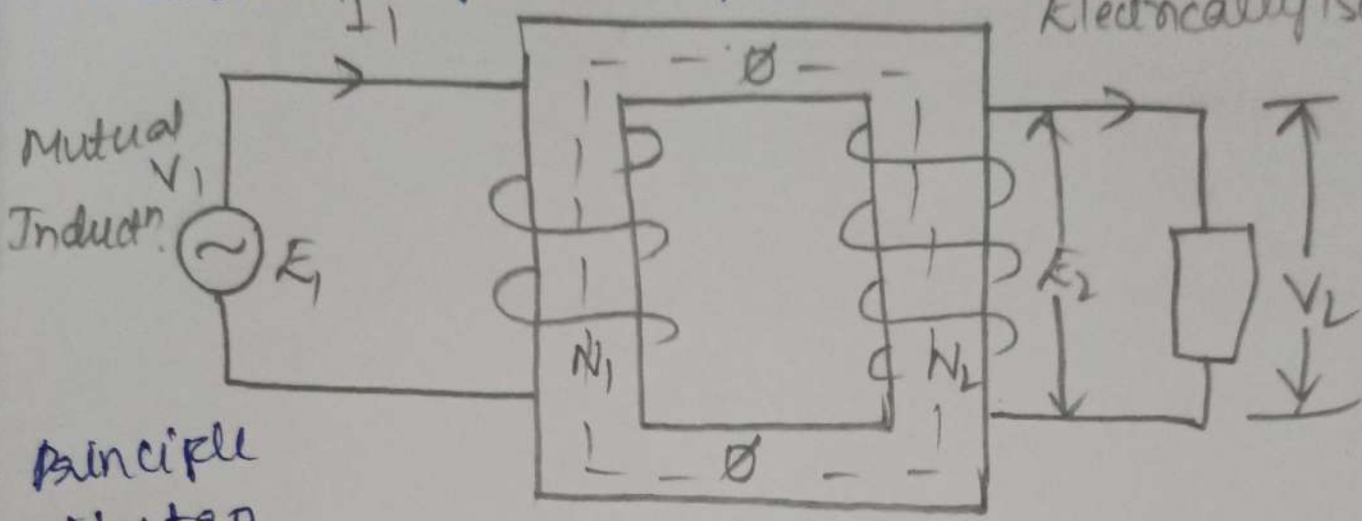
UNIT-III

AC MACHINES ↗ static machine.

Construction of Transformers:- Magnetically coupled
Electrically isolated



Principle
Electro

$V_1 \longrightarrow I_1 \longrightarrow \phi_1 \longrightarrow$ core $\longrightarrow \phi_2 \longrightarrow E_2 \longrightarrow I'$

M.P
Magnetic path.

A.C

classification:

construction	windings	phase
1. core	1. step Up	1. 1ϕ
2. Shell	2. step down	2. 3ϕ
3. Berry		

Principle: Faraday's laws of electromagnetic inducti,
mutual induction b/w 2 coils: .

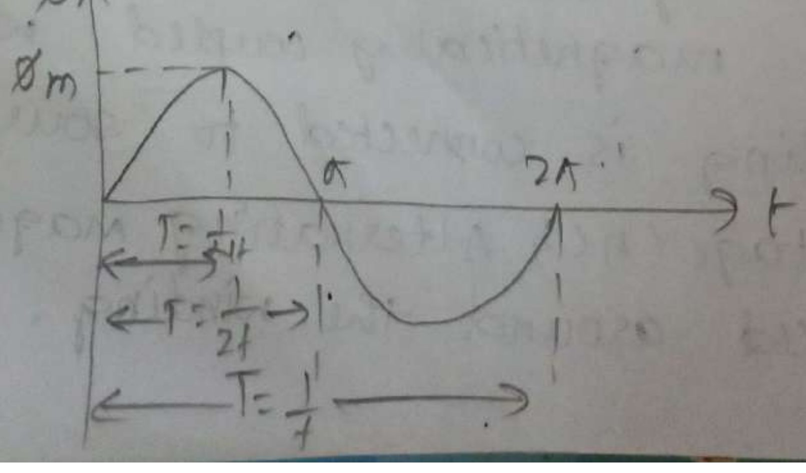
Working principle of transformer:

The basic principle behind working of transfor-mer is mutual induction b/w two windings linked by common magnetic flux. Basically a transformer consists of two inductive coils primary & secondary these are electrically separated but magnetically coupled when primary winding is connected to source of alternating voltage (AC); Alternating magnetic flux is produced around the winding.

The core provides magnetic path for the flux to get link with the secondary winding. Most of the flux gets linked with 2ndary is called useful flux or main flux. & the flux which doesnot link with 2ndary winding is called leakage flux. The flux which is produced is alternating in nature.

Emf gets induced in the 2ndary winding according to faraday's laws of electro magnetic inductn. This emf is called mutually induced Emf & this frequency is same as supply emf. If the 2ndary winding is closed then mutually induced current flows through it & hence electrical energy is transferred from 1 circuit (primary) to another circuit (secondary)

Emf eqn of a transformer:



According to faraday's laws of electromagnetic induction:

$$\boxed{E = N\frac{d\phi}{dt}}$$ N = no of turns.

$N = 1$

$$E = \frac{d\phi}{dt}$$

change in flux

$$d\phi = \phi_m - 0$$

$$dt = \frac{1}{4f}$$

$$E = \frac{\phi_m}{\frac{1}{4f}}$$

$$E = 4f\phi_m$$

$$\text{form factor} = \frac{\text{Rms value}}{\text{avg value}}$$

form factor = 1.11 (sin)

$$E = 4f\phi_m \times 1.1$$

$$= 4.4 f\phi_m$$

Emf induced in primary winding

$$\boxed{E_1 = 4.44 f\phi_m N_1}$$

Emf induced in secondary winding

$$\boxed{E_2 = 4.44 f\phi_m N_2}$$

turns ratio

$$\boxed{k = \frac{N_2}{N_1} = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2}}$$

Q) A 40 kVA single phase single phase ideal transformer has 400 turns on primary & 100 turns on 2ndary the primary is connected to 2000V, 50 Hz (i) supply determine secondary voltage on f open circuit.

(ii) current flowing through 2 windings on full load.

(iii) Max value of ϕ.

$P = 40\,kVA$

$N_1 = 400$.

$N_2 = 100$.

$E_1 = 2000V$.

$f = 50Hz$.

$\frac{V_2}{\cancel{40}\,2000} = 4$.

$V_2 = 8000$.

$\frac{V_2}{2000} = \frac{1}{4}$

$V_2 = 500V$.

$V_2 = ?$ $\quad I_1 = ?, I_2 = ?$ $\quad \phi_{max} = ?$

$\frac{V_2}{V_1} = \frac{N_2}{N_1}$

$P = 40KVA.$

$N_1 = 400$

$N_2 = 100$

$E_1 = 2000V, f = 50Hz$

$E_2 = V_2 = ?\ I_1 = ?\ I_2 = ?\ \phi m = ?$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

$$P_1 = V_1 \times I_{\cancel{2}}$$

$$40 \times 10^3 = (2000) I_1$$

$$I_1 = \frac{\overset{20}{\cancel{40}} \times 1\cancel{000}}{\cancel{2}\cancel{000}}$$

$$I_1 = 20A.$$

$$40 \times 10^3 = (500) I_2$$

$$I_2 = \frac{\overset{8}{\cancel{40}} \times 10\cancel{00}}{\cancel{5}\cancel{00}}$$

$$I_2 = 80A$$

$$E_1 = 4.44 f \phi_m N_1$$

$$2000 = 4.44 \phi m (400)(50)$$

$$\phi m = 0.022$$

8) the number of load ratio required to a single phase 50 Hz transformer is $\frac{6600}{600}$ 6600/600V if the max value of ϕ in core is to be about 0.08 Wb find no of turns in each winding.

