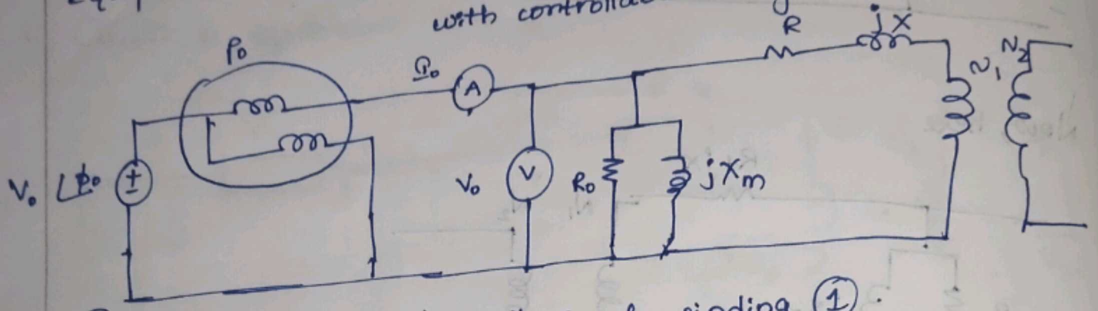
* Open circuit test :-

Transformer is given.

Equipment required:- Ammeter, Voltmeter, Watt meter, Voltage source with controllable voltage.



V_0 is equal to rated voltage of winding (1).

and $P_0 = V_0\left(\frac{V_0}{R_0}\right) = \frac{V_0^2}{R_0} \Rightarrow \boxed{\cancel{R_0 = \frac{P_0}{V_0^2}}}$ ** $\boxed{R_0 = \frac{V_0^2}{P_0}}$

$$I_0 = \frac{V_0\sqrt{R_0^2+X_m^2}}{R_0 X_m}$$

and $\Rightarrow \frac{V_0}{X_m} = \frac{R_0 I_0}{\sqrt{R_0^2+X_m^2}}$

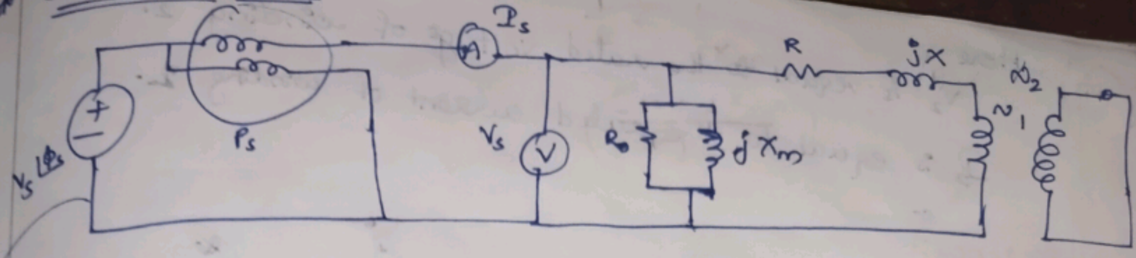
$$I_0^2 = \frac{V_0^2\left(R_0^2+X_m^2\right)}{R_0^2 X_m^2}$$

$$I_0^2 = V_0^2\left(\frac{1}{X_m^2}+\frac{1}{R_0^2}\right)$$

$$\frac{V_0}{X_m} = \sqrt{I_0^2 - \left(\frac{V_0}{R_0}\right)^2}$$

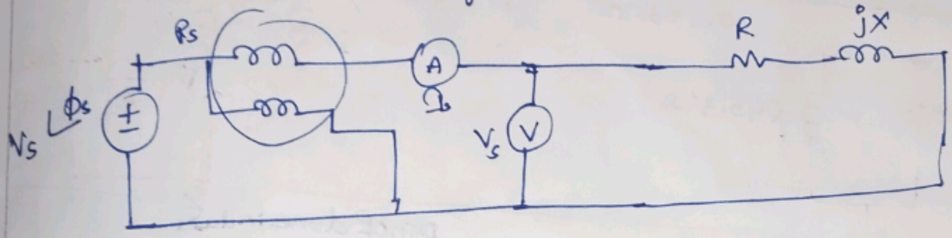
$$\Rightarrow \boxed{X_m = \frac{V_0}{\sqrt{I_0^2-\left(\frac{V_0}{R_0}\right)^2}}}$$ **

* Short circuit test:



I_s is equal to rated current of winding ①.

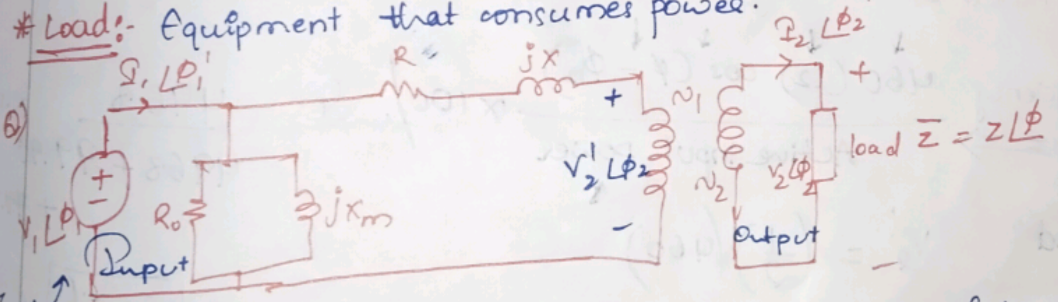
I_s approximated by



$$P_s = I_s^2 R \Rightarrow \boxed{R = \frac{P_s}{I_s^2}}$$

$$\frac{V_s}{I_s} = \sqrt{R^2 + X^2} \Rightarrow \boxed{X = \sqrt{\left(\frac{V_s}{I_s}\right)^2 - R^2}}$$

*** Load:-** Equipment that consumes power.



Type:

for this we can also measure the performance of transformer, this is called voltage regulation.

$$\text{Here } V_2' = \frac{N_1}{N_2} V_2$$

For a given power factor of the load, voltage regulation $= \frac{V_1 - V_2'}{V_2'} \times 100\%$.

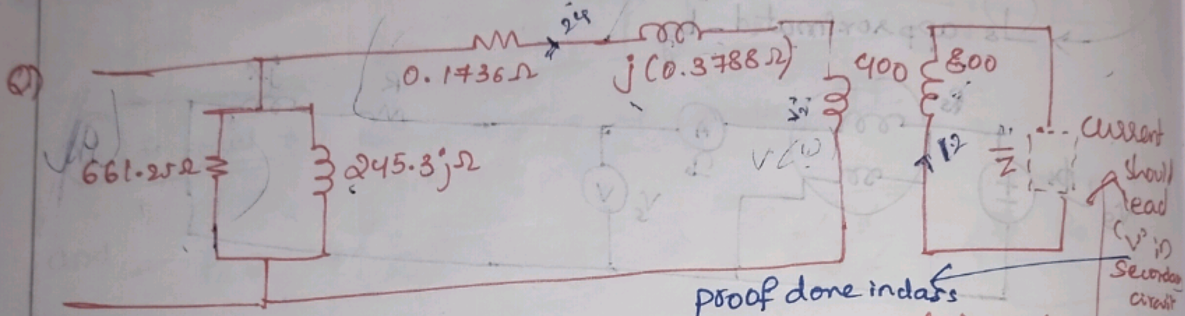
Here

V_2 is equal to the rated voltage of winding 2.

I_2 is equal to the rated current of winding 2.

* **Efficiency:**

$$\frac{\text{Output active power}}{\text{Input active power}} \times 100\%$$



Q) For transformer with this equivalent circuit, rated voltage of winding '2' is 460V and rated current of winding '2' is 12A. Find pf of the load at which voltage regulation = 0. At this pf, what is the efficiency with rated voltage at terminals of winding '2' and rated current through the load.

efficiency $\Longrightarrow$ $\dfrac{460\,(12)\cos(\phi - \phi_2)}{\text{Active input power}} \times 100\%$. So $\dfrac{4968}{4968 + 99.99 + 79.96} \times 100\%$

$= \boxed{96.5\%}$

and $V_2' = \left(\frac{1}{2}\right)(460)$

$V_2' = 230\,V$

So as regulation $= 0 \Rightarrow V_1 = 230\,V$

and hence Active input power $= V_1 I_1 \cos(\phi_1 - \phi_1')$

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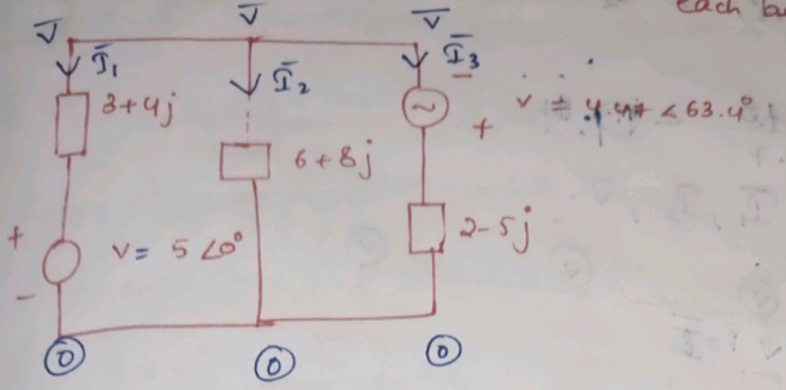
Q) Using Kirchoff law, calculate current in each branch,



Sol:

$$(\bar V - 5\angle 0) = \bar I_1 (5)\angle 53^\circ$$

$$\bar V = \bar I_2 (10)\angle 53^\circ$$

$$\bar V + 4.47\angle 63.4^\circ = \bar I_3 (2-5j)$$

and $\bar I_1 + \bar I_2 + \bar I_3 = 0$

$$\frac{(\bar V - 5)\, e^{-i(53^\circ)}}{5} + \frac{\bar V}{10} e^{-i(53^\circ)} + \frac{\bar V + 4.47\angle 63.4^\circ}{2-5j} = 0$$

$$\left(\frac{\bar V}{5}\right) - 1\left(e^{-i(53^\circ)}\right) + \frac{\bar V}{10}\left(e^{-i(53^\circ)}\right) + \frac{\bar V}{2-5j} + \frac{4.47\angle 63.4^\circ}{2-5j} = 0$$

$$\frac{\bar V}{5} - 1\angle -53^\circ + \frac{\bar V}{10}\left(1\angle -53^\circ\right) + \frac{\bar V}{2-5j} + 0.83\angle 131.78^\circ = 0$$

$\cancel{0.18\angle 68.19^\circ}$

$$(1.96\angle 26.68^\circ) + \frac{\bar V}{1}\left(\frac{1}{5} + \angle -53 + \frac{1}{2-5j}\right) = 0$$

$$(0.2\angle 0 + 0.91\angle 43.0) = 0$$

$$1.07\angle -35.72$$

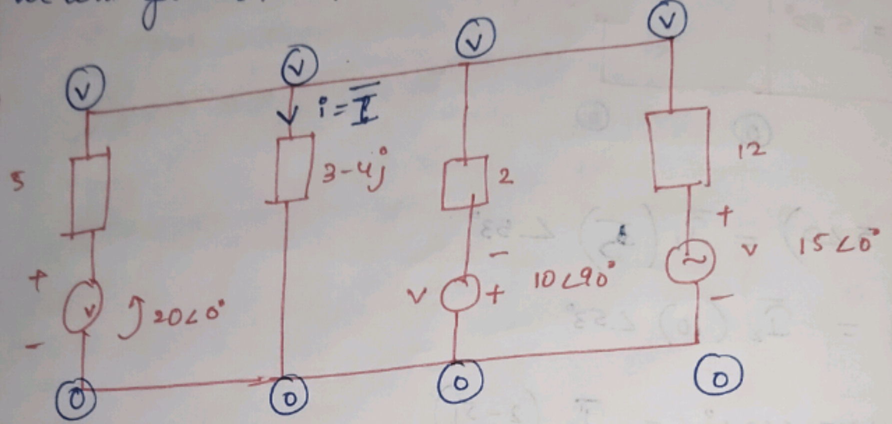
$$\bar V = \frac{+1.96}{1.07}\angle 62.4$$

$$\frac{\overline{V}}{10}\,(\angle -53^\circ) = \overline{I_2}$$

$$\overline{I_2} = \frac{+\cancel{6.6}}{10.7}\angle \cancel{117}.84$$

We will get $\overline{I_2}, \overline{I_1}, \overline{I_3}, \overline{V}$.

Q.)



Sol.

$$\frac{\overline{V}}{3-4j} + \frac{\overline{V}-20}{5} + \frac{\overline{V}+10\angle 90^\circ}{2} + \frac{\overline{V}-15\angle 0^\circ}{12} = 0$$

$$\frac{\overline{V}}{5}(1\angle +53^\circ) + \frac{\overline{V}}{5} - 4 + \frac{\overline{V}}{2} + 5j + \frac{\overline{V}}{12} - \frac{5}{4} = 0$$

$$\frac{\overline{V}}{5}\left(1\angle +53^\circ + 1 + \frac{30}{12} + \frac{5}{12}\right) + 5j - \frac{21}{4} = 0$$

$$\frac{\overline{V}}{5}\left(1\angle +53^\circ + \frac{47}{12}\right) + 5j - \frac{21}{4} = 0$$

$$\overline{V}\left(\frac{4.58\angle 10.90}{\cancel{0.903\angle +10.02}}\right) = \frac{21}{4} - 5j$$

$$\boxed{\overline{V} = \cancel{8.02\angle -33.9}} \quad \frac{7.25}{2.32}\angle -63.67$$

So $\cancel{\frac{\overline{V}}{5}}\ \frac{8.02}{5}\angle -53.6 = \overline{I}$

$$\boxed{\overline{I} = 1.604\angle -53.6^\circ}$$

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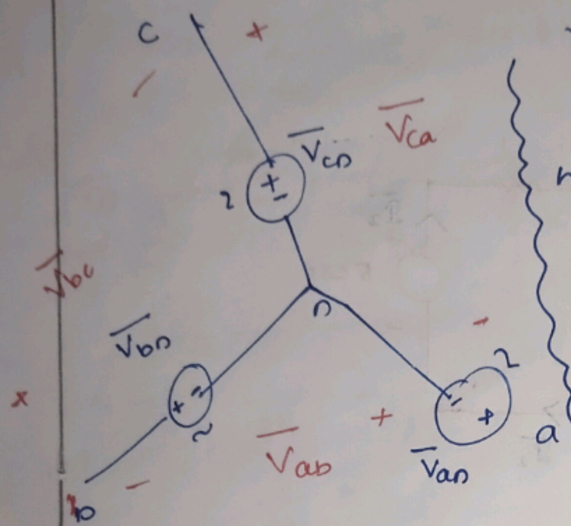
* **Three phase AC-circuits:-**



Y-connection
(or)
Wye-connection
(or)
Star-connection

a, b, c are line terminals
'n' is neutral.

