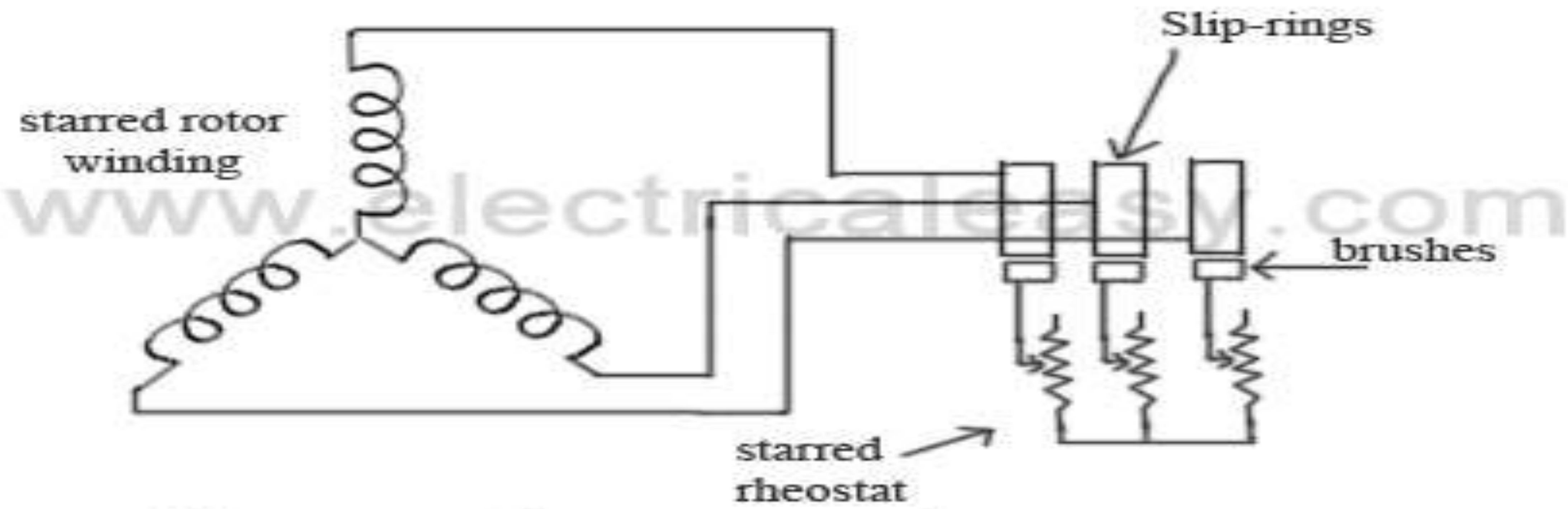
MODEL-2

THREE PHASE INDUCTION MOTORS

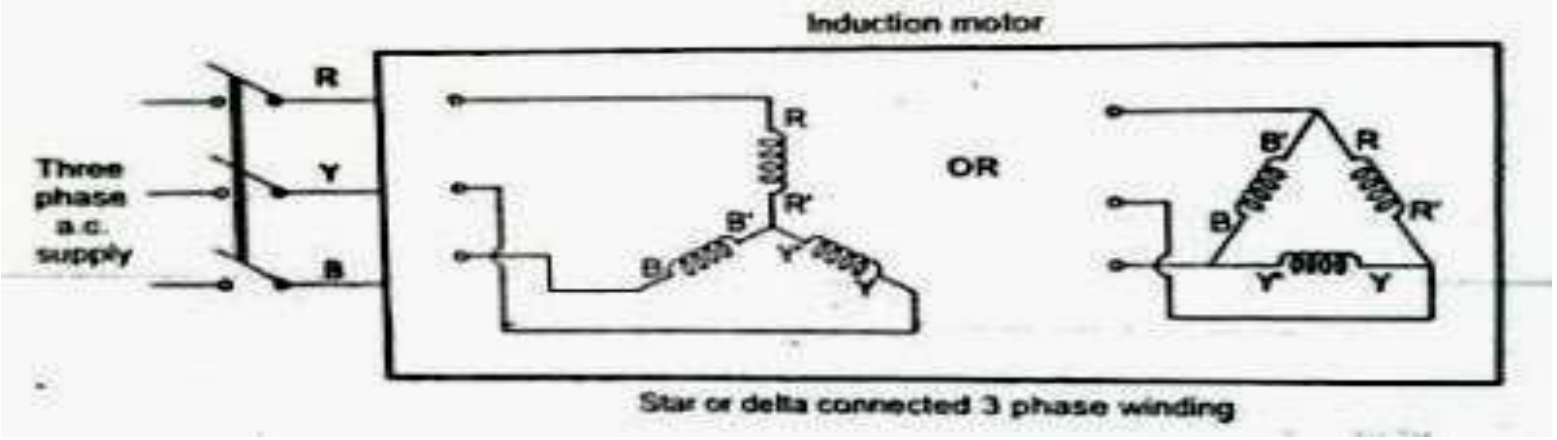
Review of concept and generation of rotating magnetic field, Principle of operation, construction, classification and types; squirrel-cage, slip-ring (No question shall be set from the review portion). Slip, Torque equation, torque-slip characteristic covering motoring, generating and braking regions of operation, Maximum torque, significance of slip.

