(KEE503) Electrical Machines 2nd Syllabus.

Date

Unit-1 Synchronous Machines - I

Constructional features, Armature winding, EMF Equation, Winding coefficients, Equivalent circuit and phasor diagram, Armature reaction, O.C. & S.C. tests, Voltage regulation using Synchronous Impedance method, MMF ~~equation~~ method, Potier's Triangle method, Voltage and frequency control (Governor system) of alternators, Parallel operation of synchronous generators, Operation of infinite bus, Synchronizing power and torque co-efficient.

Unit-2 ~~Sy~~ Synchronous Machines - II

Two reaction Theory, Transient and sub-transient reactance, Power flow equations of cylindrical and salient pole machines, Operating characteristics. Synchronous Motor - Starting methods, Effect of varying field current at different loads, V-curves, Hunting & damping, Synchronous condenser.

Unit-3 Three Phase Induction Machine - I

Constructional features, Rotating magnetic field, Principle of operation, Phasor diagram, Equivalent circuit, Torque and power equations, Torque-slip characteristics, No load & blocked rotor tests, Efficiency.

Unit-4 Three Phase Induction Machine - II

Starting, Deep bar and double cage rotors, Cogging & Crawling, Speed control (with and without em ~~em~~

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injection in rotor circuit).

Unit - V Single phase Induction Motor.

Double revolving field theory, Equivalent circuit, No load and blocked rotor tests, Starting Methods, Repulsion motor, Universal motor.

Synchronous machine :-

Alternator works on the principle of electromagnetic induction (of Farraday's law

500 MW , 11KV , 0.8 lagging

$\sqrt{3} V_L I_L \cos\theta = 500 \times 10^6$

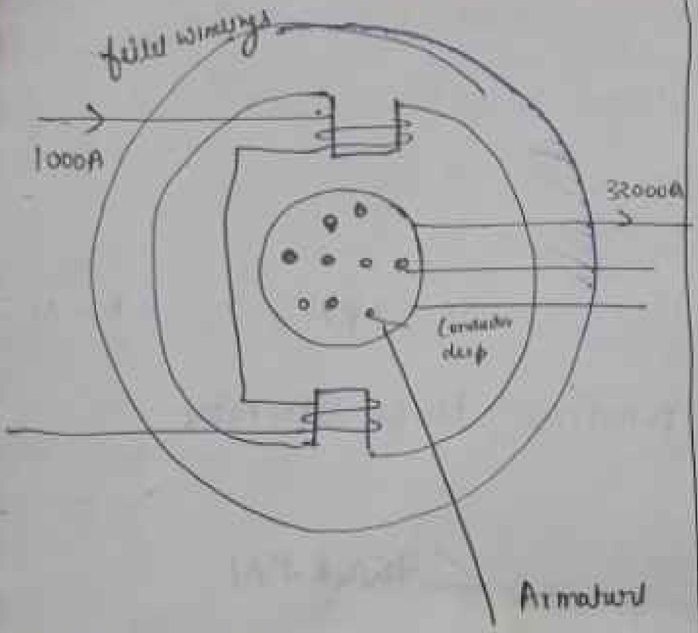
$\sqrt{3} \times 11000 \times I_L \times 0.8 = 500 \times 10^6$

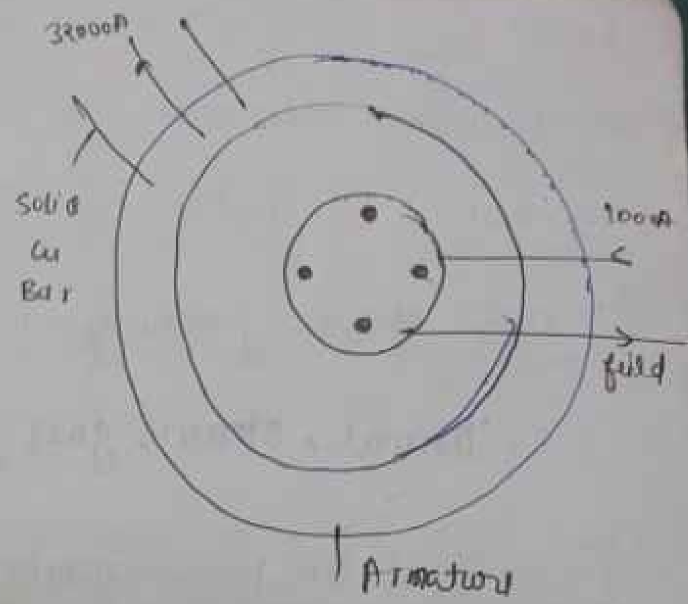
$\boxed{I_L = 32000 A}$

Armature winding :- 11000V, 32000A, Insulated for (AC) high voltage.

Feild Winding :- DC 125V - 200V, 1000A, Insulated for low Voltage

Stationary field rotating armature	Rotating field stationary armature
(1) Collecting large current threw sliprings and brushes is vary difficult practically	(1) Since armature is stationary so, current can be collected by solid copper bar and it requires 2-sliprings for excitation purpose.





② Required larg mechanical input to rotate bulk armature and does not offer high speed

② Require lesser mechanical input to rotate small field winding so, offer high speed.

③ Providing insulation and cooling to rotating armature is difficult

③ Providing insulation and cooling is easy for stationary armature

④ Offer less space and demand high depth slot in armature. So, more leakage.

Offer more space & demand low depth slot in ~~arma~~ armature so, less leakage

⑤ Result :-

① Mordern

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Result :-

① Modern alternator are designed with stationary armature & rotating field.

② High speed power generration :- 1800RPM, 3000RP.M

Thermal, steam, gass, Nuclear, Turbo alternator.

③ Low speed power generation :- < 750 R.P.M

Eg :- Hydro power plant, Diesel power plant.

Stator construction :- refferred to I-M.

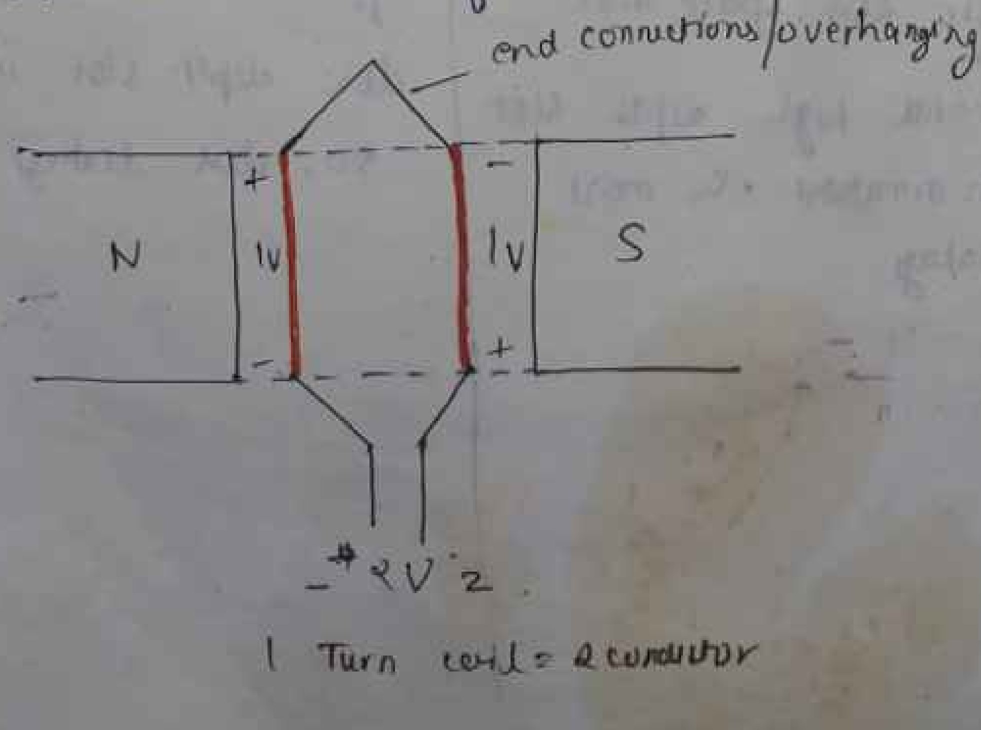
Stator contain 3-ϕ star connected, distributed winding with

Conductor :- Active length of wire which participate in energy conversion known as a conductor.

Eg :- AB and CD are two conductor.

S

Turn :- One turn consist of two conductor

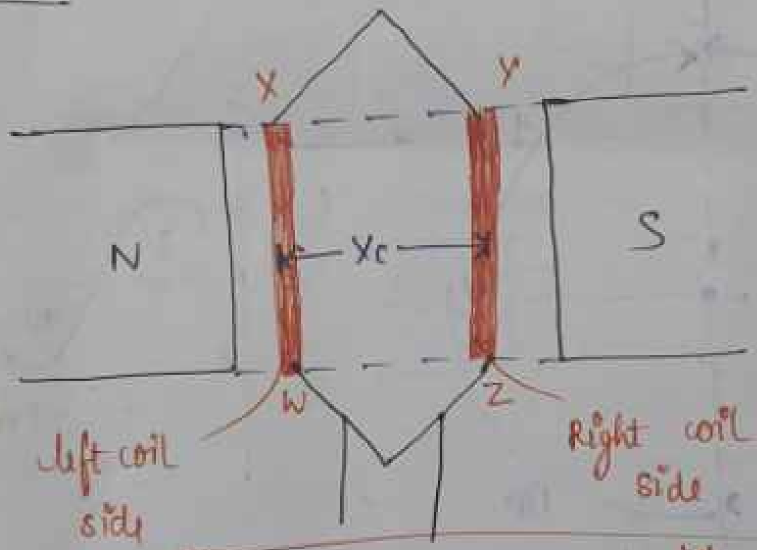


1 Turn coil = 2 conductor

Coil :- One coil consist of any number of turns

Coil side :- A coil consist of 2 so coil sides which are placed in two different slots. ~~Hair~~ Here, WXLYZ are two coil sides.

coil pitch :- or coil span (Y_c) Centre to centre distance between two coil sides of a coil known as coil pitch

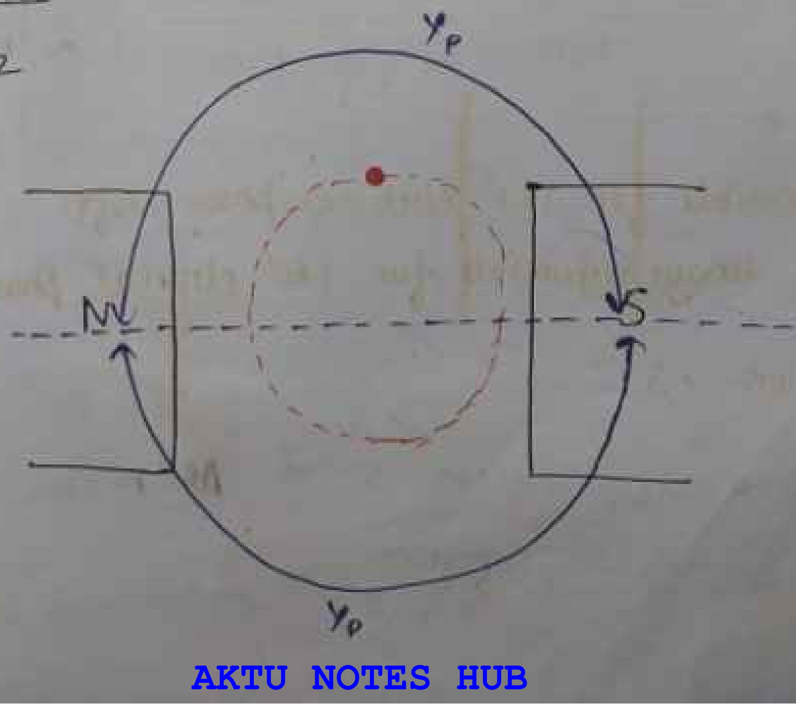


$\boxed{\text{N Turn coil} = 2N \text{ conductors}}$

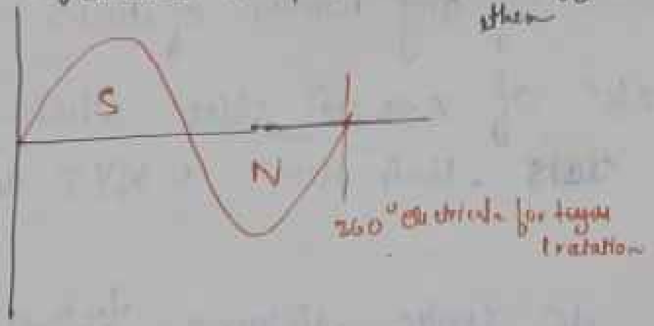
Y_c = coil pitch / coil span

Pole pitch :- (Y_P) Centre to centre distance b/w two adjacent poles.

(1) P = 2

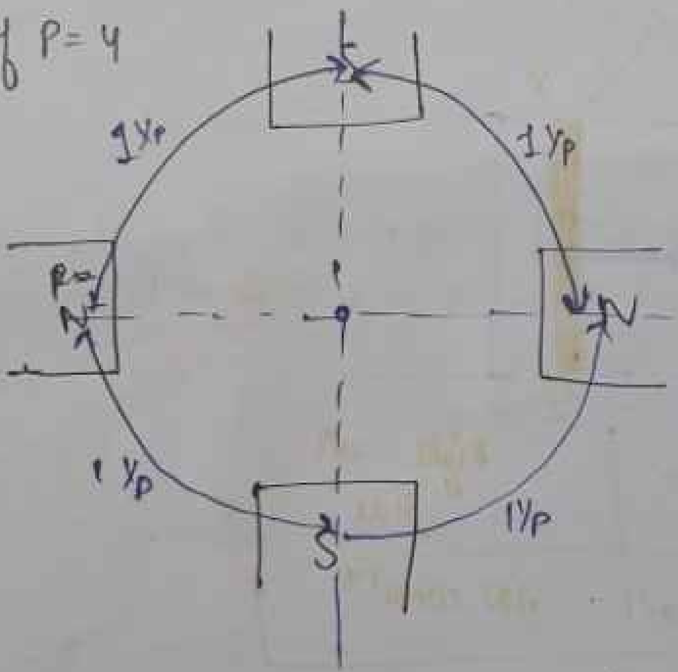


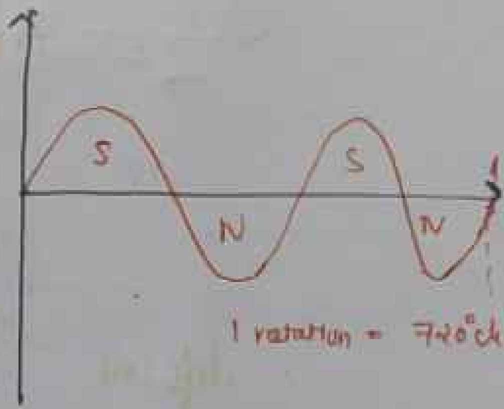
If conductor is at place show in above figure then



$2\, Y_P \longrightarrow 360°$ electrical
$1\, Y_P \longrightarrow 180°$ electrical

(2) If $P = 4$





$4\, Y_P \longrightarrow 720$ electrical
$1\, Y_P \longrightarrow 180°$ electrical.

$$\boxed{\text{Pole pitch} = Y_P(n) = \frac{\text{total number of slots}}{\text{total no of poles}}} = \boxed{n = \frac{S}{P}}$$

slot/pole

'n' slots are responsible for 180° electrical phase shift

→ 1 pole pitch is always responsible for 180° electrical phase shift.

~~Eg 2 pole, 12 slots, 3-~~

Eg → 2 pole, 12 slots, 3-ϕ Alternator

$P = 2,\ S = 12\quad \phi_{\text{phase}} = 3$

$$n = \frac{S}{P} = \frac{12}{2} = 6$$

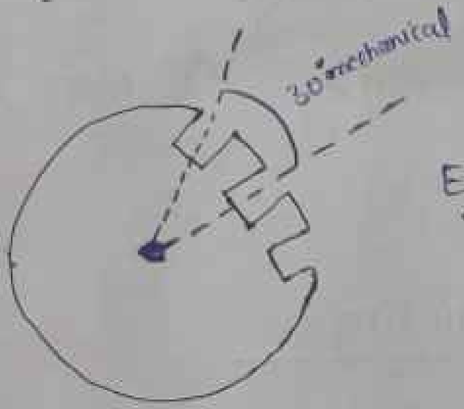
6 slots are responsible for 180° electrical phase shift.

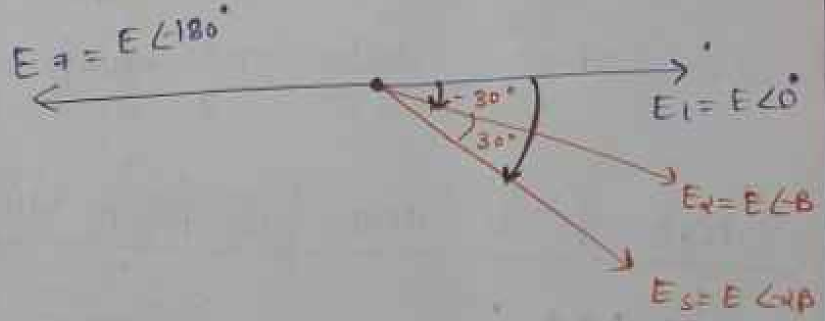
7. Slots angle (β) :-

Phase difference contributed by 1 slot is known as slot angle β

$$\boxed{\beta = \frac{180^\circ}{n}} \text{ electrical}$$

$$\left\{ Eg = \frac{180^\circ}{6} = 30^\circ \text{ electrical} \right\}$$





Types of 3-ϕ winding:-

(1) Single layer and double layer winding:-

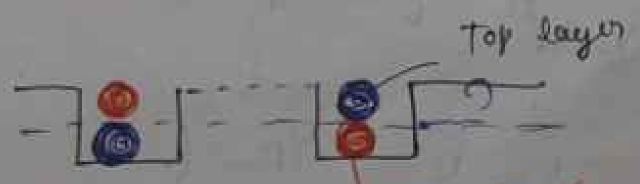
If 1 slot contains 1 coil side then it is known as single layer winding

Eg :- for 2 pole, 12 slot alternator.

6 coils requires for single layer winding.

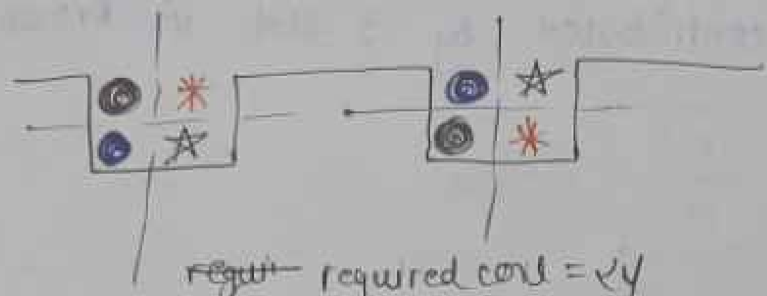
Double layer :- If 1 slot contains more than 1 coil side then it is known as double layer winding.

Eg :- 1 slot contains 2 coils side



This is done for uniform flux distribution and for less harmonics

Eg :- 1 slots contains 4 coil sides.



~~regur~~ required coil = 24

Result :- Generally double layer windings are preferred because easier to house the winding in slot, less leakage better emf waveform.

Short pitch and full pitch winding :-

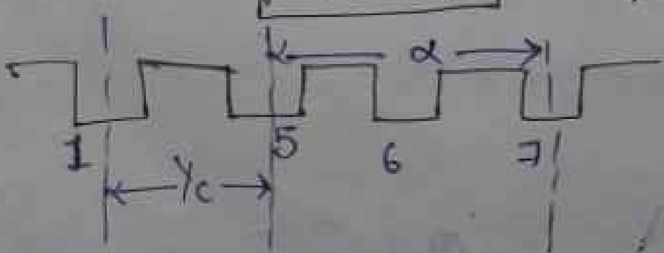
Full pitch :- If $\boxed{y_c = y_p}$

$$E_{net} = \sqrt{E^2 + E^2 + 2E(-E)\cos(180)}$$

$$= \sqrt{2E^2 + 2E^2}$$

$$\boxed{N_{net} = 2E}$$

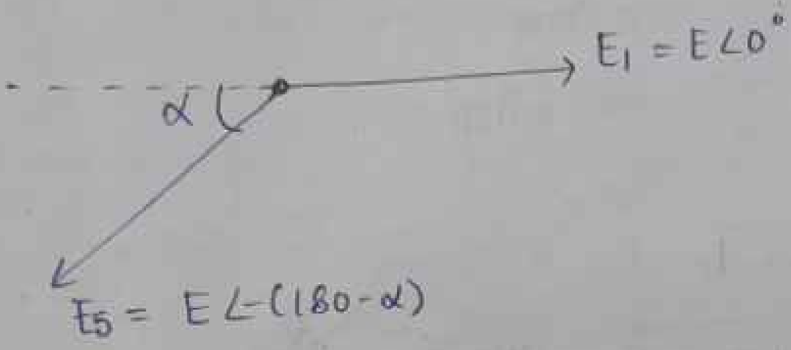
Short pitch :- $\boxed{y_c < y_p} \Rightarrow \boxed{y_c = y_p - \alpha = \pi - \alpha}$



$y_c = 4$, $y_p = 6$

$\cancel{y_c = y_p - \alpha}$ α = angle b.y which coils are short pitch

α = chording angle.



~~Enet~~

$$E_{net} = \sqrt{E^2 + E^2 + 2E(-E)\cos(+180° - \alpha)}$$

$$= \sqrt{2E^2 + 2E^2\cos\alpha}$$

$$E_{net} = 2E\cos\alpha/2$$

$$\boxed{E_{net} = 2E\cos\alpha/2}$$

$\cos\alpha/2$ = pitch factor | coil span factor (K_p | K_c)

$$\boxed{K_p = \frac{\text{induced emf in short pitch}}{\text{induced emf in full pitch}}}$$

$$K_p = \frac{2E\cos\alpha/2}{2E}$$

$$\boxed{K_p = \cos\alpha/2}$$

$\Rightarrow \boxed{K_p = 1}$ —— full pitch → 100% पाया, 0% खोया

$\Rightarrow \boxed{K_p = .8}$ ⟶ short pitch → 80% पाया, 20% खोया

$\Rightarrow \boxed{K_p = 0}$ ⟶ 0% पाया, 100% खोया

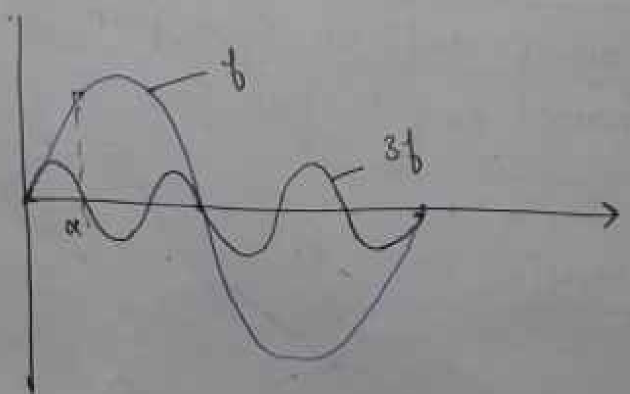
In, short pitch

$$\boxed{0 < K_p < 1}$$

Generally windings are short pitch by 1 or 2 slot angle

Result :- Generally short pitch windings are preffered because the length of end connections reduces, higher order harmonics can be eliminated, lesser volume of copper required.

Harmonics reduction by short pitch winding :-



If fundamental is short pitch by angle (α) then the (r^{th}) order harmonics short pitch by angle ($r\alpha$)

Pitch factor corresponding to rth order harmonics.

$$\boxed{K_{pr} = \cos\left(\frac{r\alpha}{2}\right)}$$ # #

If rth order harmonics ~~ha~~ are completely reduced then

$$[K_{pr} = 0]$$

$$\cos\left(\frac{r\alpha}{2}\right) = 0$$

$$\frac{r\alpha}{2} = \frac{\pi}{2}$$

$$r\alpha = \pi$$

$$\alpha = \frac{\pi}{r}$$

$$\boxed{\alpha = \frac{\pi}{r}}$$

$\because$ $(y_c = \pi - \alpha)$

$\therefore$ $y_c = \pi - \frac{\pi}{r}$

$$\boxed{y_c = \pi\left(\frac{r-1}{r}\right)}$$ #

Concentrated and distributed windings :— (m)

Slots per pole per phase or phase group or "

phase belt or 'm'.

$$\boxed{m = \frac{\text{slots per pole}}{\text{total no of phase}}}$$

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$$\boxed{m = \frac{n}{phase}}$$

n = slots responsible for 180° displacement.

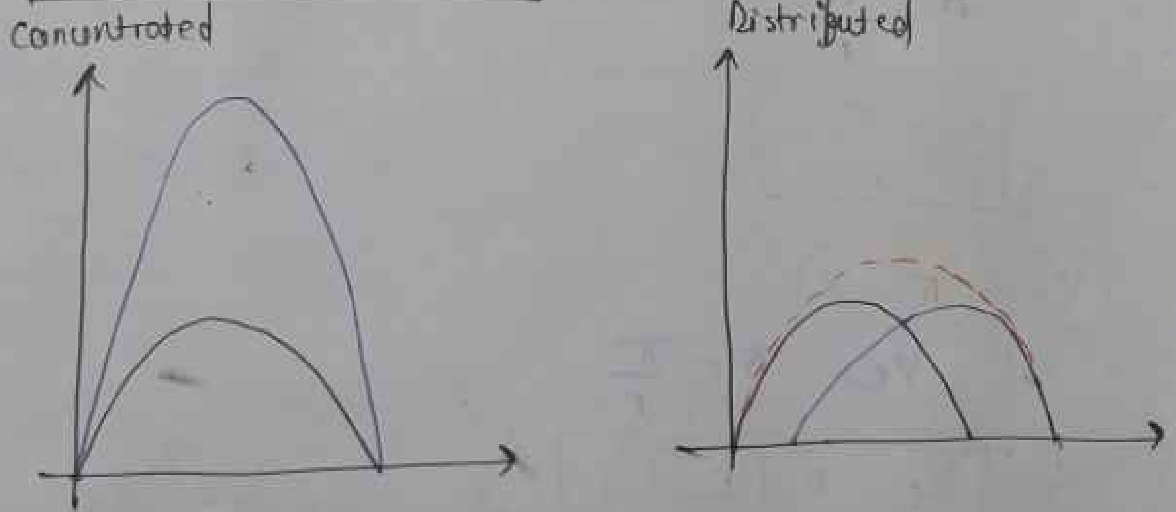
$m = \frac{6}{3}$ = 2 slots per pole per phase

let Z = total number of conductor

Zph = total no of condʳ per pole per phase.

let Z = 60

$$\boxed{Z_{ph} = \frac{60}{2 \times 3} = 10}$$



⇒ If all the Zph conductors are placed in 1 slot keeping remaining 1 slot per pole per phase empty then winding is concentrated.

→ If all the Zph conductors are distributed uniformly in all the two slots per pole per phase available then it is called as distributed windings.

⇒ ## Generally distributed windings are preffered because the waveform of induced emf is more sinusoidal.

Distribution factor | Breadth factor :- (K_d)

$$\boxed{K_d = \frac{\text{Net induced emf in distributed winding}}{\text{Net induced emf in concentrated winding}}}$$

$$\boxed{K_d = \frac{\sin\left(\frac{m\beta}{2}\right)}{m\sin\frac{\beta}{2}}}$$

for

⇒ $\boxed{K_d = 1}$ — 100% पाया, 0% खोया

⇒ $\boxed{0 < K_d < 1}$ — distributed

⇒ $\boxed{K_d = \cdot 7}$ — 70% पाया, 30% खोया

for $\boxed{K_d = 0}$ — 0% पाया, 100% खोया

In alternators β is very small therefore $\left[\sin\frac{\beta}{2} \simeq \frac{\beta}{2}\right]$

$$\boxed{K_d = \frac{2\sin\left(\frac{m\beta}{2}\right)}{m\beta}}$$

Case I :- If 60° phase spread preffered.
$\{m\beta = 60°\}$

$$\left[(K_d)_{60} = \frac{2\sin(60/2)}{\pi/3} = \frac{3}{\pi} \quad \cdot 95\right]$$

Case → II :- of 120° phase spread.

$$\boxed{(K_d)_{120} = \frac{2\sin\frac{120^\circ}{2}}{2\frac{\pi}{3}} = \frac{3\sqrt{3}}{2\pi} = .82}$$

$$\therefore \frac{(K_d)_{120^\circ}}{(K_d)_{60^\circ}} = \frac{3\sqrt{3}\pi}{2\pi \times 3} = \frac{\sqrt{3}}{2}$$

$$\boxed{(K_d)_{60^\circ} = 1.15\,(K_d)_{120^\circ}}$$

∴ Modern alternator are designed with 60° phase spread.

Reduction of harmonics by distributed windings :-

$$K_{dr} = \frac{\sin\left(\frac{mr\beta}{2}\right)}{2\sin\left(\frac{r\beta}{2}\right)}$$

If r^{th} harmonics are completly removed

$$[K_{dr} = 0]$$

$$\frac{\sin\left(\frac{mr\beta}{2}\right)}{2\sin\left(\frac{r\beta}{2}\right)} = 0$$

$$\sin\left(\frac{mr\beta}{2}\right) = 0$$

$$\frac{mr\beta}{2} = \pi$$

$$\boxed{m\beta = \frac{2\pi}{r}}$$

Note:- Winding factor (K_w)

$K_p = .8$

$K_d = .7$

$$\boxed{K_w = K_d \cdot K_p}$$

$K_w = .8 \times .7$

$= .56 \longrightarrow$ 44% खोया

(due to distributed + short pitch)

$E = 4.44\, \phi_{max}\, f N_1 = 100\,V$

In a Transformer concentrated

$K_d = 1$, $K_w = 1$

Emf equation of alternator:-

$$\boxed{E_f = 4.44\, \phi_f \cdot f\, T_{ph}\, K_w} = 56\,V$$

E_f = induced emf per phase | Excitation emf

ϕ_f = Net flux in Air | main flux

f = frequency | T_{ph} = Turn per phase

$T_{ph}\, K_w$ = Effective No of turn

$$\boxed{E_f \propto \phi_f} \rightarrow \text{excitation}$$

is varied to change induced emf.

(4) Fractional slot and integral slot winding :-

//

m = fractional ~~slot~~ → winding = fractional
n = integral slot winding = integer

— Slots per phase ≠ always integer

Eg = (1) 12/2/3 —— Integral
(2) 16/4/3 —— ✗(not possible) ∵ {Slots per phase is not integer}
(3) 18/4/3 —— fractional

Rotor construction :-

According to construction their are two types of rotor :-

(1) Salient pole/Projected pole rotor :- (8)

These rotors have concentrated field windings. So, not suitable for high speed and preferred for preffered for low speed power generation. So, used in hydro power plant.

⇒ These ~~rot~~ rotors have small axial length and large radial length. ~~this~~

⇒ These rotors have large number of poles.

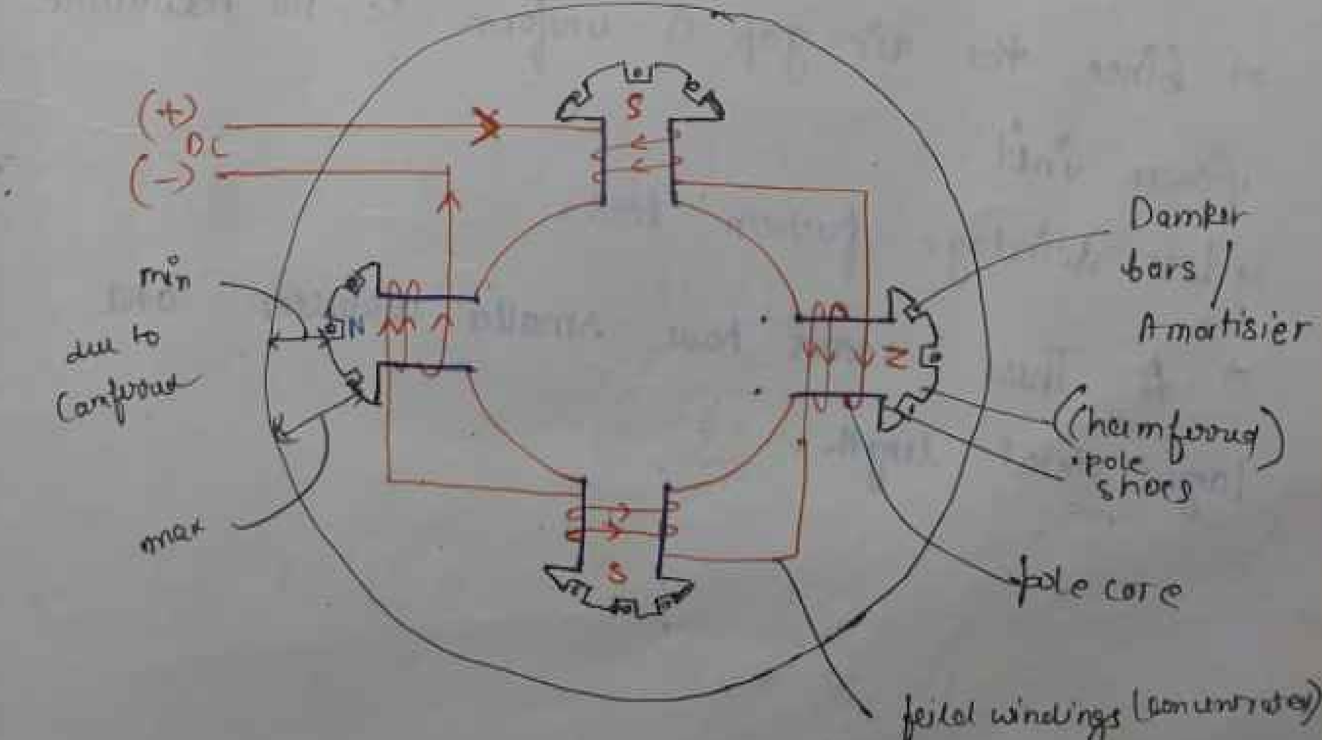
⇒ Pole shoes are chamferred in shape to shape sinusoidal variation in air gap. So, flux becomes sinusoidal.

⇒ The airgap is non-uniform. so, reluctance power present in it.

⇒ Damper bars are present to reduce hunting in the slots on pole shoes which are short circuited by 2 end rings.

⇒ More windage loss. (cost)

⇒ In modern alternators both pole core and pole shoes are laminated.



Smooth cylindrical rotor :- / non salient pole rotor :- / non projected pole rotor :-

⇒ Cylindrical rotor does not have any lamination and also its smooth surface will act as damper. So, no need of damper bar.

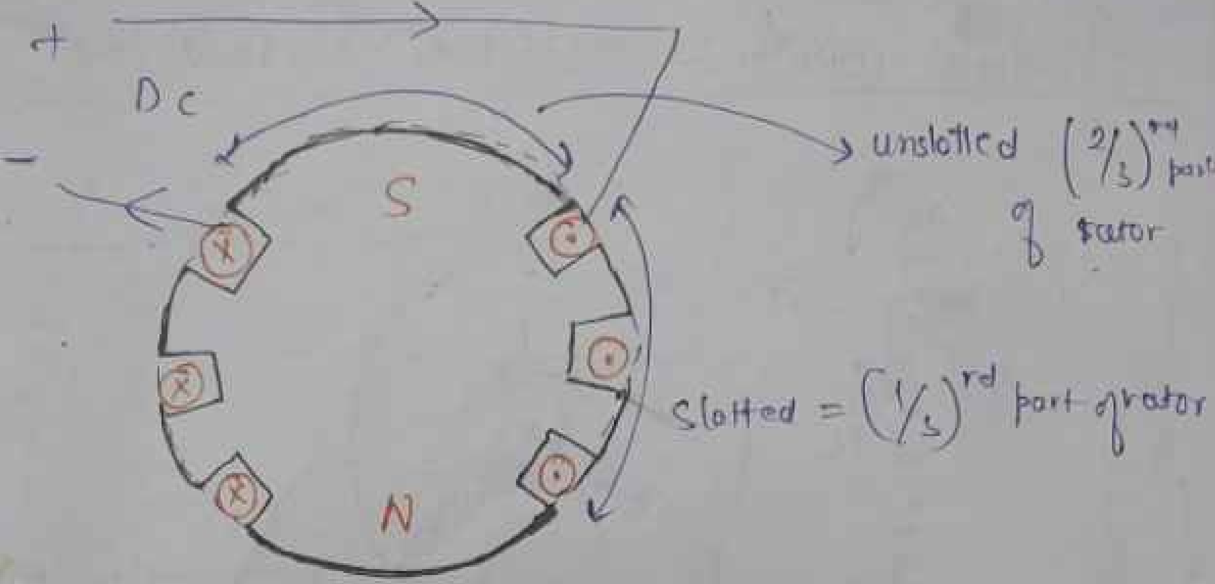
→ These rotors generally have two or four poles and field winding is distributed type. So, offer high speed and used in thermal, gas, nuclear, and turbo alternator.

⇒ For turbo alternators forged (जालीदार) is steel is used to make ~~rotor~~.

⇒ Since the air gap is uniform. So, no reluctance power init.

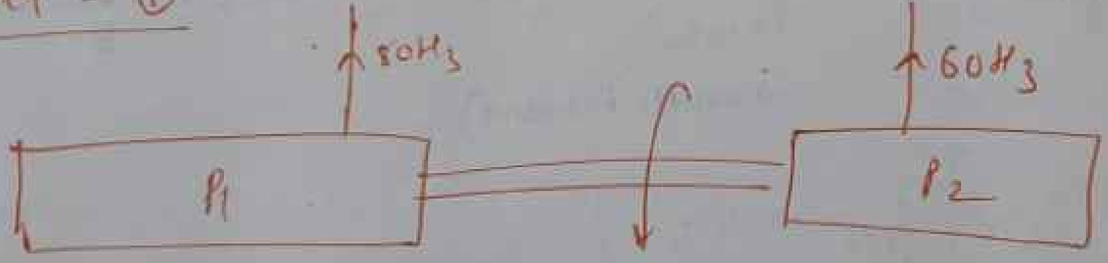
⇒ Less windage friction loss.

⇒ ~~A~~ These rotors have smaller diameter and large axial length.



Eg :-

P 244 - ①



$N_{s1} = N_{s2}$

$$\frac{120 f_1}{P_1} = \frac{120 f_2}{P_2}$$

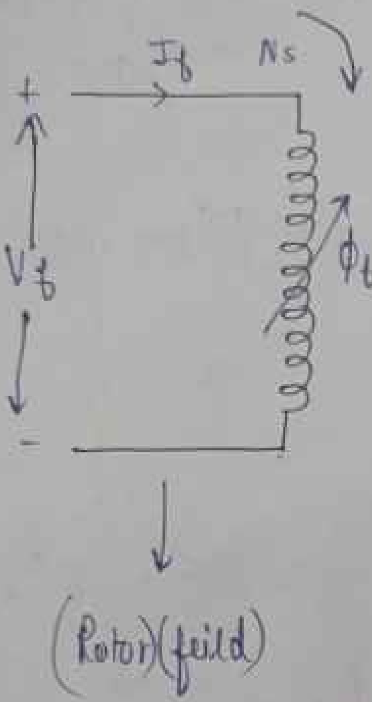
$$\boxed{P_2 = 1.2 P_1}$$

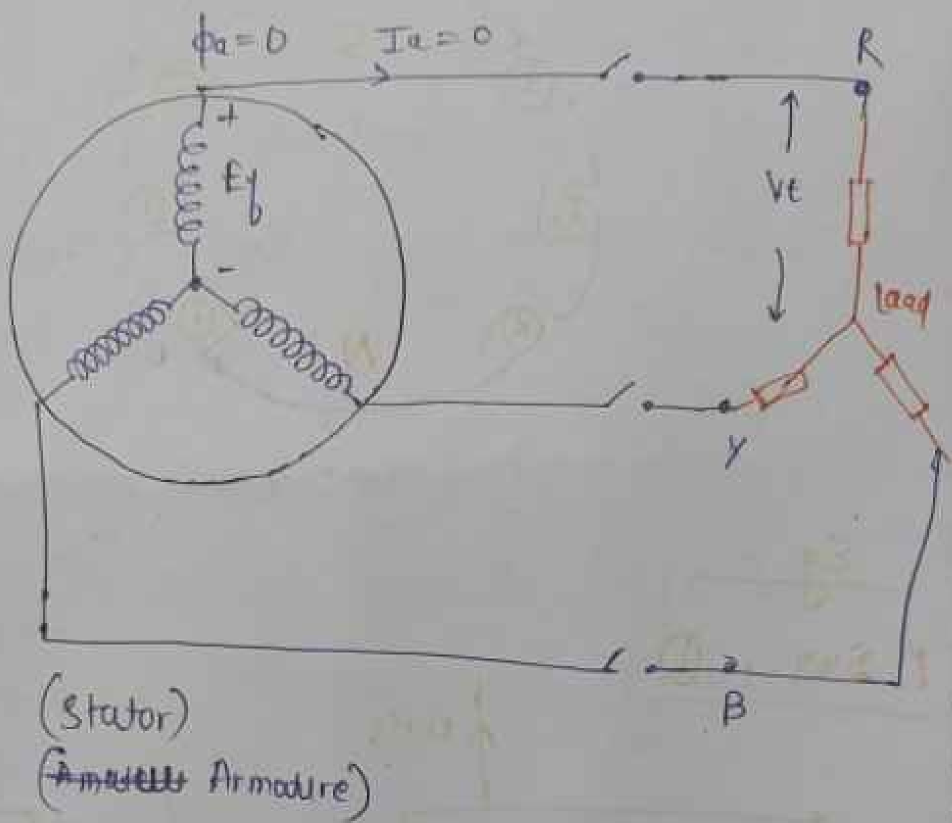
P_1	P_2
2	2.4
4	4.8
6	7.2
8	9.6
10	12
20	24

$P_1 = 10$, $P_2 = 12$

$$N_{s1} = \frac{120 \times 50}{10} = 600 \text{ R.P.M}$$

Armature reaction :- Case-1 Under No load condⁿ





$$\boxed{\phi_{net} = \phi_f}$$

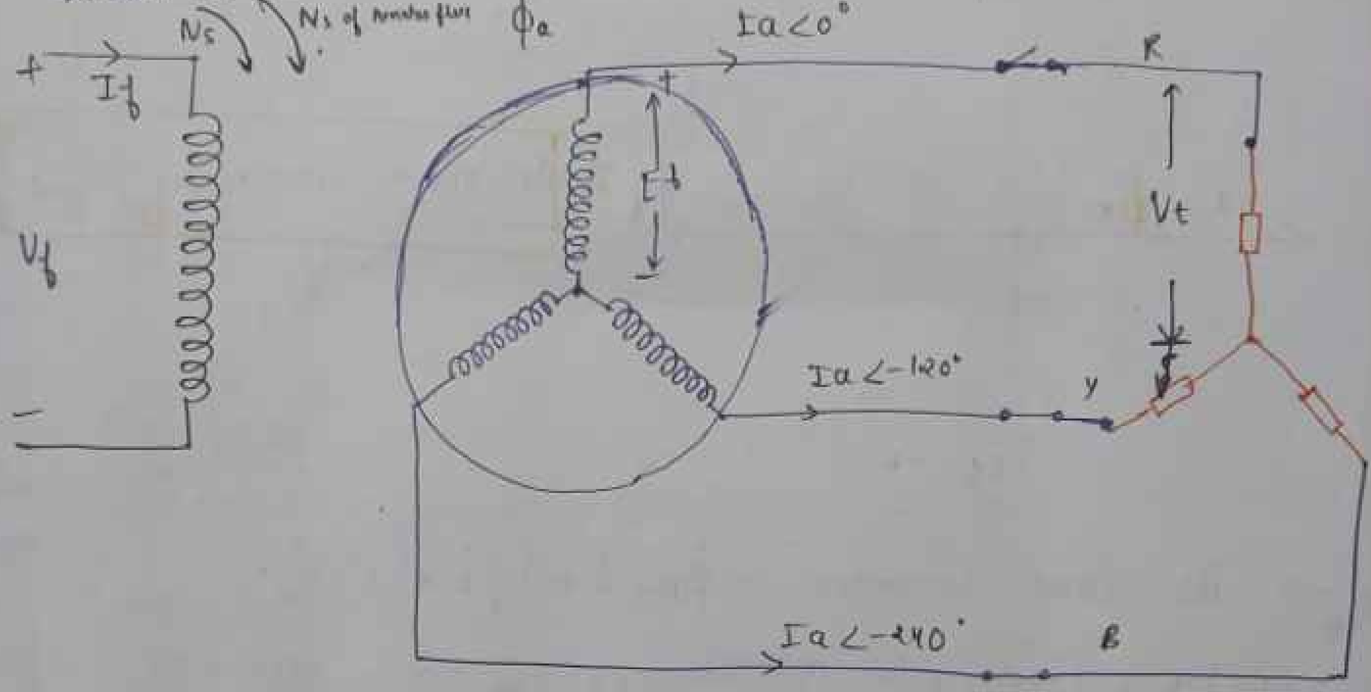
Under noload condition $I_a = 0$, so, $\phi_a = 0$. so, there is no armature reaction.

Case-2:- Under loaded condⁿ :-

⇒ As alternator loaded a current start flowing in all the three phases having mutual displacement of 120°. So, these produces an R.M.F which runs at synchronous speed known as armature flux.

⇒ Relative speed of main flux and armature flux is zero. So, their phasor sum is possible.

⇒ Armature flux will take an action on main flux known as armature reaction.



$$\boxed{\bar{\phi}_{Net} = \bar{\phi}_s + \bar{\phi}_a}$$

Note :- For armature reaction analysis we always take ideal alternator.

$$\boxed{\bar{E}_f = \bar{V}_t}$$

$$E_f \angle\delta = V_t \angle 0^\circ$$

$|E_f| = |V_t|$ / $\delta = 0$

(same phase) then

Ideal cases :-

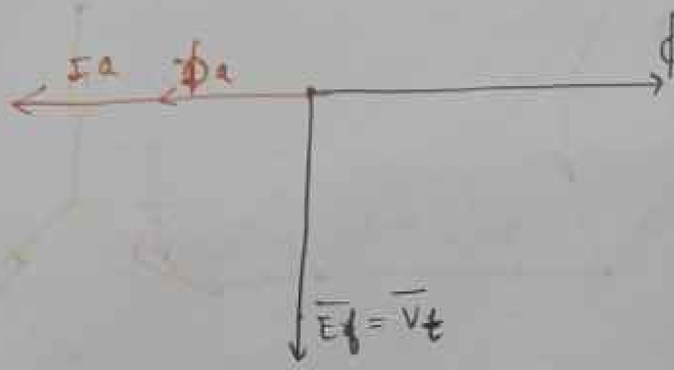
Case-I :- If load is pure inductive :-

(3)

Ia Lags Vt by angle '90'.

$$\boxed{\phi_{Net} = \phi_f - \phi_a}$$

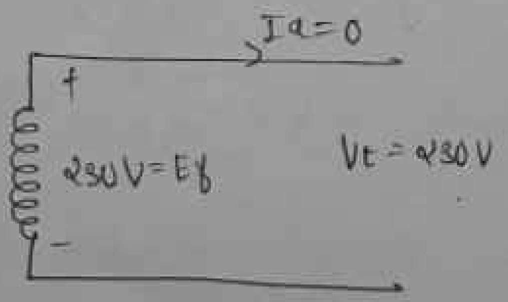
It shows demagnetising effect

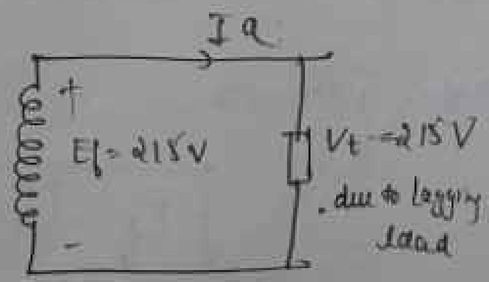


⇒ As load connected, $\phi_{Net}\downarrow$, $E_f\downarrow$, $(V_t\downarrow)_{load}$,

⇒ V.R = +ive, to maintain $V_R = 0$. So, alternator is to be overexcited.

⇒ An overexcited alternator operate at lagging power factor





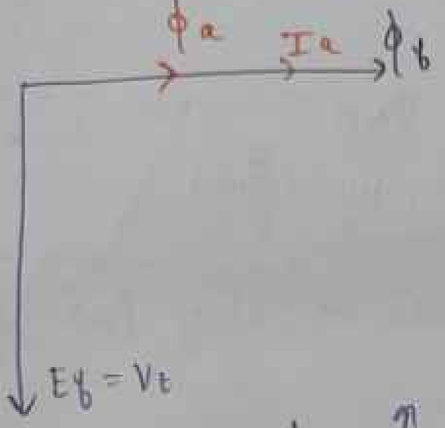
Case-II If load is pure capacitive :-

Ia leads Vt by angle '90'.

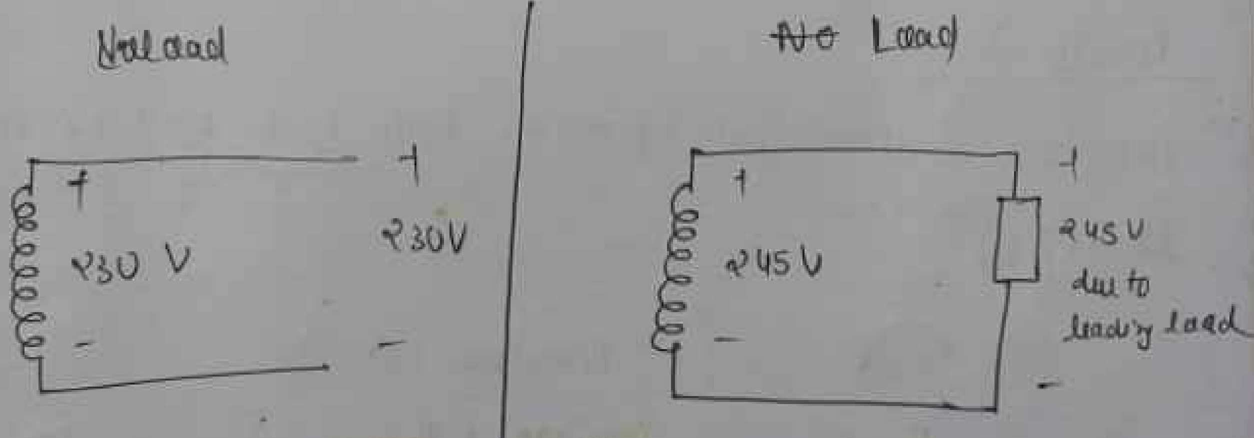
$$\boxed{\phi_{Net} = \phi_f + \phi_a}$$

↓

Magnetising effect.



- ⇒ As load connected $\phi_{Net} \uparrow$, $E_f \uparrow$, $(V_t)\uparrow_{load}$
- ⇒ V_R = –ive, so, to maintain $(V_R = 0)$ alternator must be under excited
- ⇒ Under excited alternator operate at leading p.f.



Case → III :– If load is pure Resistive :–

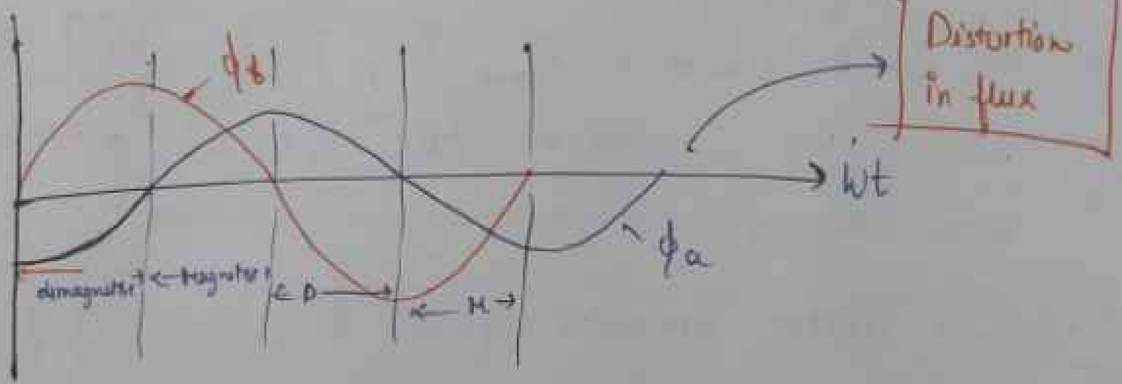
I_a is in phase with V_t

$$\boxed{\phi_{Net} = \sqrt{\phi_a^2 + \phi_f^2}}$$ — {Cross magnetising effect.}

⇒ As load connected, ϕ_{net} = constant, E_f = constant

⇒ So, alternator is normally excited

Normally alternator operates at Unity power factor



Result :-

① Armature reaction effect depends on both load (magnitude) and nature of load (pf)

②

Load	Armature reaction
R-L	'Cross' mag + Demag
R-C	'Cross' mag + Magnetising

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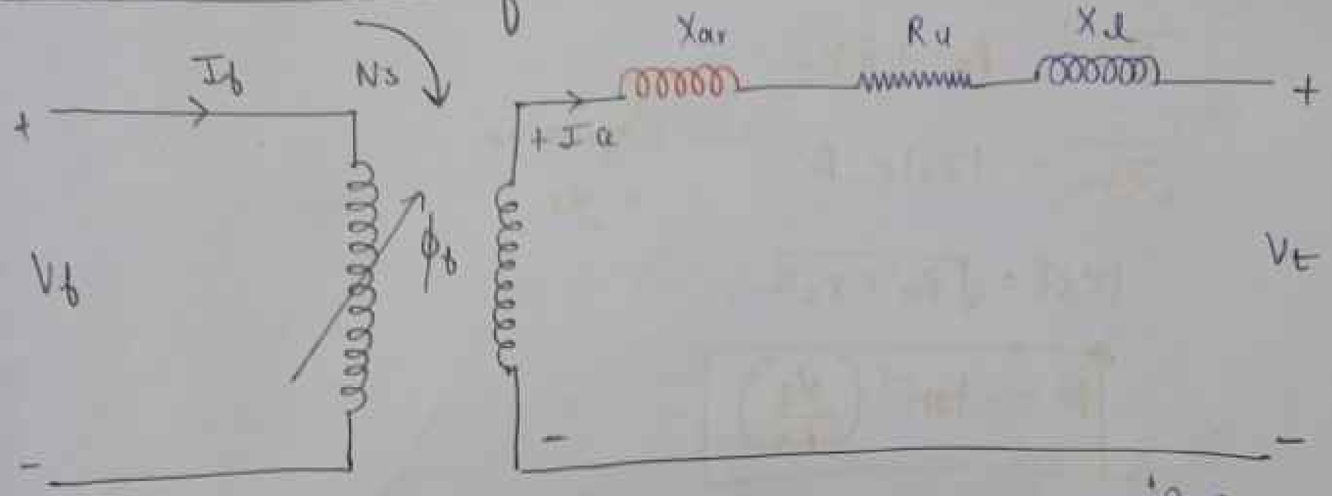
Equivalent circuit of alternator :-



X_{ar} = Armature reaction reactance (fictions) काल्पनिक parameter (or voltag drop due to drop in MMF)

R_a = Armature ~~reactance~~ resistance.

