IES/GATE

Electrical Engineering

VOLUME-VIII

Power System-II

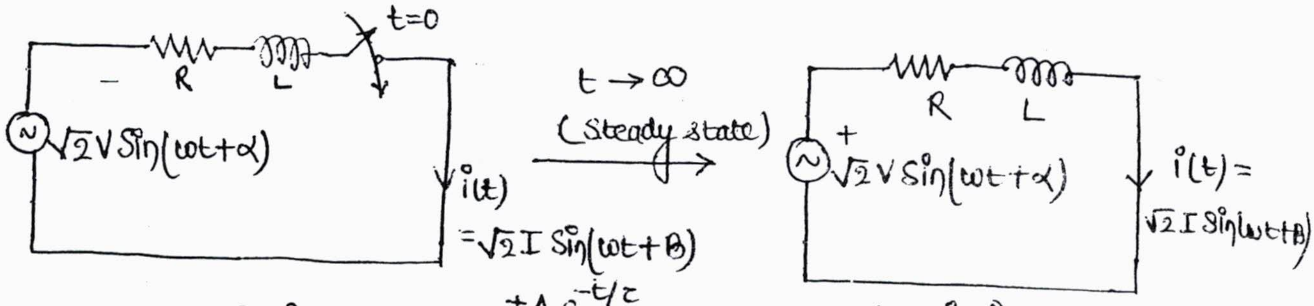
Contents

POWER SYSTEM - 2

BY: BHUPENDRE - SIR

* Power analysis of A.C. circuit

A circuit which is in steady state corresponding to a given sinusoidal excitation is called AC circuit.

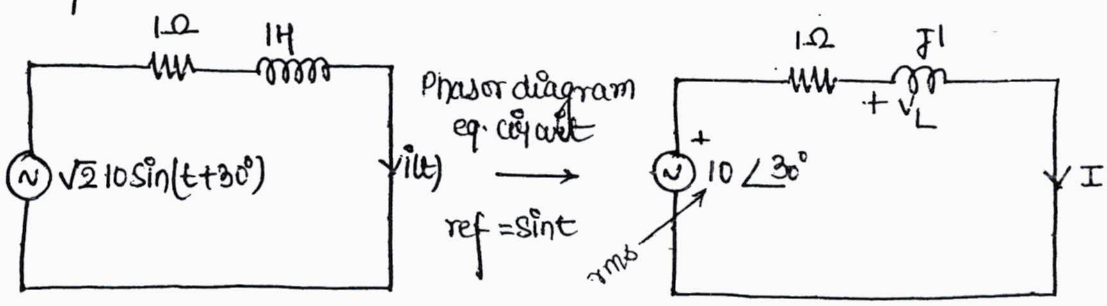


not an AC circuit — AC circuit

Responses are non-sinusoidal — Responses are sinusoidal.

→ All the responses of an AC circuit are sinusoids with frequency equal to the source frequency.

→ The magnitude & phase of the response in an AC circuit is determined by phasor technique.

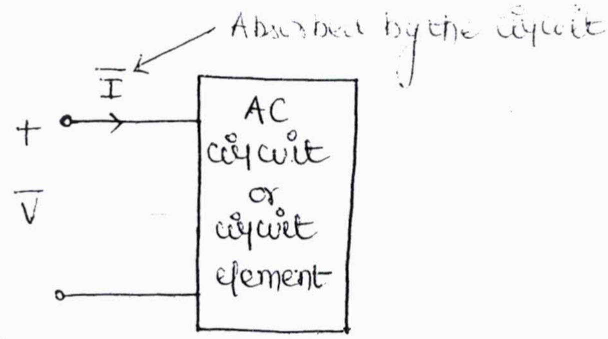


$$I=\frac{10\angle30^\circ}{1+J1}=\frac{10}{\sqrt{2}}\angle{-15^\circ}$$

$$i(t)=10\sin(t-15^\circ)$$

$$V_L=\left(\frac{J1}{1+J1}\right)10\angle30^\circ$$

$$=\frac{10}{\sqrt{2}}\angle75^\circ$$



Complex power absorbed by the circuit or circuit element

$$S = VI^* = P + jQ$$

P → Active power / useful power / Avg. power / power absorbed by the ckt or ckt. element (watt)

Q → Reactive power / lagging VAR absorbed by the circuit or ckt. element (VAR).

