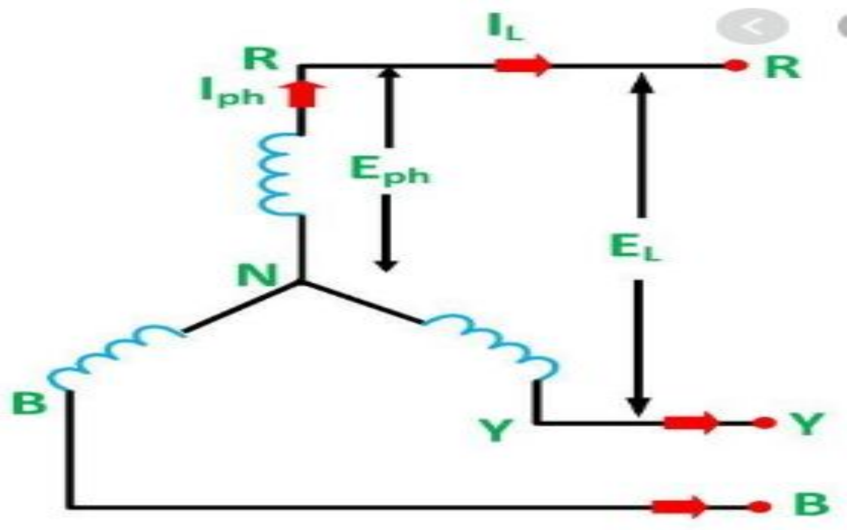
**Line Voltage:** $E_L = V_{RY} = V_{RN} - V_{YN}$

$E_L = V_{YB} = V_{YN} - V_{BN}$

$E_L = V_{BR} = V_{BN} - V_{RN}$

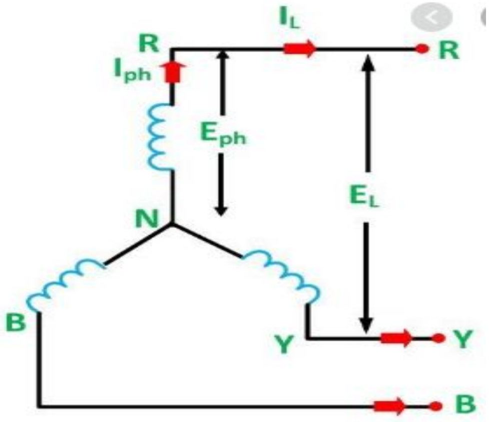
**Line current :** $I_L$ = ***Phase current*** $I_{ph}$ **-----(1)**