X_l = Leakage reactance

I_a = Rated / full load Armature current

V_t = Full load / Rated terminal voltag e

By KVL

$$\boxed{\bar{E_f} = \bar{V_t} + \bar{I_a} R_a + j \bar{I_a} X_l + j \bar{I_a} X_{ar}} \ \#$$

emf   emf   emf   emf   mmf

$$\bar{E_f} = \bar{V_t} + \bar{I_a} R_a + j \bar{I_a} \underbrace{(X_l + X_{ar})}_{X_s = \text{Synchronous reactance}}$$

$$\boxed{\bar{E_f} = \bar{V_t} + \bar{I_a} R_a + j \bar{I_a} X_s} \ \#$$

$$\bar{E_f} = \bar{V_t} + \bar{I_a} (R_a + j X_s)$$

$$\boxed{Z_s = \text{synch Impedance}}$$

$$\boxed{\bar{E_f} = \bar{V_t} + \bar{I_a} \cdot \bar{Z_s}}$$

$$\bar{Z_s} = R_a + jX_s$$

$$\bar{Z_s} = |Z_s|\angle\beta$$ impedance angle

$$|Z_s| = \sqrt{R_a^2 + X_s^2}$$

$$\boxed{\beta = \tan^{-1}\left(\frac{X_s}{R_a}\right)}$$

Result :-

① $\bar{Z_s} = R_a + jX_s$

$$\boxed{R_a <<<< X_{l} <<< X_{ar}}$$ ## ##

$$R_a <<< X_s$$

$$\boxed{\bar{Z_s} \simeq jX_s}$$

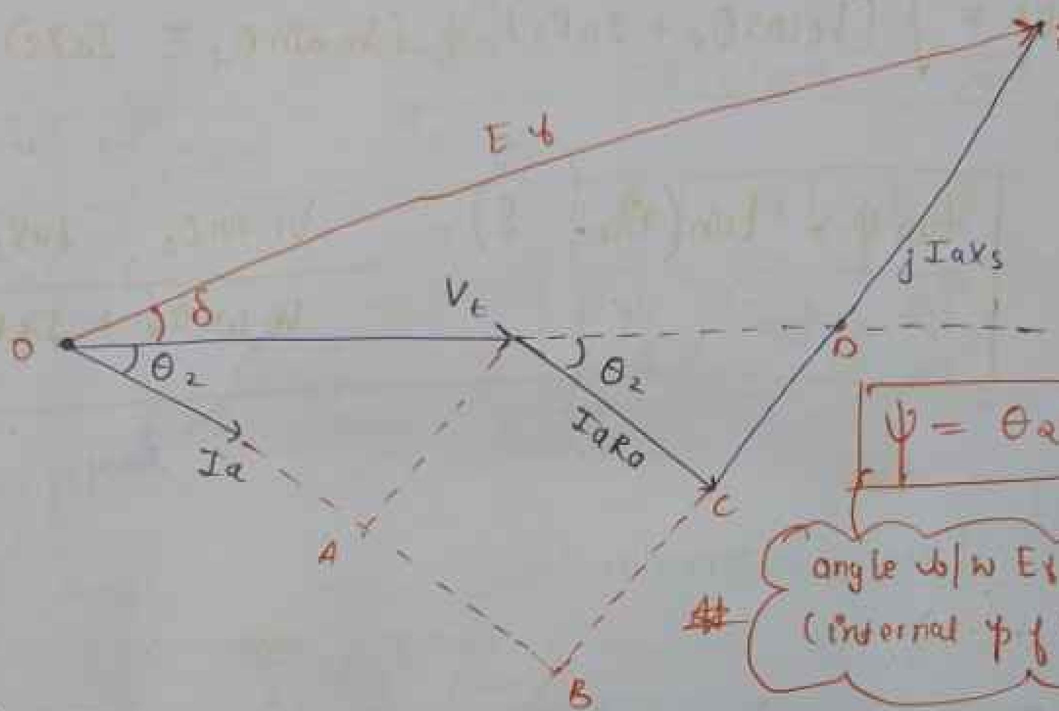
if R_a न question में नहीं दिया हो then neglect it.

** ② Here X_{ar} is a ficticious parameter whose value value depends on a load and nature of load and it represent drop due to armature reaction.

Phasor diagram :-

I_a lags V_t by angle 'θ_2' (p.f angle) Load,

$$\boxed{\bar{E_f} = \bar{V_t} + \bar{I_a}R_a + j\bar{I_a}X_s}$$



$$\boxed{\psi = \theta_2 + \delta}$$

angle b/w E_f and I_a (internal p.f angle)

$$\boxed{V_R = \frac{|E_f| - |V_t|_{Load}}{|V_t|} \times 100}$$

$|E_f| = OE$

$$|OE| = \sqrt{(OB)^2 + (BE)^2}$$

$$= \sqrt{(OA + AB)^2 + (BC + CE)^2}$$

$$\boxed{|OE| = \sqrt{(V_t \cos\theta_2 + I_aR_a)^2 + (V_t \sin\theta_2 + I_aX_s)^2}}$$

$$\boxed{\tan\psi = \tan(\theta_2 + \delta) = \frac{V_t \sin\theta_2 + I_aX_s}{V_t \cos\theta_2 + I_aR_a}}$$

Result :-

$$\boxed{E_f = \sqrt{(V_t\cos\theta_2 + I_a R_a)^2 + (V_t \sin\theta_2 \pm I_a X_s)^2}}$$

lagging / leading

$$\boxed{\tan\phi = \tan(\theta_2 \pm \delta) = \frac{V_t \sin\theta_2 \pm I_a X_s}{V_t \cos\theta_2 + I_a R_a}}$$

lagging / leading

KVA ratting of Alternator :-

A $\boxed{10\ KVA}$, $\boxed{400V}$, 50 Hz, 3-ϕ, Alternator ———

10 KVA → Full load | Rated power O/P

400V → Rated | Full load terminal voltage (Line value)

50 Hz → output frequency.

$$\boxed{S = \sqrt{3}\, V_{tL} I_{aL}}$$

$$\boxed{S = 3 V_t I_a}$$

If any connection is not given in question then alway take λ connection

$S = \sqrt{3} V_{Lt} I_{aL}$

$\boxed{\cos^{-1} .8 = 36.86}$

$10K = \sqrt{3} \times 400 \, I_{aL}$

$\boxed{I_{aL} = I_a = 14.43A}$

Q. A 10KVA, 400V, 50Hz, 3-ϕ alternator supply rated load, .8 p.f lagging. If armature resistance is 5Ω and synchronous reactance is 10Ω then the value of internal induced emf, voltage regulation, load angle ?

Take phase value because of equivalent ckt parameter.

Rated Load

$\cos\theta_2 = 0.8$ Lagg

$R_a = 5\Omega$, $X_S = 10\Omega$

E_f, V.R, δ

$$\boxed{V.R = \frac{|E_f| - |V_t|}{|V_t|} \times 100}$$

$V_{tL} = 400V$

$$\boxed{V_t = \frac{400}{\sqrt{3}} = 231V}$$

of at full load

$\boxed{I_a = 14.43A}$

$$E_f = \sqrt{(V_t \cos\phi_2 + I_a R_a)^2 + (V_t \sin\theta_2 + I_a X_s)^2}$$

$$E_f = \sqrt{(231 \times 0.8 + 14.43 \times 5)^2 + (231 \times 0.6 + 14.43 \times 10)^2}$$

$$\boxed{E_f = 382\ V}$$

$$\boxed{V.R = \frac{382 - 231}{231} \times 100 = 65\ \%}$$

$$\tan(\theta_2 + \delta) = \left| \frac{V_t \sin\theta_2 + I_a X_s}{V_t \cos\theta_2 + I_a R_a} \right|$$

$$\boxed{\tan(\theta_2 + \delta) = \left| \frac{231 \times .6 + 14.43 \times 10}{231 \times 0.8 + 14.43 \times 5} \right|}$$

$$\boxed{\theta_2 = 36.86}$$

$\cos^{-1} .8 = 36.86$

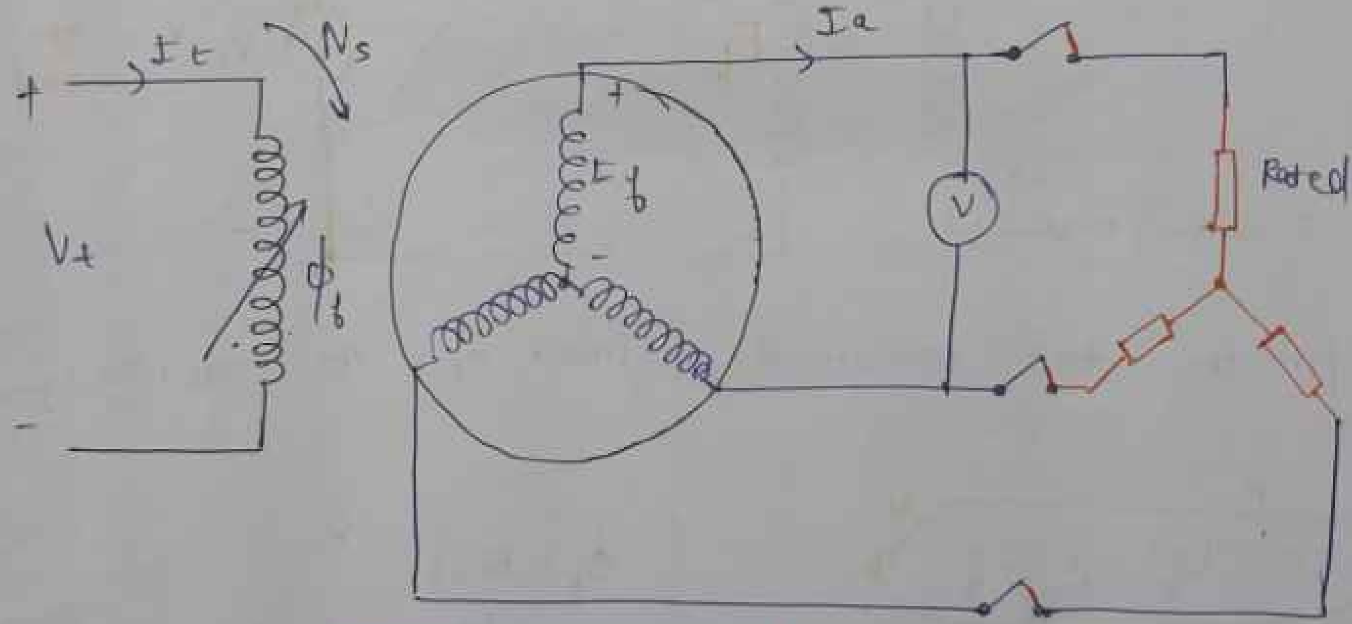
$$\boxed{\delta = 18^\circ}$$

Testing of alternator or determination of voltage regulation

Direct method :-

Direct methods can be applied only for small ratting alternator and also load is directly connected so, it gives accurate results.

=> For high capacity alternators that much full load ~~to be~~ cannot be ~~to~~ directly connected to the alternator. so, direct method cannot be used for high ratting alternator.



$$\boxed{V.R = \frac{|E_f| - |V_t|}{|V_t|} \times 100}$$

II Indirect method :-

① Synchronous Impedance method / emf method / Pessimestic :-

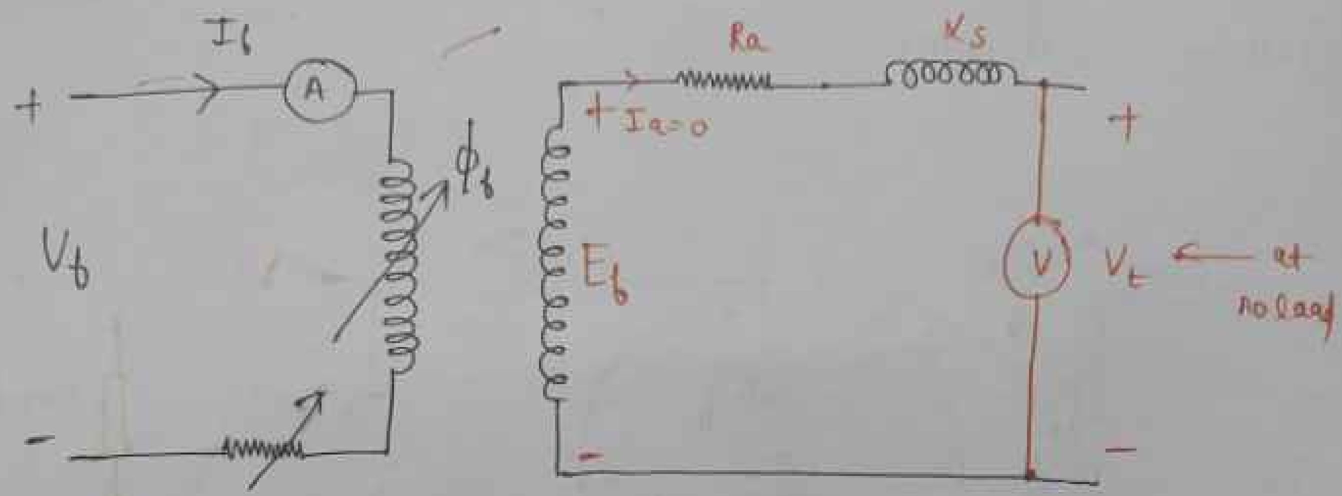
$$\boxed{E_f = \sqrt{(V_t \cos\theta_a + I_a R_a)^2 + (V_t \sin\theta_a + I_a X_s)^2}}$$

By D.C test

O.C test
S.C Test

D.C Test = $\boxed{R_{ac} = (1.2 \text{ to } 1.3) R_{DC}}$

② Open ckt test (OC test)



open ckt test conducted to Draw open ckt characteristics (O.CC)

O.CC E_f V/F I_f

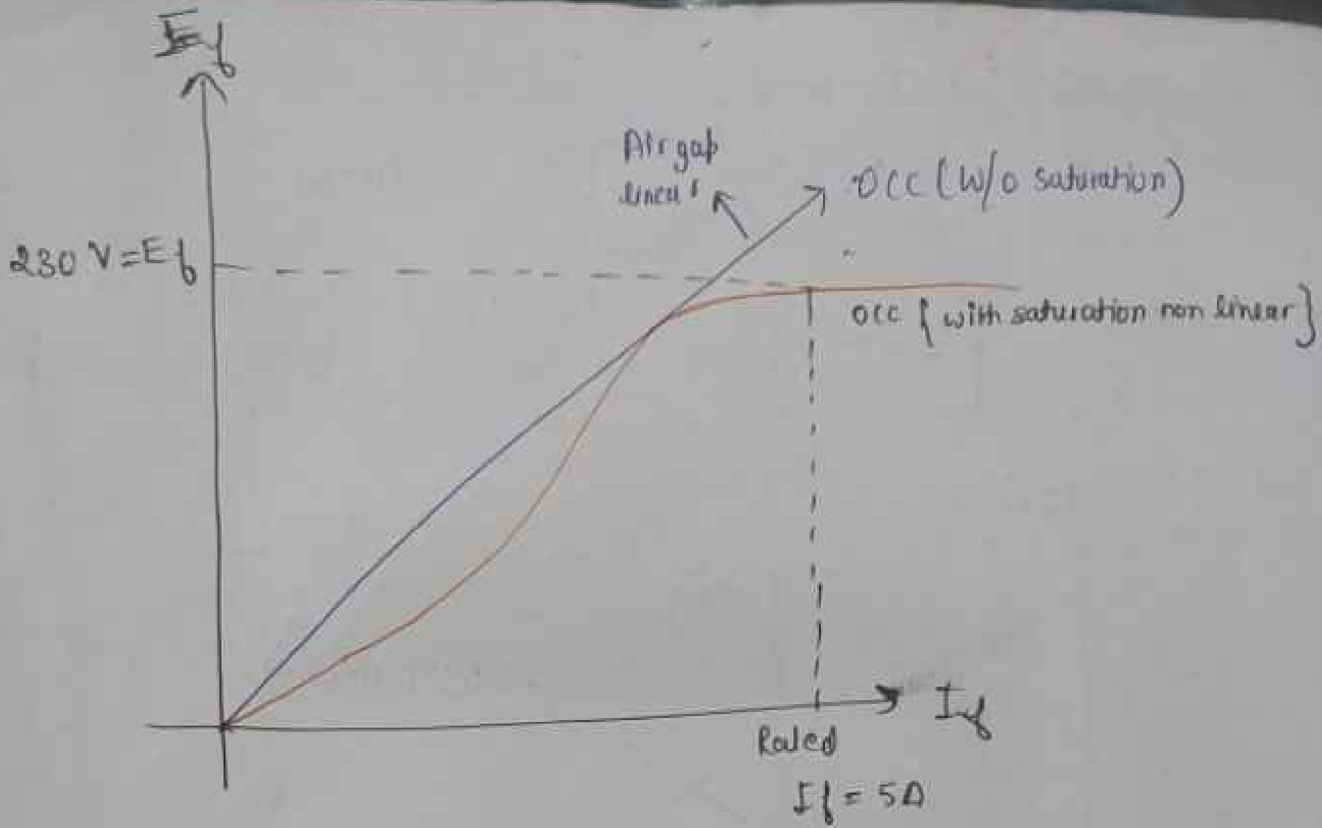
$$\boxed{E_f = 4.44 \phi_f f \cdot T_{ph} \cdot K_w}$$

$\boxed{E_f \propto \phi_f}$ → Linear

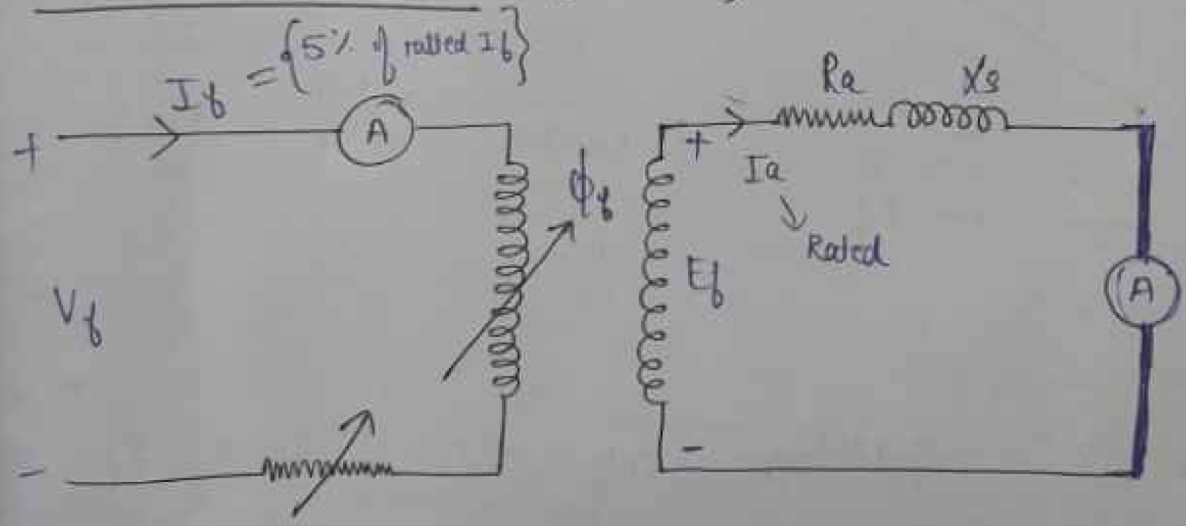
$$\phi_f = \frac{N I_f}{R_e}$$

$\phi_f \propto I_f$ → (W/o saturation) Non magnetic (Air) (Linear)

$E_f \propto I_f$ → Magnetic material (Core) Non linear (B-H curve) (with saturation)



Short ckt test :- (S.C test)



Short ckt test conducted to draw S.C characteristics (S.CC)

$\therefore$ $\boxed{\text{S.CC } I_a \text{ V/S } I_f}$

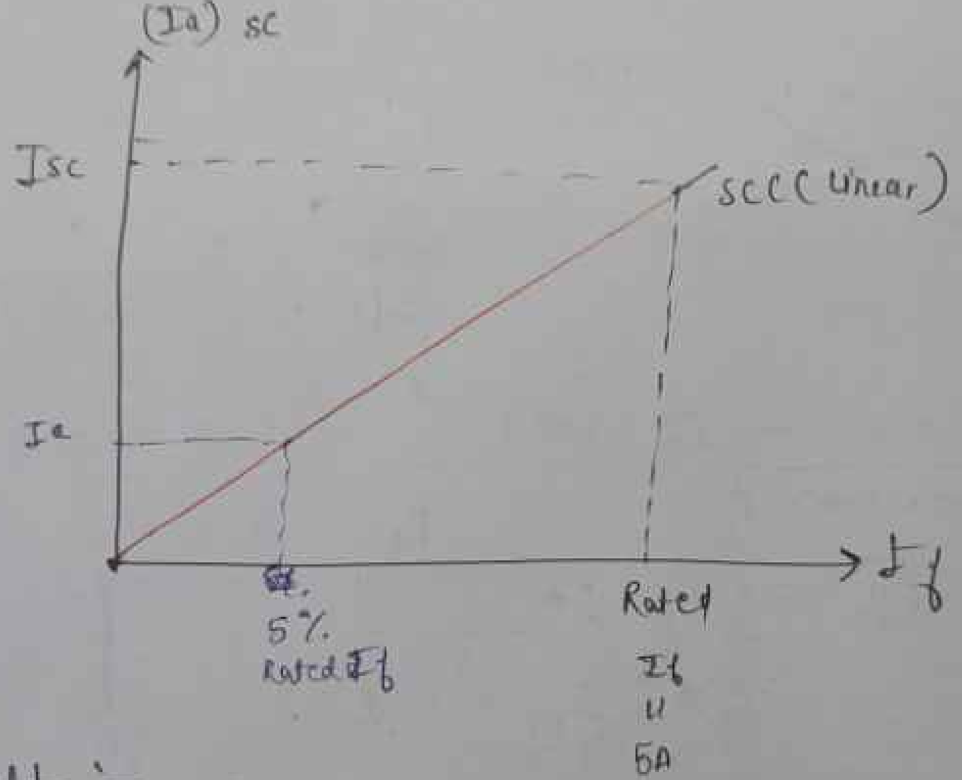
$$\boxed{I_a = \frac{E_f}{\sqrt{R_a^2 + X_s^2}}}$$ $\Rightarrow$ $I_a \propto E_f$

$E_f \propto \phi_f$

$I_f \propto \phi_f$

$\boxed{\phi_f \propto I_f}$ — linear

$\{I_a \propto I_f\}$ ∵ only 5% of rated I_f is taken so core not get saturated



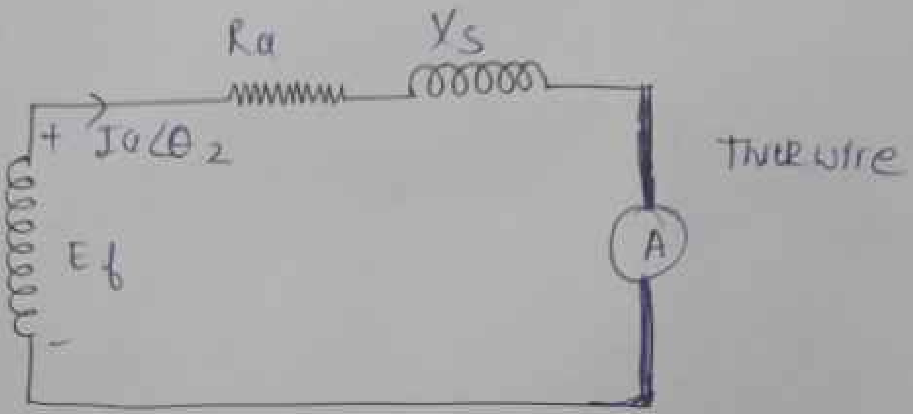
Result :-

① Under S.C condition only 5% of rated I_f is suffient to circulate rated current in the armature under short ckt condition. So, the core is not saturate and S.CC is a linea characteristics

② Since S.SC is ~~aligned~~ a line passing through origin

So, only one reading is sufficient to draw SCC.

(3) Under short circuit condition the power factor of alternator is almost 0 lagging.



$R_a <<< X_s$

$$\boxed{\beta = \tan^{-1}\left(\frac{X_s}{R_a}\right)}$$

$$I_a \angle \theta_{sc} = \frac{E_f \angle 0^\circ}{|Z_s| \angle \beta}$$

$$\boxed{\theta_{sc} = \tan^{-1}\left(\frac{X_s}{R_a}\right)}$$

$$\boxed{\theta_{sc} \approx -\pi/2}$$

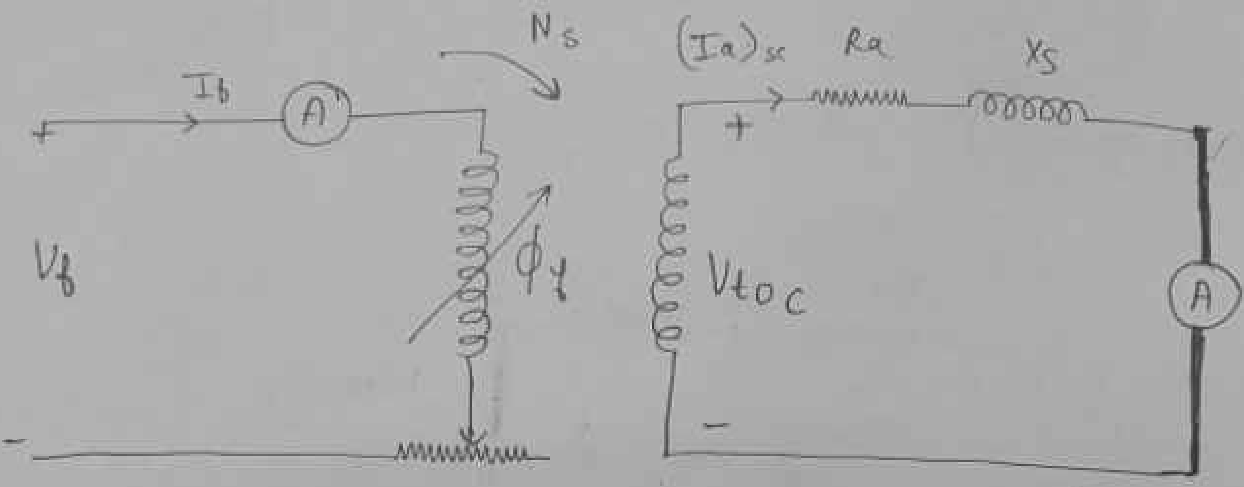
$$\boxed{\cos\theta_{sc} = 0 \text{ lagging}}$$

$R_a = .01$ pu

$X_s = 1$ pu

So lagg

Determination of Z_s from OCC and SCC :-



By KVL

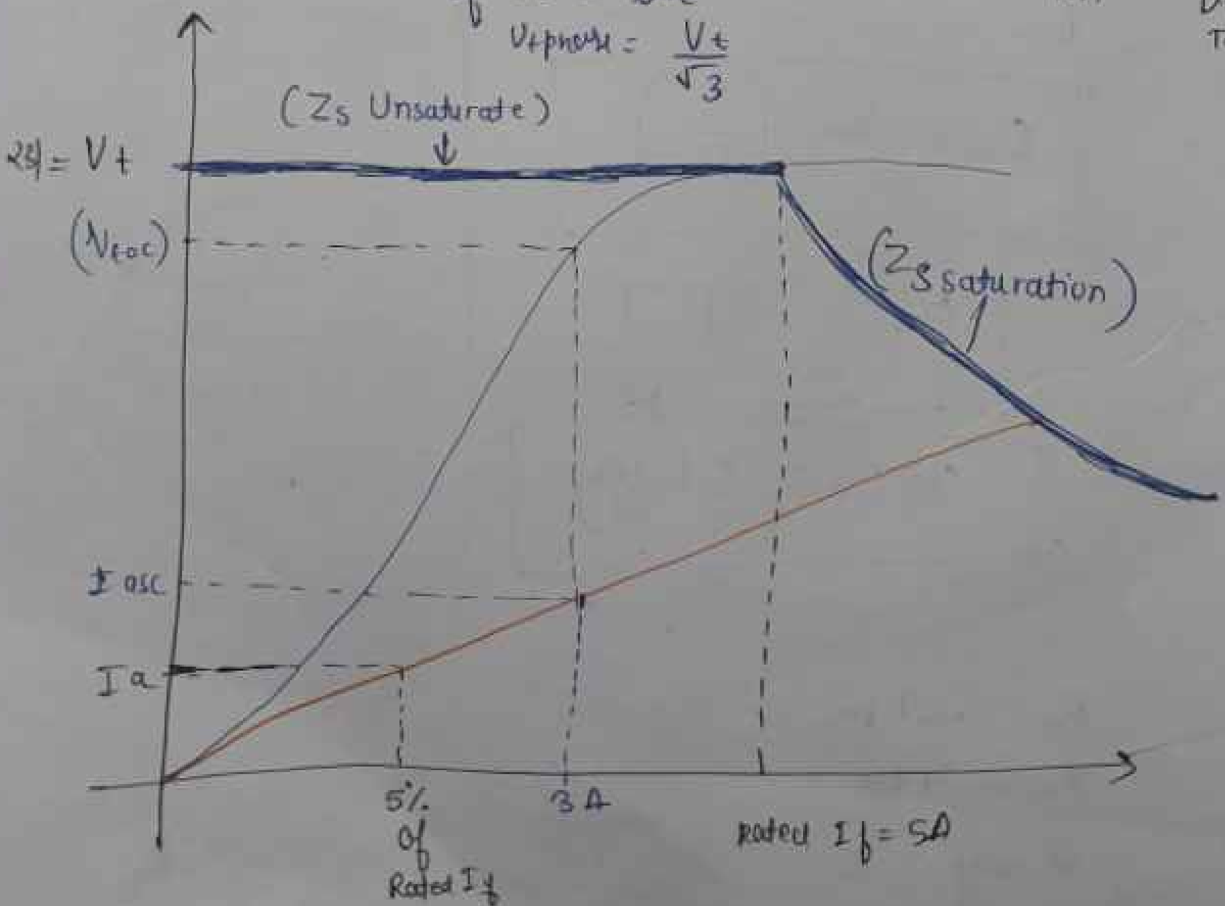
$$\boxed{Z_s = \frac{(V_t)_{oc}}{I_{asc}} \Bigg|_{I_f = const}}$$

$Z_s = \sqrt{R_a^2 + X_s^2}$

Kn DC Test cal

If V_t = line

$V_{t\,phase} = \frac{V_t}{\sqrt{3}}$



$$\boxed{Z_{s\,(sat)} < (Z_s)_{unsat}}$$

$\because$ after sat V_t = const

$$\therefore \boxed{Z_s \propto \frac{1}{I_{asc}}} \quad \therefore Z_s \downarrow$$

Result :-

① In this method all the quantities are assumed to be emf quantity and the value of obtained of regulation are more than actual. So, it is known as pessimistic method.

② The value of Z_s is different for different / different field current

Ques:- A star connected 400 V 50 Hz 4-pole synchronous machine gives following test results

S.C Test — 10A, $I_f = 1.5A$.

O.C Test → 400 V, $I_f = 2.3A$

Find the Z_s for rated voltage?

As

$$Z_s = \left.\frac{V_{toc}}{I_{asc}}\right| I_f = 2.3\,A$$

S.C is linear

$\therefore \frac{10}{I_{asc}} = \frac{1.8}{2.3}$

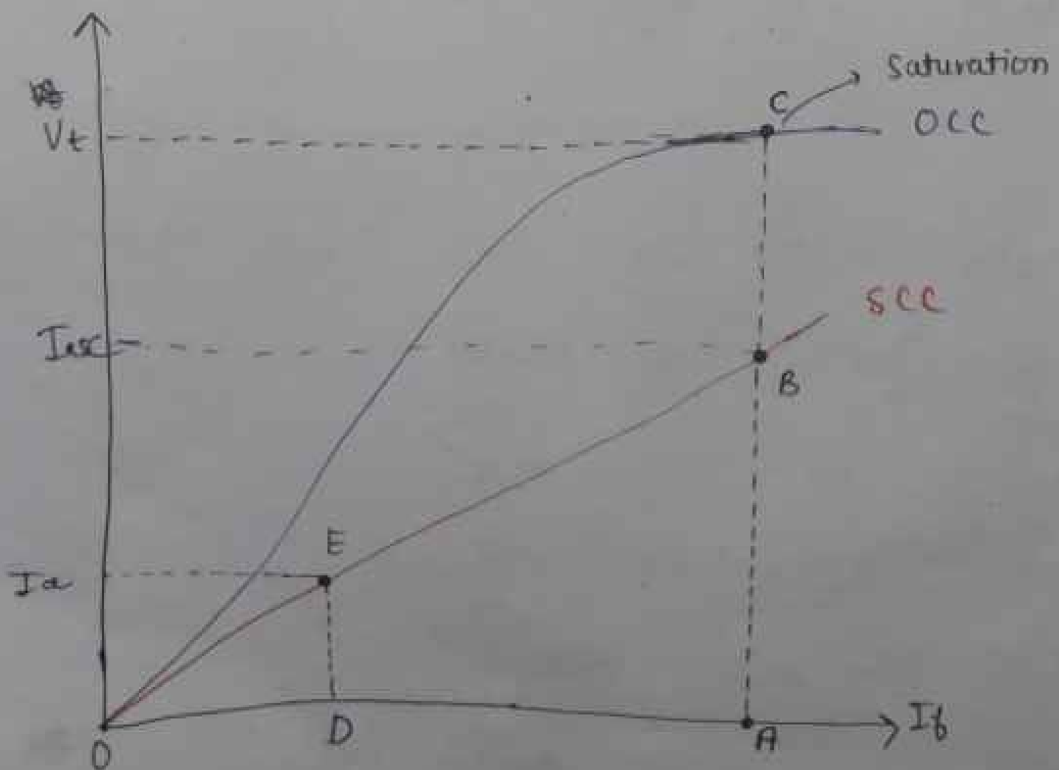
$\therefore \boxed{I_{asc} = 15.33\,A}$

$$Z_s = \frac{400}{\sqrt{3} \times 15.33\,A}$$

$$\boxed{Z_s = 15.06\,\Omega}$$

Short circuit ratio (SCR) :-

$$\left(P_{0(max)} = \frac{E_f V_t}{Z_s} - \frac{V_t^2}{Z_s^2} R_a\right)$$



$$\boxed{SCR = \frac{\text{feild current required to produce rated voltage at o.c}}{\text{feild current required to produce rated current at s.c}}}$$

$$\boxed{SCR = \frac{OA}{OD}}$$

$\because$ ~~$\Delta ODE \approx \Delta OAB$~~

$\therefore$ ~~$\frac{OD}{OA} = \frac{DE}{AB}$~~

$\Rightarrow$ ~~$\frac{I_a}{AB} = \frac{1}{SCR}$~~

$$(Z_s)_{sat}(\Omega) = \frac{V_{toc}}{I_{asc}} \quad \Big| \quad I_f = OA$$

$$(Z_s)_{sat}(\Omega) = \frac{V_t}{AB}$$

$$(Z_s)_{Base}(\Omega) = \frac{V_{rated}}{I_{rated}} = \frac{V_t}{I_a}$$

$$(Z_s)_{sat}(PU) = \frac{(Z_s)_{sat}(\Omega)}{(Z_s)_{base}(\Omega)}$$

$$= \frac{(Z_s)_{sat}(\Omega)}{(Z_s)_{base}(\Omega)}$$

$$(Z_s)_{sat}(P.U) = \frac{V_t}{AB} \times \frac{I_a}{V_t} = \frac{I_a}{AB}$$

$$\boxed{\Delta ODE \approx \Delta OAB}$$

$$\therefore \frac{OD}{OA} = \frac{DE}{AB}$$

$$\frac{I_a}{AB} = \frac{1}{SCR}$$

$$(Z_s)_{sat}\,(PU) = \frac{1}{SCR}$$

$$\boxed{SCR = \frac{1}{(Z_s)_{sat}\,(PU)}}$$

$$\boxed{SCR = \frac{1}{(Z_s)_{adjusted}\,(P.U)}}$$

∵ for modern alternator

$$\boxed{Z_{s\,sat}(PU) = X_{s\,(sat)}\,PU}$$

$$\boxed{SCR = \frac{1}{(X_s)_{sat}(PU)}}$$

$SCR \propto \frac{1}{X} \propto \frac{1}{L} \propto R_e \propto$ Air gap

$\boxed{SCR \propto \text{air gap}}$

Case→I High SCR :- X↓, Air gap ↑

(2) X↓, Voltage Drop ↓, V.R↓, Better voltage regulation.

(3) $\uparrow I_{sc} \propto \frac{1}{\sqrt{R^2+X^2}\downarrow}$, High S.C current

(4) Stability $\propto \frac{1}{X\downarrow}$, more stable

Case → II Low SCR :- $X\uparrow$, Air gap$\downarrow$

① $X\uparrow$, Voltage drop ↑, V.R ↑, poor Voltage regulation.

② $\downarrow I_{sc} \propto \frac{1}{X\uparrow}$, Low short circuit current.

③ $\downarrow$ stability $\propto \frac{1}{X\uparrow}$, less stability.

Result :-

① Modern alternators are designed with high S.CR.

Typical value of SCR = .5

Cylindrical : 0.5 to 0.9 } So, salient pole rotor

Salient : 1 to 1.5 } is more stable.

② Ro thery's method / MMF method / ATs method / optimistic (आशावादी)

→ In this method all the quantities are assumed to be MMF quantity. So, it is known as MMF method and obtained value of regulation are less than actual. So, it is known as optimistic method.

→ In this method MMF required to produce rated induced Emf E_f having two components (f_{net})

The first component is MMF required to produce rated terminal voltage V_t under open circuit condition (f_o).

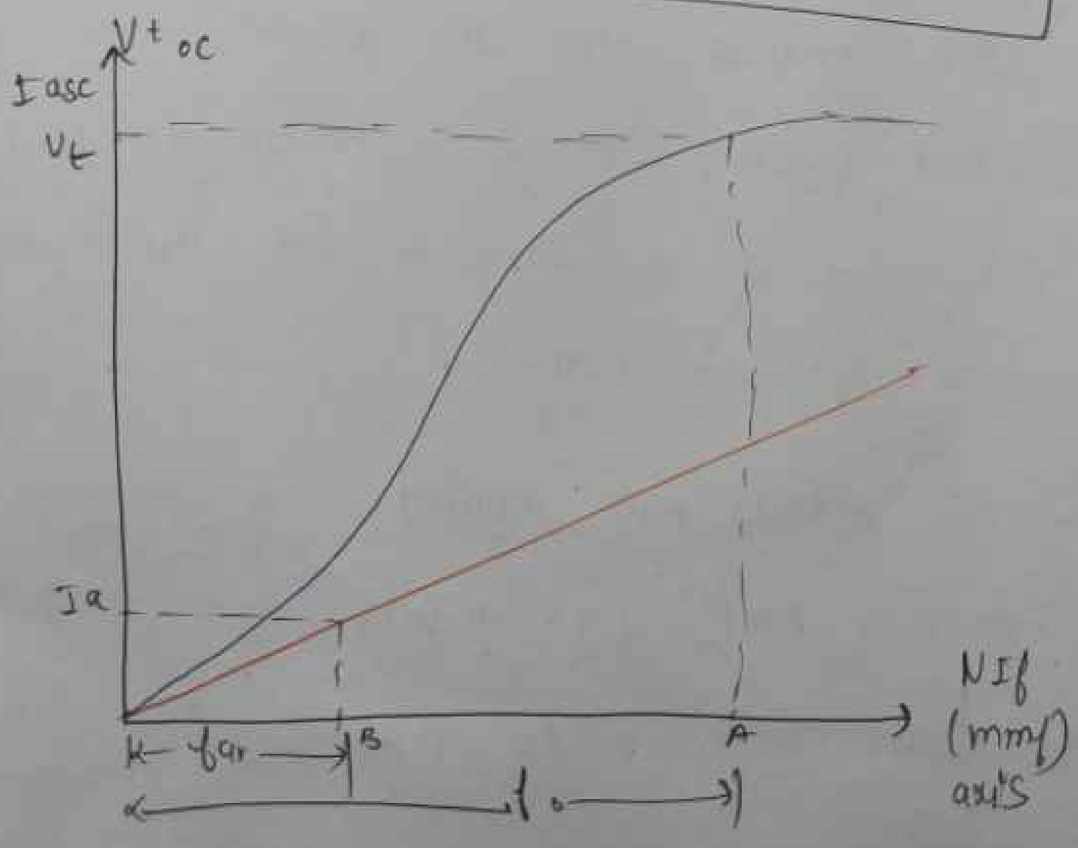
Another componet is MMF required to compensate all the drops under short circuit condition (f_{ar}).

$$\overline{E_f} = \overline{V_t} + \overline{I_a}\,\overline{Z_s}$$

$$E_f \propto \phi_f \propto NI_f \propto MMF \propto f_{net}$$

$$\boxed{\overline{f_{net}} = \overline{f_o} + \overline{f_{ar}}}$$

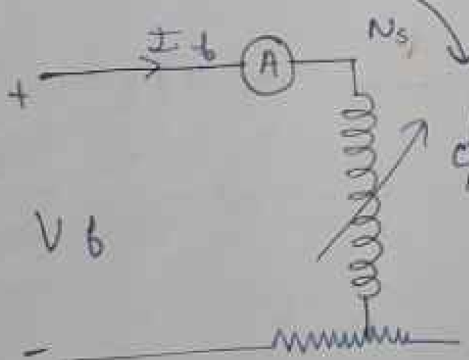
$$\boxed{V.R = \frac{|E_f| - |V_t|}{|V_t|} \times 100 = \frac{|f_{net}| - |f_o|}{|f_o|} \times 100}$$

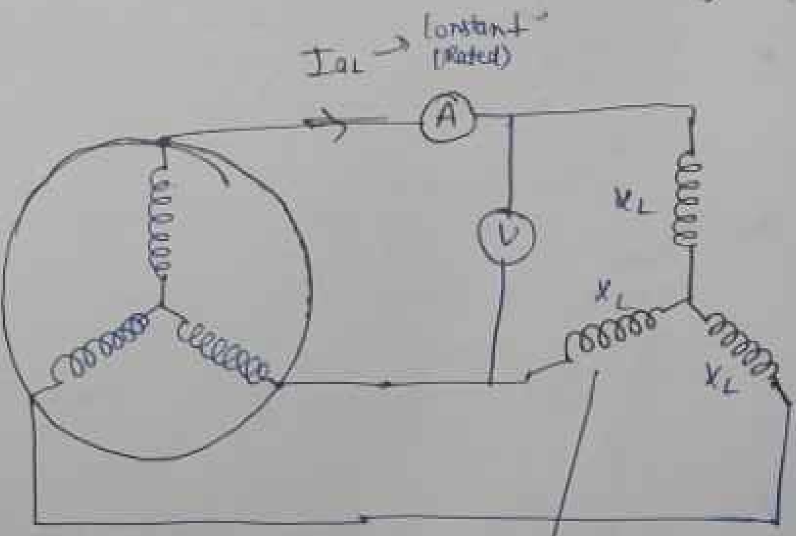


(3) Potier triangle method / Zero power factor characteristics method (ZPFC) :-

Potier seperated all the drops according to their nature. So, this method gives more accurate results. In this method two operating characteristics required.

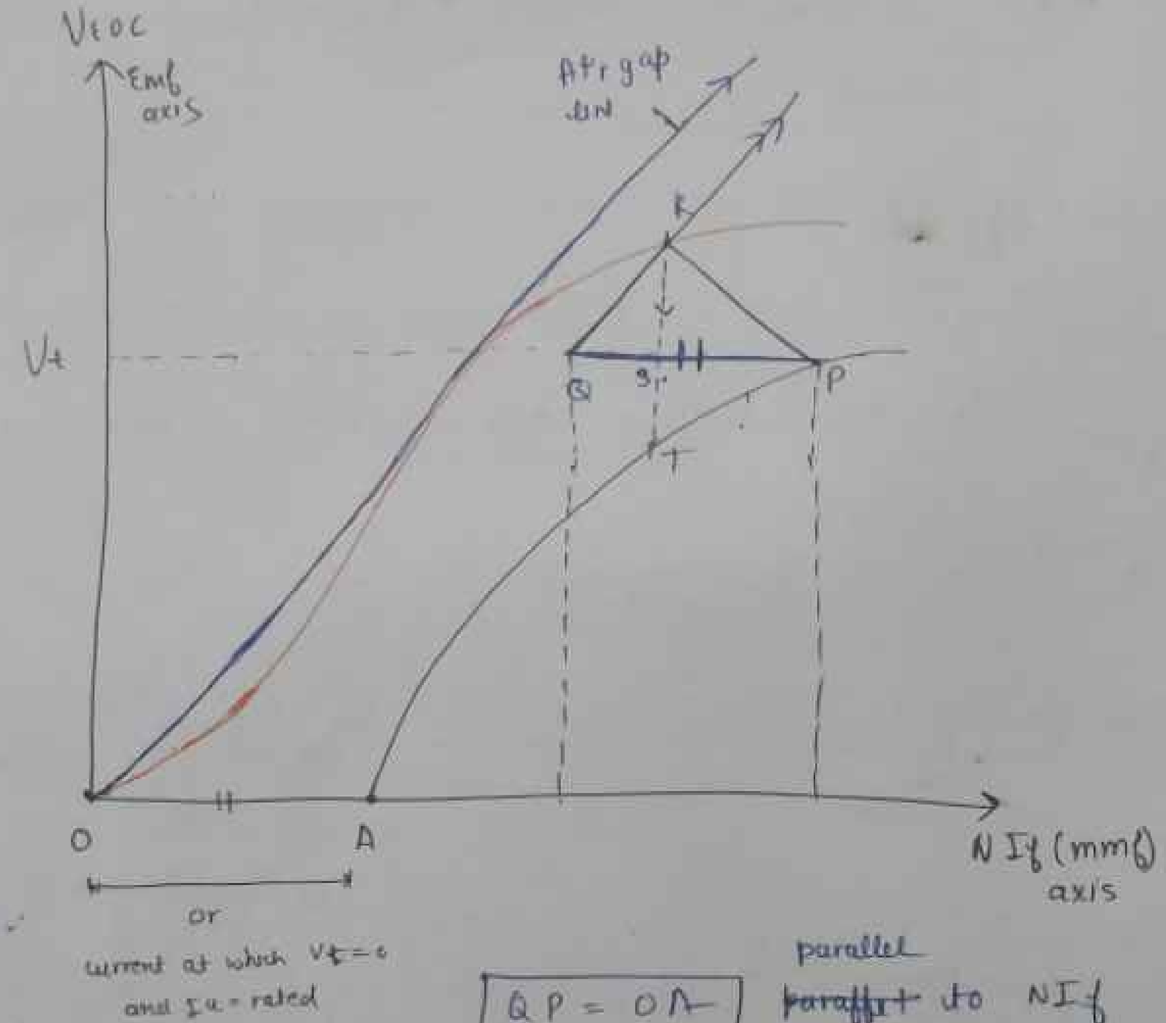
(2) Zero power factor char (ZPFC) V_t V/s I_f, I_a = constant (Rated)





Load

Pure inductor / Under excited syn motor



$\boxed{QP = OA}$ parallel ~~paraffrt~~ to NIf

now draw QR parallel to air gap line

from RP

$l(PQ) = l(OA)$ = mmf required to compensate 'X_s' Drop.

(1 to Vta) emf $= l(RS)$ = emf required to compensate (X_l)

$l(QS)$ = mmf required to compensate X_L Drop.

$l(RT)$ = emf drop due to (X_s)

$l(ST)$ = emf drop due to (AR)

$l(PS)$ = mmf drop due to (A R)

$$\boxed{(P_o)_{max} = \frac{E_f V_t}{Z_s} - \frac{V_t^2 R_a}{Z_s}}$$

$$V_{ph} = \frac{V_t}{\sqrt{3}} = \frac{17.32 \times 10^3}{\sqrt{3}} = 10 \times 10^3 = 10\,kV$$

$$= \frac{\cancel{12} \times 10^3 \times 10 \times 10^3}{\cancel{9}}$$

P_{omax} per phase $= \frac{4}{3} \times 10^7$

$$\boxed{\text{for 3 phase} = 39 \text{ or } 40 \times 10^6}$$

where $E_f = 12\,kV$, $V_L = 17.3\,kV$, $Z_s = 9\,\Omega$, MVA $= 30\,MVA$,

→ The positive, negative and zero sequence impedances of 3-ϕ synchronous generator are $j.5$ p.u, $j.3$ p.u, and $j.2$ pu respectively. When symmetrical fault occurs on the machine terminals. Find the fault current. The generator neutral is grounded through reactance of .1 pu.

$$\therefore \boxed{I_F = \frac{1\angle 0^\circ}{j(.5+.1)} = -j\,1.67\,pu}$$

Hrdike

Two reactance theory for salient pole rotor :-

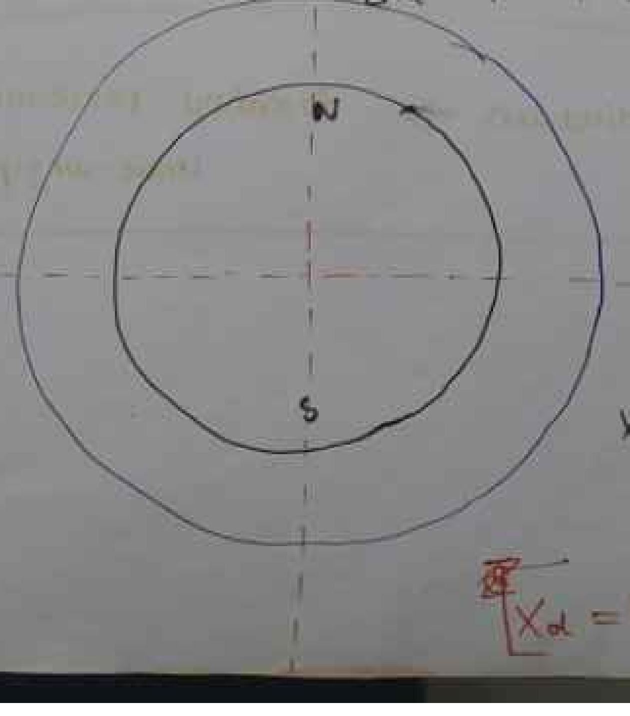
d - axis   direct axis - N - S pole
q axis   90° Electrical to d-axis.

In case of cylindrical rotor alternator air gap is uniform so main field flux and armature flux are sinusoidal in nature. But in case of ~~cylinder~~ salient pole rotor alternator. The length of airgap is different for ~~different different~~ both d-axis & q-axis. So, reluctance also different. So, the theory which gives the disturbing behaviour of salient pole rotor known as two reactance theory.

⇒ Along direct axis armature reaction effect is demagnetising or magnetising. But along q-axis it is ~~two~~ always cross magnetising.

(d-axis) direct/ polar axis :-

d-axis $[X_d = X_{ad} + X_l = X_s]$



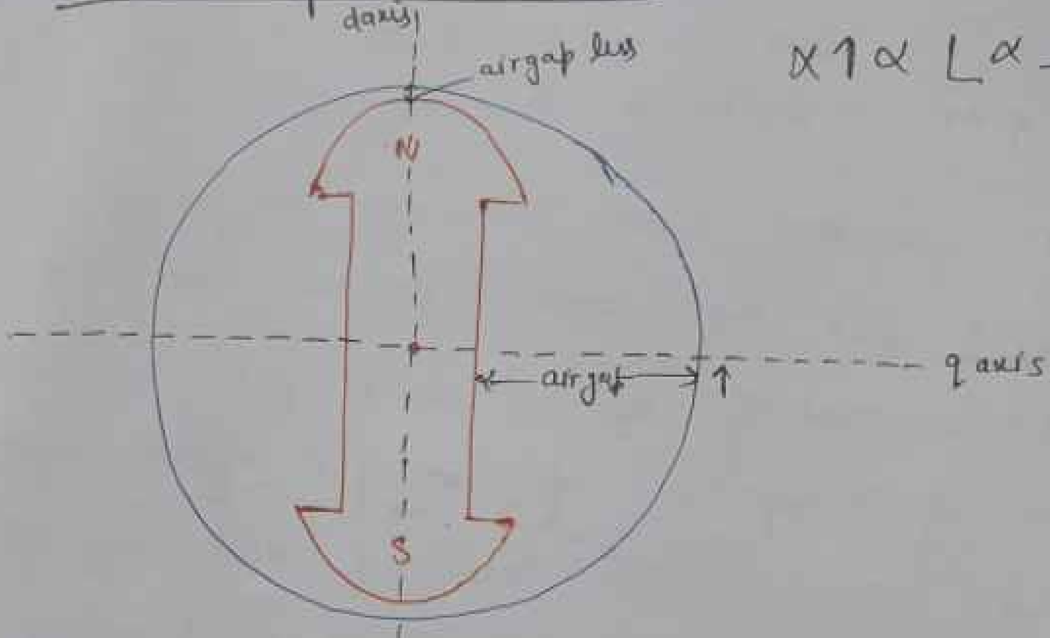
$X_q = X_{aq} + X_L = X_s$ quadrature/ indirect/interpolar axis (q-axis)

$\left[X_d - X_q = 0\right]$ (cross)

$\boxed{X_d = X_q = X_s}$

Salint pole Rotor :-

$X \uparrow \propto L \propto \frac{N^2}{S} \propto \frac{1}{\text{Air gap}}$



Synchranous reactance along q-axis

\# \# $\boxed{X_{ad} > X_{aq}}$ \# \#

Synchranous reactance along d-axis

$\boxed{X_d - X_q \neq 0}$ (~~Sa~~ Saliency)

Armature reactance direct axis (less air gap) > Armature reactance q-axis (more air gap)

$$\phi_a \begin{cases} \phi_d \\ \phi_q \end{cases}$$

$$I_a \begin{cases} I_d \\ I_q \end{cases} , \quad X_s \begin{cases} X_d \\ X_q \end{cases}$$

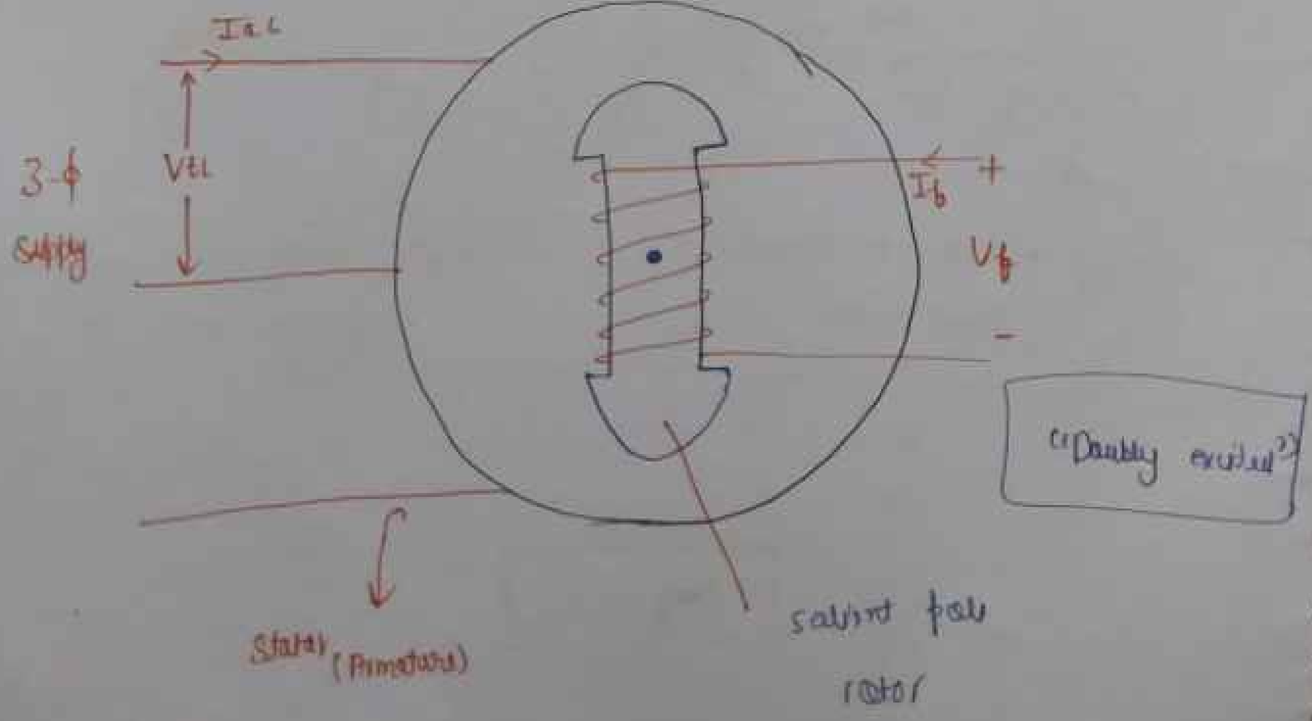
3-ϕ synchronous motor :-

(S)

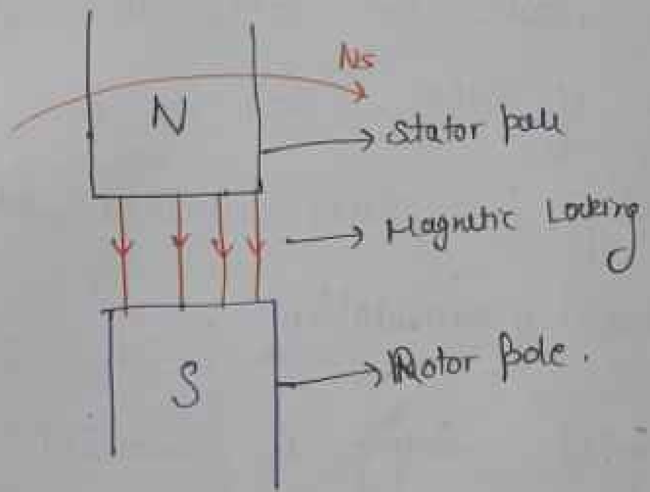
→ Synchronous machines are popular for mega watt loading (alternator) and for low speed (synchronous motor).

