INDUCTION MOTOR

Induction Motor :-

The electrical motor which is widely used in industries (about 90% motor used). It is used because of rucked Construction, Smaller size, easy phase reversal, high power factor, high power supply, high efficiency & absence of Commutator.

Construction :-

⇒ Frame.
⇒ Stator Core
⇒ Stator
⇒ Rotor
⇒ Squirrel cage rotor type
⇒ phase wound rotor type / slip ring rotor type.
⇒ Shaft's & bearing

* Frame :-

- It supports the stator Core & winding.
- Each helps in Ventilation.
- It is made up of dry cast or fabbricated up to 50KW rating dry cast frame in a strong sillcon, alluminium alloied from 250 KW to 10000 KW. Fabricated frame in the form of box type encloser.

* Stator Core :-

- stator Cores has a ringing edge Called tooths & slots to allumated winding.
- To reduced eddy Current loss & hysterisis loss in the Stator Core.
- It is made up of high grade low electrical loss Silicon steel.
- The material is CRGO Silicon Steel.
- The air gap between rotor & stator which gap minimum. To improve power factor & maximize flux.

CRGO = Cold rolled grain Oriented)

* Stator :-

- Here stator beams stator winding.

Motors	Voltage Rating
Less 250 KW	380-440 KV
250 - 300 KW	3.3 KV
750 KW	11 KV

- The 3-ϕ winding are either Connected in start or delight.

* Rotor :-

- Rotor is cylindrical laminated iron Core.
- Light stator laminated are punched into small pieced to reduce eddy Current loss.
- Ducts are provided in the rotor Core & a fan blade is Connected at a shaft end. For Cooling purpose.
- The rotor windings are sketched to above magnetic locking between stator & Rotor.
- These are 2 types rotor
  1) Squirrel cage rotor
  2) phase wound rotor / slip ring rotor.

Squirrel Cage rotor :-

- 90% of induction motor used Squirrel cage rotor.
- The Conductors are not insulated from the Core.
- The rotor Conductors are short circuited at both the edge by continous end rings.

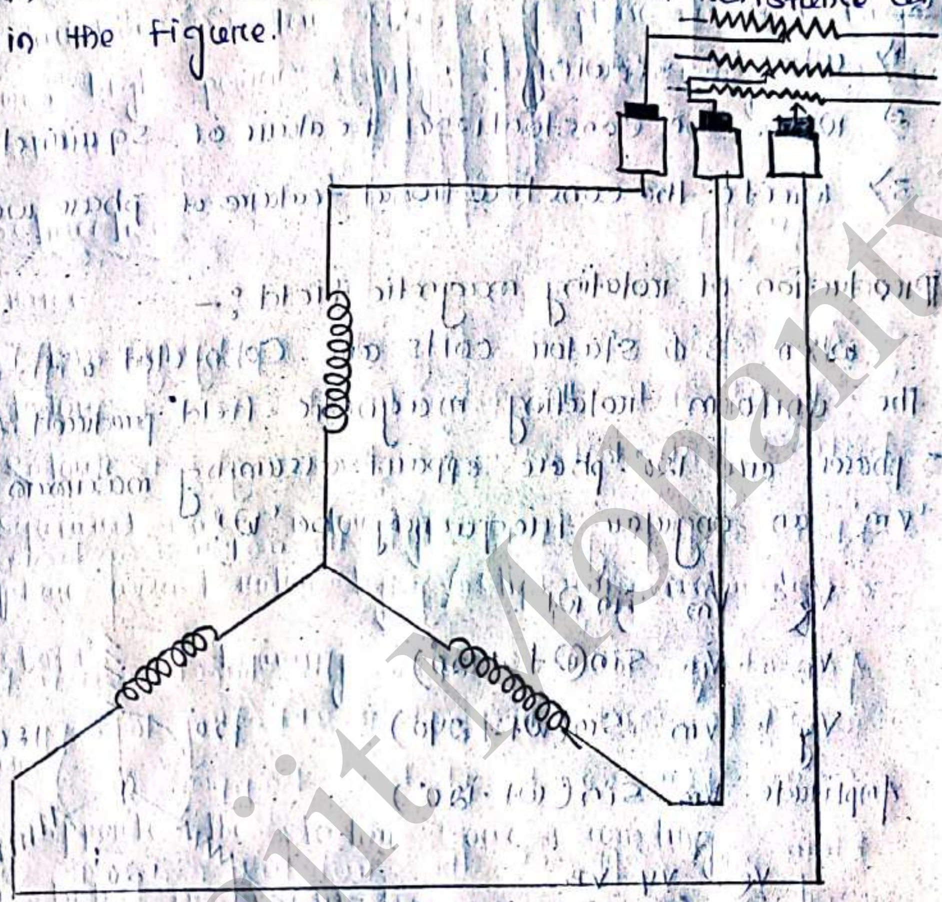
Advantage :- The effective cross Sectional area of the air gap increased therefore magnetising current is reduced. Hence loss is reduced.

Disadvantage :- Due to open slots lowest the power factor & reduces starting breakdown turns.

* As the rotor winding permanently short circuit there is no possibility adding any external resistance to the rotor.

Phase wound rotor / slip ring rotor :-

- There are a number of slots which are smaller & finger turns per phase.
- The rotor is connected with external resistance as shown in the figure.



Advantage :- During starting the entire resistance so starting current is reduced during ~~sam~~ normal running condition the resistance is cut out & rotor winding are short circuit through the slip ring by a metal colour

Disadvantage :- It can be generally used by high rating motor.

- The losses particular mechanical losses & frictional losses are visceal viewers. This motor is called as slip ring induction motor.

Shaft & bearing :-

- It is support the rotor maintaining air gap it maintain the balanced magnetic pull.
- Generally ball & roller bearings are used.

Q

1) What is skewing?
2) Write the constructional feature of squirrel cage rotor?
3) Write the constructional features of phase wound rotor.

Production of rotating magnetic field :-

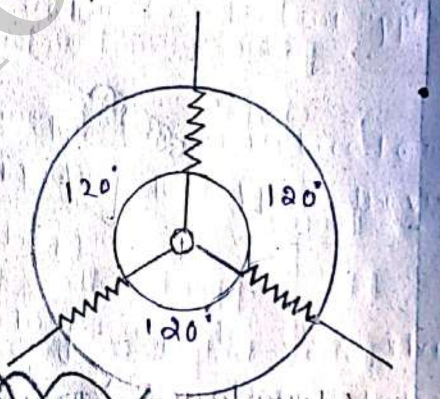
When 3-ϕ stator coils are connected with a 3-ϕ supply the uniform rotating magnetic field produced. As all the 3 phases are 120° phase appart assuming maximum voltage be 'Vm' an angular frequency be 'ω'.

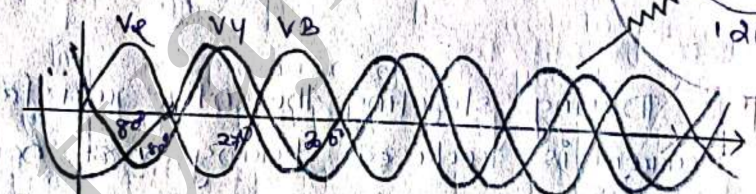
$V_R = V_m \sin \omega t$

$V_B = V_m \sin(\omega t + 120°)$

$V_Y = V_m \sin(\omega t + 240°)$

Amplitude $V_m \sin(\omega t - 120°)$





- Due to voltages magnetic flux is produced.

