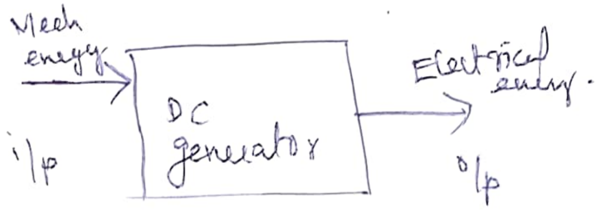
Unit - II

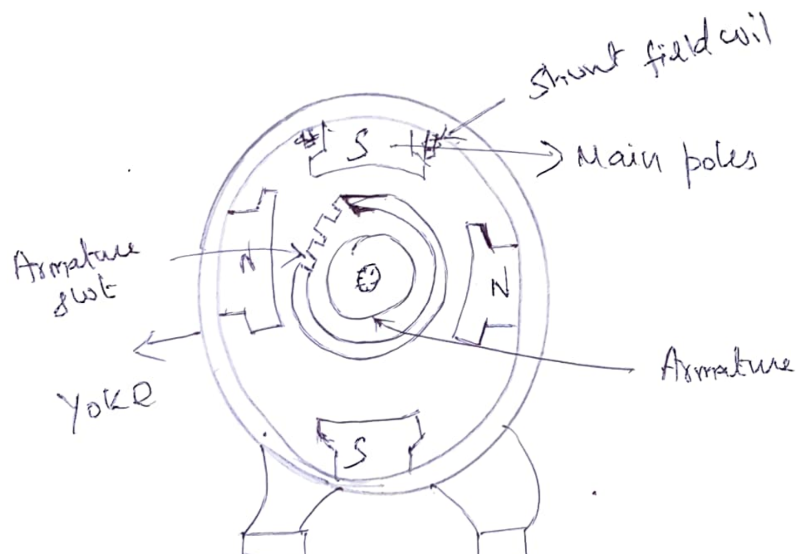
Electrical Machines

DC Generator:-



Constructional Details:-

1. Magnetic frame (or) Yoke
2. poles, interpoles, windings, pole shoes
3. Armature
4. Commutator
5. Brushes, bearings and shaft.



Magnetic frame:-

* It acts as a protecting cover for the whole m/c. and provides mechanical support for the poles.

Poles:-

The poles consist of (i) pole core, (ii) pole

Shoes, (iii) pole coil. The pole cores pole shoes form the magnetic field.

For very small machines the poles are made Cast iron. For large m/c cast steel is used. To minimize eddy current losses, the poles is laminated.

3)

Armature:-

The armature consists of an armature core and armature windings. The armature along with the conductors ~~rotates~~ rotates under the poles and hence the flux produced by the field magnets is cut by the armature conductors.

Commutator:-

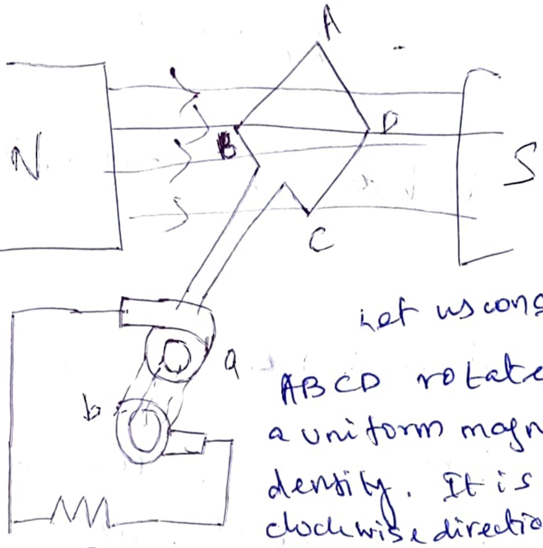
The Commutator converts the alternating emf into uni directional (or) direct emf. It is made up of copper segments.

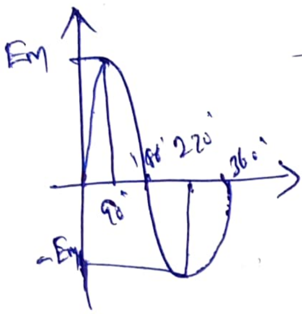
Brushes and Bearings:-

The brushes which are made up of Carbon (or) graphite, collect the current from the commutator and to convey it to the external load resistance.

Ball bearings are employed for light ~~machines~~ Machines. For heavy duty machines roller bearings are used.