⇒ From no-load to full-load its speed remains constant. So, its speed regulation is zero.

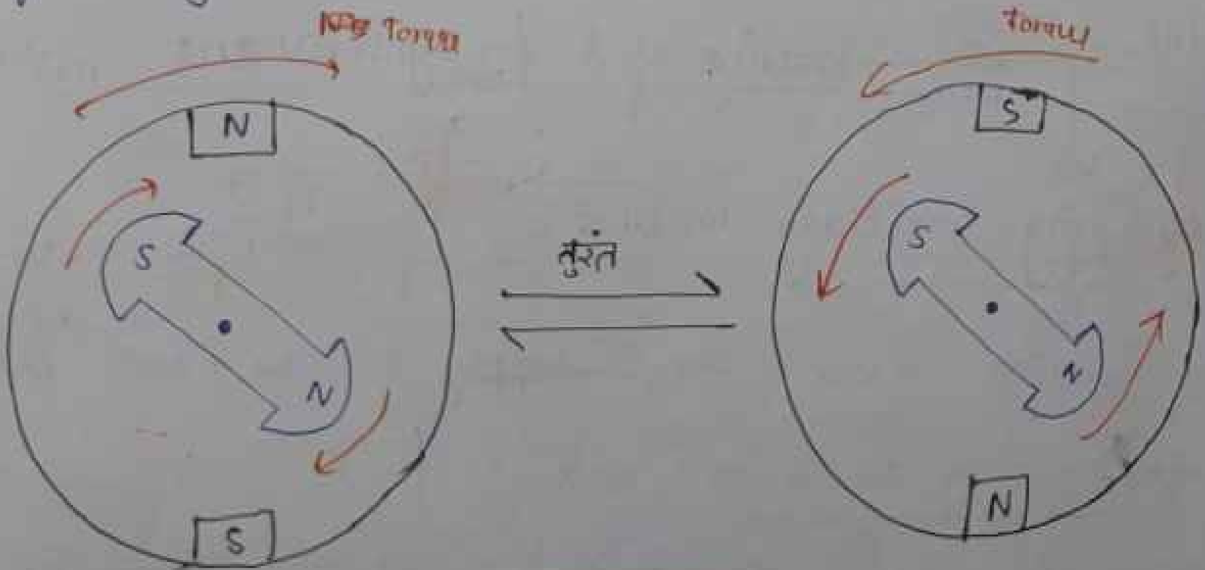
⇒ Stator of 3-ϕ synchronous motor is similar to 3-ϕ alternator contains 3-ϕ star connected distributed windings. But the rotor must be salient pole.



⇒ Synchronous motor works on the principle of magnetic locking b/w two opposite poles.



Since, the average torque experience by the rotor in 1 cycle becomes zero. so, 3-ϕ Synchronous motor are not self starting in nature.



$\boxed{T_{avg} = 0}$

Procedure to start 3-ϕ synchronous motor :-

⇒ First connect the stator to the 3-ϕ supply without exciting its feild winding. So, stator R.M.F is produced. Now rotate the rotor by external device in the direction of R.M.F near to Ns during starting. & the feild winding is short circuitted with a low resistance to avoid damage of insulation.

⇒ Now the feild winding is connected to D.C supply. So, rotor poles forms and rotor poles gets magnetically locked with stator poles and rotor start rotation a Ns. As the motor start external device decoupled.

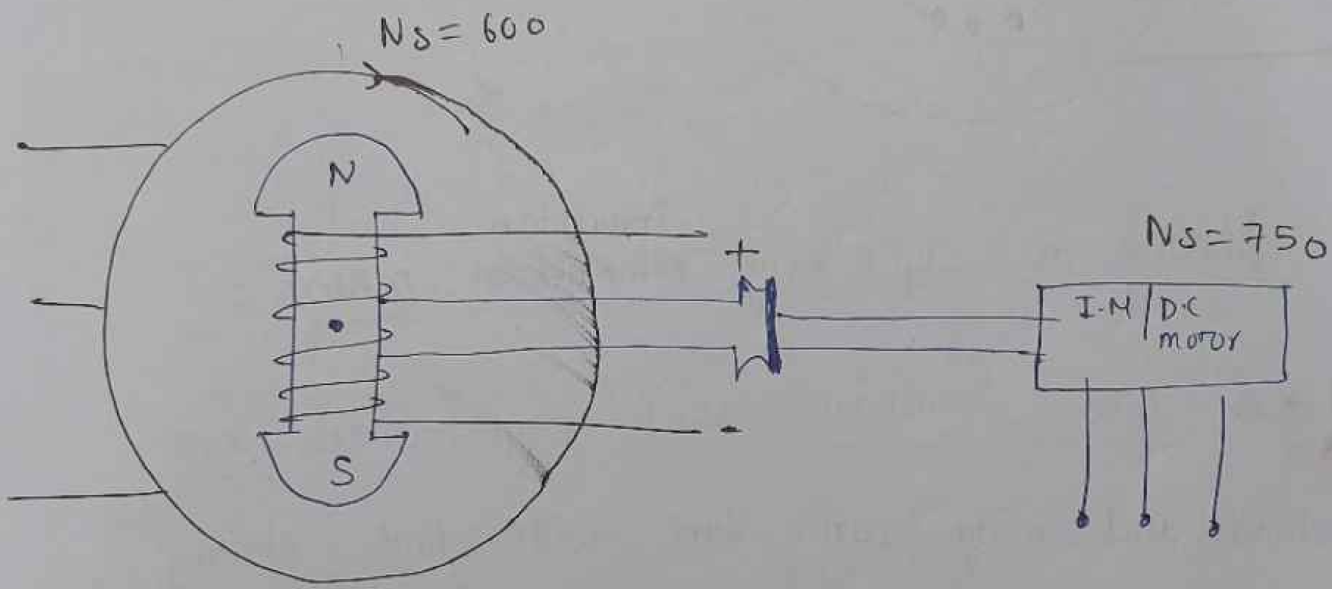
Methods for starting of 3-ϕ synchronous motor :-

① **By using auxillary motor :-** If auxillary motor is induction motor the supply to this motor disconnected after starting the motor but if it is a D.C motor. The same motor can be used as exitor of synchronous motor..

16/12/20
Ns

⇒ Pony motor is a small induction motor ~~whose~~ which having poles

$$\boxed{P_{PONY} = P_{syn} - 2}$$

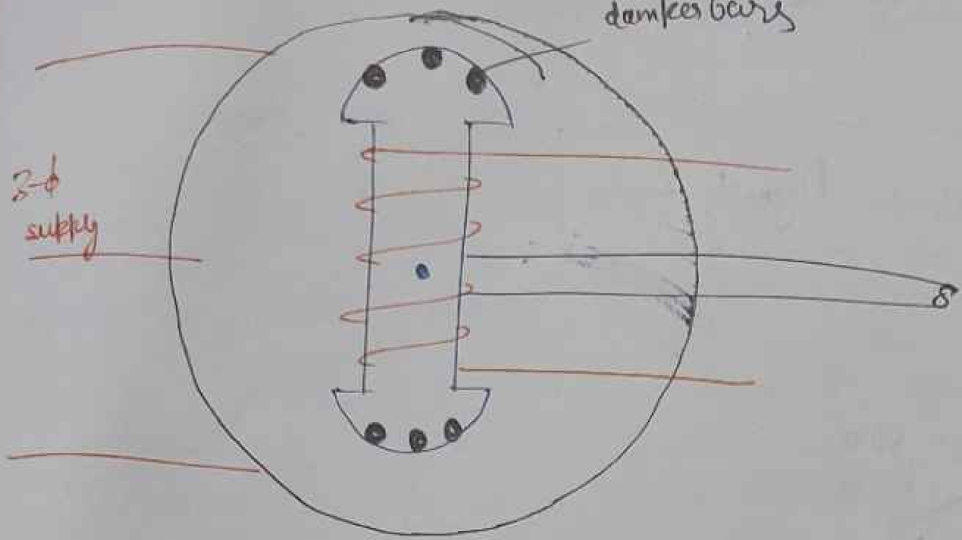


at

$P_{syn} = 10$ $\qquad$ $P_{pony} = 8$

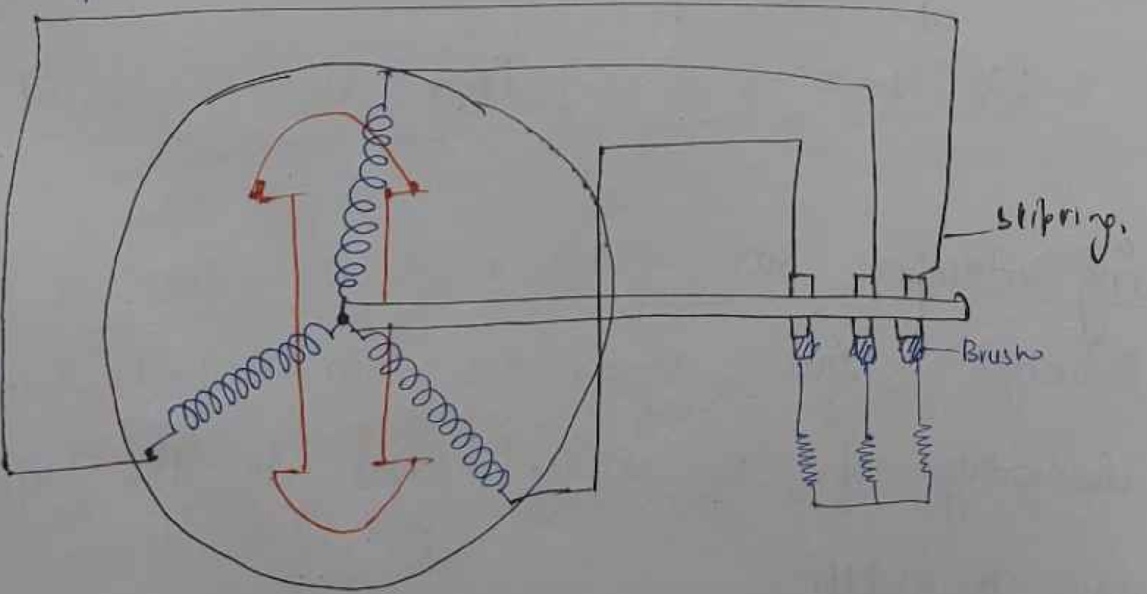
② By using damper bar :-

It is induction start synchronous run method. But having disadvantage of low starting torque. In this method motor start as SCIM.

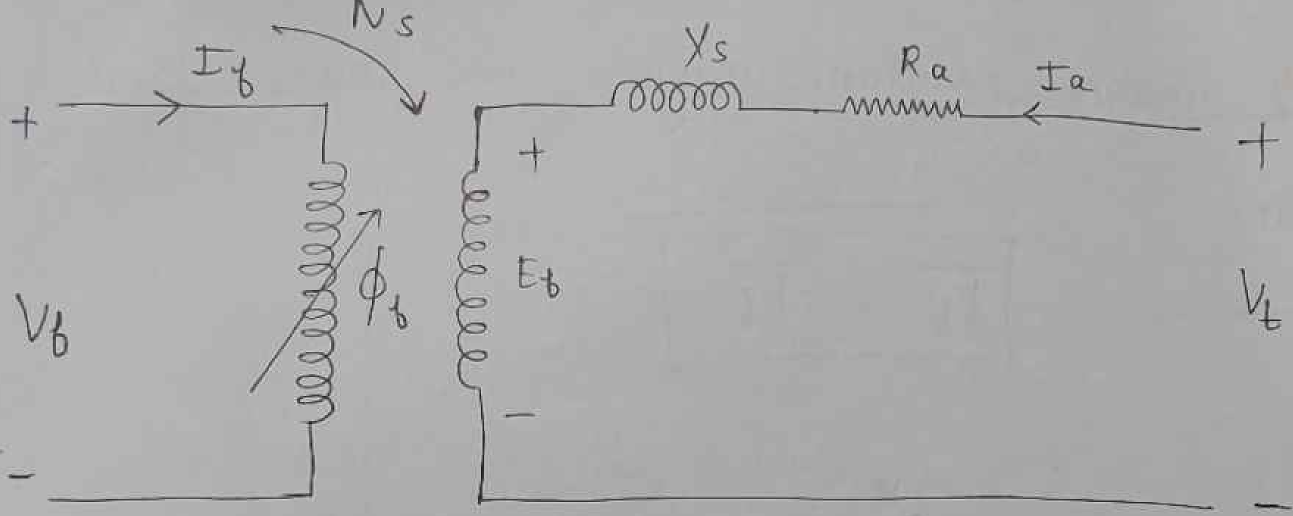


Starting as slip ring ~~induction~~ induction motor :-

It is also induction start synchronous run method and motor can start with high starting torque.



Equivalent ckt of synchronous motor :-



KVL $\boxed{\overline{V_t} = \overline{E_f} + \overline{I_a} R_a + j \overline{I_a} X_s}$ → Numericals

phasor lenz law $\boxed{\overline{V_t} = -\overline{E_f} + \overline{I_a} R_a + j \overline{I_a} X_s}$

$$\boxed{E_f = 4.44\, \phi_f \cdot f T_{ph} \cdot K_w}$$

$$\boxed{\overline{I_a} = \frac{\overline{V_t} + \overline{E_f}}{Z_s} = \frac{\overline{E_R}}{\overline{Z}_s}}$$

$\overline{E_R} = \overline{V_t} + \overline{E_f}$

Net / Resultant emf

Let E_R refrence है तो

$\overline{E_R} = E_R \angle 0^\circ$

$Z_s = X_s \angle 90^\circ = 0 + jX_s$

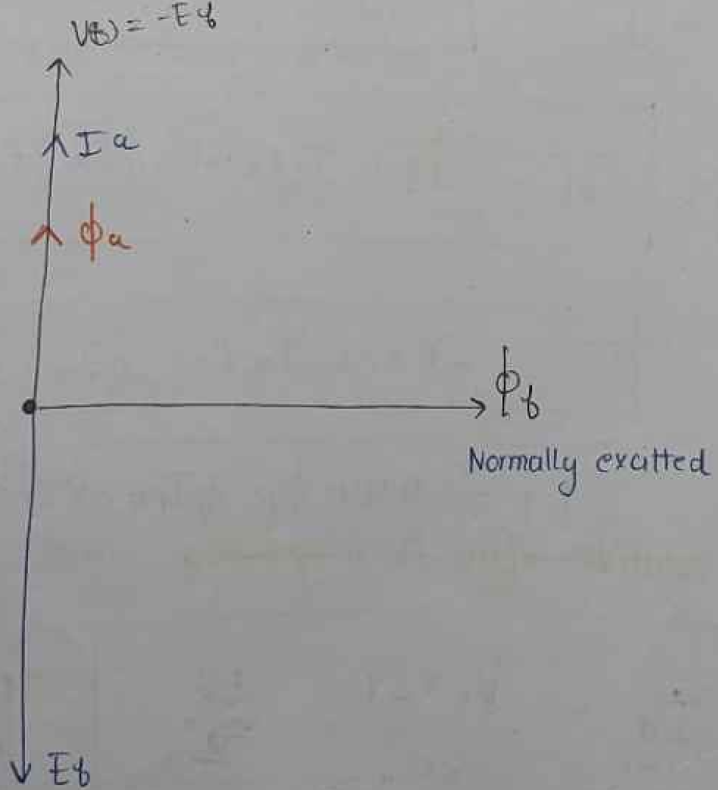
$$\boxed{\overline{I_a} = \frac{E_R \angle 0^\circ}{X_s \angle 90^\circ}} = \frac{E_R \angle -90^\circ}{X_s}$$

from above I_a lags E_R by Approx 90°.

Armature reaction ~~in sy~~ analysis :-

for armature reaction analysis we takes ideal machine.

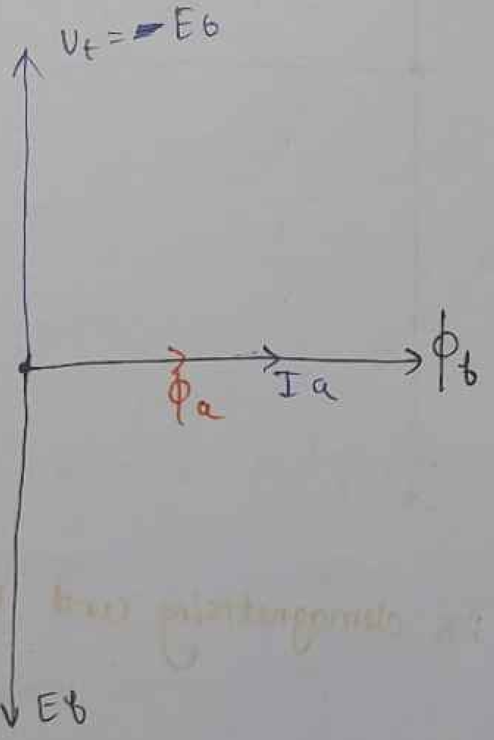
$$\boxed{\overline{V_t} = -\overline{E_f}}$$



⇒ Armature reaction effect is cross magnetising and the motor is normally excited.

Case → II :- If synchronous motor is operate at zero lagging p.f :-

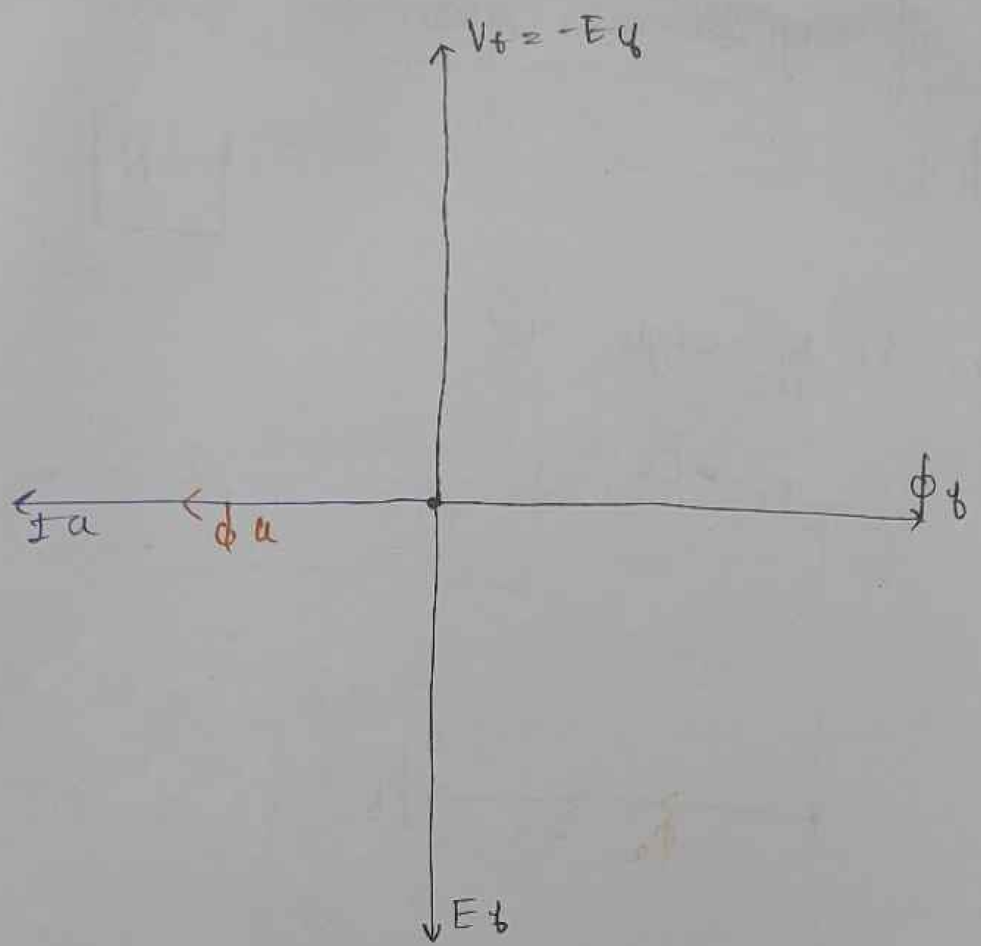
Ia lags Vt by angle 90°



Armature reaction effect is magnetising and motor is under excited.

Case → III :- If synchronous motor is operates at zero leading p.f.

Ia leads Vt by angle '90°'.



Armature reaction is demagnetising and motor is over excited

Result :-

1. Normally excited synchronous motor operate at unity power factor and armature reaction effect is cross magnetising in nature.

Ideal synchronous motor :-

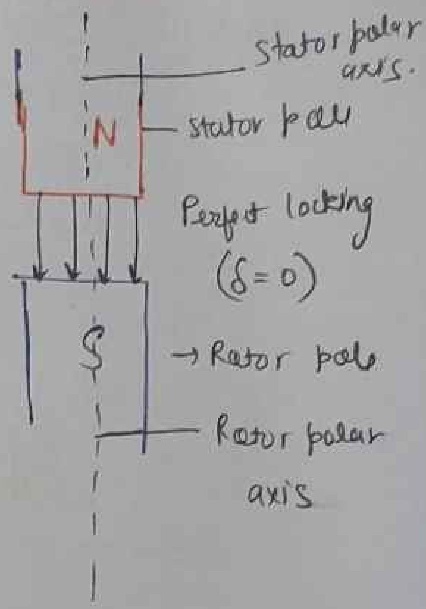
$$\boxed{\overline{V_t} = \overline{E_b}}$$

$$V_t \angle 0 = E_b \angle -\delta$$

$$\boxed{|V_t| = |E_b|} \quad \boxed{\delta = 0}$$

$$\boxed{I_{a0} = 0}$$

No load armature current.

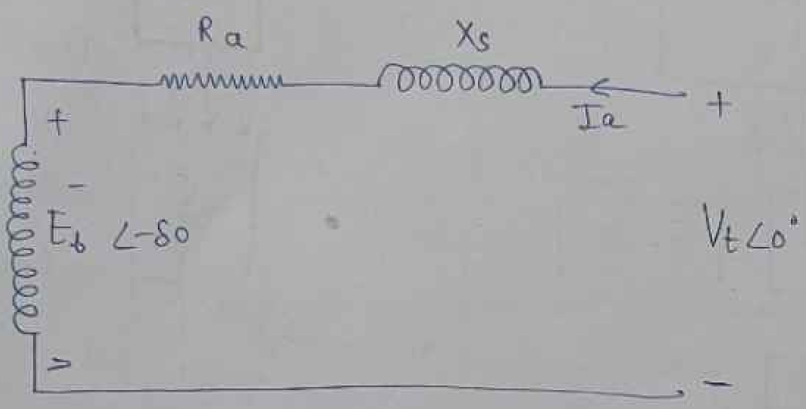


⇒ If rotor polar axis is आगे then stator polar axis then generator

⇒ If stator polar axis is आगे then R.P.A then motor.

⇒ • consider ~~for~~ ideal case of locking

Practical Synchronous motor at noload :-



By KVL :-

$$\boxed{V_t = E_f + I_{a0}R_a + jI_{a0}X_s}$$

$V_t\angle 0°$ for phasor diagram :

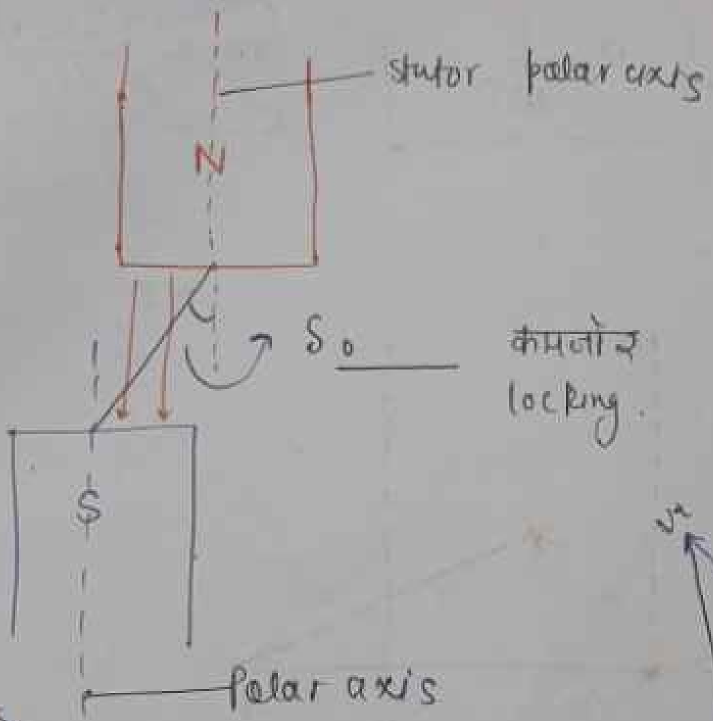
$$\overline{V_t} = -\overline{E_f} + \overline{I_{a0}}R_a + j\overline{I_{a0}}X_s$$

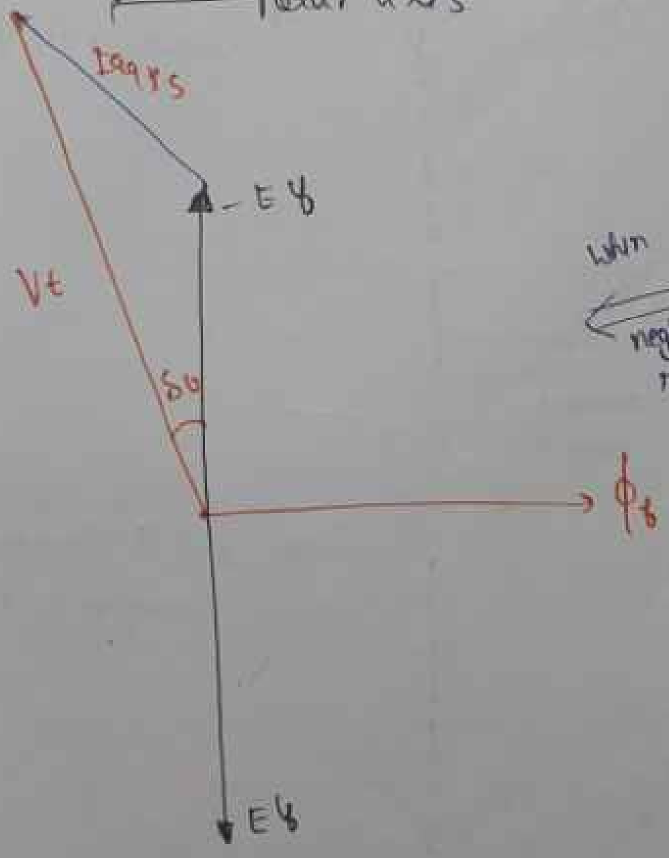
$$\overline{I_{a0}} = \frac{\overline{V_t} + \overline{E_f}}{Z_s} = \frac{\overline{E_R}}{\overline{Z_s}}$$

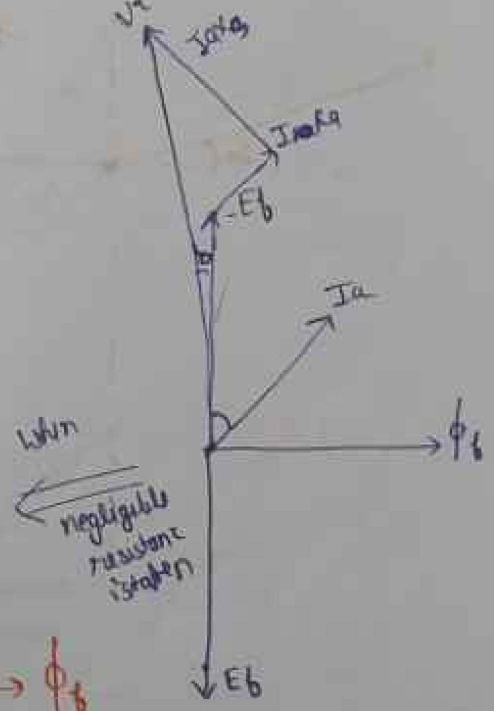
If $R_a \simeq 0$

$$\boxed{\overline{I_{a0}} = \frac{E_R\angle -90°}{X_s}}$$

I_{a0} lags E_R by angle '90'







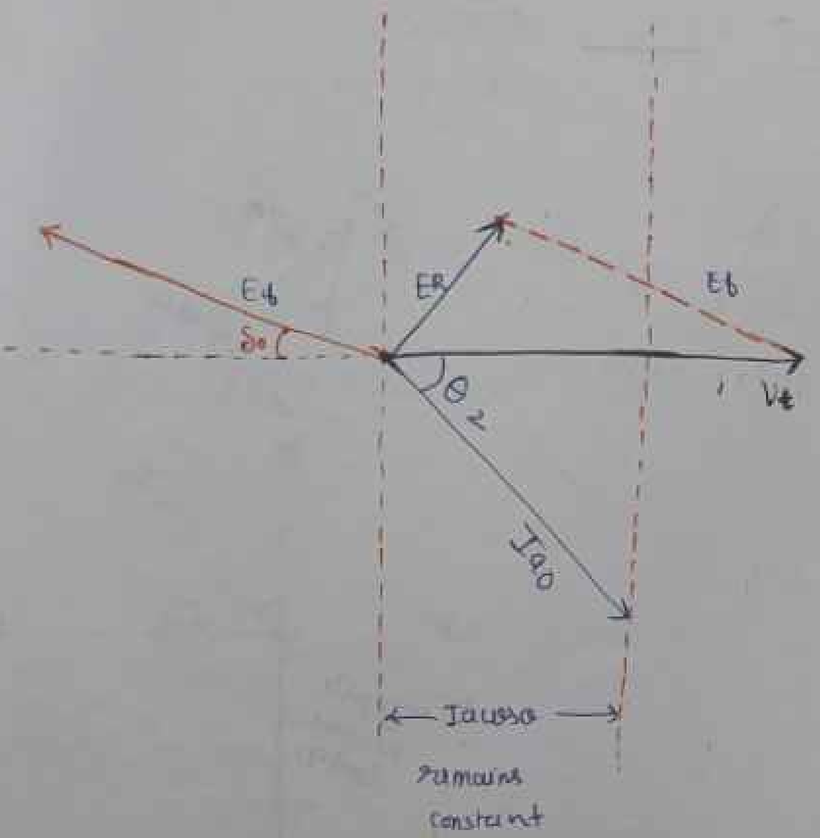
If $Exc_{itation}$ = constant & Load ↑, then Te ↑,
|Ef| = cons

δ↑

$$\boxed{P = 3 V_t I_a \cos\theta_2 = \text{constant}}$$

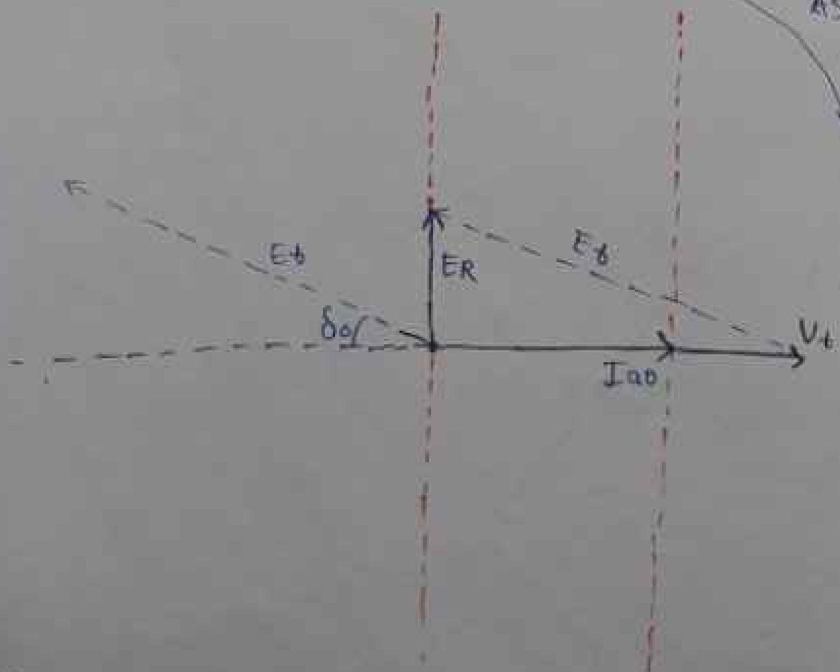
$$\boxed{I_a \propto \frac{1}{\cos\theta_2}}$$

$$\cancel{T_e = \frac{3 E_b V_t}{X_s} \cos\delta}$$



under excited

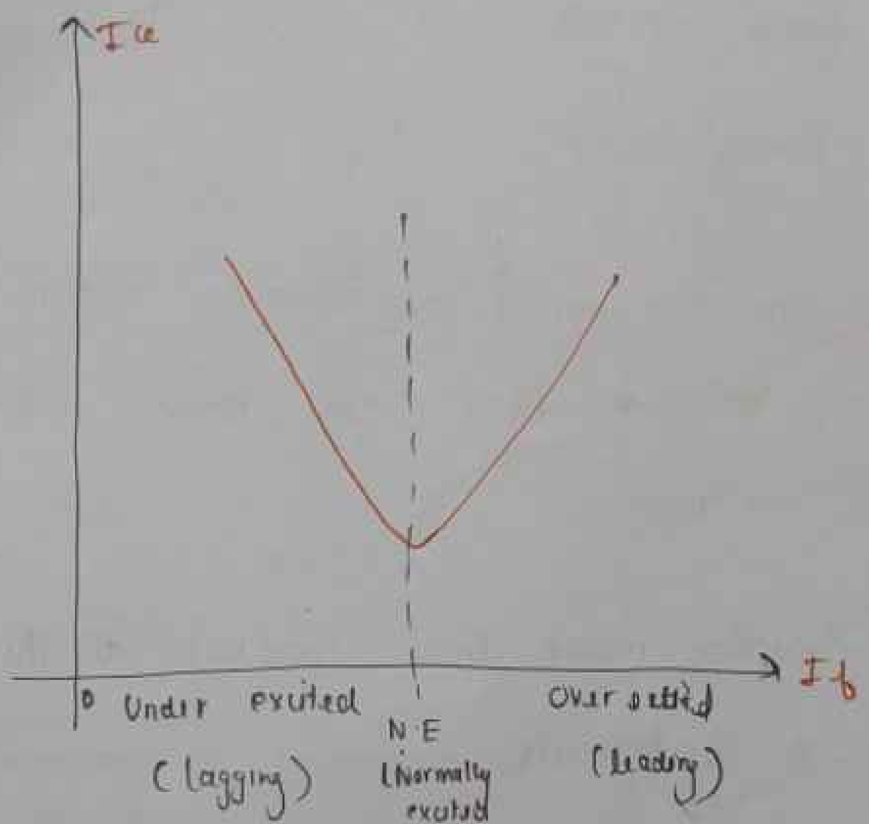
As Load ↑ Ia becomes lag according to excitation



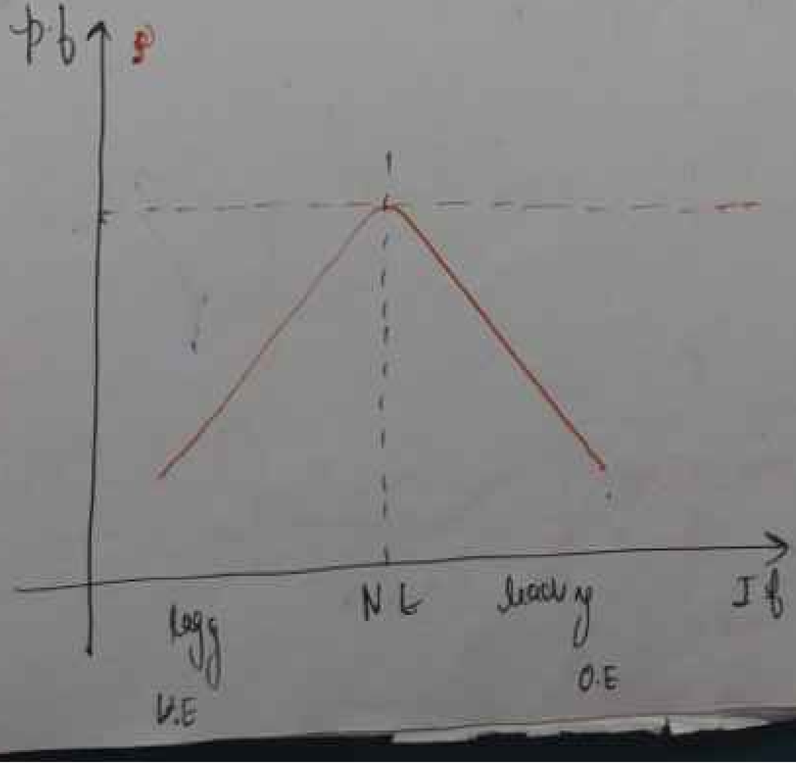
Normally excited

V-curve :-

Ia V/s If



Inverted V-curve :-



Synchronous condenser :-

① It is an over excited synchronous motor used for power factor correction at ~~~~ sub station and industrial load, transmission line.

② It is an over excited synchronous motor which generally operate at no-load and made without any shaft extension.

Q. A 3-ϕ induction motor draw 1000 KVA at the p.f of .8 lagging. A synchronous condenser is connected in parallel to draw an additional 750 KVA at .6 p.f leading. The power factor of the total load supplied by the mains is

$$S_L = S_i + S_c$$

$$S_i = P_i + jQ_i$$

$$\boxed{P_i = S_i \cos\phi_i = 1000 \times .8 = 800 \text{ KW}}$$

$$\boxed{Q_i = S_i \sin\phi_i = 1000 \times .6 = 600 \text{ KVar}}$$

$$\boxed{S_i = 800\ KW + j\ 600\ KVAR}$$

$$S_s = P_s - jQ_s$$

$$P_s = S_s \cos\phi_s = 750 \times .6 = 450 KW$$

$$Q_s = S_s \sin\phi_s = 750 \times .8 = 600\ KVAR$$

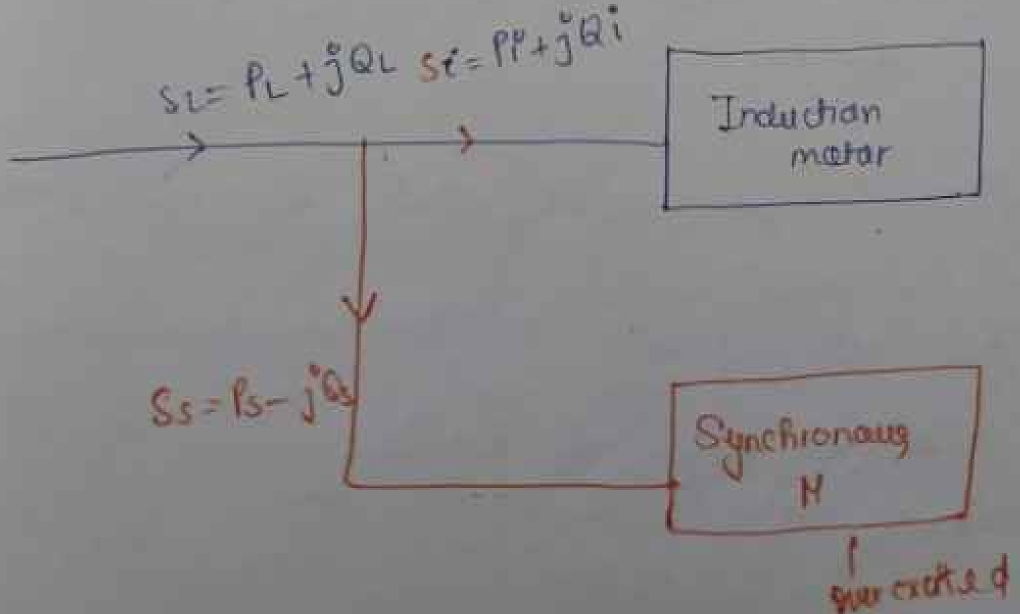
$$\boxed{S_s = 450 KW - j600\ KVAR}$$

$$S_L = S_i + S_s$$

$$\boxed{S_L = 1250 KW + 0}$$

$$\tan\phi_L = 0^\circ$$

$$\therefore \boxed{\cos\phi_L = 1}\ \text{U.P.F}$$



Single phase synchronous motor :-

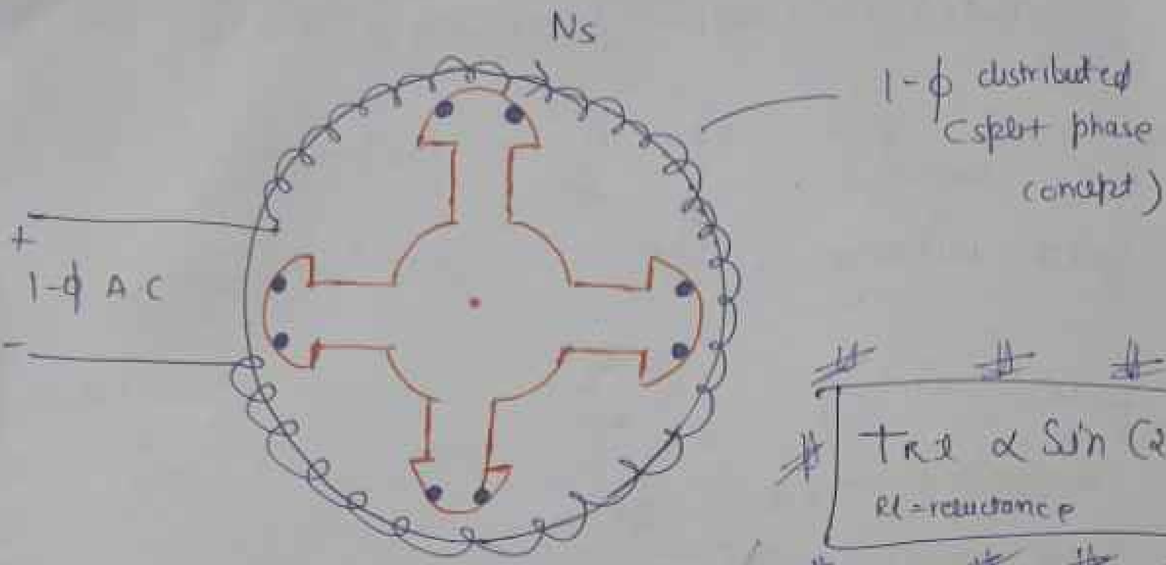
Stator of a single phase synchronous motor is similar to single phase induction motor split phase type and according to rotor construction these motors can be classified into two types.

① Reluctance motor :-

① Reluctance motor works according to reluctance principle and due to reluctance power rotor get locked with stator ~~~~ pole and motor runs at Ns.

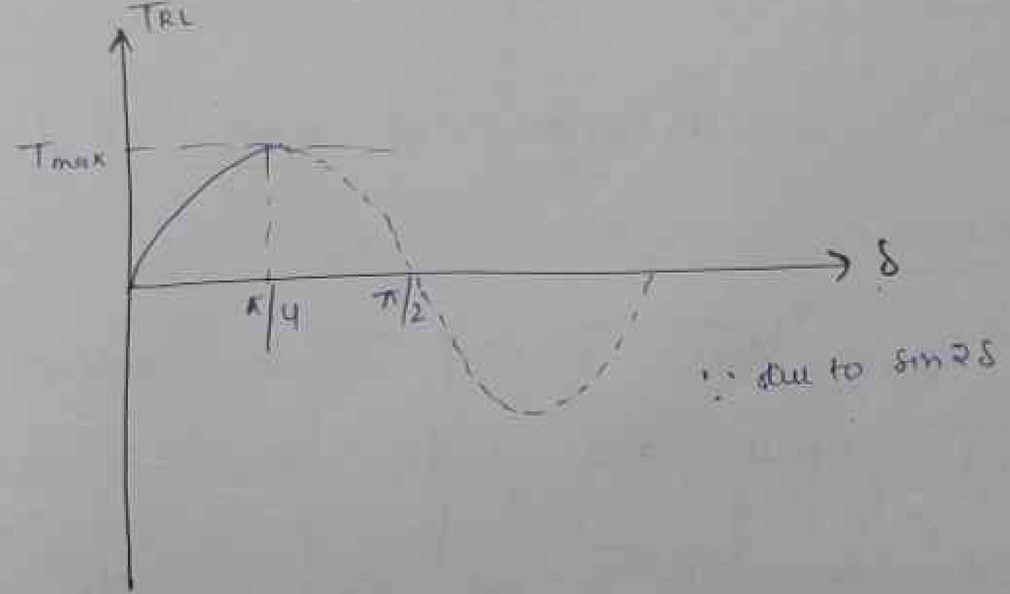
② Reluctance motor does not have any feild winding on rotor. So, damper bar start it as an ~~induction~~ SCIM near to Ns and due to reluctance power it runs at Ns

③ Before rotor gets locked their is an induction torque but after locking it becomes zero and only reluctance torque is present.



$$\boxed{T_{Rl} \propto \sin(2\delta)}$$

Rl = reluctance



Result :-

① Due to non uniform air gap reluctance motor runs with vibration and noise.

② If in a salient pole synchronous motor excitation is made zero under normal running condition it will continue to run at synchronous speed as a reluctance motor

Q) In a cylindrical rotor synchronous motor excitation is made zero and if

If field winding is O.C :- speed '0'

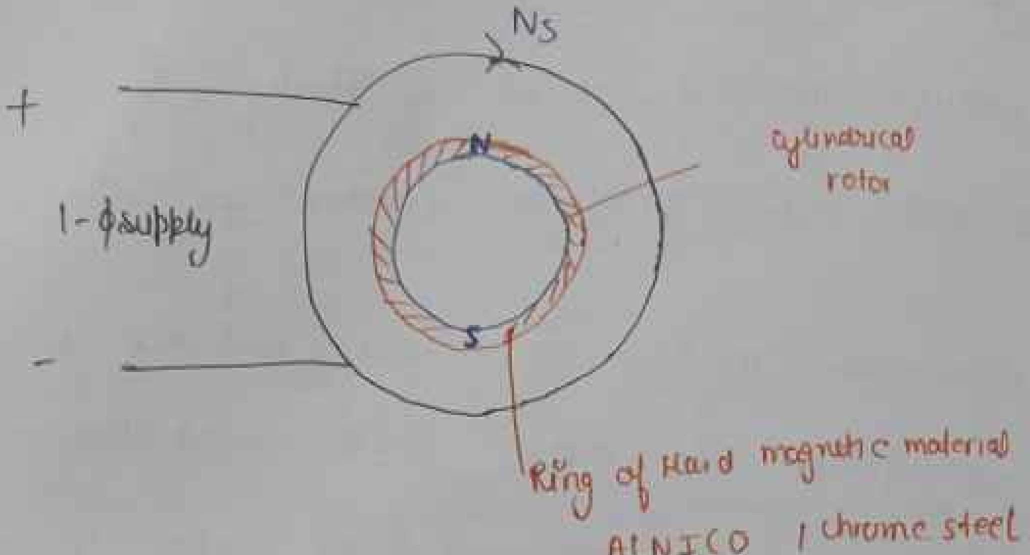
If field winding is S.C :- Runs at slip ring induction motor $\{N_r < N_s\}$

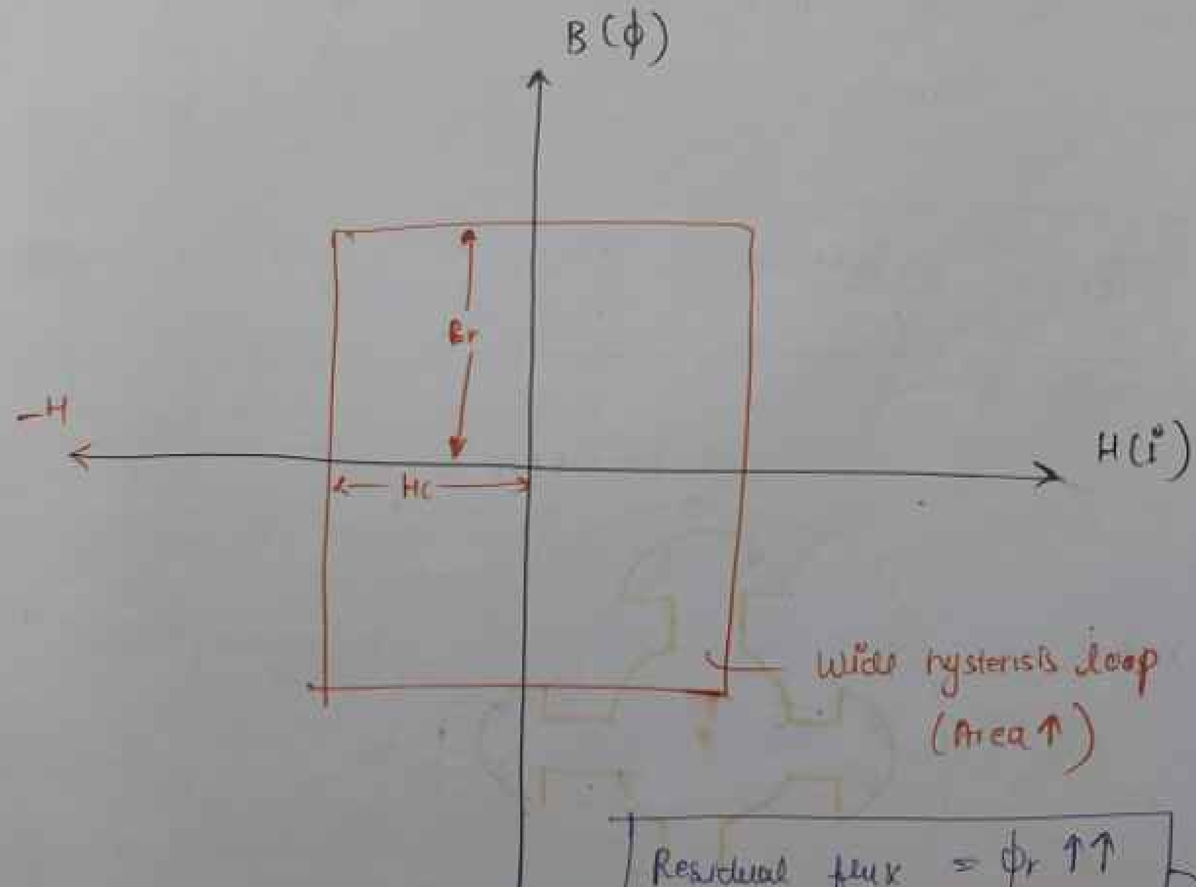
Hysterisis motor :-

① The rotor is smooth cylindrical made by hard magnetic material.

② Initially rotor starts rotation due to combined effect of hysterisis torque and torque due to eddy current. But under running condition once the rotor gets locked the torque due to eddy current becomes zero and only hysterisis torque is present.

③ Due to uniform air gap its operation is silent so it is ~~us~~ used in sound producing instrument such as ~~chrom~~ tape recorder, recording threater, compact disk drive.





Residual flux = ϕ_r ↑↑

Co-ersive force = H_c ↑↑

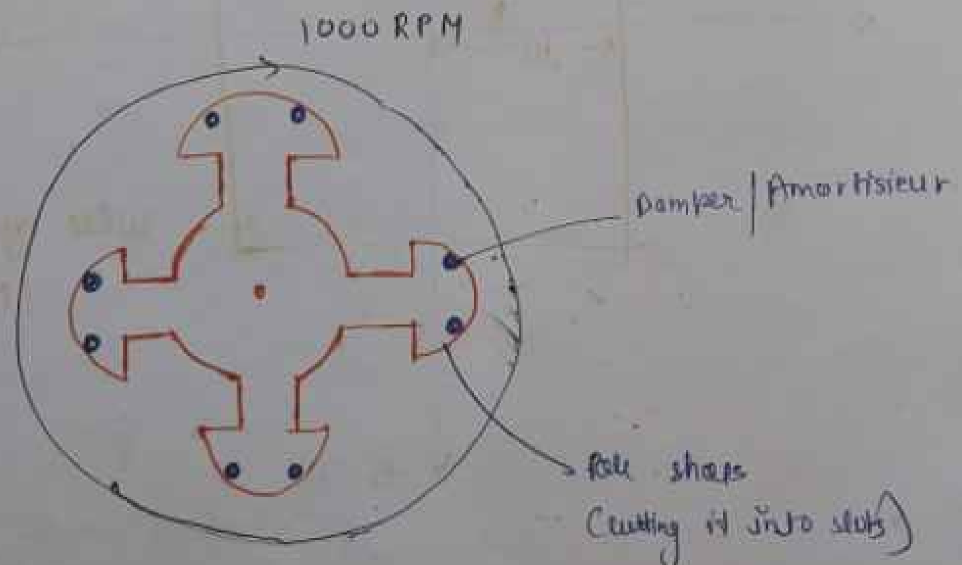
High retentivity

Hunting :-

⇒ A synchronous machine operate effectively if mechanical speed of the rotor is equal to synchronous speed.