⇒ Voltage source with voltage $\overline{V_{an}}$ is said to be in phase 'a' or belong to phase 'a'. Similarly for $\overline{V_{bn}}$ for 'b' and $\overline{V_{cn}}$ for 'c'.

⇒ $\overline{V_{an}}, \overline{V_{bn}}, \overline{V_{cn}}$ are phase voltages.

⇒ $\overline{V_{ab}}, \overline{V_{bc}}, \overline{V_{ca}}$ are called line-to-line voltages / Line voltages.

let,

$$\overline{V_{an}} = V_p \angle 0, \quad V_{bn} = V_p \angle -120^\circ, \quad \overline{V_{cn}} = V_p \angle 120^\circ$$

P : phase,

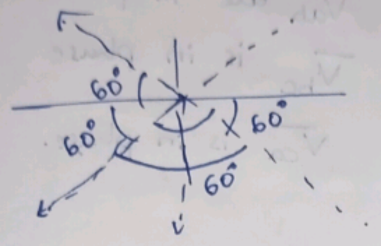
If three voltages are having same RMS value and if the modulus of phase difference b/w any two of these three voltages is 120°, then the three voltages are said to be balanced.

Now

$$\overline{V_{ab}} = \overline{V_{an}} - \overline{V_{bn}} = V_p \angle 0 - V_p \angle -120^\circ = \sqrt{3}\, V_p \angle 30^\circ$$

$\overline{V}_{bc} = \overline{V}_{bn} - \overline{V}_{cn}$

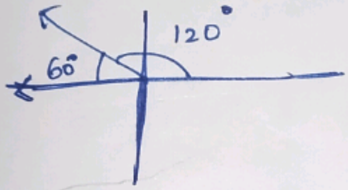
$= V_p \angle -120^\circ - V_p \angle 120^\circ = \sqrt{3}\, V_p \angle -90^\circ$



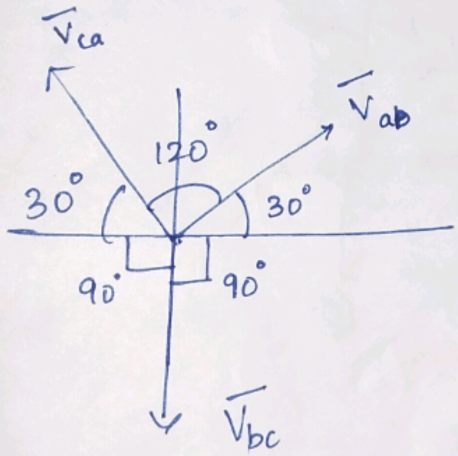
$\overline{V}_{ca} = \overline{V}_{cn} - \overline{V}_{an}$

$= V_p \angle 120^\circ - V_p \angle 0^\circ$

$= \sqrt{3}\, V_p \angle +150^\circ$



So



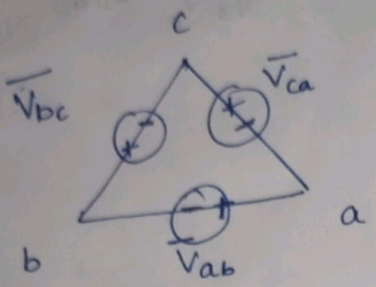
Let $V_L = \sqrt{3}\, V_p$

So $\overline{V}_{ab} = V_L \angle 30^\circ$

$\overline{V}_{bc} = V_L \angle -90^\circ$

$\overline{V}_{ca} = V_L \angle 150^\circ$

Delta Connection: (Δ-connection)



$\overline{V_{ab}}$ is in phase

$\overline{V_{bc}}$ is in phase

$\overline{V_{ca}}$ is in phase.

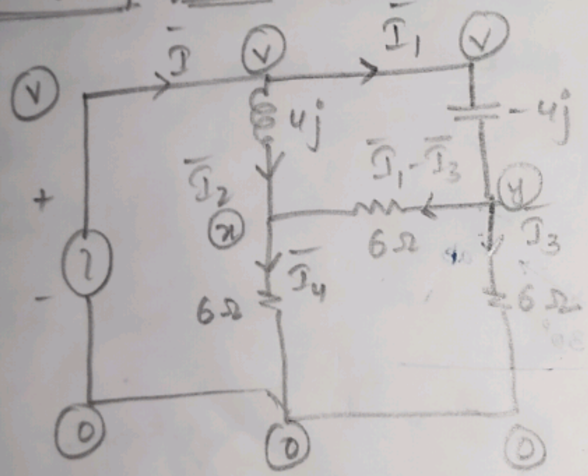
$\Rightarrow$ a, b, c are the line terminals

$\Rightarrow$ $\overline{V_{ab}}$, $\overline{V_{bc}}$, $\overline{V_{ca}}$ are phase voltages. We can also call them as line voltages.

continued from pg. 117.

Some imp questions:

Q)

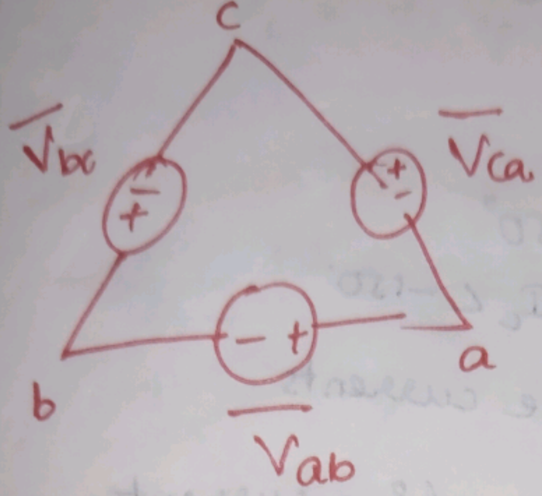


$$\bar{v} - \bar{x} = \bar{I}_2 (4j)$$

and
$$\frac{(\bar{x} - \bar{v})}{4j} + \frac{\bar{x} - \bar{y}}{6} + \frac{\bar{x}}{6} = 0$$

$$\frac{\bar{y} - \bar{v}}{-4j} + \frac{\bar{y} - \bar{x}}{6} + \frac{\bar{y}}{6} = 0$$

*



let $\overline{V}_{ab} = V_p \angle 0$

$\overline{V}_{bc} = V_p \angle -120°$

$\overline{V}_{ca} = V_p \angle 120°$

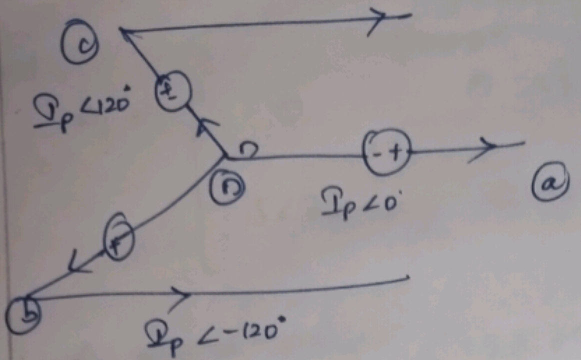
3 phase voltage source.

line voltage = phase voltage

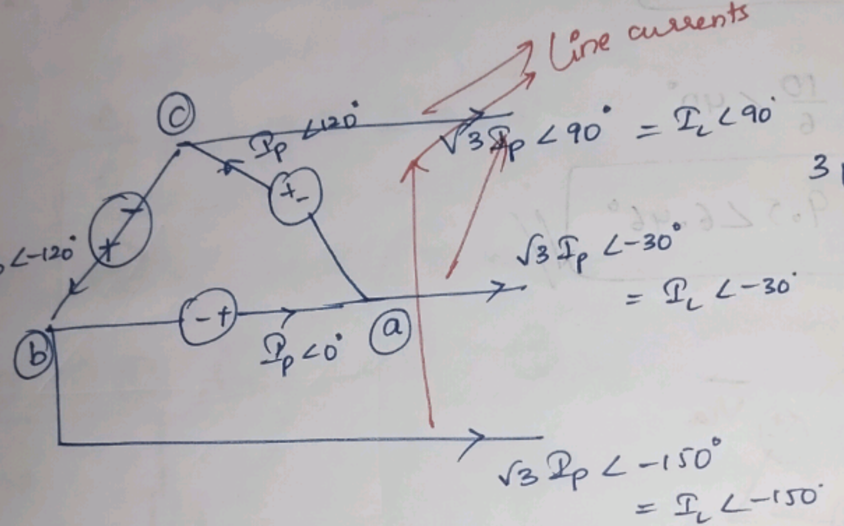
V_p : RMS value of phase voltage

V_L : RMS value of line voltage.

* Comparision:-



3phase voltage source
phase
(currents)



3 phase voltage source
(currents)

$\Rightarrow$ $I_p \angle 0$, $I_p \angle -120°$, $I_p \angle 120°$ are phase currents

$\Rightarrow$ $\sqrt{3} I_p \angle 90°$, $\sqrt{3} I_p \angle -30°$, $\sqrt{3} I_p \angle -150°$ are line currents.

$\Rightarrow$ Line current RMS value $= \sqrt{3}$ (phase current RMS value)

$$\boxed{I_L = \sqrt{3} I_p}$$

Wye

$$\boxed{\begin{aligned} V_L &= \sqrt{3} V_p \\ I_L &= I_p \end{aligned}}$$

Delta.

$$\boxed{\begin{aligned} V_L &= V_p \\ I_L &= \sqrt{3} I_p \end{aligned}}$$

where,

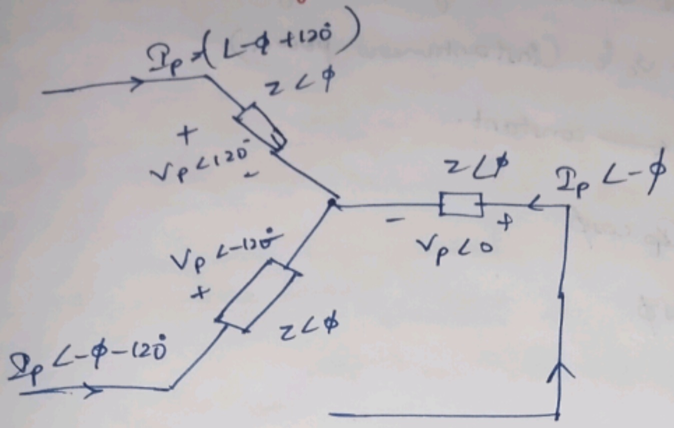
V_L = RMS value of line voltage

V_p = RMS value of phase voltage

I_L = RMS value of line current

I_p = RMS value of phase current.

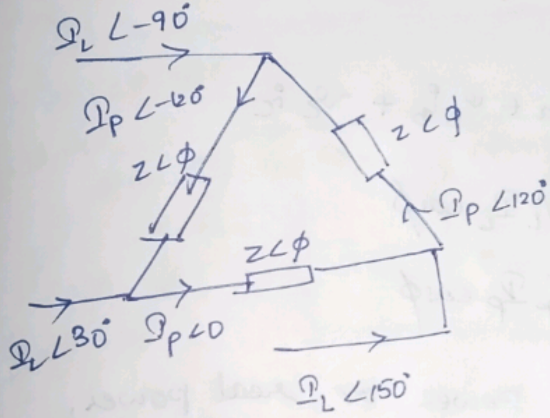
Impedences in star/or wye connection:-



Here $I_L = I_P$

$V_L = \sqrt{3}V_P$

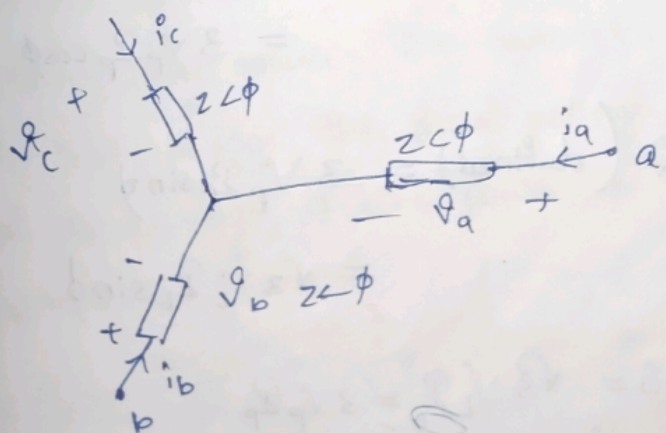
Impedences in delta connection:



$V_P = V_L$

$I_L = \sqrt{3}I_P$

Instantaneous voltages:



$V_a = \sqrt{2}V_p\sin(\omega t)$

$V_b = \sqrt{2}V_p\sin(\omega t-120^\circ)$

$V_c = \sqrt{2}V_p\sin(\omega t+120^\circ)$

$i_a = \sqrt{2}I_p\sin(\omega t-\phi)$

$i_b = \sqrt{2}I_p\sin(\omega t-\phi-120^\circ)$

$i_c = \sqrt{2}I_p\sin(\omega t-\phi+120^\circ)$

⇒ Instantaneous power consumed by the wye-connected impedances,

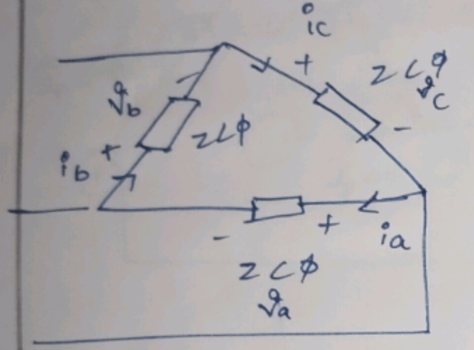
$p = v_a i_a + v_b i_b + v_c i_c$ (instantaneous power)

$= 3 V_p I_p \cos\phi \leftarrow$ constant.

