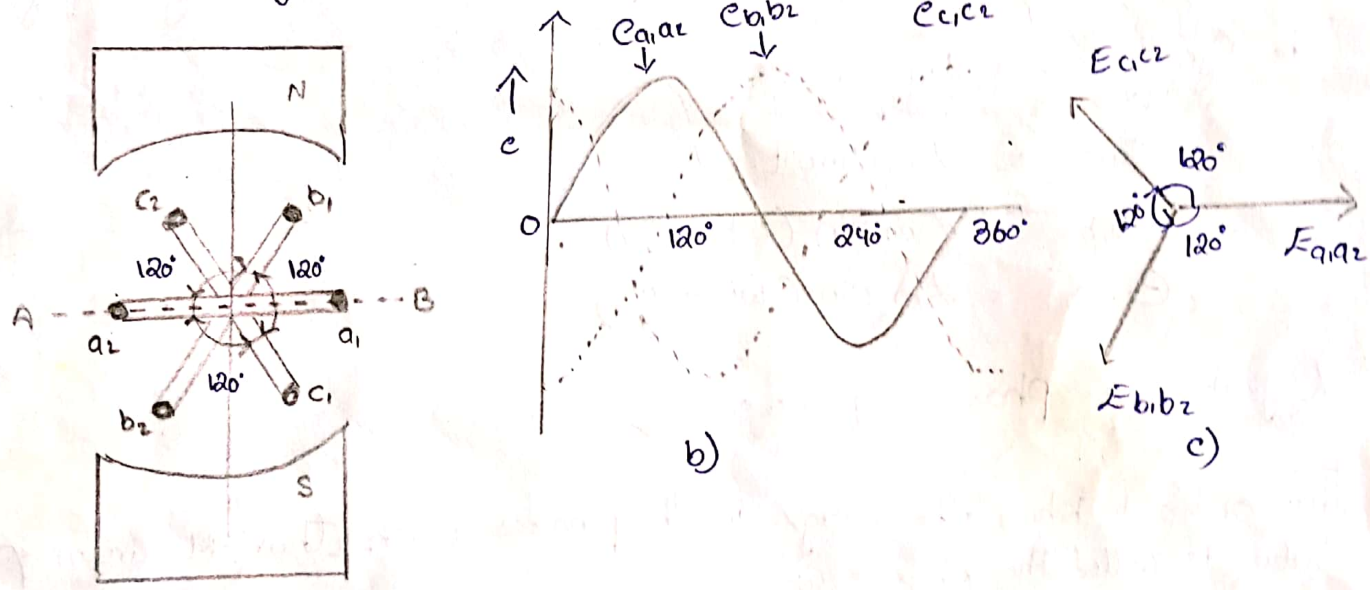
Module 2

b) Three Phase Circuits :-

Generation of Three Phase Voltages :-

- There are three Equal voltages of same frequency but displaced from one another by 120° Electrical
- These voltages are produced by 3ϕ generators which has 3 identical winding or phases displaced by 120° Electrical apart.
- When these winding are rotated in magnetic field Emf is induced in Each winding /phase
- These Emf are of the same magnitude and Frequency but are displaced from one another by 120° Electrical.



a)

- Consider 3 electrical Coils $a_1 a_2$, $b_1 b_2$ and $c_1 c_2$ Mounted on same axis but displaced from each other by 120° Electrical.
- Let the 3 coil's be rotated in an anticlockwise direction in a bipolar magnetic field with a angular velocity of radians/sec
- here a_1, b_1 and c_1 are Starting terminals
  a_2 b_2 and c_2 are ending terminals

- When the coil $a_1 a_2$ in the position AB the Magnitude and direction of the E.m.f induced in various coil is

a) Emf induced in coil $a_1 a_2$ is zero and is increasing in +ve direction
This is indicated by $e_{a_1 a_2}$ wave

b) The Coil $b_1 b_2$ is 120° electrically behind Coil $a_1 a_2$.
The emf Induced in the coil is -ve and approching Maximum negative value.
This is indicated by $e_{b_1 b_2}$ wave

c) The coil $c_1 c_2$ is 240° Electrically behind Coil $a_1 a_2$ or Coil $c_1 c_2$ is 120° Electrically behind Coil $b_1 b_2$
The emf induced in this coil is +ve and is decreasing
This is indicated by $e_{c_1 c_2}$

