MODULE 4

3 PHASE INDUCTION MOTORS

INDUCTION MOTOR : Induction Motors are the most commonly used motors in many applications. These are also called as Asynchronous Motors, because an induction motor always runs at a speed lower than synchronous speed. Synchronous speed means the speed of the rotating magnetic field in the stator.

Basic working principle of an Induction Motor : In a DC motor, supply is needed to be given for the stator winding as well as the rotor winding. But in an induction motor only the stator winding is fed with an AC supply.

1. Alternating flux is produced around the stator winding due to AC supply. This alternating flux revolves with synchronous speed. The revolving flux is called as "Rotating Magnetic Field"
2. The relative speed between stator RMF and rotor conductors causes an induced emf in the rotor conductors, according to the Faraday's law of electromagnetic induction. The rotor conductors are short circuited, and hence rotor current is produced due to induced emf. That is why such motors are called as induction motors.

3.Now, induced current in rotor will also produce alternating flux around it. This rotor flux lags behind the stator flux. The direction of induced rotor current, according to Lenz's law, is such that it will tend to oppose the cause of its production.

4. As the cause of production of rotor current is the relative velocity between rotating stator flux and the rotor, the rotor will try to catch up with the stator RMF. Thus the rotor rotates in the same direction as that of stator flux to minimize the relative velocity. However, the rotor never succeeds in catching up the synchronous speed. This is the **basic working principle of induction motor.**

Synchronous speed: The rotational speed of the rotating magnetic field is called as synchronous speed.

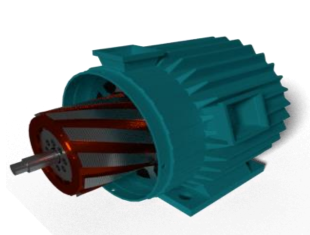
$$N_s = \frac{120 \times f}{P} \quad \text{(RPM)}$$

where, f = frequency of the supply,P = number of poles

Constructional features:

There are two types a) Squirrel cage Induction motors b) Slip ring Induction motors.

a) Squirrel cage Induction Motors : The rotor of the squirrel cage three phase induction motor is cylindrical and have slots on its periphery. The slots are not made parallel to each other but are bit skewed as the skewing prevents magnetic locking of stator and rotor teeth and makes the working of the motor more smooth and quieter. The squirrel cage rotor consists of aluminum or copper bars. These bars are called rotor conductors and are placed in the slots on the periphery of the rotor.



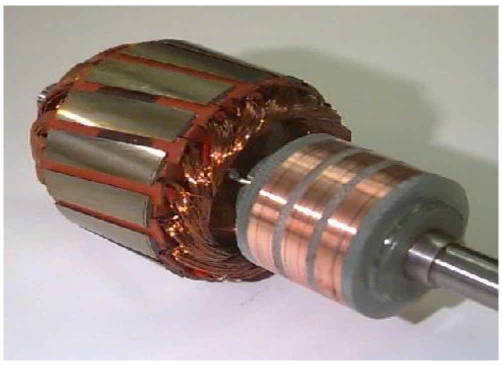
The rotor conductors are permanently shorted by the copper, or aluminum rings called the end rings. To provide mechanical strength. These rotor conductors are braced to the end ring and hence form a complete closed circuit resembling like a cage and hence got its name as squirrel cage induction motor.

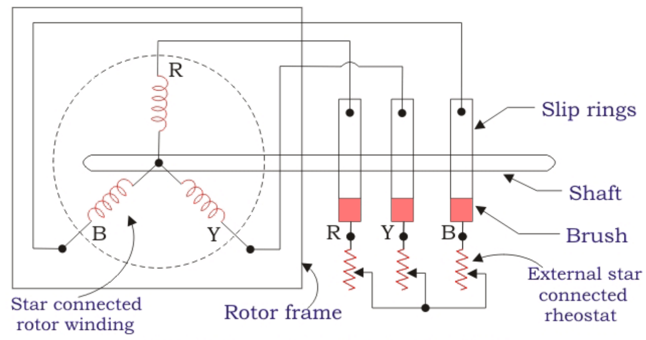
The squirrel cage rotor winding is made symmetrical. As end rings permanently short the bars, the rotor resistance is quite small, and it is not possible to add external resistance as the bars get permanently shorted. The absence of slip ring and brushes make the construction of Squirrel cage three-phase induction motor very simple and robust and hence widely used three phase induction motor.