Principle of Operation:-





Let us consider a single turn coil ABCD rotated on shaft within a uniform magnetic field of flux density. It is rotated in an anti clockwise direction.

Let 'l' be the length and 'b' be the breath of coil in meters. AB and CD are moving ll^el to the magnetic field, the flux lines are not being cut and no emf is induced in the coil.

The vertical position of the coil is the ~~starting~~ starting position. According to Faradays law, the emf induced is proportional to the rate of change of flux linkages.

$$e = -N\frac{d\phi}{dt}$$ ~~volts~~

Where N is the number of turns, ϕ is the flux t is the time,

As $N=1$, $e = -\frac{d\phi}{dt}$ volts

When coil is moving ll^el to the flux lines, no flux line is cut and hence,

$$\frac{d\phi}{dt} = 0 \text{ and } e = 0$$

After time 't' sec, the coil would have rotated through an angle ωt radians in the anticlockwise direction.

The flux then linking with the coil is $Blb\cos\theta$.

$$\therefore e = -\frac{d}{dt}(Blb\cos\omega t)$$

$$\boxed{e = E_m \sin\omega t}$$

$E_m - Blb\omega$; E_m - max. value of induced emf.

EMF Induced in A DC Generator:-

Let ϕ be the flux per pole in webers.

Let P be the no. of poles.

Let Z be the total number of conductors in the armature. Each parallel path will have Z/A conductors in series.

Let N be the speed of rotation in revolutions per minute. (rpm).

~~conductor~~ conductor makes one complete revolution, it cuts $P\phi$ webers. As the speed in N rpm, the time taken for one revolution is $\frac{60}{N}$ sec.

Since the emf induced in the conductor = rate of change of flux cut,

$$e \propto \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{NP\phi}{60} \text{ volts.}$$

$$e = \frac{NP\phi}{60} \text{ volts.}$$

Since there are Z/A conductors in series in each $\parallel^{el}$ path the emf induced,

$$E_g = \frac{NP\phi}{60}\frac{Z}{A} = \frac{\phi Z N}{60}\frac{P}{A} \text{ volt.}$$

$\therefore$ lapwinding is $A = P$, wave winding $A = 2$ always.

bearings are worn.

1) Calculate the emf generated by a 6 pole DC generator having 480 conductors and at a speed 1200 rpm. The flux per pole is 0.012 Wb. Assume the generator to be (a) lap wound, b) wave wound.

Sol:-

$$E_g = \frac{\phi Z N}{60} \times \frac{P}{A}$$

a) For a lap wound Machine, $A = P = 6$

$$E_g = \frac{0.012 \times 480 \times 1200 \times 6}{60 \times 6} = 115.2 \text{ volts}$$

$\boxed{E_g = 115.2V}$

b) For a wave wound machine, $A = 2$

$$E_g = \frac{0.012 \times 480 \times 1200 \times 6}{60 \times 2} = 345.6 \text{ volts}$$

$\boxed{E_g = 345.6V}$

2) The armature of a 4 pole, 600 rpm, lap wound generator has 100 slots. If each coil has 4 turns, calculate the flux per pole required to generate an emf of 300V.

Given:

$P = 4$, $N = 600$ rpm, No. of slots $= 100$, $E_g = 300V$.

Each turn has two Active conductors and 100 coils are required to fill 100 slots. ∴ number of conductor $Z = 100 \times 4 \times 2 = 800$; for lap wound generator $A = P = 4$.

To find,

Flux per pole (ϕ)

Sol:-

$$E_g = \frac{P\phi Z N}{60 A}$$

$$\phi = \frac{E_g \, 60 A}{P Z N} = \frac{300 \times 60 \times 4}{4 \times 800 \times 600}$$

$\boxed{\phi = 37.5 \text{ mWb.}}$

According to Lenz's law,

The direction of the back emf opposes the supply voltage. The back emf is given by the equation for induced emf,

$$E_b = \frac{\phi Z N}{60} \times \frac{P}{A} \text{ Volts.}$$

The voltage equation of DC motor is,

$$V = E_b + I_a R_a \text{ Volts.}$$

From above equation armature current, is,

$$I_a = \frac{V - E_b}{R_a} \text{ Amps.}$$

Power relationship of DC motor:-

$$V = E_b + I_a R_a \rightarrow (1)$$

$\times I_a$ equ (1)

$$V I_a = E_b I_a + I_a^2 R_a \rightarrow (2)$$

Power developed by Motor is, $P_m = E_b I_a \rightarrow (2a)$

From equ (2).

$$V I_a - I_a^2 R_a = E_b I_a \rightarrow (4)$$

equ (2a) sub in equ (3)

$$P_m = V I_a - I_a^2 R_a$$

diff. $\frac{d P_m}{d I_a} = V - 2 I_a R_a$

For Maximum Mech. power $\frac{dP_m}{dI_a}$ is zero.