$f = 50Hz$.

$$\frac{V_2}{V_1} = \frac{6600}{600}.$$

$\phi_m = 0.08$.

$N = ?$

$E = 4.4 f \phi m$.

$= 4.4 \times 50 \times 0.08$.

$E = 17.6$.

$E_2 = 6600$

$E_1 = 600$.

$6600 = 4.4 f \phi m N_2$

$$\frac{6600}{4.44 \times 50 \times 0.08} = N_2$$

$$\frac{6600}{17.76} \Rightarrow \cancel{375}.$$

$= 371.62$

$E_1 = 4.4 f \phi m N_1$

$$\frac{600}{4.44 \times 50 \times 0.08} = N_1$$

$$\frac{600}{17.76} = 33.78.$$

losses in transformer:

1) Cu < Primary → $I_1^2 R_1$
secondary → $I_2^2 R_2$.

2) Iron loss < hysterisis → $W_h = \eta_h B_m^{1.6} f_v$
Eddycurrent losses → $W_e = \eta_e B_m t^2$

$f_v \Rightarrow$ Volume of core

$t \Rightarrow$ thickness of transformer.

Efficiency (η): ratio of output power & input power is called η.

$$\eta = \frac{P_0}{P_i}$$

~~$P_0 = +$~~

$P_i = P_0 + \text{losses}$

$\text{losses} = W_{cu} + W_{\text{iron losses}(P)}$

$$\% = \frac{P_0}{P_0 + \text{losses}} \times 100$$

Q) A single phase transformer is connected to a 230V, 50Hz supply the net cross sectional area of the core is 60cm² the no of turns efficiency in primary is 500 & in secondary is 100 determine transformation ratio

2) Max value of flux density in the core

3) Emf induced in 2ndary winding.

$f = 50Hz$.

$V_1 \Rightarrow E_1 = 230V$ $\quad\quad \phi_m = B_m A$.

$A = 60cm^2$ $\quad\quad B_m = ?$

$N_1 = 500$

$N_2 = 100$. $\quad\quad \frac{N_2}{N_1} = \frac{100}{500} = 0.2$.

~~$\phi_m = \phi_m B$~~

$k = \frac{E_2}{E_1}$

$E_2 = ?$

$5)230(46$
$\frac{20}{3}$

$\frac{E_2}{E_1} = \frac{N_2}{N_1}$.

$E_2 = \frac{100}{500} \times \overset{46}{\cancel{230}}$

$\frac{23}{1332 \times 5}$

$$\boxed{\phi_m = B_m A}$$

$$E_1 = 4.44 f \phi_m N_1$$

$$E_1 = 4.44 f B_m A N_1$$

$$B_m = \frac{230}{4.44 \times 50 \times 60 \times 10^{-4} \times 500}$$

$$B_m = 0.345 \ wb/m^2 \text{ (or) Tesla.}$$

$$E_2 = 4.44 f \phi_m N_2 = 45.95V.$$

$$\phi_m = B_m A = 2.07 mwb$$

Q) A 500 kVA transformer is desired to have a 4.13 mwb maximum core flux in a transformer at 110V & 50 Hz determine the required no of turns in primary $N_1 = ?$

$$P = 500 \times 10$$

$$\phi_m = 4.13 \times 10^{-3}$$

$$V_1 = E_1 = 110 \ V \qquad f = 50Hz.$$

$E_2 = 4.44\, \phi_m f N_2$

$110 = 4.44 \times 4.13\times10^{-3} \times 50 \times N_1.$

$110 = 916.86 \times 10^{-3}$

$110 = 0.916\, N_1$

$N_1 = 120.08$

6400
×0.5

3200 + 1562.5

Q) A 400KVA transformer has a primary winding resistance of 0.5 Ω & a secondary winding resistance of 0.001 Ω & the iron loss is 2.5KW & primary & secondary voltages are 5KV & 320V respectively if the power factor of the load is 0.85 determine the efficiency of transformer on full load & Half full load.

$E_1 = 5\times10^3\, V$ $P = 400\, KVA.$ $\cos\phi = 0.85$

$E_2 = 320V.$ $\eta_{FL} = ?$

$r_1 = 0.5\, \Omega$

$\eta_{H.FL} = ?$

$\boxed{\text{Power factor} = \cos\phi}$ $r_2 = 0.001\, \Omega.$

$W_i = 2.5KW = 2.5\times10^3$

$$\eta = \frac{P_0}{P_0 + \text{losses}}$$

4762.5

$$\boxed{P_0 = \text{rating} \times \text{power factor}}$$

$P_0 = 400 \times 10^3 \times 0.85$

$161925 0 \times 10^3$

$= 340\,kW$.

$\text{losses} = W_{cu} + W_i$

$P = V_2 I_2$

$$I_2 = \frac{400 \times 10^3}{320}$$

$W_{cu} = I_1^2 R_1 + I_2^2 R_2$

$= 1250\,A$.

$P = V_1 I_1$

$\cancel{400 \times 10^3}^{80} = \cancel{5} \times \cancel{10^3} \times I_1$

$$\boxed{I_1 = 80\,A}$$

$W_{cu} = (80)^2 \times 0.5 \times (1250)^2 \times 0.001$

$= 4762.5\,W$.

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$$\boxed{\eta_{HFL} = \frac{\frac{1}{2}P_0}{\frac{1}{2}P_0 + \left(\frac{1}{2}\right)^2 w_{cu} + w_i}}$$

$$\eta_{FL} = \frac{340\times10^3}{340\times10^3 + 4762.5 + 2.5\times10^3}$$

$$= \frac{340000}{340000 + 4762.5 + 2500} \times 100$$

$$= \frac{340000}{347262.5} \times 100$$

$$= 97.9$$

$$\eta_{HFL} = \frac{\frac{1}{2}P_0}{\frac{1}{2}P_0 + \frac{1}{4}w_{cu} + w_i}$$

$$\frac{12.5\times10^3}{12.5\times10^3 + 450} = \frac{125\times100}{12500 + 450} = 96.52$$

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Q) In a 25kVA, 2000/200V power transformer the Iron loss & full load copper loss are 350 & 400W respectively calculate the η at unity power factor at full load & HFL

P= 25kVA

$\cos\phi = 1$ $\quad \eta_{FL} = ?$

$\frac{V_2}{V_1} = \frac{2000}{200}$

$W_i = 350.$

$W_{cu} = 400.$ $\quad \eta_{HFL} = ?$

P_0 = rating x power factor.

$P_0 = 25\times10^3.$

losses = 350+400 = 750.

$\eta_{HFL} = \frac{P_0}{P_0 + losses} \times 100.$

$\eta_{HFL} = \frac{\frac{25}{2}\times10^3}{\frac{25}{2}\times10^3 + \frac{1}{4}(750)} \times 100.$

$= \frac{12.5\times10^3}{12.5\times10^3 + 187.5}$

$= \frac{125\times10^2}{12500+187.5}$

$= \frac{25\times10^3}{25\times10^3+750}\times100$

$= \frac{25\times10^3}{25750}$

$= 97.087.$

Q) calculate the current drawn by the primary of transformer which steps down 200 to 20V to operate a device of resistance 20Ω assume η of transformer to be 80%.