- The Rms Value of 3phase Voltages are shown vectorially in fig "c"

The Eqn for 3 voltages are

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

$$e_{b_1 b_2} = E_m \sin\left(\omega t - \frac{2\pi}{3}\right)$$

$$e_{c_1 c_2} = E_m \sin\left(\omega t - \frac{4\pi}{3}\right)$$

Definition of phase Sequence:-

The order in which the Voltage in the phases reach their Maximum positive Value is called the phase sequence

Naming the Phases :- 3φ May be numbered as 1, 2, 3
alphabets as a, b, c
colours as R, Y, B

RYB is Considered as positive
RBY is considered as Negative

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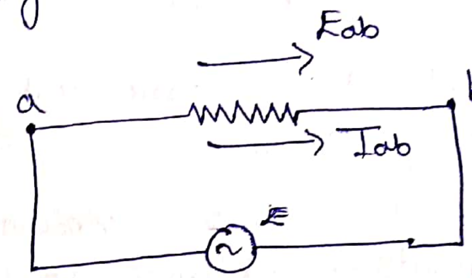
Subscript Notation :-

necessary the Employ some systematic notation for the soln of ac cuits and system containg a number of E.m.f.s acting and currents flowing so that the process of solution is simplified and less prone to error.

- It is normally preferred to Employ double - subscript notation while dealing with ac Electrical circuits.
- In this system the order in which the subscripts are written indicate the direction in which Emf acts or current flows.



- For example if Emf is expressed as E_{ab}
- this indicates that Emf acts from a to b
- if Emf is expressed as E_{ba}
- this indicates that emf acts from b to a (EMF is acting in opposite direction)

i,e $E_{ab} = E_{ba}$

Similarly I_{ab} indicates current flow's in the direction from a to b but I_{ba} indicates current flow's in the direction from b to a