∴ The power developed in armature is max. when the back emf is equal to the half of the i/p voltage.

$$\frac{dP_m}{dI_a} = 0.$$

$$V - 2 I_a R_a = 0$$

$$-2 I_a \cdot R_a = -V$$

$$\boxed{I_a R_a = V/2}$$

$$\therefore V = E_b + \underline{I_a R_a}$$

$$\therefore V = E_b + \frac{V}{2}$$

$$\boxed{E_b = V/2}$$

∴ lap winding is A = P,

1. A DC Motor connected to a 460V supply has an armature resistance of 0.15Ω. Calculate (a) the value of back emf when the armature current is 120A. (b) the value of armature current when the back emf is 447V.

$V = 460V$; $R_a = 0.15\Omega$, $I_a = 120A$. $E_b = ?$

Sol:-

a) $V = E_b + I_a R_a$

$E_b = V - I_a R_a$

$= 460 - (120 \times 0.15)$

$\boxed{E_b = 442V}$

b) $I_a R_a = V - E_b$

$I_a = \frac{V - E_b}{R_a}$

$I_a = \frac{460 - 447}{0.15} = \frac{13}{0.15}$

$I_a = 86.67A.$

2. A 4 pole DC motor takes an armature current of 150 A at 440V. If its armature circuit has a resistance of 0.15Ω, what will be the back emf at this load.

$P = 4$, $I_a = 150A$, $R_a = 0.15\Omega$, $V = 440V$

Sol:-

$V = E_b + I_a R_a$

$E_b = V - I_a R_a = 440 - (150 \times 0.15) = 417.5V$

Applications:-

* Cranes, fans, conveyers, lift etc.

Transformer:-

The transformer works on the principle of electromagnetic induction. A transformer is an electrical device, having no moving parts, which by mutual induction transfers electric energy from one circuit to another at the same frequency. It consists of two winding,

(i) Primary winding (ii) Secondary winding.

[Alternating voltage is connected across one of the windings called the primary winding.]

$$\text{Form Factor} = \frac{\text{Rms value}}{\text{Avg. value}} = 1.111$$

$$\text{Rms value} = 1.11 \times \text{Avg. value}.$$

$$= 1.11 \times 4f\phi_m = 4.44 f\phi_m \text{ volts}.$$

∴ Rms Value of emf induced in the entire primary winding.

$$E_1 = 4.44 f\phi_m \times N_1 \rightarrow (1)$$

∴ Rms value of emf induced in the secondary winding.

$$E_2 = 4.44 f\phi_m \times N_2 . \rightarrow (2)$$

Transformation Ratio:- (K):-

For an ideal transformer,

$$V_1 = E_1 \; ; \; V_2 = E_2 \text{ and } V_1 I_1 = V_2 I_2$$

$$\frac{V_2}{V_1} = \frac{I_1}{I_2}.$$

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} \; ; \; \frac{E_2}{E_1} = \frac{I_1}{I_2}.$$

equ (1) ÷ (2).

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = k.$$

Where, 'k' is called transformation ratio.

$$\text{Voltage ratio} \Rightarrow \frac{E_2}{E_1} = k$$

$$\text{Current ratio} \Rightarrow \frac{I_2}{I_1} = \frac{1}{K}$$

$$\text{Form Factor} = \frac{\text{Rms Value}}{\text{Avg. value}} = 1.111$$

$$\text{Rms value} = 1.11 \times \text{Avg. value.}$$

$$= 1.11 \times 4 f \phi_m = 4.44 f \phi_m \text{ volts.}$$

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1) The no load ratio required in a single phase 50Hz transformer is 6600/300 V. If the maximum value of flux in the core is to be about 0.09 weber. Find the number of turns in each winding.

Given:-

$f = 50Hz$, Primary winding $V_1 = 6600\,V$

Secondary voltage $V_2 = 300V$, max. value of flux $\phi_m = 0.09$ wb.

