SYNCHRONOUS GENERATOR (ALTERNATOR):

Introduction: An Alternator is an Alternating current Voltage generator, it is also called as Synchronous generator.

In a D.C generator, Field System is Stationary & the Armature rotates.

In an Alternator the field System is rotating & the Armature is Stationary.

↳ The Stationary armature of the Alternator has the following advantages

(i) The generated voltage can be directly connected to the load, so the load current need not pass through Brush Contacts.

(ii) It is easy to insulate the Stationary armature for High A.C generated voltages as high as 11KV to 33KV.

(iii) The excitation voltage is Only of the order of 110V to 220V D.C voltage.

(iv) The Armature windings can be easily prevented from Deformation produced due to large Short Circuit Currents Mechanical Stress due to & large Centrifugal forces.

(v) Radial & Axial Ventilating ducts are provided in the Stator Core of the armature. The Ventilation & Cooling arrangement can be easily made if the Stationary Armature is used.

CONSTRUCTION : An Alternator consists of 2-parts (i) Stator (ii) Rotor.

(i) STATOR :-

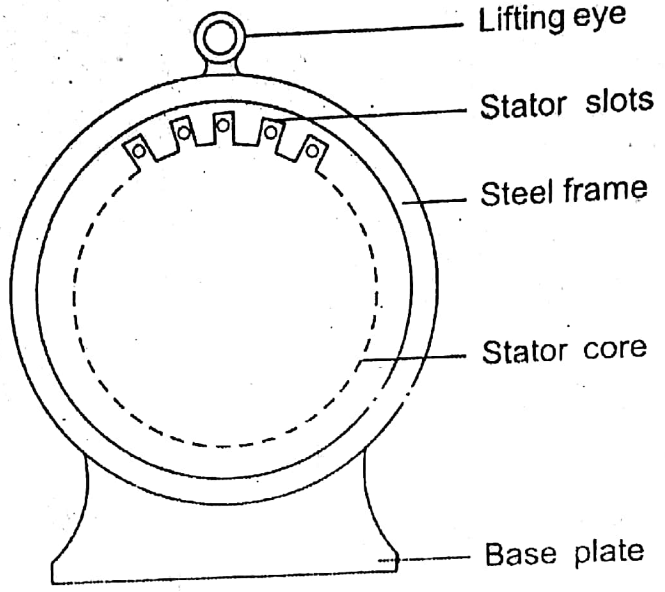


Fig.9.1

- It consists of Stator frame made of Mild Steel plates, Welded together to form a cylindrical drum.
- Circular Stator Laminations are made from Steel alloy.
- On the inner periphery of the Stator core, Uniform Slots are cut to place the Stator conductors.
- There are holes in the Stator frame & Radial Ventilating spaces in the Laminations for free circulation of air, helps in cooling the Alternator.

ROTOR : There are two types of Rotor

(a) Salient Pole type.

(b) Smooth Cylindrical type.

Accordingly we have Salient Pole Alternator and Non-Salient pole Alternator.

(a) SALIENT POLE TYPE ROTOR :

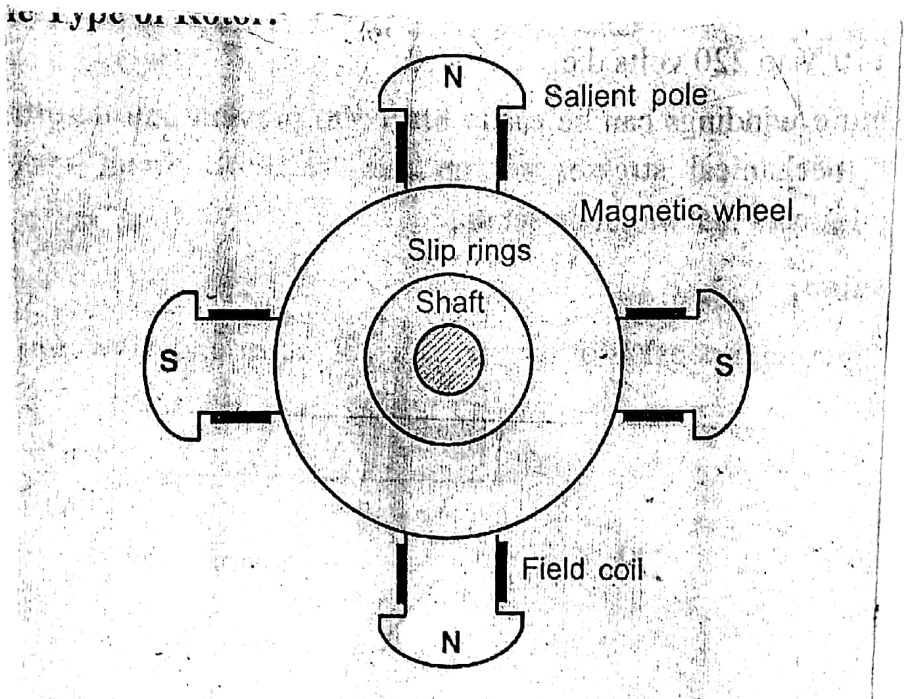


Fig.9.2

↳ This type of Rotors are used in low & medium speed Alternators [300 to 600 r.p.m]