P > 0 → ckt. absorbs active power

P < 0 → ckt. delivers active power

Q > 0 → ckt. absorbs reactive power or lagging VAR or lagging current

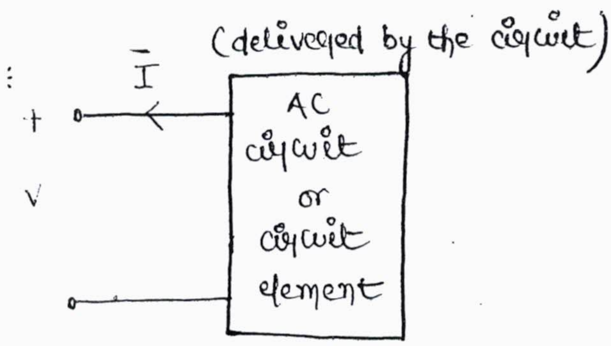
or

circuit delivers leading VAR / leading current

Q < 0 → circuit delivers reactive power / which is lagging VAR / lagging current

or

The circuit absorbs leading VAR / leading current



Complex power delivered by the circuit or circuit element -

$$S = VI^* = P + jQ$$

P → Active power delivered by the circuit or circuit element

Q → Reactive power delivered by the circuit or circuit elements

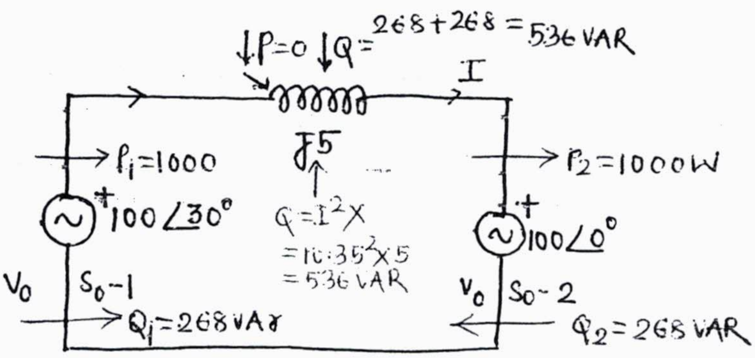
P > 0 → circuit delivers active power

P < 0 → circuit absorbs active power

Q > 0 → circuit delivers reactive power

Q < 0 → circuit absorbs reactive power

*



$$I = \frac{100\angle 30^\circ - 100\angle 0^\circ}{j5}$$

$$= 10.35\angle 15^\circ$$

Complex power absorbed by V.S.2

$$S_2 = (100\angle 0^\circ)(10.35\angle 15^\circ)^*$$

$$= 1000 - j268$$

V.S.2 →

Absorbs 1000W & delivers 268 VAR

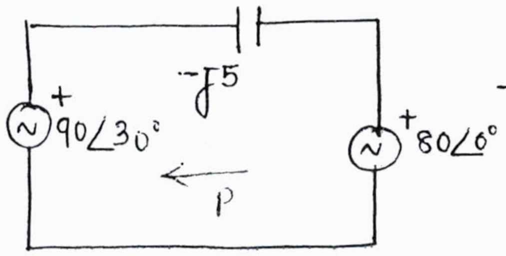
V.S.1 →

Complex power absorbed by V.S.1

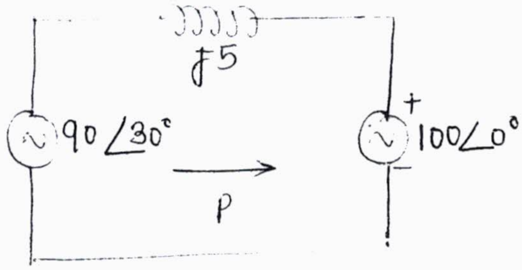
$$S_1 = (100\angle 30^\circ)(10.35\angle 15)^*$$

$$= 1000 + j268$$

Voltage source-1 delivers 1000W & 268 VAR.

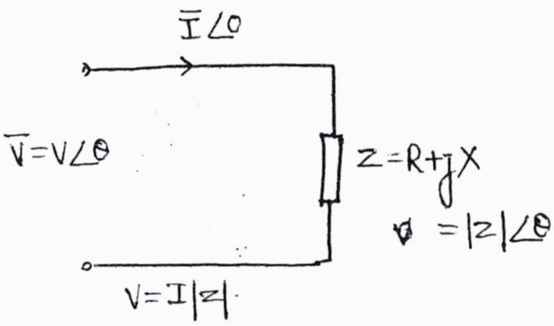


→ not a practical power system circuit. capacitor not connected in series



Reactive power generally* flows from higher to low value.
* But not always.

In power system (with inductive series branch) active power always flows from leading voltage source towards lagging voltage source.



$$|Z| = \sqrt{R^2+X^2}$$

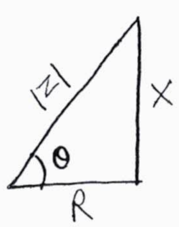
$$\theta = \tan^{-1}\frac{X}{R}$$

Complex power absorbed by Z=R+jX

$$S = \bar{V}\bar{I}^* = VI\angle\theta = P+jQ$$

$$P = VI\cos\theta = VI\frac{R}{|Z|} = I^2R$$

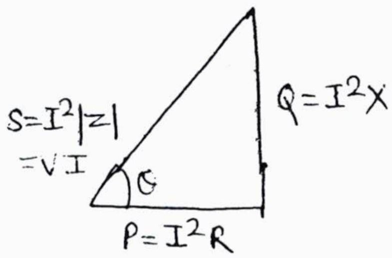
$$Q = VI\sin\theta = VI\frac{X}{|Z|} = I^2X$$



$$\cos\theta = \frac{R}{|Z|}$$

$$\sin\theta = \frac{X}{|Z|}$$

Impedance Triangle



$$\boxed{P.f. = \cos\theta = \frac{P}{S}}$$

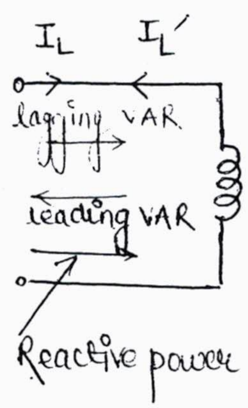
$R \geq 0 \Rightarrow P \geq 0$ ($Z = R + jX$ can't deliver active power)

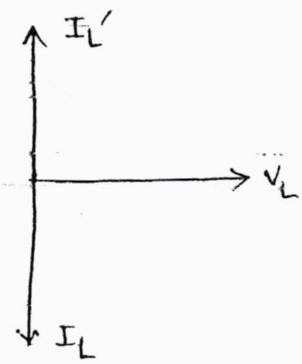
$X > 0$ (Inductive) $= Q > 0$ Inductive circuit absorbs reactive power

$X = 0$ (Resistive) $= Q = 0$

$X < 0$ (Capacitive) $\Rightarrow Q < 0$ capacitive ckt. delivers reactive power.

*





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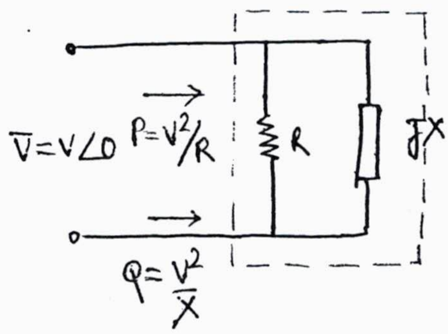


Balance 3-ϕ circuit / concept of phase sequence

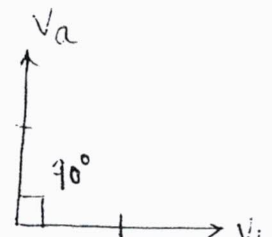
A polyphase system is said to be balance if –

› The magnitude of corresponding quantities are equal in each phase.