To find:-

The number of turns in primary and secondary winding (N_1 and N_2)

Sol:-

$$V_1 = E_1 = 4.44 f \phi_m N_1$$

$$V_2 = E_2 = 4.44 f \phi_m N_2$$

primary turns

$$N_1 = \frac{V_1}{4.44 f \phi_m} = \frac{6600}{4.44 \times 50 \times 0.09} = 330$$

secondary turns

$$N_2 = \frac{V_2}{4.44 f \phi_m} = \frac{300}{4.44 \times 50 \times 0.09} = 15.$$

2. A 1ϕ, 25 Hz transformer has 50 primary turns and 600 secondary turns. The cross sectional area of the core is 400 sq.cm. If the primary of the transformer is connected to 230V supply. Find (i) the secondary induced emf (ii) the flux density in the core.

Given:-

$f = 25\,Hz$; $N_1 = 50$; $N_2 = 600$, $E_1 = 230V$,

cross sectional area of the core $A = 400$ sq.cm $= 400 \times 10^{-4}$ sq.m

Sol:- The secondary induced emf

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

$$E_2 = E_1 \cdot \frac{N_2}{N_1} = 230 \times \frac{600}{50}$$

$$E_2 = 2760\,V$$

(ii) maximum Value of flux density :- (B)

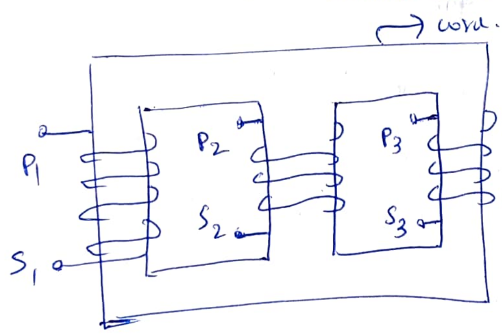
$$E_1 = 4.44 f \phi_m N_1$$

$$\phi_m = \frac{E_1}{4.44 f N_1} = \frac{230}{4.44 \times 25 \times 50} = 0.0414 \text{ Wb}$$

$$B_m = \frac{\phi_m}{A} = \frac{0.0414}{400 \times 10^{-4}} = 1.036 \text{ Wb/sq.m}$$

3φ Transformer:-

In a 3φ System, the 3phase voltage can be stepped up (or) stepped down by using a single unit of 3φ Transformer. It consist of 3φ core type Transformer and each winding (primary ~~or~~ and secondary) to provide path of returning flux. The primary and secondary windings may be star (or) Delta Connected. Based on the construction



of core, (i) core type 3φ Transformer (ii) shell type 3φ Transformer

3φ Transformer connection:-

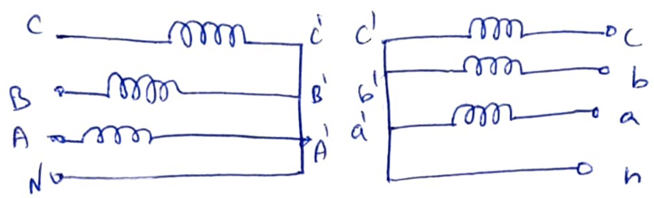
The Different 3φ Transformer Connections are,

(i) Star to Star connection (ii) Delta - Delta connection.

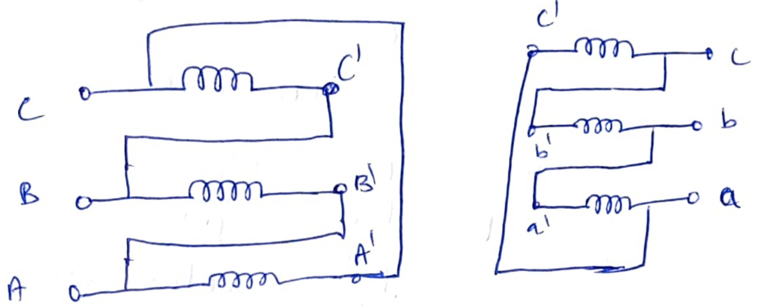
(3) Star - Delta (4) Delta star (5) open Delta.

synch

Star to star:-



Delta Delta:-



Application:-

*) It is used to Regulating alternating current

*) It is used to increase (or) decrease the alternating voltages in electric power applications.

*) It is used for Impedance matching.

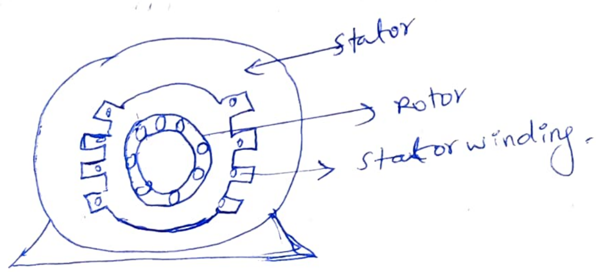
*) It is used in Electrochemical Industry and Battery charging purpose.