$I_R = I_r, I_Y = I_y, I_B = I_b$




LOOP : NRRYYN , Apply KVL,
+VRN-VRY-VYN=0
VRN-VYN=VRY

RELATION BETWEEN $I_L$ AND $I_{ph}$, $V_L$ AND $V_{ph}$ of STAR-**3ϕ sy**




**Line Voltage:** $E_L = \sqrt{3}$ **Eph --------(2)**

$$V_{RY} = \sqrt{3}\, V_{RN}$$

**Line current :** $I_L = I_{ph}$

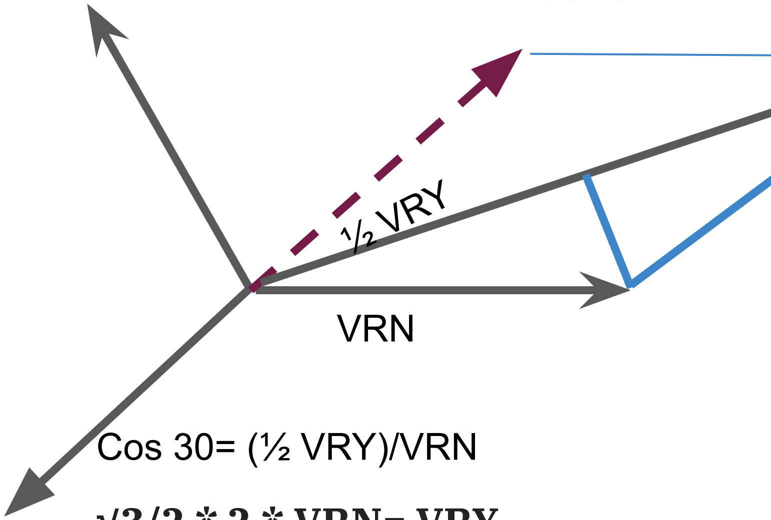
$$I_R = I_r,\ I_Y = I_y,\ I_B = I_b$$

Power consumed in each phase = $V_{ph} I_{ph}\ COS\ \phi$

*In Star connection,* $= 3\ x\ (V_{ph} I_{ph}\ COS\ \phi)$

$$= 3((VL/\sqrt{3})*IL*COS\ \phi)$$

$$= \sqrt{3}\, V_L I_L \,COS\ \phi$$



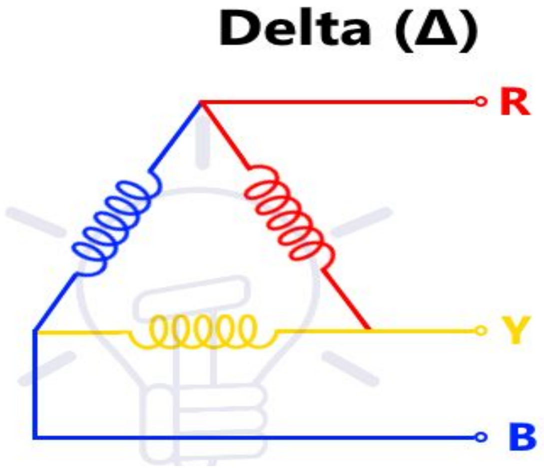

Cos 30= (½ VRY)/VRN

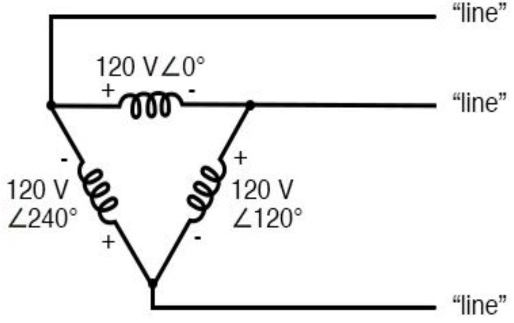
**√3/2 * 2 * VRN= VRY**

**√3VRN= VRY**

# Connection of **3ϕ system-** DELTA(Δ) Connection

In Delta (also denoted by Δ) system of interconnection, the starting ends of the three phases or coils are connected to the finishing ends of the coil.
The starting end of the first coil is connected to the finishing end of the second coil and so on (for all three coils) and it looks like a closed mesh or circuit as shown in fig



# Connection of **3ϕ system-** DELTA(Δ) Connection

**Line Voltage:** $E_L = V_{RY} = V_{YB} = V_{BR}$

**Phase voltage :** $E_{ph} = V_{RY} = V_{YB} = V_{BR}$

**Line current :** $I_L = I_R = I_Y = I_B$

**Phase current** $I_{ph} = I_r = I_y = I_b$

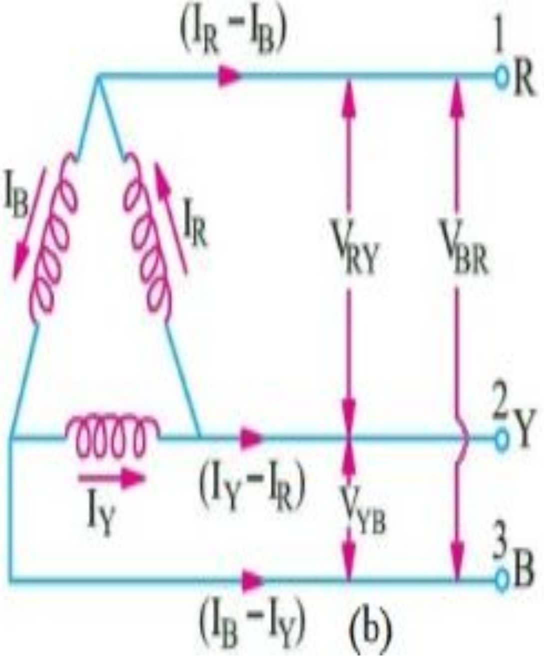
**Line Voltage,** $E_L$ = **Phase voltage.**$E_{ph}$ --------**(3)**