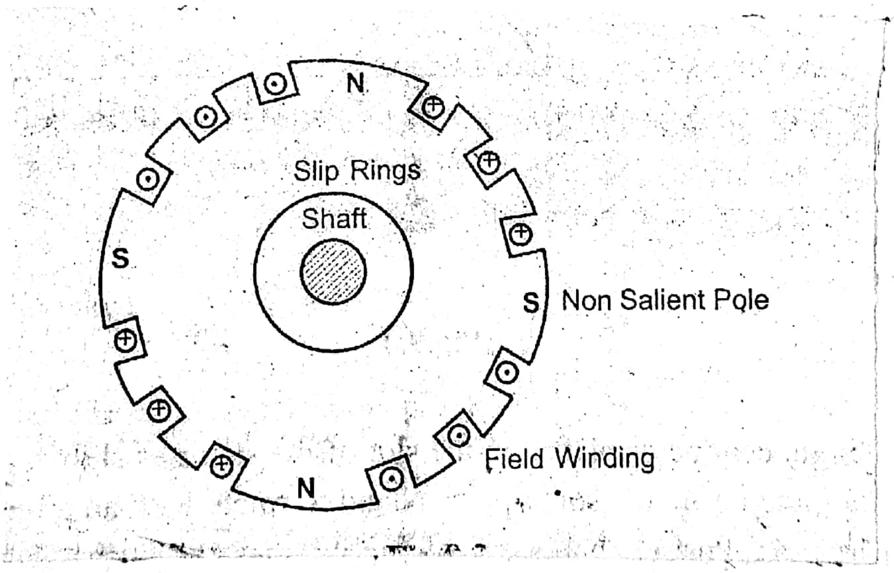
↳ This type of Rotor has large number of Projecting poles having their cores bolted to a heavy Magnetic wheel of cast Iron or Steel, Such Rotors have large diameter & Short Axial lengths.

↳ The poles are laminated to reduce eddy current losses. Coils are wound on these poles & when D.C supply is given to these coils, the poles become Electromagnets

↳ The D.C voltage required to excite the pole coils is obtained from the Pilot exiter (D.C generator), which is fixed on the shaft of the Alternator itself.

↳ The D.C voltage is fed to the field coils through two carbon Brushes, which slide on the slip rings fixed to the shaft of the Alternator.

SMOOTH CYLINDRICAL TYPE ROTOR :



↳ This type of Rotor is driven by Turbine & Rotates at very high speed (1500 to 3000 rpm)

↳ The Rotor consists of Steel Laminations which are insulated from each other & Pressed to form a Cylindrical Core having Slots on its Outer Periphery, in which Conductors are placed.

↳ Two or Four regions corresponding to Central Polar areas are left Un-Slotted & these areas are Sorrounded by field windings placed in the Slots.

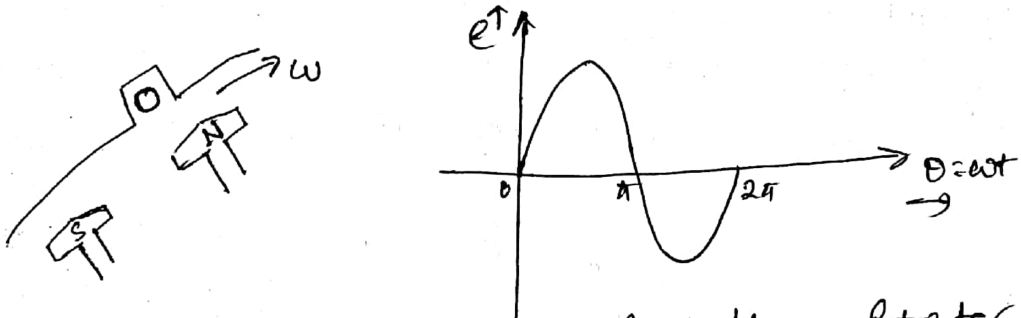
↳ This type of Rotor construction provides quieter Operation & Winding losses are less.

WORKING PRINCIPLE :

↳ The Field Windings of the Rotor are Supplied with a D.C Voltage of 110V or 220Volts, generated by a pilot exciter, through the two Brushes which slide on the Slip rings fixed on the Shaft of the Alternator.

↳ The Rotor is rotated by a Prime mover & the flux produced by the rotor poles sweep across the stator conductors & hence EMF is induced in them.

FREQUENCY OF THE INDUCED EMF :



- A conductor is placed in the stator slot as shown in fig.
- Positive Half cycle of the EMF is induced in the conductor, when the North pole sweeps across the conductor.

  Negative Half cycle of the EMF is induced in the conductor, when the South pole sweeps across the conductor.
- Hence One cycle of EMF is induced in the Conductor when One pair of North & South-poles sweeps across it.

∴ Number of cycles of EMF induced in One revolution $= P/2$

Number of revolutions per second $= N/60$

where, N = Speed in rpm.

∴ Frequency of Induced EMF 'f' is,

$$f = \left.\begin{array}{l}\text{Number of cycles of} \\ \text{EMF Induced per} \\ \text{Revolution}\end{array}\right\} \times \left\{\begin{array}{l}\text{Number of Revolutions} \\ \text{Per second.}\end{array}\right.$$

$$= P/2 \times N/60$$

$$\therefore \boxed{f = \frac{PN}{120}\ Hz}$$

EMF EQUATION OF AN ALTERNATOR :

Let,

Z : Number of Stator Conductors per phase.

P = Number of Poles.

f = Frequency of the Induced EMF in Hz.

ϕ = Flux per pole in Webers.

↳ The Flux Cut by the Conductor in One Revolution is $d\phi = P\phi$

↳ The time taken for One revolution $dt = \frac{60}{N}$ sec

∴ Average EMF induced in One Conductor is $\frac{d\phi}{dt} = \frac{P\phi}{\left(\frac{60}{N}\right)} = \frac{PN\phi}{60}$ volts.