Single phase Induction Motor.

The single phase motors are small motors. These motors are used in homes, offices, and factories. The single phase motors are simple in construction. The main disadvantages of these motors are,

*) Lack of starting torque, *) Reduced power factor *) Low efficiency.

Construction:-



It consists of two parts. one is stator and another one is rotor. The air gap b/w stator and rotor is uniform. There is no external connection b/w stator and rotor,

working:-

Double Revolving Field Theory:-

A single phase Ind consists of single phase winding on the stator and a cage winding on the rotor. When a 1ϕ supply is connected to the Stator winding, a pulsating magnetic field is produced. In the pulsating field, the rotor does not rotate due to inertia. There fore a 1ϕ IM is not self starting and requires some particular starting torque. fo rotating Machine.

The single phase supply is applied to the stator winding which produces the alternating flux. The alternating field produces an emf of the rotor conductor by the Principle of Mutual Inductance when the rotor circuit is closed.

There are Different methods for starting a 1ϕ IM, and it can classified into:

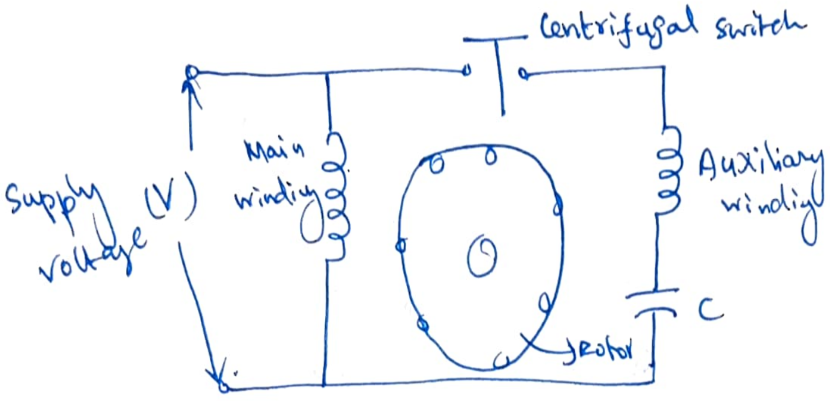
*) split phase IM *) capacitor start and cap. Run IM.

*) shaded pole type IM

Split Phase IM:-

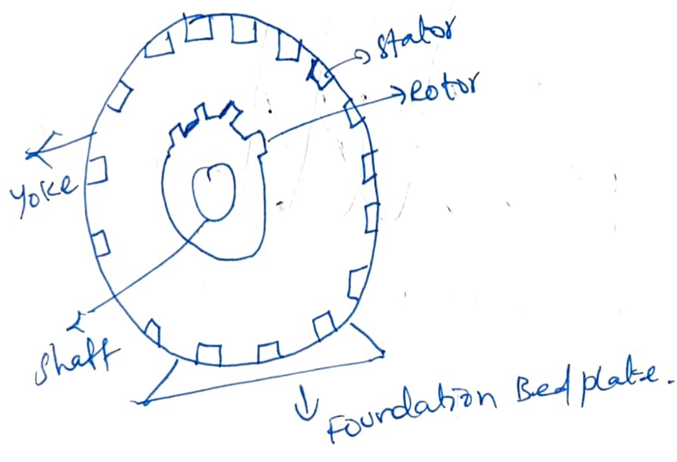
The stator of a split phase IM consists of 2 windings such as,

1. Main windings (or) Running winding.
2. Auxiliary winding (or) starting winding.



The 1ϕ supply is given to the stator due to which a rotating magnetic field is produced. The rotating magnetic field which cuts the conductor and the magnetic field is produced in the rotor. According to the magnetic field, the interaction b/w the stator and rotor magnetic field, the torque is developed and the motor starts to rotate.

3ϕ Induction Motor:-



Stator:-

The stator is the stationary part of the motor. The stator winding may be 3ϕ star connection (or) Delta connection format.

Rotor:-

The Rotor is the rotating part of IM. Rotor types

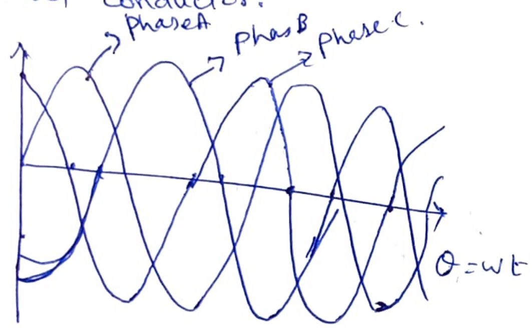
* Squirrel cage Induction Motor
* Wound Rotor Induction Motor. (or) slip ring.