**Line current :** $I_L = DIFFERNCE\ (I_{ph})$

$$I_R = I_r - I_b$$

$$I_Y = I_y - I_r\ ,$$

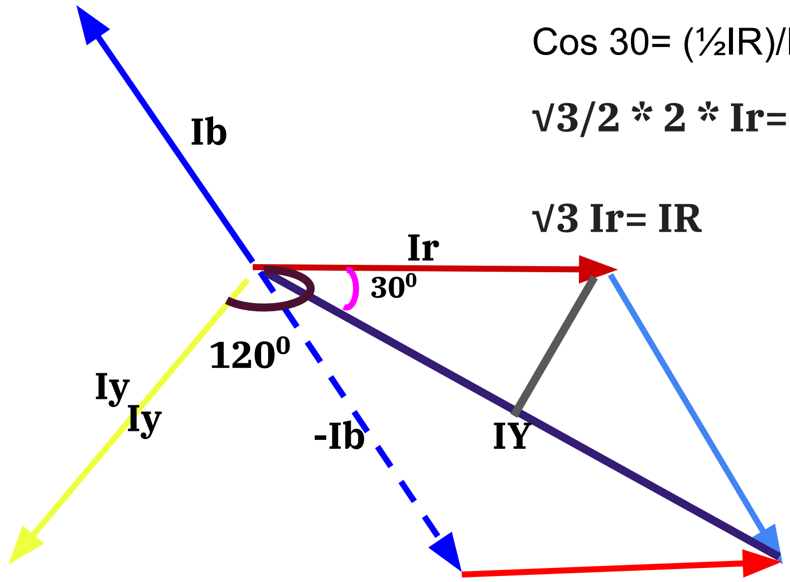
$$I_B = I_b - I_y$$



# RELATION BETWEEN $I_L$ AND $I_{ph}$, $V_L$ AND $V_{ph}$ of DELTA- **3ϕ system**

**Line Voltage= Phase Voltage,** $E_L = E_{ph}$

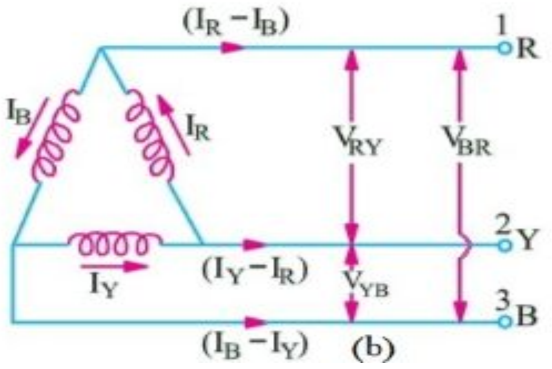
**Line current =√3 Phase Current------(4)**




Cos 30= (½IR)/Ir

**√3/2 * 2 * Ir= IR**

**√3 Ir= IR**




Power consumed in each phase = $V_{ph} I_{ph}$ $COS\ \phi$

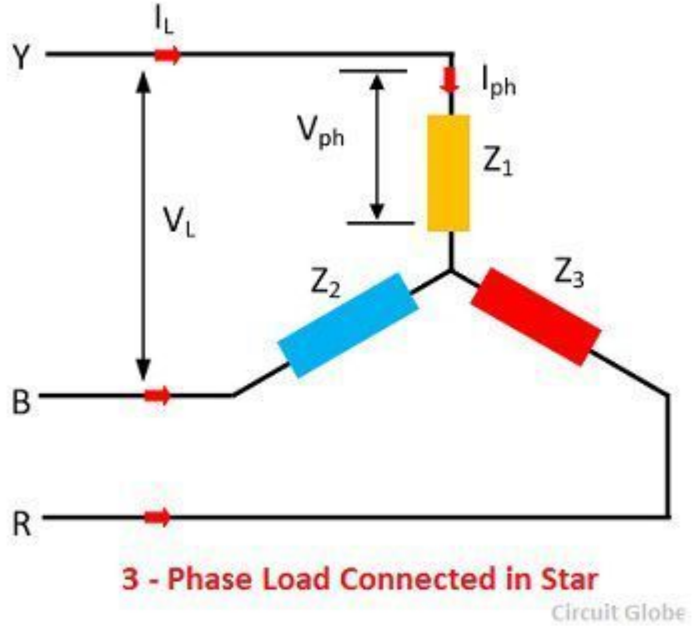
*In Delta connection,* $= 3 x (V_{ph} I_{ph}\ COS\ \phi)$

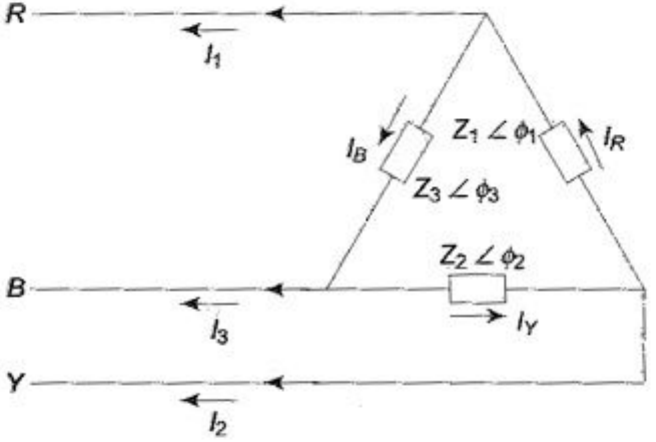
$= 3((VL$ ***(IL/√3)** $*COS\ \phi$**)**