› The phase difference between corresponding quantities is given by θ.

$$\theta = \frac{360^\circ}{n} \rightarrow n \neq 2$$

$$90^\circ \rightarrow n = 2$$

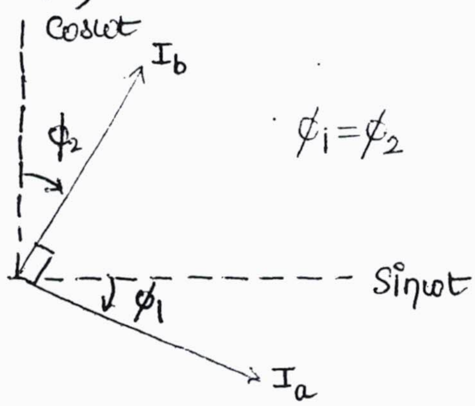


2-ϕ system.

The currents in two phases of a 2-ϕ system is given below. Find the relation between ϕ_1 & ϕ_2 so that these current represents a balance 2-ϕ system.

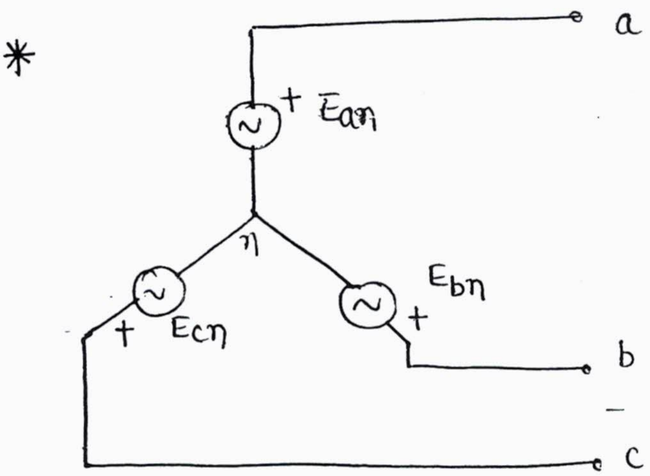
$$i_a = \sqrt{2}\, I \, \sin(\omega t - \phi_1)$$

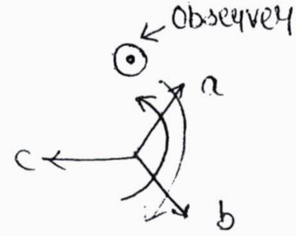
$$i_b = \sqrt{2}\, I \, \cos(\omega t - \phi_2)$$



$\phi_1 = \phi_2$

*

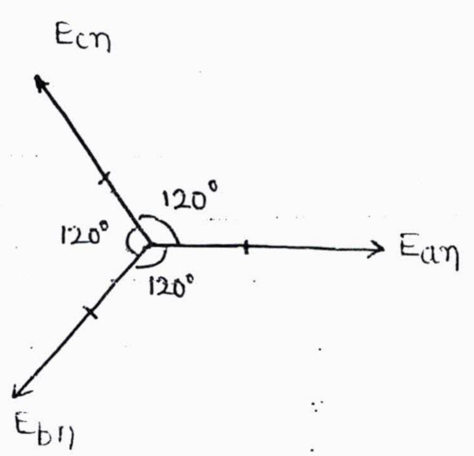


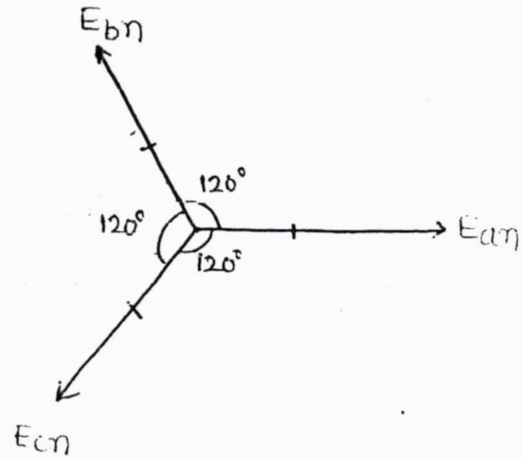


abc
anticlockwis

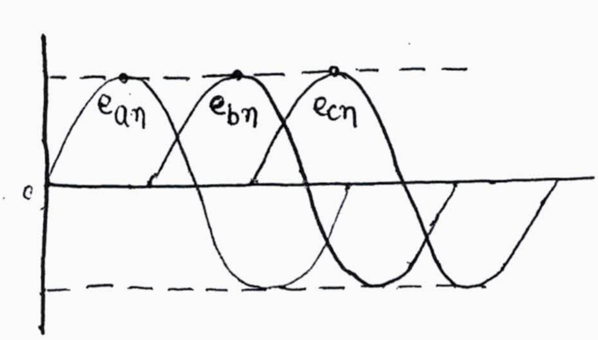
→ observer moves clockwise to detect phase sequence.

→ The 3-ϕ voltage source represents a synchronous machine

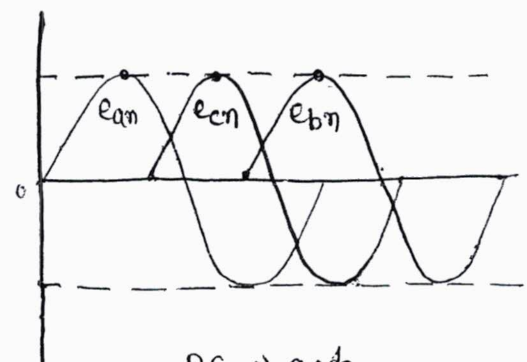




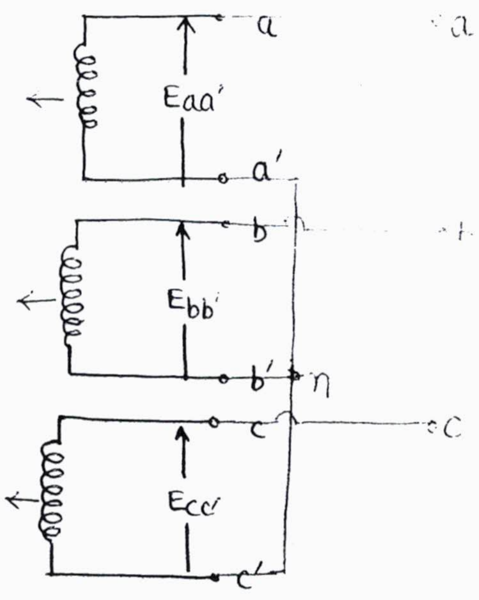
→ Both phasor diagram represents balance condition but they do differ in phase sequence.