$= \sqrt{3} (\sqrt{3} V_p) I_p \cos\phi$

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

Now,



Instantaneous power $= v_a i_a + v_b i_b + v_c i_c$

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

$= 3 V_p I_p \cos\phi$

* For both wye & delta.

Active power or average power or real power,

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

$$= 3 V_p I_p \cos\phi$$

Reactive power, Q (defined) $= 3 V_p I_p \sin\phi$

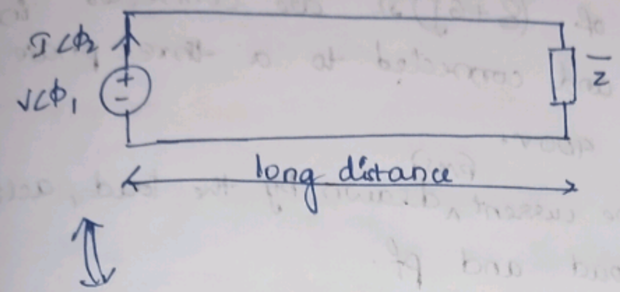
$= \sqrt{3} V_L I_L \sin\phi$

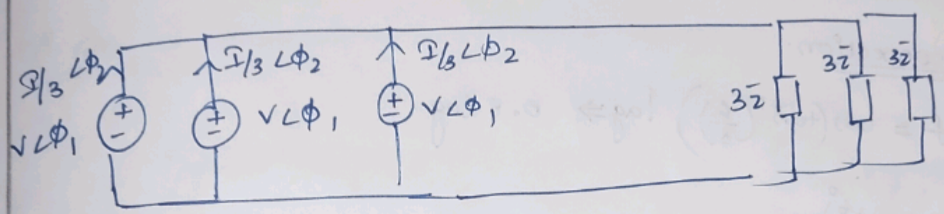
Apparent power, $S = \sqrt{3} V_L I_L = 3 V_p I_p$

Complex power, $\boxed{\bar{S} = P + jQ}$

Now,

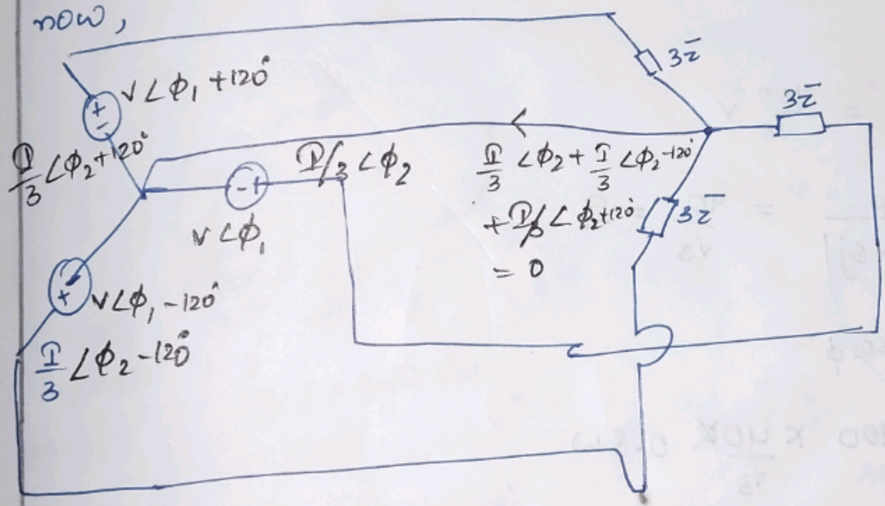
For,





So,

now,



Q) A star connected load is supplied from a 400V three phase voltage source. The current in each phase of load is 30A & lags the phase voltage by 30°. Find RMS value of phase voltage, active power of load & reactive power consumed by load.

Sol: $V_p = \frac{400}{\sqrt{3}} = 230.9$, Active power consumed by load $= 3\left(\frac{400}{\sqrt{3}}\right)(30)\left(\frac{\sqrt{3}}{2}\right)$

$\Rightarrow 18000W$

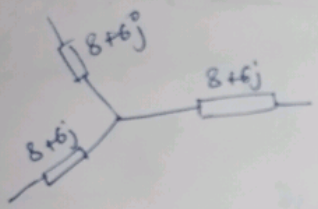
reactive power = $6\sqrt{3}$ kVAR.

$= 6\sqrt{3} \times 10^{3}$ VAR.

Q) Three identical impedances of $(8+6j)\,\Omega$ are connected in wye and then in delta and connected to a three phase voltage source of voltage 400V.
In each case find the line current drawn by the load, active power consumed by the load and pf.

Wye connection.

$$pf = \cos\left(\tan^{-1}\left(\frac{6}{8}\right)\right) \text{ lag} \Rightarrow 0.8 \text{ lag}$$



$$V_P = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}}\ \text{V}.$$

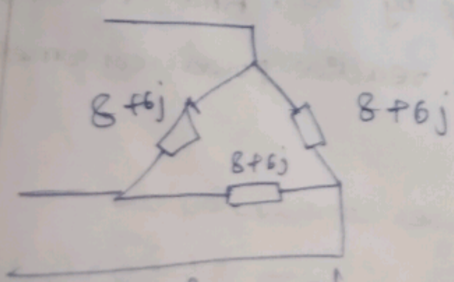
$$I_P = \frac{V_P}{|8+6j|} = \frac{40}{\sqrt{3}} = I_L$$

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

$$= \sqrt{3} \times 400 \times \frac{40}{\sqrt{3}} \times 0.8\ \text{W}$$

$$= 12.80\ \text{kW}$$

Delta connection



$pf = 0.8$ lag

$$V_L = 400 = V_P$$

$$I_P = \frac{V_P}{|8+6j|} = 40$$

$$I_L = \sqrt{3}\, I_P = 40\sqrt{3}$$

(18) $P = \sqrt{3} V_L I_L \cos\phi = \sqrt{3} \times 400 \times 40\sqrt{3} \times 0.8$

$= 3(12.80\,kW)$

$= 38.40\,kW$

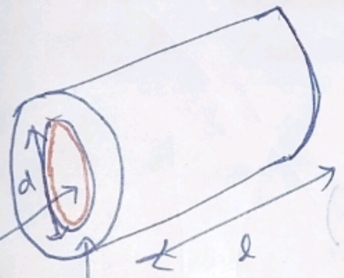
* Three phase induction motor:-

Rotating machine → stationary part — Stator
→ Rotatory part — Rotor

Principle of operation:-

Cylindrical shape,

1. Magnetic core.
2. Conductors
3. Insulation

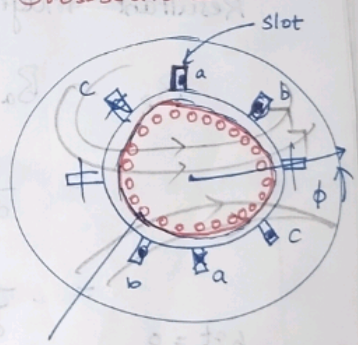


Solid cylinder (rotor)

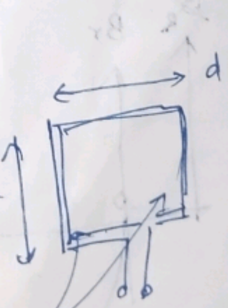
anular cylinder (stator)

(Both are magnetic cores)

Cross sectional view



rotor conductors.



Coils a, b, c form a three phase winding

— stator winding

The stator winding is connected across a three phase voltage source.

⇒ Let the currents in the three coils be i_a, i_b, i_c. Let

$i_a = \sqrt{2} I \sin(\omega t)$ where 'ω' is angular frequency of voltage source.

$i_b = \sqrt{2} I \sin(\omega t - 120°)$

$i_c = \sqrt{2} I \sin(\omega t + 120°)$

Flux density in the radial outward direction due to i_a, at any point at an angle ϕ on the inner surface of stator or outer surface of rotor.

$$B_a = B_m \sin(\omega t) \cos\phi$$

$$B_b = B_m \sin(\omega t - 120°) \cos(\phi - 120°)$$

$$B_c = B_m \sin(\omega t + 120°) \cos(\phi + 120°)$$

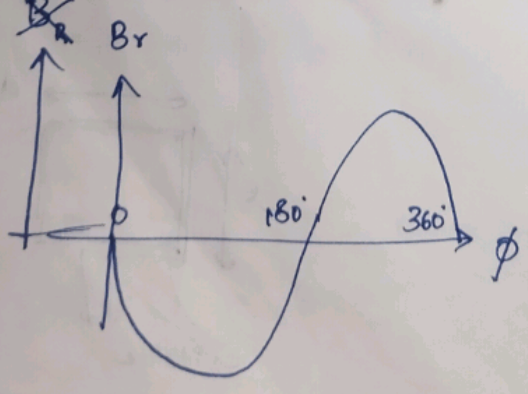
Resultant magnetic flux density

$$B_R = B_a + B_b + B_c$$

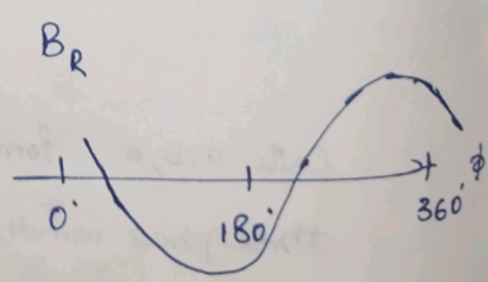
$$= \frac{3}{2} B_m \sin(\omega t - \phi)$$

$$= \frac{-3}{2} B_m \sin(\phi - \omega t)$$

$\omega t = 0$

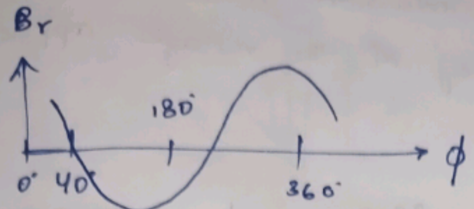


$\omega t = 20°$



and after some more time,

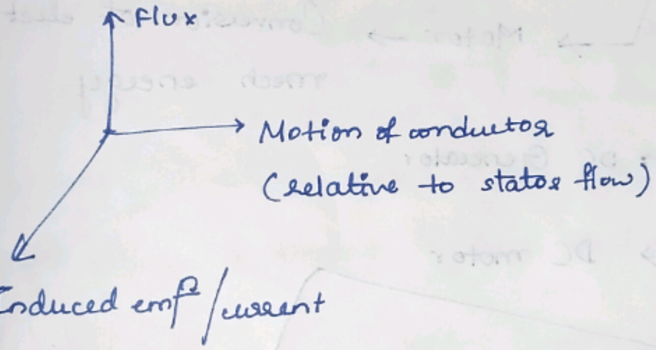
$\omega t = 40^\circ$

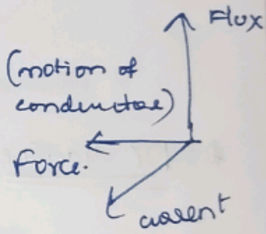


Rotating speed → ω (rad/s)
→ rotating magnetic field.

Initially rotor is at rest. Faraday's law, emf induced in the rotor conductors. Rotor current flows. Rotor conductors will carry current are placed in a magnetic field ⇒ they experience a force/torque. Rotor rotates in the dirⁿ of rotating magnetic field.

Fleming's right hand rule





⇒ Rotor at steady state rotates at a speed which is less than 'ω'.

ω_r = speed of rotor in rad/s, $\omega_r < \omega$.

Slip, $s = \dfrac{\omega - \omega_r}{\omega} = \dfrac{N_s - N_r}{N_s}$.

$$\boxed{\begin{aligned} N_s &= \frac{30}{\pi}\omega \\ N_r &= \frac{30}{\pi}\omega_r \end{aligned}}$$

rpm :- revolutions per minute.

Speed of rotating magnetic field in RPM,
name given
N_s : synchronous speed.

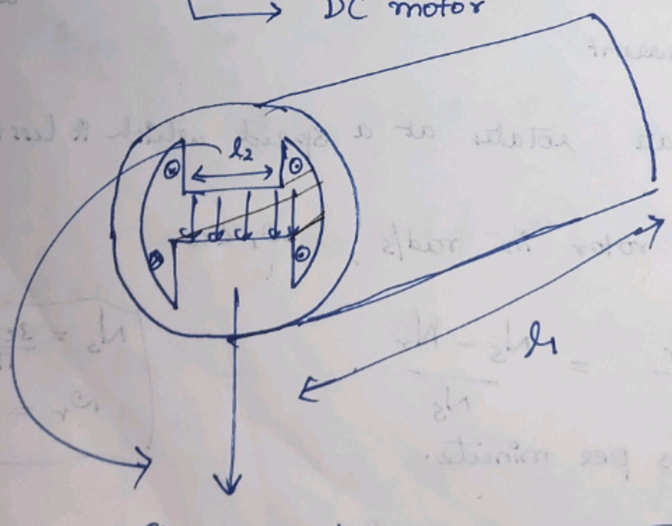
N_r : speed of rotor in RPM.

Q) The speed of the rotor of an induction motor is 2940RPM, & the slip is 2%. find the frequency of the voltage applied to the stator winding.

$$S = \frac{N_s - N_r}{N_s} \Rightarrow 0.02 = \frac{N_s - 2940}{N_s} \Rightarrow N_s = 3000\,RPM.$$

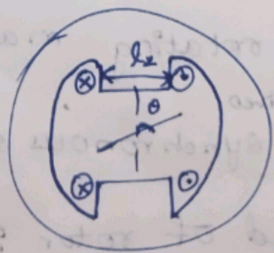
$\omega = \frac{N_s \pi}{30}$, frequency of voltage applied to stator winding $= \frac{\omega}{2\pi} = 50Hz$.