∴ Average EMF induced Per Phase is $E_{av} = \frac{PN\phi}{60} \times Z$

$$= \frac{P\phi Z}{60} \times \frac{120f}{P}$$

$$E_{av} = 2f\phi Z \text{ volts}$$

For a Sinusoidal Wave, $\frac{E_{rms}}{E_{av}} = 1.11$

∴ RMS value of Induced EMF Per phase $E_{rms} = 1.11 \times E_{av}$

$$= 1.11 \times 2f\phi Z$$

$$E_{rms} = 2.22 f\phi Z \text{ volts}$$

∴ EMF equation of an Alternator is $E_{ph} = 2.22 f\phi Z$ volts

$$= 4.44 f\phi T \text{ volts}$$

$\left[\because T = Z/2,\ T \rightarrow \text{Num of Turns}\right]$

where $T = Z/2 \rightarrow$ Number of turns.

↳ In practice the coils are short pitched, i.e. the conductors are not uniformly distributed in the slots of the stator.

∴ The EMF induced in the alternator gets reduced by a small quantity.

∴ The EMF equation of Alternator is modified as,

$$\boxed{E_{ph} = 2.22\, K_p K_d f \phi Z \text{ volts}}$$

where $K_p \rightarrow$ Pitch factor
$K_d \rightarrow$ Distribution factor.

PITCH FACTOR (K_p or K_c) : It is also known as Chord factor or Coil Span factor.

↳ The Pitch factor is defined as the ratio of the Vector sum of the EMFs induced per coil to the Arithmetic sum of the EMFs induced per coil.

$$\text{Pitch factor } 'K_p' = \frac{\text{Vector sum of the EMFs induced per coil}}{\text{Arithmetic sum of the EMFs induced per coil.}}$$

$$K_p = \frac{2E_s \cos \beta/2}{2E_s} = \cos(\beta/2)$$

where,
$\beta =$

Where, β = Phase difference b/n the EMFs induced in the two Coil sides.

E_s = EMF induced in each Side of the coil.

DISTRIBUTION FACTOR : (K_d, K_b or K_w) :-

It is also known as Breadth factor or Winding factor.

↳ The Distribution factor is defined as the ratio of EMF induced in a Distributed winding to the EMF induced in a Concentrated winding.

$$K_d = \frac{\sin\left(\frac{n\alpha}{2}\right)}{n \sin(\alpha/2)}$$

where,

$n \rightarrow$ Number of Slots per pole per phase.

$\alpha \rightarrow$ Slot angle $= \frac{180}{3n}$

STAR - DELTA STARTER :

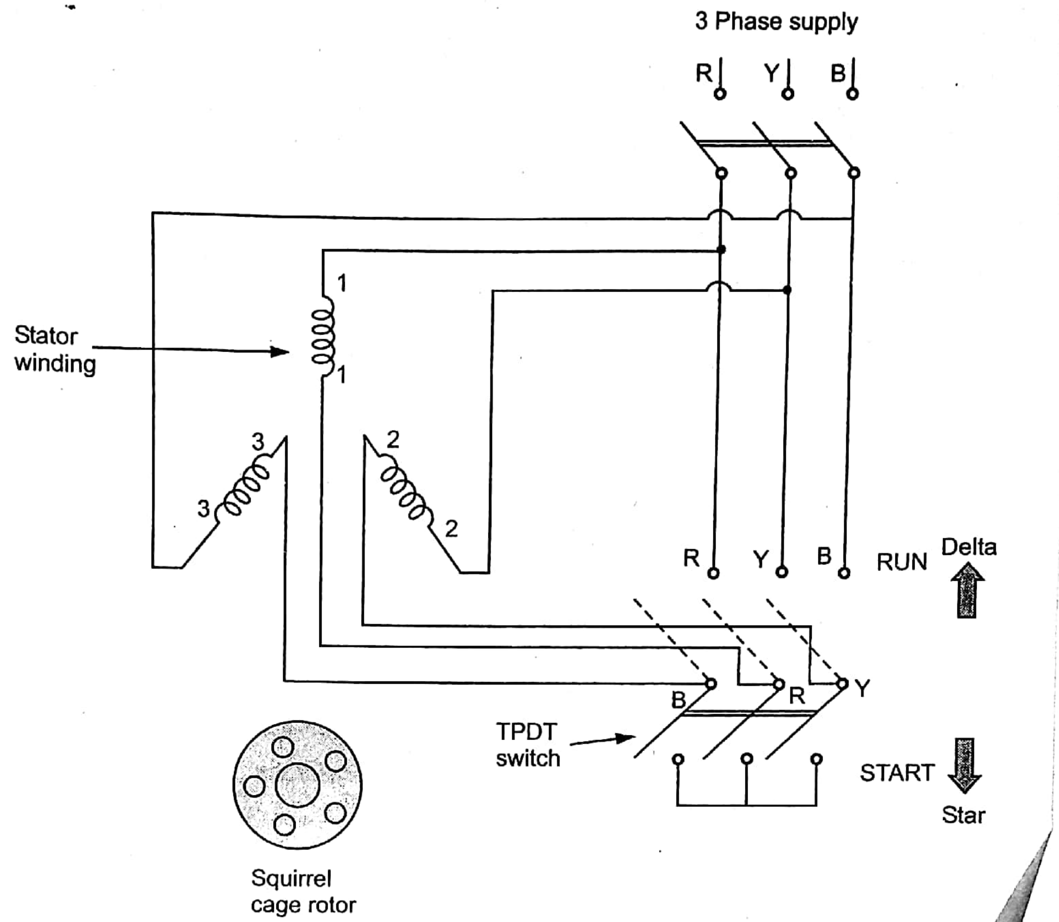


Fig. 10.10.1 Star-delta starter

↳ It uses a TPDT [Triple Pole Double Throw] Switch, which connects the Stator winding in Star at Start & then in Delta while normal running. Hence this Starter is Suitable only for those motors designed to run with Delta Connected Stator winding.