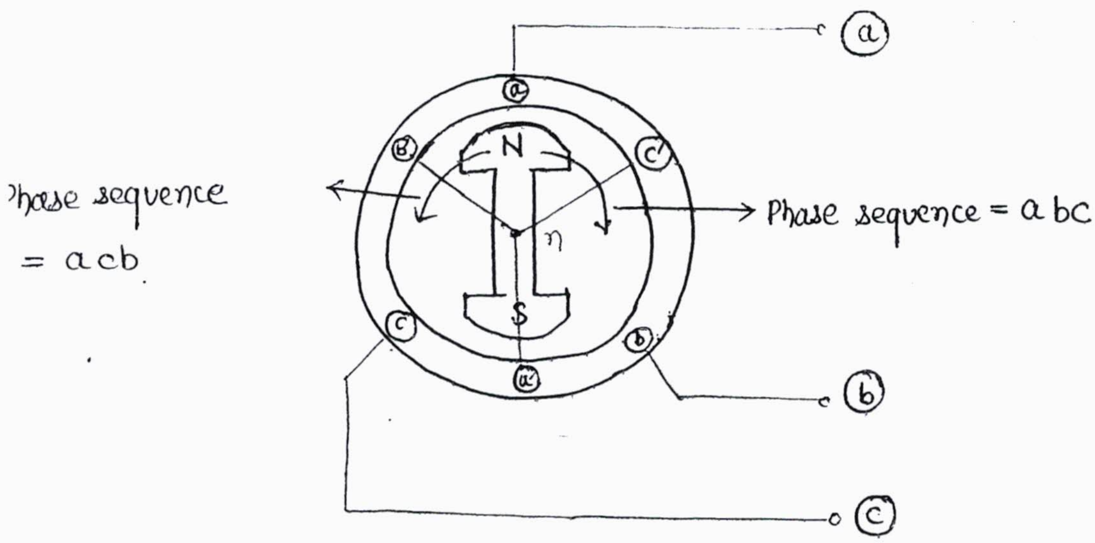
PS ⇒ abc



P.S. ⇒ acb



Identical winding for all three phases to produce equal magnitude of voltage in all three phases

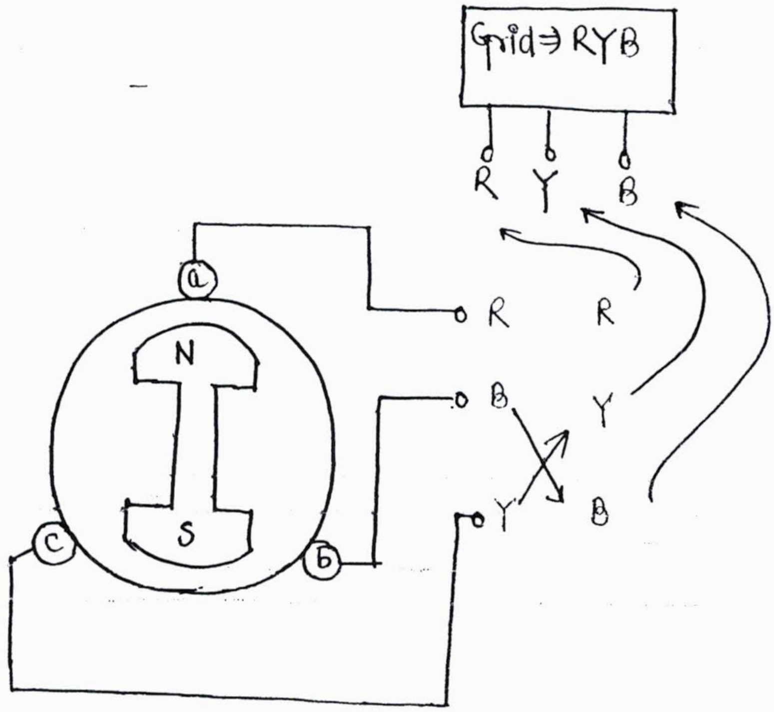


$$\boxed{\theta_e = \frac{P}{2}\,\theta_M}$$

nly two type of phase sequence (abc & acb) is possible in 3-ϕ system.
heoretically phase sequence can be reversed by reversing the direction of rotation of the rotor but practically this is not feasible.

→ If field winding excitation is reversed phase sequence will not reversed.