= **√3** $V_L I_L$ COS ϕ **Watts**

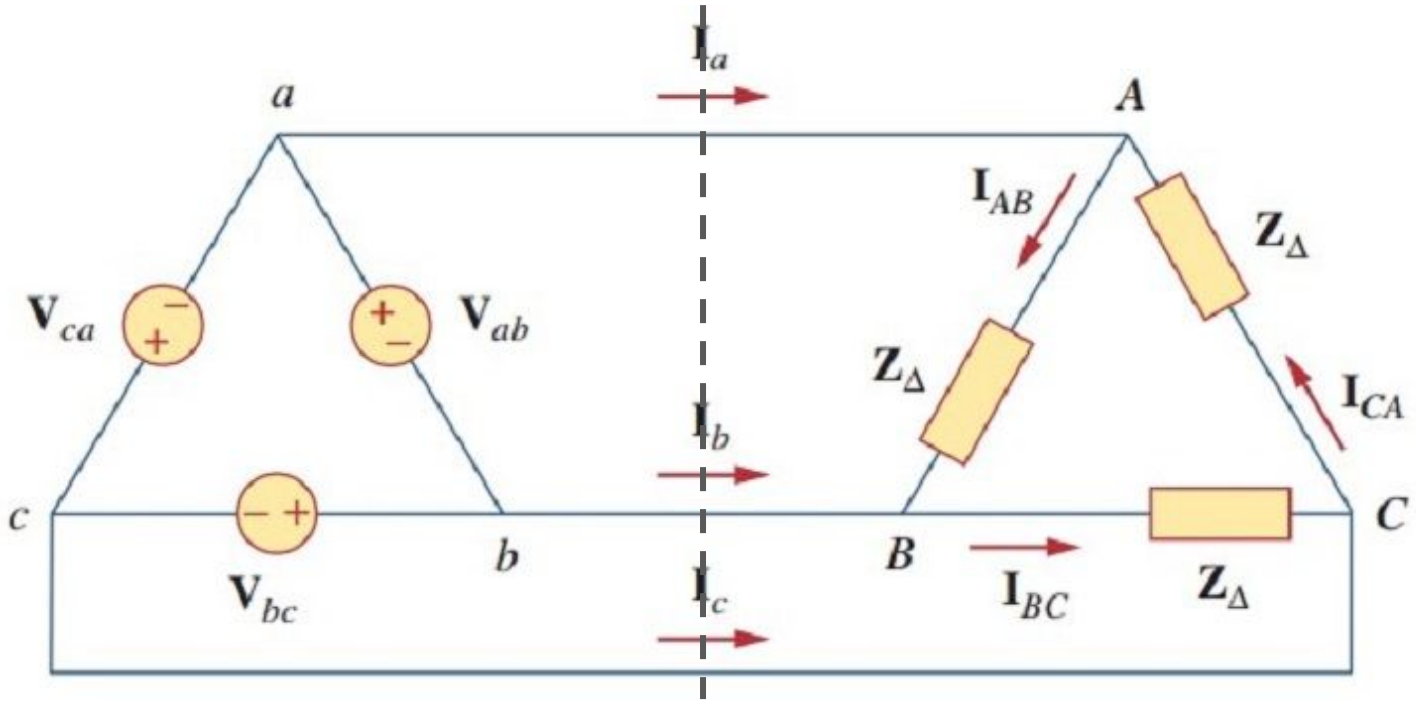
$\mathbf{V=E_b+I_aR_a}$

# Connection of 3ϕ lOAD-STAR AND DELTA(Δ) Connection



# COMBINATION -STAR AND DELTA(Δ) Connection



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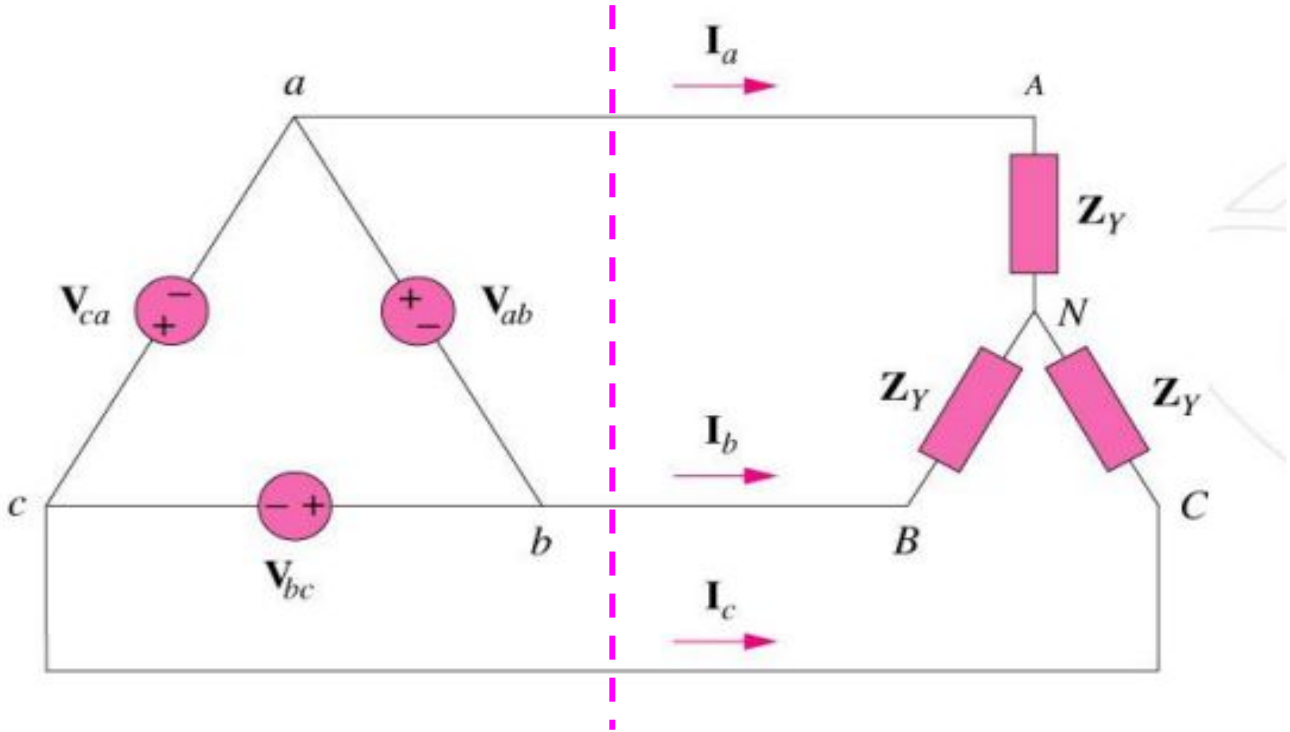