Let ϕ_R, ϕ_Y & ϕ_B be the respective fluxes & ϕ_m be the maximum fluxes.

$\Rightarrow$ Case-1

At $\theta = 0$, $\phi_R = \phi_m \sin 0° = 0°$.

$\phi_B = \phi_m \sin(\omega t + (120°))$

$= \phi_m \sin(120°)$

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

$\phi_Y = \phi_m \sin(\omega t + 240°)$

$= \phi_m \sin(240°)$

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

$$\Phi_{Res} = \vec{\Phi_R} + \vec{\Phi_B} + \vec{\Phi_Y} = 0 + \left(\frac{\sqrt{3}}{2}\Phi m\right) + \left(-\frac{\sqrt{3}}{2}\Phi m\right)$$

$$|\Phi_{Res}| = \sqrt{\left(-\frac{\sqrt{3}}{2}\Phi m\right)^2 + \left(\frac{\sqrt{3}}{2}\Phi m\right)^2 + 2\left(-\frac{\sqrt{3}}{2}\Phi m\right)\left(\frac{\sqrt{3}}{2}\Phi m\right)\cos 120^\circ}$$

$$= \sqrt{\frac{9}{4}\Phi m^2 + \frac{3}{4}\Phi m^2 + \frac{3}{4}\Phi m^2} = \sqrt{\frac{9}{4}\Phi m^2} = \frac{3}{2}\Phi m = 1.5\Phi m$$

Case-2

Let $\theta = 60^\circ$, $\Phi_R = \frac{\sqrt{3}}{2}\Phi m$

$$\Phi_B = \Phi m \sin(\omega t + 120^\circ) = \Phi m \sin(180^\circ) = 0$$

$$\Phi_Y = \Phi m \sin(\omega t - 120^\circ) = \Phi m \sin(-60^\circ) = -\frac{\sqrt{3}}{2}\Phi m$$

$$|\Phi_{Res}| = \vec{\Phi_R} + \vec{\Phi_Y} + \vec{\Phi_B} = \frac{\sqrt{3}}{2}\Phi m + -\frac{\sqrt{3}}{2}\Phi m + 0$$

$$|\Phi_{Res}| = \sqrt{\left(\frac{\sqrt{3}}{2}\Phi m\right)^2 + \left(-\frac{\sqrt{3}}{2}\Phi m\right)^2 + 2\left(\frac{\sqrt{3}}{2}\Phi m\right)\left(-\frac{\sqrt{3}}{2}\Phi m\right)}$$

$$= 1.5\,\Phi m$$

Case-3

Let $\theta = 120^\circ$, $\Phi_R = \frac{\sqrt{3}}{2}\Phi m$, $\Phi_B = -\frac{\sqrt{3}}{2}\Phi m$, $\Phi_Y = 0$

$|\Phi_{Res}| = 1.5\,\Phi m$

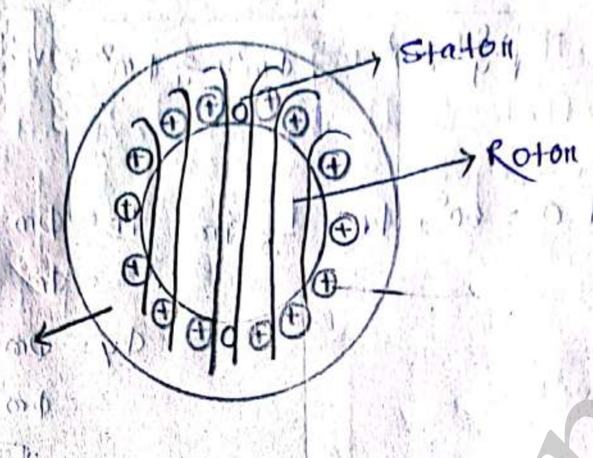
Working principle of operation of induction motor:-

+ In an induction motor, unlike DC motor there are no brushes & commutator like DC motor there is no electrical connection between stator & rotor.
- When the stator connected to a 3Φ AC supply a rotating magnetic field is established.
- Which rotates at synchronous speed (N_s).

$$N_s = \frac{120F}{P}$$ where F = frequency of supply, P = No. of poles.

- The direction of revolution / rotation depends upon the phase sequence of the supply.
- As the rotating magnetic field produces flows across the rotor conductor. An emf is induced in rotor conductor due to induction.

- As the rotor short circuited are Both ends a Current flows in the winding.



- As shown in the fig the applying right hand thumb rule the magnetic flux is clockwise in left half & anticlockwise of the right half.
- Now applying left half the rotor conduct on appearance a force move to the right.
- According to lenz's law the direction of induced emf would be such that it would try to oppose the very Cause for which it has happen.
- Here emf opposes the rotating magnetic flux. Therefore try to produce a torque to follow the rotating magnetic field & reducing the electric field rotor speed. speed is denoted as 'N_R'. This speed gap is called as slip (s).

$$S = N_S - N_R$$

$$\% \, S = \frac{N_S - N_R}{N_S} \times 100$$

Q

- What is slip

Ans:- The difference of the speed between stator & Rotor with respect to stator speed is called as slip.

$$S = \frac{N_S - N_R}{N_S}$$

$$\Rightarrow N_R = (1-S) N_S$$

Problem :-

A 6 pole induction motor working on 50 Hz supply with 3% slip find running speed/ rotor speed?

Ans :-

$p = 6$

$F = 50\ Hz$

$\% s = 3\% = 0.03$

$$N_s = \frac{120 \times 50}{6} = 1000\ rpm.$$

$$N_R = (1-s)N_s = (1-0.03) \times 1000 = 970\ rpm.$$

Frequency of Rotor :-

Let the supply frequency = F

$\therefore$ stator frequency = F

Let rotor frequency = F'

Rotor frequency is given by the equation.

$$F' = \frac{\text{Relative speed}}{(120/P)}$$

$$\Rightarrow F' = \frac{N_s - N_R}{120/P} \Rightarrow F' = \frac{N_s - N_R}{N_s} \times \frac{P}{120} \times N_s$$

$$\Rightarrow \boxed{F' = s \times F}$$

Thus the frequency of the rotor current is the product of slip & frequency, so it has called as slip frequency.

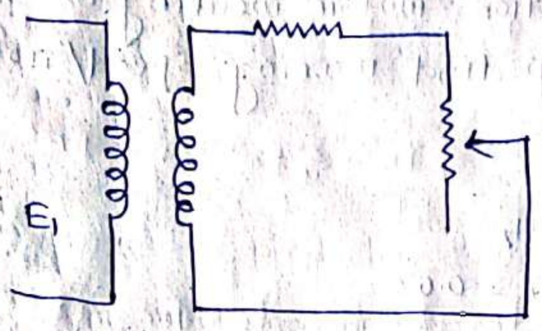
Rotor frequency = 0.03 × 50 = 1.5 Hz

Note :- Induction motor is such a transformer which changes the o/p frequency.

Derivation of torque :-

- A torque of a induction motor depend on the strength of the field & phase relation between them.
- Torque is directly propersional to
  (i) Rotor current (I_2)
  (ii) stator current (Φ)
  (iii) power factor of the rotor circuit (Φ_2)

where K = proportional Constant.