Advantages

1. Its construction is very simple and rugged.
2. As there are no brushes and slip ring, these motors requires less maintenance.

b)Slip ring Induction Motors: In this type of three phase induction motor the rotor is wound for the same number of poles as that of the stator, The rotor also carries star or delta winding similar to that of the stator winding.
The three ends of three-phase windings are permanently connected to these slip rings. The external resistance can be easily connected through the brushes and slip rings and hence used for speed controlling and improving the starting torque of three phase induction motor.





Slip Ring Three Phase Induction Motor

The brushes are used to carry current to and from the rotor winding. These brushes are further connected to three phase star connected resistances. An electrical diagram of a slip ring three phase induction motor is shown below. At starting, the resistance is connected to the rotor circuit and is gradually cut out as the rotor pick up its speed.
When the motor is running the slip ring are shorted by connecting a metal collar, which connects all slip ring together, and the brushes are also removed.
Advantages: a) It has high starting torque and low starting current. b) Possibility of adding additional resistance to control speed (Hence construction is complicated compared to Squirrel cage rotors)

Sl. No	Squirrel Cage induction Motors	Slip Ring or Phase Wound Induction Motors
1.	Construction is very simple	Construction is complicated due to presence of slip ring and brushes
2.	The rotor consists of rotor bars which are permanently shorted with the help of end rings	The rotor winding is similar to the stator winding
3.	Since the rotor bars are permanently shorted, its not possible to add external resistance	We can easily add rotor resistance by using slip ring and brushes
4.	Staring torque is low and cannot be improved	Due to presence of external resistance high starting torque can be obtained
5.	Slip ring and brushes are absent	Slip ring and brushes are present
6.	Less maintenance is required	Frequent maintenance is required due to presence of brushes
7.	The construction is simple and robust and it is cheap as compared to slip ring induction motor	The construction is complicated and the presence of brushes and slip ring makes the motor more costly
8.	Due to its simple construction and low cost. The squirrel cage induction motor is widely used	This motor is rarely used only 10% industry uses slip ring induction motor
9.	Less rotor copper losses and hence high efficiency	Rotor copper losses are high and hence less efficiency
10.	Speed control by rotor resistance method is not possible	Speed control by rotor resistance method is possible
11.	Squirrel cage induction motor is used in lathes, drilling machine, fan, blower printing machines etc	Slip ring induction motor are used where high starting torque is required i.e in hoists, cranes, elevator etc

Slip: Rotor tries to catch up the synchronous speed of the stator field, and hence it rotates. But in practice, rotor never succeeds in catching up. If rotor catches up the stator speed, there wont be any relative speed between the stator flux and the rotor, hence no induced rotor current and no torque production to maintain the rotation. However, this won't stop the motor, the rotor will slow down due to lost of torque, the torque will again be exerted due to relative speed. That is why the rotor rotates at speed which is always less the synchronous speed.

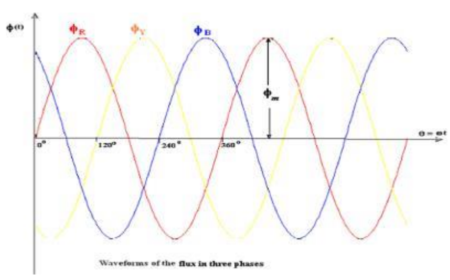
The difference between the synchronous speed (N_s) and actual speed (N) of the rotor is called as slip.

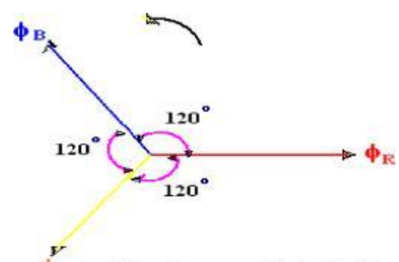
$$\% \text{ slip } \quad s = \frac{Ns - N}{Ns} \times 100$$

Here Slip S is expressed in terms of percentage

The Rotating Magnetic field theory(RMF): Consider a 3- phase induction motor whose stator windings mutually displaced from each other by 120° are connected in Star/delta and energized by a 3- phase supply.