↳ Initially when Switch is in 'START' position, the Stator winding gets connected in Star ∴ the phase voltage gets ~~reduced~~ reduced by a factor $1/\sqrt{3}$

$$\boxed{V_{ph} = \frac{V_L}{\sqrt{3}}}$$

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↳ Hence Starting current also gets reduced by $\frac{1}{\sqrt{3}}$

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

where,

I_{st} = Starting current

I_{sc} = Starting current that would have flown in the Stator winding if direct Supply was given.

↳ When the motor attains 50 to 60% of Normal speed, Switch is thrown in the Run position. Hence winding gets connected in Delta.

$$\therefore \boxed{V_{ph} = V_L = \text{Rated voltage}}$$

THREE PHASE INDUCTION MOTOR :

Introduction : The 3-ϕ Induction motor is the most widely used A.C motor. It differs from other types of motors in that there is no connection from the Rotor winding to any source of supply.

↳ The necessary Voltage & Current in the Rotor circuit are produced by induction from the Stator winding, which is why it is called as Induction Motor.

Advantages :

(i) Its cost is low & highly reliable.

(ii) Its maintainance requires minimum attention.

(iii) Its Construction is Simple, rugged & almost Unbreakable.

(iv) It works with reasonably good power factor at rated load. (Squirrel cage Induction motor)

(v) Its efficiency is high

(vi) It has a Simple Starting arrangement.

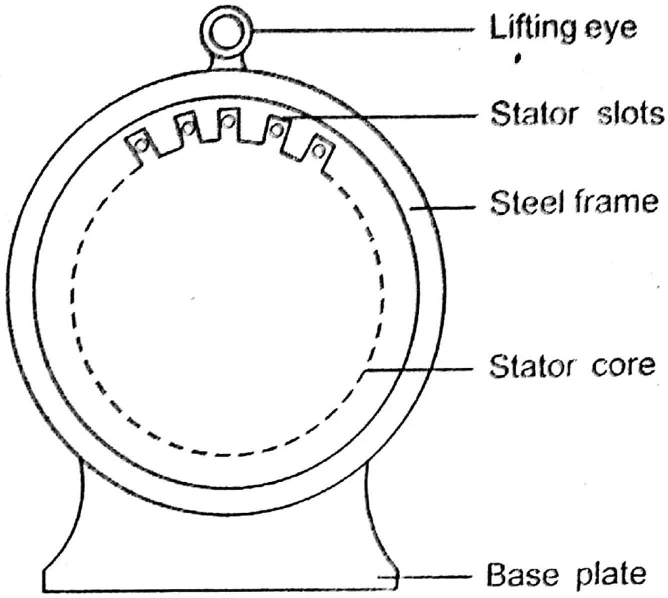
Dis-Advantages :

(i) It is essentially a Constant Speed motor & the Speed of the motor cannot be changed easily. ∴ The Speed ~~efficiency~~ Variation can be done at the Cost of efficiency.

(ii) The Starting Torque is inferior to that of a D.C Shunt motor.

CONSTRUCTION: A 3-ϕ Induction motor mainly consists of two parts (1) STATOR.

STATOR:



Stator consists of a steel frame, which encloses a Hollow cylindrical core made up of thin laminations of silicon steel to reduce Eddy current loss & Hysteresis loss.

A large number of Uniform slots are cut on the inner periphery of the core. The stator conductors are placed in these slots, which are insulated from one another & also from the slots.

These conductors are connected as Balanced three-phase star winding or Delta winding.

In-order to keep air-gap reluctance minimum the air gap between the stator & Rotor is made as small as practicable (1 to 1.5mm in High power machines).

The windings are wound for a definite number of poles, depending on the requirement of the speed.

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

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

where,

N_s = Synchronous speed (Speed of the Rotating magnetic field)

f = Frequency of Supply.

P = Number of poles.

↳ This rotating magnetic field $N_s = \frac{120f}{P}$, induces an EMF in the Rotor by Mutual Induction.

ROTOR : It is the Rotating part of the Motor. following are the 2-types of Rotors employed in 3-ϕ Induction motors.

(i) Squirrel Cage Rotor : Motors with this type of Rotors are known as 'SQUIRREL-CAGE INDUCTION MOTORS'

(ii) Phase wound Rotor : Motors with this type of Rotor are known as 'PHASE WOUND' or 'SLIP RING' INDUCTION MOTORS.

SQUIRREL CAGE ROTOR : The Rotor is placed inside the ~~Rotor~~ Stator, the air gap between Stator and the Rotor is 0.4mm to 4mm

↳ The Rotor Core is Cylindrical & Slotted on its Periphery.

↳ The Rotor Consists of Un-insulated copper or Alluminium bars called Rotor conductors. The bars are placed in the Slots.

↳ These bars are permanently shorted at each end with the help of conducting copper ring called end ring. The bars are usually brazed to the end rings to provide good Mechanical Strength.

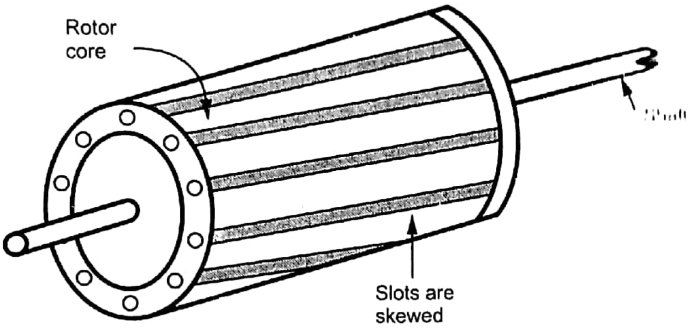


Fig. 10.3.3 Skewing in rotor construction

↳ The entire Structure looks like a cage, forming a closed electrical circuit. So the Rotor is called Squirrel cage Rotor.