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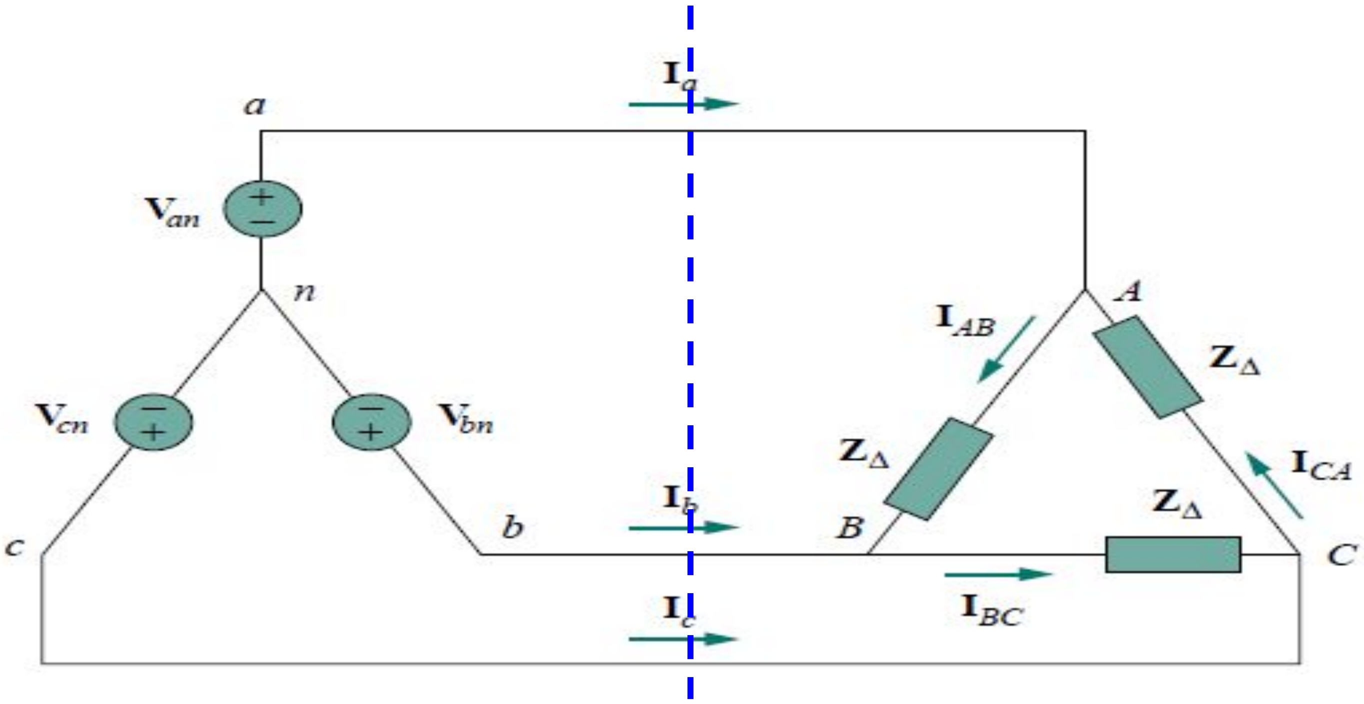