The currents flowing in each phase will set up a flux in the respective phases as





The magnetic flux produced by the current in each phase can be represented by the equations

$$\phi_R = \phi_m \sin(\omega t)$$
$$\phi_Y = \phi_m \sin(\omega t - 120^o)$$
$$\phi_B = \phi_m \sin(\omega t - 240^o)$$

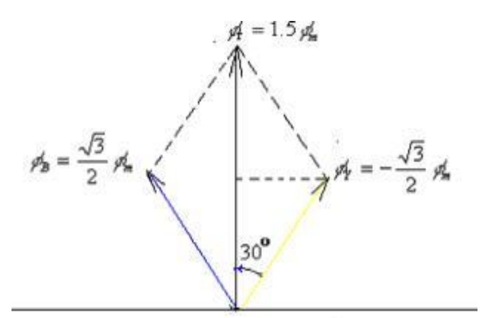
Case (i) : When ωt = 0

$ø_R = 0;$

$ø_Y = -\frac{\sqrt{3}}{2} ø_m$

$ø_B = \frac{\sqrt{3}}{2} ø_m$

$ø_r = 1.5\, ø_m$



Resultant flux at θ = 0°

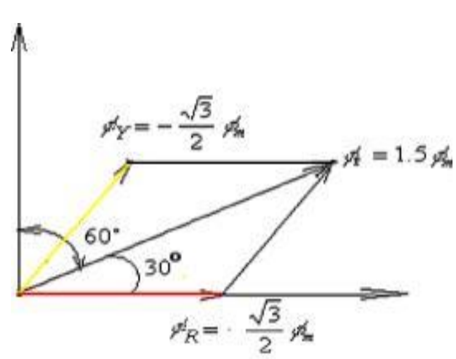
Case (ii) When ωt = 60°

$ø_R = \frac{\sqrt{3}}{2} ø_m$

$ø_Y = -\frac{\sqrt{3}}{2} ø_m$

$ø_B = 0$

$ø_r = 1.5\, ø_m$



Resultant flux at θ = 60°

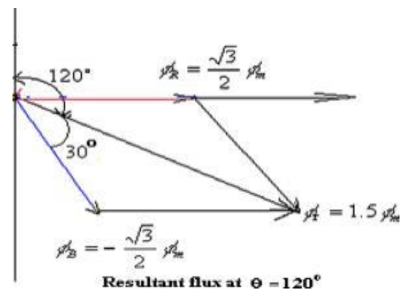
Case (iii) : When ωt = 120^{o}

$ø_R = \frac{\sqrt{3}}{2} ø_m$

$ø_Y = 0$

$ø_B = -\frac{\sqrt{3}}{2} ø_m$

$ø_r = 1.5\, ø_m$



Resultant flux at θ =120°

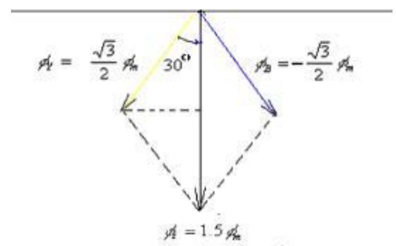
Case (iii) : When ωt = 180^{o}

$ø_R = 0;$

$ø_Y = \frac{\sqrt{3}}{2} ø_m$

$ø_B = -\frac{\sqrt{3}}{2} ø_m$

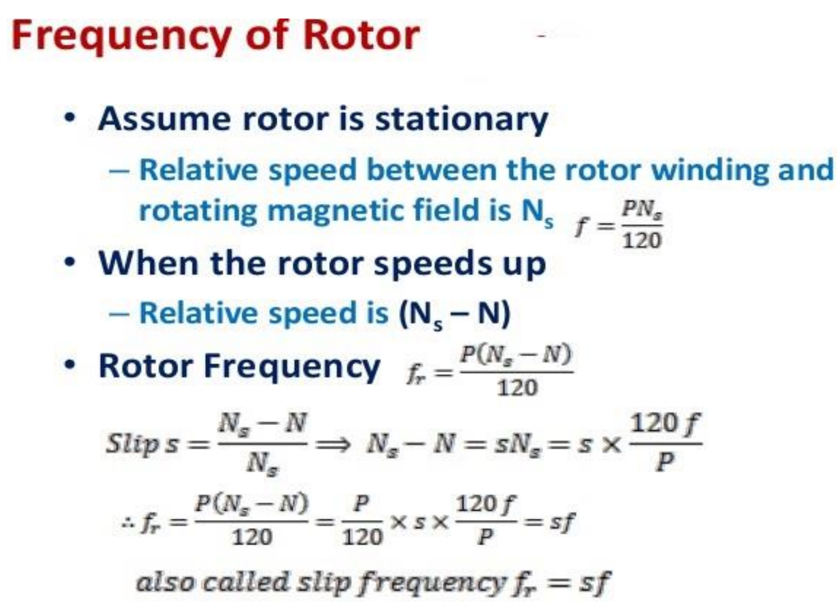
$ø_r = 1.5\, ø_m$



Resultant flux at θ = 180°

The resultant of these fluxes at that instant **($φ_r$) is 1.5$φ_m$** which is shown in the figure. Here it is clear that the resultant flux vector is rotated 30^{o} further clockwise without changing its value.