↳ As the Rotor itself is Short circuited, no external resistance can have any effect on the Rotor Resistance. Hence no external resistance can be introduced in the Rotor circuit. So Slip Ring & Brush assembly is not required for this Rotor. Hence the construction of this rotor is very small.

↳ Fan Blades are generally provided at the ends of the Rotor core. This circulates the air through the machine while in operation, providing the necessary cooling.

↳ The slots are slightly skewed, which helps in 3-ways.

(i) Reduces the Locking tendency b/n Rotor & Stator.

(ii) Reduces the noise due to Magnetic hum & makes the Rotor run quietly.

(iii) More Uniform Torque is obtained while running.

APPLICATIONS & ADVANTAGES :- It is simple in construction, rugged & can withstand rough handling. Cost of maintainance & repairs are less.

↳ Nearly 90% of Induction motors are of Squirrel cage type.

↳ Squirrel cage motors are having moderate Starting Torque & constant speed characteristics, hence used in.

(i) Driving Fans, Blowers, Water pumps.

(ii) Grinders, Lathe machines, Printing Machines & Drilling Machines.

PHASE WOUND (OR) SLIP RING ROTOR :

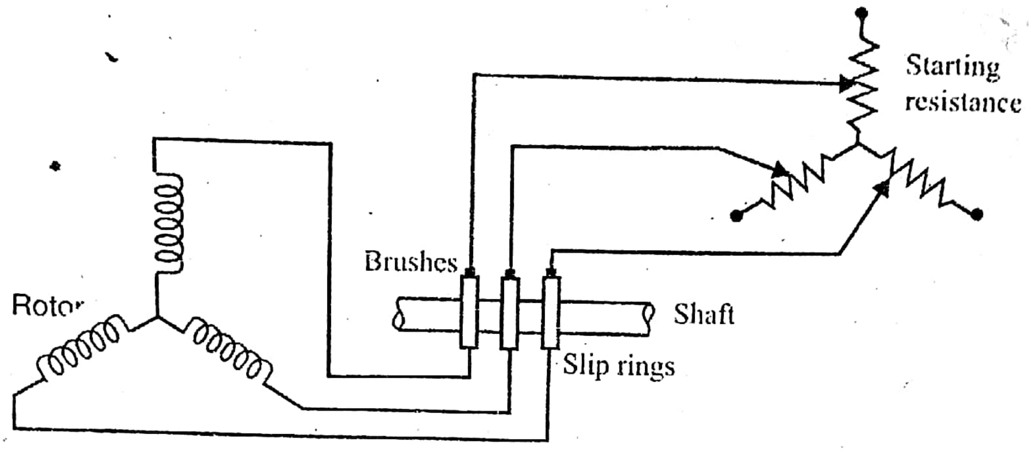


Fig.11.3

↳ The Rotor is laminated, cylindrical core having Uniform Slots on its Outer periphery. A three phase winding which is Star connected is placed in these Slots.

↳ The open ends of the Star windings are brought out & Connected to three insulated Slip rings, mounted on the Shaft of the motor, with carbon brushes resting on them.

↳ The three Brushes are externally connected to three phase Star connected Rheostat, which is used as Starter. This helps to Control some of the Important characteristics of the motor like Speed, Starting torque, etc.

APPLICATIONS & ADVANTAGES :

↳ The Motor is Smooth Running.
↳ The Slip ring Induction motors are used for loads which require high Starting Torque such as,
* Conveyors, Cranes, compressors, Crushers
* Elevators, hoists, etc.

WORKING PRINCIPLE :

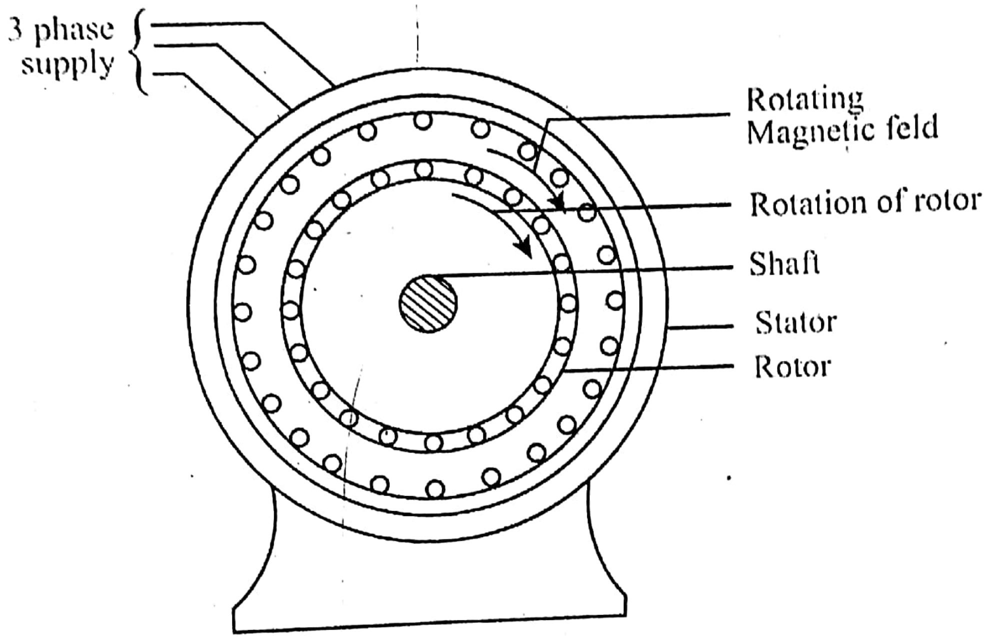


Fig.11.11

↳ When a 3-phase Supply is given to the three phase Stator winding, A Magnetic field of Constant Magnitude 1.5 ϕ_m & rotating with Synchronous speed N_s is produced.