* Motor ⟶ Rotating machine,
* Rotating machine ⟶ Generator ⟶ Conversion of mechanical to electrical energy.
  ⟶ Motor → Conversion of elect to mech energy
* DC Machine :- ⟶ DC Generator
  ⟶ DC motor

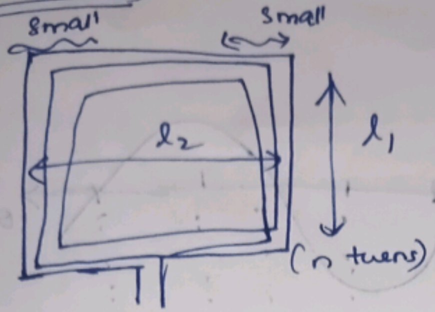


Crosssection :-

(plane $\perp^{er}$ to axis of cylinder)



DC Generator:-

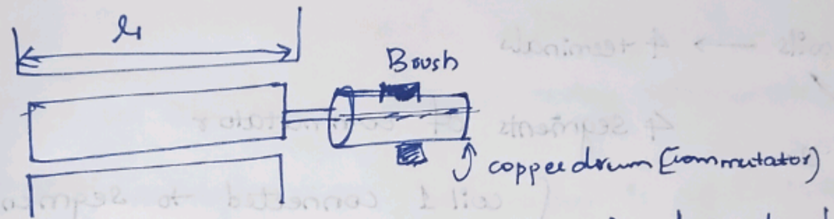


Flux linkage of coil = Number of turns x Flux linking the coil.

Coil is placed between the two poles of electromagnet.

Crosssection:-

(plane parallel to axis of cylinder)



Coil is rotated at a speed ω (in rad/s). Let ϕ be the magnetic flux produced by the electromagnet.

'θ': Angle made by coil wrt direction of flux.

Flux linking the coil $= \phi \sin\theta$

EMF induced in the coil $= n \frac{d}{dt}(\phi \sin\theta)$

$$= n\phi \cos\theta \frac{d\theta}{dt}$$

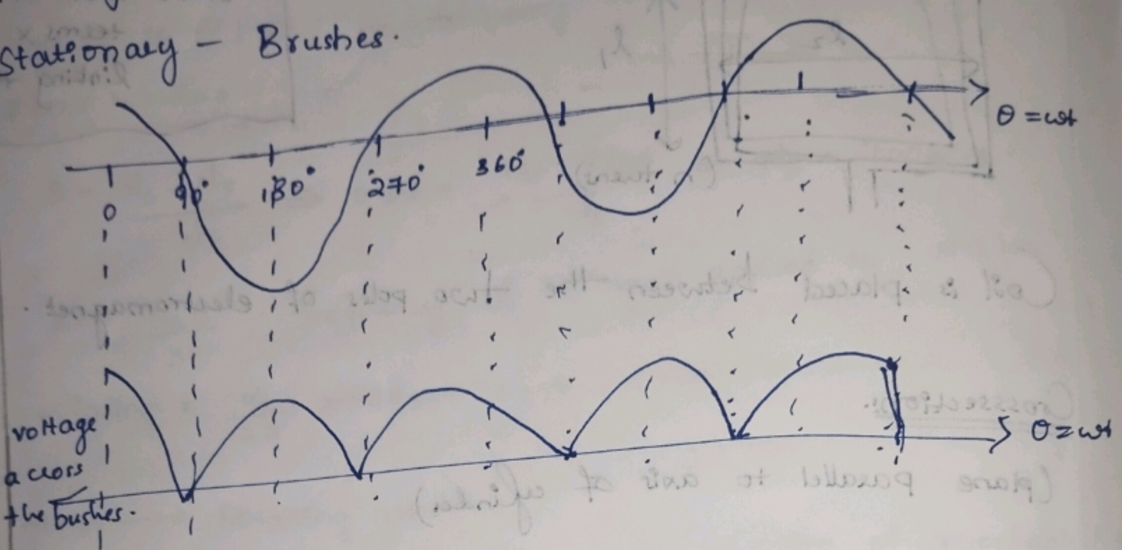
$$= n\phi \cos\theta \, \omega$$

$\boxed{\theta = \omega t}$ ('ω' is kept const as we are only rotating)

$$V_e = \boxed{EMF = n\phi\omega \cos(\omega t)}$$

Rotating-coil, commutator

Stationary – Brushes.



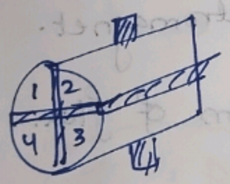
2 coils ⟶ 4 terminals

4 segments of commutator

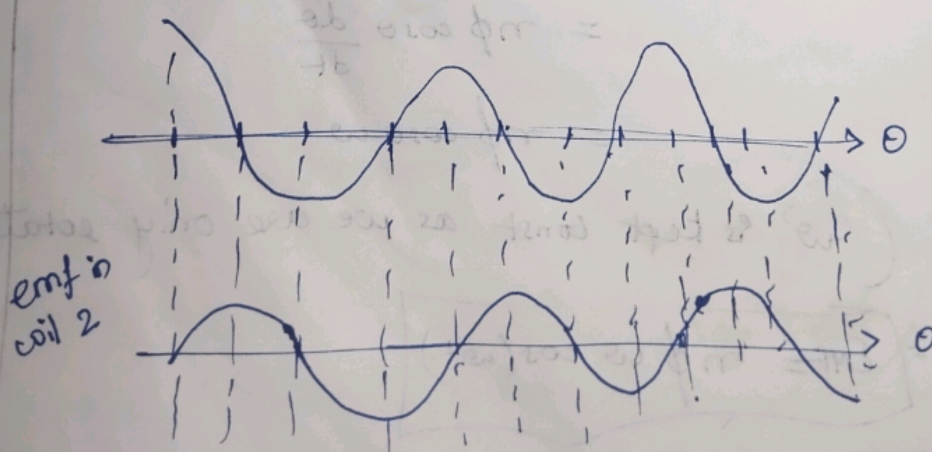
coil 1 &

coil 2

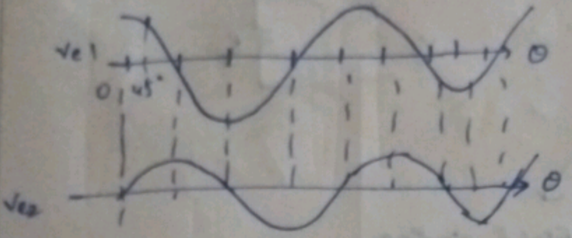
{ coil 1 connected to segments 1 & 3
coil 2 connected to segments 2 & 4.

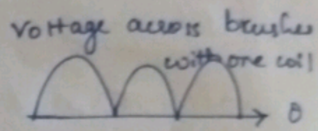


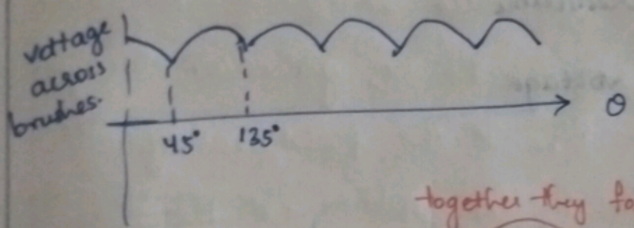
EMF in coil 1



DC Generators







together they form "armature winding".

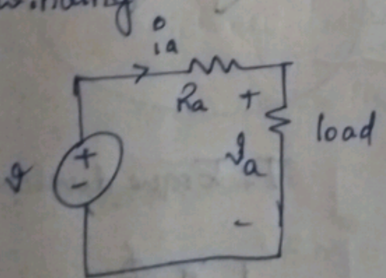
⇒ In practice there are many coils & many commutator segments, so that the voltage across the brushes is DC (constant).

⇒ The load is connected across the brushes.

⇒ Brushes are terminals of armature winding.

⇒ Voltage across brushes is called EMF induced in armature winding.

⇒



Subscript 'a' for armature.

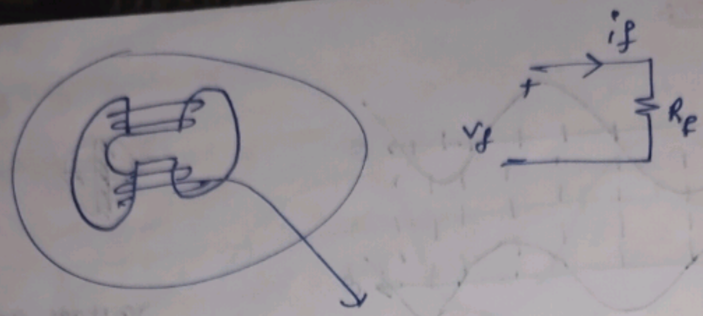
v : EMF induced in armature winding.

v_a : armature terminal voltage.

R_a : armature resistance.

i_a : armature current.

$$\boxed{v_a = v - i_a R_a}$$



Field winding

R_f : field winding resistance

V_f : field winding voltage

i_f : field current.

$V \propto \phi$ where 'ϕ' is magnetic flux

N : speed of rotor in RPM

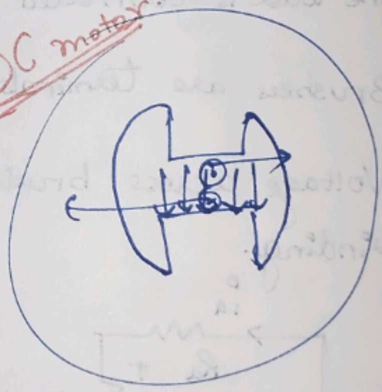
$V \propto N$

$\boxed{V \propto N\phi}$

DC Machine

- DC Generator
- DC motor

DC motor



T : Torque developed

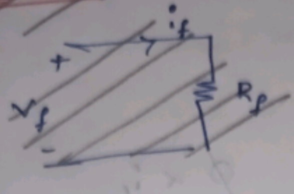
$T \propto \phi$

$T \propto i_a$

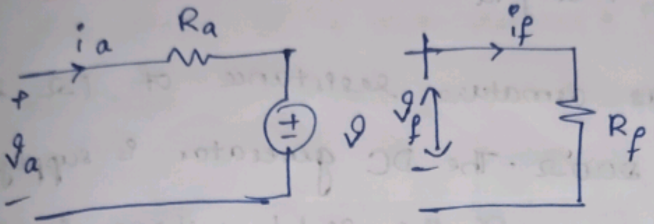
$\boxed{T \propto \phi i_a}$

131

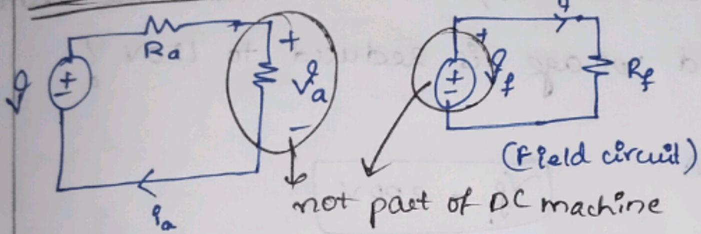
~~DC motor~~



DC motor



DC Generator:-



(Field circuit)

(Armature circuit)

(Assumption:- Effect of 'i_a' on magnetic flux is negligible)

all same for DC motor also

v : emf induced in armature

R_a : armature resistance

i_a : armature current

v_a : armature terminal voltage.

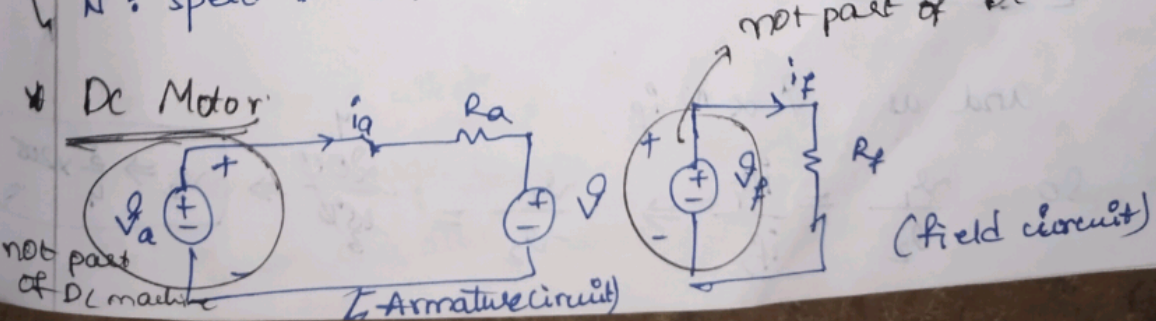
v_f : Voltage applied to field winding

i_f : field current

ϕ : Magnetic flux produced by i_f

N : speed in RPM

DC Motor



(Armature circuit)

(field circuit)

T: Torque developed

DC Generator & DC motor

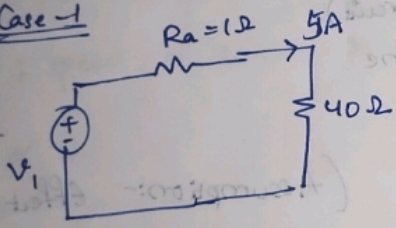
$V \propto N\phi \Rightarrow V \propto N i_f$ | $\phi \propto i_f$

DC motor

$T \propto \phi i_a \Rightarrow T \propto i_f i_a$

Q.) A DC generator has armature resistance of 1Ω & field resistance of 200Ω. The DC generator is supplying power to a 40Ω resistor. If the field voltage is 200V, the armature current is 5A, what will be the armature current if the field voltage is reduced to 150V?