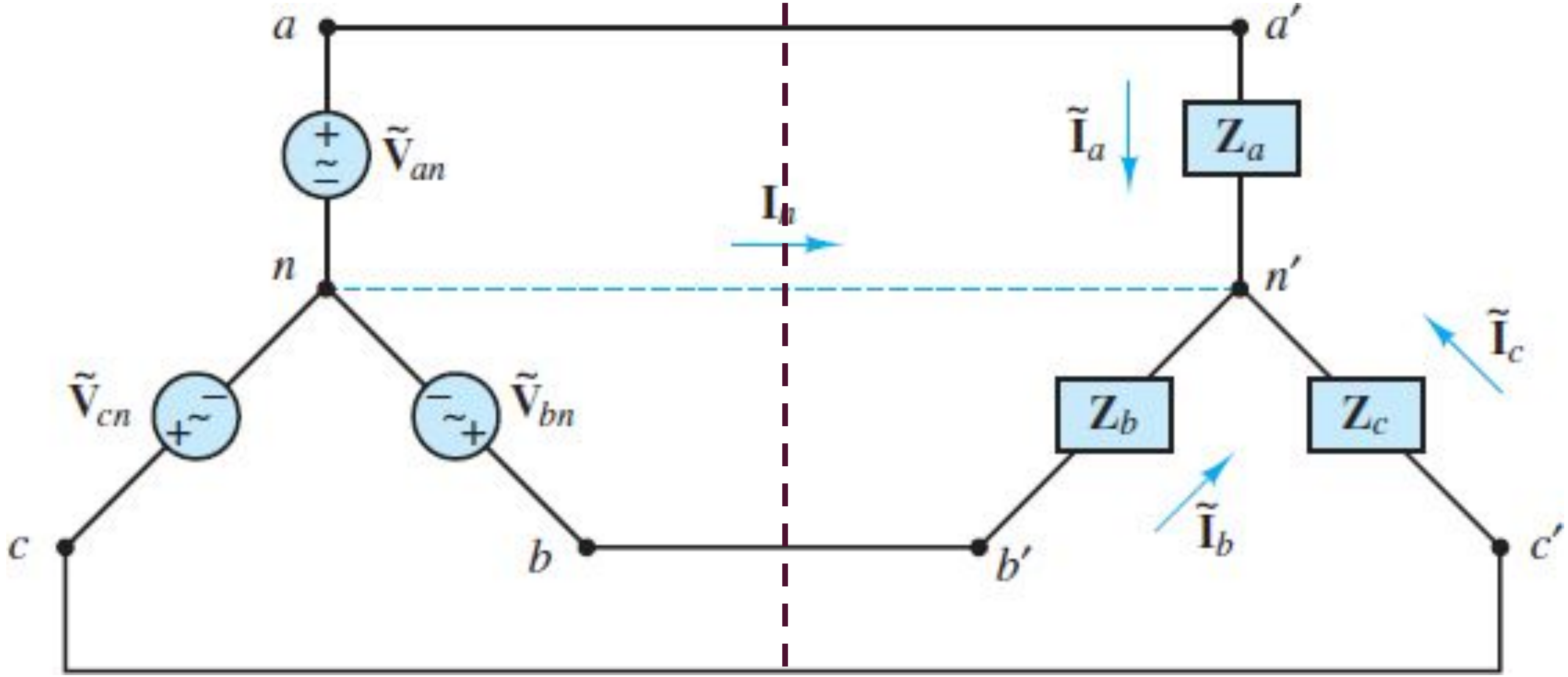
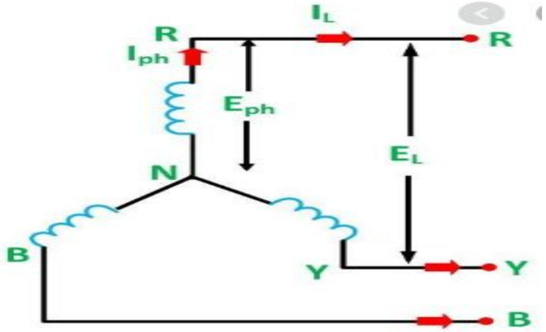
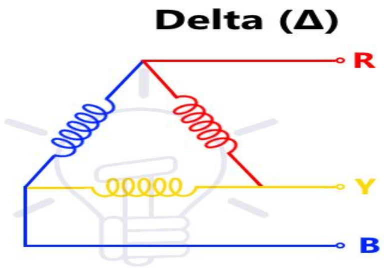