↳ This rotating magnetic field Sweeps across the Rotor conductors & hence an EMF is induced in the Rotor Conductors.

↳ As the Rotor Conductors are Short Circuited the Induced EMF Sets up a Current in the Rotor conductors in such a direction as to produce a Torque, which rotates the Rotor in the Same direction as that of the Magnetic field.

<u>SLIP & SLIP SPEED</u> : The difference b/n the Synchronous speed (N_s) of the Magnetic field & the Actual speed of the Rotor (N) is called Slip speed.

$$\therefore \boxed{\text{Slip speed} = N_s - N}$$

↳ The Slip 'S' of an Induction motor is defined as the ratio of the Slip speed to the Synchronous Speed

$$\boxed{S = \frac{N_s - N}{N_s}}$$

$$\left.\begin{matrix}\text{Percentage}\\ \text{Slip}\end{matrix}\right\} \% S = \frac{N_s - N}{N_s} \times 100$$

<u>NOTE</u> :

↳ At Start, Motor is at Rest and hence Speed N is zero.

$$\boxed{S = 1 \quad \text{at Start}}$$

↳ $S = 0$, gives us $N = N_s$ which is not possible for an Induction motor. So Slip of an Induction motor cannot be zero under any circumstances.

NOTE :- The Rotor Speed 'N' cannot catchup with the Magnetic field i.e Synchronous Speed 'N_s', If it catches up, the Relative speed becomes zero & hence no EMF is induced in the Rotor conductors ∴ the Torque becomes zero.

FREQUENCY OF ROTOR CURRENT (f') : When the Rotor is Stationary, the frequency of the Rotor Current is Same as the Supply frequency.

↳ When the Induction motor is rotating, the frequency of the Current induced in the Rotor conductors is proportional to the Relative Speed or Slip Speed.

$$N_s - N = \frac{120 f'}{P} \quad \ldots\ldots (a)$$

$$\text{But} \quad N_s = \frac{120 f}{P} \quad \ldots\ldots (b)$$

where, f → Supply frequency when Rotor is Stationary.

comparing eqns (a) & (b)

$$\frac{N_s - N}{N_s} = \frac{f'}{f}$$

$$S = \frac{f'}{f}$$

$$\therefore \boxed{f' = Sf}$$

∴ The Frequency of the Induced Rotor Current is Slip times the Supply frequency.

NECESSITY OF STARTER IN INDUCTION MOTOR:

- Induction motors at the time of starting draw out 5 to 7 times the full load current & produce only 1.5 to 2.5 times the full load Torque, when they are directly connected to the supply.
- This large inrush of current is due to the absence of Back EMF during starting.
- Such high currents at start damages the motor winding & appliances connected to the same line are subjected to voltage spike which affects their working.

Hence starters are used for 3-phase Induction motors.

Eg: In slip ring Induction motors resistance is included in the Rotor circuit during starting & can be removed, when the motor picks up speed.

- In squirrel cage Induction motors, the starting current is limited by applying a reduced voltage during starting & full voltage is applied when the motor picks up speed.

STAR - DELTA STARTER :