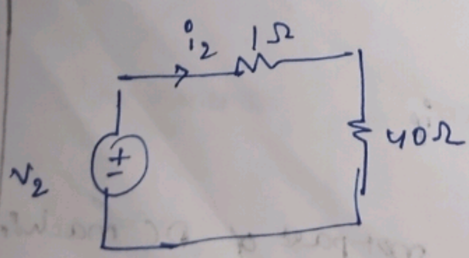
Sol: Case-1

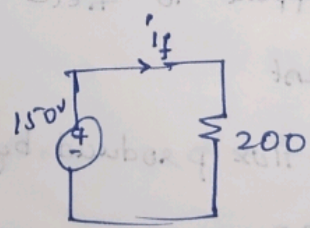


$\boxed{V_f = 200V}$

$V_1 = 5(41) = 205\,V$

Case-2





and as $V \propto N i_f$

So $\dfrac{V_1}{V_2} = \dfrac{i_{f_1}}{i_{f_2}} \Rightarrow \dfrac{V_1}{V_2} = \dfrac{\cancel{200}^{4}}{\cancel{150}_{3}} \Rightarrow \boxed{V_2 \Rightarrow \frac{3}{4} \times 205}$

and hence

$$\frac{3}{4}(\overset{5}{205}) = i_2(41)$$

$$i_2 = \frac{15}{4} A \Rightarrow 3.75 \text{ Amp.}$$

Q) A DC generator while running at 1000 RPM is supplying 1KW power to a 50Ω resistor. If speed is reduced to 800 RPM, what will be power supply. ($R_a = 1\Omega$)

Sol.

$$1000 = i_{a_1}^2(50) \Rightarrow \boxed{i_{a_1}^2 = 20} \Rightarrow \boxed{v_1 = 51(\sqrt{20})}$$

$$\boxed{v_1 = 228.1 \text{ volts}}$$

$$x = i_{a_2}^2(50)$$

$$\boxed{x = \frac{i_{a_2}^2}{i_{a_1}^2}}$$

$$\frac{v_2}{v_1} = \frac{N_2 i_{f_2}}{N_1 i_{f_1}} = \frac{N_2}{N_1}$$

$$\Rightarrow \frac{v_2}{228.1} = \frac{800}{1000}$$

$$\boxed{v_2 = \sqrt{\ }}$$

$\cancel{i_{a_1} = \frac{v_1}{1+50}}$ $\cancel{i_{a_2} = \frac{v_2}{51}}$

$\cancel{i_{a_2} = \frac{v_2}{1+x}}$ $\boxed{\cancel{x = \frac{v_2^2}{v_1^2}}}$

$\cancel{x = \frac{N_2^2}{N_1^2}}$

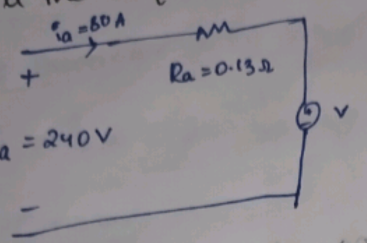
$\cancel{x = }$

and power $= \left(\frac{v_2}{51}\right)^2 (50)$ ⇓

Q) The armature winding of a DC motor is connected to a 240V voltage source. Armature resistance ~~of~~ is 0.13Ω & armature current is 80A. Motor runs at ~~8~~40 RPM

(134) Find the torque developed.

Sol:



$V(i_a) =$ mechanical power

$v = v_a - i_a R_a = 240 - 80(0.13) = 229.6V$

$N = 440 RPM = 440 \times \frac{2\pi}{60}$

$\Rightarrow \frac{880\pi}{60} \Rightarrow \frac{44\pi}{3}$

$$\boxed{T = \frac{(229.6)(80)(3)}{44\pi}}$$

and $\boxed{T\omega = \text{mechanical power}}$

$$\boxed{T = 398.6\ Nm}$$

* DC Machines:-

$V \propto N\phi \Rightarrow V = k_1 N \phi$

$T \propto \phi i_a \Rightarrow T = k_2 \phi i_a$

and as $v i_a = \frac{T N \pi}{30}$

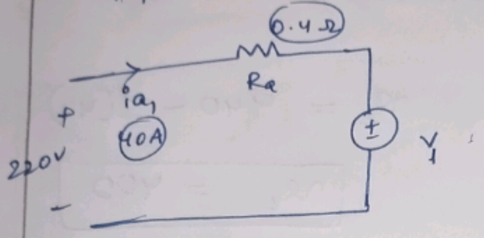
$$\boxed{K_1 = \frac{K_2 \pi}{30}}$$

Q) A DC motor has armature resistance of 0.4Ω. The armature is connected to a 220V voltage source. The motor runs at 1500RPM when the armature current is 40A. What will be

(185) the speed if the armature current is 40 A. What will be the speed if armature current changes to 10A.

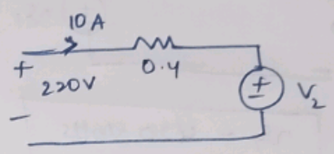
Case-1

$N_1 = 1500 RPM$, $i_{a_1} = 40A$



Case-2

$N_2 = ?$, $i_{a_2} = 10A$



$v_1 = 220 - 40(0.4)$

$$\boxed{v_1 = 204 \text{ volts}}$$

$v_2 = 220 - 10(0.4)$

$$\boxed{v_2 = 216 \text{ volts}}$$

$$\frac{v_2}{v_1} = \frac{N_2}{N_1}$$

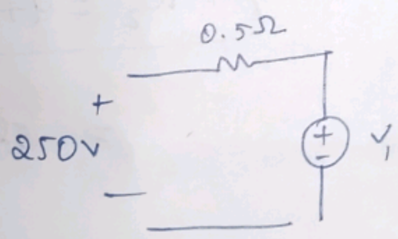
$$\left(\frac{216}{204}\right) = \left(\frac{N_2}{1500}\right)$$

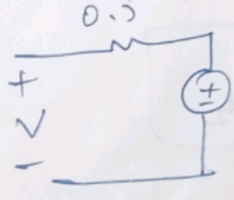
$$\boxed{N_2 = 1588 \text{ RPM}}$$

Q) A DC motor draws an armature current of 20A and runs at 1000 RPM, when the armature is connected to a 250 V voltage source, armature resistance is 0.5 Ω. If the speed is reduced to 500 RPM without torque change, what should be armature terminal voltage

$N = 1000 RPM$

500 RPM





$V_2 = \left(\frac{v_1}{2}\right)$

$250 - i_a(0.5) = v_1$

$V - i_a(0.5) = \frac{v_1}{2}$

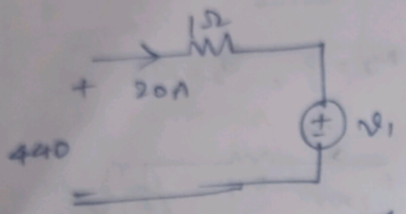
$2V - i_a = 250 - \frac{i_a}{2}$

$2V = 125 + \frac{i_a}{4}$ ($\&$ $i_a = 20A$)

$\Rightarrow \boxed{V = 130}$

Q) A DC motor draws an armature current of 20A and runs at 500RPM, when armature is connected to 440V source. ($R_a = 1\Omega$) If the flux reduces by 30% and 'τ' increases by 40% simultaneously what are new values of armature current & speed.

$N = 500RPM$



$$\boxed{v_1 = 420 \text{ volts}}$$

$$v_2 = 440 - 1(40)$$

$$\boxed{v_2 = 400}$$

$$\phi_2 = \frac{7\phi_1}{10}$$

$$\frac{T_1}{T_2} = \frac{\phi_1 i_{a_1}}{\phi_2 i_{a_2}} = \left(\frac{10}{7}\right)\frac{i_{a_1}}{i_{a_2}}$$

$$T_2 = \frac{14 T_1}{10}$$

$$\frac{\cancel{10}}{\cancel{14}_2} = \frac{\cancel{10}}{\cancel{7}}\left(\frac{i_{a_1}}{i_{a_2}}\right)$$

$$2 = \frac{i_{a_2}}{i_{a_1}}$$

$$\boxed{40A = i_{a_2}}$$

$$\frac{v_1}{v_2} = \frac{N_1 \phi_1}{N_2 \phi_2}$$

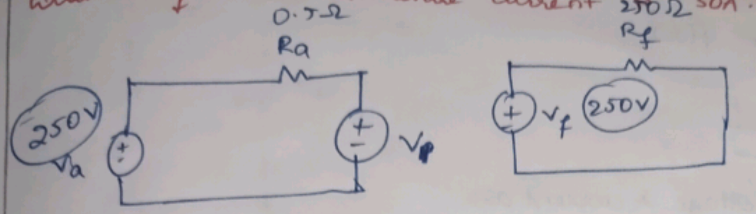
$$\frac{42\cancel{0}}{40\cancel{0}} = \frac{500}{N_2}\left(\frac{10}{7}\right)$$

$$\boxed{N_2 = 476.19 \times \frac{10}{7} \text{ RPM}}$$

$$= 680.27 \text{ RPM}$$

Q) The armature resistance and field resistance of a DC motor are 0.5Ω and 250Ω respectively. Both the armature & field windings are connected to a 250V voltage source. The motor

(13?) is running at 600RPM by $i_a = 20A$. If 'N' changed to 800RPM, 'τ' same, what is V_f. Rated armature current 30A.



$250 - 10 = 240$

$$\boxed{i_{f_1} = \frac{250}{250} = 1\,\text{Amp}}$$

$$\boxed{i_{a_1} = 20A}$$

$N_1 = 600RPM$

$N_2 = 800RPM$

$T_1 = T_2 \Rightarrow i_{f_1} i_{a_1} = i_{f_2} i_{a_2}$

$$\Rightarrow 20 = \left(\frac{v_f}{250}\right)(i_{a_2})$$

$$\frac{v_1}{v_2} = \frac{N_1}{N_2} \frac{i_{f_1}}{i_{f_2}}$$

183.59

$$\frac{240}{250 - i_{a_2}(0.5)} = \frac{600}{800} \frac{1}{i_{f_2}} \quad i_{f_2} \rightarrow \frac{20}{i_{a_2}}$$

we get quadratic in i_a and one will be rejected as $i_a \leq 30A$.

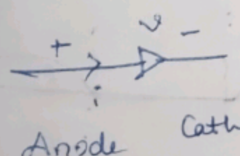
$$\left(\frac{240}{235}\right)\frac{800}{600} = \frac{1}{i_{f_2}}$$

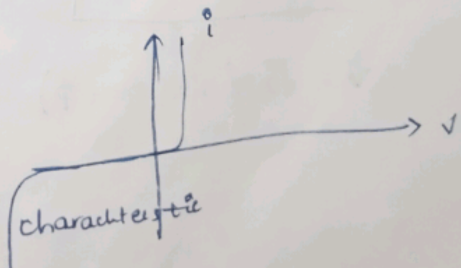
and

$$\frac{v_f}{250} = i_{f_2} \Rightarrow \boxed{v = 183.59\,\text{volts}}$$

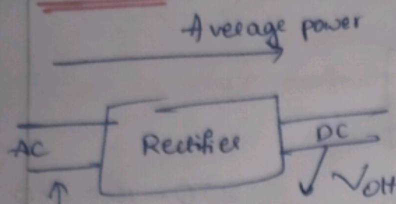
Rectifier circuits:

Diode - semiconductor device





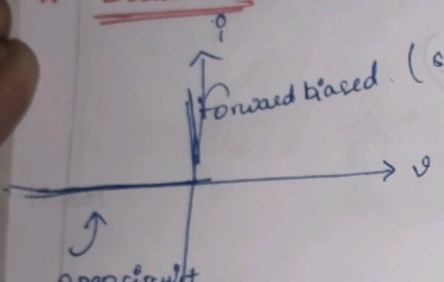
* Rectifier.



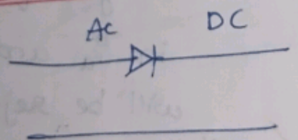
Voltage is sinusoidal
no comment on current's nature

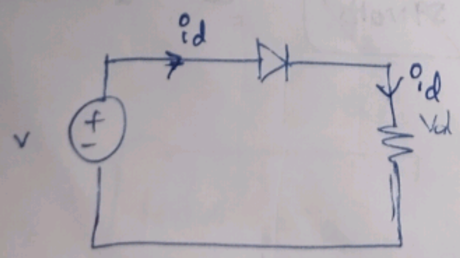
Voltage & current are periodic & have a nonzero avg value.