$V_1 = 200V$ $I_1 = ?$

$V_2 = 200V$. $R_2 = 20\Omega$.

$\eta = 80\%$.

I_2

$80\% = \frac{V_2 \times I_2}{V_1 \times I_1} \times 100$.

$\frac{V_2}{R_2} = I_2$.

$8\cancel{0} = \frac{200 \times 10}{20 \times I_1} \times 10\cancel{0}$

$I_2 = \frac{20\cancel{0}}{2\cancel{0}}$

$0.8 = \frac{2000}{20 I_1}$

$I_2 = 10$

$20 I_1 = \frac{20000}{8}$

$I_1 = \frac{\cancel{2}000\cancel{0}}{8 \times \cancel{20}}$

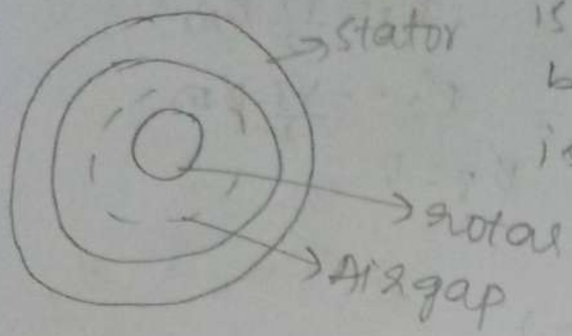
$= \frac{1000}{8}$

$I_1 = 125$.

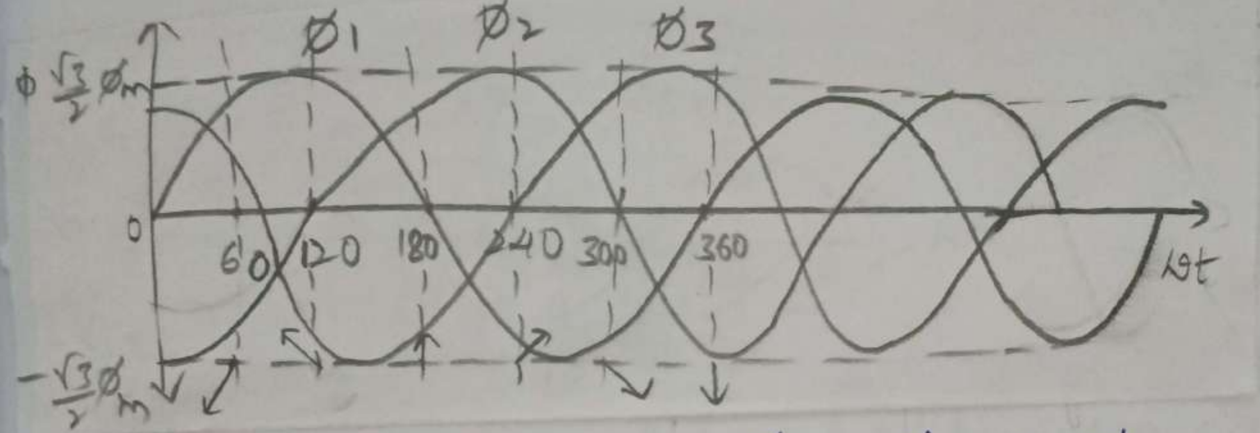
Induction Motors:

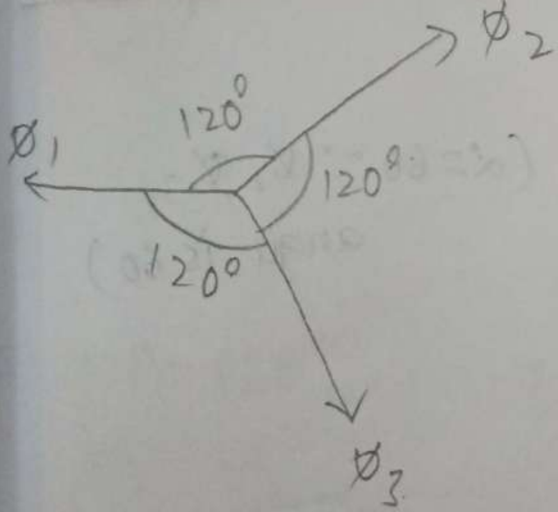
It consists of two parts stator, rotor & has air gap in b/w them & due to current in R, Y, B a magnetic flux is generated & due to the interaction b/w these fluxes a rotating field is produced in the air gap

(i)



(i) Rotating Magnetic field:





$\phi_1 = \phi_m \sin\omega t$

$\phi_2 = \phi_m \sin(\omega t - 120°)$

$\phi_3 = \phi_m \sin(\omega t - 240°)$

a) at position 1; $\omega t = 0$

$\phi_1 = \phi_m \sin(0) = 0.$

$\phi_2 = \phi_m \sin(0 - 120°)$

$= -\phi_m \sin 120°$

at position ③

$$= -\phi_m \sin(90+30)$$

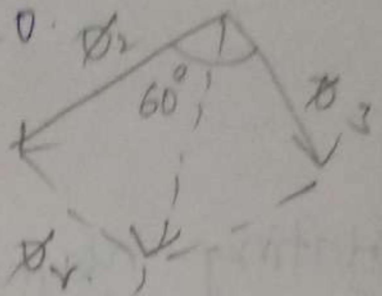
$$= -\phi_m \cos 30^\circ$$

$$\phi_2 = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_1 = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_2 = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_3 = 0$$



$$\phi_3 = \phi_m \sin(0-240)$$

$$= -\phi_m \sin(180+60^\circ)$$

$$= +\phi_m \sin 60^\circ$$

$$\phi_3 = \phi_m \frac{\sqrt{3}}{2}$$

According to parallelogram law resultant
phasor magnitude
flux $\phi_r = 2a\cos\frac{\alpha}{2}$

($\alpha = 60$ ∵ ϕ_2, ϕ_3 angle is 60)

$$= 2\frac{\sqrt{3}}{2}\phi_m \cos\frac{60}{2}$$

$$= 2\frac{\sqrt{3}}{2}\phi_m \cos 30^\circ$$

$$= \cancel{2}\left(\frac{\sqrt{3}}{\cancel{2}}\right)\left(\frac{\sqrt{3}}{2}\right)\cdot\phi_m$$

$$= \frac{3}{2}\phi_m$$

$$\boxed{\phi_r = 1.5\phi_m}$$

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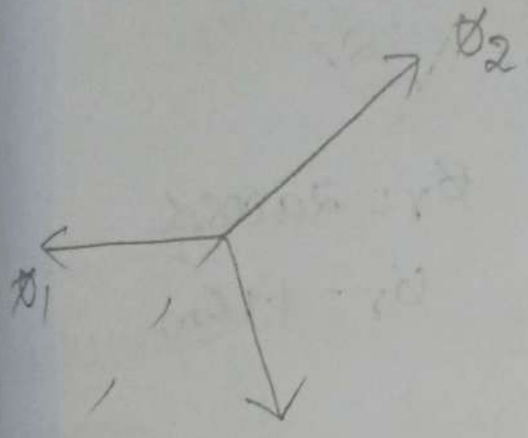
a) at position ②

$\phi_1 = \frac{\sqrt{3}}{2}\phi_m$

$\phi_2 = -\frac{\sqrt{3}}{2}\phi_m$

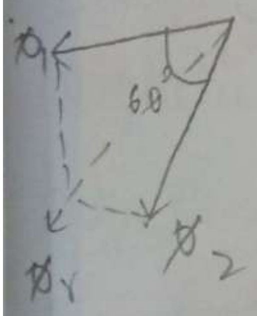
$\phi_3 = 0$.