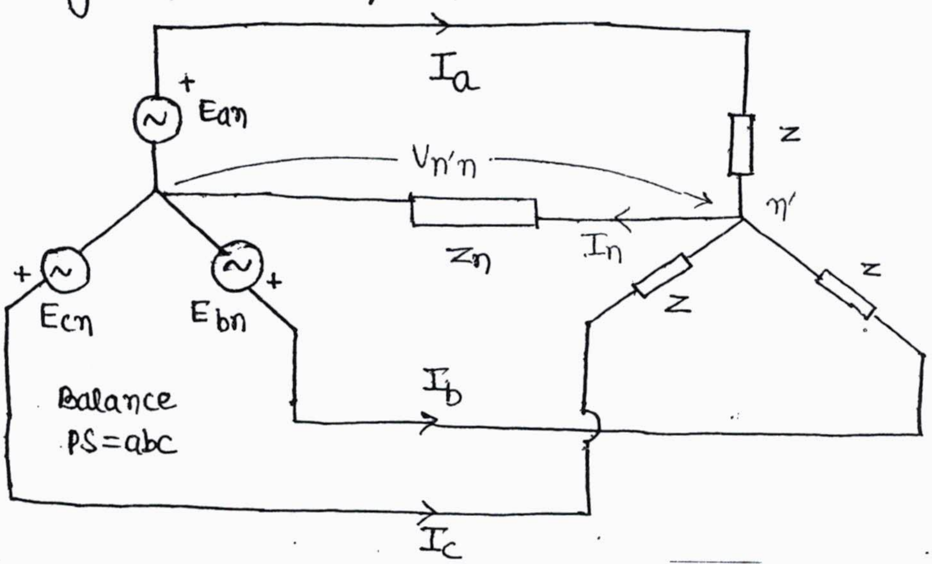
* Phase sequence of the machine is practically reversed by interchanging any two terminals of a machine.



Otherwise heavy circulating current will run/flow

In a particular power system all the machines operates at same phase sequence & it is the sequence of whole system.

*Analysis of Balance 3-ϕ circuit



$\Rightarrow I_a + I_b + I_c - I_n = 0$

$\Rightarrow \dfrac{E_{an} - V_{n'n}}{Z} + \dfrac{E_{bn} - V_{n'n}}{Z} + \dfrac{E_{cn} - V_{n'n}}{Z} - \dfrac{V_{n'n}}{Z_n} = 0$

$\dfrac{1}{Z}\left(E_{an} + E_{bn} + E_{cn}\right) - \left(\dfrac{3}{Z} + \dfrac{1}{Z_n}\right) V_{n'n} = 0$

Since, the source is balanced

$E_{an} + E_{bn} + E_{cn} = 0 \quad \Rightarrow V_{n'n} = 0$

$I_n = 0$

$I_a = \dfrac{E_{an}}{Z}$

$I_b = \dfrac{E_{bn}}{Z}$

$I_c = \dfrac{E_{cn}}{Z}$

$E_{an} = 100\angle 0^\circ$

$E_{bn} = 100\angle -120^\circ$

$E_{cn} = 100\angle +120^\circ$

$P.S. = abc$

$Z = 10\angle 30^\circ$

$$\left.\begin{aligned} I_a &= \frac{E_{an}}{Z} = \frac{100\angle 0^\circ}{10\angle 30^\circ} = 10\angle -30^\circ \\ I_b &= \frac{E_{bn}}{Z} = \frac{100\angle -120^\circ}{10\angle 30^\circ} = 10\angle -150^\circ \\ I_c &= \frac{E_{cn}}{Z} = \frac{100\angle +120^\circ}{10\angle 30^\circ} = 10\angle +90^\circ \end{aligned}\right\} \; PS = abc$$

*In a balance 3-ϕ circuit

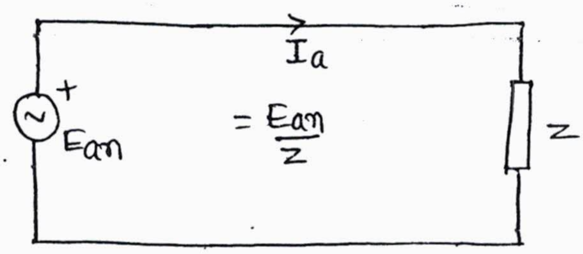
i) All the responses are balance & they have phase sequence as of the sources in the circuit.

ii) All the neutrals are at same potential & hence there will be no current in the neutral connection irrespective of the value of Z_n.

Hence the neutral connection can be replaced by O.C. or S.C. but we prefer S.C. to show the fact that neutrals are at same potential.

iii) All the three phases are decoupled i.e. independent of each other hence the analysis can be done on individual phase basis.

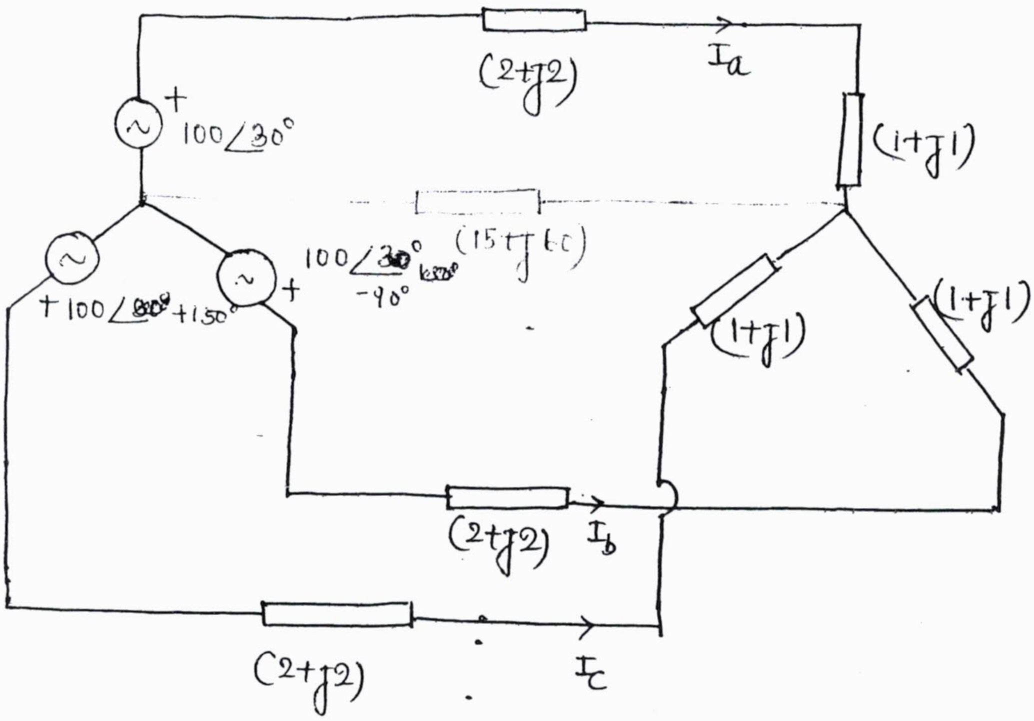
→ For the analysis of phase 'a' of the balance circuit phase A equivalent circuit drawn as follows:-

