3-Φ Circuits

Advantages of three phase systems

1. Three phase apparatus is more efficient than a single phase apparatus.
2. Three phase apparatus costs is less than a single phase apparatus.
3. The size of three phase apparatus is smaller than the size of single phase apparatus.
4. Three phase motors produce uniform torque, whereas torque produced by single phase motor is pulsating.

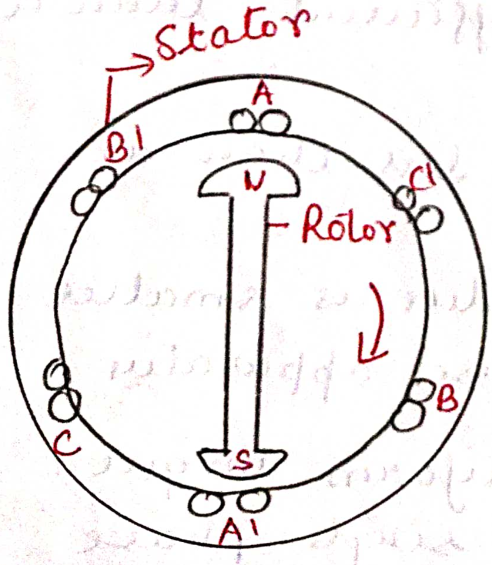
(5) Connection of 1-ϕ generators in parallel gives rise to harmonics while in 3-ϕ generators, no harmonics is produced

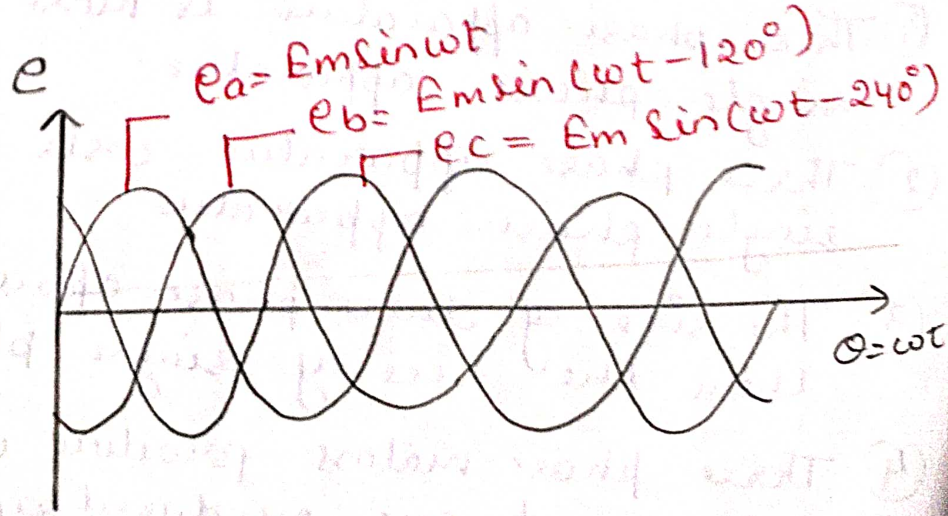
(6) In three phase system, two different voltages can be obtained. one between the lines and other between the line and phase. whereas only one voltage can be obtained in single phase system

(7) Three-phase motors are self-starting where as single phase motors are not self-starting.

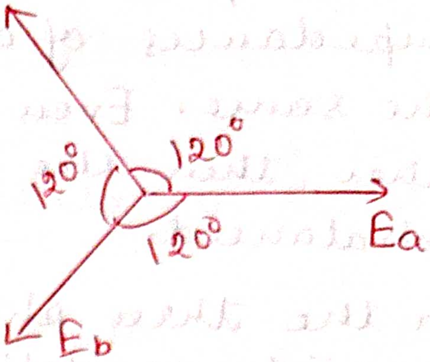
Generation of three phase voltages

AA', BB' and CC' are the three independent coils which are electrically displaced by 120° with respect to one another. When the rotor rotates in the clockwise direction with a particular speed Ns, the flux produced by it sweeps across the stator conductors and hence e.mf are induced in all the three phases, which have a phase displacement of 120° with respect to one another.