a
a′
$\tilde{\mathbf{V}}_{an}$
$\tilde{\mathbf{I}}_a$
$\mathbf{Z}_a$
$\mathbf{I}_n$
n
n′
$\tilde{\mathbf{V}}_{cn}$
$\tilde{\mathbf{V}}_{bn}$
$\mathbf{Z}_b$
$\mathbf{Z}_c$
$\tilde{\mathbf{I}}_c$
$\tilde{\mathbf{I}}_b$
c
b
b′
c′

# Difference between star and delta connected system




1. The terminals of the three branches are connected to a common point. The network formed is known as **Star Connection**.
2. In a star connection, the starting and the finishing point ends of the three coils are connected together to a common point known as the neutral point.

1. The three branches of the network are connected in such a way that it forms a closed loop known as **Delta Connection**.
2. In Delta connection, there is no neutral point. The end of each coil is connected to the starting point of the other coil

# Difference between star and delta connected system

3. In Star connection, the line current is equal to the Phase current, IL= Iph

4. In Star connection, line voltage is equal to root three times of the Phase Voltage, VL= √3Vph

5. Star Connections are mainly required for the Power Transmission Network for longer distances

6. The amount of Insulation required in Star Connection is low

7. Star Connections are often used in application which require less starting current

3. In Delta Connection the line current is equal to root three times of the Phase Current. Il=√3 Iph

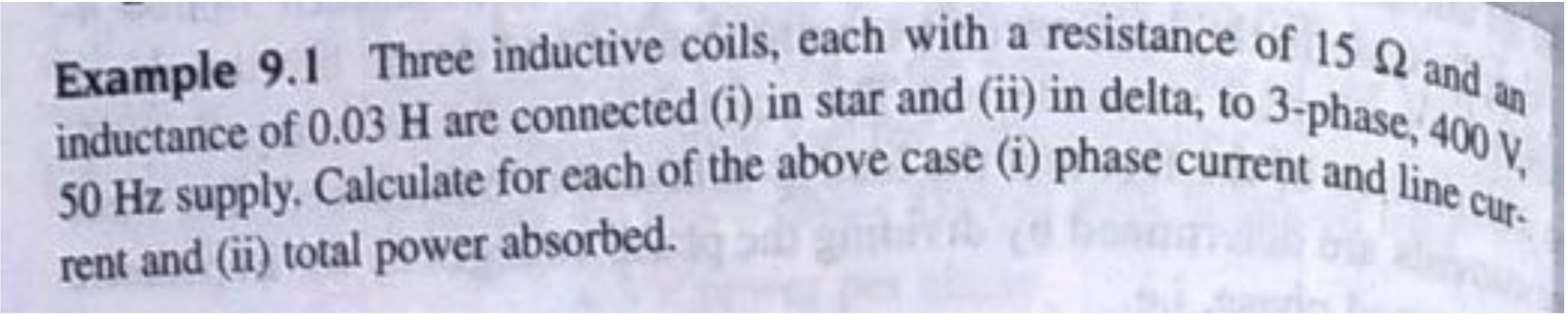
4. In Delta Connection line voltage is equal to the Phase voltage. VL= Vph

5.In Delta connection mainly in Distribution networks and is used for shorter distances.

6. in Delta Connection high insulation level is required.