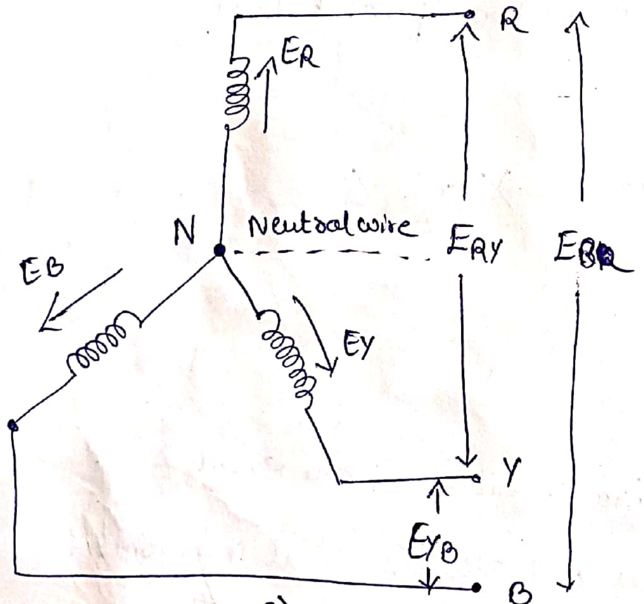
i,e $I_{ba} = I_{ab}$

* Three-phase balanced Supply and load Y and Δ

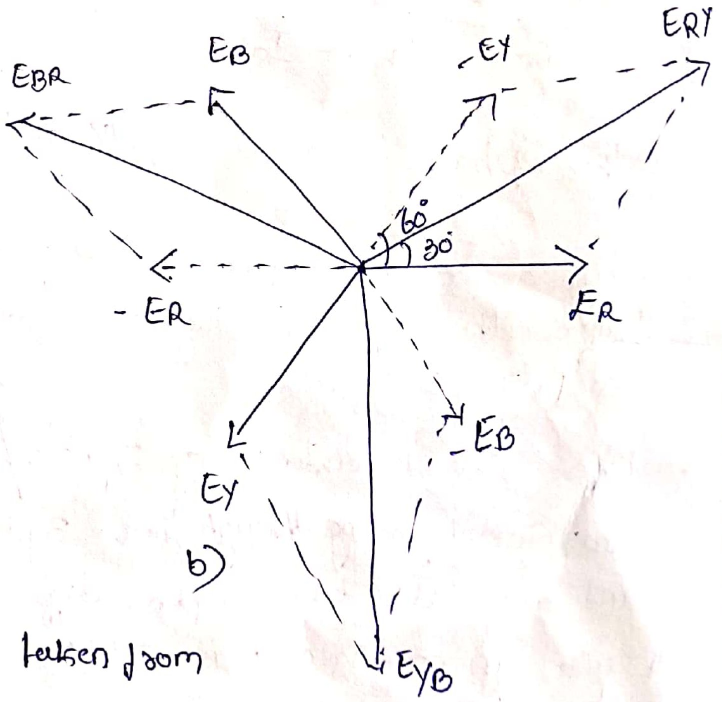
- When a balanced generating supply, where the 3 phase voltage are Equal phase difference is 120°
- Where the impendences of 3phase / three circuit load are Equal. then current flowing through these 3 phases will also be Equal in magnitude and will also have a phase difference of 120° with one another. such an arrangement is called a balanced load.

* Relationship b/w line & phase Quantities and expression for balanced 3phase star connection.

- Three phase star connection is obtained by joining similar terminals together. [Either starting ends or finishing ends are joined together]
- The common point at which these ends are connected together is called Neutral or starpoint denoted by N
- Normally only 3 wires carried out for external circuit giving 3φ-3wire star connected system.
- Some times a fourth wire known as neutral wire is carried to neutral point of external load circuit giving rise to 3φ-4wire star connected system.
- "The voltage b/w any line and neutral point is called Phase voltage"
- "The voltage b/w any two lines is called line voltage"



a)



b)

- In Fig a) (+)ve directions of EMF are taken from star point outward
- The arrow heads on EMF and Current indicates the (+)ve direction
- Here 3 phases are numbered as usual R, Y B indicates Red, Yellow and Blue

nation, sequence RYB is taken as positive and RBY as negative

ne Figure b) EMF induced in the 3 phases are shown vectorially

n Star connection there are two winding b/w each pair of outer

Due to ~~joing~~ joining of similar ends together the Emf induced in them are in opposition.

- The voltage b/w R and Y line is line voltage E_{RY} it is the vector difference of phase E.mfs E_R and E_Y or it is the vector sum of phase Emfs E_R & E_Y

i,e $E_{RY} = E_R - E_Y$ [Vector difference]

$E_{RY} = E_R + (E_Y)$ [Vector sum]

$\sqrt{a^2+b^2+2ab\cos\theta}$

- Phase angle b/w E_R & E_Y is 60°

From Vector diagram $E_{RY} = \sqrt{E_R^2 + E_Y^2 + E_R E_Y \cos 60^\circ}$

$E_R = E_Y = E_B = E_P$ (phase voltage)

$E_{RY} = \sqrt{E_P^2 + E_P^2 + 2E_P^2 \times 0.5}$

$= \sqrt{3E_P^2}$

$E_{RY} = \sqrt{3}E_P$

Then line voltage $E_{RY} = \sqrt{3}E_P$

Illy $E_{YB} = E_Y - E_B = \sqrt{3}E_P$

$E_{BR} = E_B - E_R = \sqrt{3}E_P$

- In a balanced star system E_{RY}, E_{YB}, and E_{BR} are equal in magnitude are called line voltages

$E_L = \sqrt{3}E_P$

- Since in a star connection each line conductor is connected to seperate phase so current flowing through line and phases are the same.

Line Current I_L = Phase current I_P

If phase current has phase difference of ϕ with the phase voltage

Power output per phase $= E_p I_p \cos\phi$

Total power output $P = 3 E_p I_p \cos\phi$

$$= 3 \frac{E_L}{\sqrt{3}} I_p \cos\phi$$

$$P = \sqrt{3} E_L I_L \cos\phi$$

Power $= \sqrt{3} \times$ line voltage $\times$ line current $\times$ Power factor