$\phi_r = 2a\cos 30°$

$= \left|\frac{\sqrt{3}}{2}\phi_m\right|$

$\boxed{\phi_r = 1.5\phi_m}$

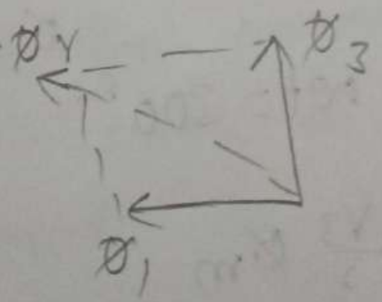


3) $\omega t = 120°$

$\phi_1 = \frac{\sqrt{3}}{2}\phi_m$

$\phi_2 = 0$

$\phi_3 = -\frac{\sqrt{3}}{2}\phi_m$



$\phi_r = 2a\cos 30°$

$= \left|\frac{\sqrt{3}}{2}\phi_m\right|$

$\boxed{\phi_r = 1.5\phi_m}$

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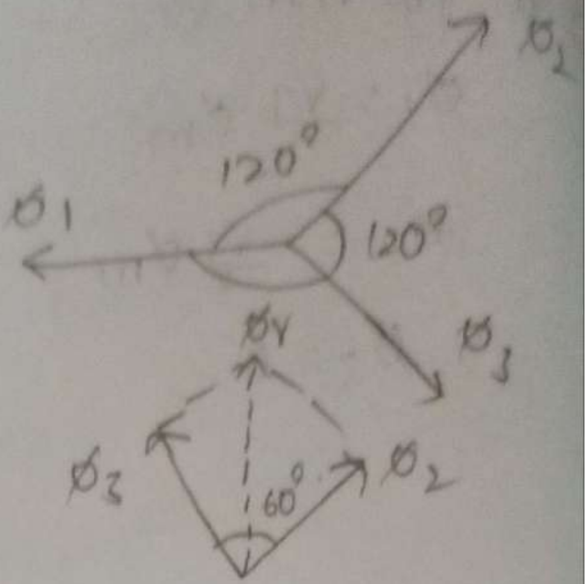
at ④ position. $\omega t = 180^\circ$

$\phi_1 = 0.$

$\phi_2 = \frac{\sqrt{3}}{2}\phi_m$

$\phi_3 = -\frac{\sqrt{3}}{2}\phi_m.$



$\phi_r = 2a\cos\frac{\alpha}{2}$

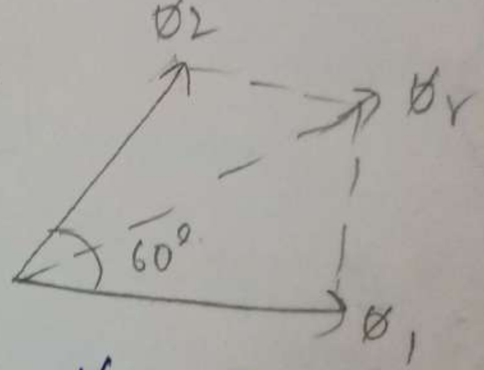
$\phi_r = 1.5\phi_m$

at position ⑤ $\omega t = 240^\circ.$

$\phi_1 = -\frac{\sqrt{3}}{2}\phi_m$

$\phi_2 = \frac{\sqrt{3}}{2}\phi_m$

$\phi_3 = 0.$



$\phi_r = 2a\cos\frac{\alpha}{2}$

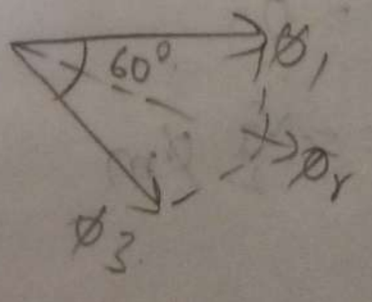
$\phi_r = 1.5\phi_m$

at position. ⑥ $\omega t = 300^\circ.$

$\phi_1 = -\frac{\sqrt{3}}{2}\phi_m$

$\phi_2 = 0.$

$\phi_3 = \frac{\sqrt{3}}{2}\phi_m.$



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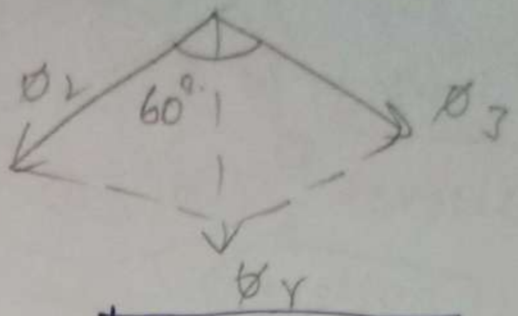
at position ⑦ $\omega t = 360°$

$$\phi_1 = 0$$

$$\phi_2 = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_3 = \frac{\sqrt{3}}{2}\phi_m$$



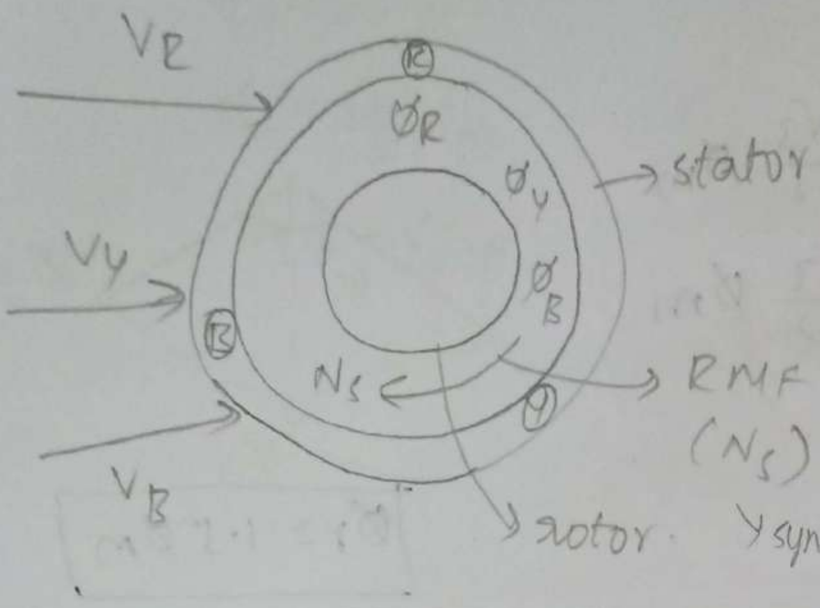
$$\boxed{\phi_r = 1.5\,\phi_m}$$

$\therefore$ whenever three phase (3ϕ) input AC voltage given to the induction motor three phase currents starts flowing which produce magnetic flux a

Definition of rotating magnetic field (RMF):

The magnetic field due to three phase flux interaction ~~the magnetic~~ rotates in the air gap with a fixed speed & constant magnitude is known as rotating magnetic field!

Working principle of 3ϕ induction motor: 3ϕ.