PHASE WOUND ROTOR OR SLIP RING ROTOR



Phase wound rotor connections

PRODUCTION OF ROTATING MAGNETIC FIELD



- The stator of an induction motor consists of a number of overlapping windings offset by an electrical angle of 120°. When the primary winding or stator is connected to a three-phase alternating current supply, it establishes a rotating magnetic field which rotates at a synchronous speed.

SLIP OF A 3 PHASE INDUCTION MOTOR

SLIP OF A 3 PHASE INDUCTION MOTOR

We have seen above that rotor rapidly accelerates in the direction of rotating field. In practice, the rotor can never reach the speed of stator flux. If it did, there would be no relative speed between the stator field and rotor conductors, no induced rotor currents and, therefore, no torque to drive the rotor. The friction and windage would immediately cause the rotor to slow down. Hence, the rotor speed (N) is always less than the suitor field speed (Ns). This difference in speed depends upon load on the motor. The difference between the synchronous speed Ns of the rotating stator field and the actual rotor speed N is called slip. It is usually expressed as a percentage of synchronous speed i.e.

SLIP OF A 3 PHASE INDUCTION MOTOR

$$\% \text{ age slip, } s = \frac{N_s - N}{N_s} \times 100$$

(i) The quantity $N_s - N$ is sometimes called slip speed.

(ii) When the rotor is stationary (i.e., $N = 0$), slip, $s = 1$ or 100 %.

(iii) In an induction motor, the change in slip from no-load to full-load is hardly 0.1% to 3% so that it is essentially a constant-speed motor.

MODEL-2 : PRODUCTION OF ROTATING MAGNETIC

- The production of Rotating magnetic field in 3 phase supply is very interesting. When a 3-phase winding is energized from a 3-phase supply, a rotating magnetic field is produced. This field is such that its poles do no remain in a fixed position on the stator but go on shifting their positions around the stator. For this reason, it is called a rotating field. It can be shown that magnitude of this rotating field is constant and is equal to 1.5 Øm where Øm is the maximum flux due to any phase.