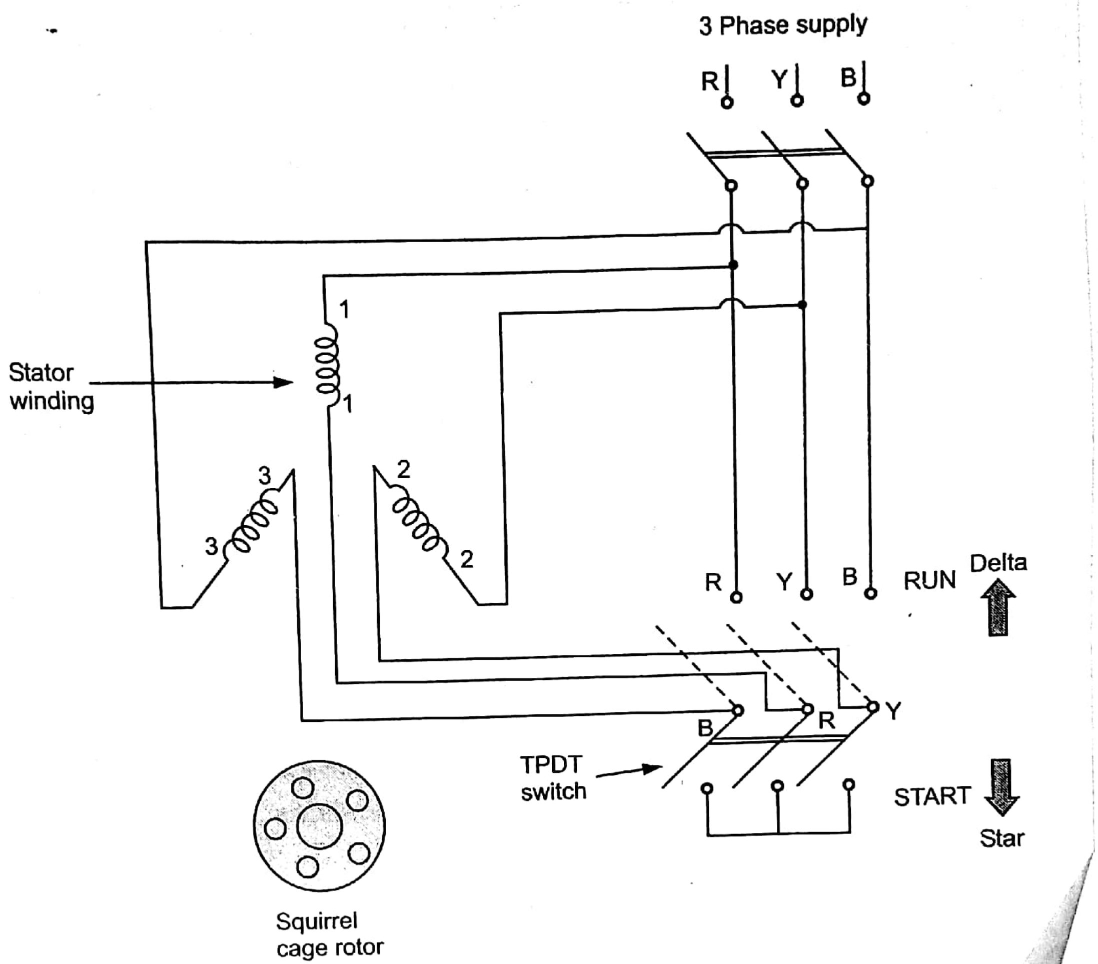


Fig. 10.10.1 Star-delta starter

↳ It uses a TPDT [Triple Pole Double Throw] Switch, which connects the Stator winding in Star at Start & then in Delta while normal running. Hence this Starter is Suitable only for those motors designed to run with Delta Connected Stator winding.

↳ Initially when Switch is in 'START' position, the Stator winding gets connected in Star ∴ the phase voltage gets reduced by a factor $1/\sqrt{3}$

$$\boxed{V_{ph} = \frac{V_L}{\sqrt{3}}}$$

↳ Hence Starting current also gets reduced by $\frac{1}{\sqrt{3}}$

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

where,

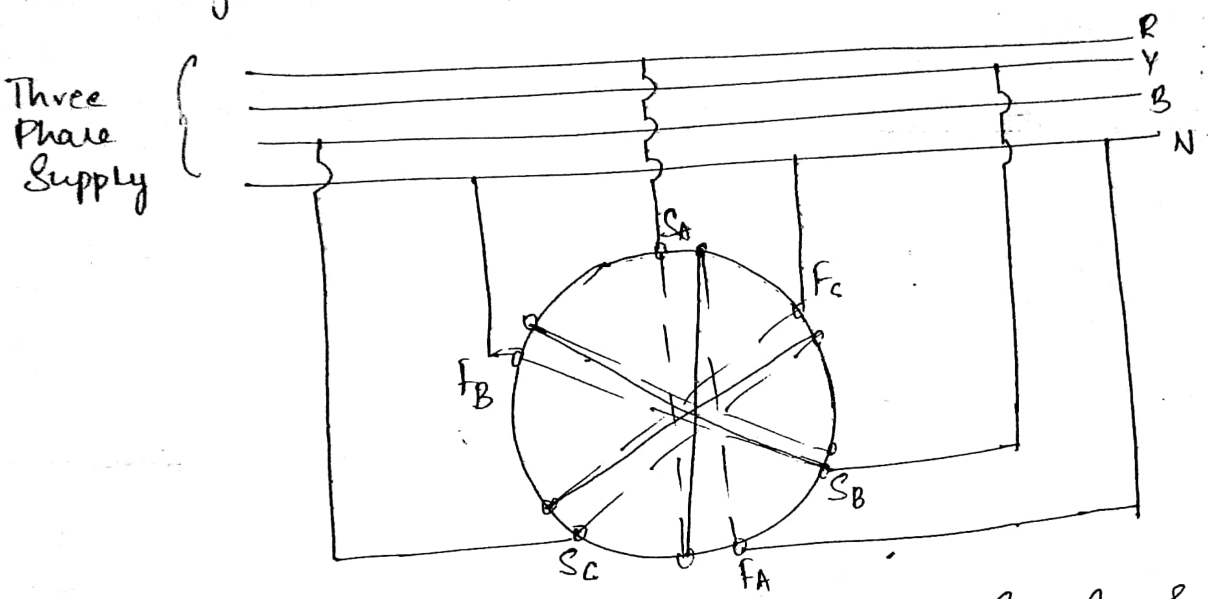
I_{st} = Starting Current

I_{sc} = Starting Current that would have flown in the Stator winding if direct Supply was given.

↳ When the motor attains 50 to 60% of Normal speed, Switch is thrown in the Run position. Hence winding gets connected in Delta.

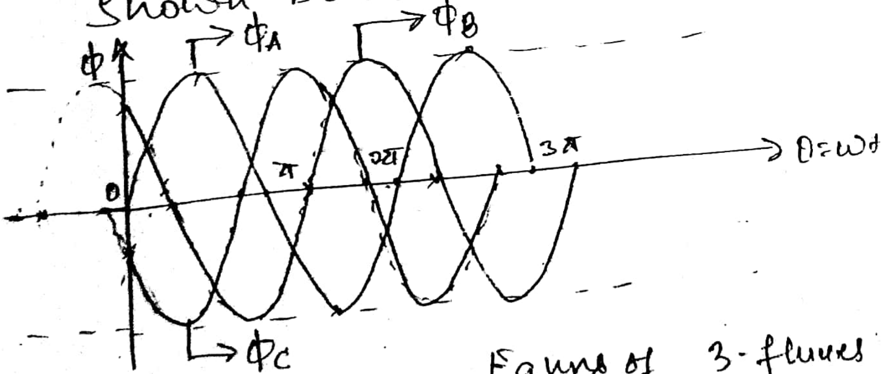
$$\therefore \boxed{V_{ph} = V_L = \text{Rated voltage}}$$

Rotating Magnetic Field :- When a 3-ϕ supply is given to the three phase winding of the stator, A Rotating magnetic field of constant magnitude of $1.5\,\phi_m$ & rotating with synchronous speed 'N_s' is produced.