Relation between Frequency of Rotor current and supply frequency(Frequency of RMF):



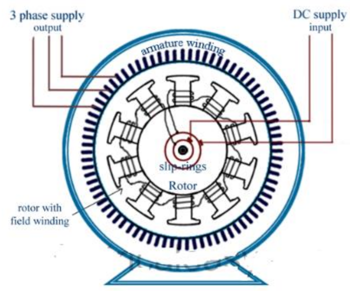
Three Phase Synchronous generators

DEFINITION OF AN ALTERNATOR: It is a machine that converts the input mechanical power into an output alternating electrical energy. It works just like a generator. Hence, it is also called as AC generator.

Working Principle:

It works on the principle of faradays law of electromagnetic Induction. Any rotating machine when rotated in the magnetic flux works according to this principle.
The working of this machine is similar to that of an AC generator. The working figure of an AC generator is shown in the figure below.
Armature winding is a collection of coils placed in the magnetic field. The field magnets when rotated by the prime mover, armature conductors cuts the magnetic lines of forces thus, generating an induced emf. This generated induced emf is according to the principle of faradays law of electromagnetic Induction. The induced emf develops current to flow in the armature winding. The direction of the armature current is found by using the Flemings right-hand rule.

The induced emf will be zero when the armature coil is in the alignment of magnets and is maximum when the coil is perpendicular. As the coil is cutting the flux continuously the current changes continuously which can be observed in a galvanometer. The current is passed through the slip rings and then to the brushes. The slip rings are used for the smoother operation of the machine and brushes are used to collect the current from the slip rings and deliver to the load. The coil movement in the magnetic field at different points is shown in the figure below.

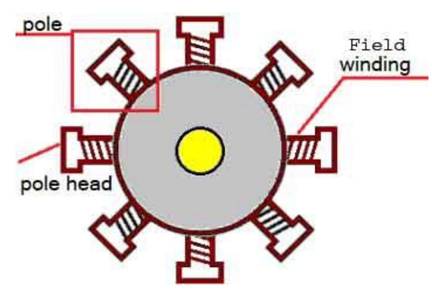


CONSTRUCTION:

It consists of a Yoke, pole core, stator, rotor, armature, slip rings, bearings, and fan. The yoke is the outer portion of it is used as a protecting cote for the machine. It protects against the environmental conditions such that the inner parts do not get damaged. It also gives mechanical support to the machine as well. Pole core is consists of pole shoe that gives support for the windings to rest on the pole shoe. The entire winding and pole shoe are considered as the pole core. The stator is the stationary part on which armature winding is wound. The rotor is the rotating part of the machine on which the field winding is wound.

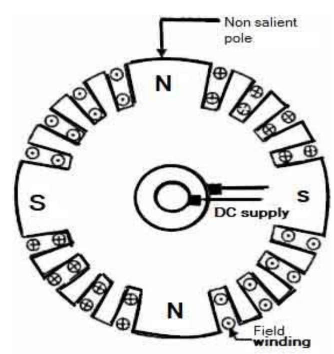
Salient (or projecting Pole) Type:

It consists of a more number of poles so, rotor diameter is large. It has a larger diameter and a smaller axial length. the prime movers or turbines used are of low speed such as hydraulic turbines like Pelton wheel, Kaplan, and Francis turbines. It is used for low and medium speed applications. These are used in hydropower stations and diesel power stations. These are also called as Hydro Alternators. The salient pole rotor type figure is shown in the figure



Non Salient (Cylindrical) Type:

The number of poles used here is either 2 or 4. As the poles used are minimum, the rotor diameter is small and the axial length is larger. The speed of this type ranges between 1500-3000 rpm. The turbines or prime movers used here are of high speed such as the steam and gas turbine. These are used in steam power stations and gas power stations. The cylindrical rotor type machine is shown in the figure



z	SALIENT POLE TYPE	NON SALIENT POLE TYPE
1	Poles are projecting out from the surface.	Portion of the cylinder acts as poles ,hence poles are non-projecting.
2	Air gap is non uniform.	Air gap is uniform due to smooth cylindrical periphery.
3	Diameter is high and axial length is small.	Small diameter and large axial length is the feature.
4	Mechanically weak.	Mechanically robust.
5	Preferred for low speed alternators.	Preferred for high speed alternators i.e. for turbo alternators.
6	Prime mover used is water turbines, I.C.Engines.	Prime mover used are steam turbines, electric motors.
7	For same size, the rating is smaller than cylindrical type.	For same size, rating is higher than Salient pole type.
8	Separate damper winding is provided	Separate damper winding is not necessary.