* Ideal diode

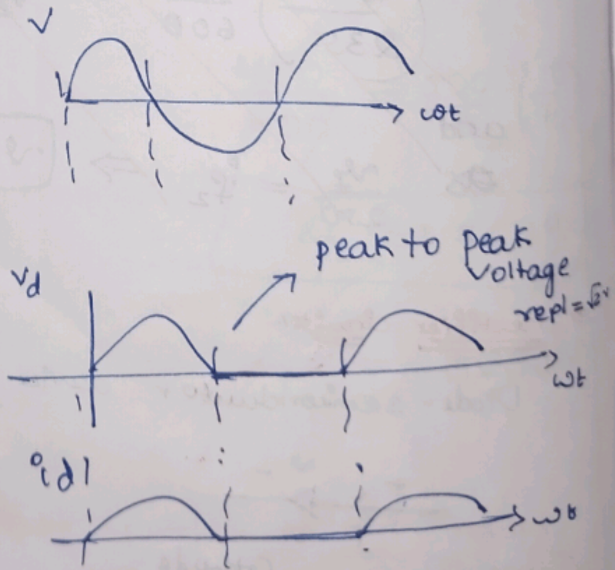


* Halfwave rectifier:-

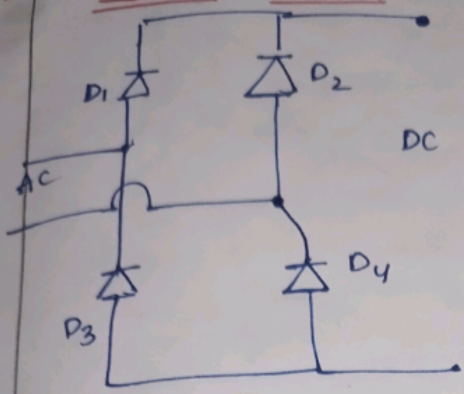




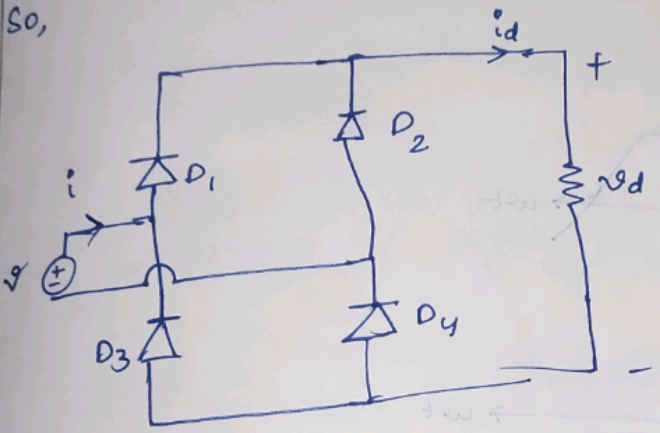
$v = \sqrt{2}\, V \sin(\omega t + \phi)$



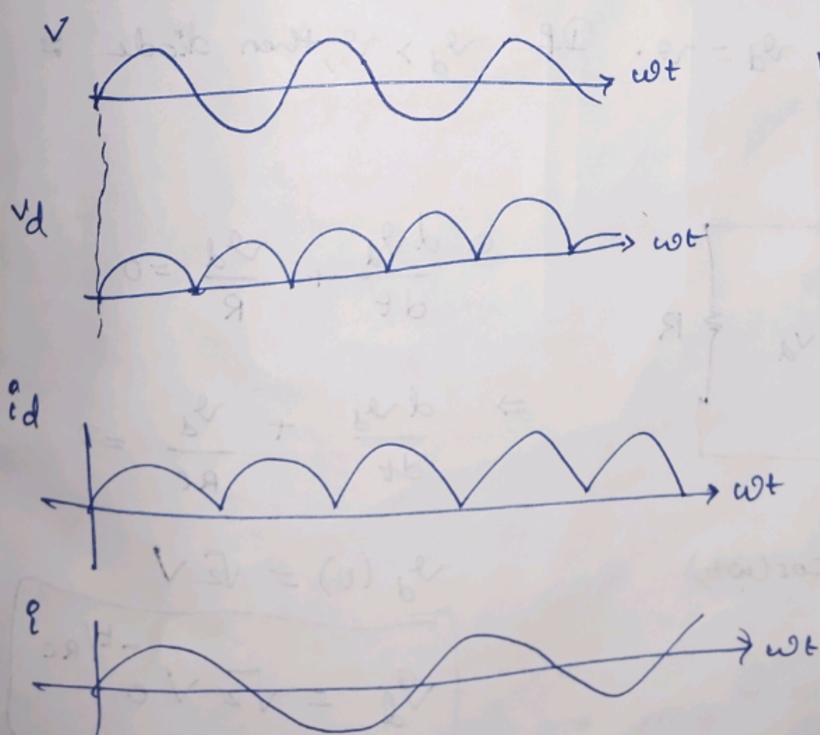
Full wave rectifier :-



So,

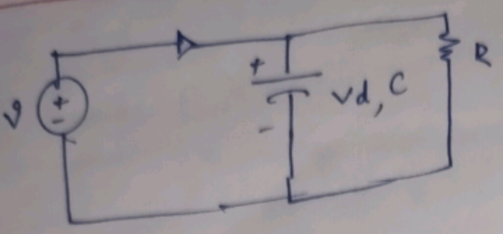


$v = \sqrt{2}\, V \sin(\omega t + \phi)$



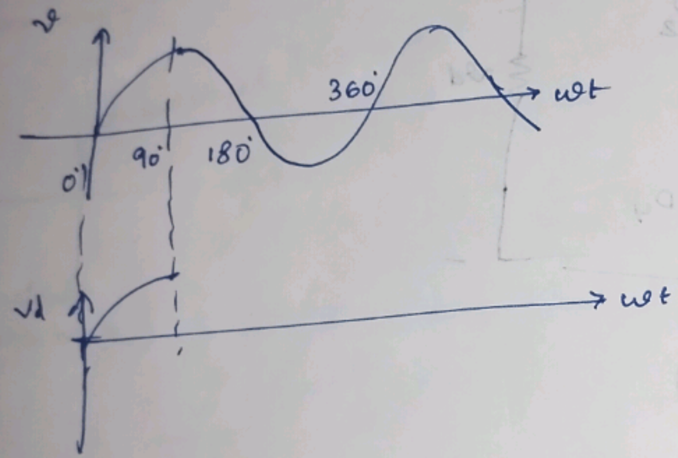
peak to peak voltage repl $= \sqrt{2}\, V$

(40) * Peak to peak voltage repl:

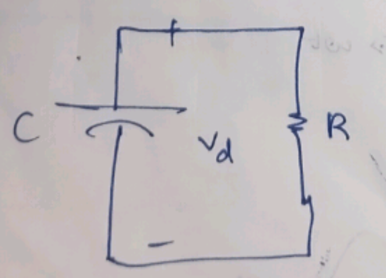


$v = \sqrt{2}\, V \sin(\omega t)$

$v_d(0) = 0$



If $v > v_d$ diode is forward bias. One diode is forward biased, $v_d = v$. If $v_d > v$, then diode is reverse biased.



$$C \frac{dv_d}{dt} + \frac{v_d}{R} = 0$$

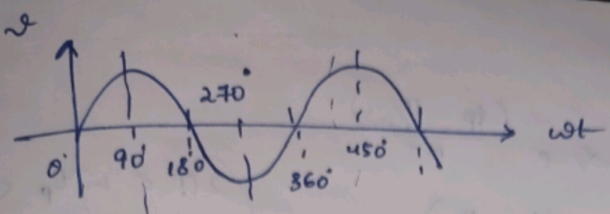
$$\Rightarrow \frac{dv_d}{dt} + \frac{v_d}{RC} = 0$$

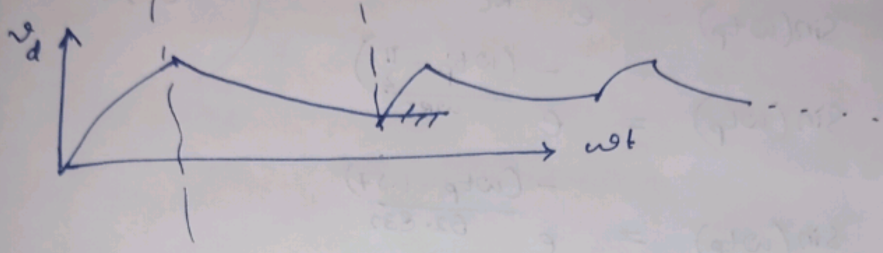
$v = \sqrt{2}\, V \cos(\omega t)$

$v_d(0) = \sqrt{2}\, V$

$$\boxed{v_d = \sqrt{2}\, V e^{-t/RC}}$$

(c)





Q) $V = 230$ volts, frequency $= 50\,Hz$, $R = 100\,\Omega$. Find 'c' such that peak-peak riple is 20V.

Sol: $230\sqrt{2}$ = is one peak.

$$(230\sqrt{2})\, e^{-\frac{t}{100C}} = (230\sqrt{2}) \sin\left(2\pi (50)(t)\right)$$

and $\quad 230\sqrt{2} - 230\sqrt{2}\sin(100\pi t) = 20V$

$$\frac{230\sqrt{2} - 20}{\cancel{230\sqrt{2}}} = 230\sqrt{2}\sin(100\pi t)$$

from here

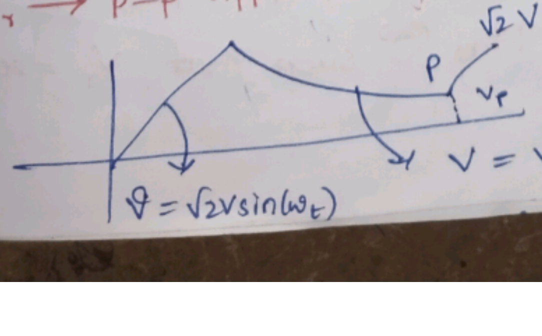
$$\boxed{2\pi < \omega t_p < \frac{5\pi}{2}}$$

$$(230\sqrt{2} - 20) = (230\sqrt{2})\, e^{-\frac{(t - \pi/2\omega)}{100C}}$$

we get 'C'.

Q) If in the previous problem $C = 2mF$, then what is the value of

$V_r \rightarrow$ p-p ripple voltage



$$V = \sqrt{2}\, V e^{-\frac{(t - \pi/2\omega)}{RC}}$$

$$\vartheta = \sqrt{2} V \sin(\omega t)$$

"Our dreams have to be bigger. Our ambitions higher. Our commitment deeper. And our efforts greater."

$V_r = \sqrt{2}V - V_p$

At $p \rightarrow$

$$\cancel{\sqrt{2}V}\sin(\omega t_p) = \cancel{\sqrt{2}V}\, e^{-\frac{(t_p - \pi/2\omega)}{RC}}$$

$$\sin(\omega t_p) = e^{-\frac{(t_p - \frac{\pi}{2\omega})}{RC}}$$

$$\sin(\omega t_p) = e^{-\frac{(\omega t_p - \frac{\pi}{2})}{\omega RC}}$$

$$\sin(\omega t_p) = e^{-\frac{(\omega t_p - 1.57)}{62.832}}$$

$$\left(\begin{array}{c} 2\pi < \omega t_p < \frac{5\pi}{2} \\ 6.28 < \omega t_p < 7.85 \end{array}\right)$$

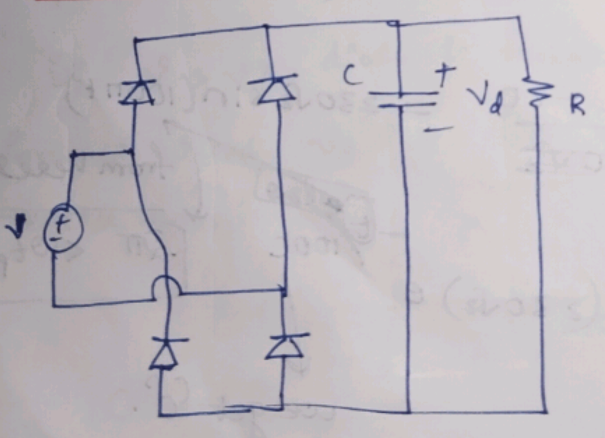
$$\omega t_p = 7.429$$

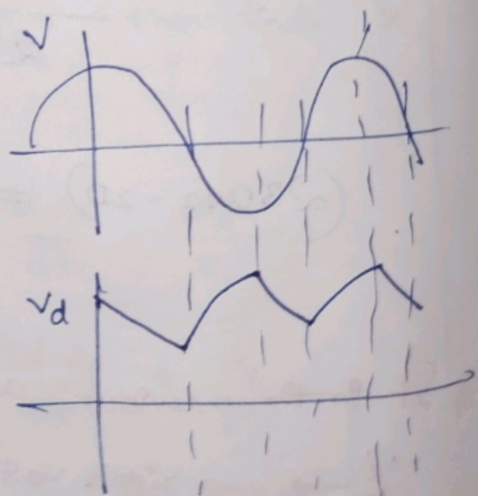
$$V_p = \sqrt{2}V\sin(7.429)$$

$$= \sqrt{2}V(0.911)$$

$$V_r = \sqrt{2}V(0.089) = 28.95V$$

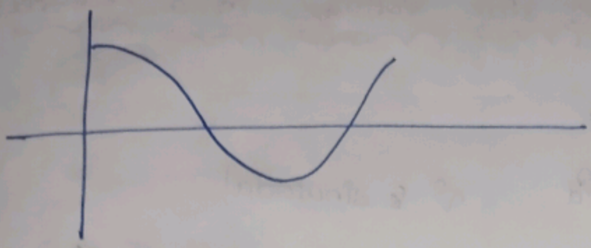
* Fullwave rectifier:-

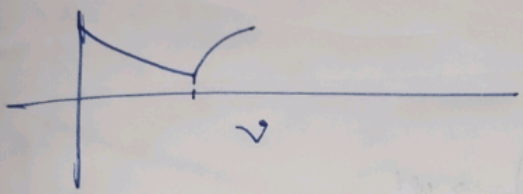


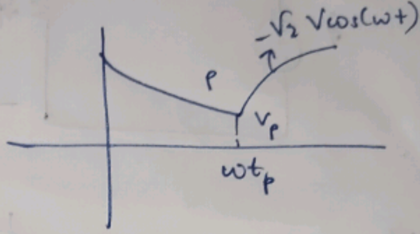


Q.) $V = 230$ volts, $f = 50$ Hz, Find 'C' such that $V_r = 20V$, $R = 100\Omega$.

(143)







$$V_r = \sqrt{2}V - V_p$$

$$V_p = \sqrt{2}(230) - 20 = 305.27V$$

$$\sqrt{2}Ve^{-\frac{t_p}{RC}} = -\sqrt{2}V\cos(\omega t_p)$$

$$e^{-\frac{t_p}{RC}} = -\cos(\omega t_p)$$

$$V_p = -\sqrt{2}V\cos(\omega t_p) = 305.27$$

$$\cos(\omega t_p) = -0.9385 \qquad \left(\frac{\pi}{2} < \omega t_p < \pi\right)$$

$$\omega t_p = 2.789 \qquad 1.57 < \omega t_p < 3.14)$$

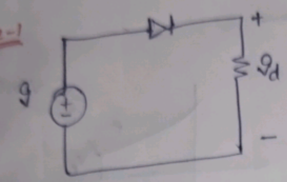
$$e^{-\frac{2.789}{\omega RC}} = 0.9385$$

$$\frac{2.789}{-\ln(0.9385)\omega R} = C$$

$$\Rightarrow \quad C = 0.001399F = 1.399mF$$

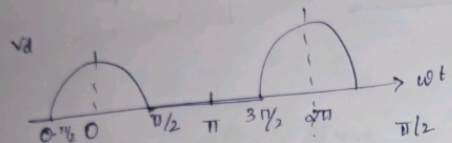
* Average value of a DC side voltage in a Rectifier:-

Case-1



v is sinusoidal

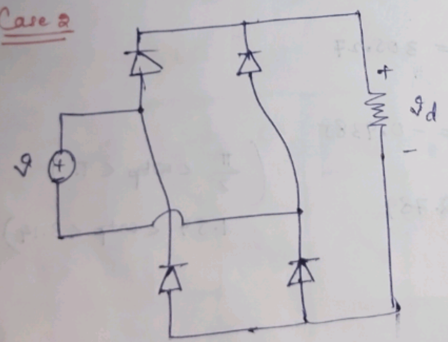
V is RMS value of v.