⇒ If a synchronous machine is loaded suddenly or due to disturbance the rotor starts acceleration and deacceleration and the speed of the rotor becomes more or less then synchronous speed this is known as hunting.

$$\boxed{T_{er} = \frac{3 E_f V_t}{X_s} \sin\delta}$$



$$\boxed{T_{accelerating} = T_{em} - T_{load}}$$

let

$\boxed{T_e = 1N\text{-}m = T_L}$ at N_s

and $T_L = 5N\text{-}m$ applied.

T_L ∴ $T_{acc} = -ive$, Deaccelerating, $N_s\downarrow$, $\delta\uparrow$, $T_e\uparrow$

when $T_e > T_L$, $T_{ac} = +ive$, accelerating, $N_r\uparrow$, $\delta\downarrow$, $T_e\downarrow$

again $T_e < T_L$.

Causes of hunting :-

(i) Sudden change in load, sudden change in supply, sudden change in feild system

Methods to reduce hunting :-

(i) By using damper winding, by using fly wheels, by designing the machine with high synchranising power coffiient.

$N_r = N_s$, 0 torque in damper Bar

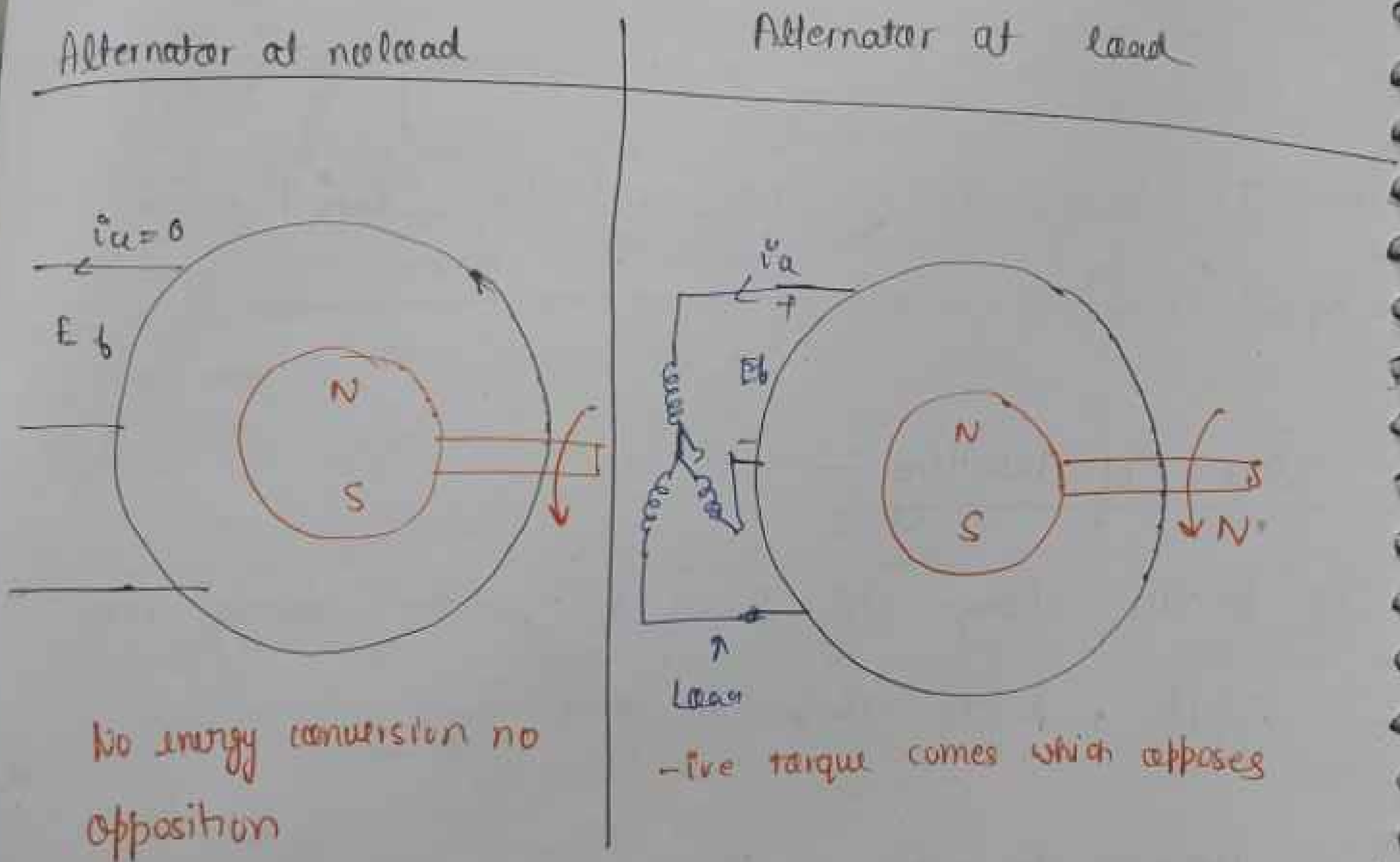
$N_r > N_s$, Induction generating torque

$N_r < N_s$, Induction motor torque.

Power flow equation of alternator :-

Case → 1

Salient pole rotor alternator :-



Active power :- (P_g)

$$\boxed{P_g = \underbrace{\frac{3E_f V_t}{X_d} \sin\delta}_{P_e} + \underbrace{\frac{3V_t^2}{2}\left[\frac{X_d - X_q}{X_d \cdot X_q}\right]\sin(2\delta)}_{P_{RL}}}$$

P_e → electromagnetic power

~~ele~~ reluctance power $= P_{RL}$

$$\therefore \boxed{P = T\omega_s}$$

$$\therefore \boxed{T_e = \frac{3E_f V_t}{\omega_s X_d} \sin\delta}$$

Electromagnetic torque

$$\boxed{T_{Rl} = \frac{3V_t^2}{2\omega_s}\left[\frac{X_d - X_q}{X_d \cdot X_q}\right] \sin(2\delta)}$$

Reluctance torque.

Result :-

⇒ Reluctance power is present because armature flux having a tendency to pass threw field structure along its minimum reluctance and this is present due to difference in reluctance along direct and quardrature axis. so, it is called as a reluctance power or power due to ~~rt~~ saliency.

(B) ~~Res~~ Reactive power :-

$$\boxed{Q_g = \frac{3E_f V_t \cos\delta}{X_d} - \frac{3V_t^2}{2}\left[\left(\frac{1}{X_d} + \frac{1}{X_q}\right) + \left(\frac{1}{X_d} - \frac{1}{X_q}\right)\cos 2\delta\right]}$$

② Cylindrical Rotor alternator:-

Active Power :-

$$\boxed{P_g = \frac{3 E_f V_t}{X_D} \sin\delta + \frac{3 V_t^2}{2}\left(\frac{X_d - X_q}{X_d \cdot X_q}\right)\sin 2\delta}$$

Salient

cylindrical

Reluctance power = 0

$\because X_d = X_q = X_s$

$$\boxed{P_g = \frac{3 E_f V_t}{X_s} \sin\delta}$$

electromagnetic power

$$\therefore \boxed{T_e = \frac{3 E_f V_t}{\omega_s X_s} \sin\delta}$$

$T_e = T_L$ as load $\uparrow$, $(T_L\uparrow) = T_e\uparrow$, $\sin\delta \uparrow$, $\delta\uparrow$

load / torque angle

$\boxed{\text{Excitation} = \text{const}}$

$\therefore E_f = \text{cons}$
$V_t = \text{cons}$
$f = \text{cons}$
$X_s = \text{cons}$
$\omega_s = \text{cons}$

Reactive power :-

$$\boxed{Q_g = \frac{3 E_f V_t}{X_d}\cos\delta - \frac{3V_t^2}{2}\left[\left(\frac{1}{X_d} + \frac{1}{X_q}\right) + \left(\frac{1}{X_q} - \frac{1}{X_q}\right)\cos 2\delta\right]}$$

put $X_d = X_q = X_s$

$$Q_g = \frac{3 E_f V_t}{X_s}\cos\delta - \frac{3 V_t^2}{3}\left[\frac{1}{X_s} + \frac{1}{X_s}\right]$$

$$\boxed{Q_g = \frac{3 V_t}{X_s}\left(E_f \cos\delta - V_t\right)}$$

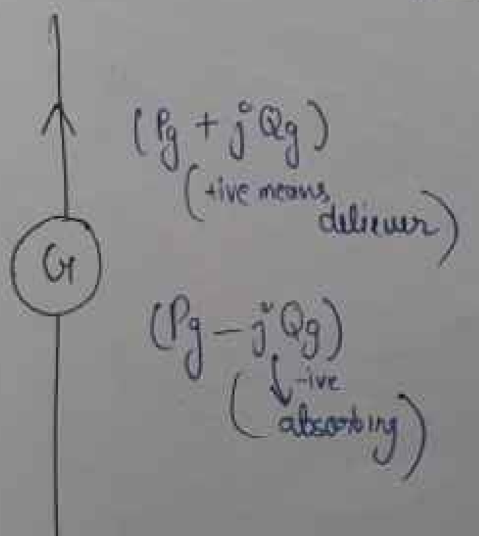
Power flow equations of synchronous motor :-

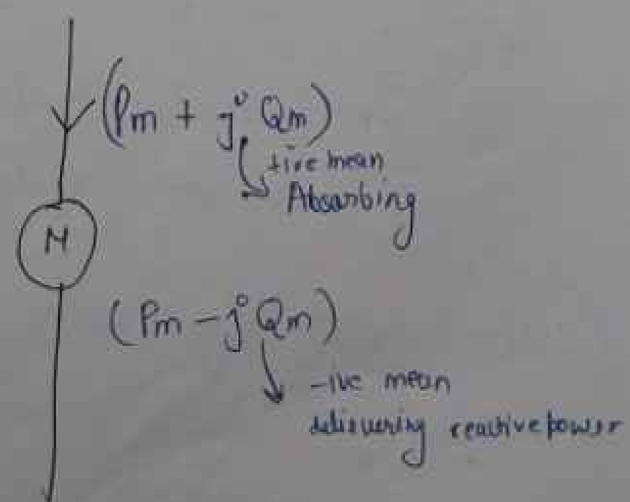
$P_g \longrightarrow$

~~Motor~~ +

Generator	to Motor
P_g	$-P_g$
Q_g	$-Q_g$
V_t	V_t
I_a	$-I_a$
E_f	E_b
δ	$-\delta$

Generator (always delivering is +ive)	Motor absorbing is positive.





① Cylindrical rotor syn - motor :- Ⓐ Active power (P_m)

$$\boxed{P_g = \frac{3 E_f V_t \sin\delta}{X_s}}$$

$$P_m = +P_g = -\frac{3 E_f V_t \sin(-\delta)}{X_s}$$

$$\boxed{P_m = \frac{3 E_f V_t \sin\delta}{X_s}}$$

Ⓑ Reactive power :-
Q_m

$$Q_g = \frac{3V_t}{X_s}\left(E_f \cos\delta - V_t\right)$$

$$Q_m = -\left\{\frac{3V_t}{X_s}\left[E_f \cos(-\delta) - V_t\right]\right\}$$

$$Q_m = -\frac{3V_t}{X_s}\left(E_f \cos\delta - V_t\right)$$

Q_m = +ve $\longrightarrow$ absorb

Q_m = -ive $\longrightarrow$ deliver.

Salient pole synchronous motor :-

Active power (Pm) :-

$$\boxed{P_g = \frac{3E_fV_t}{X_d}\sin\delta + \frac{3}{2}V_t^2\left[\frac{X_d - X_q}{X_d \cdot X_q}\right]\sin(2\delta)}$$

$$\downarrow$$

$$P_m = -\left\{\frac{3E_fV_t\sin(-\delta)}{X_d} + \frac{3V_t^2}{2}\left(\frac{X_d - X_q}{X_d \cdot X_q}\right)\sin(-2\delta)\right\}$$

$$\boxed{P_m = \frac{3E_fV_t\sin\delta}{X_d} + \frac{3V_t^2}{2}\left(\frac{X_d - X_q}{X_d \cdot X_q}\right)\sin 2\delta}$$

Reactive power Qm :-

$$\boxed{Q_g = \frac{3E_fV_t}{X_d}\cos\delta - \frac{3V_t^2}{2}\left[\left(\frac{1}{X_d} + \frac{1}{X_q}\right) + \left(\frac{1}{X_d} - \frac{1}{X_q}\right)\cos 2\delta\right]}$$

$$\boxed{Q_m = -\left\{\frac{3E_fV_t}{X_d}\cos\delta - \frac{3V_t^2}{2}\left[\left[\frac{1}{X_d} + \frac{1}{X_q}\right] + \left(\frac{1}{X_d} - \frac{1}{X_q}\right)\cos 2\delta\right]\right\}}$$

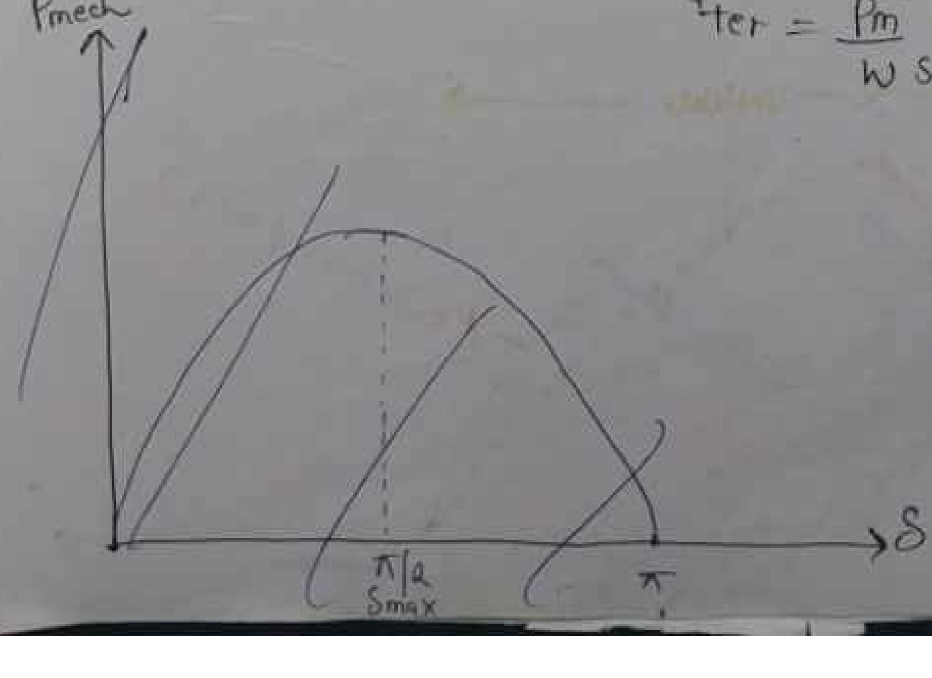
Power angle characteristics :-

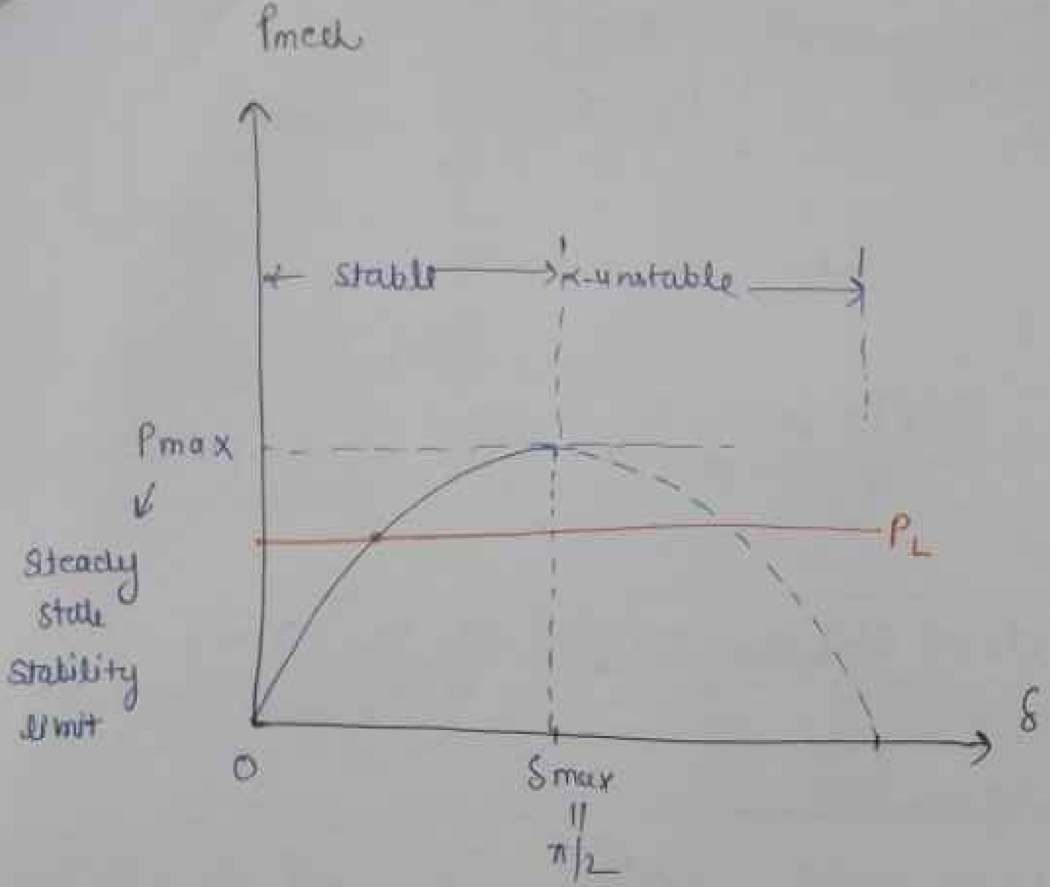
$$P_m = \frac{3E_fV_t}{X_S}\sin\delta$$

$$T_{er} = \frac{P_m}{\omega_S} = \frac{3E_fV_t}{\omega_s \cdot X_S}\cdot\sin\delta$$

For Excitation = const

$$\boxed{T_{er} \propto \sin\delta}$$





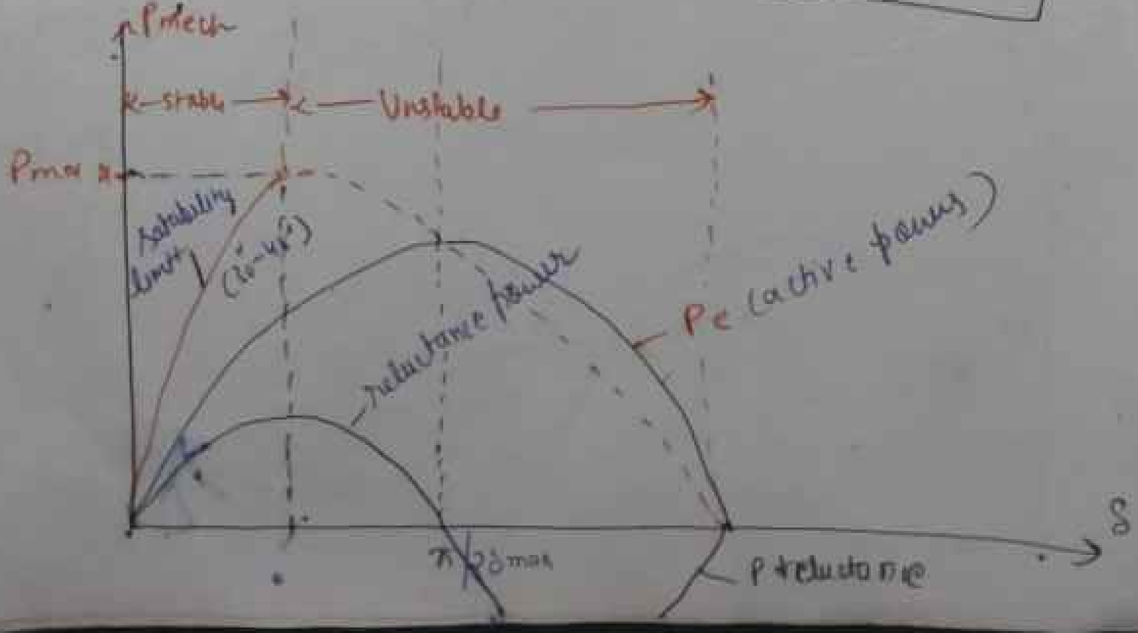
Steady state stability limit obtained at $\delta = \pi/2$

after this alternator fails to rotate

for nonsalient pole stability limit (60°-90°)

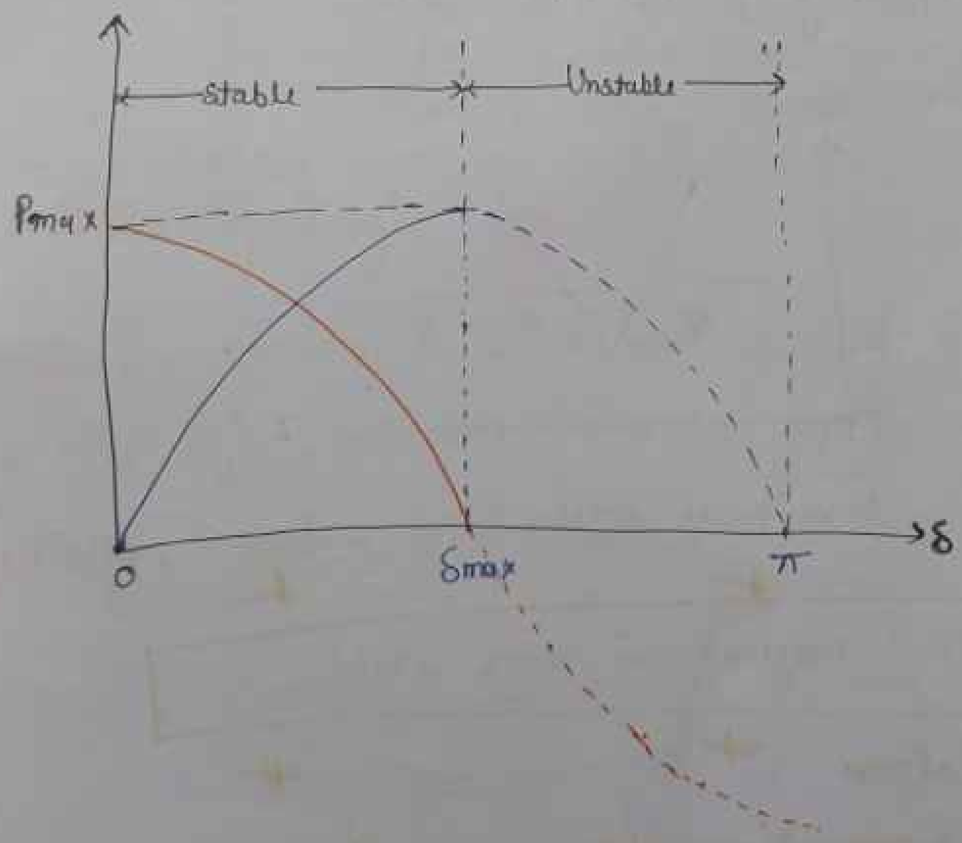
② Salient pole syn m/c :-

$$\boxed{P_{mech} = \frac{3 E_f V_t}{X_d} \sin\delta + \frac{3 V_t^2}{2}\left(\frac{X_d - X_q}{X_d \cdot X_q}\right)\sin(2\delta)}$$



⇒ Due to reluctance ~~power~~ net power angle characteristics gets distart and steady state ~~stat~~ stability limit obtained at 'δ' less than 90°.

Synchronising Power coffecient :- / stability factor / factor of rigidity .



$$P_g = \frac{3E_f V_t}{X_s} \sin\delta$$

$$\boxed{\frac{dP_g}{d\delta} = \frac{3E_f V_t \cos\delta}{X_s}} = P_{sy}$$

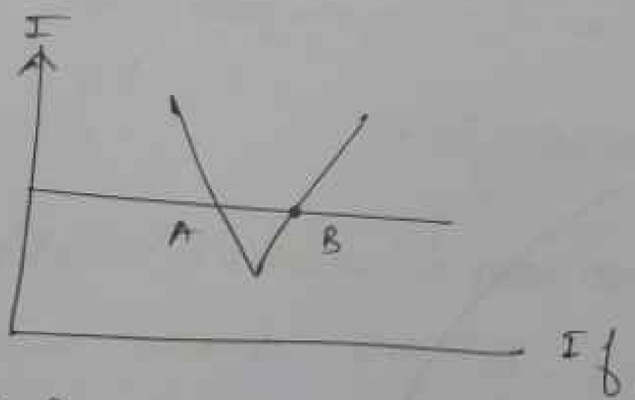
$$\boxed{P_{sy} = \frac{dP_g}{d\delta} = \frac{3E_f V_t}{X_s} \cos\delta}$$

The machine in stable if P_{sy} is +ive.

Stability $\propto P_{sy}$

Stability $\propto E_f \; \phi_f \propto$ Excitation

Q Which operating pt is more stable ÷



B is more stable.

$\boxed{\text{More excited machine is more stable}}$

By keeping mechanical input constant or load is constant ~~then~~ and excitation change

Alternator :- {Excitation = variable , Mechanical I/P = const}

$3V_t I_a \cos\theta_2 = \cancel{const}$ const

$$\boxed{I_a \propto \frac{1}{\cos\theta_2}}$$

$P_g = const$

$\frac{3E_f V_t \sin\delta}{X_s} = cost$

$$\boxed{\sin\delta \propto \frac{1}{E_f}}$$

→ If alternator is normally excited operate at Unity power factor, I_a → minimum and armature reaction effect is 'cross magnetising'.

→ Excitation ↓, alternator is under excited operate at leading p.f, Pf ↓, I_a↑ and armature reaction effect is magnetising, E_f↓, $\sin\delta$↑, δ↑.

→ Excitation ↑, alternator is overexcited operated at lagging pf↓, I_a↑, armature reaction effect is demagnetising, E_f↑, $\sin\delta$↓, δ↓.

Synchronous motor :- {Excitation = variable , Mechanical load = const}

$3V_t I_a \cos\theta_2 = const$

$$\boxed{I_a \propto \frac{1}{\cos\theta_2}}$$

$P_m = const$

$\frac{3E_f V_t}{X_s} \sin\delta = cost$

$$\boxed{\sin\delta \propto \frac{1}{E_b}}$$

→ If motor is normally excited operate at unity power factor, $I_a \longrightarrow$ minimum, and armature reaction is cross magnetising.

→ Excitation ↓, underexcited, operate at lagging p.f., P.f ↓, I_a ↑, E_b ↓, δ ↑. armature reaction is magnetising.

→ Exc ↑, over excited, operate @ lead p.f., P.f ↓, I_a ↑, E_b ↑, δ ↓, AR effect demagnetising.

Parallel operation of alternator :-

⇒ A stationary alternator should not be connected directly to a live busbar otherwise the alternator gets damaged.

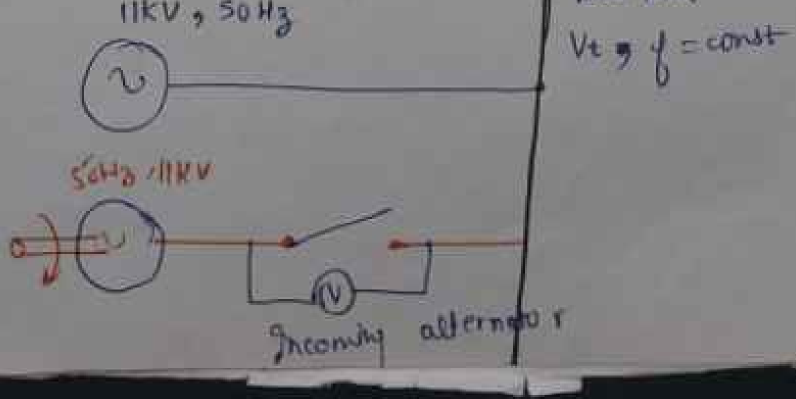
⇒ When two alternators are operating in parallel and if power I/P to one of the alternator fail then it will continue to run in the same direction at synchro- -nous speed.

⇒ Necessary condition for parallel operation :-

① The terminal voltage of incoming alternator must be same as bus voltage it can be verified by a voltmeter.

② Frequency should be same as bus frequency and also same phase sequence. It can be verified

③ by lamp method or ~~synchrospace~~ synchrosope.



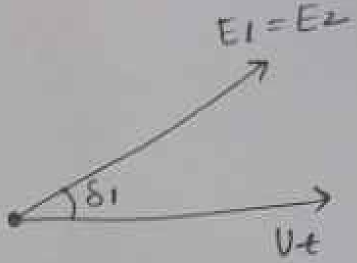
Synchronysing Power :-

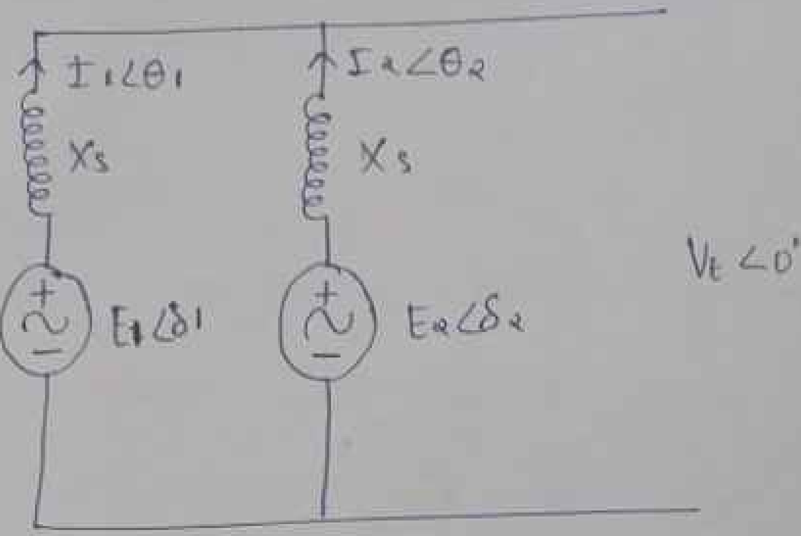
Perfectly synchronised :-

⇒ It is inherient property of alternator when they operate in ~~synchronysim~~ synchronism due to a disturbance resultant voltage E_R produces a circulating current known a synchronising current which produces a synchronising torque and synchronising power.

⇒ The synchronising power comes into picture when steady state operating conditions are disturbed (either angle b/w E_1 and E_2 changes or magnitude of E_1 & E_2 changes)

⇒ Once steady state reach the synchronising becomes zero and it is transient in nature.





$\overline{E_1} = \overline{E_2}$

No synchronized power

$$\boxed{\underset{\text{(difference of } E_1 \text{ \& } E_2)}{E_R} = 0}$$

$$\boxed{\overline{I_{sy}} = \frac{\overline{E_R}}{2jX_s}}$$

$$\boxed{I_{sy} = 0}$$

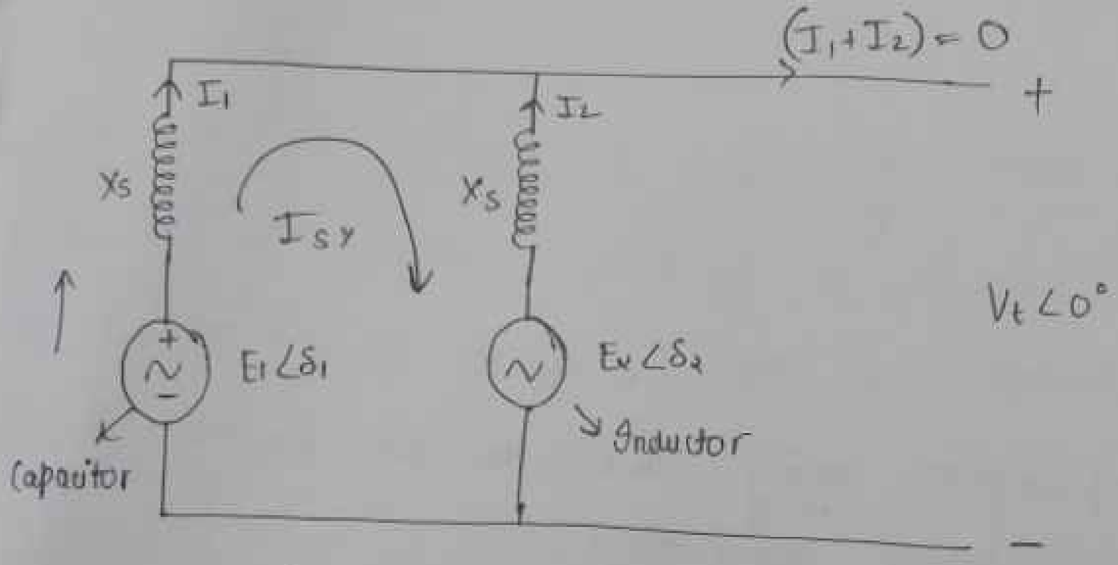
$\{\because \overline{E_R} = 0\}$

If excitation of machine 1 increased then its voltage increase. Therefor a synchranising current will develop in b/w alternator and lags E_1 by $90°$. So, machine 1 operate at 0 powerfactor lagging and the the armature reaction effect is purely demagnetising.

⇒ Synchranising current leads E_2 by $90°$ therfore machine 2 operate at zero p.f leading and armature reaction effect is purely magnetising.

⇒ If the excitation of 1 machine is increased the synchronous power comes into picture and it demagnetise the one machine whose excitation is increased and magnetise the other machine. So, that terminal voltage equalized

→ If the excitation of one machine is increased then synchranising power is reactive in nature. So, reactive power can be controlled by controlling excitation

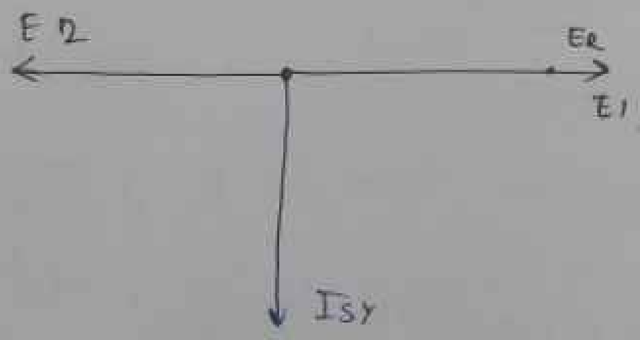


$$|E_1| > |E_2|$$

$$E_R = E_1 - E_2$$

$$\overline{I_c} = \overline{I_{sy}} = \frac{E_R\angle 0^\circ}{2X_s\angle 90^\circ}$$

$$= \frac{E_R}{2X_s}\angle -90^\circ$$



I_{sy} lags 90° w.r.t E_R

$$\boxed{I_{sy} = \frac{(E_1-E_2)}{2X_s}\angle -90^\circ}$$

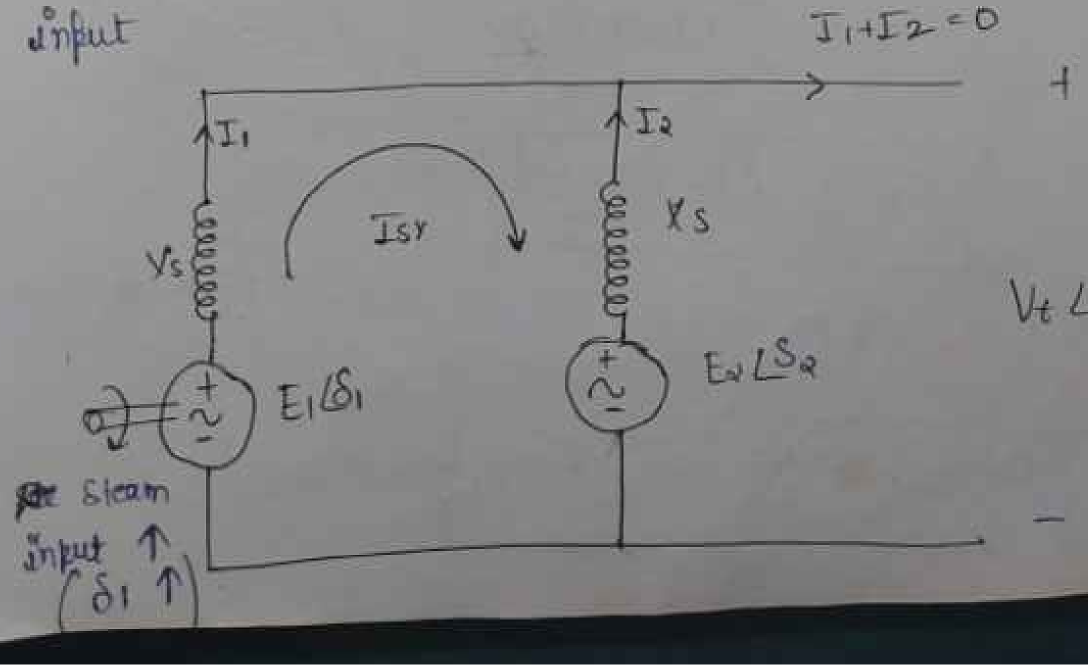
$$Q_{sy} = E_R I_{sy} \sin(90^\circ)$$

$$\boxed{Q_{sy} = \frac{(E_1-E_2)^2}{2X_s}}$$

Case → 2 :- Two alternators running in parallel at noload and effect of change in steam input

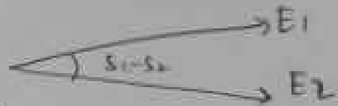
(1) If steam input of one machine is increased the synchronising power will comes into picture which is active power with respect to synchronising power machine one behave as generator and machine two behave as motor therefore the synchronising torque decelerate the first machine (generating machine) and accelerate the second machine motoring machine

(2) Since synchronising power is active in nature. So, active power can be changed by changing mechanical input

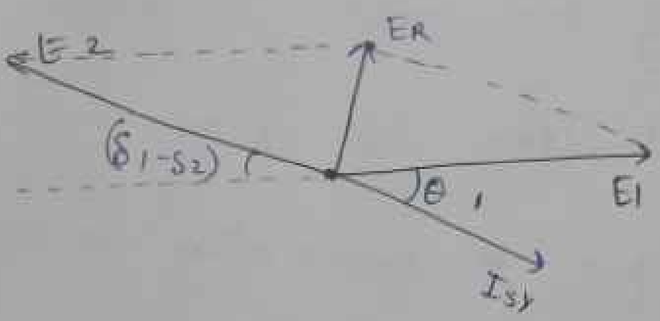


$$\boxed{I_{sy} = \frac{E_R \angle 0^\circ}{2V_s \angle 90^\circ}}$$

$|E_1| = |E_2| = E$



But both are opposite ∴



$$E_R = \sqrt{E^2 + E^2 + 2E \cdot E \cos[180^\circ - \Delta\delta]}$$

$$= \sqrt{2E_2^2 + 2E_2^2 \cos(180^\circ - \Delta\delta)}$$

$$= \sqrt{2E_2^2 (1 - \cos\Delta\delta)}$$

$$= \sqrt{2E_2^2 \left\{1 - \left(1 - 2\sin^2\frac{\Delta\delta}{2}\right)\right\}}$$

$$= \sqrt{4E_2^2 \sin^2\frac{\Delta\delta}{2}}$$

$$\boxed{E_R = 2E_2 \sin\frac{\Delta\delta}{2}}$$

$\sin\frac{\Delta\delta}{2} \approx \frac{\Delta\delta}{2}$ $\quad \because$ $\Delta\delta$ is very less

$$\boxed{E_R = 2E \cdot \frac{\Delta\delta}{2} = E \cdot \Delta\delta}$$

$$\overline{I_{sy}} = \frac{E\Delta S}{2X_s\angle 90^0}$$

$$\overline{I_{sy}} = \frac{E\Delta\delta \angle{-90^0}}{2\cdot X_s}$$

$$\boxed{I_{sy} \propto \Delta\delta}$$

$$P_{sy} = E_1 I_{sy} \cos\theta_1$$

$$P_{sy} = \frac{E\cdot E\cdot\Delta\delta}{2X_s}\cos\theta_1$$

$$\boxed{P_{sy} = \frac{E^2\Delta\delta\cos\theta_1}{2X_s}}$$

Active power

$\theta_1 \approx 0^\circ$

$$\boxed{P_{sy} = \frac{E^2\cdot\Delta s}{2X_s}}$$

$$\boxed{Q_{sy} \approx 0}$$

Steam I/P ↑ ⇒ Kw ↑ ⇒ Pf ↑ ⇒ θ ↓ ⇒ I_a ↓

Induction Machines :-

3-ϕ Induction motor :-

⇒ 90% motors are induction motor because these are rugged in construction, its design is simple, provides a maintenance free operation.

⇒ The disadvantage of induction motor is these have poor starting torque.

Induction motor
- 90% Squirrel cage | cage motor
- 10% slip ring IM | wound rotor motor

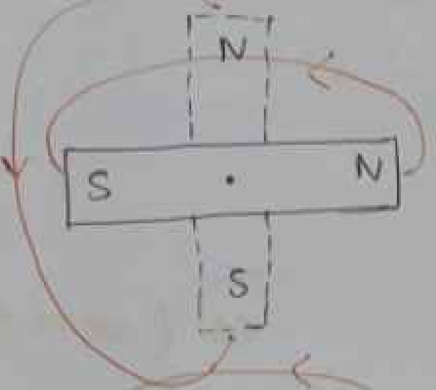
Concept :-

(1) 

time unvarying, stationary

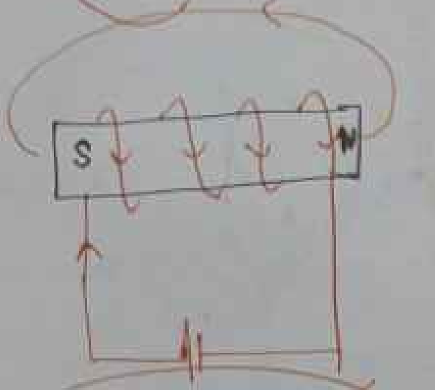
YRGYK 13

(2)



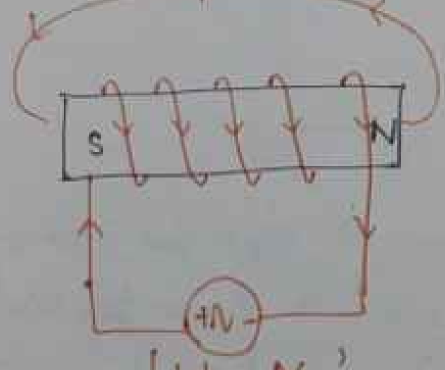
time invarying rotating.

(3)

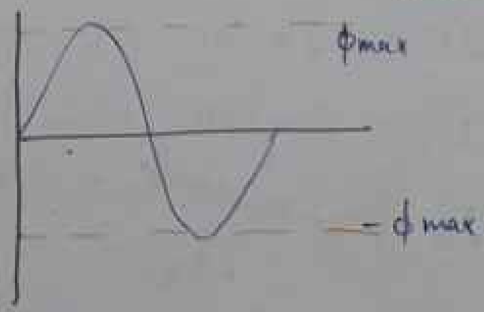


time invarying stationary.

(4)



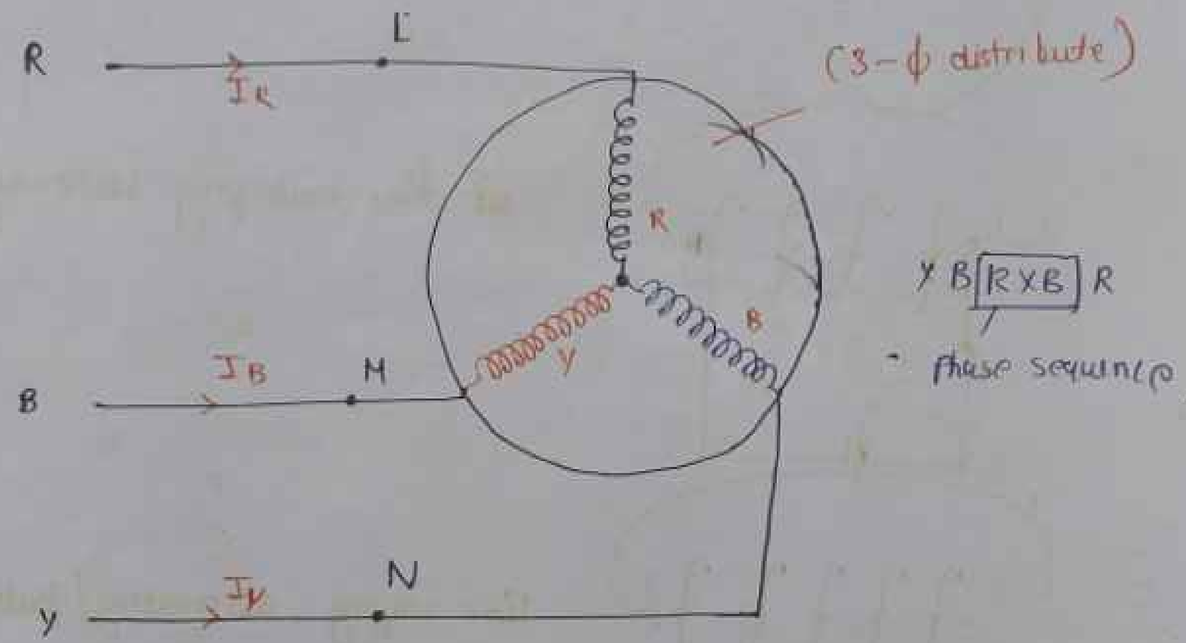
Time varying, alternating/pulsating (stationary)



Concept of rotating magnetic feild :- (R.M.F)

When a polly phase current flow in a pollyphase distributed winding a rotating magnetic feild is produced.

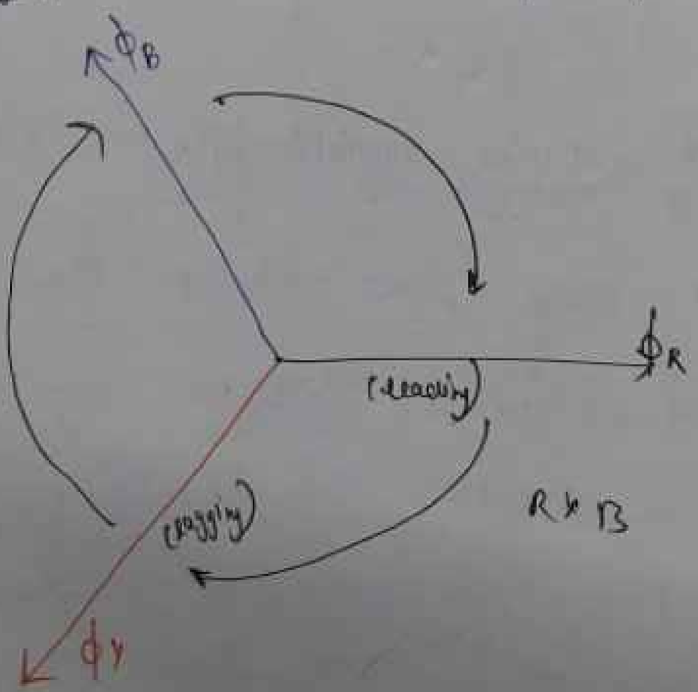
- When a balanced 3-ϕ supply is given to a 3-ϕ distributed winding an R.M.F is produced which rotate in a particular direction from leading phase to lagging phase at a particular speed known as synchronous speed which having a constant magnitude of $1.5\phi_m$



let $\overline{I_R} = I_m \sin \omega t \longrightarrow \phi_R = \phi_m \sin \omega t$

$\overline{I_Y} = I_m \sin (\omega t - 120^\circ) \longrightarrow \phi_Y = \phi_m \sin(\omega t - 120^\circ)$

$\overline{I_B} = I_m \sin (\omega t - 240^\circ) \longrightarrow \phi_B = \phi_m \sin(\omega t - 240^\circ)$

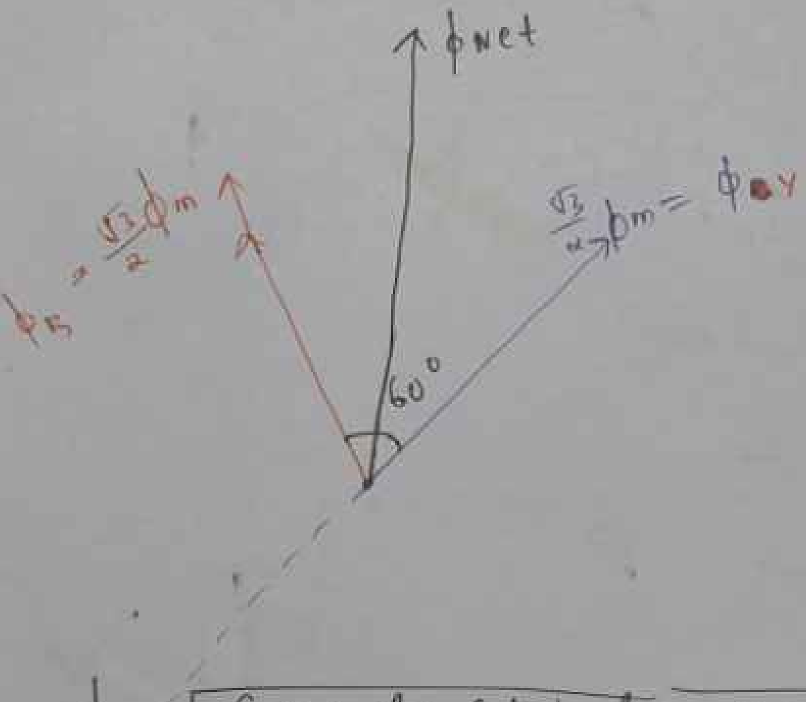


Case → I $\boxed{\omega t = 0^\circ}$

$\phi_R = 0$

$\phi_Y = \phi_m \sin(-120^\circ) = -\frac{\sqrt{3}}{2}\phi_m$

$\phi_B = \phi_m \sin(-240) = \frac{\sqrt{3}}{2}\phi_m$



$$\phi_{Net} \sqrt{\left(\frac{\sqrt{3}}{2}\phi_m\right)^2 + \left(\frac{\sqrt{3}}{2}\phi_m\right)^2 + 2\left(\frac{\sqrt{3}}{2}\phi_m\right)\left(\frac{\sqrt{3}}{2}\phi_m\right)\cos 60^\circ}$$

$$\boxed{\phi_{Net} = 1.5\,\phi_m}$$

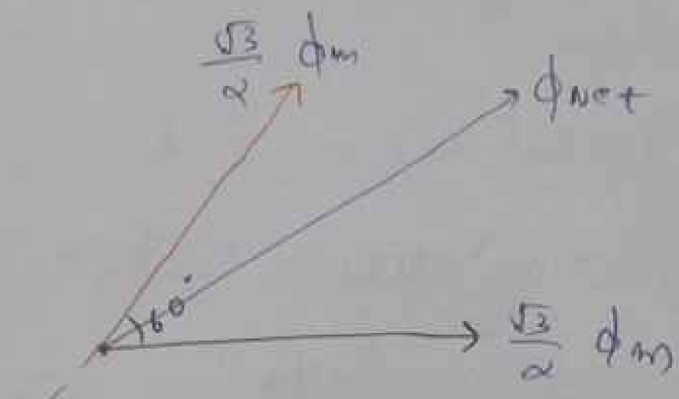
case → 2 $\omega t = 60^\circ$

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

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

$\phi_B = 0$

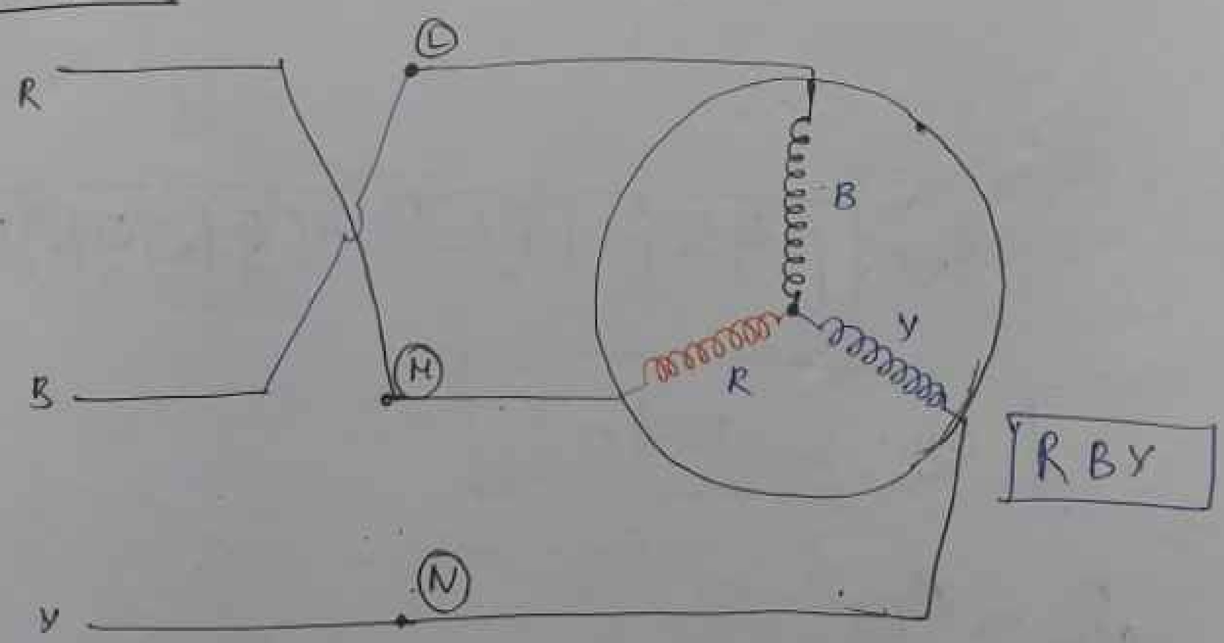
~~formula for~~

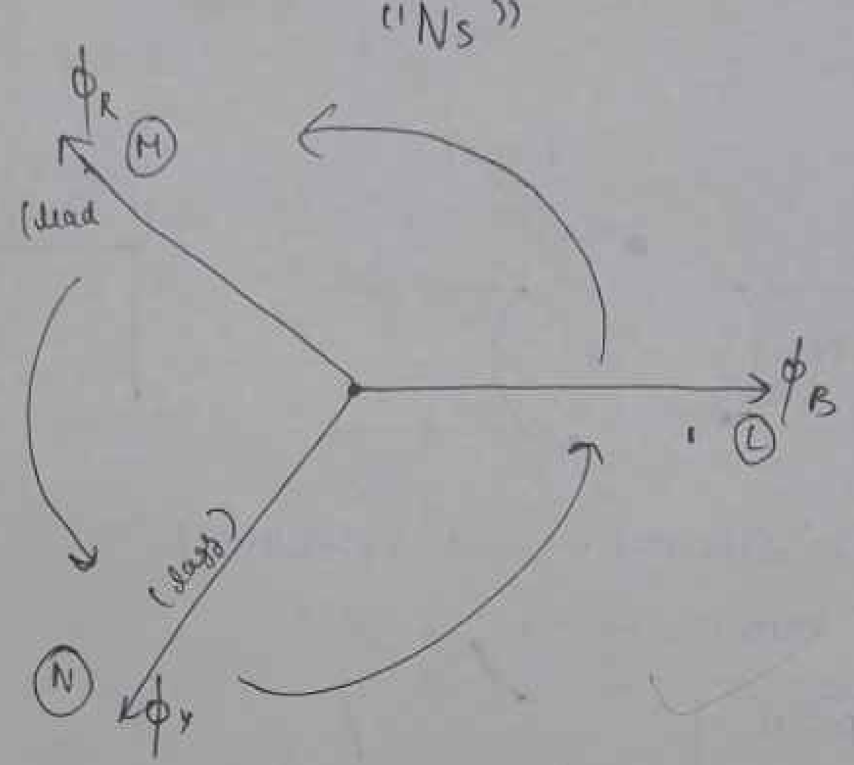


$$\boxed{\phi_{Net} = 1.5\,\phi_m}$$

~~Similarly it is [illegible]~~

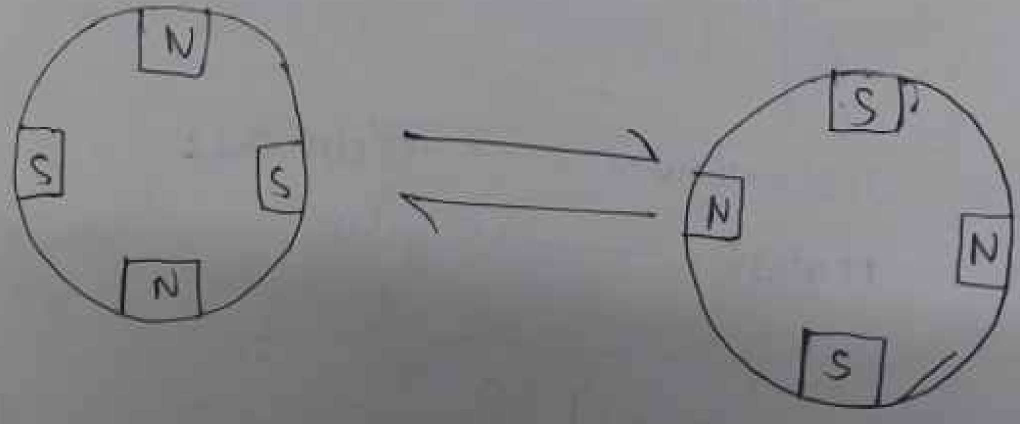
Note :-





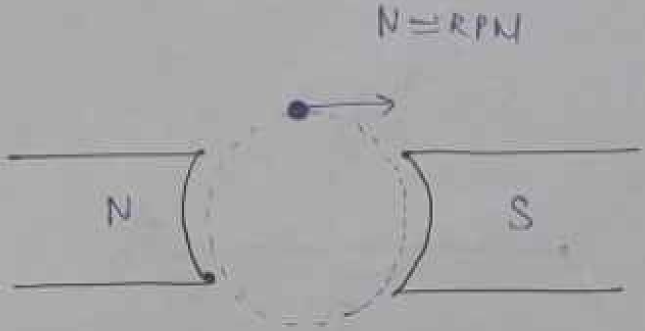
So, the direction of RMF can be reversed by inter-changing any two supply terminals.