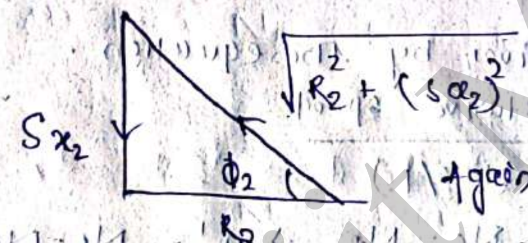


(Rotor Circuit)

$$I_2 = \frac{SE_2}{R_2 + jsx_2}$$

$$\boxed{I_2 = \frac{SE_2}{\sqrt{R_2^2 + (sx_2)^2}}}$$

We know that $\cos\phi_2 = \frac{R_2}{\sqrt{R_2^2 + (sx_2)^2}}$



Again $T = KE_2 \times \frac{SE_2}{\sqrt{R_2^2 + (sx_2)^2}} \times \frac{R_2}{\sqrt{R_2^2 + (sx_2)^2}}$

$$\Rightarrow T = \frac{KSE_2^2 R_2}{\sqrt{R_2^2 + (sx_2)^2}}$$

Q. Derive the torque of induction motor.

Case-1

Starting torque $(s) = \frac{N_s - N_R^0}{N_s} = 1$

$$T_s = \frac{KE_2^2 R_2}{R_2^2 + x_2^2}$$

Case-2

Torque at running condition $T_R = \frac{KSE_2^2 R_2}{R_2^2 + (sx_2)^2}$

Case-3

Maximum torque $\frac{dT}{ds} = 0$

$$\Rightarrow KE_2^2 R_2 \left(\frac{d}{ds}\left(\frac{s}{R_2^2 + (sx_2)^2}\right)\right) = 0$$

$$\Rightarrow K E_2^2 R_2 \left\{ \frac{R_2^2 + (s x_2)^2 \frac{d}{ds} s - s \frac{d}{ds} (R_2^2 + s x_2)^2}{R_2^2 + (s x_2)^2} \right\} = 0$$

$\Rightarrow R_2^2 + (s x_2)^2 - 2 s^2 x_2^2 = 0$

$\Rightarrow R_2^2 + (s x_2)^2 - 2 s^2 x_2^2 = 0$

$\Rightarrow R_2^2 + s^2 x_2^2 - 2 s^2 x_2^2 = 0$

$\Rightarrow R_2^2 - s^2 x_2^2 = 0$

$\Rightarrow \boxed{R_2 = \pm s x_2}$

$\Rightarrow \boxed{s = \frac{R_2}{x_2}}$

What is the condition of maximum torque?

$$T_{max} = \frac{K \times s \times E_2^2 \times s x_2}{s^2 x_2^2 + (s x_2)^2} = \frac{K s^2 x_2 \times E_2^2}{2 (s x_2)^2} = \frac{K s^2 x_2 E_2^2}{2 s^2 x_2^2}$$

$$= \frac{K E_2^2}{2 x_2}$$

$$\boxed{T_{max} = \frac{K E_2^2}{2 x_2}}$$

At starting condition for maximum torque is $\boxed{R_2 = x_2}$

Full load torque :- (T_f)

$T_f = K \times s_f$

$$T_f = \frac{K s_f E_2^2 R_2}{R_2^2 + (s_f x_2)^2}$$

$$\frac{T_{st}}{T_{max}} = \frac{K E_2^2 R_2}{R_2^2 + x_2^2} \times \frac{2 x_2}{K E_2^2} = \frac{2 x_2 R_2}{R_2^2 + x_2^2}$$

$$\frac{T_{st}}{T_{max}} = \frac{\frac{2 R_2}{x_2}}{\frac{R_2^2}{x_2^2} + 1}$$

Let $\frac{R_2}{x_2} = a$, so $\boxed{\frac{T_{st}}{T_{max}} = \frac{2a}{a^2 + 1}}$

$$\frac{T_f}{T_{max}} = \frac{K s_f E_2^2 R_2}{R_2^2 + (s_f x_2)^2} \times \frac{2 x_2}{K E_2^2} = \frac{s_f \, 2 x_2 R_2}{R_2^2 + (s_f x_2)^2}$$

Q.

1) A 3 phase 6 pole 50Hz Slipring induction motor have resistance & reactance of 0.5 Ω & 5 Ω per phase respectively.

Calculate

(i) At what speed the torque is maximum?

(ii) The ratio of $\frac{T_{max}}{T_{st}}$?

(iii) What must be the external resistance per phase have so that the stating torque is half of the maximum torque?

Ans:- Given $P = 6$

$F = 50$

$R_2 = 0.5\ \Omega \quad x_2 = 5\ \Omega$

(i) T_{max} $N_r = (1 - S_m) N_s$

$$S_m = \frac{R_2}{x_2} = \frac{0.5}{5} = 0.1$$

$$N_s = \frac{120F}{P} = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

$$N_r = (1 - 0.1) 1000 = 900 \text{ rpm}$$

(ii) $$\frac{T_{max}}{T_{st}} = \frac{a^2+1}{2a} = \frac{(0.1)^2+1}{2(0.1)} = \frac{1.1}{0.2} = 5.05$$

(iii) $$\frac{T_{st}}{T_{max}} = \frac{1}{2} = \frac{2a}{a^2+1}$$

$$\Rightarrow a^2 + 1 - 4a = 0$$

$a = 1,\ b = -4,\ c = 1$

$$a = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-4(-4) \pm \sqrt{(-4)^2 - 4 \cdot 1 \cdot 1}}{2 \cdot 1}$$

$$= \frac{4 \pm \sqrt{16-4}}{2} = \frac{4 \pm \sqrt{12}}{2} = \frac{4 + \sqrt{12}}{2} \text{ or}$$

$$\frac{4 - \sqrt{12}}{2} = 2 + \sqrt{3} \text{ or } 2 - \sqrt{3}$$

$$= 3.73 \text{ or } 8.27$$

$a = 0.27$

$$a = \frac{0.5 + R_{ext}}{5} = 0.27$$

$\Rightarrow 0.5 + R_{ext} = 0.27 \times 5$

$\Rightarrow R_{ext} = 0.27 \times 5 - 0.5 = 0.85\,\Omega$ (Ans)

2) A 746 kW 3 phase 50 Hz, 16 pole induction motor has a rotor impedance of $(0.02 + j0.15)\,\Omega$ at stand still full load torque is obtained at 360 rpm. Calculate

(i) $\frac{T_{max}}{T_f}$

(ii) The speed for maximum torque

(iii) The rotor resistance to be added to get maximum static torque.

Ans:- Given

$P_W = 746\text{ kW}$

$F = 50\text{ Hz}$

$P = 16$

$Z = (0.02 + j0.15)\,\Omega$

$N = 300\text{ rpm}$

$$N_s = \frac{120F}{P} = \frac{120 \times 50}{16} = 375\text{ rpm} \qquad S_f = \frac{375 - 300}{375} = 0.04$$

(i) $$\frac{T_{max}}{T_f} = \frac{a^2 + s_f^2}{2as_f} = \frac{(0.133)^2 + (0.04)^2}{2 \times 0.133 \times 0.04} = 1.81 \text{ or } 1.78$$

(ii) $N_R = (1-s)N_s = (1 - 0.133) \times 375 = 325.123$

(iii) Maximum static torque & According to the maximum static torque $R_2 + R_{ext} = sX_2$

$\Rightarrow 0.02 + R_{ext} = 1 \times 0.15$

$\Rightarrow R_{ext} = 0.13\,\Omega$

Torque slip characteristic:-

Torque slip characteristic is a curve between torque & slip or speed. It has four (4) types.