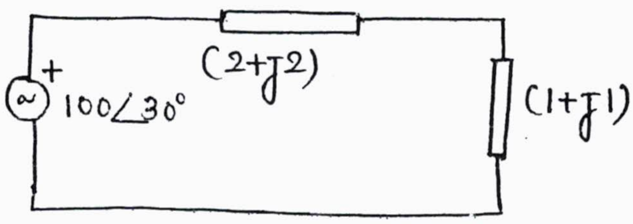


Phase-a equivalent circuit / per phase eq circuit

If phase-a quantity is computed from phase-a equivalent circuit Phase-B & phase-C quantities can be determined directly with the help of phase sequence of the source.

"The analysis of a balance 3-ϕ circuit is always ~~[illegible]~~ done on per phase basis".



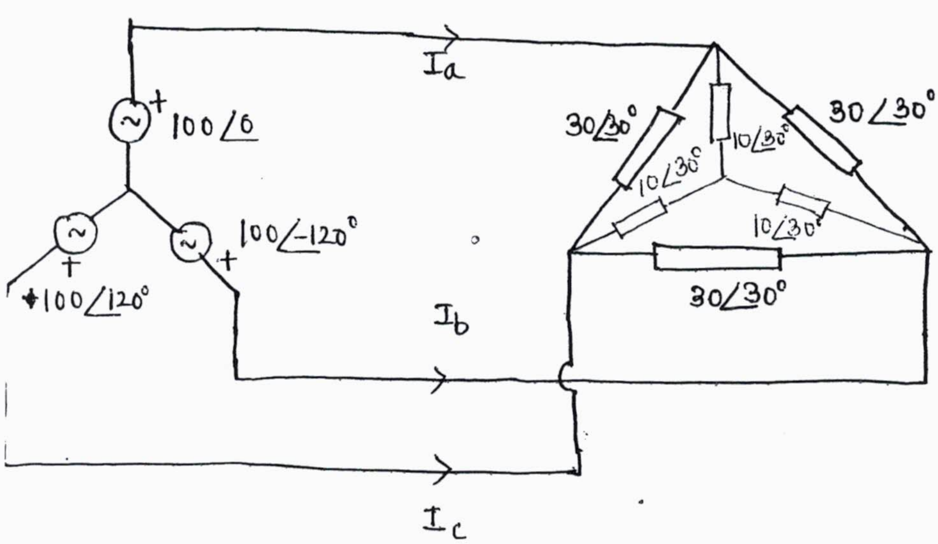


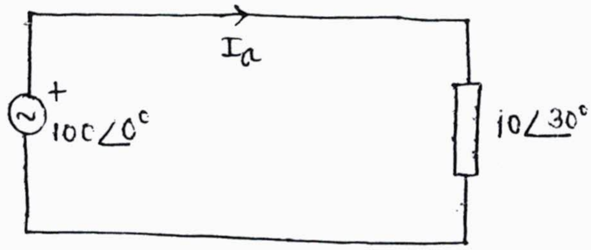
per phase equivalent circuit

$$I_a = \frac{100\angle 30^\circ}{(3+j3)} = 23.5\angle -15^\circ$$

$$I_b = 23.5\angle -135^\circ$$

$$I_c = 23.5\angle 105^\circ$$





per phase equivalent circuit

$$I_a = \frac{100\angle 0^\circ}{10\angle 30^\circ} = 10\angle -30^\circ$$

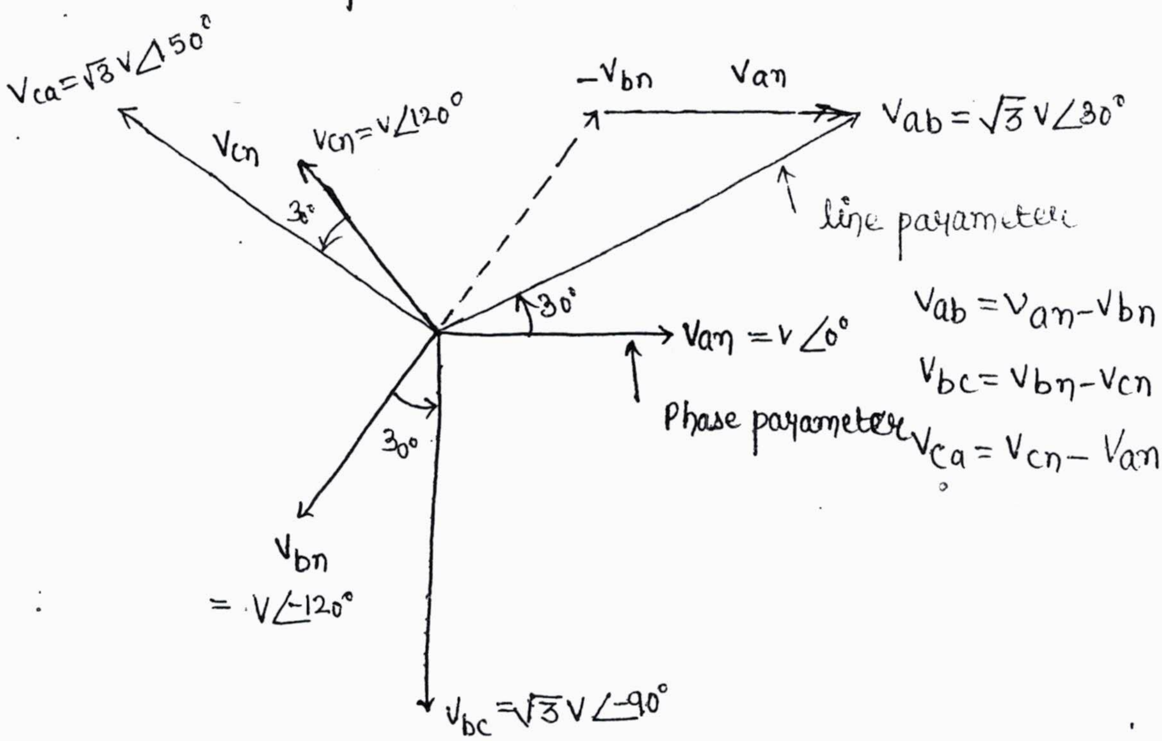
$$I_b = 10\angle -150^\circ$$

$$I_c = 10\angle 90^\circ$$

note:-

For the analysis of the balance 3-∅ circuit on per phase basis all the sources & loads of the circuits must be either star connected or converted into equivalent star.