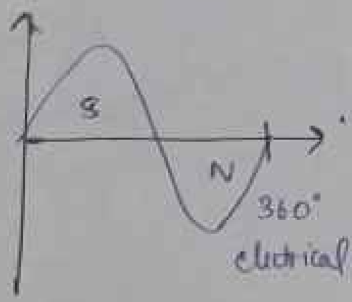
Rotating magnetic feild :-



Formula for synchronous speed :-

If $P = 2$

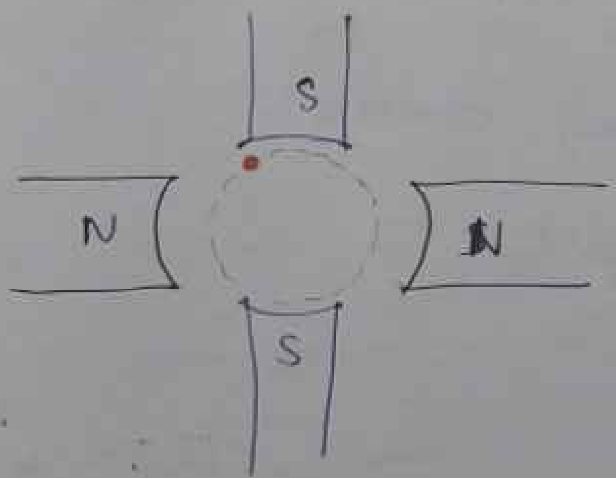


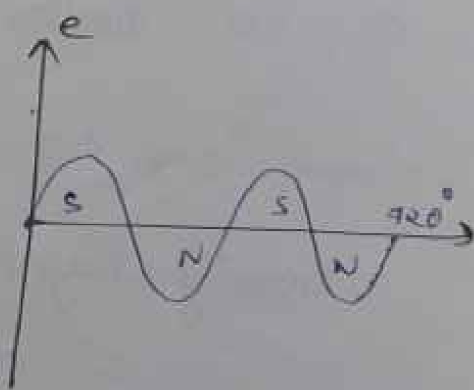


360° Mechanical ⟶ 360° electrical

1 Rotation ⟶ 1 cycle

(ii) $\boxed{P = 4}$





360° mechanical ⟶ 720° electrical

1 Rotation ⟶ 2 cycles

$$\boxed{\theta_{electrical} = \left(\frac{P}{2}\right)\theta_{mechanical}}$$

cycles per rotation $= \frac{P}{2}$

Let f = frequency = cycles per sec

$$\frac{\text{cycles per sec}}{\text{cycles per rotation}} = \frac{f}{P/2}$$

$$\boxed{\frac{\text{Rotation}}{\text{sec}} = \frac{2f}{P}}$$

n_s

$$\frac{N}{60} = \frac{2f}{P}$$

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

$n_s = \frac{N}{60}$

Rotation per unit = N

$$\frac{\text{Rotation}}{\text{sec}} = \frac{N}{60}$$

RPM

$$\boxed{\omega_s = 2\pi n_s = \frac{2\pi N_s}{60} = \frac{4\pi f}{P}}$$

Synchronous speed (radian/sec)

(Rotation/sec)

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

Note :- In case of transformer R.M.F is not produced because the windings are concentrated type.

Construction of induction machine :-

Stator construction :-

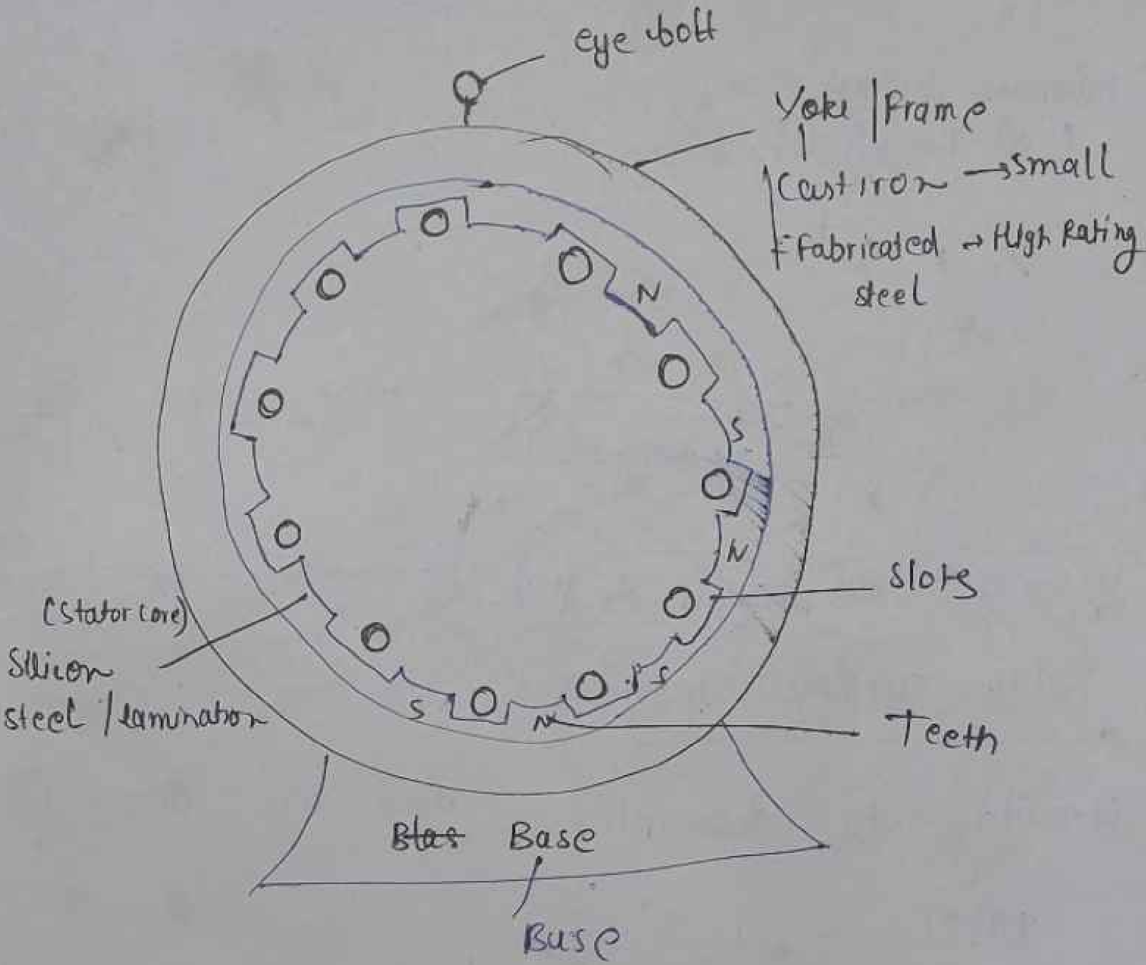
(1) **Stator core :-** In case of induction and synchronous machine its function is to cary the flux. Since, the flux is rotating. so, to reduce eddy current losses it is laminated .. It is made by silicon steel lamination

(2) **Yoke/frame :-** Its function ~~is~~ in synchronous & induction machine is to keep stator stamping in position.

(3) Stator contains a 3-ϕ star or Δ connected distributed windings

Field winding = stator

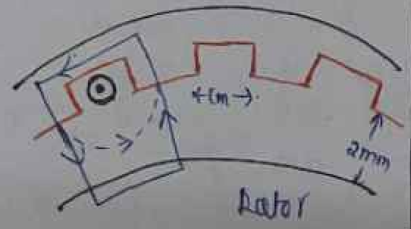
armature winding = rotor



Types of slot :-

Tmax = Torque max

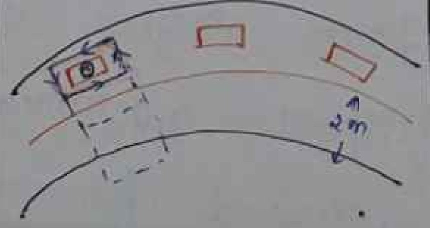
Open type slot



(1) Winding design is simple so, preferred for large ratting machines eg :- alternator

(2) Non uniform air gap. So, flux contains harmonics (space harmonics)

Closed type slot



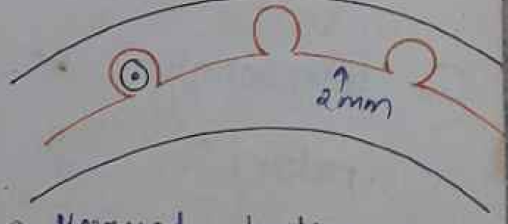
(1) Winding design is very difficult Not preffered

(2) Uniform air gap. So, no flux space harmonics

(3) Net air gap is minimum, I ↓ pf ↑ (X ↑)

(4) Maximum leakage Tmax ↓, Smd, Ist

Semi open / semi closed.



(1) Moderate preferred for medium, small ratting & generally preffered slots

(2) Moderate

(3) Moderate, moderate, moderate

③ Net air is maximum $I_{nl}\uparrow$, Pf ↓

④ Minimum leakage flux ($X_2\downarrow$) $T_{max}\uparrow$, $S_m\uparrow$, $I_{sc}\uparrow$

x_2, $x_2\downarrow$

④ Moderate.

$$\boxed{T_{max} \propto \frac{1}{X_2}, \quad S_m \propto \frac{1}{X_2}, \quad I_{sc} \propto \frac{1}{X_2}}$$

If size of slots increases the $X\uparrow$,

Rotor construction :-

According to construction their are two types of rotor

Ⓐ Squirrel cage / cage rotor :-

① This type of rotor consist of solid aluminium or copper bar.

② Intentionaly no poles designed on squirrel caged rotor. So, it respond automatically for any number of stator pole and provide as pole changing speed control.

③ It have low starting torque

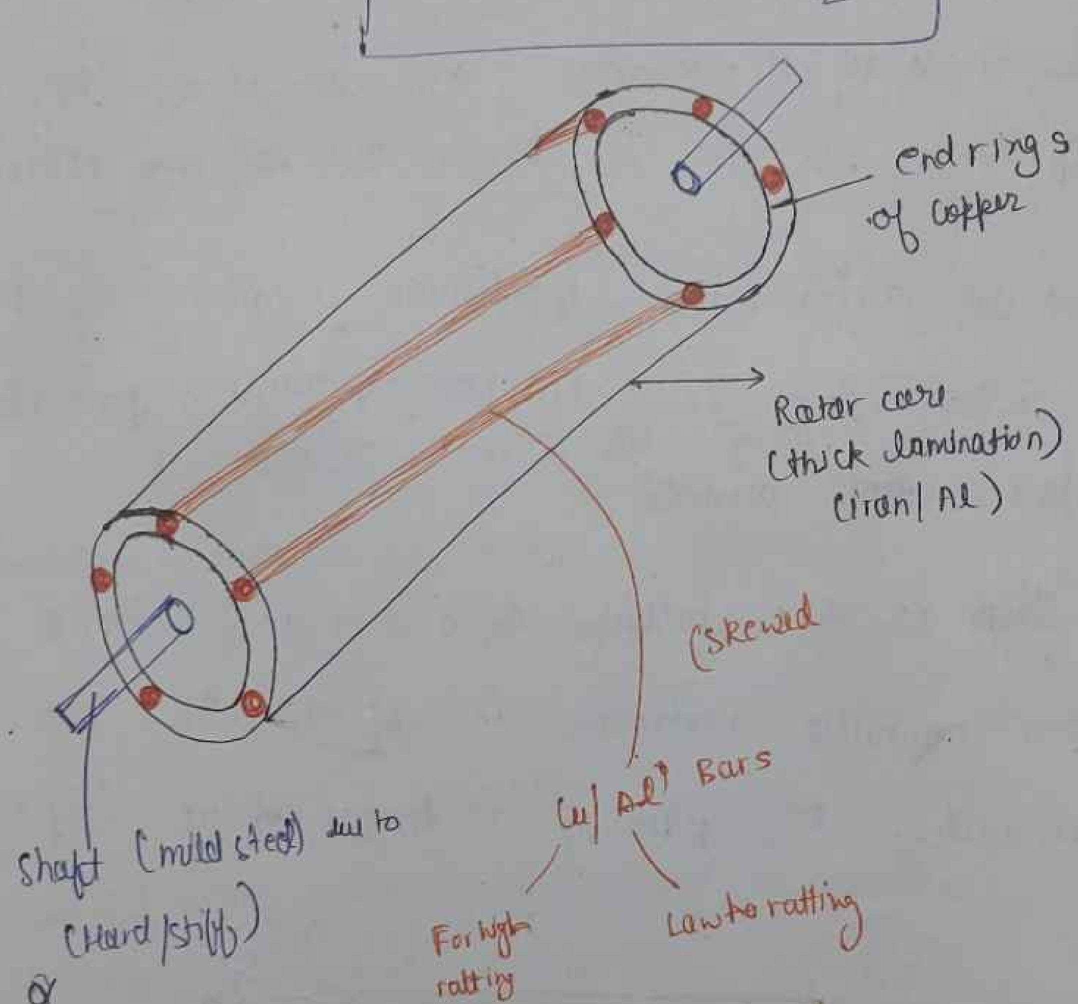
Area ↑, R ↓, $T_{starting} \propto R_2$, $\because R_2$ is ↓

$\therefore T_s$ is also less

③ Have high starting current

Squirrel cage

I_{st} $\boxed{I_{\text{starting current (SC)}} \propto \frac{1}{R_2}}$



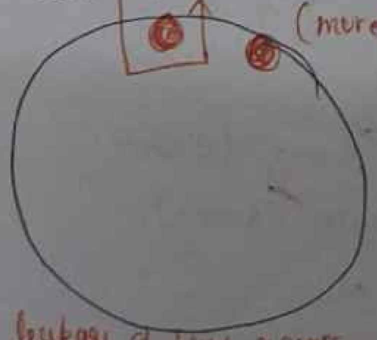
α

$I_{st} = $ [illegible]

for running any motor otherwise motor will not run

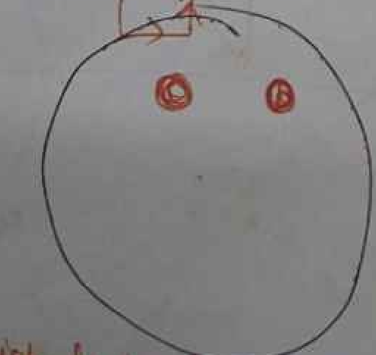
$\boxed{\text{no of stator poles } (P_s) = \text{no of rotor poles } (P_r)}$

Low depth slots (more preffered)



Low leakage of flux occurs

High depth slots



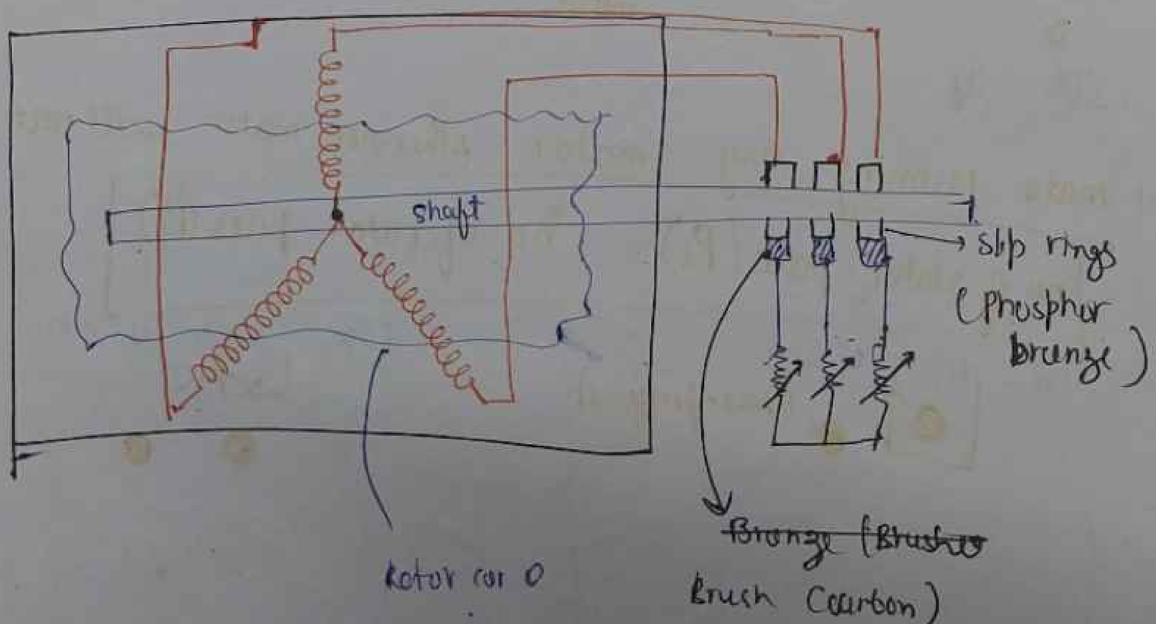
High leakage of flux occurs

Slip ring rotor :-

This type of rotor contains 3-ϕ, ⅄ connected windings terminals of the windings are connected to 3-slip rings . So, it is known as slip ring rotor .

(2) Here we design a particular number of poles on rotor . so, it does not provide pole changing speed ~~ant~~ control .

(3) Thier is the facility of add an external star connected resistor in series with rotor conductor. so, starting torque ~~rotor~~ improve



Area $\downarrow$, $R_2 \uparrow$, $\uparrow T_S \propto R_2 \uparrow \uparrow$

$$\boxed{\downarrow I_{sc} \propto \frac{1}{R_2 \uparrow}}$$

Working principle of Induction motor :-

When a 3-ϕ supply is given to stator of an induction motor an R.M.F is produced which link with the rotor conductor, so, an emf is induced in the rotor conductor. Since the rotor conductors are essentially short circuited. So, a current start flowing in rotor conductors. So, a torque is and rotation in the direction of R.M.F to oppose it's cause (According to ~~Lenz~~ Lentz law)

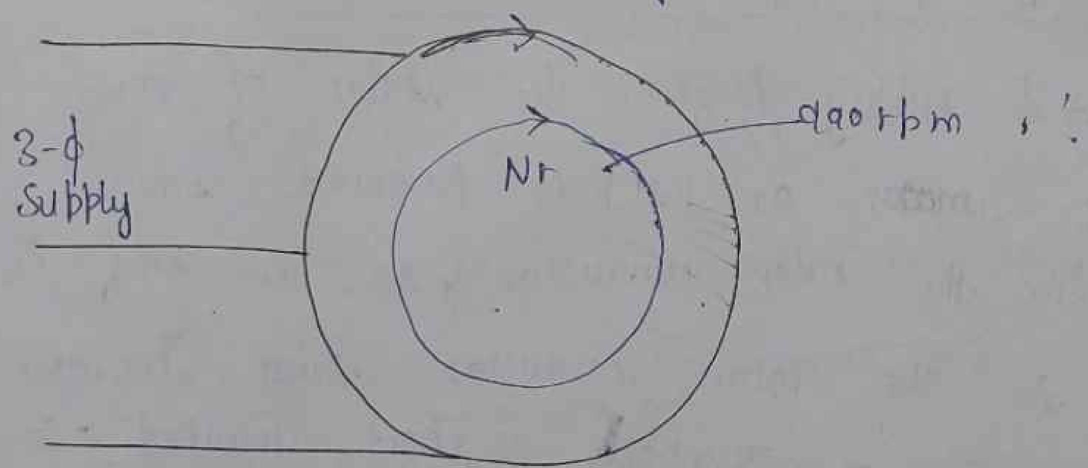
⇒ Rotor wants to catch synchronous speed but falls back by a speed due to its losses present in it. This speed is known as ~~a~~ slip speed

⇒ Induction motor also works on the principle of

Electromagnetic induction and it is a rotating transformer whose secondary is short circuited.

→ A ~~watt~~ well designed induction has slip from no load to full load 1% to 5%.

$$N_s = \frac{120f}{P} = 1000 \text{ RPM (suppose)}$$



electrical → mechanical energy

$$\boxed{\text{Slip speed} = N_s - N_r = SN_s}$$

$$\boxed{\underset{(S)}{\text{Slip}} = \frac{N_s - N_r}{N_s}} \text{ P.U}$$

At starting $N_r = 0$, $S = \frac{N_s - 0}{N_s}$

$$\boxed{S = 1}$$

(2) Under running (motor) $= N_r \longrightarrow N_s$ $\quad s \longrightarrow 0$

(3) generator $N_r > N_s$

$$s = \frac{N_s - N_r}{N_s} = -ive, \boxed{s<0}$$

is called Breaking braky.

$$s = \frac{N_s - (-N_r)}{N_s} = \frac{N_s + N_r}{N_s}$$

$$= 1 + \frac{N_r}{N_s}$$

$$= > 1$$

$s<0$ induction generator

$s = 0$. No θm (floating)

$0<s<1$ Induction motor

$s = 1$, at starting of I-M

$s>1$ Breaking mode.

Que An induction motor runs at 1250 rpm then find the number of pole on stator

$$\boxed{N_r = 1250 \text{ RPM}}$$

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{P} \Rightarrow \boxed{P = 4}$$

P	Ns (RPM)
2	3000
4	1500
6	1000
8	750
10	600

Effect of slip on rotor parameter :-

Let

f_1 = Supply frequency

V_1 = Supply voltage

f_2 = rotor induced emf frequency @ starting / standstill / Blocked rotor condn

f_{2r} = Rotor " " " " running condn

N_r = Rotor speed (RPM)

E_2 = Rotor induced emf @ starting.

E_{2r} = ——————— at running

X_2 = Rotor leakage reactance at starting

X_{2r} = ——————— at running

R_2 = rotor resistance at starting condn
R_{2r} = rotor resistance at running condn

I_2 = Rotor current at starting condn
I_{2r} = ——— running condn

θ_2 = Rotor p.f angle at starting condn
θ_{2r} = ——— running condn.

S = slip of the motor

Rotor induced emf :-

$$N_S - N_r = \frac{120 f_{2r}}{P_2} = SN_S$$

$$N_S = \frac{120 f_2}{P_2} = \frac{120 f_1}{P_1}$$

$$\boxed{f_2 = f_1}$$

$$\frac{SN_S}{N_S} = \frac{\frac{120 f_{2r}}{P_2}}{\frac{120 f_2}{P_2}}$$

$$\boxed{f_{2r} = S f_1}$$

Eg $f_1 = 50Hz$
$S_{FL} = 0.05$
$\therefore f_2 = f_1 = 50Hz$
$f_{2r} = S f_2$
$= .05 \times 50$
$= 2.5\ Hz$

Rotor leakage reactance :-

$X \propto f$
$X_{2r} \propto f_{2r}$

$X_2 \propto f_2$

$$\frac{X_{2r}}{X_2} = \frac{f_{2r}}{f_2} = \frac{sf_1}{f_1}$$

$$\boxed{X_{2r} = sX_2}$$

(3) Rotor induced emf

$$E_2 \propto N_s$$

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

$$\therefore \cancel{\frac{E_2}{E}} \quad \frac{E_2}{E_{2r}} = \frac{N_s}{N_s - N_s}$$

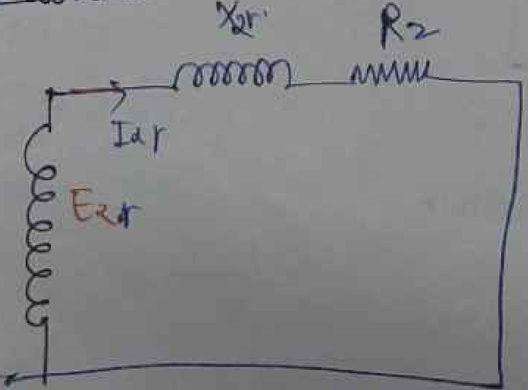
$$\frac{E_2}{E_{2r}} = \frac{1}{s}$$

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

(4) Rotor resistance :

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

(5) Rotor current



$$I_{2r} = \frac{E_{2r}}{\sqrt{R_2^2 + (X_{2r})^2}}$$

$$\boxed{I_{2r} = \frac{S E_2}{\sqrt{R_2^2 + S^2 X_2^2}}}$$

$$\boxed{I_2 = \frac{E_2}{\sqrt{R_2^2 + X_2^2}}}$$

⑥ Rotor p.f :-

$$\boxed{\cos\theta_{2r} = \frac{R_2}{\sqrt{R_2^2 + X_{2r}^2}}}$$

$$\boxed{\cos\theta_2 = \frac{R_2}{\sqrt{R_2^2 + X_2^2}}}$$

Note :- $R_2 = 0.2 r$

$X_2 = 1\Omega$

Starting

$X_2^2 >>>> R_2^2$

we can neglect R_2^2

$$I_2 \approx \frac{E_2}{X_2}$$

$$\boxed{\cos\theta_2 = \frac{R_2}{X_2}}$$

But Running :- $R_{2r} = 0.2\Omega$

$X_{2r} = 0.05 \times 1$

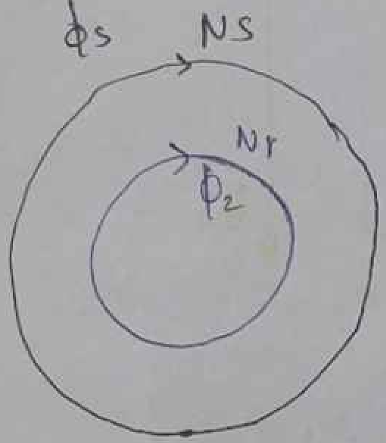
$$\boxed{X_{2r} = 0.05\Omega}$$

$\therefore \boxed{R_{2r}^2 >>>> X_{2r}^2}$

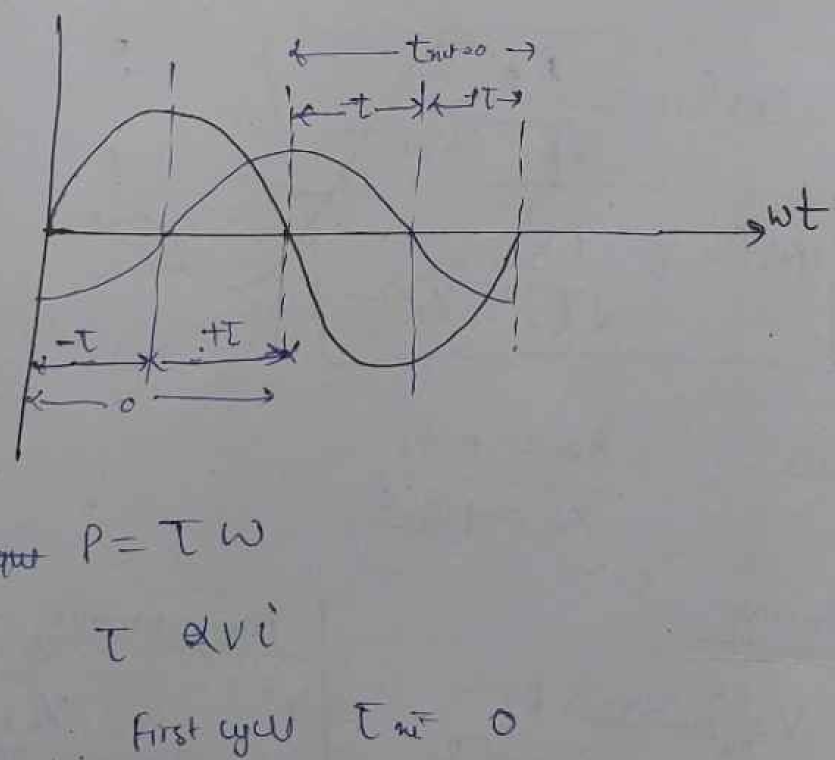
$\therefore \boxed{I_{2r} = \frac{E_2}{R_2}}$

Torque developed in an induction motor :-

If the rotor is pure ~~resistive~~ :- inductive.



∵ I_{2r} lags E_{2r} by angle '90°'.

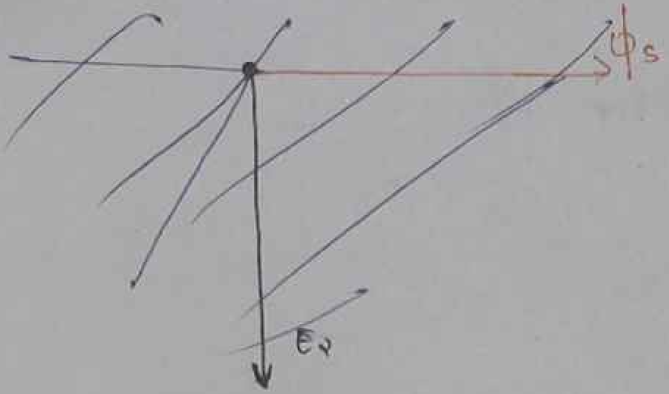


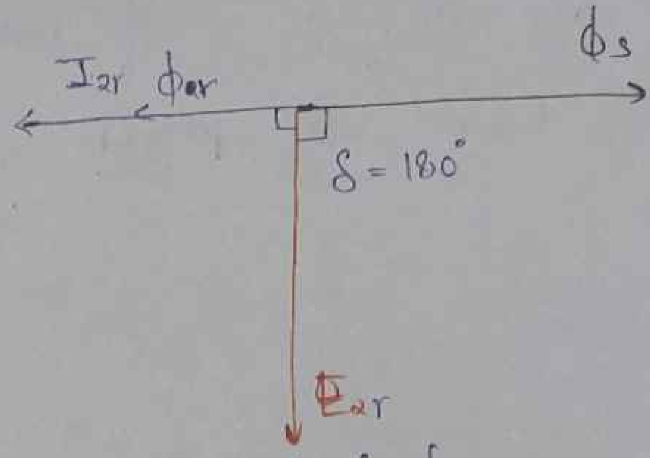
∵ ~~Torque~~ $P = \tau\omega$

$\tau \propto vi$

∴ first cycle $\tau_{net} = 0$

$$\boxed{\delta = 180^\circ}$$

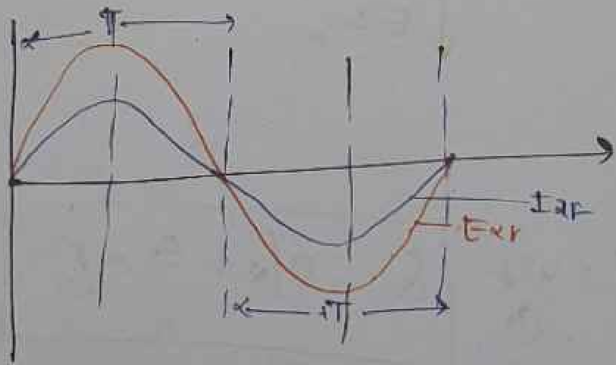


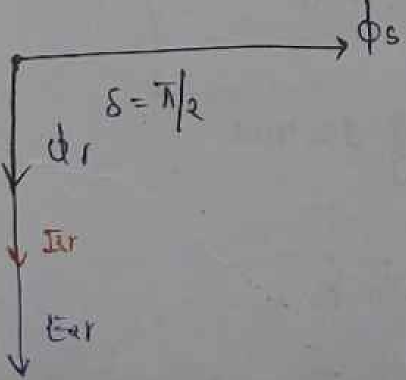


δ = angle b/w ϕ_s & ϕ_r

Case → II :- If rotor is pure resistive

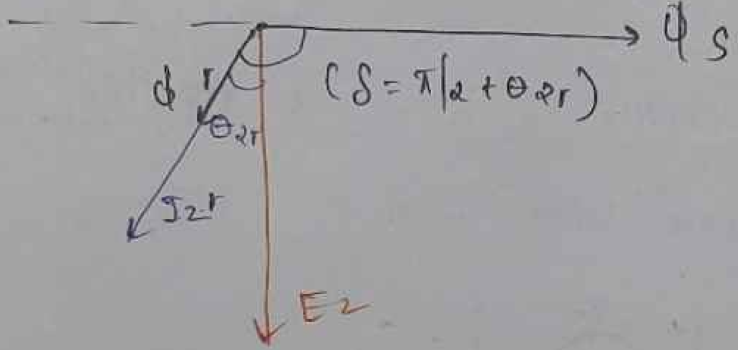
I_{2r} in phase with E_{2r}





so, in case of pure resistive rotor the average torque is maximum and $\boxed{\delta = \pi/2}$

Case → III : If rotor is R-L E_{2r} lags E_{2r} by angle ~~ϕ_{2r}~~ θ_{2r}



Result ①

$$\boxed{\delta = \pi/2 + \theta_{2r}}$$

②

$$\boxed{T_{er} \propto \phi_s \cdot \phi_r \sin\delta}$$

T_{er} = rotor running torque

$T_{er} \propto \phi_s \phi_r \sin\delta$.

$\phi_s \propto \frac{V_1}{f_1} \propto \frac{E_2}{f_1}$ | $\phi_r \propto I_{2r}$

~~$\delta = \pi/2 + \phi_{2r}$~~

$\delta = \pi/2 + \theta_{2r}$

AKTU NOTES HUB

$$\frac{V_1}{V_2} = \frac{E_1}{E_2} = \frac{1}{K}$$

$$\boxed{V_1 = \frac{V_2}{K} = \frac{E_2}{K}}$$

$$T_{er} \propto \frac{3E_2}{f_1} \cdot I_{2r} \cdot \sin(\pi/2 + \theta_{2r})$$

$$T_{er} \propto \frac{3E_2}{f_1} \cdot I_{2r} \cos\theta_{2r}$$

$$\boxed{T_{er} = \frac{3E_2 I_{2r} \cos\theta_{2r}}{W_s}}$$ #

$$\cancel{T_{er} = \frac{3}{SW_s}\left(S^2 E\right.}$$

$$E_2 \propto V_1$$

$$T_{er} = \frac{3E_2}{W_s} \frac{SE_2}{\sqrt{R_2^2+S^2X_2^2}} \cdot \frac{R_2}{\sqrt{R_2^2+S^2X_2^2}}$$

$$\boxed{T_{er} = \frac{3SE_2^2 R_2}{W_s(R_2^2+S^2X_2^2)}}$$ # #

$$T_{er} = \frac{3}{SW_s}\left(\frac{S^2E_2^2}{R_2^2+S^2X_2^2}\right)$$

$$T_{er} = \frac{3}{SW_s} I_{2r}^2 R_2$$

$$T_{er} = \frac{1}{S\omega_s}\left(3 I_{2r}^2 R_2\right)$$

$$\boxed{\text{Rotor cu Loss} = \text{Rotor copper loss} = R.C.L = 3 I_{2r}^2 R_2}$$

$$\boxed{T_{er} = \frac{1 \times RCL}{S\omega}}$$

Starting torque :-

$$T_{er} = \frac{3 S E_2^2 \cdot R_2}{\omega_s (R_2^2 + S^2 X_2^2)}$$

at starting $S = 1$

$$(T_e)_{st} = \frac{3 E_2^2 \cdot R_2}{\omega (R_2^2 + X_2^2)}$$

$$R_2^2 <<< X_2^2$$

$$\boxed{(T_e)_{st} \approx \frac{3 E_2^2 R_2}{\omega_s \cdot X_2^2}}$$

~~Result~~ $\cancel{(T_e)_{st} \propto R_2}$

Result :-

① $\boxed{(T_e)_{st} \propto R_2}$

② $\boxed{(T_e)_{st} \propto V_1^2}$

③ $\boxed{(T_e)_{st} \propto \frac{1}{f^3}}$

④ ∵ ~~in~~ case of 3-ϕ Im $(T_e)_{st} \neq 0$. So, these are self starting in nature

Condition for maximum ~~to~~ starting torque :-

$$\frac{d(T_e)_{st}}{dR_2} = 0$$

$$\boxed{R_2 = X_2}$$

Eg:- $\boxed{R_2 = 0.2\,\Omega}$ Ω

$X_2 = 1\,\Omega$

Value of max starting torque so R₂ has to increas
so अंततः में X₂ रहेगा

$$\boxed{[(T_e)_{st}]_{max} = \frac{3E_2^2 X_2}{\omega_s (X_2^2 + X_2^2)}}$$

$$\boxed{\left[(T_e)_{st}\right]_{max} = \frac{3E_2^2}{2\omega_s \cdot X_2}}$$

Result :-

1. $T_{max} \propto V_1^2$
2. $T_{max} \propto \frac{1}{f^2}$
3. Max starting does not depends on rotor resistance.
4. Rotor power factor for maximum starting torque

$\because \cos\theta_\alpha = \frac{R_2}{\sqrt{R_2^2+X_2^2}}$ at $R_2 = X_2$

$\cos\theta_\alpha = \frac{X_2}{\sqrt{X_2^2+X_2^2}}$

$$\boxed{\cos\theta_\alpha = \frac{1}{\sqrt{2}} = 45^\circ \text{ lagging}}$$

Formula for developed torque in the ~~rotating~~ rotor under running condition.

$$T_{er} = \frac{3 s E_2^2 \cdot R_2}{\omega_s(R_2^2+s^2X_2^2)}$$

$$\boxed{\left[(T_e)_{st}\right]_{max} = \frac{3E_2^2}{2\omega_s \cdot X_2}}$$

Result :-

(1) $T_{max} \propto V_1^2$

(2) $T_{max} \propto \frac{1}{f^2}$

(3) Max starting does not depend on rotor resistance

(4) Rotor power factor for maximum starting torque

i.e. $\because \cos\theta_2 = \frac{R_2}{\sqrt{R_2^2 + X_2^2}}$ at $R_2 = X_2$

$$\cos\theta_2 = \frac{X_2}{\sqrt{X_2^2 + X_2^2}}$$

$$\boxed{\cos\theta_2 = \frac{1}{\sqrt{2}} = 45°\ \text{lagging}}$$

Formula for developed torque in the rotor under running condition,

$$T_{er} = \frac{3 s E_2^2 \cdot R_2}{\omega_s (R_2^2 + s^2 X_2^2)}$$

Under running condition

$S^2 X_{2}^2 \ldots << R_2^2$

$$T_{er} = \frac{3 S E_2^2 \cdot R_2}{W_S \cdot R_2^2}$$

$$\boxed{T_{er} = \frac{3 S E_2^2}{W_S \cdot R_2^2}}$$

Result: $T_{er} \propto \frac{1}{R_2^2}$

(2) $T_{er} \propto V_1^2$

(3) $T_{er} \propto \frac{1}{f}$

Value of max. Torque:

$$\cancel{(T_{er})_{max} = \frac{3 S_m E_2^2 R_2}{W_S (R_2^2 + S_m^2 X_2^2)}}$$

$$\boxed{(T_{er})_{max} = \frac{3 S_m E_2^2 \cdot R_2}{W_S (R_2^2 + S_m^2 X_2^2)}}$$

$$\boxed{(T_{er})_{max} = \frac{3E_2^2}{2\omega_s X_2}}$$

① $t_{max} \propto V_1^2$

② $T_{max} \propto \frac{1}{f^2}$

Max starting does not depends on rotor resistance.

Torque speed or torque slip characteristics :-

$$\boxed{T_{er} = \frac{3sE_2^2 \cdot R_2}{\omega_s(R_2^2 + s^2X_2^2)}}$$

MOTORING MODE

① Low slip Region → $R_2 >>> sX_2$

$0 < S \leq S_m$

$$T_{er} \simeq \frac{3sE_2^2}{\omega_s R_2}$$

$\boxed{\downarrow T_{er} \propto S \downarrow}$ → Linear relationship

② High slip region $X_2 >>>> R_2$

$S_m \leq S < 1$

$$T_{er} \simeq \frac{3SE_2^2 R_2}{\omega_s \cdot S^2 X_2^2}$$

$\left(\uparrow T \propto \frac{1}{S \downarrow}\right)$ — rectangular Hyperbola.

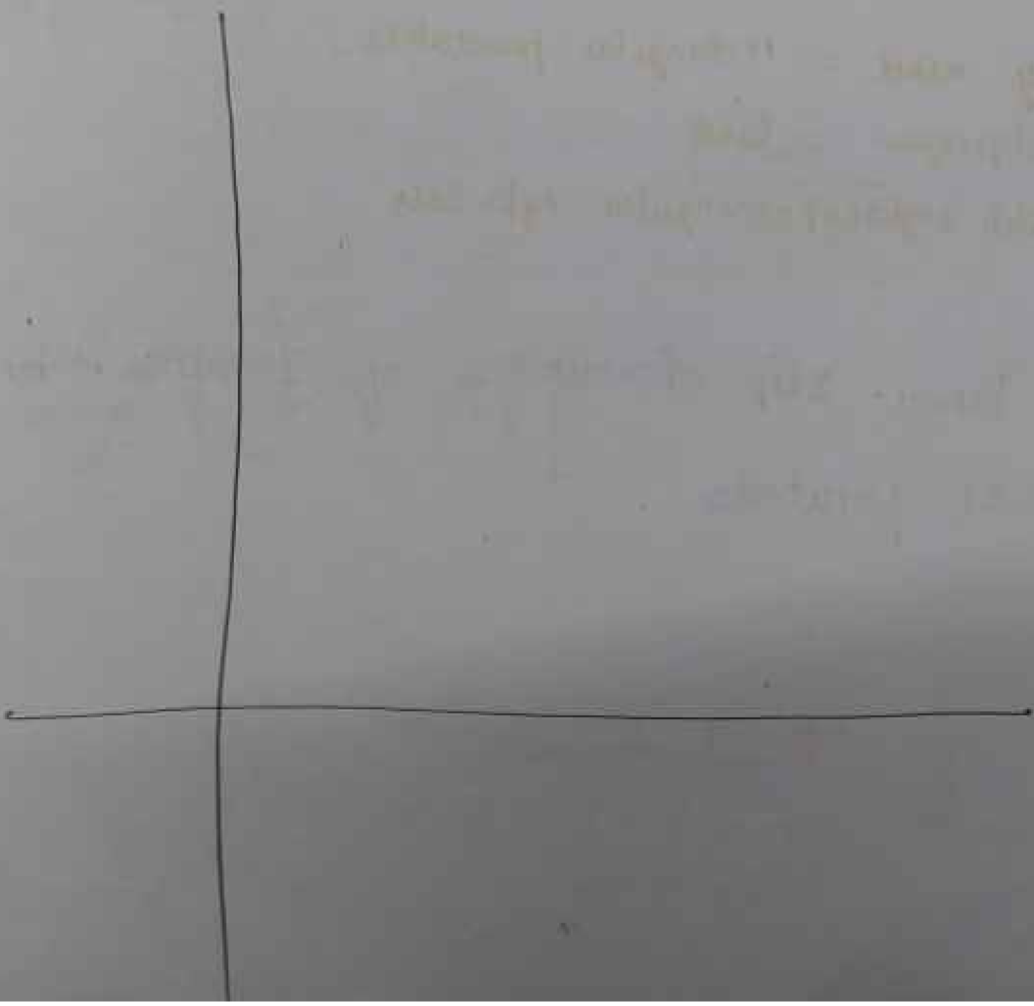
$$\left.\begin{aligned} R_2 &= .2\,\Omega \\ X_2 &= 1\,\Omega \end{aligned}\right\} S = 1$$

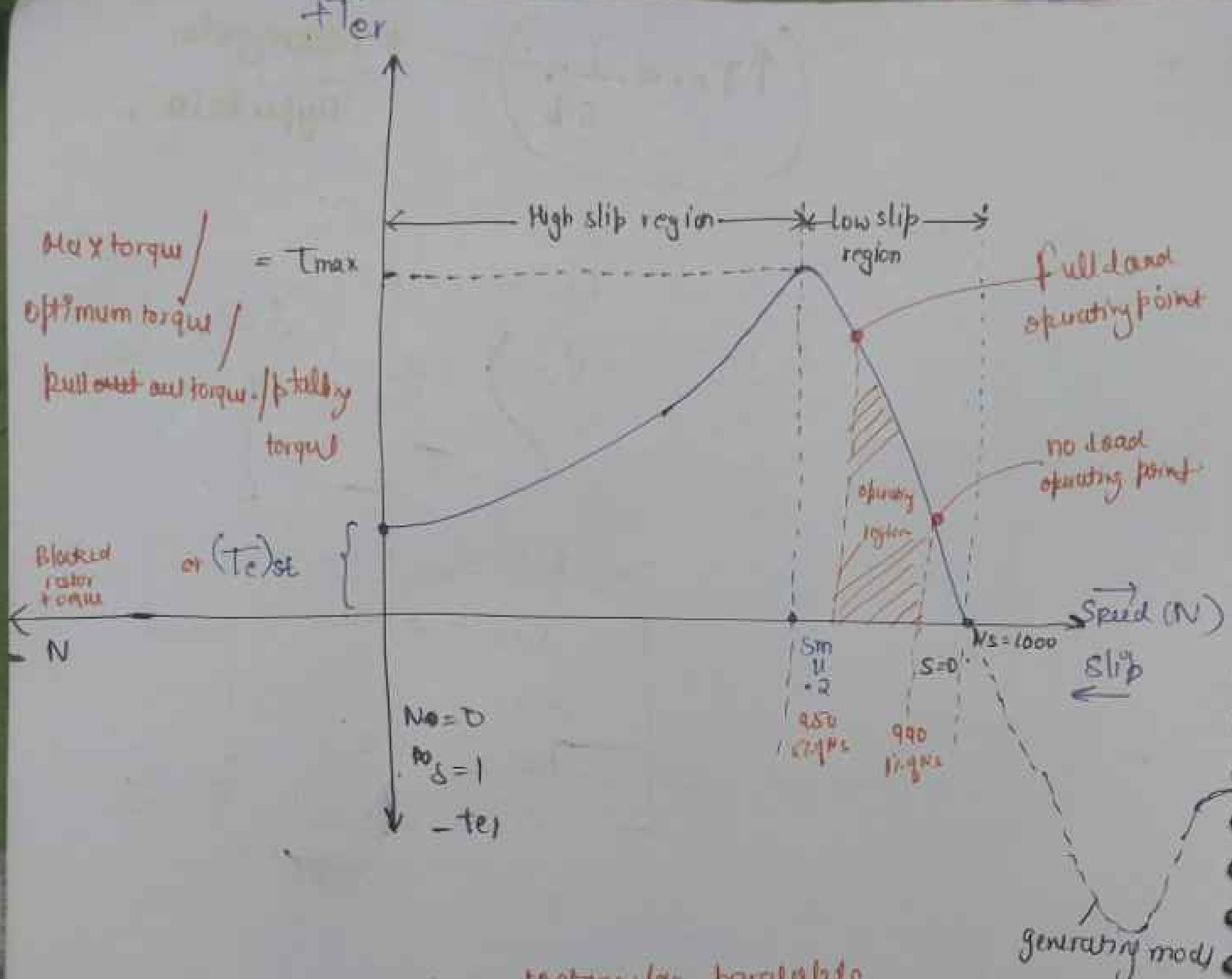
$$\downarrow$$

$$R_2 = .2\,\Omega \qquad S = .2$$
$$X_{2r} = 0.2\,\Omega$$

$$\downarrow$$

$$R_2 = .2\,\Omega$$
$$X_{2r} = .05\,\Omega \qquad S = .05$$





generally asked = rectangular paralabola.
in Low slip region = lines
High slip region = rectangular hyperbola

The Torque-slip characterstics of Induction motor is rectangular parabola.

Note :-

Note :- ~~if $T_e >$~~

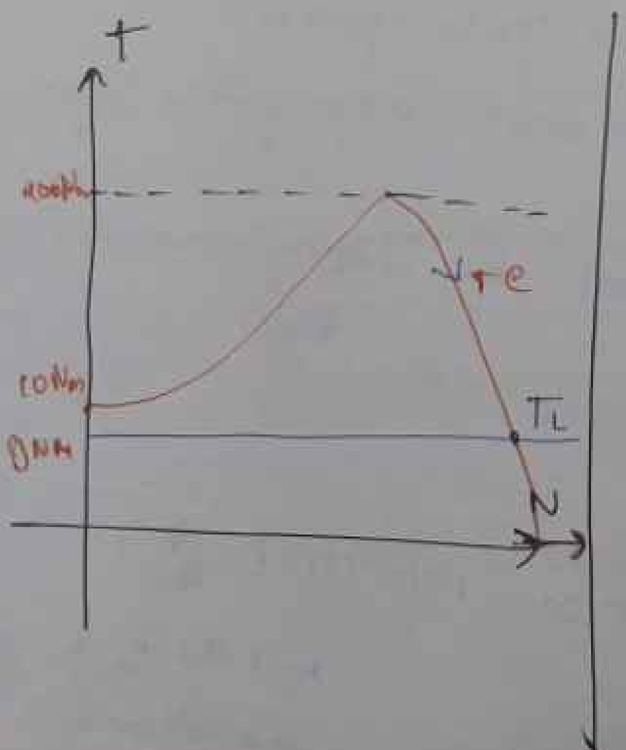
$$\boxed{T_{accelerating} = T_e - T_L}$$

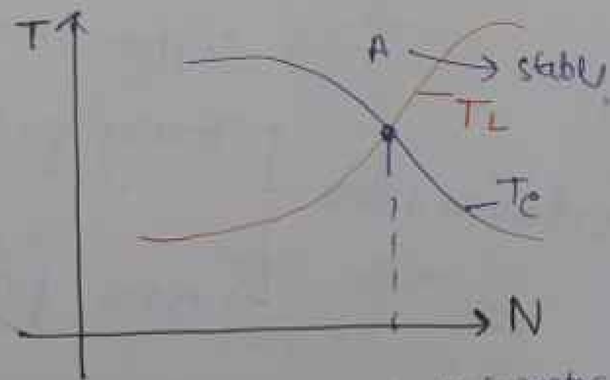
T_e — ~~electrical~~ electromagnetic; T_L — load.

① if $T_e > T_L$, T_{acc} = +ive, accelerate, $N\uparrow$

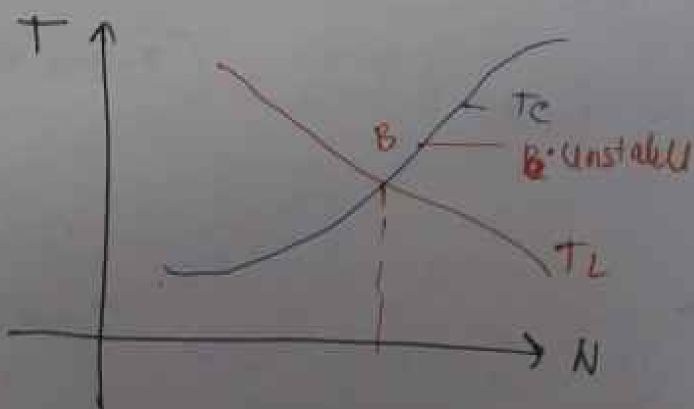
② if $T_e < T_L$, T_{ac} = -ive, decelerate. $N\downarrow$

③ if $T_e = T_L$, $T_{acc} = 0$, N = constant.





On moving left or right to point motor remains stable



~~V_ϕ $\frac{V_L}{\sqrt{3}}$ V_{ph} = V_L~~

Losses :-

① Stator losses —
- → Stator cu Loss ($3I_1^2 R_1$)
- → Stator core losses

② Rotor losses —
- → Rotor cu losses [$3I_{2r}^2 R_2$]
- → Rotor core Loss [$f_{2r} \to 25Hz \to 0$]^2 ($f_{2r}+f_{2r}^2$)

So, Rotor core loss can be neglected.