Case-1

When the rotor is at stand still

$$N_R = 0, S = 1$$

$$T = \frac{KSE_2^2 R_2}{R_2^2 + (Sx_2)^2}, \quad I \neq 0$$

As, it has a torque present at the starting the induction motor rotates automatically without any external force. So induction motor is self starting.

Case-2

When rotor starts rotating upto some point of slip $(Sx_2)^2 >> R_2^2$, so by neglecting

$$R_2, T = \frac{KSE_2^2 R_2}{Sx_2^2}$$

$$T = \sqrt{\frac{KE_2^2 R_2}{(Sx_2)^2}}$$

$$\Rightarrow \boxed{T \propto \frac{1}{S}}$$

So the curve is shown in the region A to B

Case-3

When $R_2 = Sx_2$ the torque will be maximum

$$T_{max} = \frac{KE_2^2}{4}$$

This torque is also called as break down torque or pull out torque.

Case-4

When the speed increase more & more the slip decreases proportionality

$R_2^2 >> s X_2^2$

$$T = \frac{K s E_2^2 R_2}{R_2^2}$$

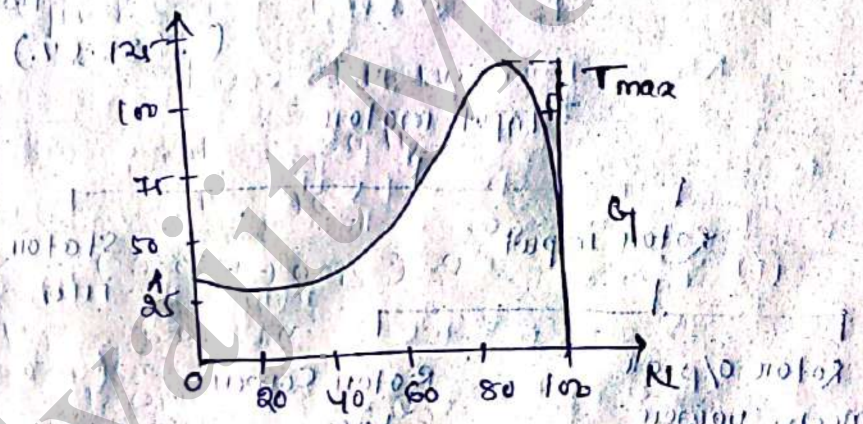
$$\Rightarrow T = \frac{K s E_2^2}{(R_2)}$$

$$\Rightarrow T \propto s$$

This is shown in the region C-D when, $s = 0$, $T = 0$

when rotor speed ~~torque becomes~~ acquires the synchronous speed the torque becomes zero & motor comes to half.

Generally, the motor operates in F-G region where, the slip varies from 0.03 to 0.05.



Losses :-

(i) Stator Copper loss ($3I_1^2 R_1 \simeq 3.5\%$)

(ii) Stator iron loss ($\simeq 2.5\%$)

(iii) Rotor Copper loss ($\simeq 3.5\%$)

(iv) Friction & windage losses ($\simeq 2\%$)

Power flow diagram :-

Electrical power i/p to stator $= 3V_1I_1 \cos\phi_1$ (100%)

air gap power to rotor $= 3E_2I_2 \cos\phi_2$

Stator copper loss $= 3I_1^2R_1$ ($\simeq 3.5\%$)

Stator iron loss ($\simeq 2.5\%$)

Mechanical power developed in rotor

rotor copper loss ($\simeq 3.5\%$)

Mech power o/p at shaft

friction & windage losses ($\simeq 2\%$)

($\simeq 88.5\%$)

Input motor

Rotor input | Stator Copper & iron loss

Rotor o/p or mech. power develop at rotor | Rotor Copper loss.

p (mech)

Rotor o/p (P(out)) at shaft | friction & winding losses

Induction motor torque :-

T_{sh} = Shaft torque

T_g = Gross torque

N = rotor speed in rpm

$$P_{out} = \omega T_s = \frac{2\pi N}{60} T_{sh}$$

$$\boxed{\begin{aligned} T_{sh} &= \frac{60}{2\pi N} P_{out} \\ T_{sh} &= 9.55 \frac{P_{out}}{N} \\ T_g &= 9.55 \frac{P_{mech}}{N} \end{aligned}}$$

$P_{mech} = T_g$

$P_{out} = T_{sh}$

Rotor Output :-

P_2 = power input to the rotor or air gap power

$P_2 = \omega T$

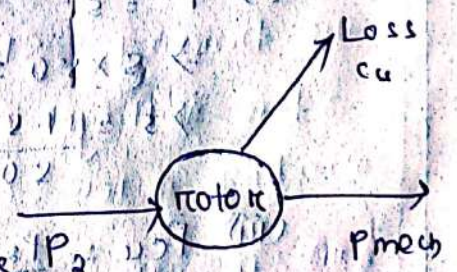
$$\boxed{P_2 = \frac{2\pi N_s}{60} T}$$

T = torque in Newton meter

N_s = Speed of rotor

$$\boxed{P_{mech} = \frac{2\pi N_r}{60} T} \qquad \boxed{P_{mech} = \frac{2\pi (1-s) N_s T}{60}}$$

Rotor Cu loss :-



$P_{cu} = P_2 - P_{mech}$

$= \frac{2\pi}{60} \cdot \frac{N_s - N_R}{N_s} T N_s$

$$\boxed{P_{cu} = \frac{2\pi}{60} s N_s T}$$

$$\boxed{\begin{gathered} P_2 : P_{mech} : P_{cu} \\ 1 : (1-s) : s \end{gathered}}$$

Q

The power input to the rotor of a 440V, 50Hz, 3 phase, 6 pole is 60 kW, it is observe that the rotor emf makes 90 revolutions per minute. Calculate.

(i) slip
(ii) Rotor
(iii) Rotor Copper loss
(iv) Mech power.

Ans:-

Given

$V = 440V$

$F = 50 Hz$

$P = 6$ pole

$P_2 = 60 kW$

$N_s = \frac{120F}{P} = \frac{120 \times 50}{6}$

$F' = \frac{90}{60} = 1.5 Hz$

(i) $F' = sF$

$\Rightarrow s \times 50 = 1.5$

$\Rightarrow s = \frac{1.5}{50} = 0.03$

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

$= (1-0.03) \times 1000$

$= 970$ rpm

(iii) $P_{cu} = \frac{P_2}{P_{cu}} = \frac{1}{s}$ $\quad \frac{60}{P_{cu}} = \frac{1}{0.03}$

$P_{cu} = 60 \times 0.03$

$P_{cu} = 1.8 kW$

(iv) $P_{mech} = \frac{P_2}{P_{mech}} = \frac{1}{(1-s)}$

$\frac{60}{P_{mech}} = \frac{1}{1-0.03}$

$P_{mech} = 60 \times 0.97$

$P_{mech} = 58.2 kW$

'start' button 'stop' button' 'No' Contactors, NVC & a NC contactor.