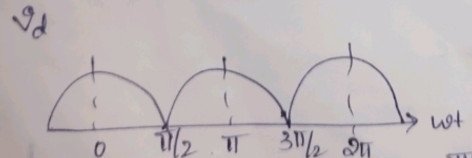
$$\text{Average value of } v_d = \frac{1}{\pi}\int_0^{\pi/2} \sqrt{2}V\cos(\omega t)\,d(\omega t)$$

$$= \frac{\sqrt{2}V}{\pi}$$

Case 2



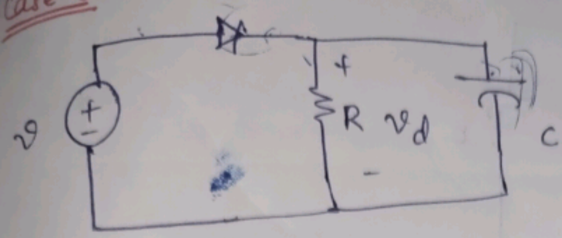
'V' is RMS of 'v'.



$$\text{Average value of } v_d = \frac{1}{(\pi/2)}\int_0^{\pi/2} \sqrt{2}V\cos(\omega t)\,d(\omega t) = \frac{2\sqrt{2}V}{\pi}$$

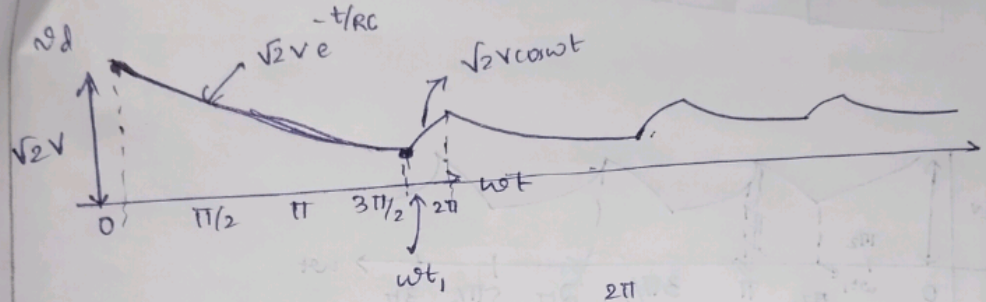
Rectifier:-

Case-3



v is sinusoidal

$v = \sqrt{2}\, V \cos(\omega t)$



Average value of $v_d = \frac{1}{2\pi}\int_0^{2\pi} v_d \, d(\omega t)$

$$= \left(\frac{1}{2\pi}\right)\left(\int_0^{\omega t_1} \sqrt{2}\, V e^{-t/RC} (\omega \, dt) + \int_{\omega t_1}^{2\pi} \sqrt{2}\, V \cos\omega t \, d(\omega t)\right)$$

$$= \left(\frac{1}{2\pi}\right)\left((\sqrt{2}\, V \omega)\left(e^{\frac{-t}{RC}}(-RC)\right)_0^{t_1} + \sqrt{2}\, V(-\sin\omega t_1)\right)$$

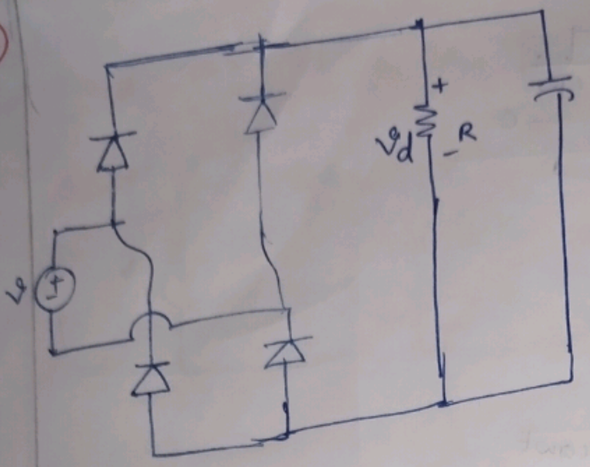
$$\Rightarrow \frac{1}{\sqrt{2}\,\pi}\left((V\omega RC)\left(1 - e^{-\frac{t_1}{RC}}\right) - V\sin\omega t_1\right)$$

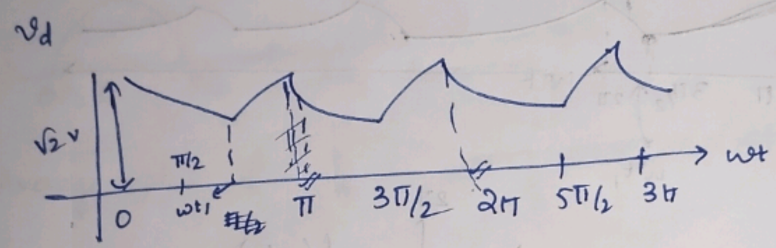
$$\Rightarrow \frac{V}{\sqrt{2}\,\pi}\left(\omega RC\left(1 - e^{-\frac{t_1}{RC}}\right) - \sin\omega t_1\right)$$

$) = \frac{2\sqrt{2}\,V}{\pi}$

* New other case

Case-4





Average value of $v_d = \frac{1}{\pi}\int_0^{\pi} v_d \, d(\omega t)$

$$= \frac{1}{\pi}\left[\int_0^{\omega t_1} \sqrt{2}\, V e^{-t/RC}\, d(\omega t) + \int_{\omega t_1}^{\pi} \left(-\sqrt{2}\, V \cos(\omega t)\right) d(\omega t)\right]$$

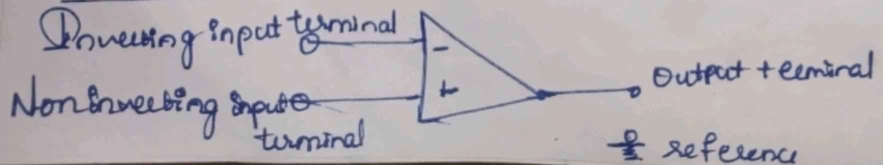
$$= \frac{\sqrt{2}\, V}{\pi}\left[\omega RC\left(1 - e^{-t_1/RC}\right) + \sin(\omega t_1)\right]$$

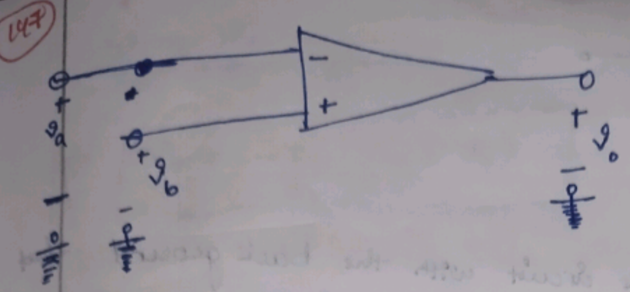
* **Operational amplifier:- (Op amp):**

Transistor (semiconductor device) — 3 terminals

→ Circuit consisting of many transistors, resistors & voltage sources.

Black box representation of op amp:-





Condition:

There should be a circuit element or short circuit between the output terminal & inverting input terminal.

Typically:

(1.) $$\frac{v_o}{v_b - v_a} = 10^5$$

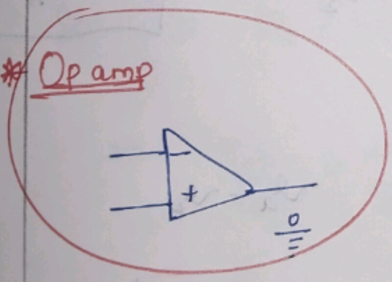
(2.) Current that flows into or out of the input terminals is of the order of nano Amperes ($10^{-9}A$) or less.

* **Ideal op amp**

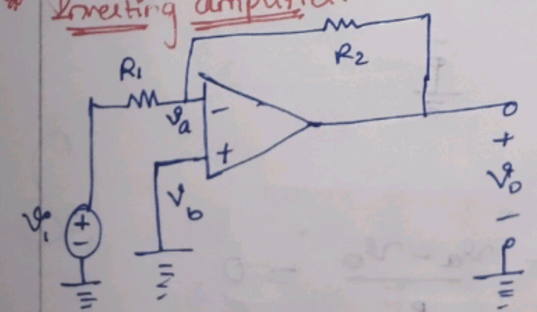
(1.) $v_b = v_a$

(2.) Current that flows into or out of the input terminals is zero.

* **Op amp**



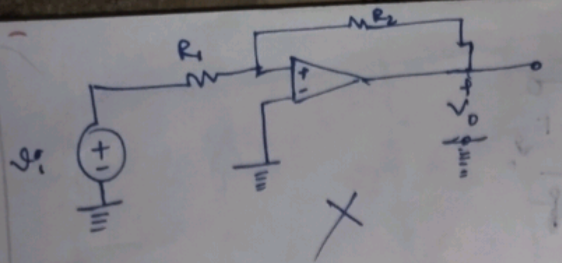
* **Inverting amplifier:-**



$$v_a = v_b = 0$$

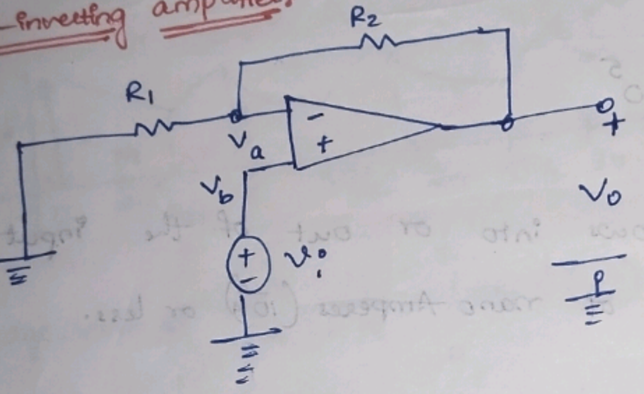
$$\frac{v_a - v_i}{R_1} + \frac{v_a - v_o}{R_2} = 0$$

$$\Rightarrow v_o = -\frac{R_2}{R_1} v_i$$



(We cannot analyse this circuit with the back ground that we have as there is no short or circuit element b/w inverting input terminal & output terminal)

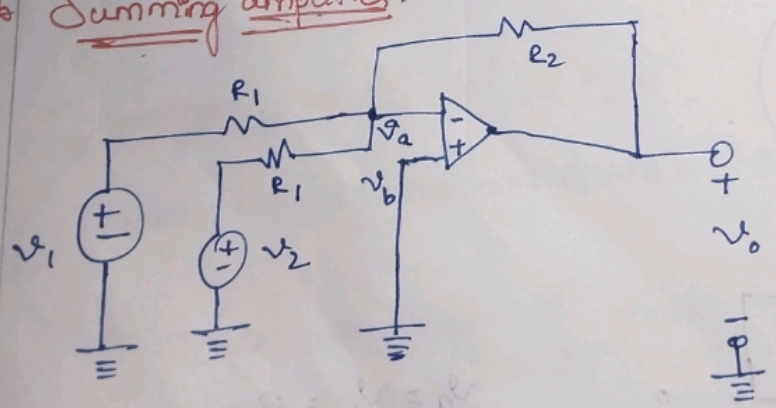
* **Non-inverting amplifier:-**



$$v_a = v_b = v_i$$

(KVL about v_a) $\dfrac{v_a}{R_1} + \dfrac{v_a - v_o}{R_2} = 0 \Rightarrow \dfrac{v_i}{R_1} + \dfrac{v_i - v_o}{R_2} = 0 \Rightarrow \boxed{v_o = \dfrac{R_1 + R_2}{R_1} v_i}$

* **Summing amplifier:-**



$$v_a = v_b$$

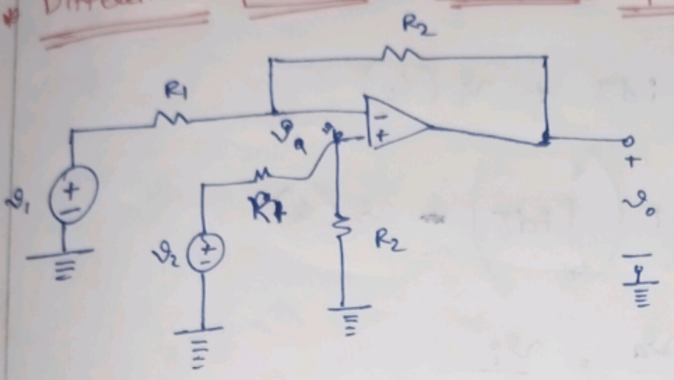
Here $v_b = 0$

(KVL about v_a) $\dfrac{v_a - v_1}{R_1} + \dfrac{v_a - v_2}{R_1} + \dfrac{v_a - v_o}{R_2} = 0$

$$\frac{v_1}{R_1} + \frac{v_2}{R_1} + \frac{v_0}{R_2} = 0$$

$$\Rightarrow \boxed{v_0 = -\frac{R_2}{R_1}(v_1 + v_2)}$$

Difference amplifier or differential amplifier :-



$$v_a = v_b$$

and (KVL about v_a)

$$\frac{v_a - v_1}{R_1} + \frac{v_a - v_0}{R_2} = 0 \Rightarrow v_a\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{v_1}{R_1} + \frac{v_0}{R_2}$$

(KVL about v_b)

$$\frac{v_b - v_2}{R_1} + \frac{v_b}{R_2} = 0 \Rightarrow v_b\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{v_2}{R_1}$$