③ Mechanical losses —
- → Bearing friction loss + windage friction loss.
- → Brush frictional loss (Slip ring Induction motor)

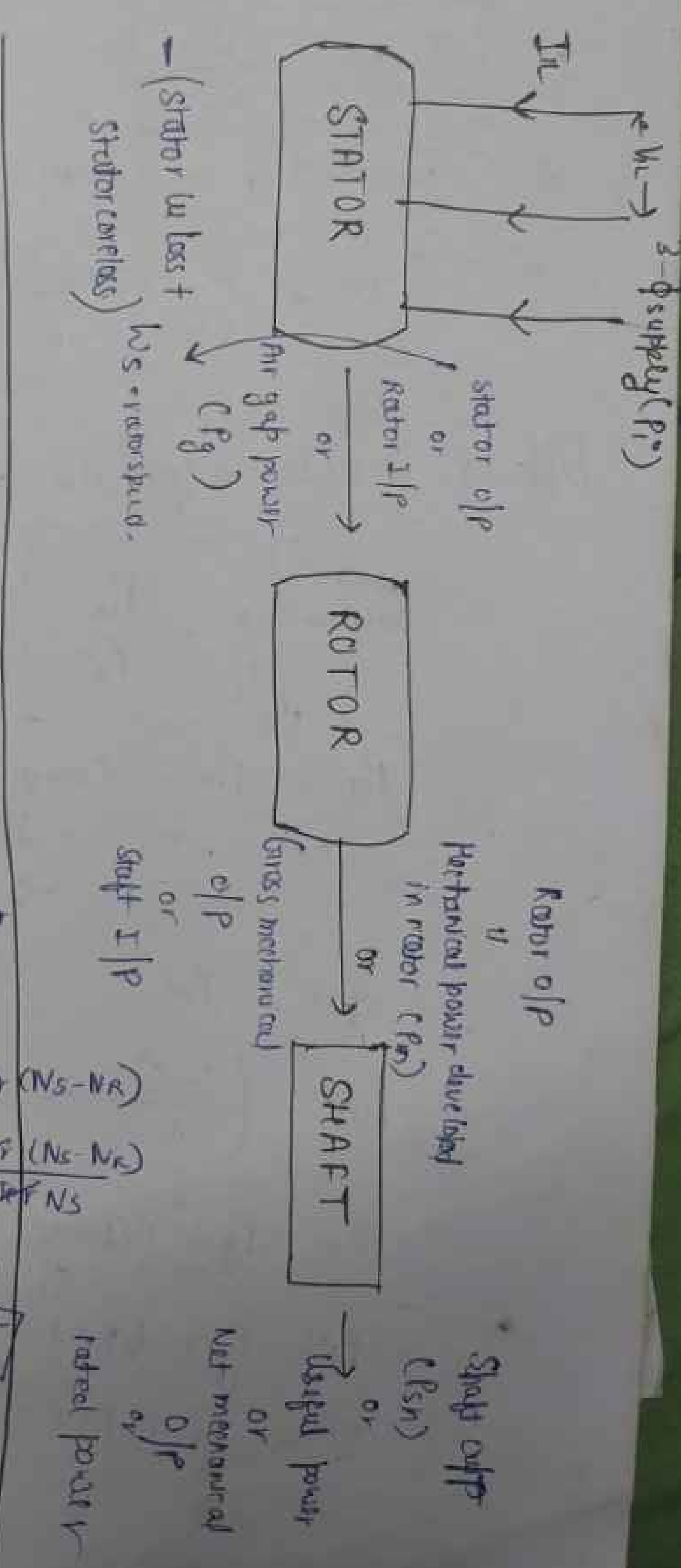
Note :-

① Constant Loss = (Stator core loss + Rotor core Loss ↑ with + mech loss ↓ with)

so overall constant

② Variable loss = Stator Cu loss + RCL.

Powerflow diagram :-



Results $\boxed{P_{in} = \sqrt{3} V_{L} I_{L} \cos\theta_1}$

p.f of I-M

$\boxed{P_{in} = 3 V_1 I_1 \cos\theta_1}$

(2) $P_g = P_i - (\text{stator Losses})$

$= 3 E_2 I_{2r} \cos\theta_{2r}$

(3) $P_m = P_g - (\text{Rotor losses})$

(4) $\boxed{P_{sh} = P_m - (\text{Mechanical losses})}$

(5) $\boxed{\eta = \frac{P_{sh}}{P_i} \times 100}$ $P_m = 2\pi N_R T_{er}$

$P_g = 2\pi N_s T_{er}$

(6) $P_g = T_{er} \cdot \omega_s$ $P_m = P_g - RCL$

$RCL = 2\pi T_{er}(N_s - N_R)$

$P_g = \frac{1}{s\cancel{\omega_s}} (RCL)\cancel{\omega_s}$

$\frac{RCL}{P_g} = \frac{\cancel{2\pi T_{er}}(N_s - N_R)}{\cancel{2\pi T_{er}} N_s}$

$\boxed{P_g = \frac{1}{s}(RCL)}$ $\frac{RCL}{P_g} = s$ $\boxed{P_g = \frac{RCL}{s}}$

(7) $P_m = P_g - (\text{rotor cu losses} + \text{Rotor core loss})$

$P_m = \frac{1}{s}(RCL) - [RCL + 0]$

$$\boxed{P_m = \left(\frac{1-S}{S}\right) RCL}$$

(8) $$\boxed{T_{SH} = \frac{P_{sh}}{\omega}}$$

(9) $T_{SH} = T_{er} - (\text{Lost torque})$

(10) $$\boxed{T_{er} = \frac{1}{S\omega_s}(RCL)}$$

Approx formula ~~o~~ formula for efficiency:-

~~Pen~~ ~~=~~ $$\boxed{\eta = \frac{P_{sh}}{P_i}}$$

$P_{sh} = P_m - (\text{mech loss})$

$\quad\quad\quad\quad\quad\quad\quad$ SS

$\quad\quad\quad\quad\quad\quad\quad$ 0

$P_{sn} = P_m$

$P_{sh} = \left(\frac{1-S}{S}\right) RCL$ ——— (1)

$P_i = P_g + (\text{Stator Cu Loss} + \text{Stator core loss})$

$\quad\quad\quad\quad\quad\quad\quad$ SS $\quad\quad\quad\quad$ SS

$P_i = P_g + (RCL + \text{Rotor core loss})$

$P_i = P_g + RCL + 0 \Rightarrow P_i = P_g + RCL$

$$P_i = \frac{1}{s}(RCL) + (RCL)$$

$$P_i = \left(\frac{1+s}{s}\right) RCL \quad \text{—— (2)}$$

$$\eta = \frac{\left(\frac{1-s}{s}\right) RCL}{\left(\frac{1+s}{s}\right) RCL}$$

$$\boxed{\eta = \frac{1-s}{1+s}}$$

$\because s \longrightarrow 0$

$1 + s \approx 1$

$$\boxed{\eta = 1 - s}$$

Example :-

$P_{sh} = 2700\,W$, $s = 4\% = .04$

Mech loss = 180 W

RCL = ?

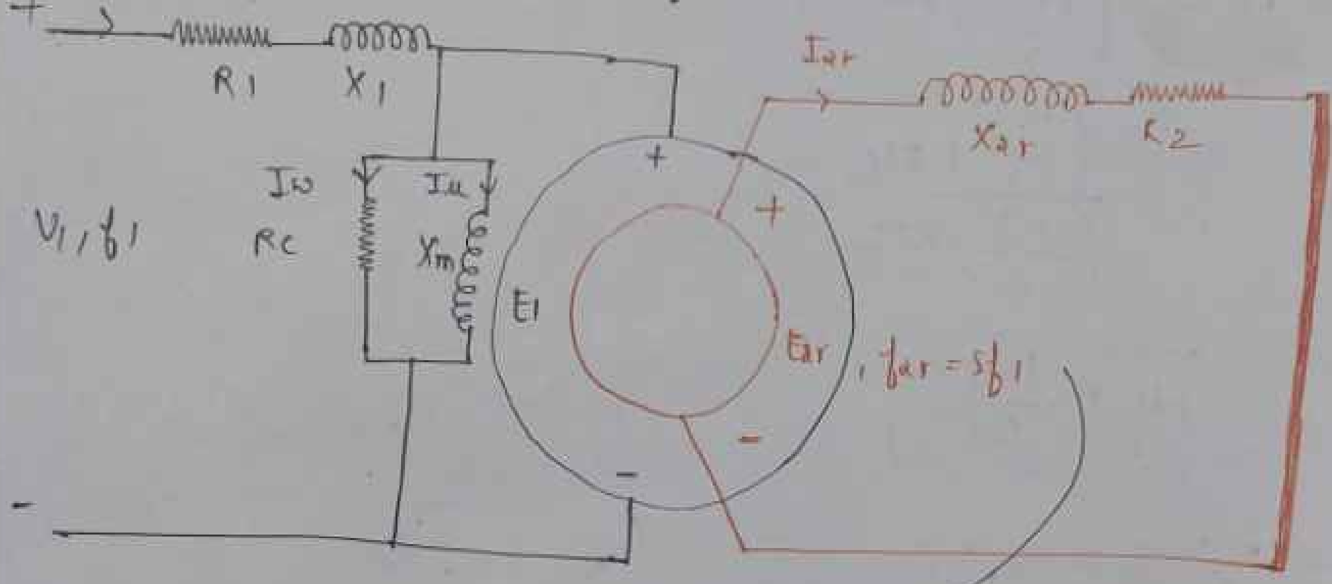
$$P_m = \left(\frac{1-s}{s}\right) RCL = P_{sh} + \text{Mech loss}$$

$$= \left(\frac{1 - .04}{.04}\right) RCL = 2700 + 180$$

$$\boxed{RCL = 120W}$$

Equivalent circuit of induction motor:-

$I_1 = I_0 + I_{2r}'$ → 30% to 40% of full load stator current

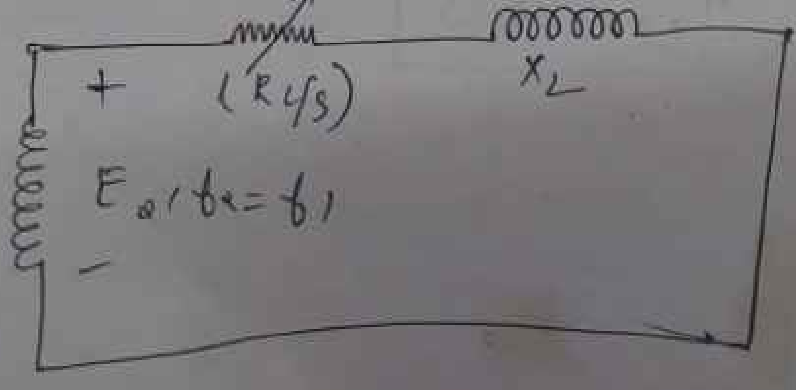


$$I_{2r} = \frac{E_{2r}}{\sqrt{R_2^2 + X_{2r}^2}}$$

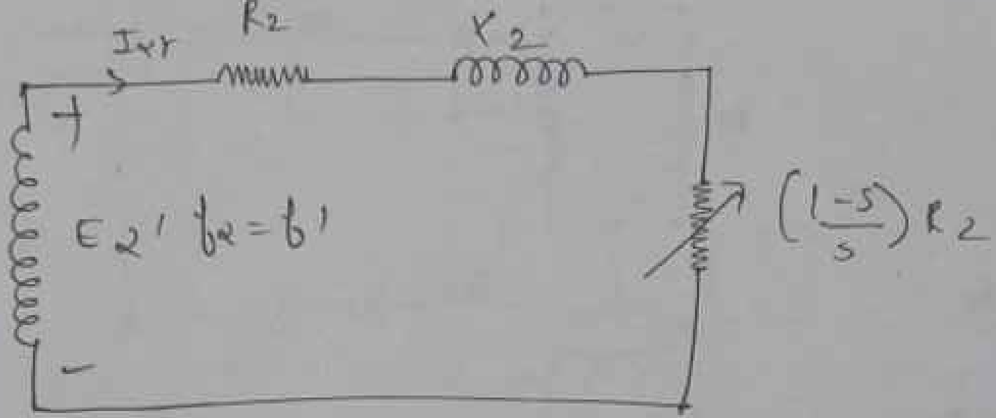
$$I_{2r} = \frac{E_{2r}}{\sqrt{R_2^2 + X_{2r}^2}}$$

$$I_{2r} = \frac{sE_2}{\sqrt{R_2^2 + s^2X_2^2}}$$

$$I_{2r} = \frac{E_2}{\sqrt{\left(\frac{R_2}{s}\right)^2 + X_2^2}}$$



$$\frac{R_2}{S} = R + \left(\frac{1-S}{S}\right)R_2$$



At no load $S \longrightarrow 0$

$\left(\frac{1-S}{S}\right)R_2 \longrightarrow \infty$ (O.C)

$I_{2r} \longrightarrow 0$

As load increases

$S \longrightarrow 1$

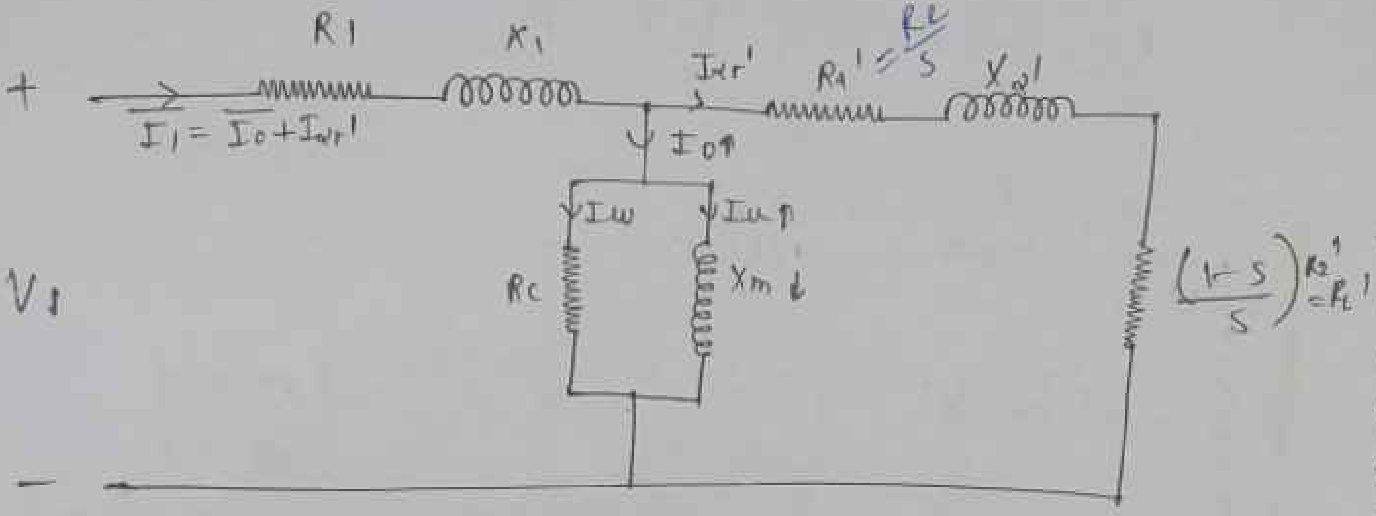
$\left(\frac{1-S}{S}\right)R_2 \longrightarrow 0$ (S.C)

$I_{2r} \longrightarrow \uparrow\uparrow$

So, $\left(\frac{1-S}{S}\right)R_2 = R_L$ it represents electrical equivalent load of Mechanical ~~loading~~ loading.

Equivalent circuit referred to primary:-

$$\boxed{R_2' = \frac{R}{S}}$$



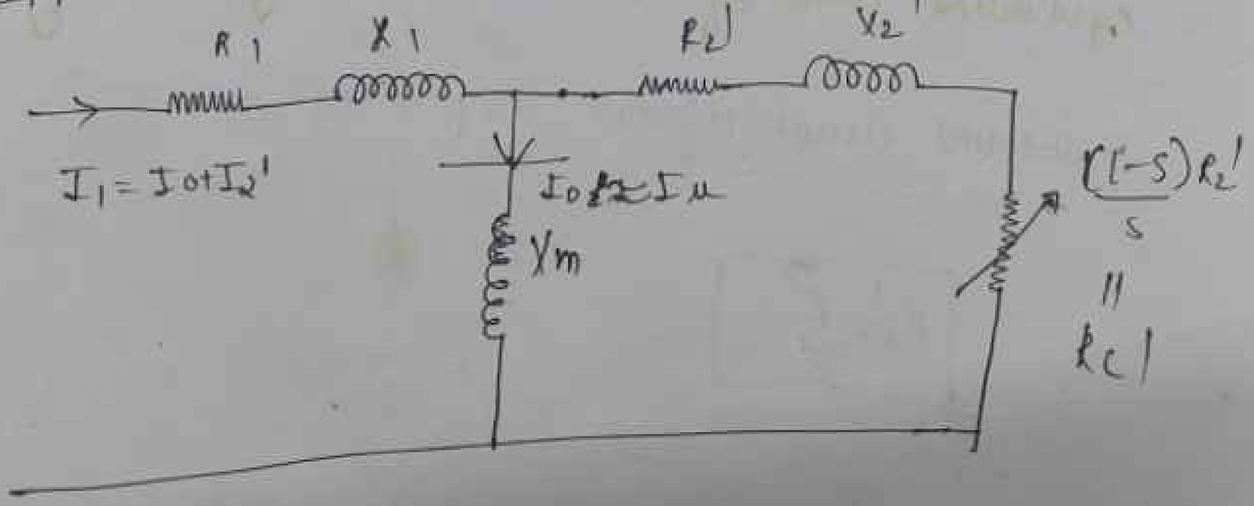
$$P = 3 I_{2r}'^{2} \cdot \left(\frac{1-S}{S}\right) R_2'$$

$$P = \left(\frac{1-S}{S}\right)(3 I_{2r}'^{2} \cdot R_2')$$

$$P = \left(\frac{1-S}{S}\right) RCL$$

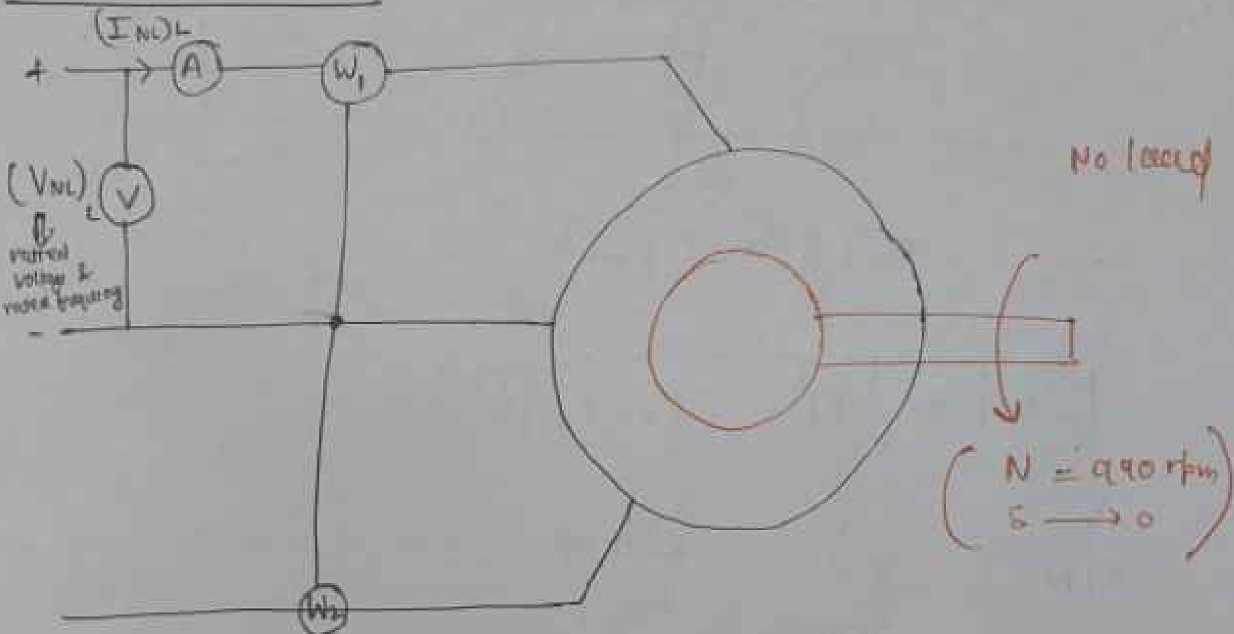
$$\boxed{P = P_m}$$

Approx ~~cotte~~ ckt for objective :-



Testing of Induction motor :-

Noload test :-



$P_i = P_o + Loss$

$P_i = 0 + Loss$

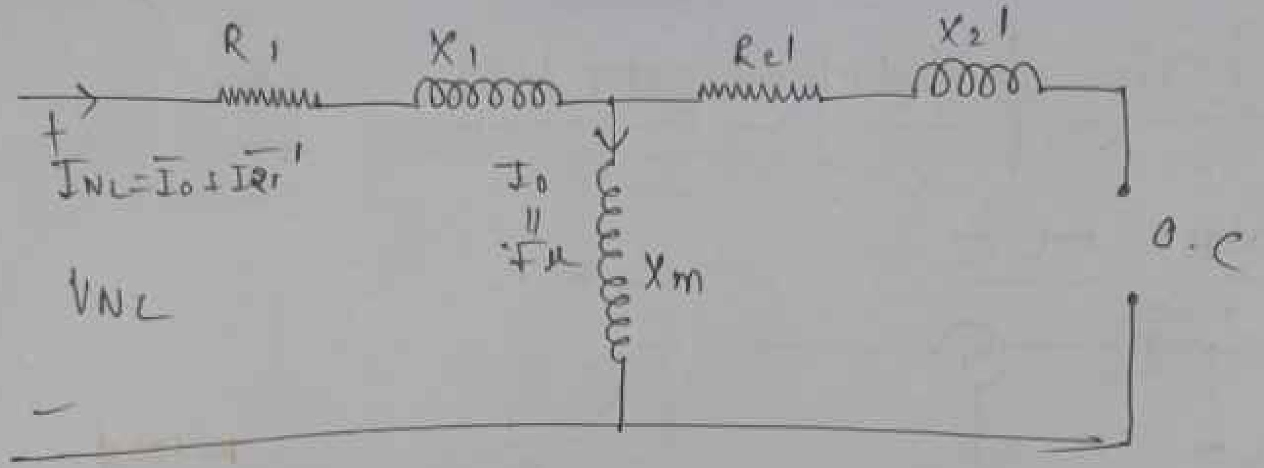
$W_{NL} = Loss$

- Stator Cu Loss $(3I_{NL}^2 R_1) = 3I_0^2 R_1$ (✓)
- Stator Core Loss $\propto (B_m^x \cdot f + B_m^2 f^2) \propto \left(\frac{V^2}{f}, V^2\right)$ (✓)
- R.C.L $(3I_{2r}^2 R_2) \to I_{2r} \to 0 \approx 0$
- Rotor core loss $(f_{2r} \to sf \to 0) \approx 0$
- mech loss (✓)

(W_{NL}) = Stator Cu Loss + Stator Core loss + Mech Loss

$$\boxed{W_{NL} = 3I_{NL}^2 R + W_0}$$

K/W A DC Test ?



$$\overline{Z_{NL}} = R_1 + j(X_1 + X_m)$$

$$|Z_{NL}| = \sqrt{R_1^2 + (X_1 + X_m)^2}$$

$|Z_{NL}| \downarrow$ K/N

$R_1^2 \downarrow$ D.C test

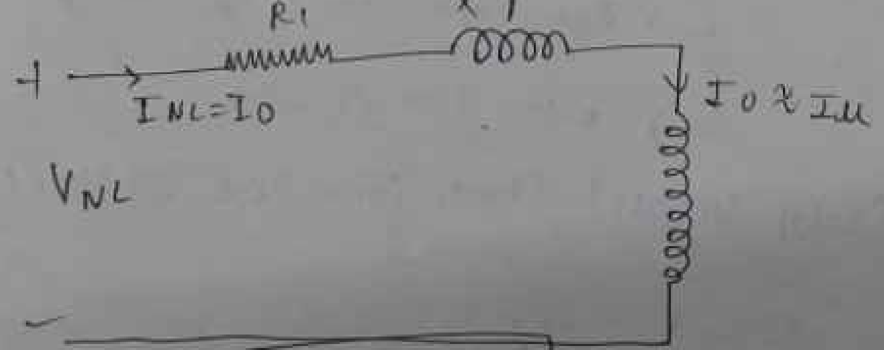
$(X_1+X_m)^2 \downarrow$ Blocked Rotor test

No load :-

$S \longrightarrow 0$

$R_L' \longrightarrow \infty$

$I_{2r}' \longrightarrow 0$

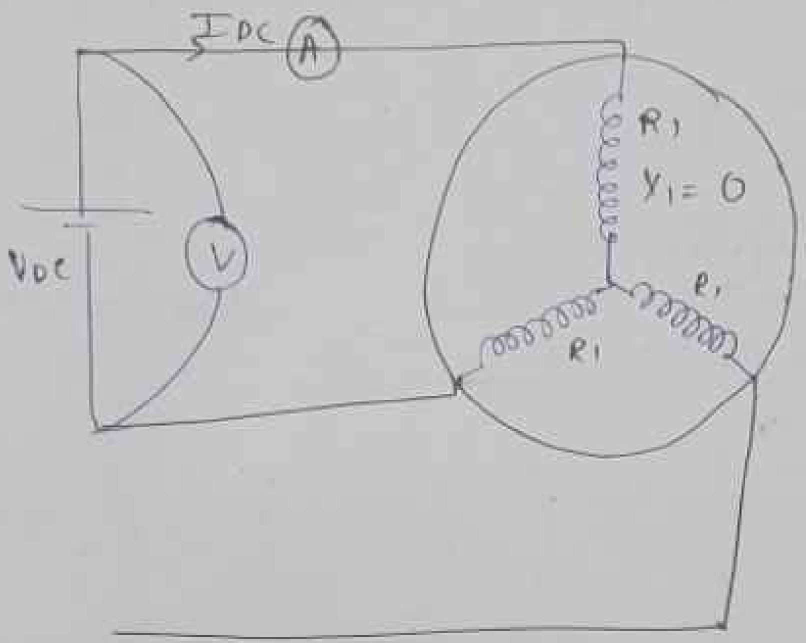


$$\boxed{|Z_{NL}| = \frac{V_{NL}}{I_{NL}}}$$

— Ⓥ

— Ⓐ

D.C Test :-



$$\boxed{\frac{V_{DC}}{I_{DC}} = 2(R_1)_{DC} \; , \; (R_1)_{DC} = \frac{V_{DC}}{2 I_{DC}}}$$

V

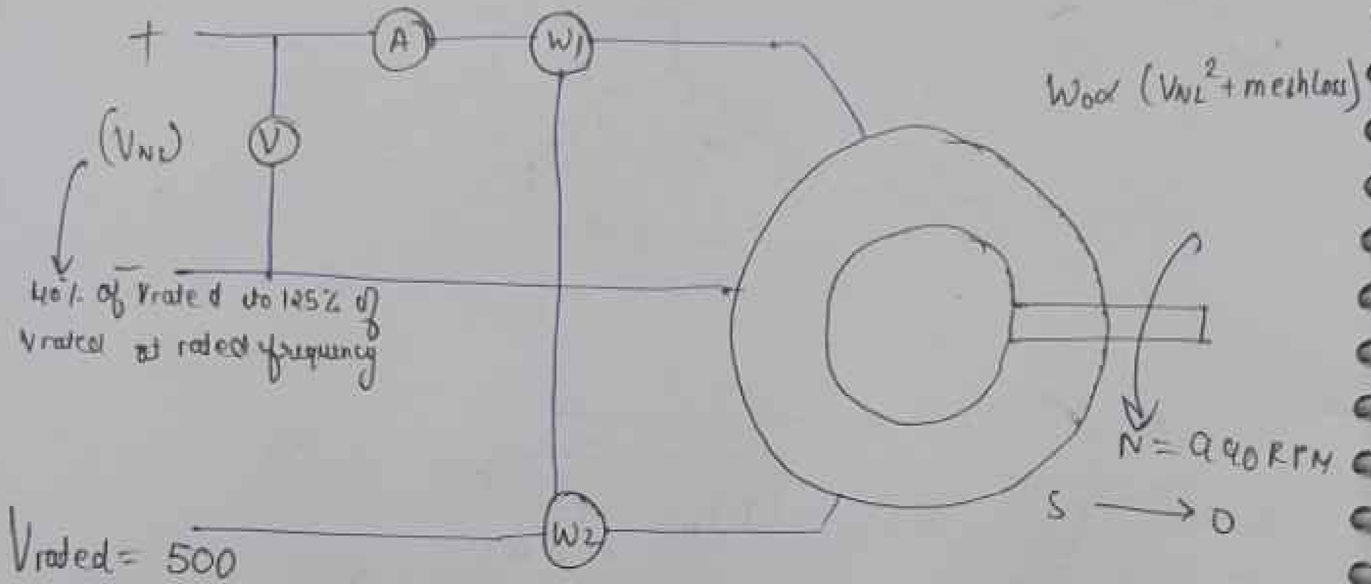
A

$$\boxed{R_1 = R_{1AC} = (1.2 \text{ to } 1.3)\,(R_1)_{DC}}$$

Seperation of stator core loss and mechanical loss :-

For seperation of mechanical loss and stator core loss the noload test should be performed at different - different supply voltages from 40 % of Vrated to 125% of V-rated at rated frequency and rotational losses calculated for different - different value of N-L. Now a graph is plotted b/w.

Wo and V_{NL} and length of O.C gives rotational loss corresponding to zero volt which is mechanical loss.



$(V_{NL})_{L1} = 200V$, W_{01}

$(V_{NL})_{L2} = 250V$, W_{02}

$(V_{NL})_{Ln} = 625V$, $W_{0n} =$

$W_0 \propto$ (stator core loss + mech loss)

$W_0 \propto$ stator core loss

$$W_0 \propto \left[\frac{V_{NL}^2}{f^2} \cdot \cancel{f} + \frac{V_{NL}^2}{f^2} \cdot f^2\right]$$

$$\boxed{W_0 \propto V_{NL}^2 \longrightarrow \text{parabolic}}$$

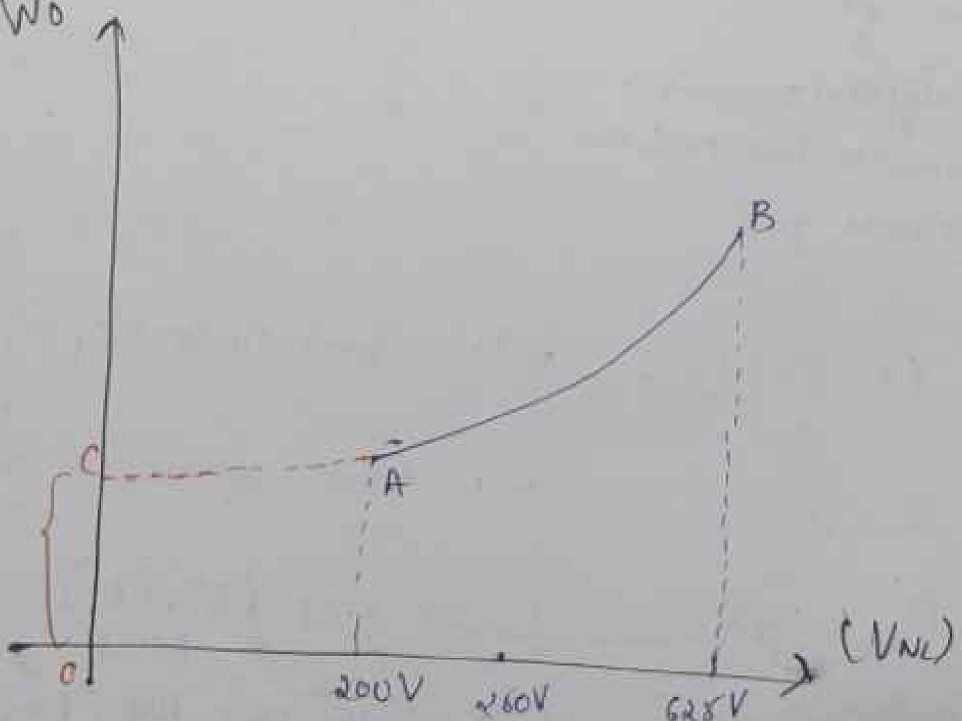
$$W_{NL} = 3I_{NL}^2 R_1 + W_0$$

K/n K/n K/n calculated

$$\boxed{W_0 = \text{stator core loss} + \text{mech loss}}$$

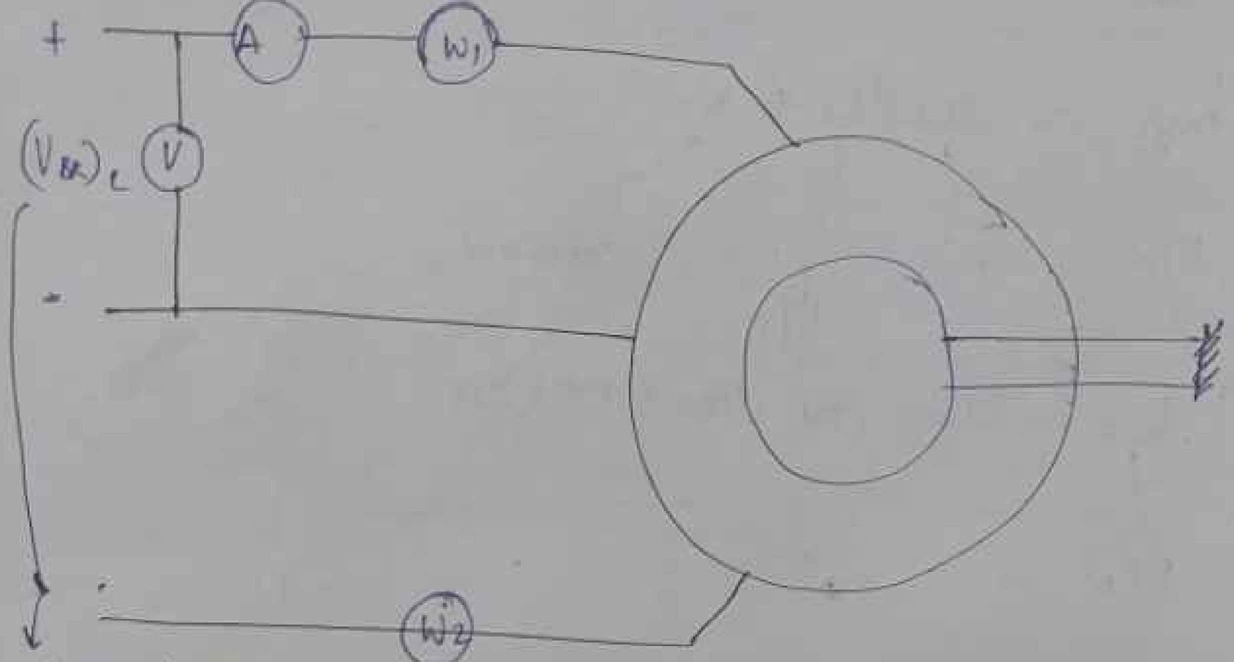
Rotating loss

K/n



$$\boxed{P_{loss}(OC) = \text{mech Loss}}$$

Blocked rotor test :-



12% to 20% of V_{rated} is sufficient to circulate rated current on both stator and rotor @ rated freq

$P_i = P_o + \text{Loss}$

$\Downarrow$ 0

$P_i = \text{Loss}$

$W_{BR} = \text{Loss}$

→ Stator cu loss (✓)

→ Stator core loss $\propto V_{NL}^2 \rightarrow 0$

→ RCL $(3 I_{2\,\text{Rated}}^2 R_2)$

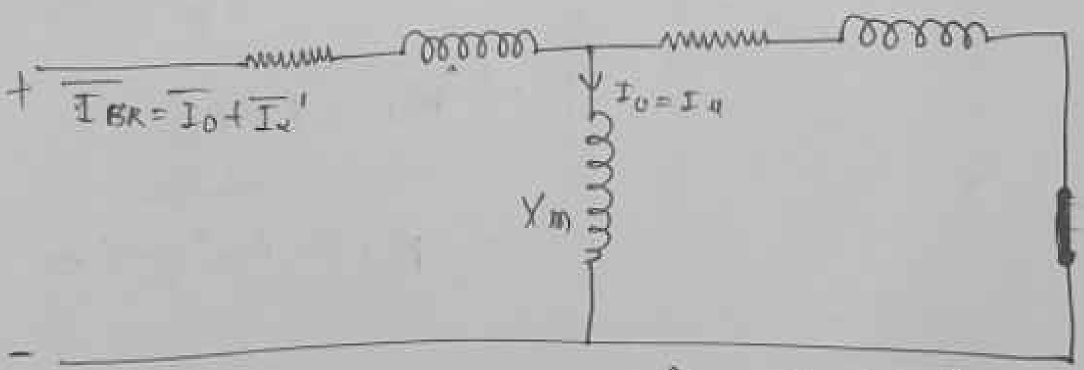
→ Rotor core loss $(B_m^2 f + B_m^2 f^2) \propto B_m^2 \propto V_{NL}^2$?? 0

→ Mech loss ≈ 0

$$\boxed{W_{BR} = \text{Stator cu loss} + \cdot RCL = \text{motor cu loss}}$$

At Blocked Rotor $N = 0$, $S = 1$

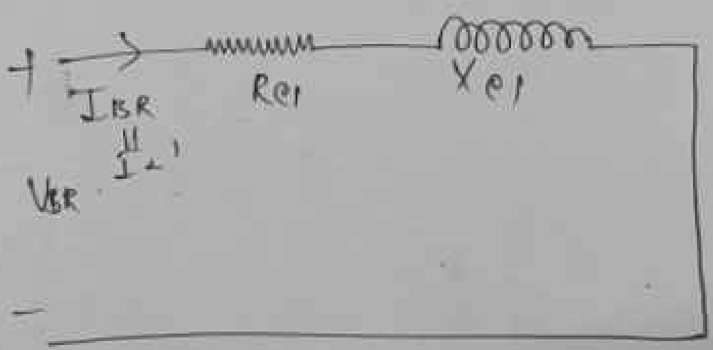
$$\boxed{R_L' = \left(\frac{1-S}{S}\right) R_2' = 0 \ (S.C)}$$



$\downarrow I_u \propto V_N \downarrow$ |||

$R_{e1} = R_1 + R_2'$

$X_{e1} = X_1 + X_2'$



$$\boxed{Z_{BR} = R_{e1} + jX_{e1}}$$

$$\boxed{Z_{BR} = \sqrt{R_{e1}^2 + X_{e1}^2}}$$

K/n K/n cal

$$X_{e1} = X_1 + X_2'$$

$$\boxed{X_1 \approx X_2' \approx \frac{X_{e1}}{2}}$$

$$\boxed{Z_{BR} = \frac{V_{BR}}{I_{BR}}}$$ V A

cal

$$W_{BR} = 3 I_{BR}^2 \cdot R_{e1}$$

k/n k/n cal

$$\boxed{R_{e1} = R_1 + R_2'}$$

$$R_1 \approx R_2' \approx \frac{R_{e1}}{2}$$

3-ϕ, 4 pole, 1440 rpm

$E_2 = 120V$
$R_2 = 2\Omega$
$X_2 = 1\Omega$

$\frac{I_{sc}}{I_{FL}} = ?$

$I_1 = I_0 + I_2'$

$I_1 \propto I_2' \propto I_2$

$$I_1 \propto \frac{SE_2}{\sqrt{R_2^2 + SX_2^2}}$$

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

$$I_{sc} \propto \frac{120}{\sqrt{(2)^2 + (1)^2}}$$

$I_s \propto 118A$ —— (1)

$$I_{FL} \propto \frac{SE_2}{\sqrt{R_2^2 + SX_2^2}}$$

$S = .04$

$$I_{FL} \propto \frac{.04 \times 120}{\sqrt{(2)^2 + (0.04 \times 1)^2}}$$

$I_{FL} \propto 23.V.A$ —— 2

$$\frac{I_{sc}}{I_{FL}} = \frac{118}{23} = 5$$

$$\boxed{I_{sc} = (5 \text{ से } 8) \text{ times of } I_{FL}}$$

Results :- During starting 3-ϕ induction motor draw 5 to 8 times of full load current it means it starts with a high starting current (inrush in current) due to such heavy inrush in current during starting their is a possibility of damage of motor and also its cause large ~~long~~ line voltage dips. So, other appliances subjected to voltage spikes. So, their performance also affect.

⇒ Starter is a device which is used to limit it high starting current this current can be limited by applying reduced voltage on stator or by increasing the rotor resistance

⇒ 3-ϕ induction motor are self starting in nature ~~so~~, due to RMF. So, Starters not to used start the motor it is only used to limit the starting current.

Types of starter:—

1. Direct online starter (DOL) < (5 HP)
2. Stator resistance / reactor starter
3. Star - delta starter
4. Auto - T/F starter
5. Rotor resistance startor.

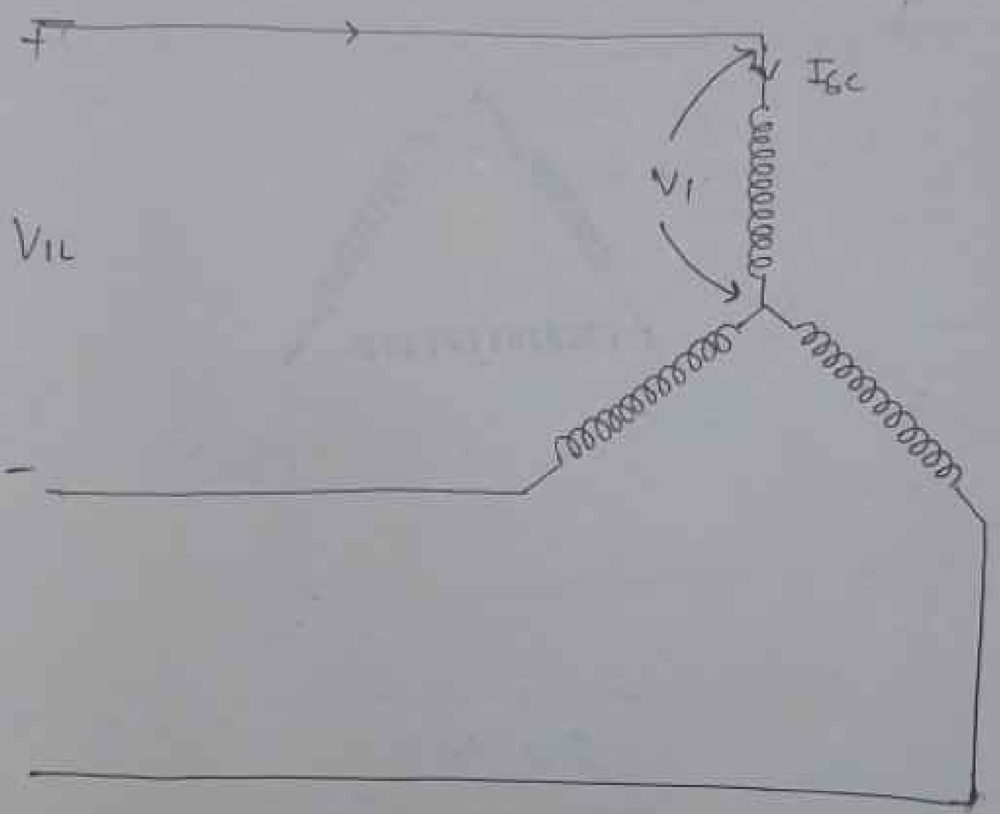
1. **DOL** :- In case of small capacity motors less than 5 HP the starting current is not such high and such motors can with stand with such a high starting current without any starter. So, such type of motor uses a startor which is used to connect the motor directly to the supply. So it is known as DOL starter.

⇒ This starter protect the motor from over loading.

$\boxed{\text{Single phasing} = \text{losing of 1 phase in 3-}\phi}$

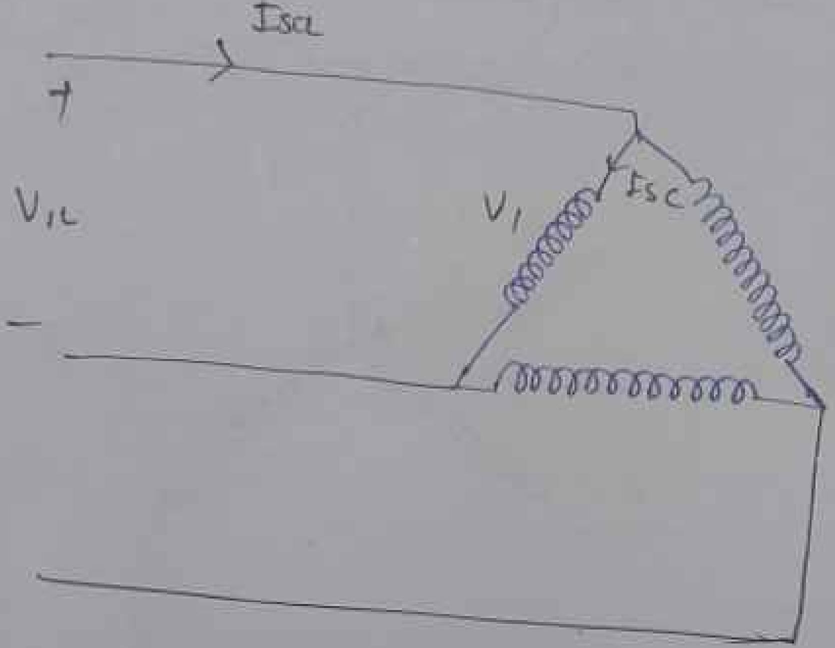
overvoltage , under voltage , single phasing and from overcurrent

$I_{SCL} \rightarrow$ Starting current



$$\boxed{I_{SC} \propto V_1}$$

$$\boxed{T_{st} \propto V_1^2}$$



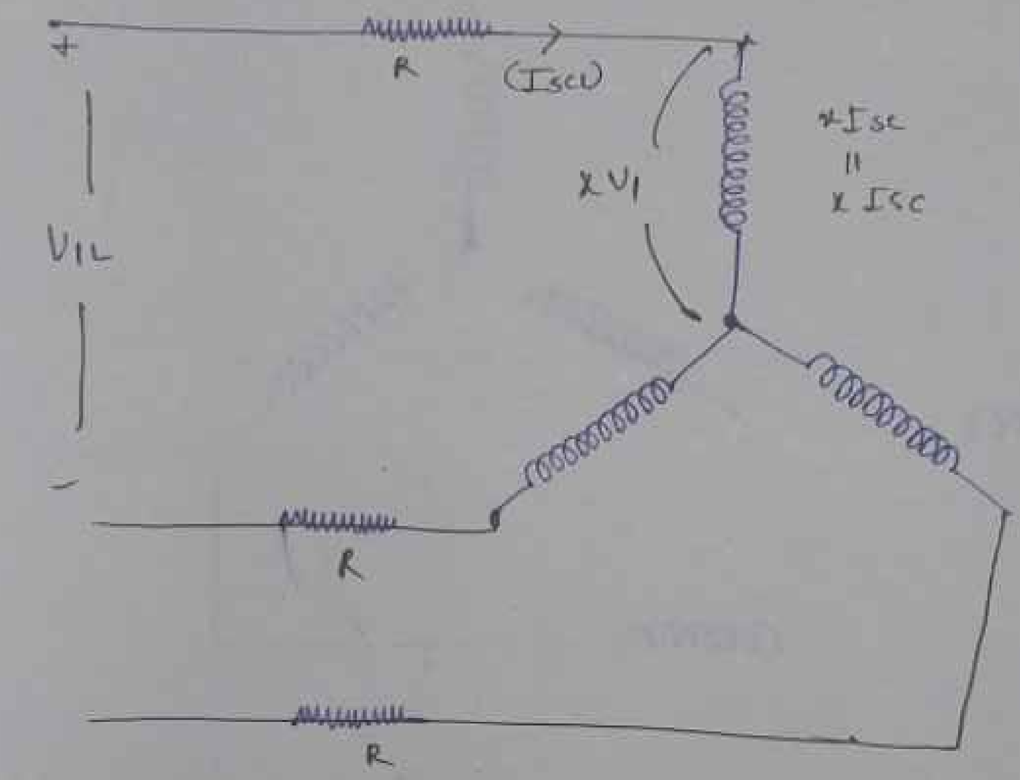
$$\boxed{I_{sc} \propto V_1}$$

$$\boxed{I_{st} \propto V_1^2}$$

Stator resistance and reactar startar :-

In order to apply reduced voltage to the stator 3- resistance or reactar are added in series with stator. So, that large voltage gets dropped and a reduced voltage is applied to the stator. So, starting current reduces by factor x and starting torque reduces by factor x^2

$(I_{scL})' = x(I_{scL})$



$\boxed{I_{st}' \propto xV_1}$

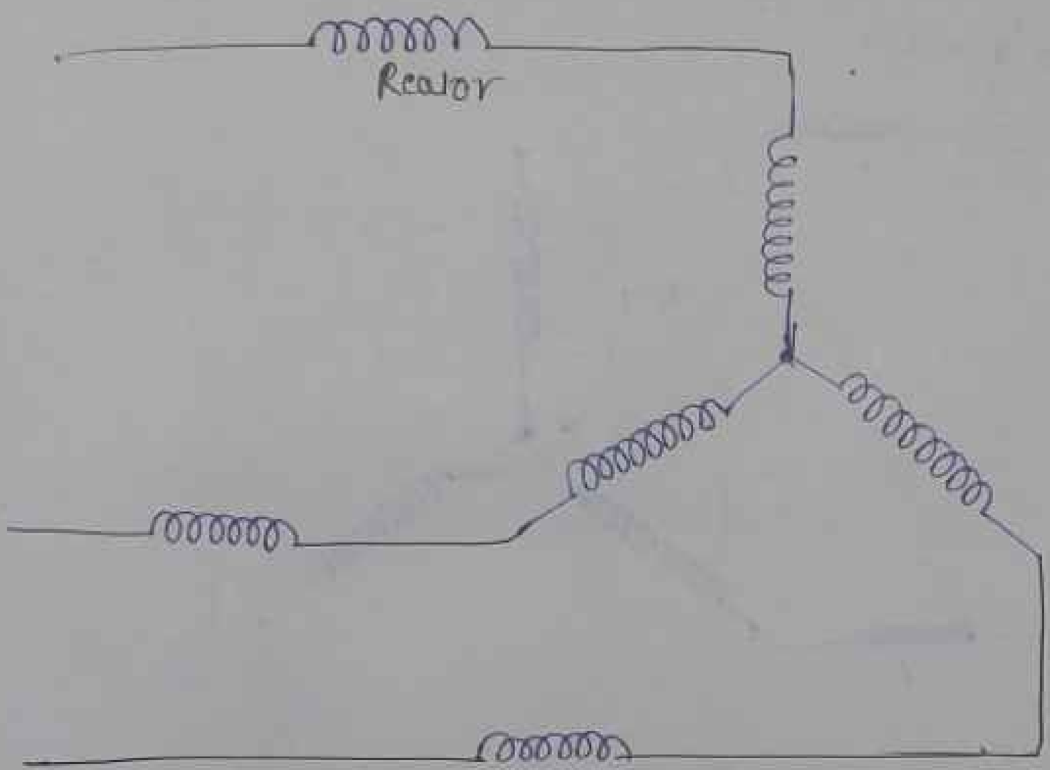
$\boxed{T_{st}' \propto (xV_1)^2}$

$\boxed{T_{st}' = x^2 T_{st}}$

x = reduction factor

$x < 1$, $\eta \downarrow$ सस्ता

Reactor use :-



$$\boxed{\downarrow \cos\theta \propto \frac{R}{\sqrt{R^2+X^2}\uparrow}}$$

$T_2 = x\sqrt{3}$

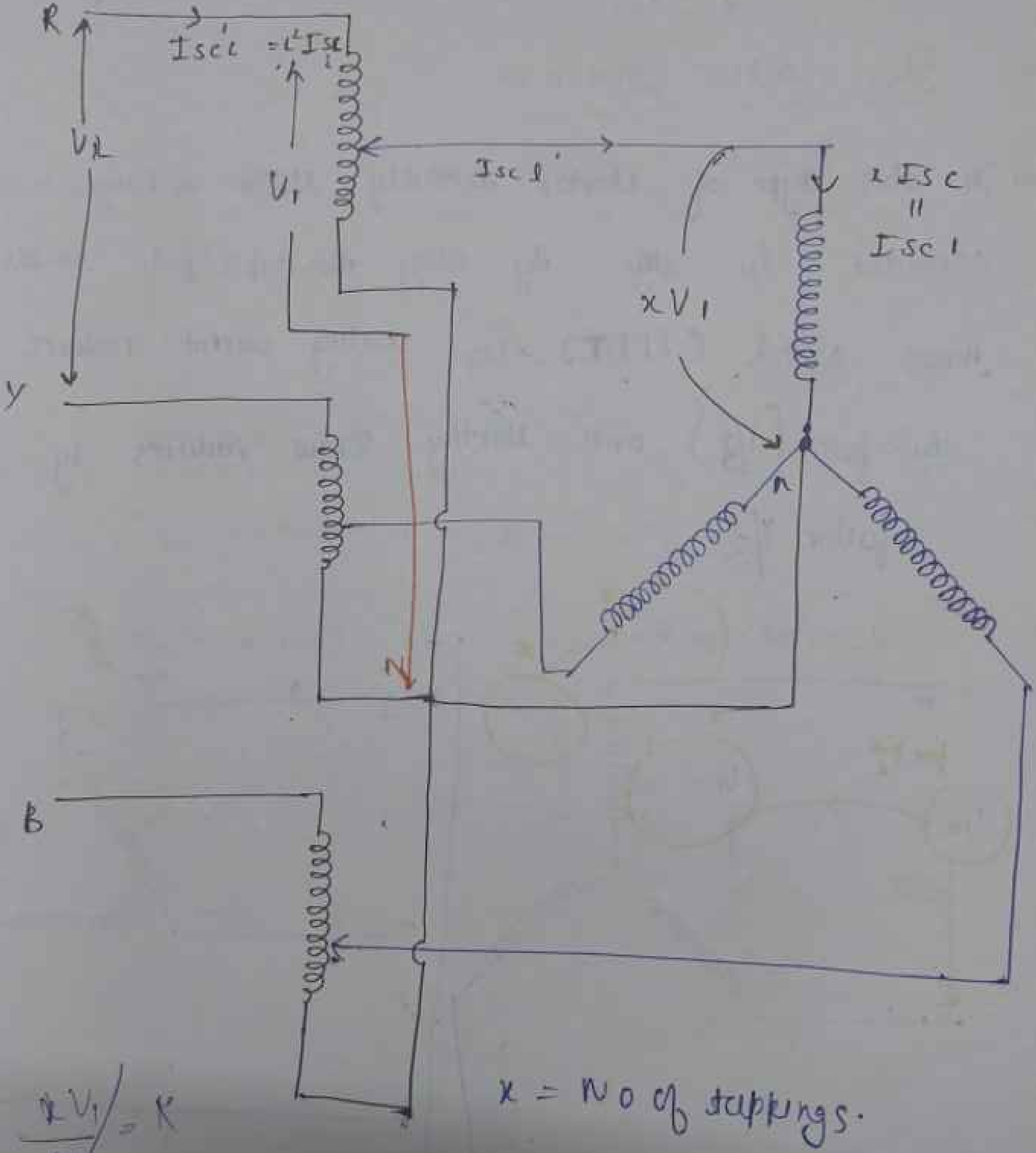
$= x^2 I x^2$

$\boxed{\text{It is used upto 20 H.P}}$

$\boxed{\eta\uparrow,\ Pf\downarrow}$

Auto transformer startor :-

In this starter both starting current and starting torque reduces by factor x^2 and this starter used ~~upto~~ for above 20 H.P.



$\frac{xV_1}{V_1} = K$

$K = x$

x = No of tappings.