When the start button is pressed the circuit is energized. as a result the No contactors becomes closed. As a result the current close in main circuit & motor starts operating.

3) Even if 'start' button released still current flows in the control circuit because of a parallel No contactor with switch.

4) When there is a overload current the relay triggers the NC contactor to be open hence the control circuit is de energized hence the motor comes to hold on motor stop.

Torque developed:-

Rotor Copper loss = Slip power i/p to the rotor

$$\Rightarrow 3I_2^2 R_2 = s \times \omega T$$

$$\Rightarrow T = \frac{3I_2^2 R_2}{s\omega}$$

$$\Rightarrow \boxed{T \propto \left(\frac{I_2^2}{s}\right)}$$

Let starter current is I_1

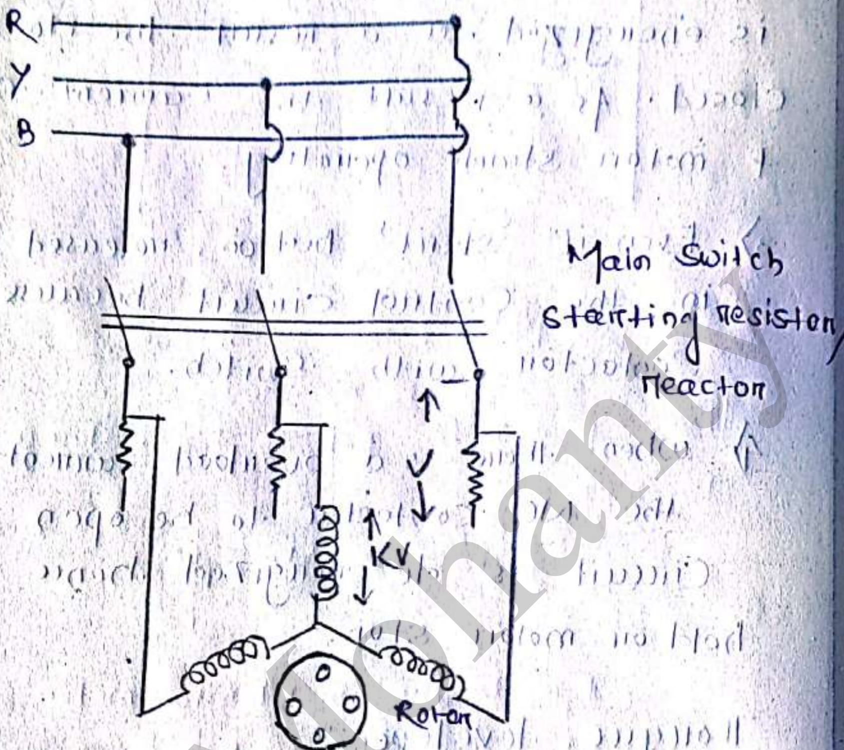
$$T_{st} = k \frac{I_{st}^2}{1} \quad (k = \text{proportional constant})$$

$$T_f = k \frac{I_f^2}{s_f}$$

$$\frac{T_{st}}{T_f} = \frac{I_{st}^2}{I_f^2} s_f = \left(\frac{I_{st}}{I_f}\right)^2 s_f$$

$$\Rightarrow \boxed{T_{st} = \left(\frac{I_{st}}{I_f}\right)^2 s_f \, T_f}$$

Primary resistor starter :-



(i) In a squirrel cage induction motor resistor or Reactor are connected in series with stator windings. Here resistors are variable resistors.

(II) During starting high resistance set up that less voltage is develope across the stator winding & less current flows accordingly.

(III) If the applied voltage is V the winding voltage becomes KV due to presence of series resistors K is proportional constant (0 to 1).

Torque developed :-

$$T_{st} = \left(\frac{I_{st}}{I_f}\right)^2 S_f T_f$$

$$\Rightarrow T_{st} = \left(\frac{K I_{sc}}{I_f}\right)^2 \times S_f T_f \quad \left[\because I_{st} = K I_{sc}\right]$$

$$\Rightarrow T_{st} = K^2 \left(\frac{I_{sc}}{I_f}\right)^2 \times S_f T_f$$

$$\boxed{\begin{array}{l} T_{st} = K^2 \times (T_{st})\ \text{DOL} \\ T_{st}\ :\ \text{resistance} = K^2\ (T_{st})\ \text{DOL} \end{array}}$$

Advantage :-

(i) Smoth accelaration

(ii) High power factor during start.

(iii) Less expensive then auto transformer starter.

(iv) Available with 7 accelerating points.

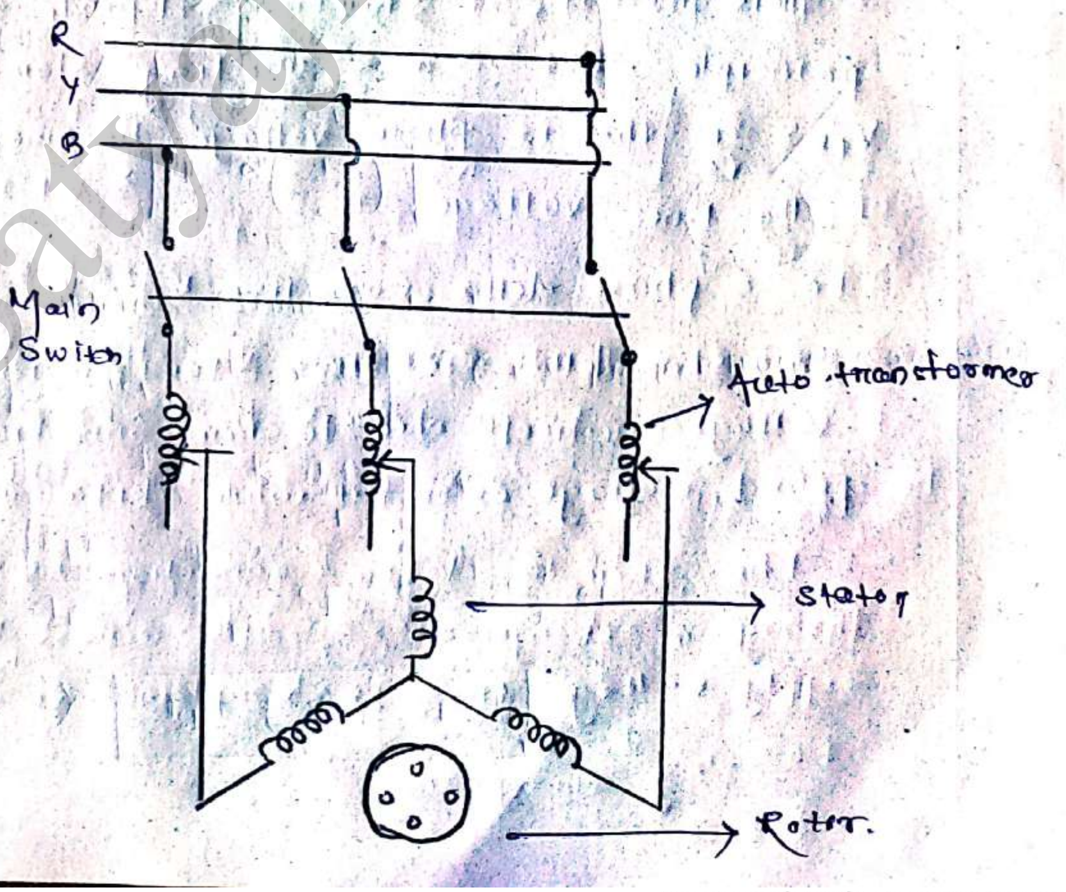
Disadvantage :-

(i) Resistors have heat loss (I^2R)