* Δ to Y source transformation

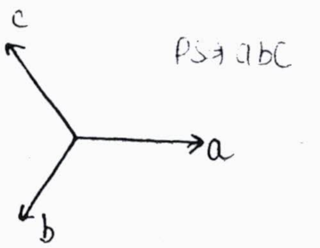


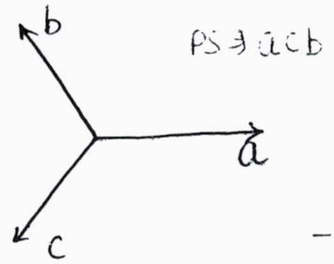
$$V_{ab} = V_{an} - V_{bn}$$

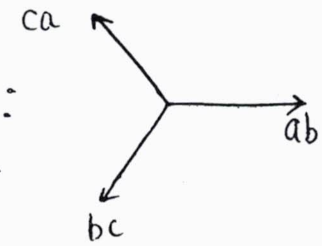
$$V_{bc} = V_{bn} - V_{cn}$$

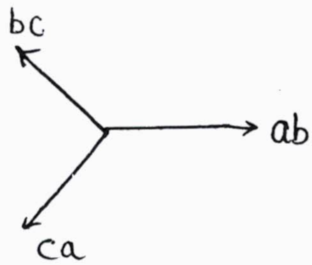
$$V_{ca} = V_{cn} - V_{an}$$

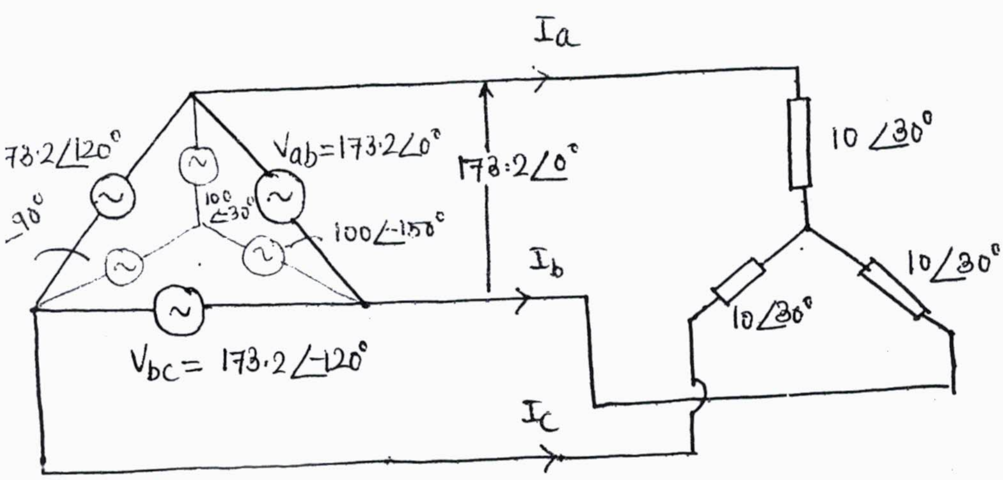
) a balance 3-ϕ system line voltage is $\sqrt{3}$ times of phase voltage & leads the phase voltage by 30°.