EMF EQUATION OF AN ALTERNATOR:

Let Z = No. of conductors or coil sides in series per phase

Φ = Flux per pole in webers

P = Number of rotor poles

N = Rotor speed in r.p.m

In one revolution (i.e., $60/N$ second), each stator conductor is cut by $P\Phi$ webers,i.e.,

$d\Phi = P\Phi$; $dt = 60/N$

$\therefore$ Average e.m.f. induced in one stator conductor

$$= \frac{d\Phi}{dt} = \frac{P\Phi}{60/N} = \frac{P\Phi N}{60} \text{ volts}$$

Since there are Z conductors in series per phase,

$$\therefore \text{Average e.m.f. per phase} = \frac{P\Phi N}{60} \times Z$$

$$= \frac{P\Phi N}{60} \times \frac{120f}{P}$$

$$= 2f\Phi Z \text{ volts} \qquad \left(N = \frac{120f}{p}\right)$$

$$\text{R.M.S value of e.m.f./ phase} = \text{Average value/ phase} \times \text{form factor}$$

$$= 2f\Phi Z \times 1.11 = 2.22\, f\, \Phi\, Z$$

$$E_{r.m.s} / \text{phase} = 2.22\, f\, \Phi\, Z \text{ volts.}$$

Since Z=2T in an Alternator EMF Equation can be written as E_{rms} /Phase = 4.44 f ø T Volts

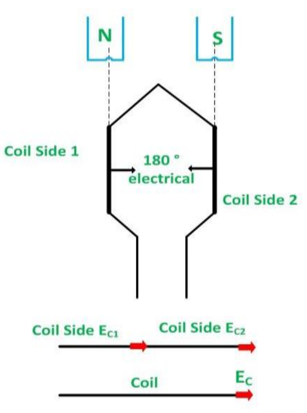
If we consider the Pitch Factor and Distribution Factor, EMF equation of Alternator becomes

E_{rms} /Phase = 4.44 f ø T K_c K_d Volts. This is actual EMF equation of an Alternator

Pitch Factor or Coil Span factor (K_P,K_c): Pitch Factor or Coil Span Factor is definite as the ratio of emf generated in short pitch coil to the emf generated in full pitch coil. It is denoted by K_p and its value is always less than unity.

A coil having a span equal to 180° electrical is called is called a **full pitch coi**l. Shown below

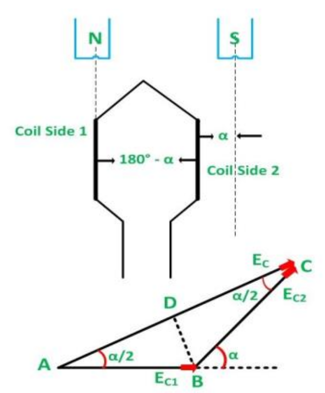
Coil having a span less than 180° electrical **short pitch coil** or fractional pitch coil, shown below



$$K_C = \frac{\text{Actual Voltage Generated in the Coil}}{\text{Voltage Generated in the coil of span } 180° \text{ electrical}}$$

$$K_p = \frac{\text{emf generated in short pitch coil}}{\text{emf generated in full pitch coil}} \quad \text{.............(1)}$$

$$K_C = \cos\frac{\alpha}{2}$$



where α is short pitch angle

Distribution Factor (K_d): It is the ratio of EMF induced for distributed winding to the EMF induced for concentrated winding.

$$k_d = \frac{EMF\ induced\ in\ distributed\ winding}{EMF\ induced\ if\ the\ winding\ would\ have\ been\ concentrated}$$

$$K_d = \frac{\text{Sin } m\,\beta/2}{m \text{ Sin } \beta/2}$$

$$m = \frac{\text{slots}}{\text{poles x phases}} \;\ldots\ldots(2)$$

$$\beta = \frac{180^\circ}{\text{slots/pole}} = \frac{180^\circ \text{ x poles}}{\text{slots}} \;\ldots\ldots(3)$$

Winding factor $K_w = K_d \text{ X } K_c$