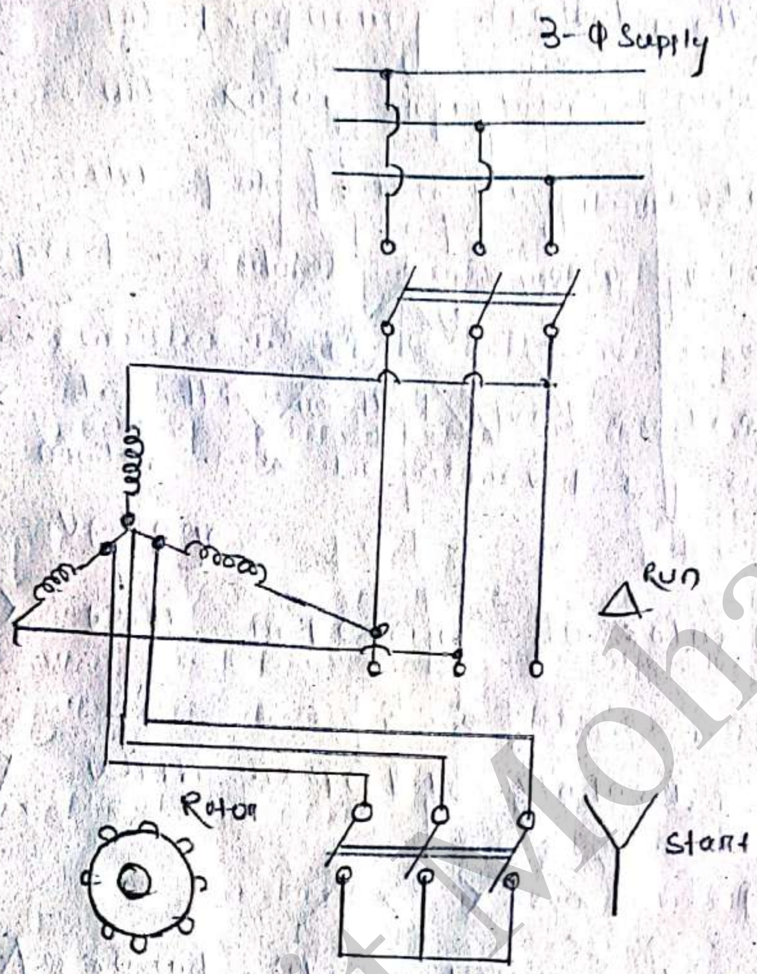
(ii) Expensive resistors are needed because starting duration exceeds 5 seconds usually.

(iv) Starting voltage is difficult to adjust.

(iii) Auto Transformer Starter :-



Star - Delta Starter :-



- This method of starting depends on the principle that in a 3 winding star connection $V_{ph} = \frac{V_L}{\sqrt{3}}$ that is phase voltage becomes 57.7% of the line voltage.
- In 3 phase delta connection $V_{Ph} = V_L$
- In star delta ~~connection~~ starter initially the voltage reduces due to star connection & the applied voltage is in full while delta connection.
- The star to delta connection is accomplished through a change over switch across the same supply voltage this is explained as the following diagram.

Torque :-

$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 s_f$$

$$V_{st} = \frac{V_{sr}}{\sqrt{3}}$$

$$\Rightarrow I_{st} = \frac{I_{sc}}{\sqrt{3}}$$

$$\Rightarrow \left(\frac{\frac{I_{sc}}{\sqrt{3}}}{I_f}\right)^2 s_f = \frac{1}{3}\left(\frac{I_{sc}}{I_f}\right)^2 s_f$$

$$\boxed{T_{st} = \frac{1}{2} \times \text{torque produced by DOL starter}}$$

Application :-

- This method has limited application where high starting torque is not an essential requirement. For example machine, tools, pumps, motor generator set, etc.
- This method is on suitable for line voltage exceeding 800 volt.
- It is used for motor of rating between 4kw to 20kw.

Precaution :-

The change over from star-to-delta should be made when the motor attain the 90% of synchronous speed.

Speed Control of an induction motor :-

We can control two speed of an induction motor by 4 ways.

(i) Voltage control method
(ii) frequency control method
(iii) Rotor resistance control method.
(iv) pole changing control method.

Speed control by voltage control method:

→ In this method speed control of induction motor can be achieved by applying varying voltage.

→ With reference to rotor $I_2 = \frac{E_2}{\sqrt{(\frac{R_2}{s})^2 + (x_2)^2}}$

→ With respect to stator $I_2 = \frac{V}{(\frac{R_2}{s})^2 + (x_2')^2}$

Arround the rated speed the slip is so small that $\frac{R_2}{s} >> x_2'$

⇒ $\boxed{I_2' = \frac{sV}{R_2'}}$ Torque $(T) \propto V I \cos\phi$

$\propto VI \times sV$

Result:-

$\Rightarrow \boxed{T \propto sV^2}$

→ At full load speed if the slip is developed at constant torque the voltage applied should be $\frac{1}{\sqrt{2}}$ time & rotor current would be $\sqrt{2}$ time.

$T \propto 2s\left(\frac{V}{\sqrt{2}}\right)^2$

$I_2' = \frac{2s\left(\frac{V_2}{\sqrt{2}}\right)}{R_2'} = \sqrt{2}\,\frac{sV_2}{R_2'}$

- The motor therefore gates over heated so special care is taken in this method of control so that the motor is not damaged because of excessive current at reduced speed.
- At constant of when voltage is reduced the speed also gates reduced.

Application :-

- It is very simple low cost low maintenance cost.
- This method is used only on loads where torque required drop off when the speed ~~too~~ is reduced. Such as small squirrel cage motor with driving fans.

Limitation:-

→ The operation voltage exciting the rated voltage is restricted by magnetic saturation.

→ Large changing voltage is required for small changing speed.

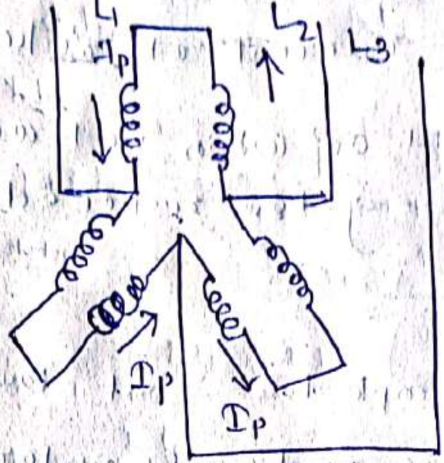
→ The range of speed control is very limited in the downward direction that is form rated speed lower speed.