Apparent power of 3-phase star-connected system

$= 3 \times$ apparent power per phase

$$= 3 \times E_p I_p$$

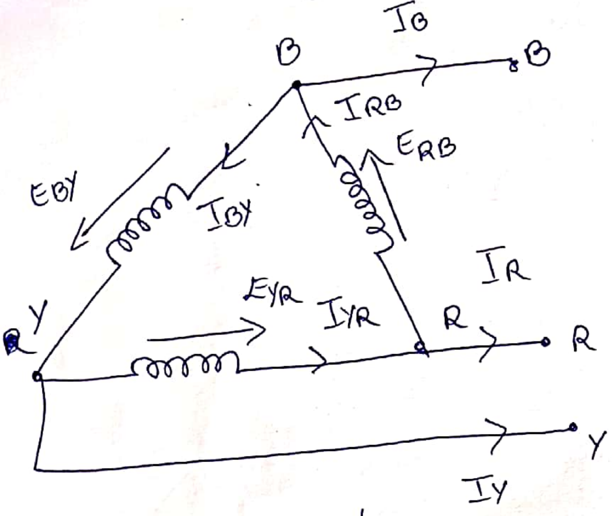
$$= 3 \times \frac{E_L}{\sqrt{3}} \times I_L \quad [I_L = I_p]$$

$$P = \sqrt{3} E_L I_L$$

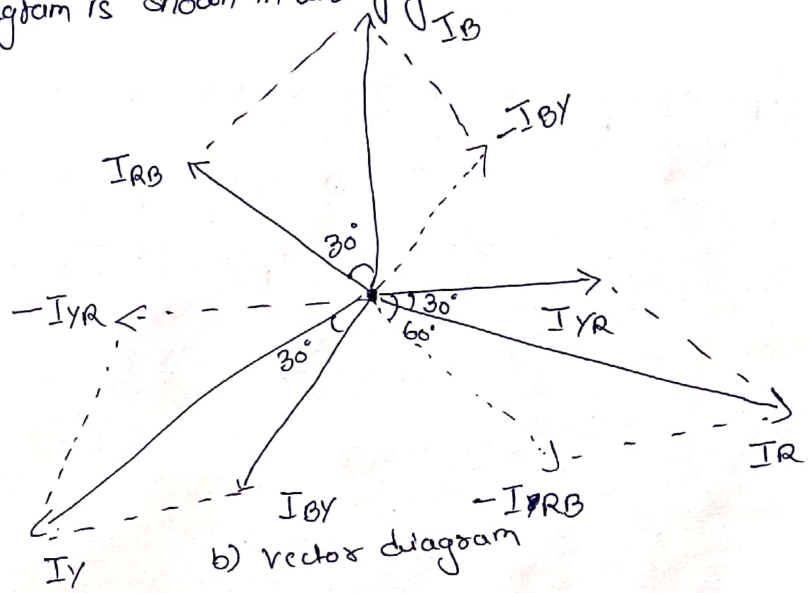
ship b/w line and Phase Quantities & Expression for power for a 3φ Delta Connection.

lta Connection is obtained when starting end of one coil is connected to finishing end of another coil.

- The connection diagram and vector diagram is shown in the figure.



a) Connection diagram



b) vector diagram

- From the vector diagram line current is the vector sum of two phase currents
- i.e I_R line current is vector sum of I_{YR} and I_{RB}

Line current $I_R = I_{YR} - I_{RB}$ (vector difference)

$I_R = I_{YR} + (-I_{RB})$ (vector sum)

- The phase angle b/w currents I_{YR} & I_{RB} is 60°
- $I_R = \sqrt{I_{YR}^2 + I_{RB}^2 + 2 I_{YR} I_{RB} \cos 60°}$

For balanced load phase current phase current in each winding is equal and let it be I_p

- line current $I_Y = I_{BY} - I_{YR} = \sqrt{3} I_p$

$I_B = I_{RB} - I_{BY} = \sqrt{3} I_p$

- In delta network there is only one phase b/w any pair of lines so the potential difference b/w the line outer called line voltage
- In delta n/w line voltage = phase voltage