$(I_{scL}) = x^2 I_{scL}'$

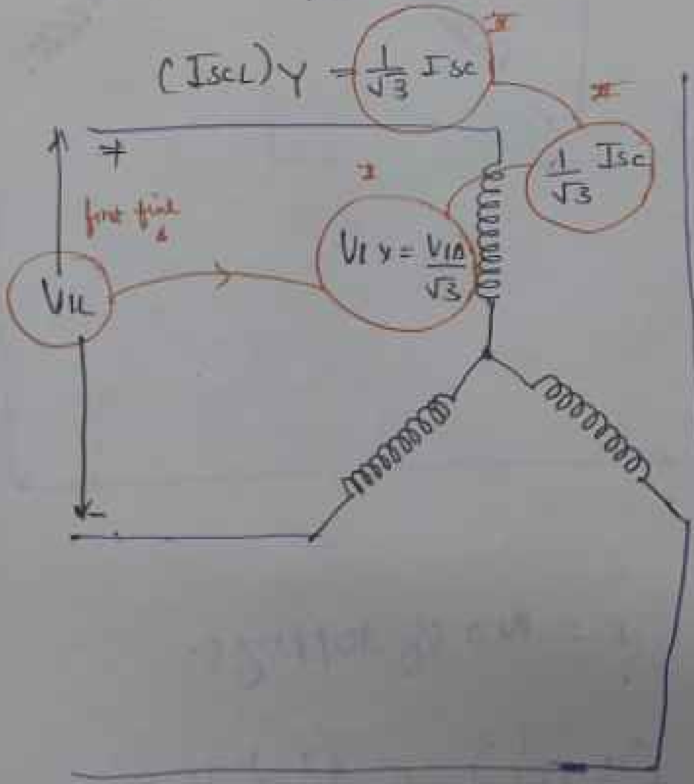
$T_{st}' \propto (xV_1)^2$

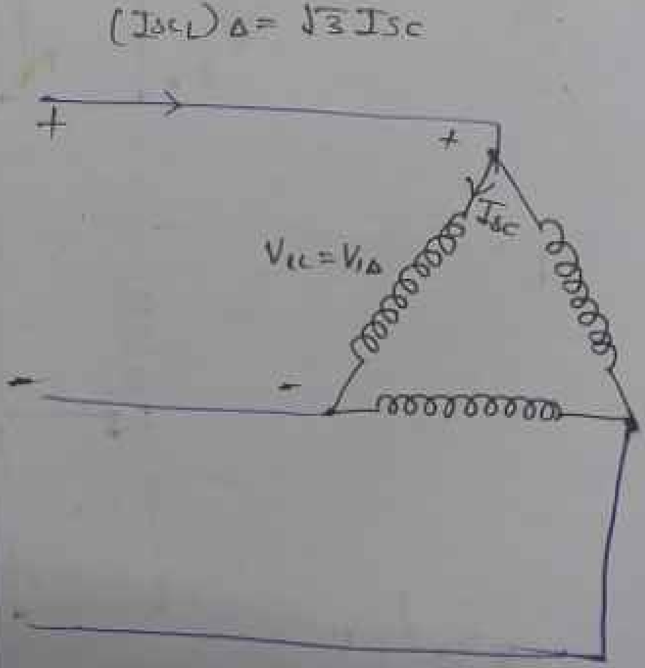
$T_{st}' = x^2 T_{st}$

$\eta \uparrow$, $Pf = \text{const}$, costly.

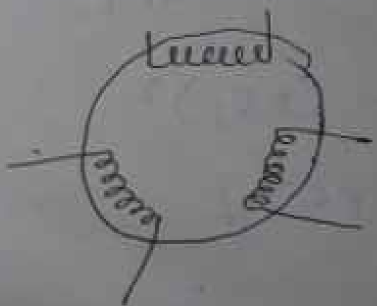
Star - delta starter :-

⇒ In this type of starter initially stator windings are connected in star by using the triple pole double throw switch (TPDT). So, starting current reduces by factor (1/3) and starting torque reduces by factor 1/3.





$$\boxed{(I_{scL})_Y = \frac{1}{3}(I_{scL})_\Delta}$$



$$\boxed{(T_{st})_Y = \frac{1}{3}(T_{st})_\Delta}$$

$$\boxed{\frac{I_{scLY}}{I_{scL\Delta}} = \frac{\frac{1}{\sqrt{3}}}{\sqrt{3}}\frac{I_{sc}}{I_{sc}} = \frac{1}{3}}$$

· ~~the~~ Line-voltage → phase voltage → phase current → line current

~~first find~~ finding sequence

Rotor resistance startor :

This is a fundamental way to ~~stro~~ start a slip ring induction motor.

$R_o, R_2 \uparrow$

(1) $\downarrow I_{sc} \propto \frac{1}{\sqrt{R_2^2 + X_2^2}}$

(2) $\uparrow T_{st} \propto R_2 \uparrow$

(3) $\uparrow \cos\theta_2 = \frac{R_2 \uparrow}{\sqrt{R_2^2 + X_2^2}}$

Note :

$$T_{er} = \frac{1}{S\omega_s} S I_{2r}^2 R_2$$

$$\boxed{T_{er} \propto \frac{I_{2r}^2}{S} \propto \frac{I_1^2}{S}}$$ stator per phase current

$I_1 \propto I_2'r \propto I_2r$

$$\boxed{T_{st}' \propto \frac{(x I_S)^2}{1}} \quad \text{--- (1)}$$

$$\boxed{T_{FL} \propto \frac{I_{FL}^2}{S_{FL}}} \quad \text{--- (2)}$$

$$\boxed{\frac{T_{st}'}{T_{FL}} = x^2 \left(\frac{I_{SC}}{I_{FL}}\right)^2 \cdot S_{FL}}$$

T_{st}' = starting torque with any starter

T_{FL} = Full load torque.

I_{SC} = starting current with DOL / w/o any starter. or at rated voltage

I_{FL} = Full load current

S_{FL} = Full load slip.

$$\boxed{(T_{st}')_{PU} = x^2 (I_{SC})^2_{PU} \, S_{FL}}$$

Page 229 — 29

$S_{FL} = 4\%$

$T_{st}' = T_{FL}$

$$\boxed{\frac{T_{st}'}{T_{FL}} = x^2 \left(\frac{I_{sc}}{I_{FL}}\right)^2 \times S_{FL}}$$

$$\frac{1}{1} = (1)\left(\frac{I_{sc}}{I_{FL}}\right)^2 \times \frac{4}{100}$$

$$25\, I_{FL}^2 = I_{sc}^2$$

$$\boxed{I_{sc} = 5 I_{FL}}$$

Page 231

Ex :-

value :-

$V_{1L} = 100V$

$\left[\begin{array}{l} V_{1L}' = 40V \\ I_{scL}' = 2.4\, I_{FLL} \end{array}\right]$

$S_{FL} = .05$

$(T_{st}')_{DOL} = ?$

$(T_{st}') = (1)^2(1.8)$
$= 1.8$ pu

$(T_{st}') = x^2 (6)^2 \times 0.05$

$\boxed{T_{st}' = 1.8 x^2}$

$\because$ 40V $\rightarrow 2.4 I_{FL}$

$\therefore 1 \rightarrow \frac{2.4}{40}$

$\therefore$ 100V $\rightarrow \frac{2.4 \times 100}{40} = 6 I_{FL}$

$\therefore I_{st} = 6 I_{FL}$

$(T_{st})_{auto}$

$x = 0.5$ or $1/2$

$\therefore \frac{1}{4} \times 1.8 = .45$

$40V \longrightarrow 2.4\ I_{FL}$

$100 \longrightarrow \frac{2.4}{40} \times 100\ I_{FL}$

$I_{sc} \longrightarrow 6 I_{FL}$

$$\frac{\cancel{(T_{st})_{\lambda\Delta}} \propto \left(\frac{1}{3}\right)}{\cancel{(T_{st})_{a}} \propto (x)^2}$$

$$x^2 = \frac{1}{3}$$

$$x = \frac{1}{\sqrt{3}}$$

$$= \frac{1}{1.732} \times 100 = 57.7\ \%$$

Speed control of induction motor :-

Speed can be controlled from rotor side as well as from stator side

At, $\boxed{Load = constant}$

$$T_{er} = \frac{3 S E_2^2}{\omega_s R_2}$$

$$\boxed{\omega_s = \frac{4\pi f}{P}}$$

4-Method

From stator side :-

① By variation is supply voltage :-

V_1 — $V_1 \uparrow$, Not permitted. (x)

$V_1 \downarrow$, (Auto Transforme) ✓

$$T_{cr} = \frac{3 S E_2^2}{\omega_s \cdot R_2}$$

constant

constant

constant

$S E_2^2 =$ constant.

$$\boxed{S V_1^2 = \text{constant}}$$

$$\boxed{\uparrow S \propto \frac{1}{V_1^2} \downarrow}$$

N↓, Below rudders

$S_m = \frac{R}{X_2} =$ constant.

$$\boxed{T_{st} = \frac{3 E_2^2 \cdot R_2}{\omega_s X_2^2}}$$

$\downarrow T_{st} \propto E_2^2 \propto V_1^2 \downarrow$

$$\boxed{T_{max} = \frac{3 E_2^2}{2 \omega_s X_2}}$$

$$\boxed{\downarrow T_{max} \propto E_2^2 \propto V_1^2 \downarrow}$$

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

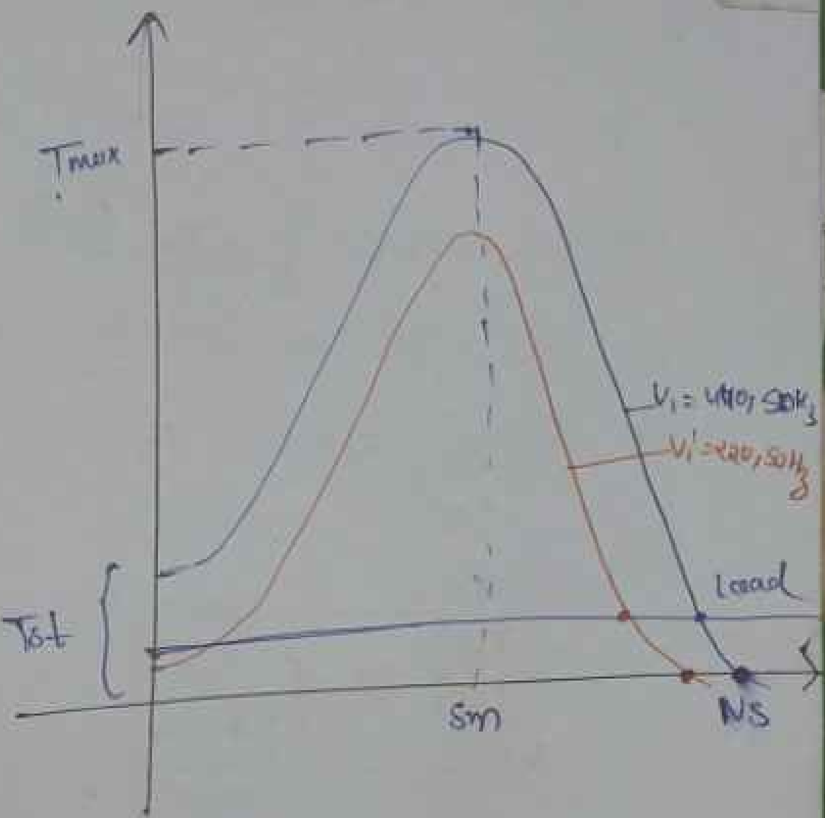
$$I_{2r} = \frac{SE_2}{R_2}$$

$I_{2r} \propto SE_2$

$I_{2r} \propto SV_1$

$I_{2r} \propto \frac{1}{V_1^2}, V\uparrow$

$$\boxed{\uparrow I_{2r} \propto \frac{1}{V_1\downarrow}}$$



Result :-

motor draw more current from the supply to maintain the torque at reduced voltage. So, due to temperature rise it cannot be used for long duration and wide range.

A - 3-ϕ 440 V, 1000 RPM = Ns, slip ring - IM is operating with 2 % slip S = .02 and taking stator current of 50 A - Speed of motor is reduce to 500 rpm by variation in supply voltage calculate. + motor stator current.

$$S = \frac{1000 - 500}{1000} = 0.5$$

$$\boxed{S = .5}$$

$$S \propto \frac{1}{V_1^2}$$

$$\frac{S_2}{S_1} = \frac{V_1^2}{V_2^2}$$

$$V_2^2 = \frac{S_1}{S_2} V_1^2$$

$$= (440)^2 \times \frac{.02}{.50}$$

$$V_2 = \frac{440}{5}$$

$$V_2 = 88 V$$

$$I_{2r} \propto \frac{1}{V_1} \qquad I$$

Q2

$I_1 \propto I_{1L} \propto I_{2r} \propto I_{2r}$'

$$I_{1L} \propto \frac{1}{V_{1L}}$$

$$\frac{I_{1L}}{I_{2L}} = \frac{V_{2L}}{V_{1L}}$$

$$I_{2L} = \frac{V_{1L}}{V_{2L}} \times I_{1L}$$

$$= \frac{\cancel{440}^{10} \times \cancel{500}^{125}}{\cancel{88}_{\cancel{2}}}$$

$$\boxed{I_{2L} = 250A}$$

② By variation ~~is~~ in supply frequency (V/f) control method :-

$f \nearrow$ →

- → $f\uparrow$, $\downarrow\phi \propto \frac{V}{f\uparrow}$ — constant ✗
- → $f\downarrow$, $\phi \propto \frac{V\downarrow}{f\downarrow}$, $\frac{V}{f}$ = constant

Constant

ϕ को बढ़ने नहीं दे सकते bcoz saturation हो जाएगा।

$$\boxed{T_{er} = \frac{3 S E_2^2}{W_s \cdot R_2}}$$

Constant   const

$$I_{2r} = \frac{SE_2}{R_2}$$

$$\boxed{I_{2r} \propto SV_1 = \text{constant}}$$

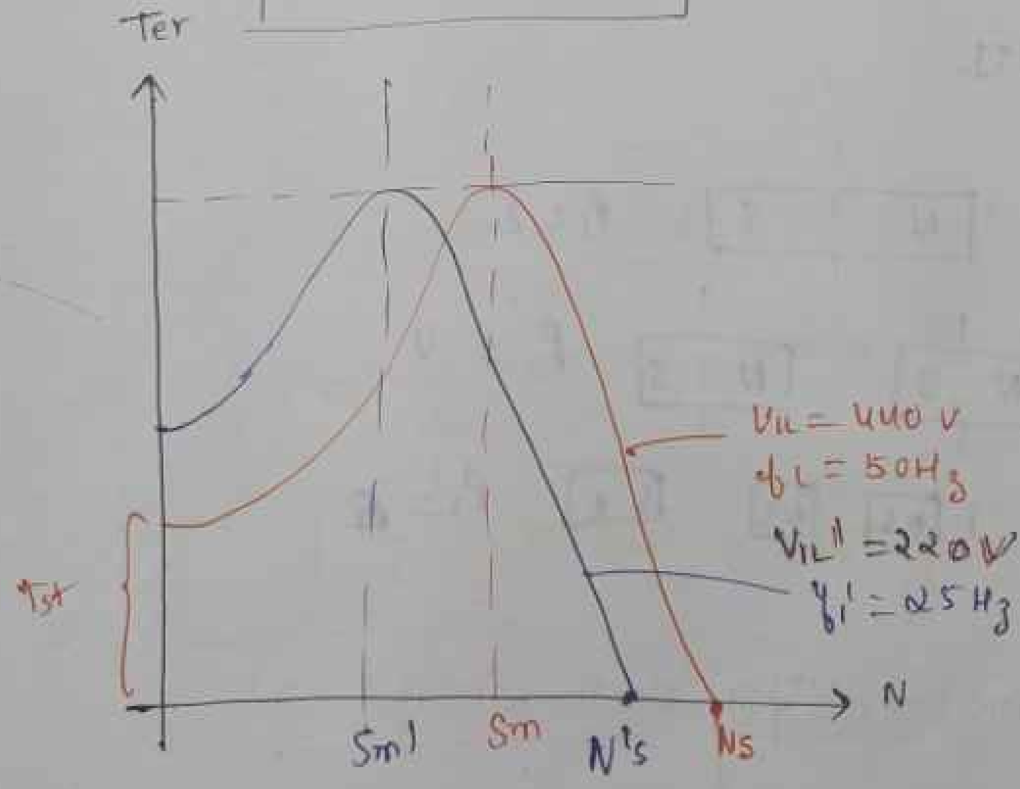
& Slip speed $= (N_s - N)$

$= SN_s$

$\propto s.f$

$\propto \frac{f}{V_1}$

$$\boxed{SN_s = \text{constant}}$$



Result :-

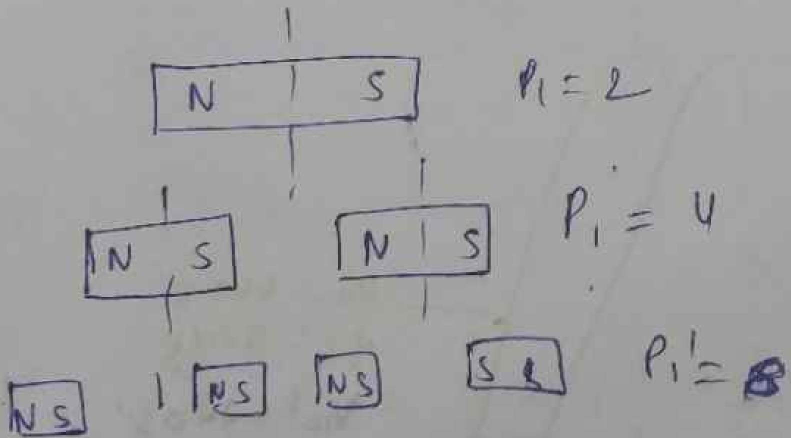
① Speed obtained are below rated, for variation in voltage and frequency it requires power electronic converter which increases its cost.

(3) Pole changing speed control :-

This method only used for SCIL.

(A) Consequent pole changing :-

In this method connection of stator windings changed with the help of simple switching. So that number of stator poles are changed in the ratio 2:1



B By using multiple stator winding :-

Stator contains two or more windings which is designed for different / different no of poles and at a time only only one winding is connected

Disadvantages :-

① Speed change in steps and smooth speed control is not possible, due to multiple stator windings size and cost $\uparrow$ increases.

④ By ~~com~~ connecting a resistance in stator circuit.

Same as method 1

From rotor side :-

① By adding external resistance in to rotor circuit :-

Only used for slipring induction motor.

If, $R_2 \uparrow$

$$T_{er} = \frac{3 S E_2^2}{\omega_s R_2}$$

constant

Constant

$$\boxed{\frac{S}{R_2} = \text{constant}}$$

$\uparrow S \propto R_2 \uparrow$

$N \downarrow$ Below rated

(1) $\boxed{\uparrow T_{st} = \frac{3E_2^2 R_2 \uparrow}{\omega_s X_2^2}}$

(2) $\boxed{\uparrow S_m = \frac{R_2 \uparrow}{X_2}}$

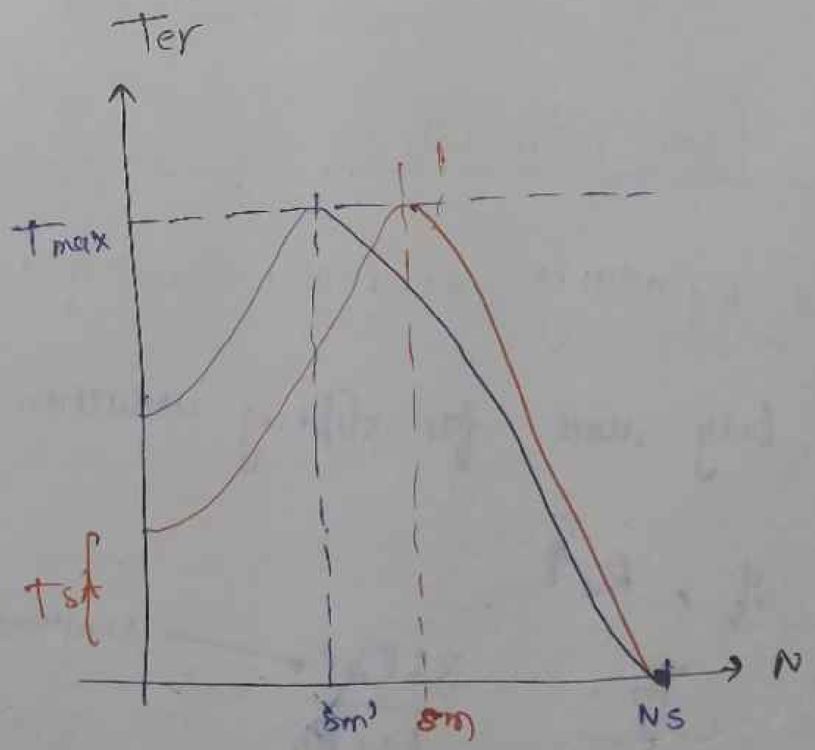
(3) $\boxed{T_{max} = \frac{3E_2^2}{2\omega_s X_2} = \text{constant}}$

(4) $\boxed{N_s = \frac{120f}{P} = \text{constant}}$

$$I_{2r} = \frac{SE_2}{R_2}$$

$$I_{2r} \propto \frac{S}{R_2}$$

$$\approx \text{constant}$$



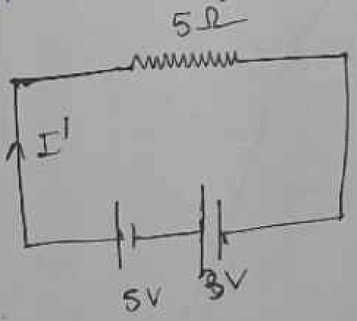
Since current in the rotor remains but rotor resistance increases so, Power loss also increases. So it is less efficient method.

(2) Slip power recovery method or by injecting emf in the rotor circuit at slip frequency :-

In this method a voltage is injected in the rotor circuit at slip frequency. It is only used for slipring ~~in~~ I-M.

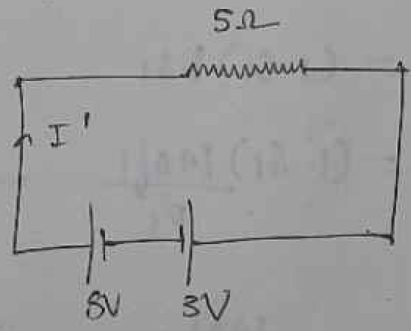
→ In this method emf is injected in the rotor circuit at subtractive polarity.. So, that effective rotor resistance increases. So, speed decreases.

same frequency of injected emf is essential condition



$I' = \frac{8}{5}$

$\boxed{I' = 1.6A \uparrow}$



$\boxed{I' = \frac{2}{5} = .4A \downarrow}$

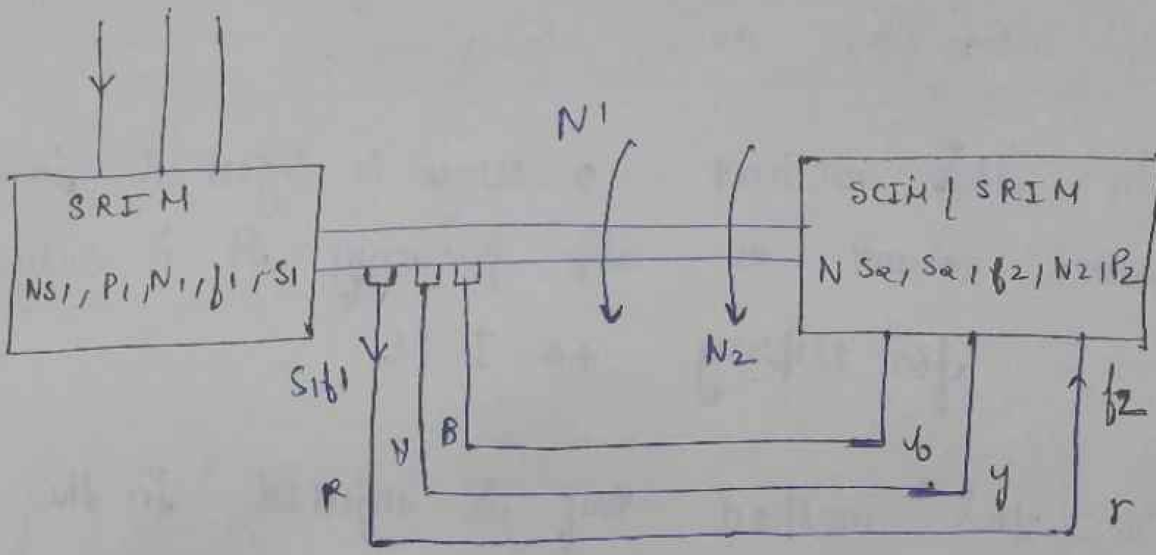
Subtractive polarity

$(R_2)_{eff} \uparrow$,

$S \uparrow$, $N \downarrow$

Below Rated.

Casked control :-



$$N_{s1} = \frac{120 f_1}{P_1}$$

$$N_1 = (1 - S_1) N_{s1}$$

$$N_1 = (1 - S_1) \frac{120 f_1}{P_1} \quad \text{—— (1)}$$

$$N_{s2} = \frac{120 f_2}{P_2}$$

$$f_2 = S_1 f_1$$

$$N_{s2} = \frac{120 f_1 S_1}{P_2}$$

$$N_2 = (1 - S_2) N_{s2}$$

$$\boxed{N_2 = (1 - S_2) \frac{120 f_1 S_1}{P_2}} \quad \text{—— (2)}$$

① = ②

$$(1-S)\frac{120 f_1}{P_1} = (1-S_2)\frac{120\, S_1 f_1}{P_2}$$

$$\frac{1}{P_1} - \frac{S_1}{P_1} = \left(\frac{1}{P_2} - \frac{S_2}{P_2}\right) S_1$$

$$\frac{1}{P_1} - \frac{S_1}{P_1} = \frac{S_1}{P_2} - \frac{S_1 S_2}{P_2}$$

$$S_1 S_2 \longrightarrow 0$$

$$\frac{1}{P_1} - \frac{S_1}{P_1} = \frac{S_1}{P_2}$$

$$\frac{1}{P_1} = S_1\left(\frac{1}{P_1} + \frac{1}{P_2}\right)$$

$$\boxed{S_1 = \frac{P_2}{P_1 + P_2}}$$

$$N_1 = N_2 = \left(1 - \frac{P_2}{P_1 + P_2}\right)\frac{120 f_1}{P_1}$$

$$N_1 = N_2 = \left(\frac{P_1}{P_1 + P_2}\right)\frac{120 f_1}{P_1}$$

$$\boxed{N_1 = N_2 = \frac{120 f_1}{P_1 + P_2}}$$ — cumulative.

for D.C. $P_1 \neq P_2$ — $$\boxed{N_1' = N_2' = \frac{120 f_1}{P_1 - P_2}}$$ — differentially cascading, (Two φ terminal interchanced)

~~Ar~~ Result :-

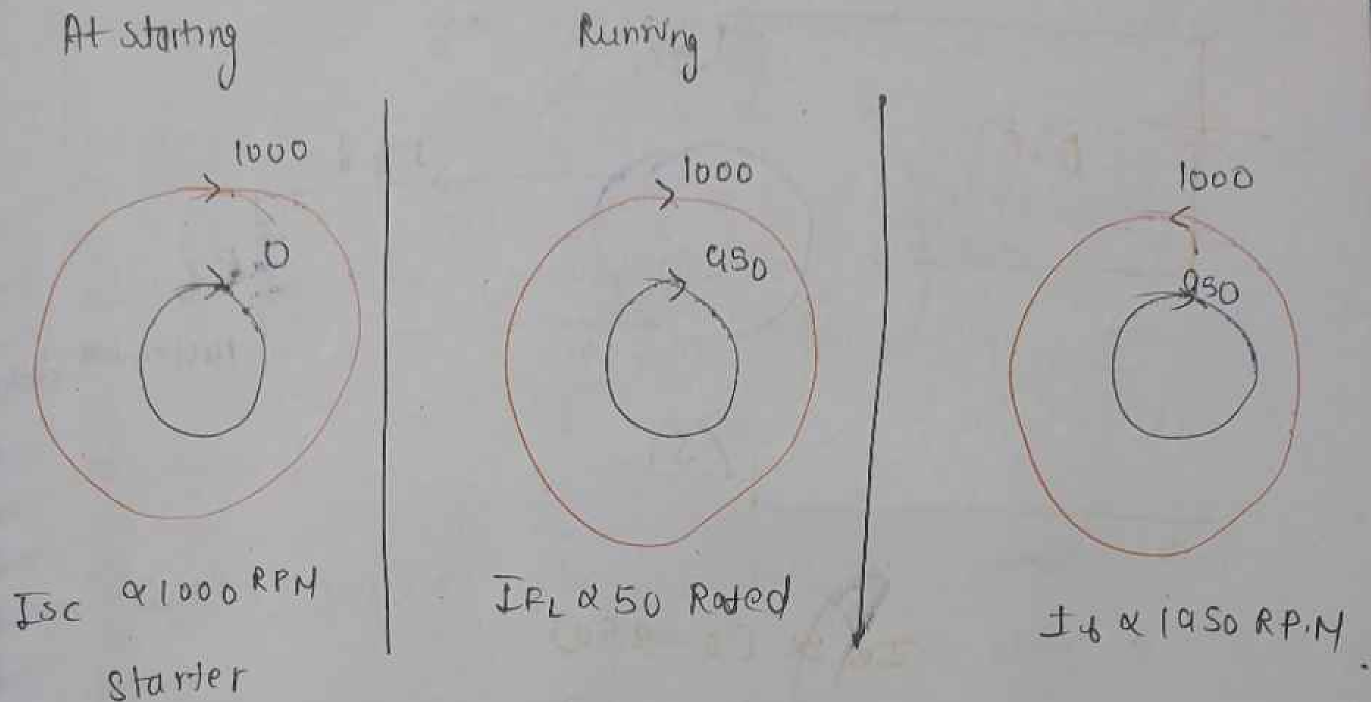
1. For ~~so~~ cascading 1 motor must be S.R.I.M.
2. And from this method 4 speed can be obtained by two motors.

~~Bea~~ Breaking :-

(1) Plugging :-

The direction of R.M.F can be reversed by interchanging ~~ea~~ any two supply terminals. So, that a high breaking current will flow which produces a negative torque and motor speed decrease quickly and before its zero speed it is disconnected from the supply. otherwise it will start rotation in opposite direction. In plugging highest breaking torque produced but it is highly inefficient method.

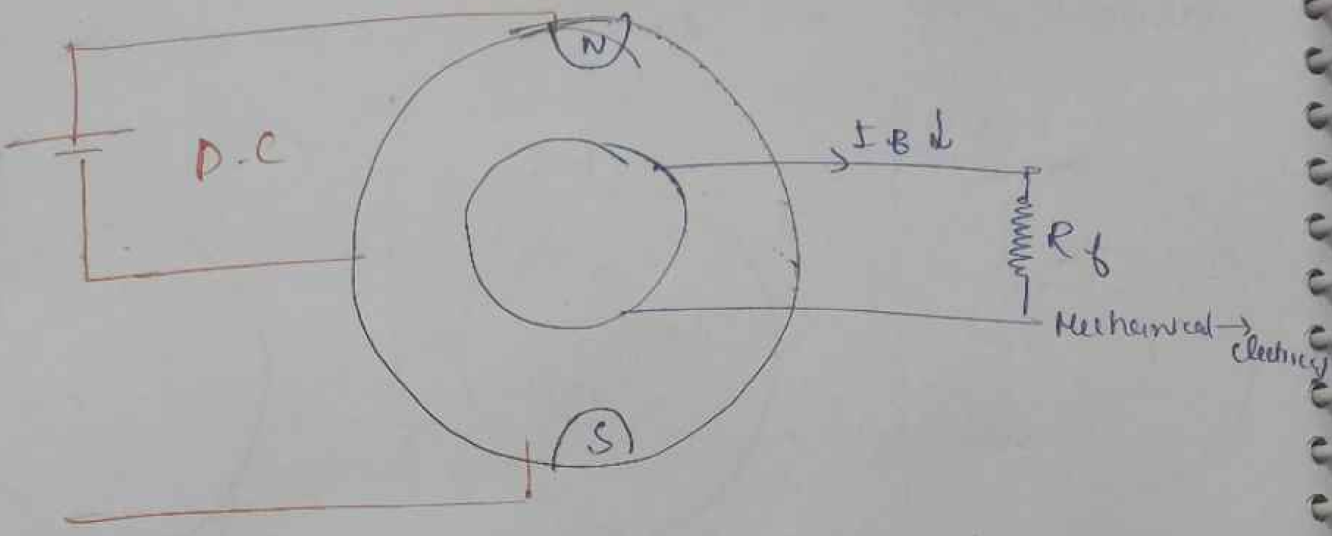
→ Plugging should not be frequently done bcz all the stored kinetic energy dissipates into heat. so, rotor conductor may melt.



② Rehostatic breaking :-
/D.C dynamic breaking

In this breaking motor is disconnected from the supply and a ~~g~~ D.C supply is given which produces a stationary flux. So, so rotor speed decreases.

=) To limit this high breaking current a braking resistance is ~~con~~ connected in series with rotor



$I_B \propto (0-90^\circ)$

$I_B \propto (-90^\circ)$

↓

generator

Regenerative breaking :-

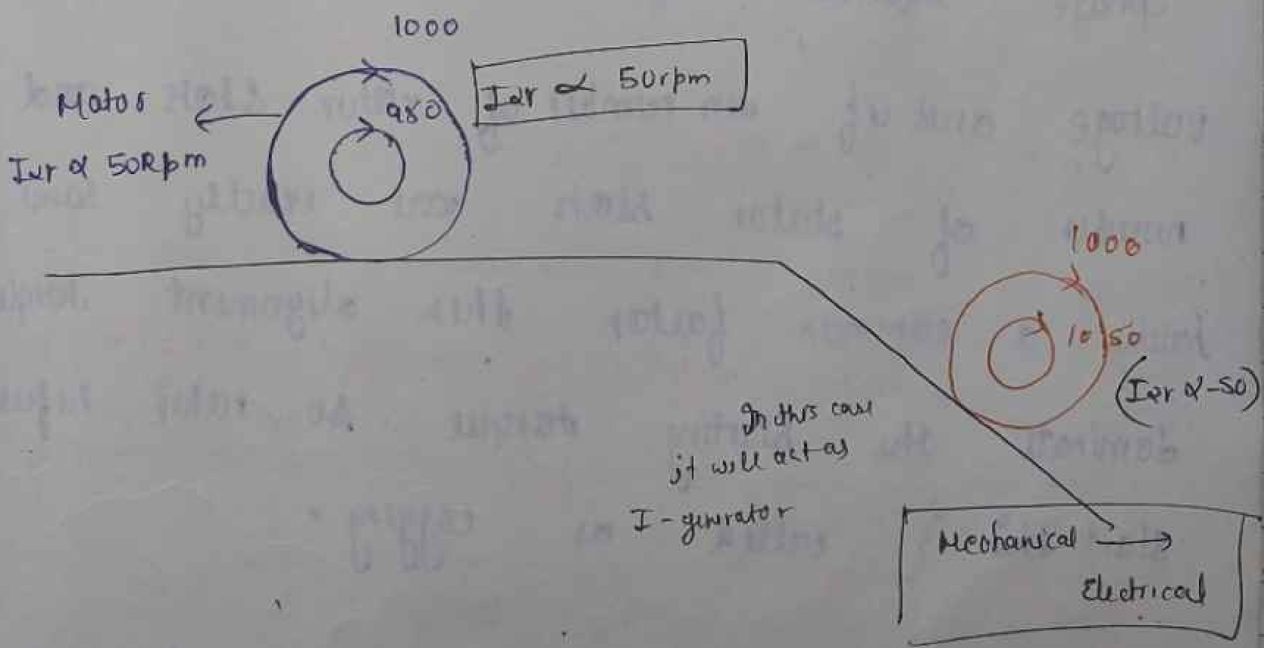
(1) Regenerative breaking is highly efficient.

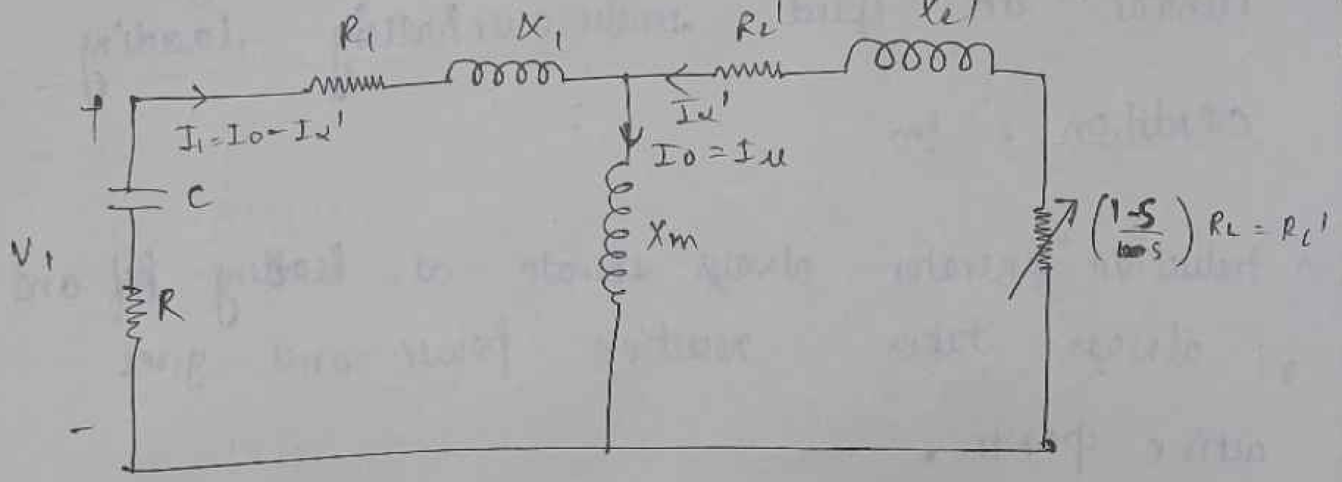
(2) If the motor speed becomes more than synchronous speed it converts mechanical energy into electrical energy which is given back to supply and it is ~~called~~ goes into generating mode and without any opposition no energy conversion. So, a negative torque is experienced by the ~~motor~~ rotor and motor speed control automatically.

⇒ Motor does not stop in this breaking but control its speed under over halling loading condition.

⇒ Induction generator always operate at ~~leading~~ lagging p.f and it always takes reactive power and gives active power.

⇒ Induction generator always used in wind power plant.

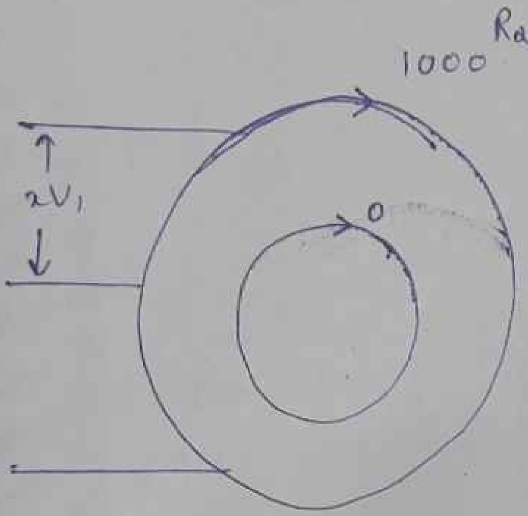




Equivalent ckt of Induction generator

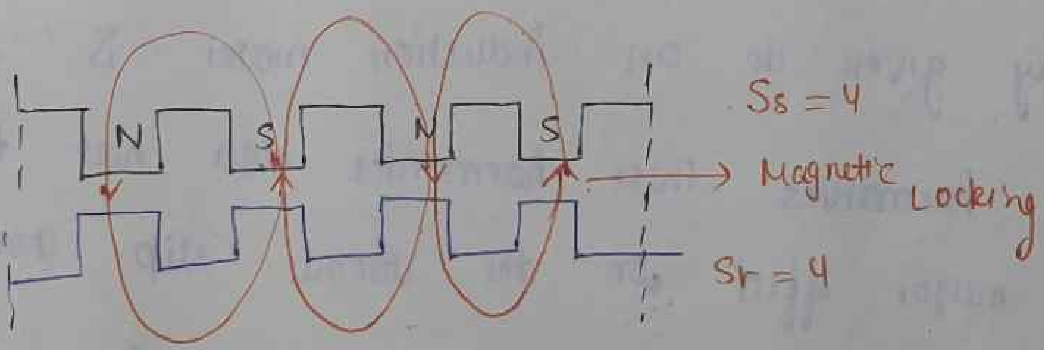
Cogging :- It specially comes when a three phase squirrel caged I-M started with reduced voltage and if ~~the~~ number of rotor slots and number of stator slots are exactly same and having a common factor then alignment torque dominate the starting torque. So, rotor refuse to start this is called as cogging.

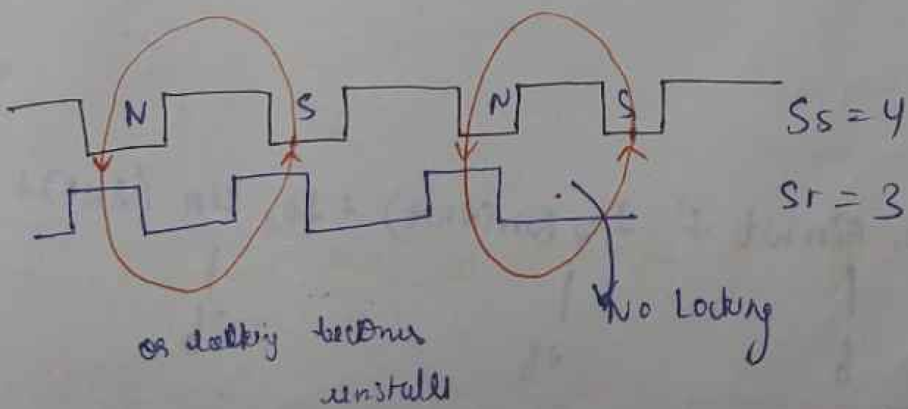
⇒ Cogging effect can be eliminated by making the number of stator and rotor slots in different numbers and does not have any common factor, by skewing the rotor slots.



$S\phi$

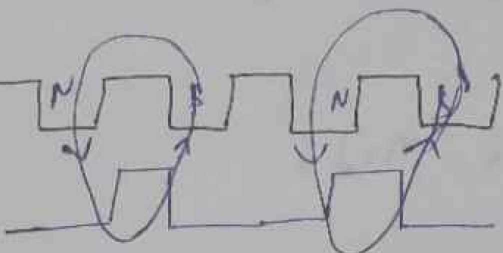
$$\boxed{\left| S_{stator} - S_{rotor} \right| = \text{odd} = 1, 3}$$





$S_s = 4$

$S_r = 2$



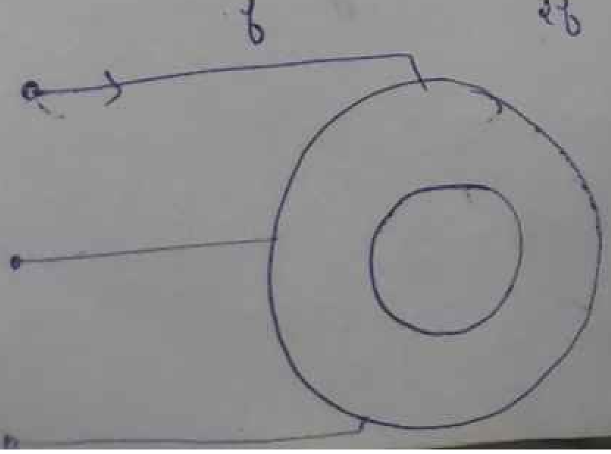
Locking ↑

Crawling effect :-

Time harmonics :- The harmonics present in the supply given to an induction motor is known as time harmonics. These harmonics does not have any major effect on the torque slip characteristics. So, these harmonics does not create crawling effect.

$$\bar{I_1} = I_{01} \sin \omega t + I_{02} \sin(2\omega t) + I_{03} \sin(3\omega t) + \text{-----}$$

$f \qquad 2f \qquad 3f$



Speed of ϕ Rmf to fundamental

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

Speed of RMS to 3rd time harmonics.

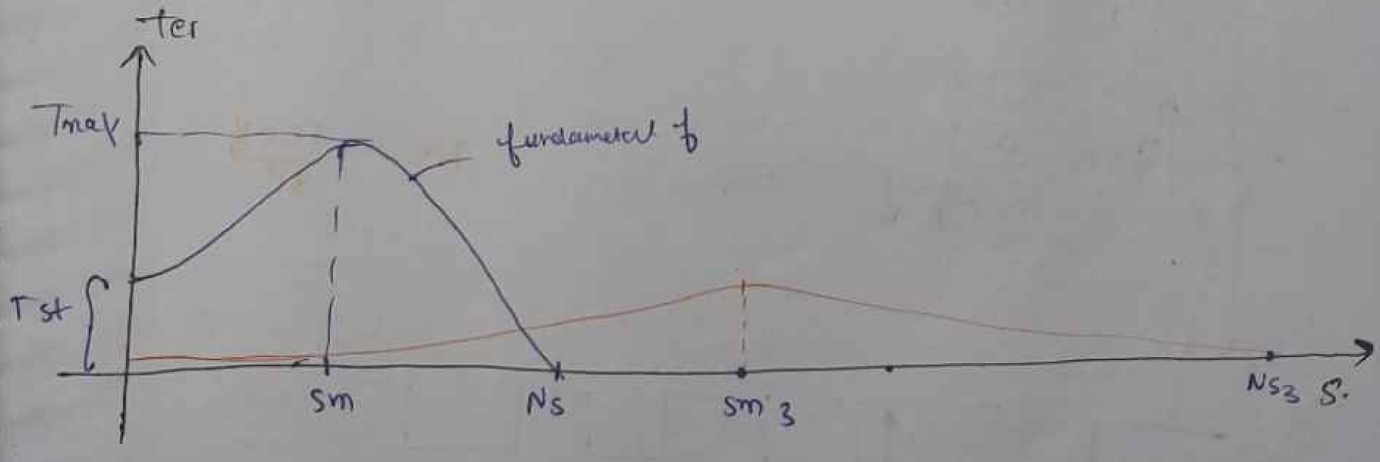
$\therefore \{ at\ f = 3f \}$ $$N_{s3} = \frac{120(3f)}{P} = \frac{360f}{P} = 3N_s$$

$\downarrow T_{st} \propto \frac{1}{f^3} \uparrow$ by 27 times

$\downarrow T_{max} \propto \frac{1}{f^2} \uparrow$ by 9 times

$\downarrow S_m \propto \frac{1}{f} \uparrow$ 2 times

$\uparrow N_s \propto f \uparrow$ 3 times



So, time harmonics does not ~~have any effect~~ cause crawling.

Space harmonics :- Harmonis present in the flux is known as space harmonics these harmonics present due to machine sloting, non uniform airgap,

speed of RMF due to fundamental

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

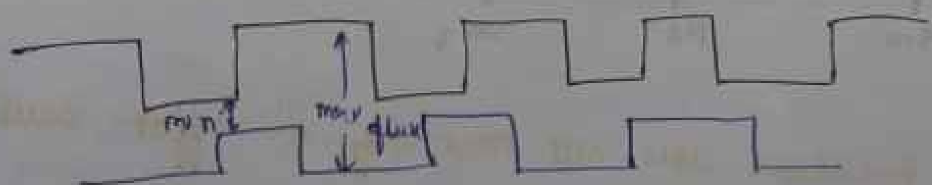
speed of RMF at 3rd space harmonics.

$$N_{s3} = \frac{120f}{3P} = \frac{N_s}{3}$$

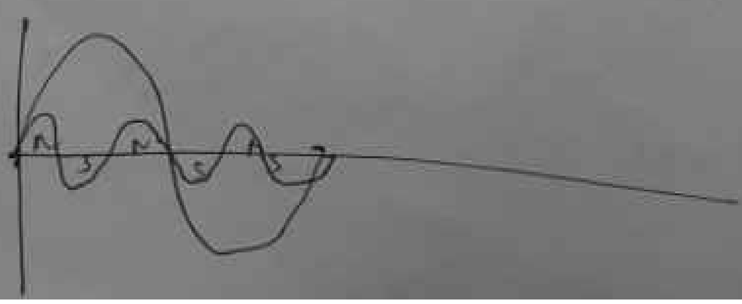
$\therefore$ {at frequency $= \frac{f}{3}$ or poles $= 3P$ }

~~$\uparrow T_{st} \propto \frac{1}{f^3 \downarrow}$~~

$N_s = \frac{120f}{3P}$



Space 3rd harmonics means 3 poles form in whole cycle 3N & 3p



Crawling definition :-

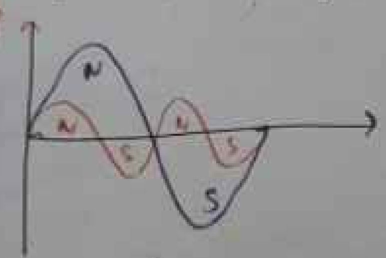
When squirrel caged induction motor started on load does not accelerate upto full speed and runs near to $N_s/7$ speed the motor is called to be in crawling. Due to crawling there is large current drawn by the motor and it runs with vibration and noise.

⇒ space harmonics can be eliminated by making uniform ~~of~~ air gap which can be obtained by. skewing ~~dong~~ the rotor slots.

Analysis of space harmonics :-

Space harmonics

- Even harmonics {2, 4, 6, 8 ------}



Avg effect of even harmonics in a cycle becoming zero. So, these harmonics also not produce crawling.

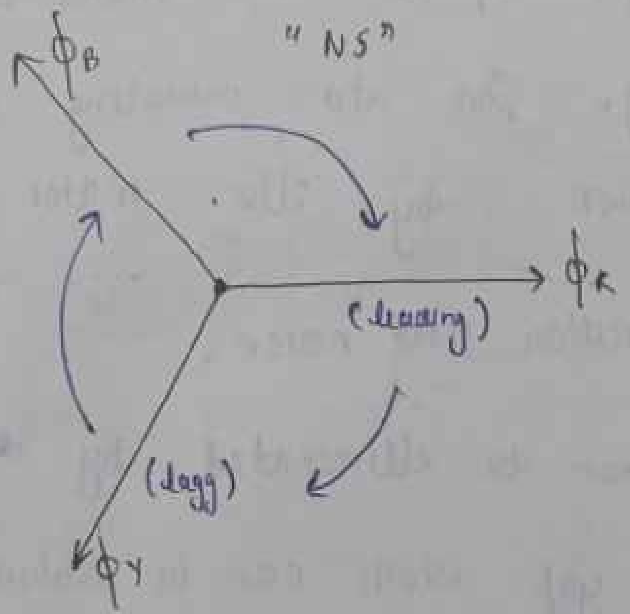
- Odd Harmonics {3, 5, 7, 9, 11, 13 -----}
  - 3N {N = odd} {3, 9, 15 ...} Triplen Harmonics
  - 3N − 1 (N = even) {5, 11, ...}
  - 3N + 1 (N = even) {7, 13 ....}

Let

$\phi_R = \phi_m \sin(\omega t)$

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

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



(1) 3rd space harmonics :-

$$\boxed{\phi_{R3} = \phi_{m3} \sin 3(\omega t)}$$

$$\phi_{Y3} = \phi_{m3} \sin 3(\omega t - 120°)$$

$$\phi_{Y3} = \phi_{m3} \sin(3\omega t - 360°)$$

$$\boxed{\phi_{Y3} = \phi_{m3} \sin 3\omega t}$$

$$\phi_{B3} = \phi_{m3} \sin 3(\omega t - 240°)$$

$$\phi_{B3} = \phi_{m3} \sin(3\omega t - 720°)$$

$$\boxed{\phi_{B3} = \phi_{m3} \sin(3\omega t}$$

Zero sequence

$\boxed{\text{3rd harmonics have zero effect}}$

These harmonics doesn't show any 3-ϕ nature. So, doesn't create RMF. So, these are also not responsible for to Crawling.

(2) <u>5^{th} space harmonics :-</u>

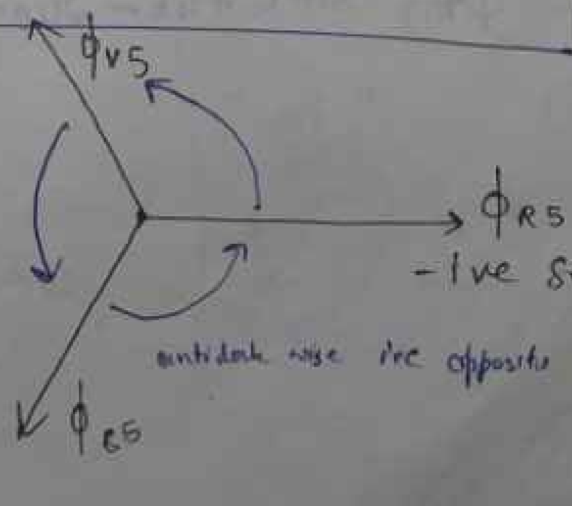
$\phi_{R5} = \phi_{m5} \sin(5\omega t)$

$\phi_{Y5} = \phi_{m5} \sin 5(\omega t - 120^\circ)$

$$\boxed{\phi_{Y5} = \phi_{m5} \sin(5\omega t - 240^\circ)}$$

$\phi_{B5} = \phi_{m5} \sin 5(\omega t - 240^\circ)$

$$\boxed{\phi_{B5} = \phi_{m5} \sin(5\omega t - 120^\circ)}$$



-ive sequence

anticlock wise ive opposite to ckt ob. before them-b

Result:- (1) Slip due to 5th space harmonics.

$$S_5 = \frac{N_5 - \left(-\frac{N_s}{5}\right)}{N_s}$$

$$\boxed{S_5 = \frac{6}{5} = 1.2}$$

−ive sequence

$\boxed{S_5 > 1}$ — Braking torque

So, motor speed decreases and crawling is due to 5th space harmonics only.