Speed control by pole changing :-

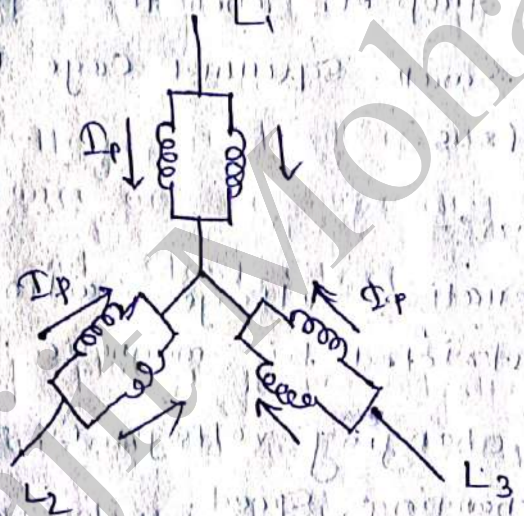
As we know stator speed depends upon pole $N_s = \frac{120f}{P}$ when number of pole is increase the synchronous speed decrease & vice-versa.

$N = (1-s) N_s$ Hence due to reduced synchronous speed the rotor speed is decreases.

→ For Constant of operation



(P↑) Low Speed Series delta

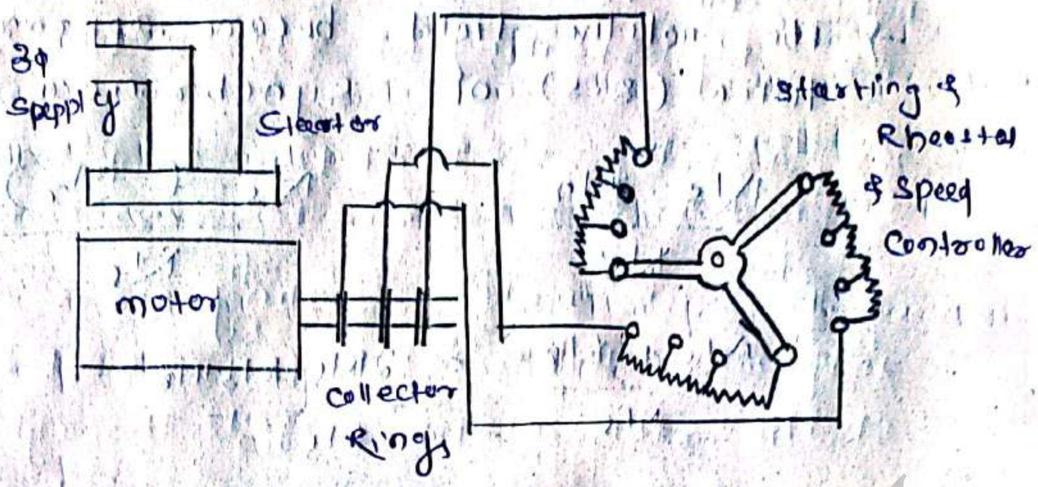


(P↓) High Speed parallel Star

Generally this method is applied as the number of pole is depends on the ckt Configuration to change the no-of pole the ckt should be rechanged.

(III) Rotor Resistance Control :-

In this method of Control which is applicable to slip ring motors, the motors speed is reduced by introducing Connecting an external resistance in the rotor ckt.



Here torque is $\boxed{T \propto \frac{S}{R_2}}$

At Constant torque $\Rightarrow S \propto R_2$

$\Rightarrow N \propto \frac{1}{R_2}$

Disadvantage:-

- With increasing rotor resistance I^2R loss increase decreasing the efficiency.
- It is speed is not only depend on R_2 but also depend on load.

Frequency Control:-

As we know that $N_s = \frac{120f}{P}$

$\Rightarrow N_r = (1-s)N_s$

$\Rightarrow N_r \propto f$

When frequency of the supply increases rotor speed also increases & vice-versa.

plugging: (Control current breaking):-

It is a mechanism of stopping a motor by reversing any two phase which cause a reversal of direction of the rotating magnetic field.

→ At the instant of switching the motor to the plugging position the motor runs in opposite direction to that of field.

→ The relative field become approximately twice (2-s) of synchronous speed.

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

$$= \frac{N_s + N_r}{N_s} = \frac{2N_s - N_s + N_r}{N_s}$$

$$= \frac{2N_s - (N_s - N_r)}{N_s}$$

$$= 2 - \frac{(N_s - N_r)}{N_s} = (2-s)$$

→ So voltage induced in the rotor will be twice on the normally induced voltage at stand steel.

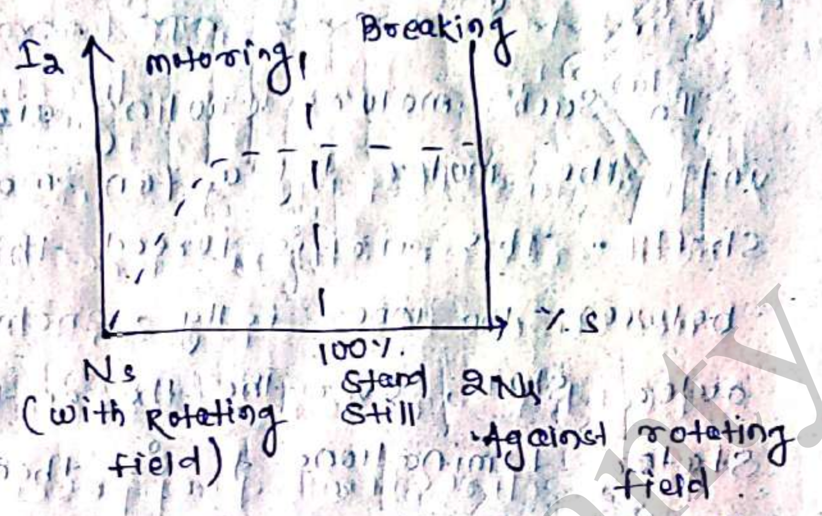
→ During plugging period the motor itself act as a break & absorve kinetic energy from the revolving load. It causes the fall of speed.

→ The associated power P_{mech} is dessipated as heat in the motor. At the same time the rotor also draws power from the stator which is also dessipated as heat.

→ Due to increase rotor frequency rotor loss & copper loss also increases.

→ Thus the heat produced during breaking period each about three times the heat produced during starting period.

→ Thus due to energy west as a form of heat there is o/p power left to rotate the rotor hence motor stops & one point of time.



Different type of motor encloser :-

1) encloser & Semienclosed motor are identical with open motor in mechanical construction & operation characteristic

Type of encloser :-

1) Totally enclosed Non-ventilated type :-

→ Such motors have solid frame & end-shields, but no openings for ventilation.

→ Such surface-cooled motors are ~~not~~ seldom furnished in sizes above two or three kw, because higher ratings require frames of much larger sizes than fan-cooled motors of corresponding rating.

2) Splash-proof Type :-

In the frame of such motor, the ventilating openings are so constructed that the liquid ~~are~~ drops or such particles falling on the motor are coming towards it in a straight line at any angle not greater than 100° from the vertical not able to enter the motor either directly or by striking of running along the surface.

3) Totally-enclosed fan-cooled Type:-

In such motors cooling air is drawn into the motor by a fan mounted on the shaft. This air is forced through the motor between the inner fully-enclosed frame & an outer shell, over the the end balls & the stator laminations & is then discharged through opening es the opposite side.

4) Cowl-covered motor:-

- These motors are simplified form of fan-cooled motors.

- There consist of totally-enclosed frame with a fan & cowl mounted at the end opposite to the driving end.