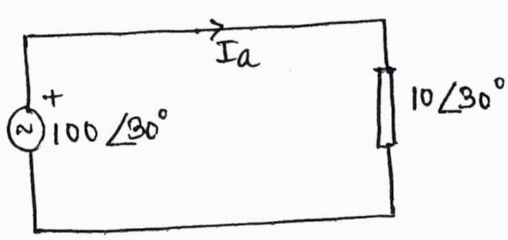










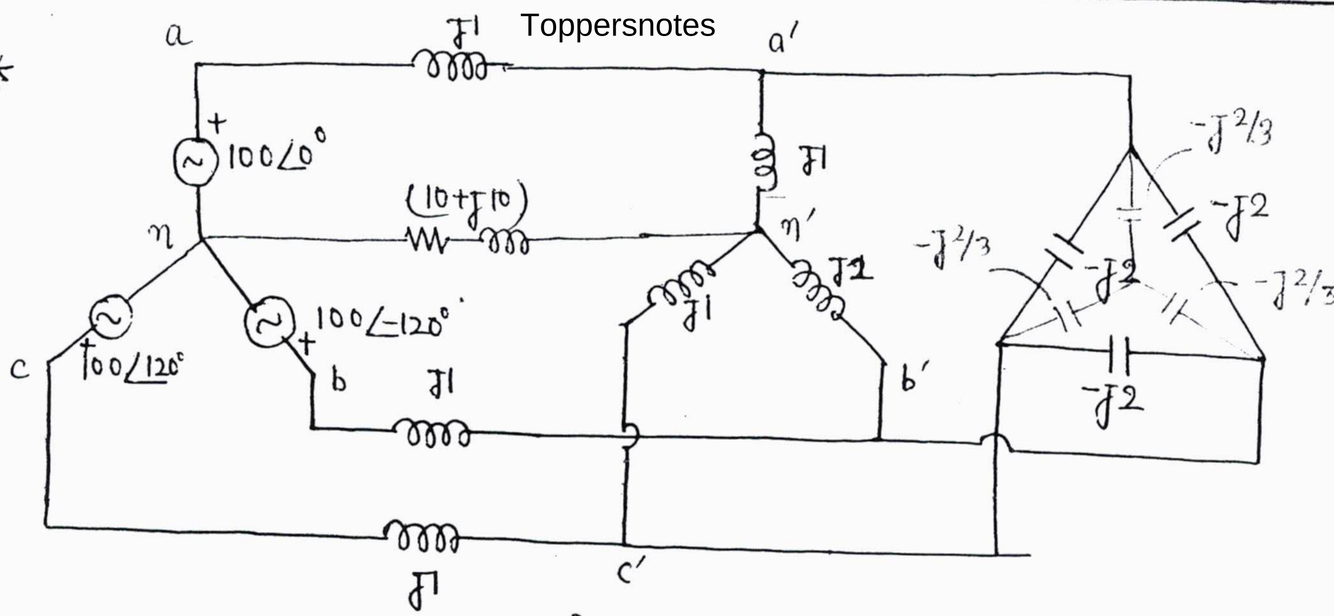


$$I_a = \frac{100\angle -30^\circ}{10\angle 30^\circ} = 10\angle -60^\circ$$

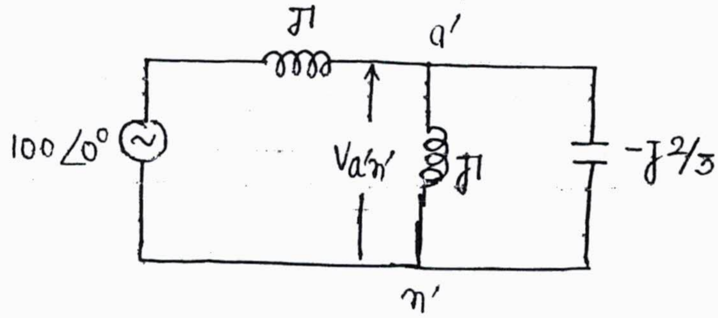
$$I_b = 10\angle -180^\circ$$

$$I_c = 10\angle 60^\circ$$

*



Determine phase voltage for the star connected load & phase current for the Δ-connected load.



$$V_{a'n'} = \left(\frac{j1 \| -j2/3}{j1 + j1 \| -j2/3}\right) 100\angle 0^\circ = 200\angle 0^\circ$$

$$V_{b'n'} = 200\angle -120^\circ$$

$$V_{c'n'} = 200\angle +120^\circ$$

Method-1

$$V_{a'b'} = 200\sqrt{3}\angle 30^\circ$$

$$I_{a'b'} = \frac{V_{a'b'}}{-j2} = 173.2\angle 120^\circ$$

$$I_{b'c'} = 173.2\angle 0^\circ$$

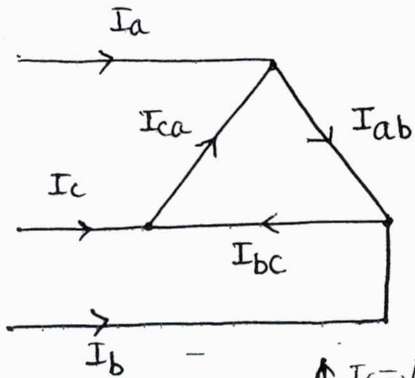
$$I_{c'a'} = 173.2\angle +240^\circ$$

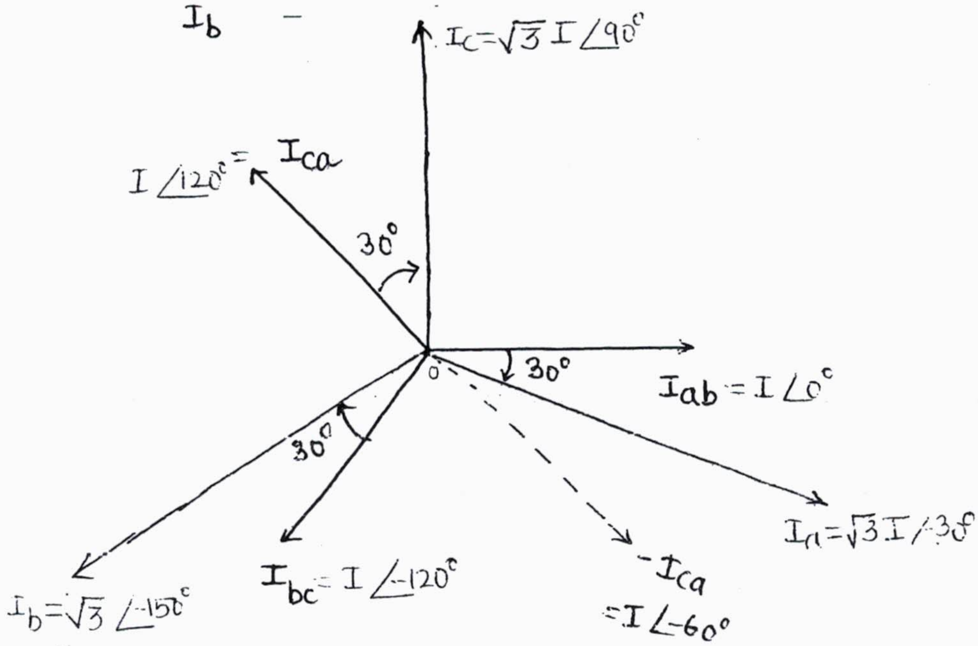
ethod-2 –

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

$I_b = I_{bc} - I_{ab}$

$I_c = I_{ca} - I_{bc}$





ote:

n a balance Δ connected system line current is $\sqrt{3}$ times of phase urrent & lags the phase current by 30°.

ine current for the Δ load –

$$I_a' = \frac{V_{a'n'}}{-j2/3} = \frac{200\angle 0^\circ}{-j2/3} = 300\angle 90^\circ$$

phase current by for Δ-load –

$$I_{a'b'} = 173.2\angle 120^\circ$$

$$I_{b'c'} = 173.2\angle 0^\circ$$

$$I_{c'a'} = 173.2\angle 240^\circ$$