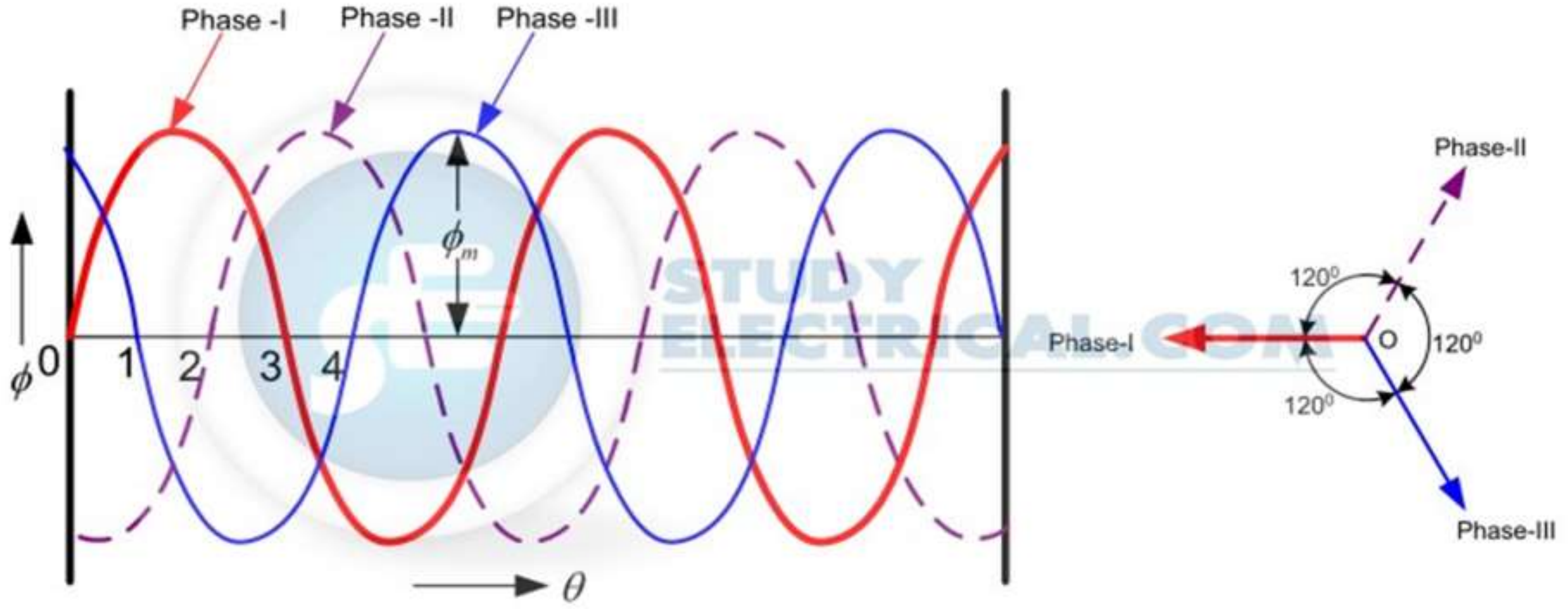
PRODUCTION OF ROTATING MAGNETIC FIELD

- The three phase currents flow simultaneously alternating phase current displaced from each other by 120° electrical. Each alternating phase current produces its own flux which is sinusoidal. So all three fluxes are sinusoidal and are separated from each other by 120°. If the phase sequence of the windings is R-Y-B, then mathematical equations for the instantaneous values of the three fluxes
- ΦR , ΦY ,ΦB can be written as,

PRODUCTION OF ROTATING MAGNETIC FIELD

- $\Phi R = \Phi m \sin(\omega t)$
- $\Phi Y = \Phi m \sin(\omega t - 120)$
- $\Phi B = \Phi m \sin(\omega t - 240)$

PRODUCTION OF ROTATING MAGNETIC FIELD



When $\theta = 0^0$ (At point 0)

When $\theta = 60^0$ (At point 1)

When $\theta = 120^0$ (At point 2)

When $\theta = 180^0$ (At point 3)

When $\theta = 0^0$:

$$\emptyset_1 = 0$$

$$\emptyset_2 = -\frac{\sqrt{3}}{2}\emptyset_m$$

$$\emptyset_3 = \frac{\sqrt{3}}{2}\emptyset_m$$

When $\theta = 60^0$:

$$\emptyset_1 = \frac{\sqrt{3}}{2}\emptyset_m$$

$$\emptyset_2 = -\frac{\sqrt{3}}{2}\emptyset_m \emptyset_3$$

$$= 0$$

When $\theta = 120^0$:

$$\emptyset_1 = \frac{\sqrt{3}}{2}\emptyset_m$$

$$\emptyset_2 = 0$$

$$\emptyset_3 = -\frac{\sqrt{3}}{2}\emptyset_m$$

When $\theta = 180^0$:

$$\emptyset_1 = 0$$

$$\emptyset_2 = \frac{\sqrt{3}}{2}\emptyset_m \ \emptyset_3$$

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

PRODUCTION OF ROTATING MAGNETIC FIELD

Case 1 : $\omega t = 0$

- $\Phi R = \Phi m \sin(0) = 0$
- $\Phi Y = \Phi m \sin(0 - 120) = -0.866\ \Phi m$
- $\Phi B = \Phi m \sin(0 - 240) = +0.866\ \Phi m$