$E_L = E_p$

- power output per phase = $E_p I_p \cos\phi$

- Total power output $P = 3 E_p I_p \cos\phi$

$$= 3 E_L \frac{I_L}{\sqrt{3}} \cos\phi$$

$$P = \sqrt{3} E_L I_L \cos\phi$$

- Apparent power of 3ϕ delta-connected System

$$= 3 \times \text{apparent power per phase}$$

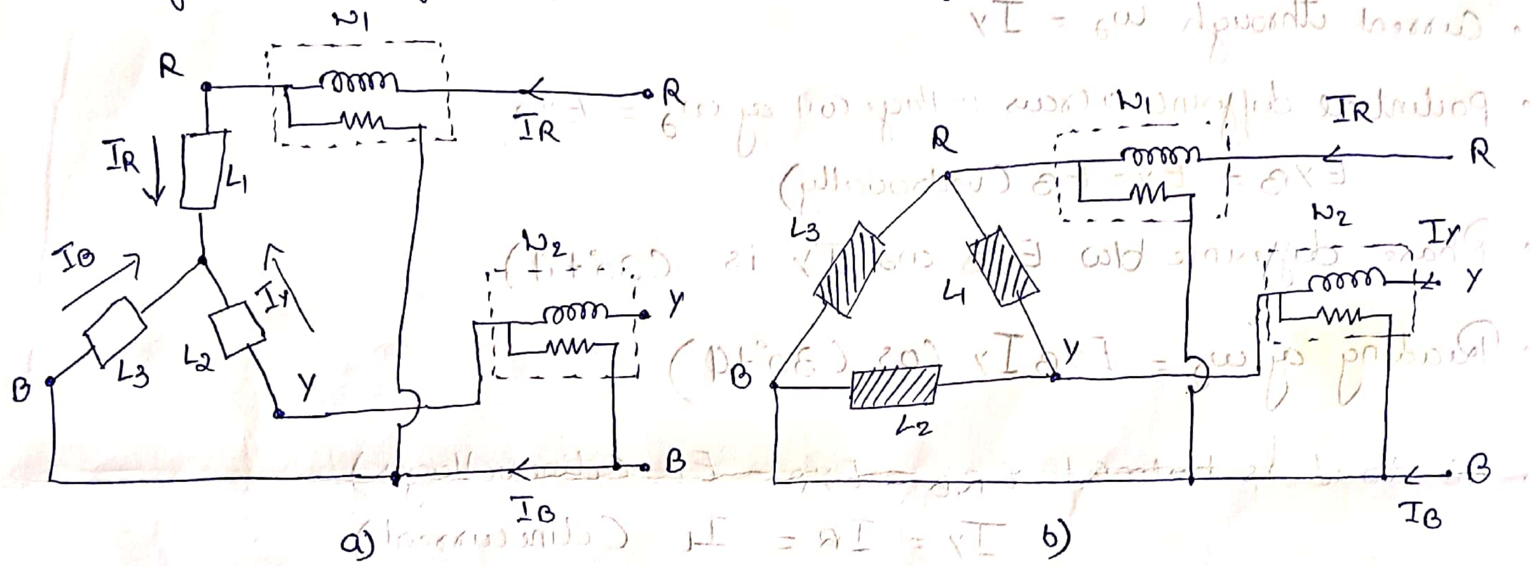
$$= 3 E_p I_p = 3 E_L \frac{I_L}{\sqrt{3}} = \sqrt{3} E_L I_L$$

. of power in 3-phase circuits :-

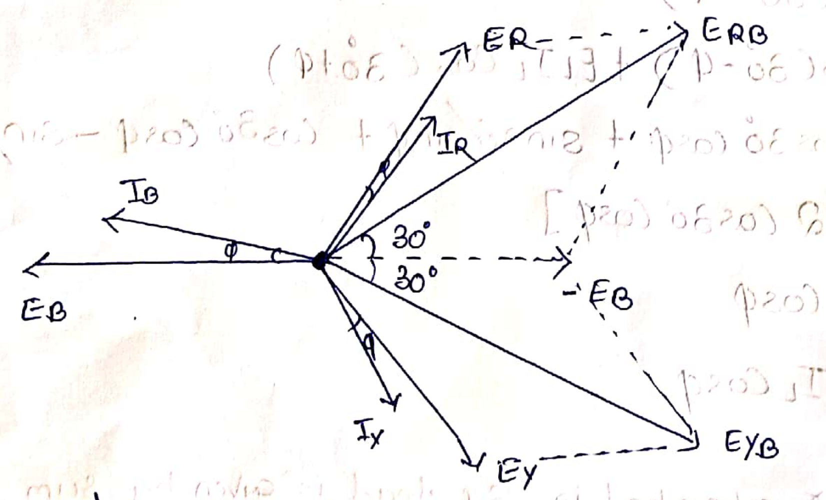
watt meter Method :- This Method is normally used for Measuring power in 3Phase - 3wire balanced load circuits.