3ϕV
↓
RMF
↓
cuts cond
↓
faraday's Emf
↓
I
↓ cuts
M.F.
↓ T
Mech.f
↓
$< N_s$

$$\boxed{N_s = \frac{120f}{P}}$$

rotating transformer.

1ϕ I.M ⇒ fan

Whenever a 3ϕ ac (AC) voltage is applied to the induction motor due to 3ϕ flux interaction an rotating magnetic field produced in the air gap which cuts the rotor conductors due to relative speed according to faraday's laws of Electromagnetic induction an Emf gets induced in the conductor due to this current starts flowing through rotor winding which acts as current carrying conductor now. Whenever a current carrying conductor placed in the magnetic field it will experience a mechanical force. This twisting or turning movement of force is called Torque. Because of this torque the rotor starts in the direction of EMF. rotor always tries to catch the synchronous speed but it can never catch the N_s (synchronous speed) and will always runs less than synchronous speed.

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3ϕ Induction motor:

Principle: Bits

Induction motor works on the principle of electromagnetic induction when three phase supply is given to stator winding RMF is produced and the induction motor will rotate with synchronous speed (N_s). The induction motor is also called as rotating transformer

$$\boxed{N_s = \frac{120f}{P}}$$

f = frequency

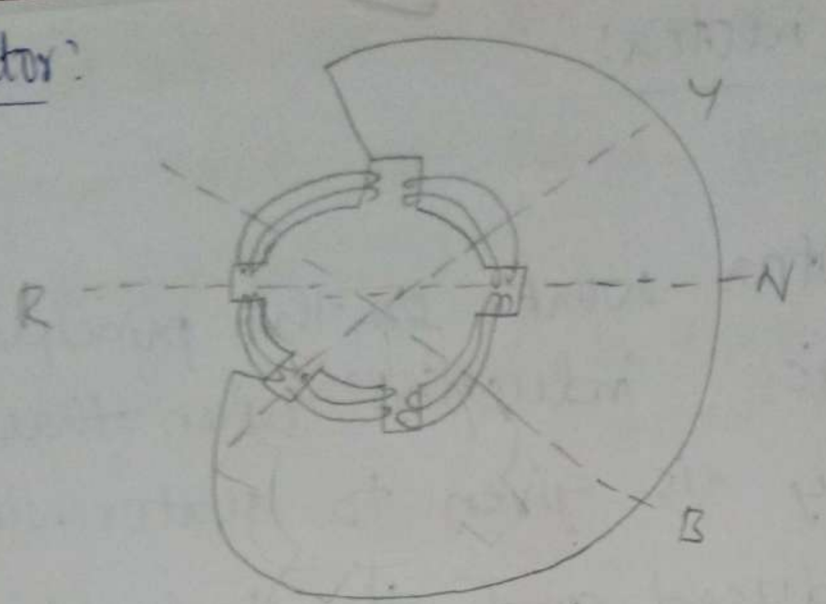
P = Poles.

units of N_s is r.p.m

Construction of Induction motor:

1) stator
2) Rotor
   - squirrel cage rotor
   - slip ring motor.

stator:



silicon laminated steel.

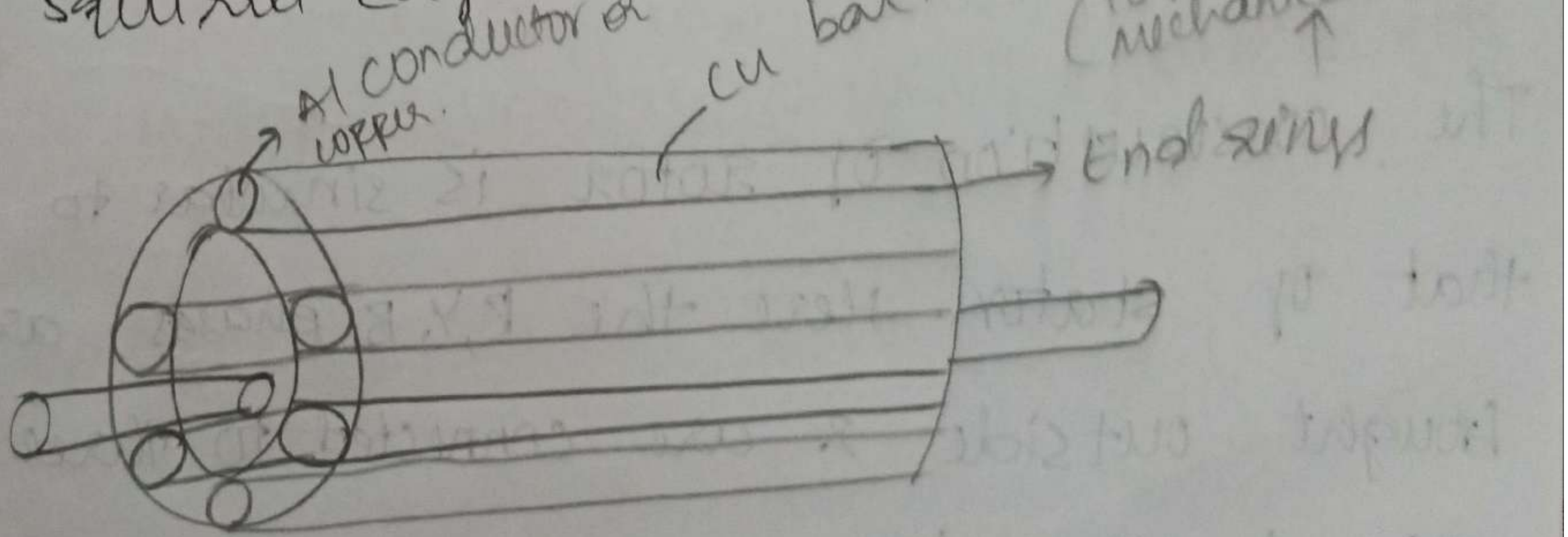
or delta

stator has laminated type of constructi and madeup of stampings and thickness of each stamping is 0.4 to 0.5mm. And these stampings are slotted to carry stator winding. Stator core carries a 3 phase winding connected either in star or delta. so, this winding is excited by 3ϕ supply produces rotating magnetic field.

2) Rotor:

low torque appli

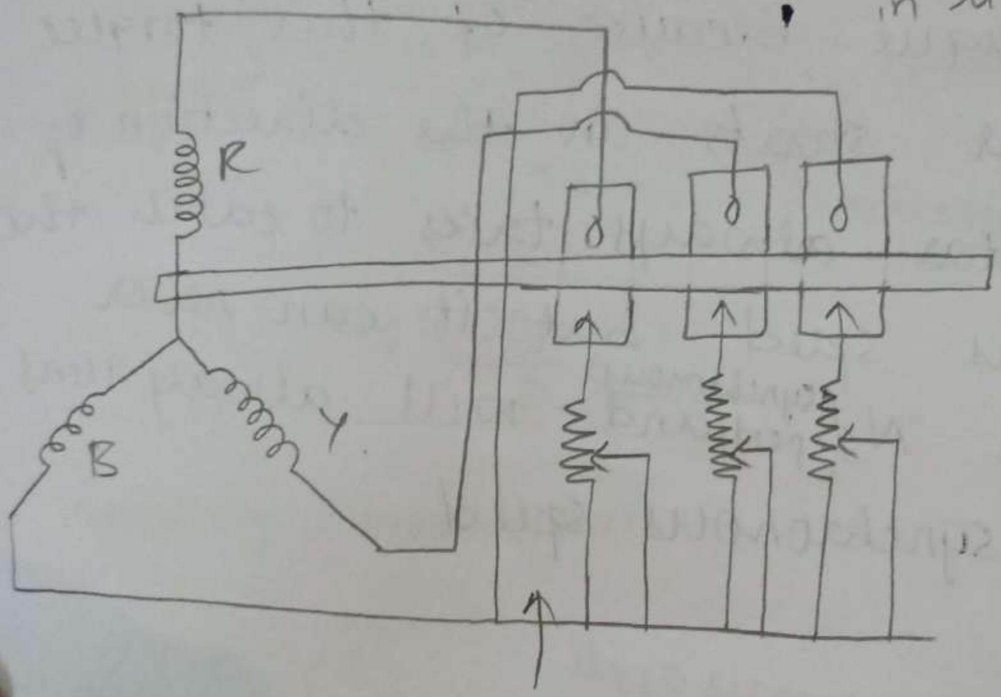
(i) squirrel cage rotor: low cost due to no use of resistance.