PRODUCTION OF ROTATING MAGNETIC FIELD

- Case 2 : $\omega t = 60$
- Case-2: $\omega t = 60$
- $\Phi R = \Phi m \ Sin(60) = +0.866 \ \Phi m$
- $\Phi Y = \Phi m \ Sin(- 60) = -0.866 \ \Phi m$
- $\Phi B = \Phi m \ Sin(- 180) = 0$

PRODUCTION OF ROTATING MAGNETIC FIELD

Case 3 : $\omega t = 120$

- $\Phi R = \Phi m \sin(120) = +0.866\ \Phi m$
- $\Phi Y = \Phi m \sin(0) = 0$
- $\Phi B = \Phi m \sin(-120) = -0.866\ \Phi m$

PRODUCTION OF ROTATING MAGNETIC FIELD

Case 4 : $\omega t = 180$

- $\Phi R = \Phi m \sin(180) = 0$
- $\Phi Y = \Phi m \sin(60) = +.866\ \Phi m$
- $\Phi B = \Phi m \sin(-60) = -0.866\ \Phi m$

PRINCIPLE OF OPERATION

- Work on the principle of Electromagnetic Induction

PRINCIPLE OF OPERATION

- RMF produces the effect of rotating poles around a rotor.
- Relative motion between RMF and Rotor conductor
- Force exerts on rotor, hence it rotates
- Induces EMF in Rotor conductors-Electromagnetic induction.

SPEED OF ROTATING MAGNETIC FIELD

- $$\mathbf{Ns} = \frac{120f}{p}$$

DIRECTION OF RMF

- Depends on Phase sequence
- Phase sequence can be reversed by interchanging any 2 terminals
- Direction of rotation of motor can be changed by changing phase sequence

TORQUE EQUATION OF THREE PHASE INDUCTION MOTOR

The torque produced by three phase induction motor depends upon the following three factors:

- Firstly the magnitude of rotor current,
- secondly the flux which interact with the rotor of three phase induction motor and is responsible for producing emf in the rotor part of induction motor,
- lastly the power factor of rotor of the three phase induction motor.

TORQUE EQUATION OF THREE PHASE INDUCTION MOTOR

- By combining all these factors, we get the equation of torque as

- $\mathbf{T} \propto \emptyset\, I_2\, Cos\emptyset_2$

- Where, T is the **torque produced** by the induction motor,

  $T \propto \phi I_2 \cos\theta_2$

  ϕ is **flux responsible for producing induced emf**,
  I_2 is **rotor current,**
  $\cos\theta_2$ is the power factor of rotor circuit.

$\phi \propto E_2$

Rotor current I_2 is defined as the ratio of rotor induced emf under running condition , SE_2 to total impedance, Z_2 of rotor side,

$$I_2 = \frac{SE_2}{Z_2}$$

and total impedance Z2 on rotor side is given by ,

$$Z_2 = \sqrt{R_2^2 + (sX_2)^2}$$

$$I_2 = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$\cos\theta_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$T \propto E_2 \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}} \times \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$T \propto sE_2^2 \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$T = KsE_2^2 \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$This\ comstant\ K = \frac{3}{2\pi n_s}$$

Where, n_s is synchronous speed in r. p. s, $n_s = N_s / 60$. So, finally the equation of torque becomes,

$$T = sE_2^2 \times \frac{R_2}{R_2^2 + (sX_2)^2} \times \frac{3}{2\pi n_s} N - m$$

CONDITION FOR MAXIMUM TORQUE

Condition for Maximum Starting Torque

It can be proved that starting torque will be maximum when rotor resistance/phase is equal to standstill rotor reactance/phase.