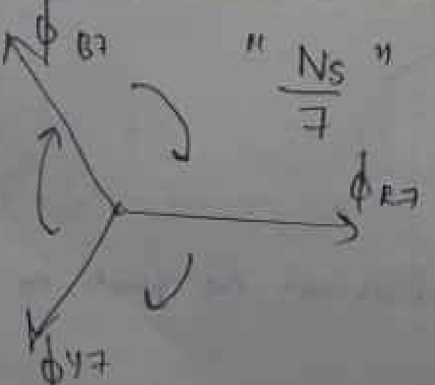
(3) 7th space harmonics :-

$$\phi_{R7} = \phi_{m7} \sin(7\omega t)$$

$$\phi_{Y7} = \phi_{m7} \sin 7(\omega t - 120^\circ)$$

$$\phi_{Y7} = \phi_{m7} \sin(7\omega t - 120^\circ)$$

$$\phi_{B7} = \phi_{m7} \sin(7\omega t - 240^\circ)$$



+ive sequence

$$S_7 = \frac{N_s - \frac{N_s}{7}}{N_s}$$

$$= \frac{6}{7} = .82$$

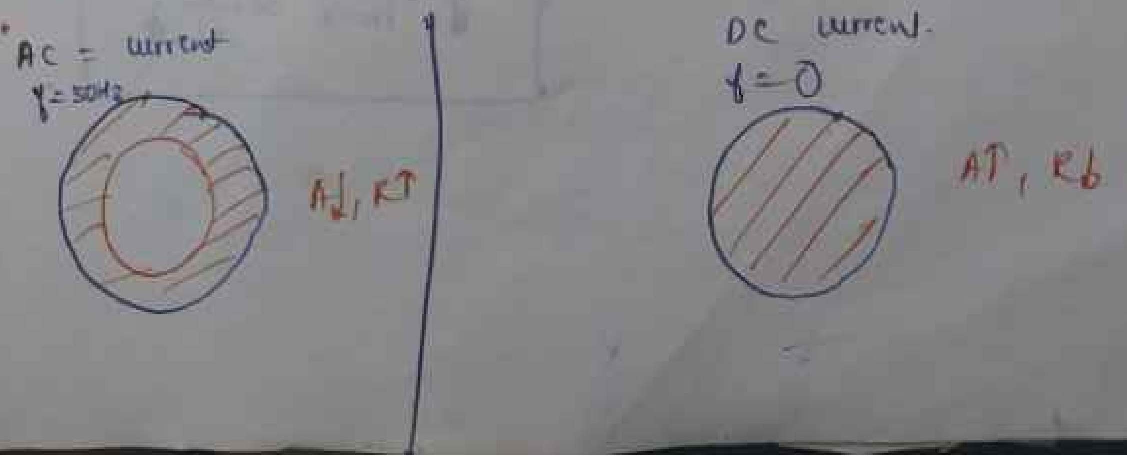
Methods to eliminate crawlling :-

(1) By skewing the rotor slots, by starting the motor at noload.

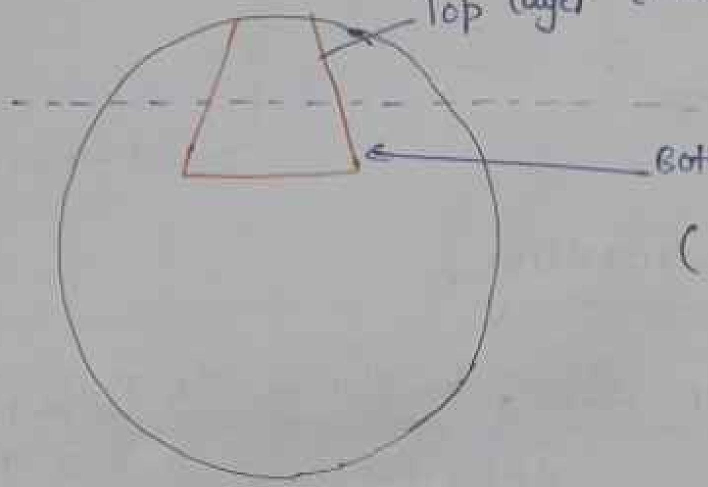
Special rotor construction :-

Squirrel caged induction motor having small rotor resistance so, at starting its performance is poor. So, to improve its starting performance special rotor constructions are used. There are two types of special rotor construction.

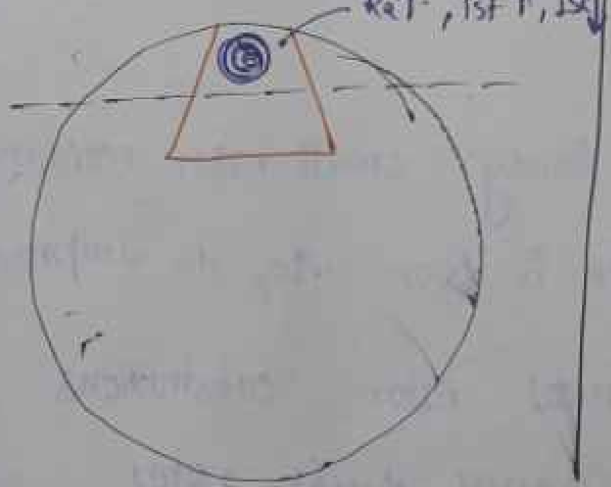
The working of special rotor construction depends on skin effect.



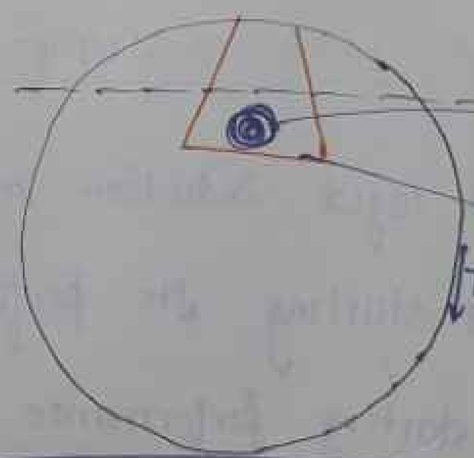
(A) Deep Bar rotor construction :-



(a) Under starting $f_e = f_1 = 50Hz$



Under Running condn :-



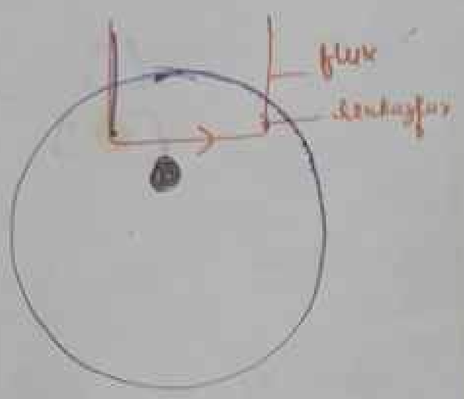
$$\boxed{f_{2r} = sf_1 = 2.5Hz \approx DC}$$

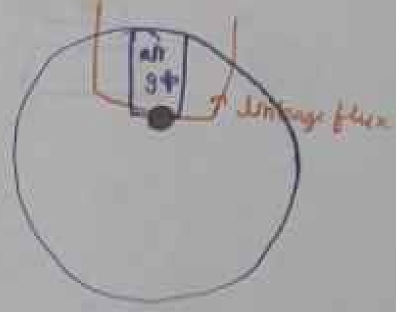
$$\boxed{R_{2ac}\downarrow, T_{er}\uparrow \propto \frac{1}{R_2\downarrow}}$$

$X_2 \uparrow$

$$\boxed{\downarrow T_{max} \propto \frac{1}{X_2\uparrow}}$$

Concep to solve above proble of X_2 :-



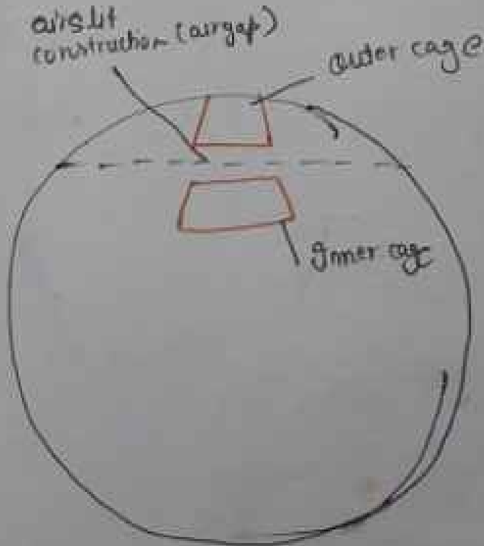


air gap is made up in path of leakage flux. so, it will flow from low S fun.

(8) Double cage rotor construction :-

→ Its rotor consist of 2 cage outer cage and Inner cage which are short circuited by two end rings

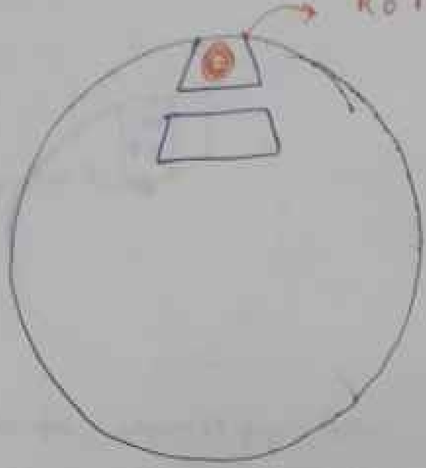
→ Both the cages are seperated by narrow airgap



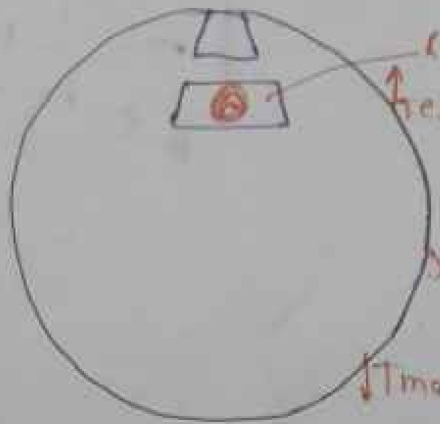
($A_o \downarrow$, $R_o \uparrow$, $X_i \downarrow$)

($A_i \uparrow$, $R_i \downarrow$, $X_i \uparrow$) but less than previous case.

a) Starting $f_r = f_1 = 50Hz$ AC



b) Running :-

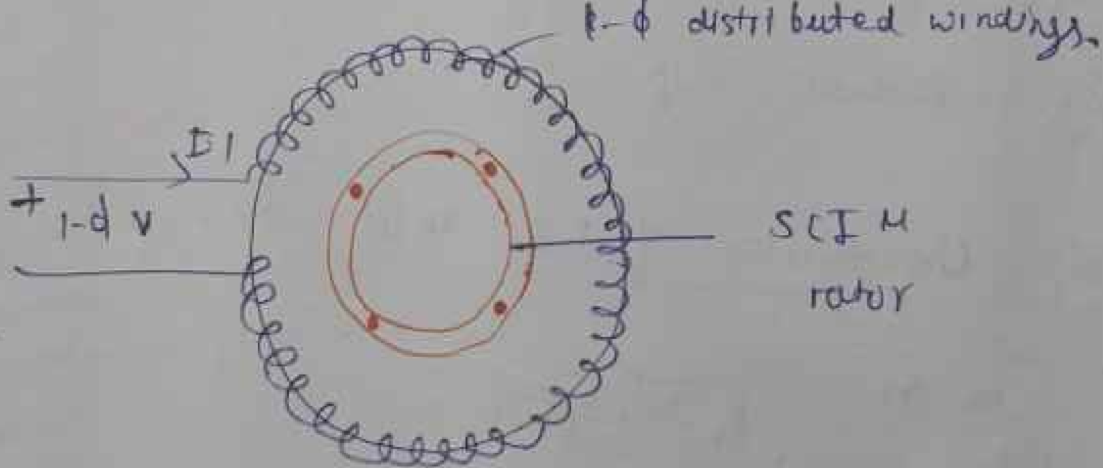


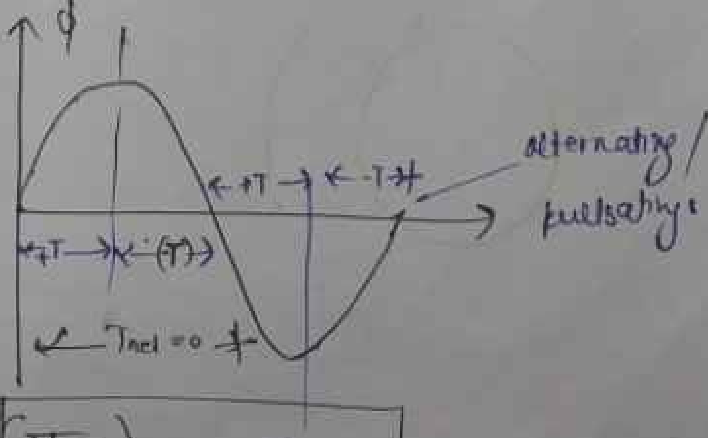
$$f_r = sf = 2.5Hz = DC$$

R

1-ϕ Induction motor:-

Since average torque ~~express~~ experience by single-ϕ induction motor in a complete cycle becomes zero. So, 1-ϕ I-M ~~of~~ are not self starting in nature. This behaviour of non self starting of 1-ϕ, I-M is explained by double field revolving theory.





$$\boxed{(T_{st})_{avg} = 0}$$

Double feild revolving theory :-

According to this theory alternating flux contains two components ; forwards R.M.F and backward R.M.F. which have same magnitude. and rotating at synchronous speed Ns in opposite direction to each other.

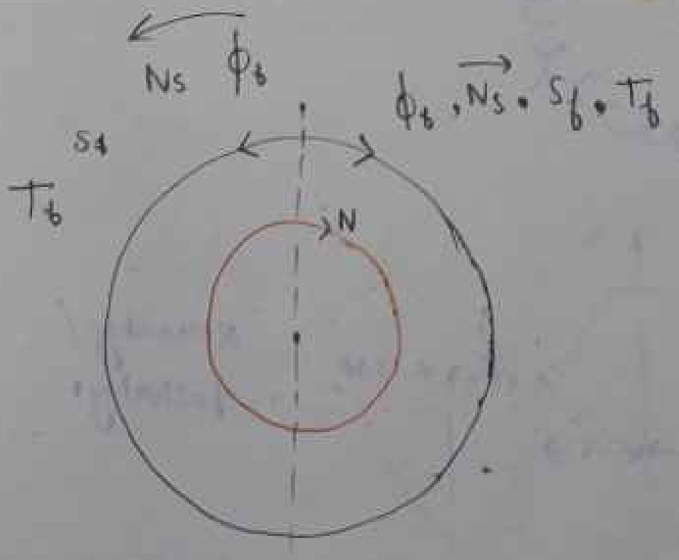
$$\boxed{\text{Pulsating flux} = \text{Forward R.M.F} + \text{Backward R.M.F}}$$

S_f = forward slip

S_b = Backward slip.

Torque slip charcteristics of 1-φ induction motor :-

T_b = backward torque



$$S_f = \frac{N_s - N}{N_s} \quad \text{——} \quad (1)$$

$$S_b = \frac{N_s - (-N)}{N_s}$$

$$\boxed{S_b = \frac{N_s + N}{N_s}} \quad \text{——— (2)}$$

$$\boxed{S_b + S_f = 2}$$

$$\boxed{T_{er} = \frac{1}{s\omega_s}(RCL)}$$

at starting.

$$\boxed{RCL = 1 \cdot T_{2r}^{2} R_2}$$

$$\boxed{T_f = \frac{R.CL}{S_f \cdot \omega s}} \quad \text{——— (3)}$$

$$\boxed{T_b = -\frac{1}{S_b \omega s}(RCL} \quad \text{——— (4)}$$

- represents opposition

$$\boxed{T_{net} = T_f + T_b}$$

from (3) & (4)

$$\boxed{T_{net\ at\ starting} = T_f + T_b = 0}$$

$\therefore$ 1-ϕ I-M is not self starting.

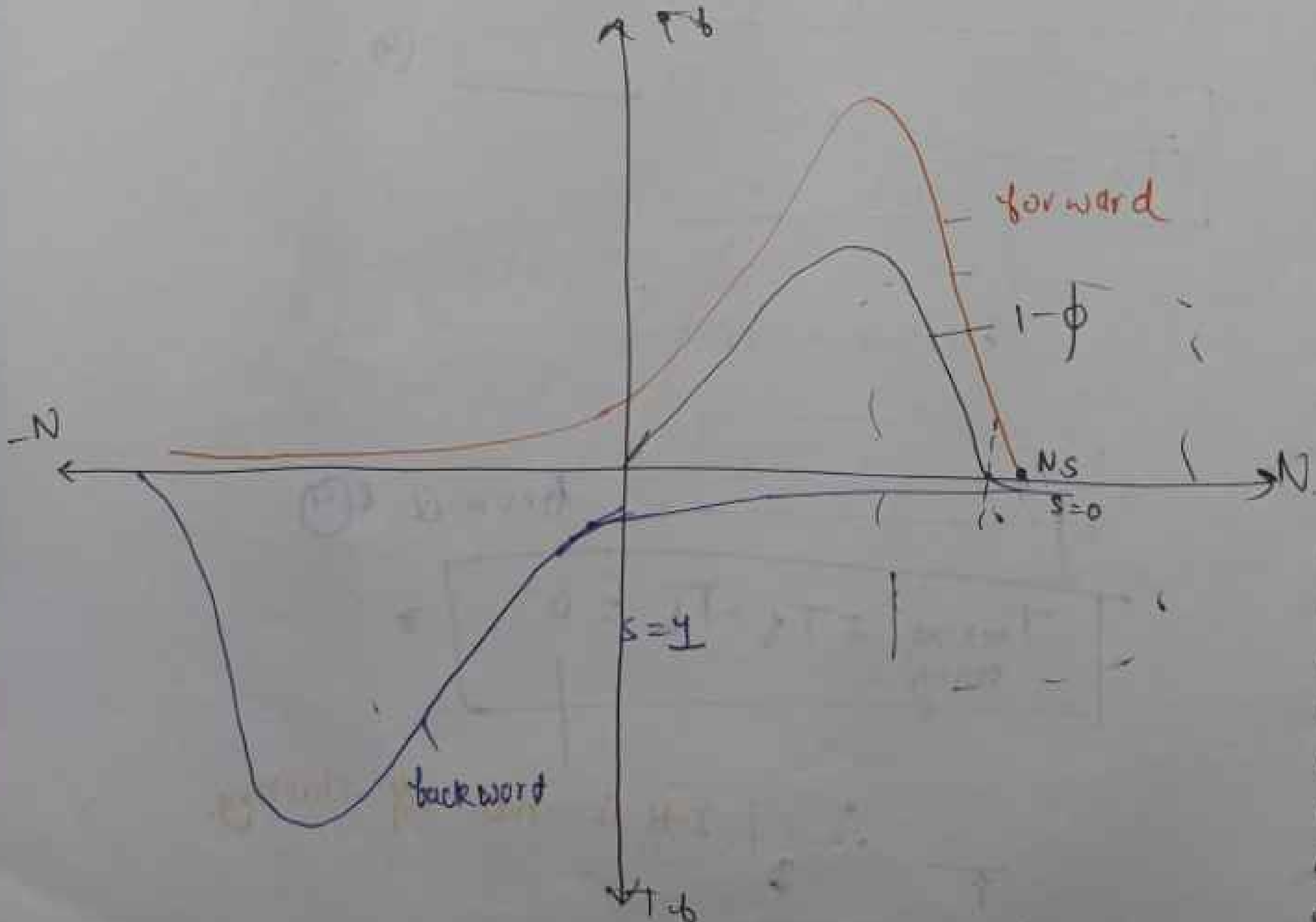
Under running :- $N \longrightarrow N_s$

$S_f \longrightarrow 0, \quad S_b \longrightarrow 2$

$T_f \longrightarrow \infty$

$$\boxed{T_b = -\frac{1}{2\omega_s} \text{ (RCL)}}$$

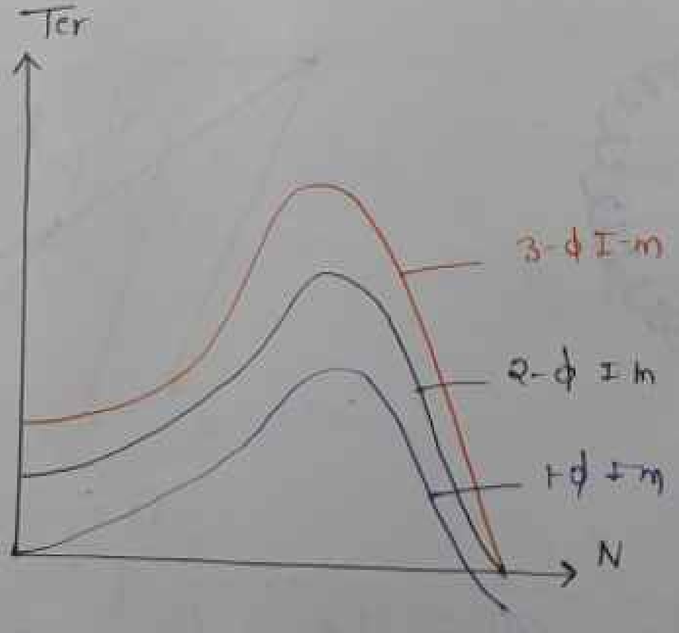
Since, backward torque is also present in running condition also, so, it's performance is not smooth.



Result :-

(1) Torque developed by 1-ϕ induction motor drops to zero slightly before synchronous speed and ~~~~ becomes ~~zero~~ negative at synchronous speed. It means it act as induction generator slightly before synchronous speed. (negative torque is also present)

Single-ϕ I-M becomes self starting by split phase concept.



$$\boxed{\overline{I_1} = \overline{I_R} + \overline{I_L}}$$ or $\overline{I_R} + \overline{I_C}$

split phase I-N

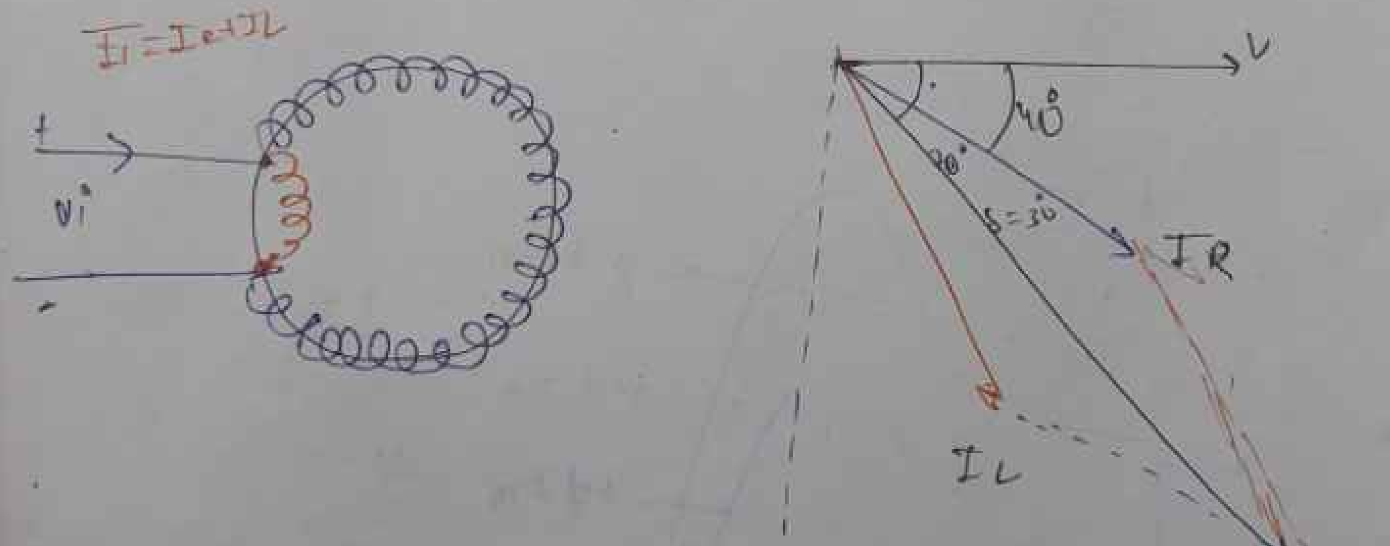
Types of 1-φ I-M :-

(i) split phase type

(2) Shaded pole induction motor

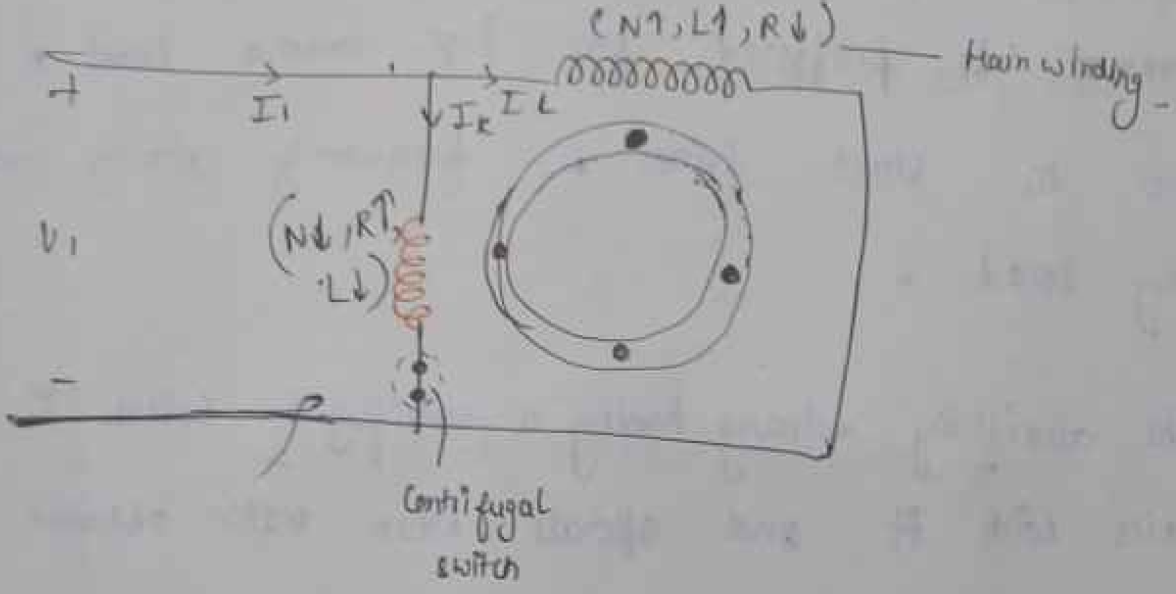
(1) Split phase type Motor :-

(a) Resistance phase split ~~I-M~~ : or resistance start induction run or split phase motor



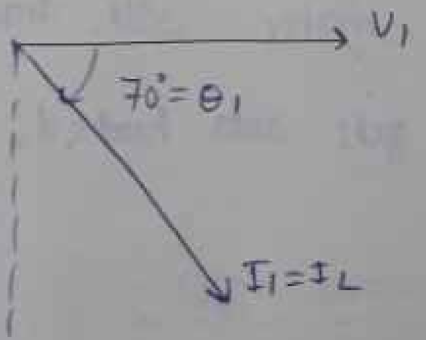
$$\boxed{T_{st} = (1.5\%) T_{FL}}$$

$$\boxed{I_{st} \propto |I_R||I_L| \sin\delta}$$



Under running :-

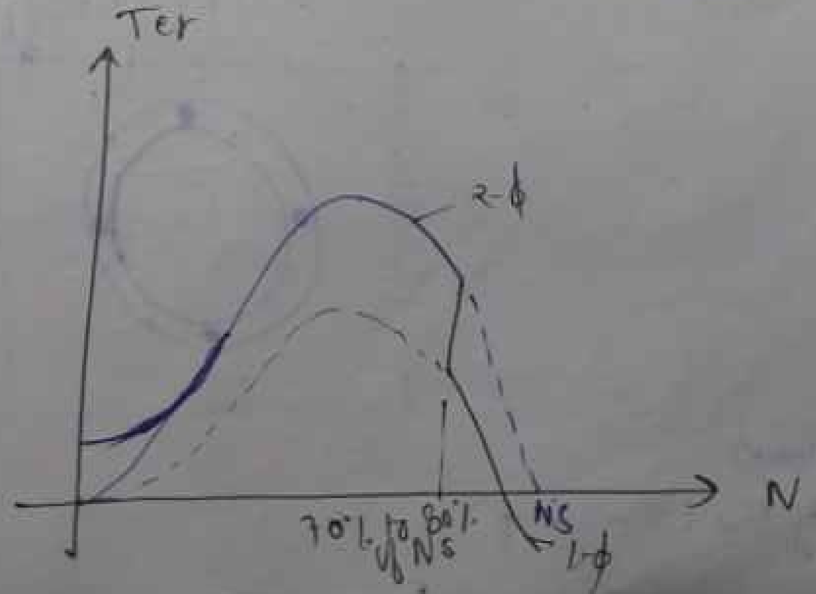
Switch gets open ∴ $I_R = 0$



Rq $P_f = \cos(70°)$

$P_f = .2$ lagg

$\boxed{\text{poor pf}}$

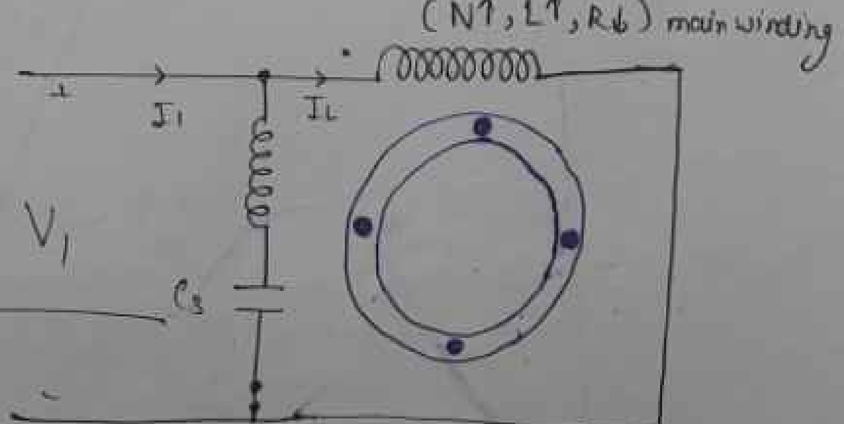


⇒ These are used for low anertia load upto 250 watt cannot be preffered for high anertia load, hard to start load, frequently starting and stoping load.

⇒ The auxillary winding having a centrifugal switch in series with it and operate when motor obtaines 70–80% of synchronous speed.

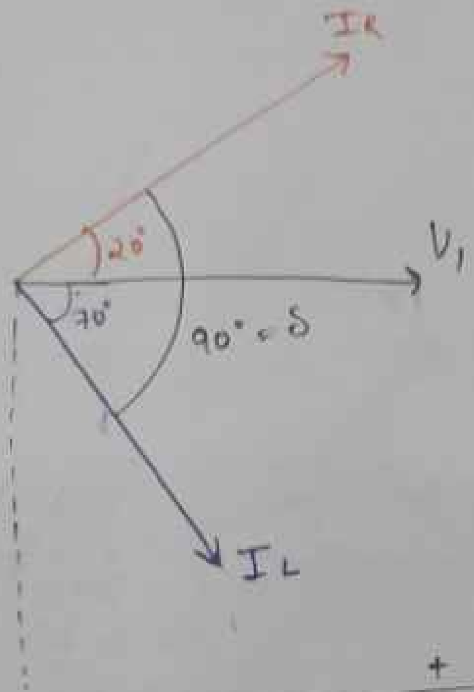
⇒ If centrifugal switch ~~does~~ does not open mechanically after starting the motor motor will draw ~~lag~~ large current and stator gets over heated.

(4) Capacitor start induction run motor :-



सस्ता
Electrolytic type
C↑↑ (more)
It is short duty s/w (50–300 uf)

Starting :-



$$\therefore \boxed{T_{st} = |I_R|\,|I_L| \sin\delta}$$

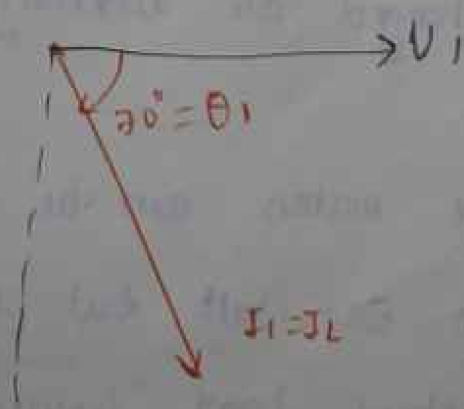
$$\boxed{T_{st} = (3 \text{ to } 4)\, T_{FL}}$$

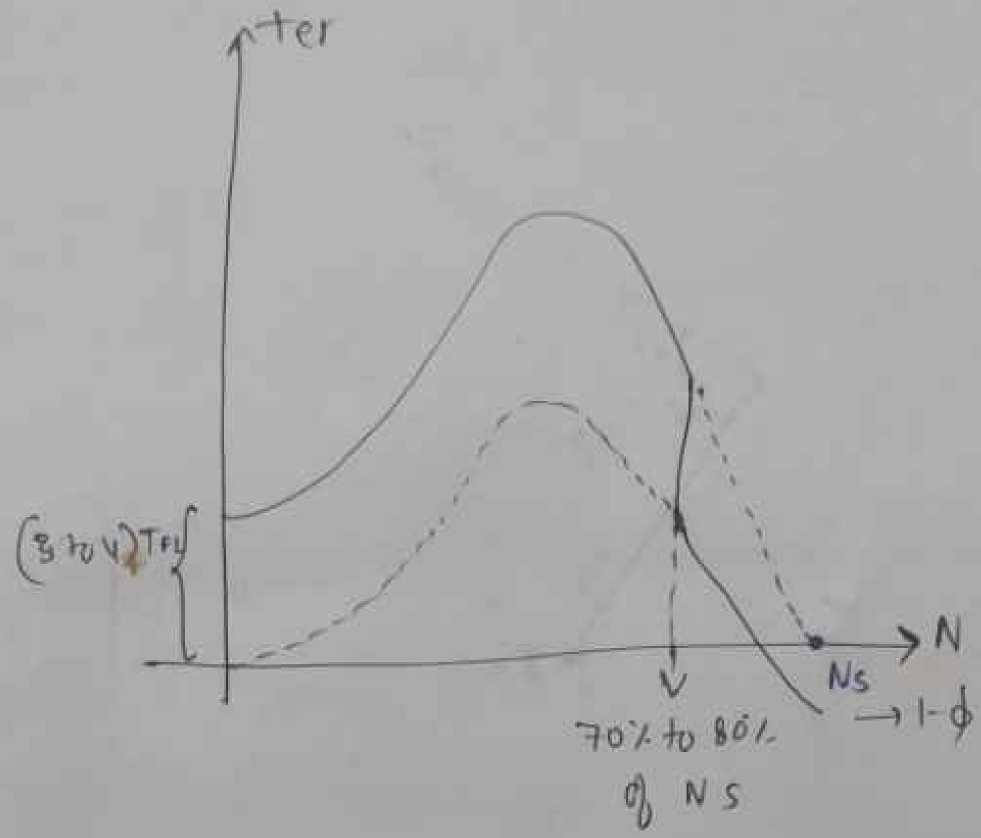
Under Running :-

$Pf = \cos 70^\circ$

$Pf = \cdot 2$ Lagg

poor pf

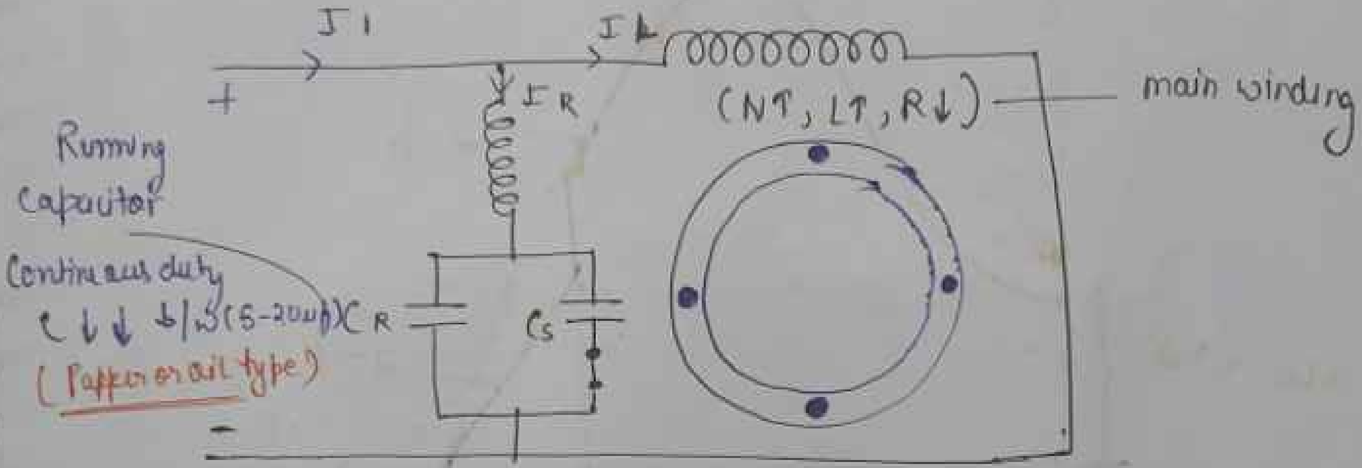




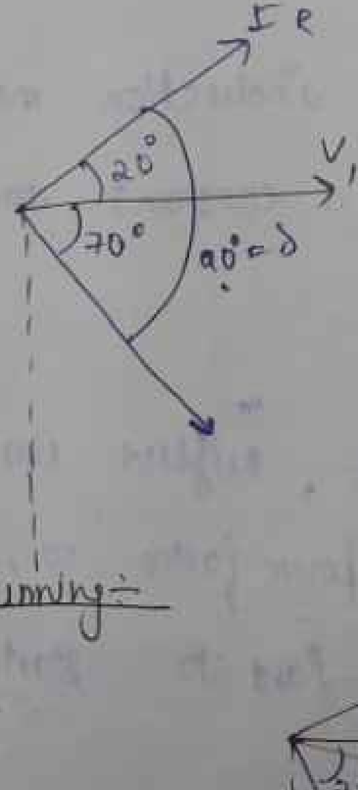
⇒ As if the supply terminals are interchanged then the direction of motor rotation remains the same. For reversing the direction of rotation main winding terminals are interchanged or auxiliary winding terminals are interchanged.

⇒ These motors can be used for high inertia load upto 500 watt but cannot be preffered for hard to start load, frequently starting & stopping load.

Capacitor start capacitor & run motor / capacitor run motor :-



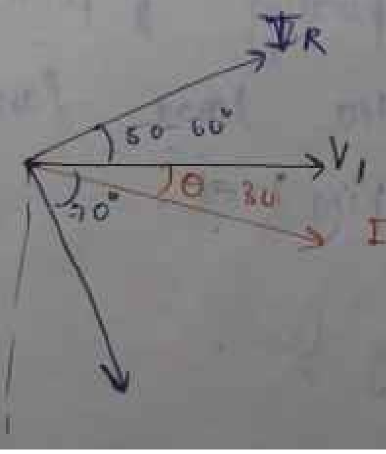
Starting



$$\boxed{T_{st} \propto |I_R||I_L| \sin\delta}$$

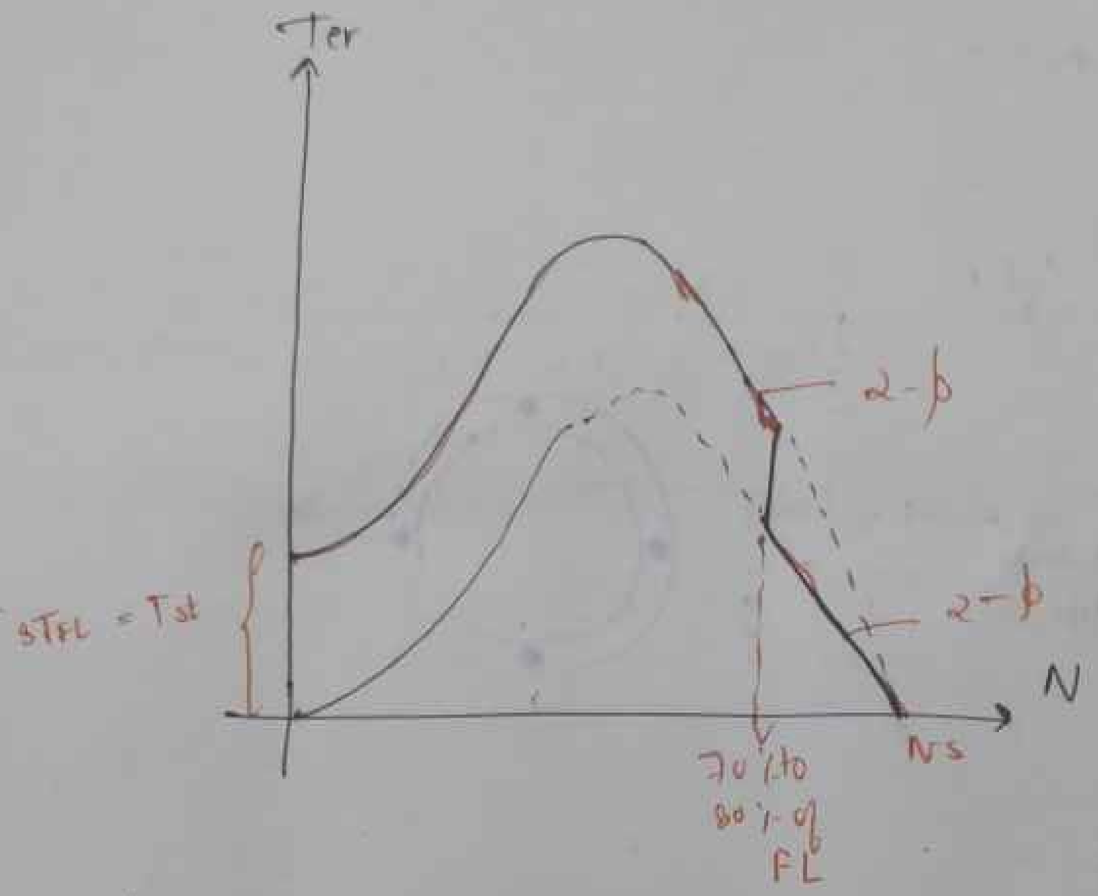
$$\boxed{T_{st} = (5)\,T_{FL}}$$

Running :-



$\boxed{Pf = 0.7 \text{ Lagging}}$

∴ P.f get improved



Result :-

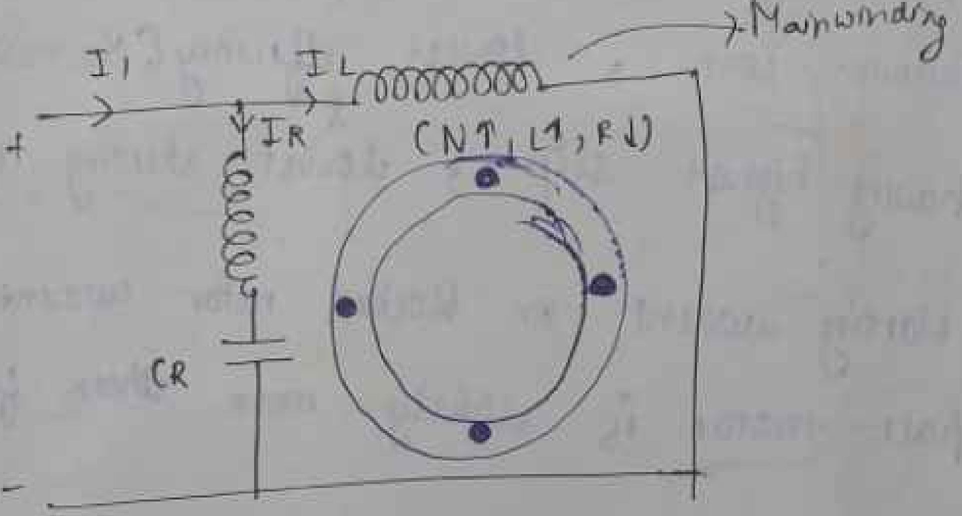
① Such a motor runs as 2-ϕ induction motor from 1-ϕ supply . So, produces a constant torque not a pulsating torque .

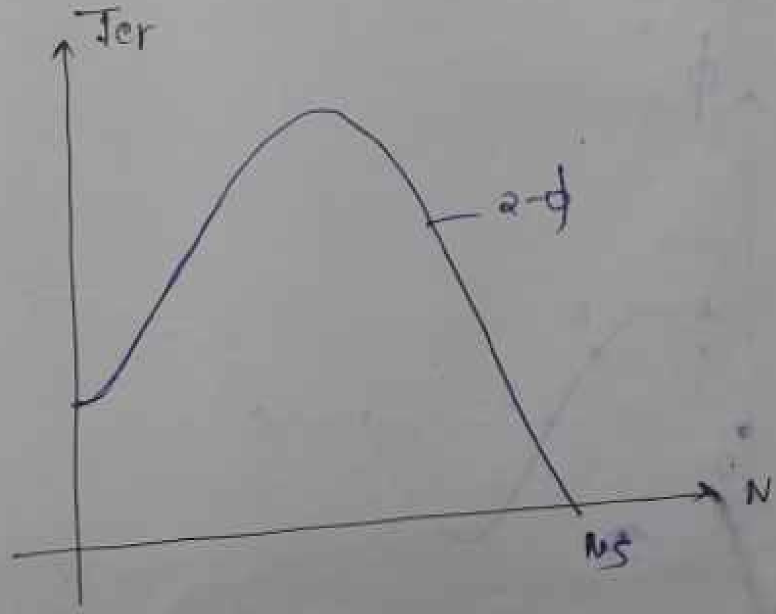
② These motors have highest cost , highest starting torque , highest operating of power factor . so, can be used for high inertia load, hard to start loads, frequently starting & stoping load .

③ Used in ceiling fan.

① Permanent split capacitor motor / Capacitor run motor :-

It is the only motor which does not have ~~only~~ any centrifugal switch and have smooth torque slip characteristics.





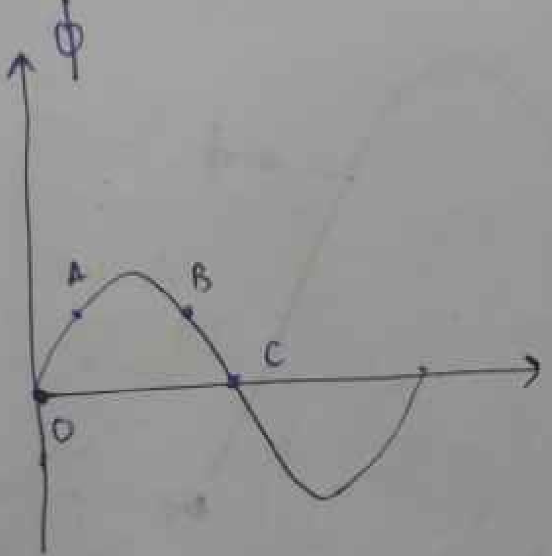
Shaded pole induction motor :-

→ Stator having shaded pole generally 2 or 4 . since,

\# these are ~~conf~~ compact in size . so, used in toys and table fan .

\# It is the factional killowatt motor which have minimum cost , lowest efficiency (30 – 50) %, having highest slip , lowest starting torque.

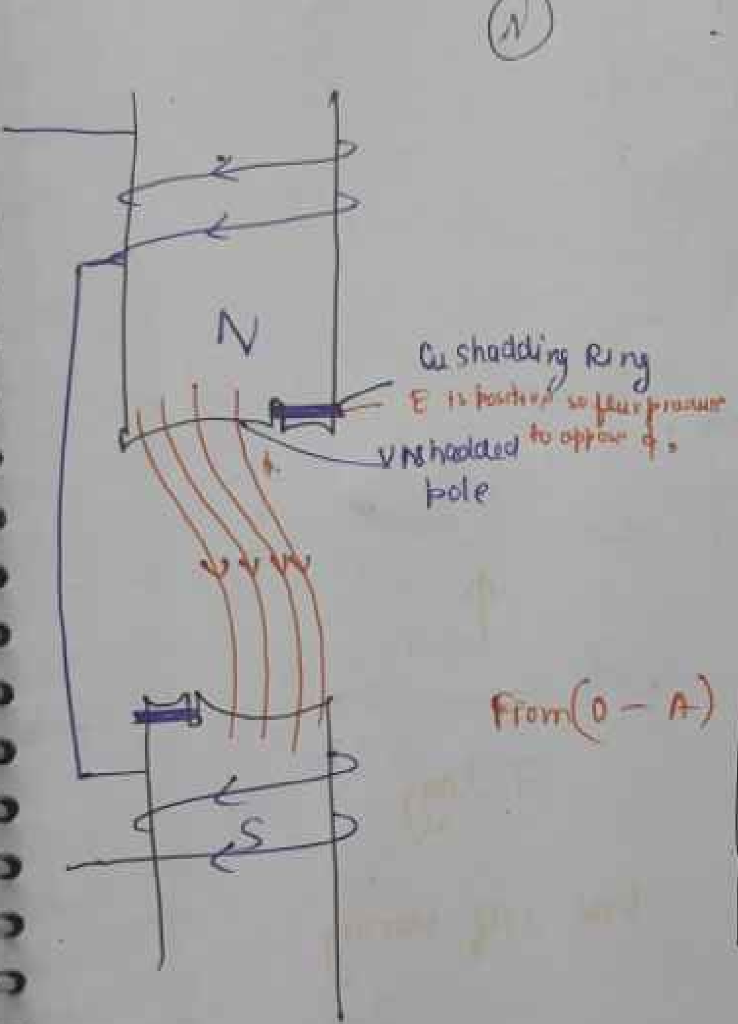
⇒ The starting current or blocked rotor current ~~is~~ of shaded pole motor is slightly more than full load current

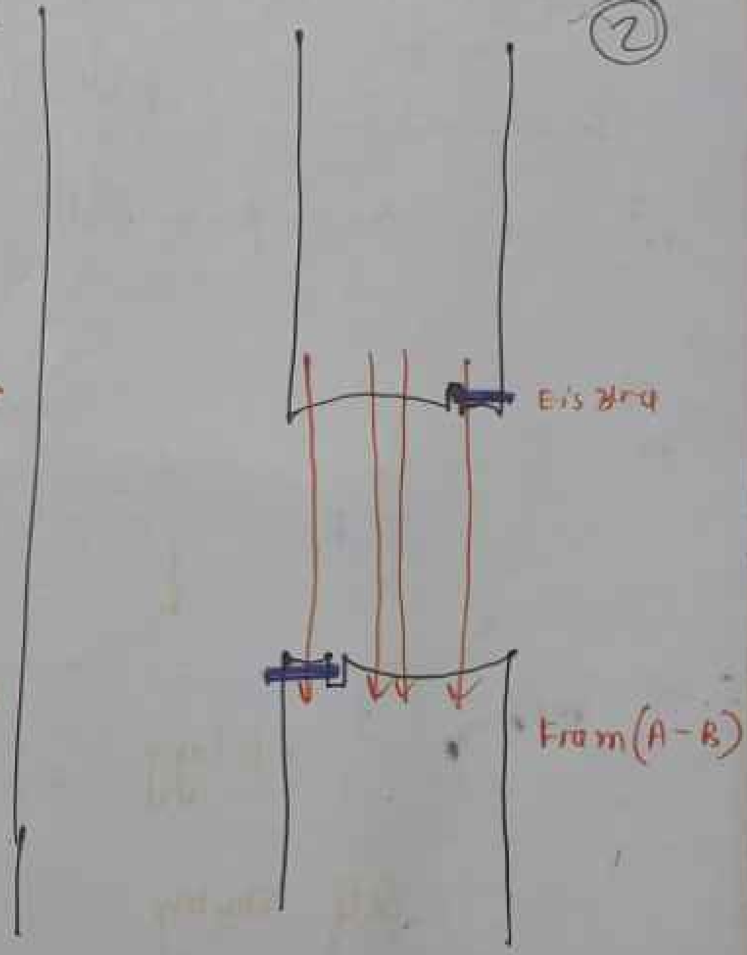


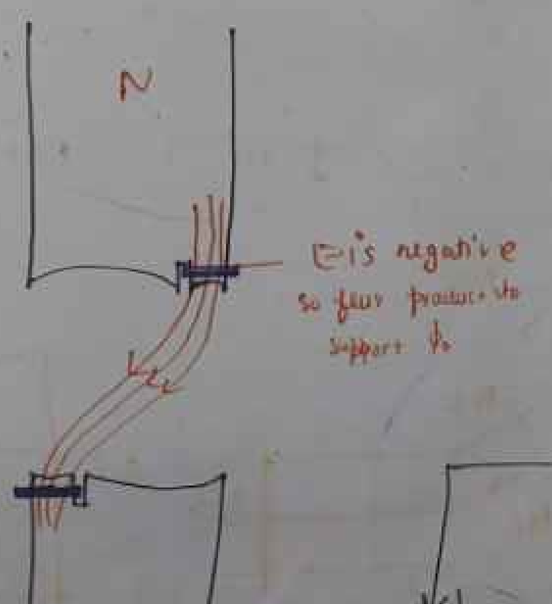
OA $\phi\uparrow, \frac{d\phi}{dt} = +ive$, $e = -ive$

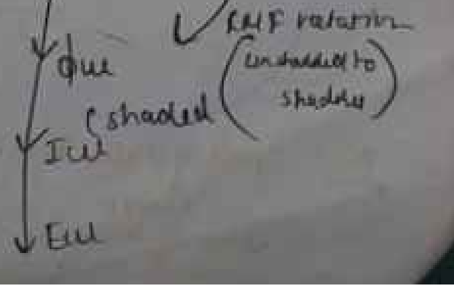
AB $\phi \simeq const$, $\frac{d\phi}{dt} \approx 0$, $e = 0$

BC , $\phi \downarrow$, $\frac{d\phi}{dt} = -ive$, $e = +ive$









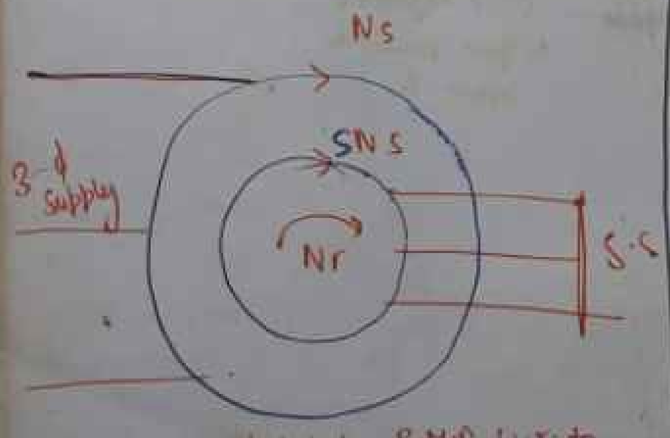
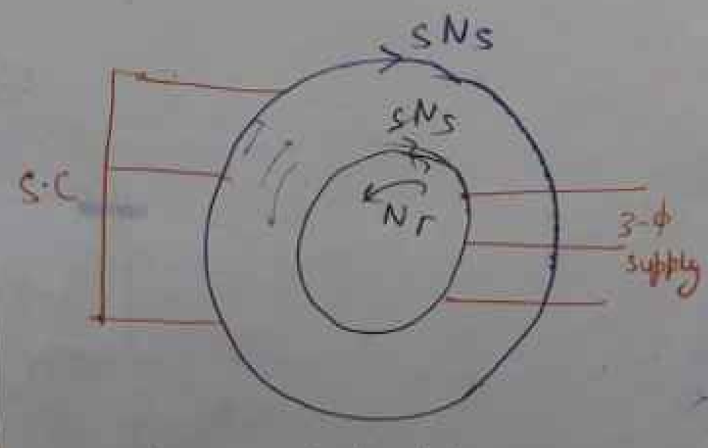
Note :-

$$\boxed{① \ \underset{\text{(machine)}}{\text{Size}} \propto \frac{\text{Power O/P}}{\text{speed} \propto \text{freq} \propto \text{voltage}}}$$

② For same power ratting :-

	3-ϕ Im	1-ϕ Im
Size	↓	↑
pf	.8 lagg	.7 lagg
	Self starting	Not self starting

③

Stator fed I-M	Rotor fed I-M
	

N_s = speed of stator R.M.F w.r.to stator

SN_s - speed of rotor ———— w.r.to stator