- Consider the figure shown, which consist of two wattmeter, in which current coil are inserted in any two lines and potential coil of Each wattmeter is joined to third line.

- In case of balanced load impedances of all the 3phases are Equal and power factor of load can be found by two wattmeter readings.



- Let the Star connected load be inductive the vector diagram is shown in figure



- Let 3phase voltage have rms value E_R, E_Y and E_B
- Let 3 phase Current have rms value I_R, I_Y and I_B
- Currents are lagging behind their respective Phase angle ϕ

- Current through $W_1 = I_R$
- potential difference across voltage coil of $\omega_1 = E_{RB}$

$$E_{RB} = E_R - E_B \text{ (vectorially)}$$

- phase difference b/w E_{RB} and I_R is $(30^\circ - \phi)$

- Reading of $\omega_1 = E_{RB} I_R \cos(30^\circ - \phi)$

- Current through $\omega_2 = I_Y$
- potential difference across voltage coil of $\omega_2 = E_{YB}$

$$E_{YB} = E_Y - E_B \text{ (vectorially)}$$

- Phase difference b/w E_{YB} and I_Y is $(30^\circ + \phi)$
- Reading of $\omega_2 = E_{YB} I_Y \cos(30^\circ + \phi)$

- As load is balanced $E_{RB} = E_{YB} = E_L$ (line voltages)

$$I_Y = I_R = I_L \text{ (line current)}$$

$$W_1 = E_L I_L \cos(30^\circ - \phi)$$
$$W_2 = E_L I_L \cos(30^\circ + \phi)$$

$$W_1 + W_2 = E_L I_L \cos(30^\circ - \phi) + E_L I_L \cos(30^\circ + \phi)$$
$$= E_L I_L [\cos 30^\circ \cos\phi + \cancel{\sin 30^\circ \sin\phi} + \cos 30^\circ \cos\phi - \cancel{\sin 30^\circ \sin\phi})$$
$$= E_L I_L [2 \cos 30^\circ \cos\phi]$$
$$= E_L I_L \sqrt{3} \cos\phi$$

$$W_1 + W_2 = \sqrt{3} E_L I_L \cos\phi$$

"Thus total power absorbed in 3ϕ load is given by sum of two wattmeter reading"

It is shown that two wattmeter are sufficient to measure 3ϕ power

Power factor – Balanced 3-phase load

Case 1 :- Lagging power factor :-

$$W_1+W_2 = E_L I_L \cos(30°-\phi) + E_L I_L \cos(30°+\phi)$$

$$= E_L I_L \sqrt{3}\cos\phi$$

$$W_1+W_2 = \sqrt{3} E_L I_L \cos\phi \rightarrow (1)$$

$$W_1-W_2 = E_L I_L \cos(30°-\phi) - E_L I_L \cos(30°+\phi)$$

$$= E_L I_L \cancel{2} \times \sin\phi \times \frac{1}{\cancel{2}}$$

$$W_1-W_2 = E_L I_L \sin\phi \rightarrow (2)$$

÷ Eqn (2) by (1)

$$\frac{W_1-W_2}{W_1+W_2} = \frac{\cancel{E_L I_L} \sin\phi}{\sqrt{3}\cancel{E_L I_L}\cos\phi}$$

$$\frac{\sqrt{3}(W_1-W_2)}{(W_1+W_2)} = \tan\phi \rightarrow (3)$$

If W_2 reading is negative, its Reading is taken after Reversing the Pressure coil, then Eqn (3) would become

$$\tan\phi = \sqrt{3}\frac{(W_1-(-W_2))}{W_1+(-W_2)}$$

$$\tan\phi = \sqrt{3}\frac{(W_1+W_2)}{(W_1-W_2)}$$