in case of low starting torque we use it

The rotor consisting of copper and aluminium bar conductor these are the rotor conductors the copper bars are permanantly shorted at each end with the help of end rings. These end rings provide good mechanical strength.

~~2)~~ (ii) slip Ring rotor: To limit the starting current & are allowed in lifts.



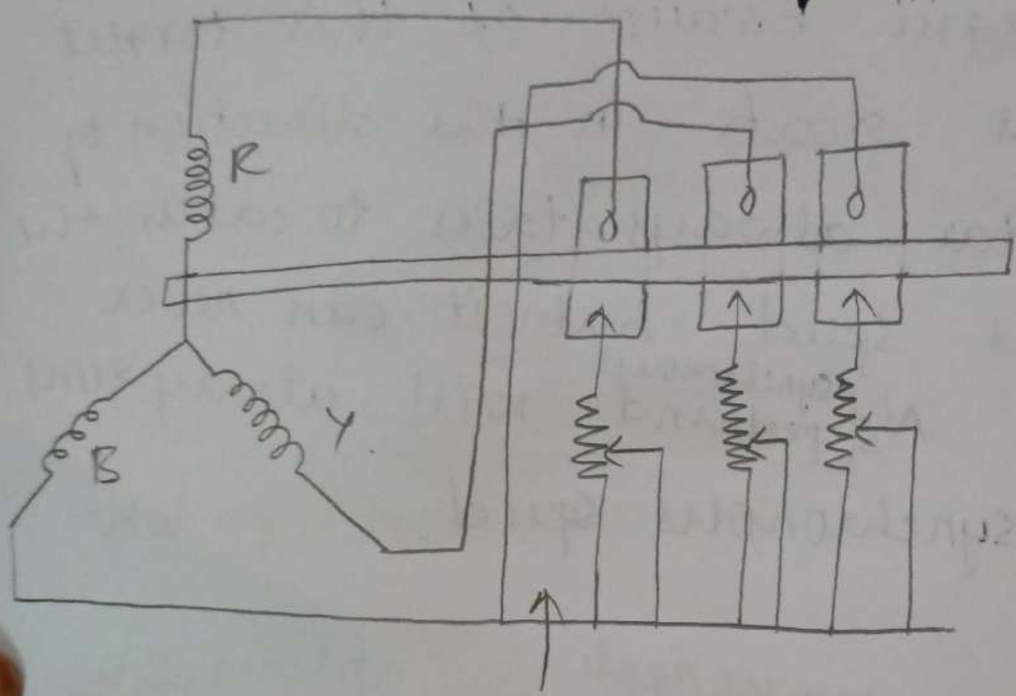
External resistance box

in case of High torque applications
High cost due to the use of resistances & brushes.

The construction of rotor is similar to that of stator. Here the R, Y, B phases are brought outside & are connected to three slip rings with the help of brushes & then external resistances will be added in each phase to ~~impo~~ improve the starting Torque.

shorted at each end with the help of end rings.. These end rings provide good mechanical strength.

~~2)~~ (ii) slip Ring rotor: To limit the starting current & are allowed in lifts.



$T_{st} \propto \frac{R_2}{X_2}$

External resistance box

in case of High torque applications
High cost due to the use of resistances & brushes.

The construction of rotor is similar to that of stator. Here the R, Y, B phases are brought outside & are connected to three slip rings with the help of brushes & then external resistances will be added in each phase to ~~impo~~ improve the starting Torque.

Under running condition the brushes will be removed & now 3 slip rings form closed path that is joined together to form a simple bar. Now, it will act similar to that of squirrel cage rotor (motor) to limit losses.

slip(s):

$$s = \frac{N_s - N_r}{N_s}$$

N_s = synchronous speed.

N_r = rotor speed / motor) actual speed.

$$N_s = \frac{120f}{P}.$$

$$sN_s = N_s - N_r.$$

$$N_r = N_s - sN_s$$

$$\boxed{N_r = N_s(1-s)}$$

$$\boxed{\% s = \frac{N_s - N_r}{N_s} \times 100}$$

It is defined as the ratio of difference b/w synchronous speed & motor speed to the synchronous speed.

And it is denoted by s.

Rotor frequency (f_r):

slip speed = $N_s - N_r$

dividing with N_s on both sides.

$$\frac{\text{slip speed}}{N_s} = \frac{N_s - N_r}{N_s}$$

$$\frac{\frac{120 f_r}{\cancel{P}}}{\frac{120 f}{\cancel{P}}} = s$$

$$\boxed{f_r = sf}$$

f_r = rotor frequency.

f = supplied frequency.

s = slip.

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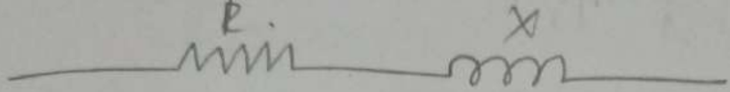
Rotor Emf (E_{2r}):
Emf induced is α N_s (synchronous speed)
in rotor.

E_{2r} = rotor emf at running cond$^{t^n}$.

$$I = \frac{V}{R} \Rightarrow \text{for DC circuits}$$



$$I = \frac{V}{Z} \Rightarrow \text{for AC.}$$

$Z \Rightarrow$ Impedence.

$$= \frac{V}{R+jX}$$

$$= \frac{V}{\sqrt{R^2+X^2}}$$

$\sqrt{R^2+X^2} \Rightarrow$ magnitude

$E_2 \propto N_s$

$E_{2r} \propto N_s - N_r$

$$\frac{E_{2r}}{E_2} \propto \frac{N_s - N_r}{N_s}$$

$$\frac{E_{2r}}{E_2} = s$$

$$\boxed{E_{2r} = sE_2}$$

→ Rotor resistance (R_2):

$$\boxed{R_{2r} = R_2}$$

→ Rotor reactance X_2:

$X_2 = \omega L$ $\quad [\because \omega = 2\pi f]$

$= 2\pi f_r L$

$X_{2r} = 2\pi(f_s s) L$ $\quad f_r = s f_s$

$= (2\pi f_s) \cdot s \cdot L$

$$\boxed{X_{2r} = s \cdot X_2}$$

→ Rotor Impedence Z_2

$Z_2 = \sqrt{R_2^2 + X_2^2}$

$Z_{2r} = \sqrt{R_{2r}^2 + (X_{2r})^2}$ $\quad [\because R_{2r} = R_2]$

$$\boxed{Z_{2r} = \sqrt{R_2^2 + (sX_2)^2}}$$

Z_{2r} = Impedence of rotor at running condition

R_2 = Resistance of rotor.