Now $$T_s = \frac{K_1 R_2}{R_2^2 + X_2^2} \qquad \text{(i)}$$

Differentiating eq. (i) w.r.t. R_2 and equating the result to zero, we get,

$$\frac{dT_s}{dR_2} = K_1\left[\frac{1}{R_2^2 + X_2^2} - \frac{R_2(2R_2)}{\left(R_2^2 + X_2^2\right)^2}\right] = 0$$

or $$R_2^2 + X_2^2 = 2R_2^2$$

or $$R_2 = X_2$$

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

$$T = K\,s E_2^2 \frac{R_2}{R_2^2 + (sX_2)^2}$$

$$s^2 = \frac{R_2^2}{X_2^2}$$

So, when slip s = R2 / X2, the torque will be maximum and this slip is called maximum slip Sm and it is defined as the ratio of rotor resistance to that of rotor reactance.

From the above equation it is concluded that

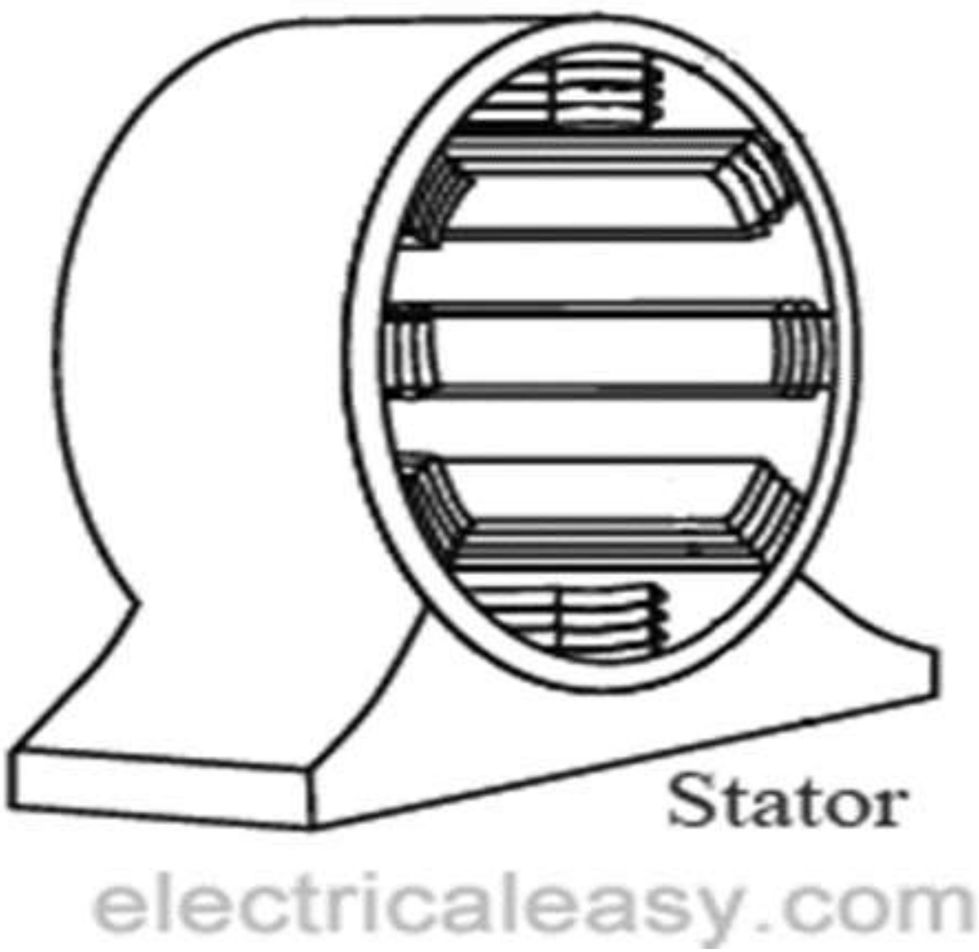
- The maximum torque is directly proportional to square of rotor induced emf at the standstill.
- The maximum torque is inversely proportional to rotor reactance.
- The maximum torque is independent of rotor resistance.
- The slip at which maximum torque occur depends upon rotor resistance, R2. So, by varying the rotor resistance, maximum torque can be obtained at any required slip.