The equations for the voltages induced in three windings are



$e_a = E_m \sin \omega t$

$e_b = E_m \sin(\omega t - 120°)$

$e_c = E_m \sin(\omega t - 240°)$

$= E_m \sin(\omega t + 120°)$

from the waveform, at any instant

$e_a + e_b + e_c = 0$

it can be proved

$e_a + e_b + e_c = E_m [\sin \omega t + \sin(\omega t - 120°) + \sin(\omega t + 120°)]$

$e_a + e_b + e_c = E_m [\sin \omega t + \sin \omega t \cos 120° - \cos \omega t \sin 120° + \sin \omega t \cos 120° + \cos \omega t \sin 120°]$

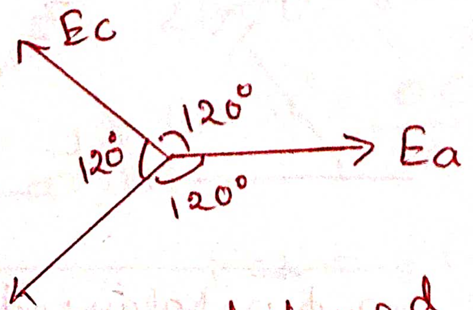
$e_a + e_b + e_c = E_m [\sin \omega t + 2 \sin \omega t \cos 120°]$

$e_a + e_b + e_c = E_m [\sin \omega t + 2 \sin \omega t (-1/2)]$

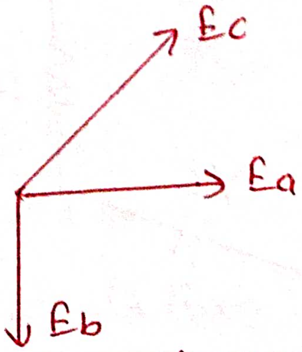
$e_a + e_b + e_c = 0$

Balanced three phase supply

A three phase supply is said to be balanced, when all the three voltages have the same magnitude but differ in phase by 120° with respect to one another. The three phase supply is said to be unbalanced even if one of the above conditions is not satisfied.



(a) balanced supply

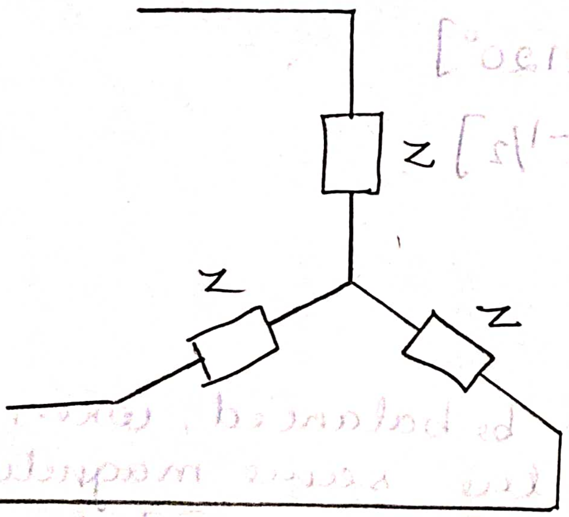


(b) Unbalanced supply.

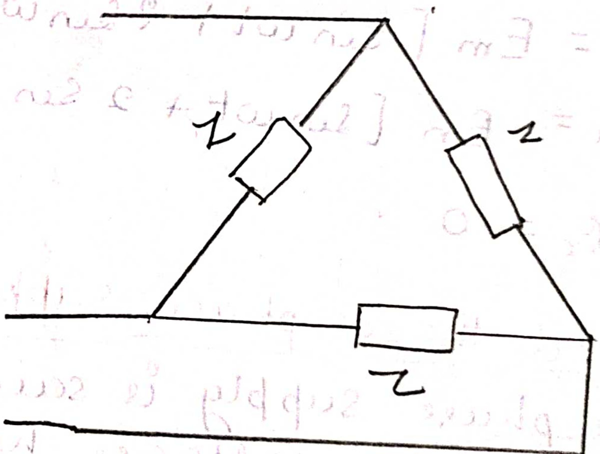
Balanced load

A three phase is said to be balanced, when the impedances of all the three phases are exactly the same. Even if one of them is different from the other, then the three phase load is said to be unbalanced.