X_2 = rotor reactance

s = slip

Rotor current (I_{2r}):

$$I_2 = \frac{E_2}{Z_2}$$

$$= \frac{E_2}{\sqrt{R_2^2 + X_2^2}}$$

E_{2r} = Emf induced in rotor under running condition.

$$\boxed{I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}}$$

Rotor power factor:

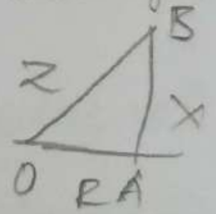
$$\cos\phi_2 = \frac{R_2}{Z_2}$$

$$= \frac{R_2}{\sqrt{R_2^2 + X_2^2}}$$

$$\cos\phi_{2r} = \frac{R_{2r}}{Z_{2r}}$$

$$\boxed{\cos\phi_{2r} = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}}$$

Impedence triangle.



$OB^2 = OA^2 + AB^2$

$OB = \sqrt{OA^2 + AB^2}$

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

$\cos\phi = \frac{adj}{Hypotenuse}$

$= \frac{R}{\sqrt{R^2 + X^2}}$

** Torque Equation of 3 phase I.M:

$T \propto \phi I$

$T \propto \phi_2 I_{2r} \cos\phi_{2r}$

I_{2r} = rotor current at running condition.

$$T \propto E_2 \cdot \frac{E_{2r}}{Z_{2r}} \cdot \frac{R_{2r}}{Z_{2r}}$$

$$T \propto E_2 \cdot \frac{sE_2}{\sqrt{R_2^2+(sX_2)^2}} \frac{R_2}{\sqrt{R_2^2+(sX_2)^2}}$$

$$\boxed{T \propto \frac{sE_2^2 R_2}{R_2^2+(sX_2)^2}}$$

$$T = \frac{k \cdot sE_2^2 R_2}{R_2^2+(sX_2)^2}$$

$$k = \frac{3}{2\pi N_s}$$

$$T = \frac{3sE_2^2 R_2}{2\pi N_s(R_2^2+(sX_2)^2)}$$

$$\boxed{T = \frac{3}{2\pi N_s} \frac{sE_2^2 R_2}{R_2^2+(sX_2)^2}}$$

N_s = synchrous speed

E_2 = Emf induced in rotor

R_2 = rotor resistance.

X_2 = rotor reactance

s = slip

T = Torque

I_2 = current Induced in rotor

$I_2 \rightarrow$ stand still.

$\cos\phi_2$ = Power factor of rotor

X_{2r} = rotor reactance at running condition.

$\cos\phi_{2r}$ = Power factor of rotor at running condition.

Q) A 10 pole, 50Hz, 3Ø I.M runs at 485 rpm what will be the rotor frequency of rotor current.

$$\begin{array}{r} \cancel{6}00 \\ 485 \\ \hline 115 \end{array}$$

$P=10 \quad f=50Hz \quad N_r = 485$

$f_r = sf \qquad s = \frac{600-485}{600} = \frac{115}{600} = 0.191$

$N_s = \frac{120f}{P} = \frac{120(50)}{10} = 600\,rpm$

$\boxed{N_s = 600\,rpm}$

$s = 0.191$

$f_r = s.f$

$= 0.191 \times 50$

$f_r = 9.55 Hz$

Q) A 3ϕ induction motor is wound for 4 poles & is supplied from 50Hz system calculate:

(i) N_s

(ii) speed of motor at 4% of slip.

(iii) Rotor current frequency when motor runs at 600rpm.

$P = 4, \ f = 50Hz \qquad s = 0.04$

$N_r = N_s(1-s)$

(i) $N_s = \dfrac{120f}{P}$

$= \dfrac{\overset{30}{\cancel{120}} \times 50}{\cancel{4}}$

$= 1500 \, rpm$

$s = \dfrac{N_r - N_s}{N_s} \times 100$

(ii) $N_r = N_s(1-s)$

$= 1500(1-0.04)$

$= 1500(0.96)$

$= 1440\,rpm$

(iii) $f_r = s \cdot f$

$s = \frac{N_s - N_r}{N_s}$

$= \frac{1500-600}{1500}$

$= \frac{\cancel{700}}{\cancel{1500}} = 0.6$

$f_r = 0.6 \times 50$

$= 30Hz$

Q) A 3Ø 6 pole 50Hz induction motor is running with a slip of 4% find

(i) N_s (ii) Motor speed (iii) slip speed

(iv) frequency of Induction rotor

$P = 6 \quad f_r = 50Hz \quad s = 0.04$

(i) $N_s = \frac{\overset{20}{\cancel{120}} \times 50}{\cancel{6}} = 1000\,rpm$

(ii) $N_r = N_s(1-s) = 1000(0.96) = 960\,rpm$

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$N_r = 960$ ~~the~~ rpm.

slip speed $= 1000 - 960$

$= 40.$

$f_r = s \cdot f_s$

$s = \frac{N_s - N_r}{N_s}$

$= \frac{1000 - 960}{960}$

$= \frac{40}{960}$

$= 0.041$

$= 0.04 \times 50$

$= 0.4 \times 5$

$= 2\ Hz.$

Q) A 6 pole 3ø 50Hz induction motor is running at a full load with slip of 4% the rotor is star connected its resistance & reactances are 0.25 & 1.5Ω the emf of

$P = 6 \quad f_r = 50Hz \quad S = 0.04$

$R_2 = 0.25 \quad X_2 = 1.5\Omega$

$E_2 = 100V$

rotor is 100 V find $I_{2r} = ?$

$$I_{2r} = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$N_S = \frac{120f}{P}$$

$$= \frac{120 \times 50}{6} = 1000 Hz$$

$$I_{2r} = \frac{0.04 \times 100}{\sqrt{(0.25)^2 + (0.04 \times 1.5)^2}}$$

$$= \frac{4}{\sqrt{0.0625 + 3.6 \times 10^{-3}}}$$

$$= \frac{4}{\sqrt{0.06286}} = \frac{4}{0.2507}$$

0.06

$$= 15.5 A.$$

Q) A 6 pole 3ϕ 50 Hz induction motor is ~~50Hz~~ running at full load with a slip of 4%. rotor is star connected & it's resistances & reactance are 0.45 & 2.5 Ω

$f = 50 Hz$ $s = 0.04$ $R_2 = 0.45$, $X_2 = 2.5$

the emf b/w slip rings is 120V. Determine rotor current & Power factor assuming the slip rings are short circuited.