So as $v_a = v_b$

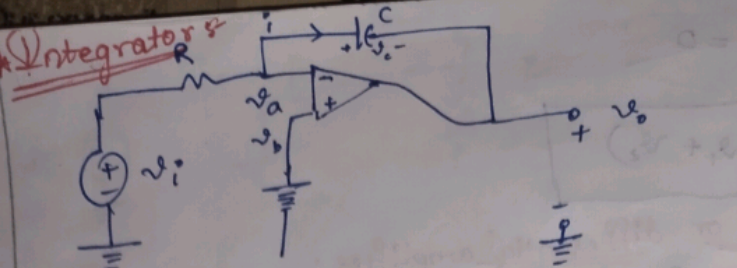
$$\Rightarrow \frac{v_1}{R_1} + \frac{v_0}{R_2} = \frac{v_2}{R_1}$$

$$\Rightarrow \boxed{v_0 = (v_2 - v_1)\left(\frac{R_2}{R_1}\right)}$$

So, $v_0 > 0$ if $v_2 > v_1$

$v_0 < 0$ if $v_2 < v_1$

(1) Integrator :



$$v_a - v_o = \frac{1}{C}\int_{t_0}^{t} i\,d\tau + v_c(t_0)$$

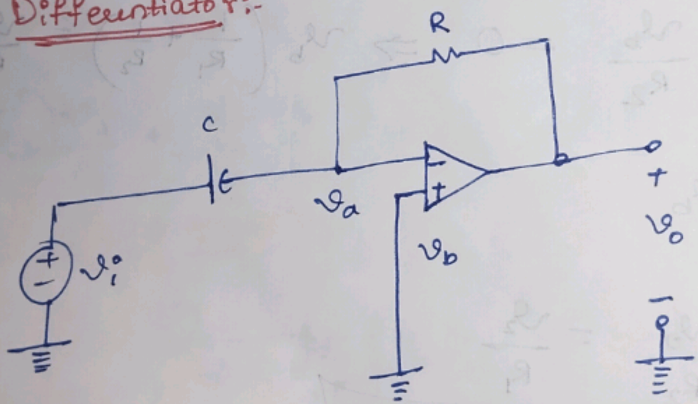
$$v_a = 0 \Rightarrow v_o = \frac{-1}{C}\left(\int_{t_0}^{t} i\,d\tau\right) - v_c(t_0)$$

and as $i = \frac{v_i - v_a}{R} = \frac{v_i}{R}$

So

$$\boxed{v_o = \frac{-1}{RC}\int_{t_0}^{t} v_i\,d\tau - v_c(t_0)}$$

Differentiator :-

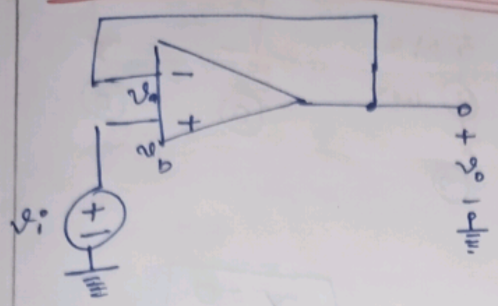


$$v_a = v_b = 0$$

$$i = \frac{v_a - v_o}{R} = -\frac{v_o}{R}$$

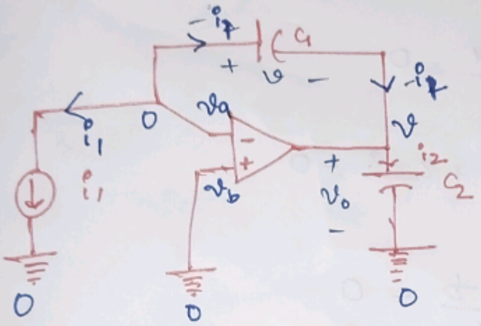
$$i = \frac{C\,dv_i}{dt}, \quad \boxed{v_o = -RC\frac{dv_i}{dt}}$$

(151) **Buffer or voltage follower:-**



$v_a = v_o = v_b = v_i$

Q)



Find expression for $\frac{i_2}{i_1}$ interms of C_1 & C_2

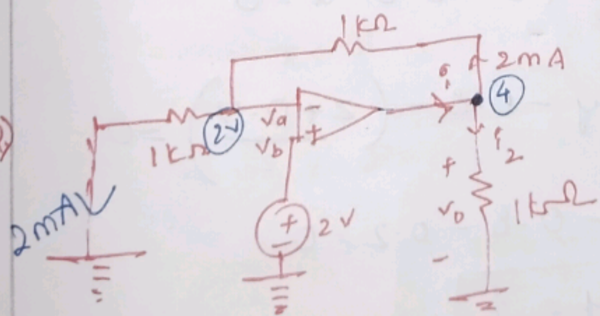
Sol. $v_a = v_b = 0$ $-i_1 = C_1 \frac{dv}{dt}$

$\cancel{\frac{\int i_2\, dt}{C_1} = -v}$ $i_2 = C_2 \frac{d v_o}{dt}$

$\cancel{\frac{\int i_2\, dt}{C_2} = v}$ & $v = v_o$

So $\boxed{\frac{C_1}{C_2} = \frac{-i_1}{i_2}}$

Q)



Find i

$i_2 = 4\,mA$

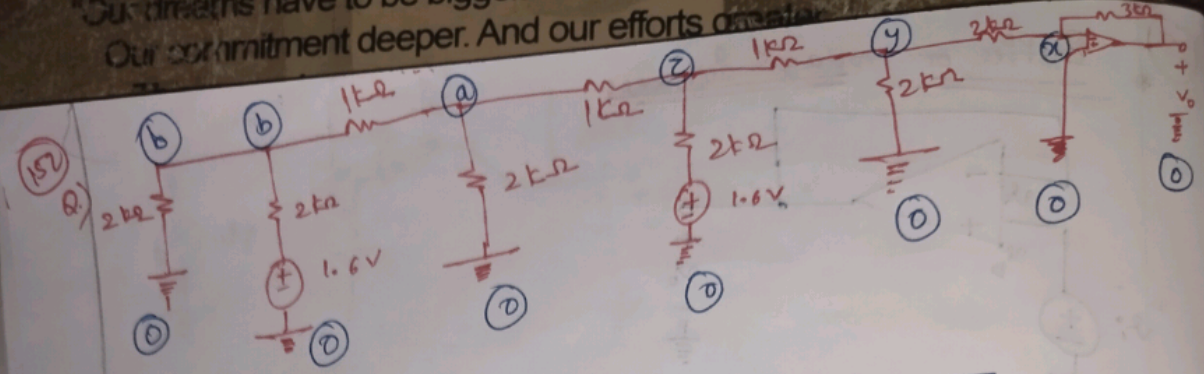
$\boxed{i = 6mA}$

Sol. $v_a = v_b = 2V$ and $\frac{V_o}{1} + 2 - i = 0$

Our dreams have to be bigger.
Our commitment deeper. And our efforts

152

Q.



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Find v_0.

Sol.

$$\frac{x-v_0}{3} + \frac{x-y}{2} = 0$$

$$\boxed{x = 0}$$

as $v_a = v_b = 0$

$$\frac{y-z}{1} + \frac{y}{2} + \frac{y-x}{2} = 0$$

$$\frac{z-y}{1} + \frac{z-1.6}{2} + \frac{z-a}{1} = 0$$

$$\frac{a}{2} + \frac{a-z}{1} + \frac{a-b}{1} = 0$$

$$\frac{b-a}{1} + \frac{b-1.6}{2} + \frac{b}{2} = 0$$

$$b - a + b - 0.8 = 0$$

$$\boxed{2b - a = 0.8}$$

$$2a + \frac{a}{2} - \left(\frac{0.8+a}{2}\right) = z$$

$$\boxed{2a - 0.4 = z}$$

$$z - y + \frac{z}{2} + z - 0.8 - a = 0$$

$$2z + \frac{z}{2} - y - 0.8 - \left(\frac{z+0.4}{2}\right) = 0$$

$$2z - y - 0.8 - 0.2 = 0$$

$$\boxed{2z - y = 1}$$

$$y - z + y = 0$$

$$2y - 2z = 0$$

$$2z - y = 1$$

$$3y = 1$$

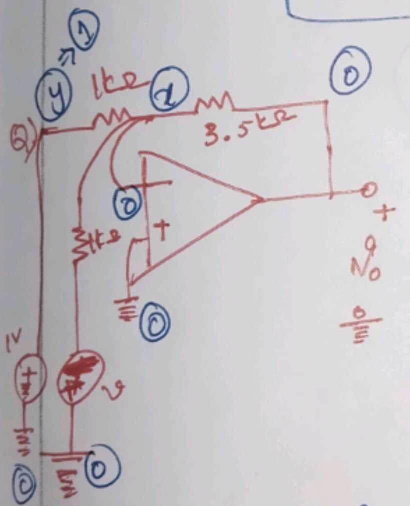
$$\boxed{y = 1/3}$$

$$z = 2/3$$

$$-\frac{v_0}{3} + \frac{0 - 1}{6} = 0$$

$$\frac{v_0}{3} + \frac{1}{6} = 0$$

$$\boxed{v_0 = -0.5 \text{ volts.}}$$



If $v_0 = 0$, find v.

$$\frac{x + v}{1} + \frac{x - y}{1} + \frac{2x}{7} = 0$$

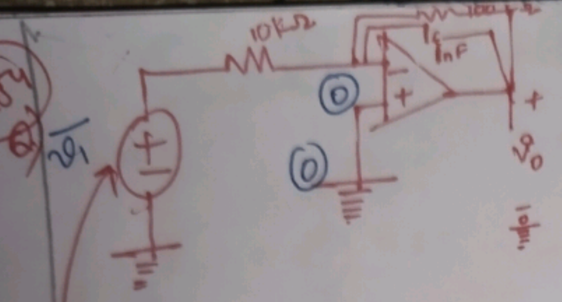
$$x + v + x - 1 + \frac{2x}{7} = 0$$

$$v + 2x\left(\frac{8}{7}\right) = 1 \qquad \text{as } \boxed{x = 0}$$

$$\boxed{v = 1}$$

(15)

(Q)

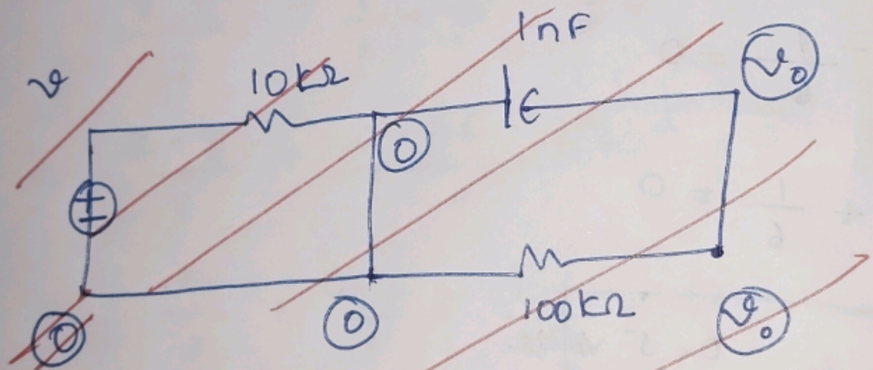


$v = \sqrt{2}\sin(2\pi f t)$

't' is time, 'f' in Hz.

All voltages and currents are sinusoidal. Find 'f' such that RMS of v_0 is 1V.

Sol:



$$\cancel{\frac{-j}{\omega C} \Rightarrow \frac{-j}{\omega(10^{-9})} \Rightarrow \frac{-j(10^9)}{\omega}}$$

$$\cancel{So \quad \frac{\omega(+j)}{-10^9(+j)^2} + \frac{10^4}{10^9} = \frac{1}{Z_{eff}}}$$

$$\cancel{\frac{(\omega j + 10^4)}{10^9} = \frac{1}{Z_{eff}}}$$

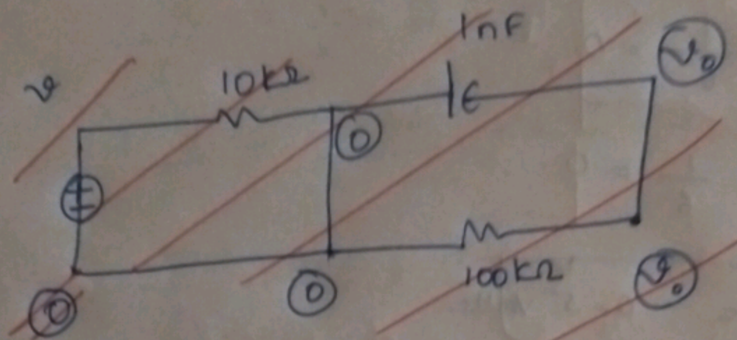
$$\cancel{(v - v_0) = (1)(10^9)}$$

$v = \sqrt{2}\sin(2\pi f t)$

('t' is time, 'f' in Hz

All voltages and currents are sinusoidal. Find 'f' such that RMS of v_0 is 1V

Sol:



$$\frac{-j}{\omega C} \Rightarrow \frac{-j}{\omega(10^9)} \Rightarrow -\frac{j(10^9)}{\omega}$$

So $$\frac{\omega(+j)}{-10^9(+j)^2} + \frac{10^4}{10^9} = \frac{1}{Z_{eff}}$$

$$\frac{(\omega j + 10^4)}{10^9} = \frac{1}{Z_{eff}}$$

$$(v - v_0) = (I)\left(\frac{10^9}{\omega j + 10^4}\right)$$

$$\bar{v}_a = \bar{v}_b = 0$$

So $$\left|\frac{\bar{v}_1}{10k\Omega}\right| = \left|\frac{\bar{v}_0}{\left(\frac{100\left(-j\frac{10^9}{2\pi f}\right)k\Omega}{100-(-j)(10^9)/2\pi f}\right)}\right|$$

and $|\bar{v}_1| = |\bar{v}_0|$

so,

$$(10\times 10^3) = \left| \frac{(100\times 10^3)\left(-j\times\frac{10^9}{2\pi f}\right)}{100\times 10^3 - \frac{j(10^9)}{2\pi f}} \right|$$

$$\boxed{f = 15.84\ \text{KHz}}$$