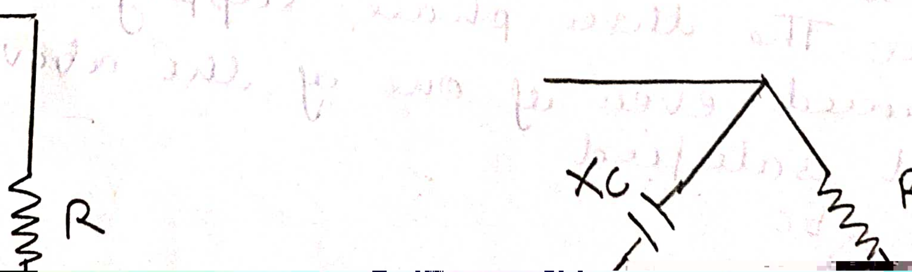
In the three phase balanced load, whether star connected or delta connected, the magnitudes of the phase currents are the same but differ in phase by 120° w.r.t one another, when a three phase supply is given to the load. But in an unbalanced load, when a three phase balanced supply is given, the magnitude and phases of all the three phase currents will be different.



3-ϕ balanced ⅄ Connected



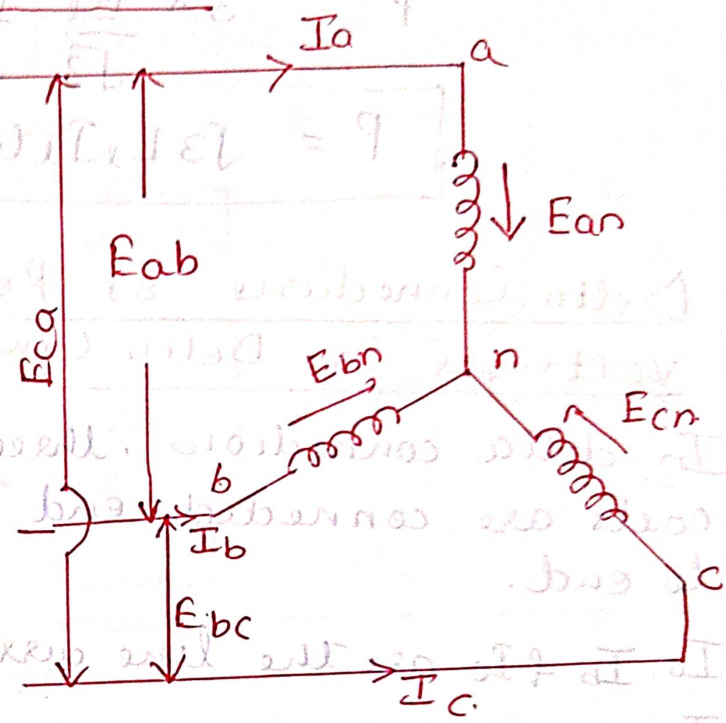
3-ϕ balanced Δ Connected



Three phase connections:
There are two types of three phase connections
(i) Star Connection (Y)
(ii) Delta connection (Δ)

i) Star connection or Relationships between currents and voltages in star connection

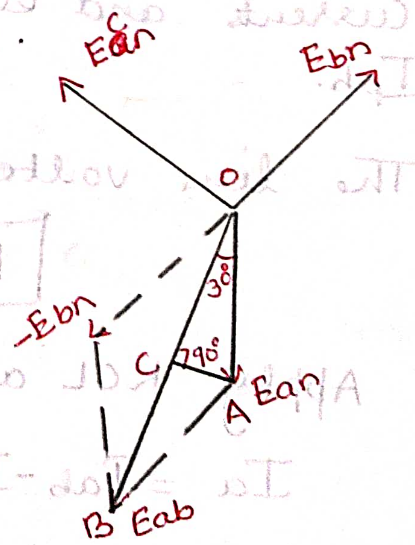
A star is formed, when ends of the three coils are joined together at point n, other three ends are free.



Ean, Ebn & Ecn are phase Voltages & each is equal to Eph.
Eab, Ebc and Eca are the line voltages & each is equal to El.