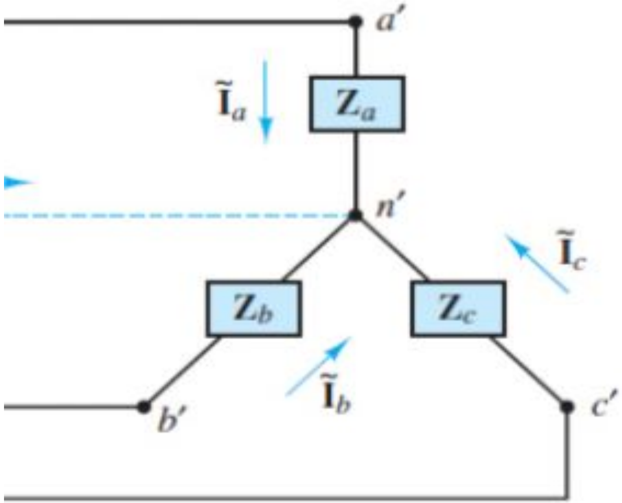
7. Delta Connections are often used in applications which require high starting torque.

# NUMERICALS

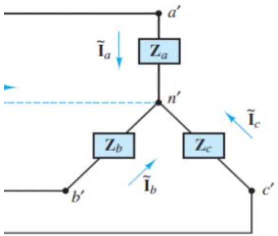


**Example 9.1** Three inductive coils, each with a resistance of 15 Ω and an inductance of 0.03 H are connected (i) in star and (ii) in delta, to 3-phase, 400 V, 50 Hz supply. Calculate for each of the above case (i) phase current and line current and (ii) total power absorbed.

SOLUTION:
gIVEN:
VL= 400v
F=50HZ
R=15 OHMS
L=0.03H
TO FIND OUT:
I) STAR CONNECTION:
IL=?
IPH=?
POWER CONSUMED:



# NUMERICALS




SOLUTION:
gIVEN:
VL= 200v
F=50HZ
R=1O OHMS
L=0.01H
C=0.02 MICROFARAD
TO FIND OUT:
I) STAR CONNECTION:
IL=?
IPH=?
POWER FACTOR:
POWER CONSUMED:

$XL = 2 \times \pi \times f \times L = 3.14\ \Omega$
$XC = 1/(2 \times \pi \times f \times C) = 0.16\ \Omega$
$Z = \sqrt{}\ (R2 + (XL-XC)2 = \sqrt{}\ (100 + 8.88) = 10.43\Omega$
$\cos \Phi = 0.96$

**$VL = \sqrt{3}\ Vph$**
$Vph = VL/\sqrt{3} = 200/\sqrt{3} = 115.47V$
**$Iph = Vph/Z = 115.47 / 10.43 = 11.07\ A$**

**$IL = Iph = 11.07A$**

**Power consumed =** $\sqrt{3}\ VL \times IL \times \cos \Phi$
$= 3681.37$watts

# NUMERICALS

L =75mH
R= 4 ohms      - Delta
If Vph = 220V
Identify 3 phase Supply voltage(VL) , Line current and current drawn by each phase(Iph)
when f= 50 Hz

Solution
As Delta connected load is given
VL= Vph
IL= √3  Iph
1. **Vl= Vph =220V**
Xl=
Z=
2. Iph = Vph/Z
3. IL= √3  Iph

# NUMERICALS

A Series combination of 3Ω resistance and 796.18µF capacitor in each branch forms a three phase star connected balanced load which is connected to a 415V, 3Φ,50Hz , a.c supply.
Calculate: i. Current drawn by each load/phase, ii)Power consumed
Also identify the power consumed by same load when connected in delta connection.
WHich connection consuming more power?

| | |
|---|---|
| As star connected load is given<br>$VL=\sqrt{3}\ Vph$<br>$IL= Iph$<br>fORMULA TO BE USED:<br>$XC=1/(2 \times \Pi \times f \times C)=4\Omega$<br>$Z=\sqrt{(R^2+XC^2)}= 5\Omega$<br>$\Theta=TAN^{-=}(XC/R)= 53.06$<br>POWER FACTOR=$COS\Theta$=0.6<br>Vph= 239.6V<br>Iph= Vph/Z =47.92 A<br>IL= Iph=47.92A<br>POWER CONSUMED =$\sqrt{3} \times VL \times IL \times COS\Theta$<br>= 20666.97 watts<br>= 20.67kWatts | Solution<br>As Delta connected load is given<br>VL= Vph<br>$IL= \sqrt{3}\ Iph$<br><br>VL= Vph= 415V<br>Iph= Vph/Z = 415/5 = 83 A<br>$IL=\sqrt{3} \times 83$ = 143.8 A<br>POWER CONSUMED =$\sqrt{3} \times VL \times IL \times COS\Theta$<br>= 62018.16 watts<br>=62.02kWatt |