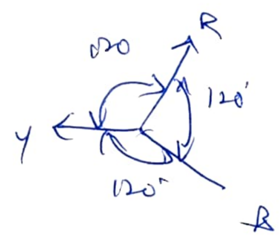
Working:-

The Induction Motor works under the principle of Electromagnetic Induction. When a 3ϕ is given to a 3ϕ stator winding a rotating magnetic field is produced in the stator. In which the ~~magnitude~~ magnetic flux is constant and rotates at synchronous speed. The syn. speed is given by,

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

According to Faraday's law of Electromagnetic Induction the emf is induced in the rotor conductor which depends on the speed b/w rotating field and rotor conductor. The direction of induced emf is given by Fleming's left hand rule. The magnitude of induced emf is proportional to velocity b/w the flux and conductor.





The Resultant flux is the phasor sum of ϕ_R, ϕ_Y, ϕ_B.

$$\phi_{Res} = \phi_R + \phi_Y + \phi_B.$$

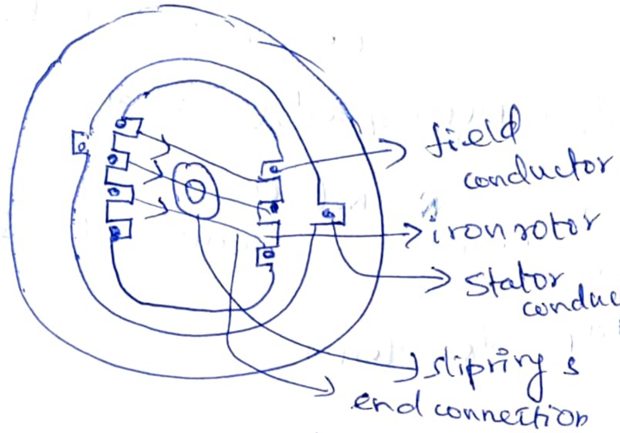
$$\phi_R = \phi_m \sin\omega t;\ \phi_Y = \phi_m \sin(\omega t - 120°);\ \phi_B = \phi_m \sin(\omega t - 240°)$$

3) Synchronous motors:-

A DC generator can run as a motor. If 3ϕ supply is given to the stator of 3ϕ alternator, it works as a motor. The motor (or) device which converts electrical energy into mechanical energy and run at synchronous speed is called synchronous motor.

$N_s = 120f/P$

~~The stator~~



The principle of operation of a syn. motor can be understood by considering the stator windings to be connected to a 3ϕ alternating current supply.

The effect of the stator current is to establish a magnetic field rotating at 120 f/p revolutions per minute for a freq. A direct current in a pole field winding on the rotor will also produce a mg. field rotating at rotor speed. If the rotor speed is made equal to that of the stator field and there is no load torque, these two magnetic field will tend to each other.

1) A 6 pole, 3 phase IM is connected to 50Hz supply. If it is running at 960 rpm. Find the % of Slip.

sol :-

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

$$\% \text{ Slip} = \left(\frac{N_s - N}{N_s}\right) \times 100\% = \frac{1000-960}{1000} = 0.04.$$

2) A 3ϕ, 20hp, 208V, 60Hz, 6 pole, Y connected IM delivers 15 kW at a slip of 5%. Calculate, (a) Syn. speed, (b) Rotor speed, (c) Freq. of rotor current.

sol :-

Sy. speed $N_s = \frac{120f}{P} = \frac{120 \times 60}{6} = 1200$ rpm

rotor speed $n_r = (1-S)N_s = (1-0.05)1200 = 1140$ rpm

freq. $f_r = sf = (0.05)(60) = 3$ Hz.

3) A 3ϕ, 460V, 100hp, 60Hz, 4pole IM. delivers rated o/p power at a slip of 0.05 (i.e) 5%. Determine the (a) syn-speed, (b) motor speed, (c) freq of the rotor circuit

$N_s = \frac{120f}{P} \sim 1800rpm$ $\quad$ $N = N_s(1-s) \sim 1710rpm$ $\quad$ $f_r = sf = 3Hz$

(d) slip speed, $N_{slip} = sN_s = 90rpm$

4