The current flowing through the line are same as current flowing through phase.

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



line voltag $E_{ab} = E_{an} + E_{nb}$
$= E_{an} - E_{bn}$

Draw perpendicular AC on OB
$\angle AOC = 30°$

$$\cos 30° = \frac{OC}{OA} = \frac{OB/2}{OA} = \frac{E_{ab}}{2E_{an}}$$

$$\therefore E_{ab} = 2E_{an}\cos 30° = \sqrt{3}\,E_{an}$$

$$\boxed{E_l = \sqrt{3}\, E_{ph}}$$

line voltage = $\sqrt{3}$ phase voltage.

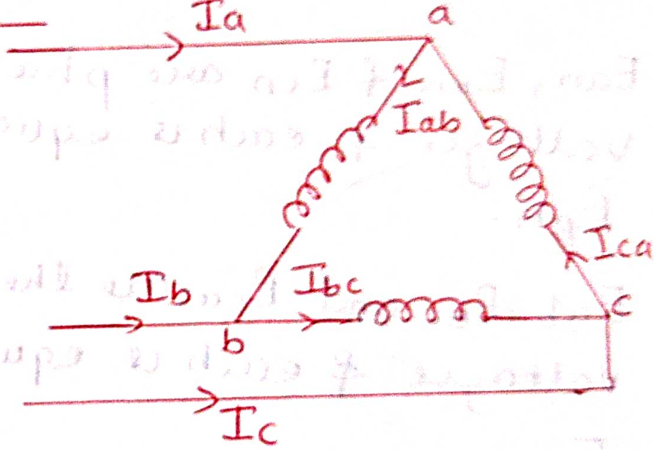
power P = $3 \times$ power in each phase.

$$\boxed{P = 3 \times E_{ph} I_{ph} \cos\phi}$$

$$P = 3 \times \frac{E_l}{\sqrt{3}} I_l \cos\phi$$

$$\boxed{P = \sqrt{3}\, E_l I_l \cos\phi}$$

Delta Connections or Relationships of currents & voltages in Delta Connection



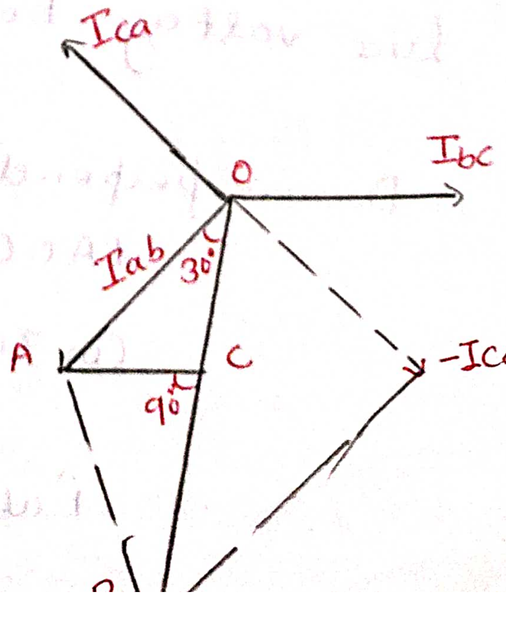
In delta connection, three coils are connected end to end.

I_a, I_b & I_c are the line current I_l

I_{ab}, I_{bc} & I_{ca} are the phase currents and each is equal to I_{ph}.

The line voltage are same as the phase voltages

$$\boxed{E_l = E_{ph}}$$



Apply KCL at point a,

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

Draw AC perpendicular to OB

$\angle AOC = 30°$

$$\cos 30° = \frac{OC}{OA} = \frac{OB/2}{OA} = \frac{I_a/2}{I_{ab}}$$

$\therefore I_a = 2 I_{ab} \cos 30^\circ$

$= 2 I_{ab} \frac{\sqrt{3}}{2}$

$I_a = \sqrt{3} I_{ab}$

$$\boxed{I_l = \sqrt{3} I_{ph}}$$

power $= 3 E_{ph} I_{ph} \cos\phi = \sqrt{3} E_l I_l \cos\phi$.