- The air is drawn into the cowl with the help of fan & is then forced over the frame.

→ These motors are superior to the usual fan-cooled motors for operation in extremely dusty atmosphere i.e gas works chemical works, Oil, callories & quarries etc. because there are no air passages which will become closed with dust.

5) protected type:-

This construction consists of perforated covers for the openings in both end shields.

6) Drip - proof motors:-

The frames of such motors are so constructed that liquid drops or dust particles, falling on the machine at any angle greater than machine at any angle greater than 15° from the vertical, cannot enter the motor, either directly or by striking & running along a horizontal or inwardly inclined smooth surface.

7) Self (pipe) ventilated Type:-

→ The construction of such motors consists of enclosed shields with provision for pipe connection on both the shields.

→ The motor fan circulates sufficient air through pipes which are of ample section.

8) Separately (forced) Ventilated Type:-

These motors are similar to the self-ventilated type, except that ventilation is provided by a separated blower.

Principle of induction Generator:-

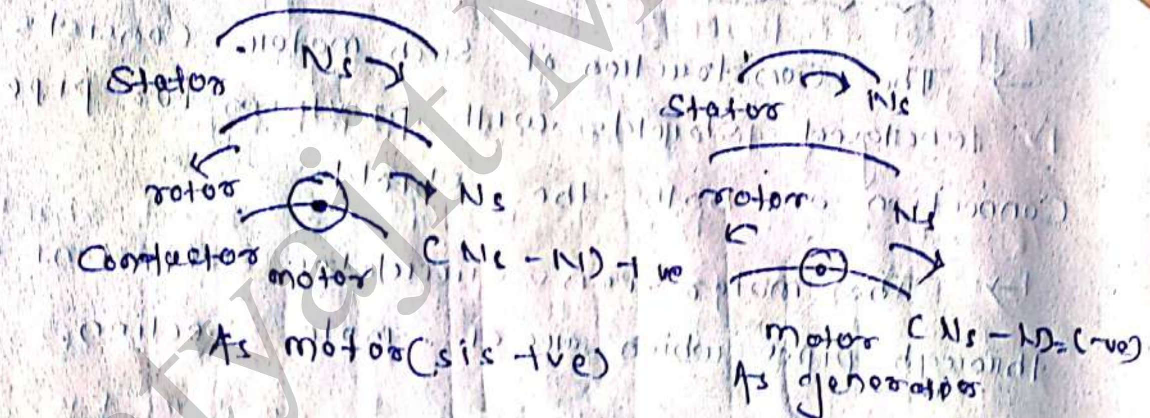
If a polyphase induction motor with constant voltage & frequency supply is coupled with a prime over & is driven by it at a higher speed than the synchronous speed then the motor act as a generator this is called as induction generator.

→ Here the rotor over take the rotor magnetic field & rotor conductor cut the magnetic flux in a reverse direction.

→ As a result EMF & currents in the rotors will reverse there direction hence the reaction force between the rotating field & rotor current also change its direction & opposes the rotation.

$$N_r > N_s$$

$$S = \frac{N_s - N_r}{N_s} = (-ve)$$



→ To maintain this rotation mechanical this required to the rotor.

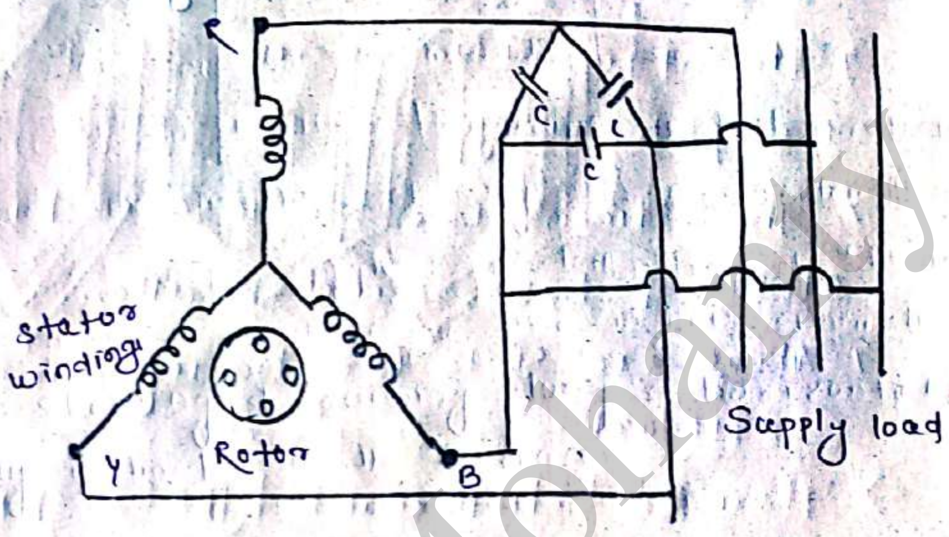
– The magnetising current remains the same as rotating field condition as same in both induction motor & generator.

– As the torque in -ve direction the power develop also be -ve $(P = \omega T)$

→ The slip is -ve & emf consist with active component of current in state of opposing it.

→ Here power supply occurs from rotor to stator

→ when stator is connected to the main supply it delivers power to the main supply or load through a capacitor ban.



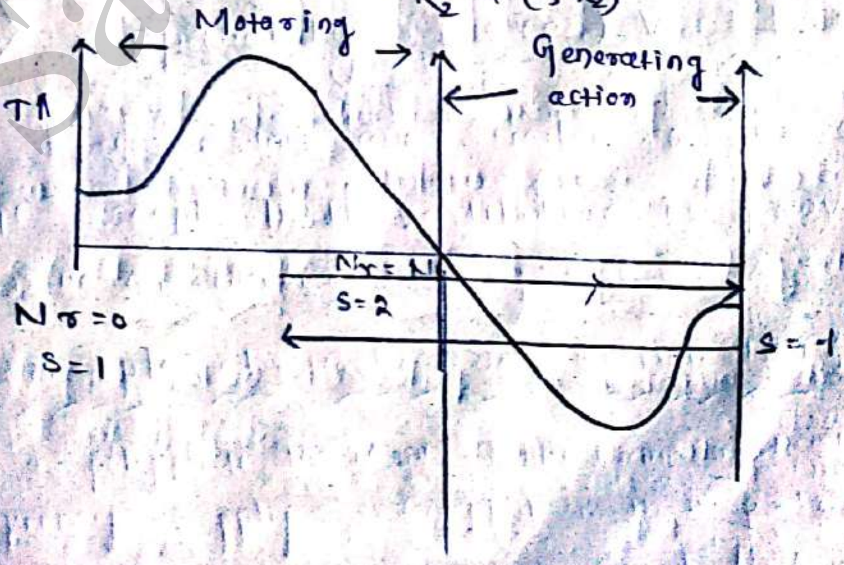
Torque characteristic (T~S):-

$$T \propto \phi_2 I_2 \cos\theta_2$$

$$T = \frac{ks I_2^2 R_2}{R_2^2 + (sx_2)^2}$$

As s is -ve

$$T = \frac{ks E_2^2 R_2}{R_2^2 + (sx_2)^2}$$



Application :-

It is used in windmills hoists in polyphase induction machine where small increasing speed caused full generation action for exhausting a applying a strong breaking action.