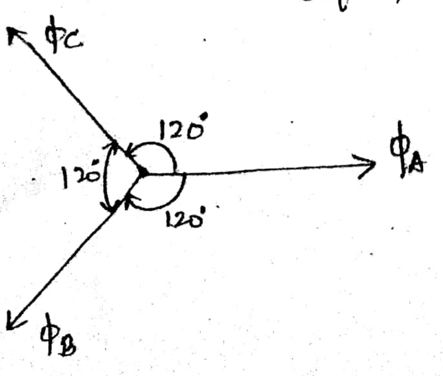


↳ The starting points of the windings S_A, S_B & S_C are connected to the three supply lines R, Y & B. The other ends F_A, F_B & F_C are connected to the neutral N.

↳ The fluxes produced in the 3-windings are shown below.



Equns of 3-fluxes are,



$$\phi_A = \phi_m \sin\omega t$$

$$\phi_B = \phi_m \sin(\omega t - 120^\circ)$$

$$\phi_C = \phi_m \sin(\omega t - 240^\circ)$$

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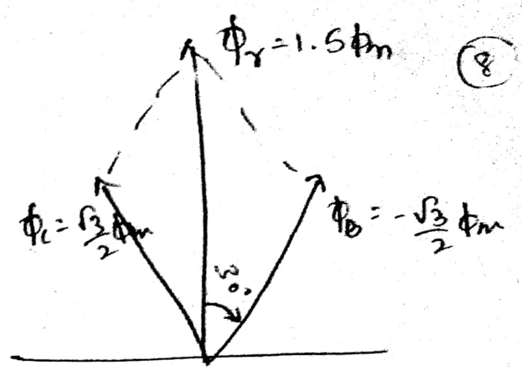
(i) when $\theta = 0°$:-



$\phi_A = 0$

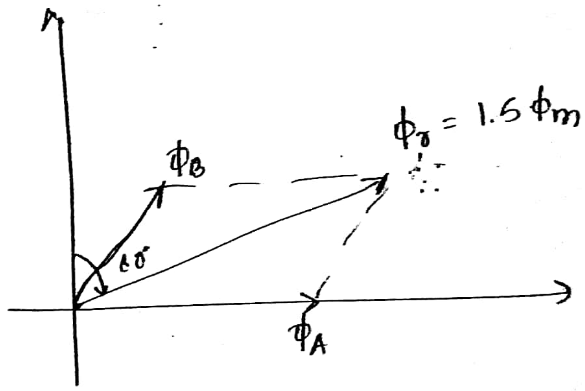
$\phi_B = \phi_m \sin(-120°) = -\frac{\sqrt{3}}{2}\phi_m$

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

The Resultant flux is along Y-axis & its Magnitude is given by,

$$\phi_r = 2 \times \frac{\sqrt{3}}{2} \times \phi_m \cos 30° = \frac{3}{2}\phi_m = 1.5\phi_m$$

(ii) When $\theta = 60°$:-



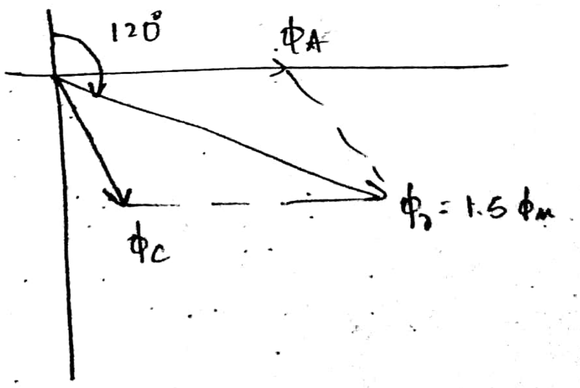
$\phi_A = \phi_m \sin 60 = \frac{\sqrt{3}}{2}\phi_m$

$\phi_B = \phi_m \sin(-60°) = -\frac{\sqrt{3}}{2}\phi_m$

$\phi_C = 0.$

The Resultant flux is rotated by 60° in the clockwise direction & its magnitude is $1.5\phi_m$.

(iii) when $\theta = 120°$:-



$\phi_A = \phi_m \sin 120° = \frac{\sqrt{3}}{2}\phi_m$

$\phi_B = 0$

$\phi_C = \phi_m \sin(-120°) = -\frac{\sqrt{3}}{2}\phi_m$

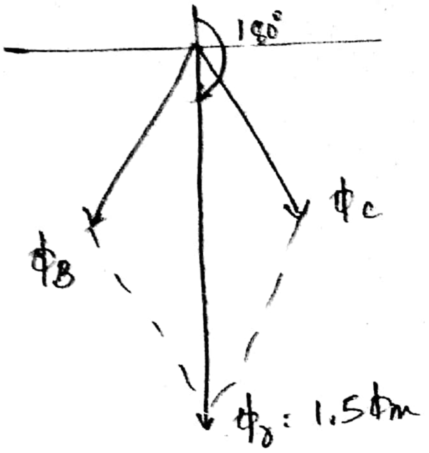
↳ The Resultant is rotated by another 60° i.e through 120° from its original position & the magnitude is $1.5\phi_m$

(iv) when $\theta = 180°$

$\phi_A = \phi_m \sin 180° = 0$

$\phi_B = \phi_m \sin 60° = \frac{\sqrt{3}}{2}\phi_m$

$\phi_C = \phi_m \sin(-60) = -\frac{\sqrt{3}}{2}\phi_m$



↳ The Resultant is rotated by another 60° i.e through 180° from its Original position & the Magnitude is $1.5\phi_m$.

∴ When a three phase supply is given to the Stator winding. A rotating magnetic field of constant magnitude $1.5\phi_m$ & rotating with Synchronous speed $N_s = \frac{120f}{P}$ is produced.