$E_2 = 120V$

$$\cos\phi_{2r} = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$= \frac{0.45}{\sqrt{(0.45)^2 + (0.04 \times 2.5)^2}}$$

$$= \frac{0.45}{\sqrt{0.2125}}$$

0.2025

0.01

$$= \frac{0.45}{0.4609}$$

$$\cos\phi_{2r} = 0.976$$

$$I_{2r} = \frac{0.04 \times 120}{\sqrt{(0.45)^2 + (0.04 \times 2.5)^2}}$$

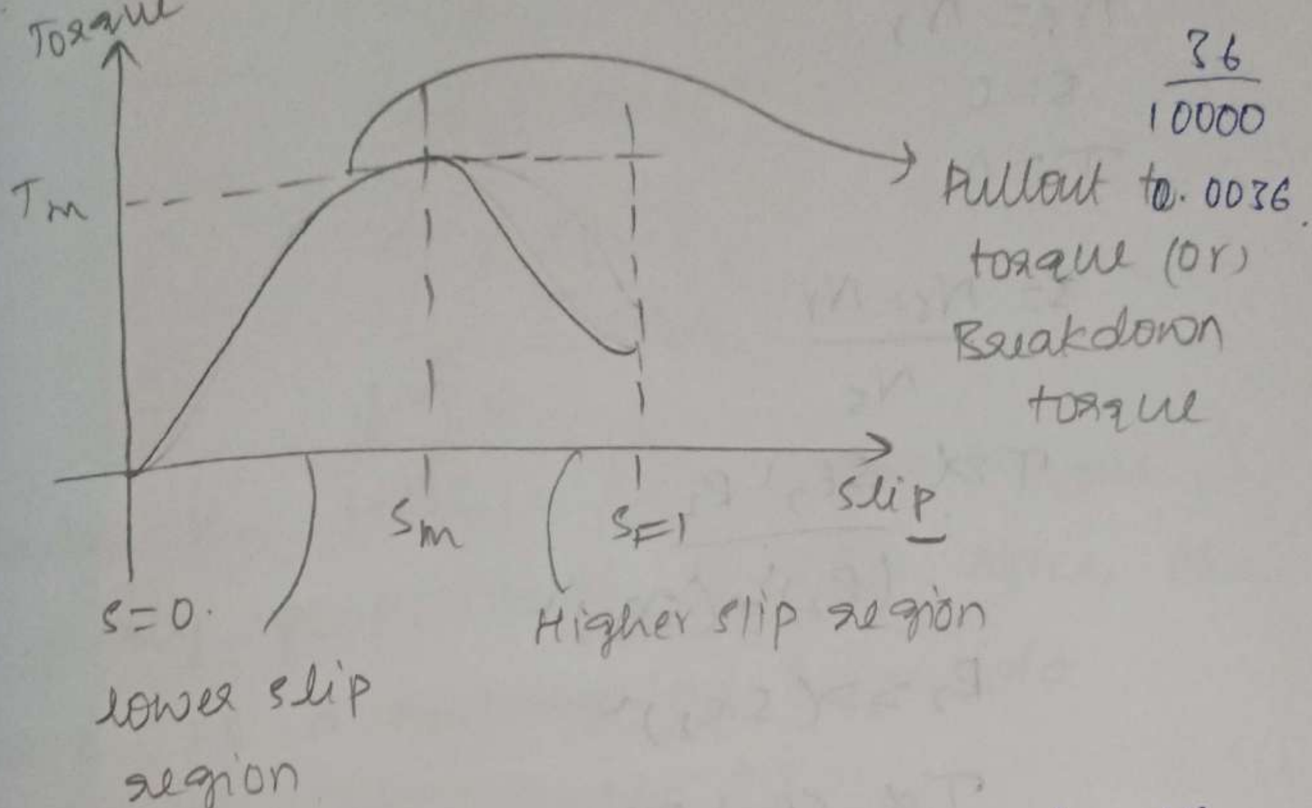
$$= \frac{4.8}{0.4609} = 10.41A$$

#10. ~~**~~

Torque - slip characteristics of 3 phase induction motor:

$\frac{3.6}{1000}$

$\frac{36}{10000}$



The performance curve drawn b/w torque against slip known as torque slip charac-teristics of an induction motor.

Torque expression:

$$\boxed{T \propto \frac{sE_2^2 R_2}{(R_2)^2 + (sX_2)^2}}$$

The relation b/w Torque and slip, the entire operating region b/w 0 & 1 is divided into two 1 is lower slip

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region & higher slip region:

lower slip region:

$$N_s = N_r$$
$$s = 0$$
$$T = 0.$$

$$s = \frac{N_s - N_r}{N_s}$$

$$T \propto \frac{sE_2^2 R_2}{(R_2)^2 + (sX_2)^2}$$

$$R_2 >> (sX_2)^2$$

$$T \propto \frac{sE_2^2 \cancel{R_2}}{R_2^{\cancel{2}}}$$

$$T \propto s$$

as $T \uparrow$ $s \uparrow$

Under the lower slip region Torque is directly proportional to slip. Hence, the curve is a straight line.

Higher slip region:

When the slip further rises beyond $s = s_m$ then the term R_2^2 is very smaller than

$s x_2^2$

$$T \propto \frac{sE_2^2R_2}{R_2^2+(sx_2)^2}$$

$$(sx_2)^2 >> R_2^2$$

$$T \propto \frac{\cancel{s}E_2^2R_2}{s^{\cancel{2}}x_2}$$

$$\downarrow T \propto \frac{1}{s}\downarrow$$

Under the Higher slip region Torque is inversely proportional to slip. Hence, the curve is a rectangular hyperbola.

Losses in 3ϕ induction Motor:

Losses are classified into two types.

(i) Constant losses

(ii) variable losses.

(i) Constant losses:

These are classified into two types

(a) Iron losses

(b) Mechanical losses

(a) **Iron losses:** The losses which occur in the core of stator & rotor. Iron losses includes hysterisis & eddy current losses

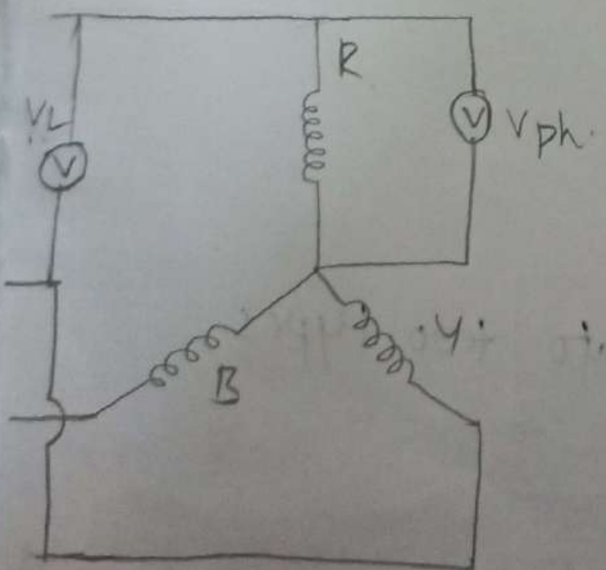
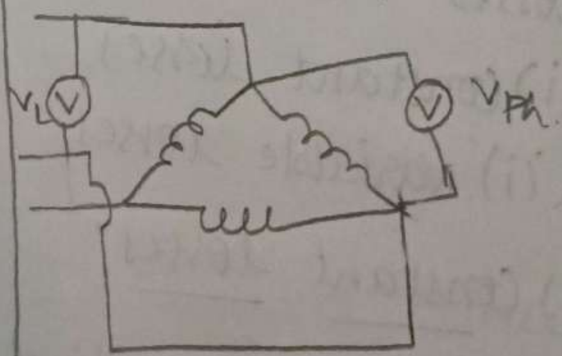
Iron losses are also known as <u>core losses</u>

(i) <u>Mechanical losses</u>:

losses which occurs in shaft of induction rotor losses includes friction & windage losses

(ii) <u>Variable losses</u>: these are also called as copper losses which occur at winding of stator & rotor. Power wasted in the form of i^2R losses known as variable losses.

Cu losses usually occur in windings.

star connection	Delta connection
	
$V_L = \sqrt{3} V_{ph}$ $I_L = I_{ph}$	$V_L = V_{ph}$ $I_L = \sqrt{3} I_{ph}$