There are mainly two types of Induction Motor:
Squirrel Cage Induction Motor and
Slip Ring or Wound Rotor Induction Motor.
This classification is based on the **constructional difference** between them. On the basis of kind of **power supply**, there are again two types: Single Phase and Three Phase.

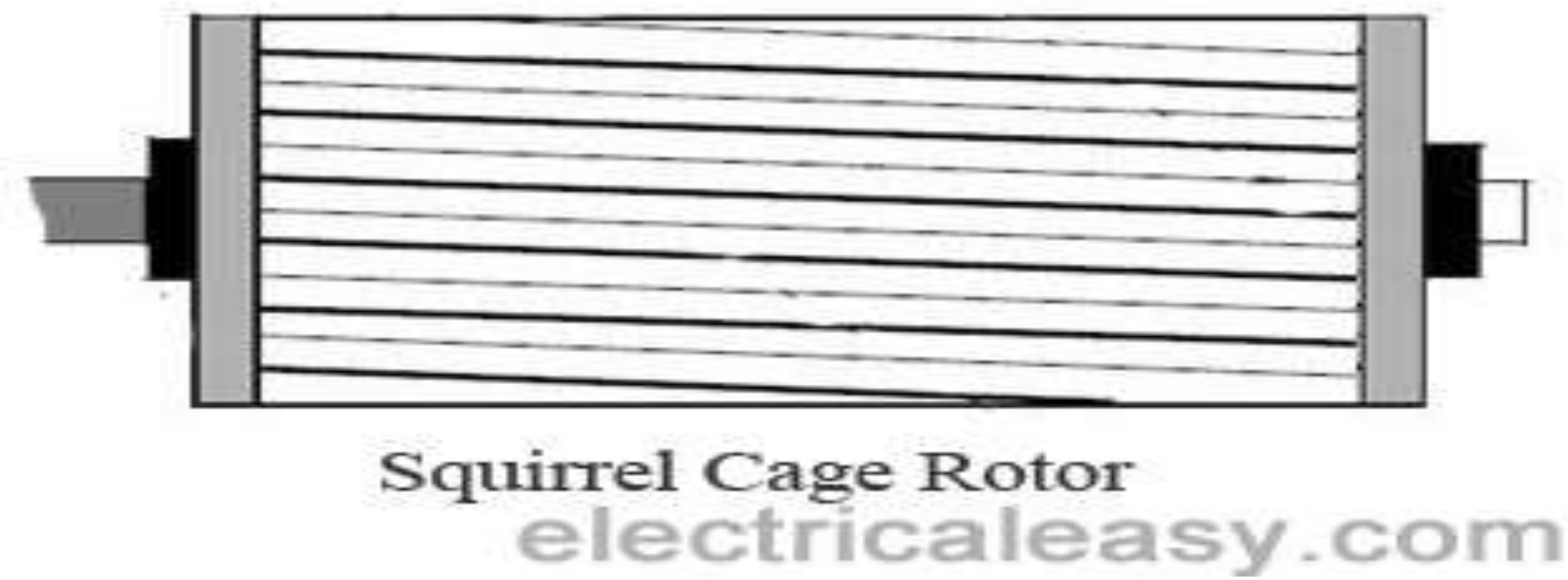
CONSTRUCTION:STATOR

- The stator of a 3 phase IM (Induction Motor) is made up with number of **stampings**, and these **stampings are slotted** to receive the **stator winding**.
- The stator is wound with a 3 phase winding which is fed from a 3 phase supply.
- It is wound for a defined number of poles, and the number of poles is determined from the required speed.
- For greater speed, lesser number of poles is used and vice versa.

STATOR OF A 3 PHASE IM



ROTOR: SQUIRREL CAGE ROTOR



ROTOR: SQUIRREL CAGE ROTOR

- Most of the induction motors (up to 90%) are of squirrel cage type.
- Squirrel cage type rotor has very simple and almost indestructible construction.
- This type of rotor consist of a cylindrical laminated core, having parallel slots on it.
- These parallel slots carry rotor conductors.
- In this type of rotor, heavy bars of copper, aluminum or alloys are used as rotor conductors instead of wires.

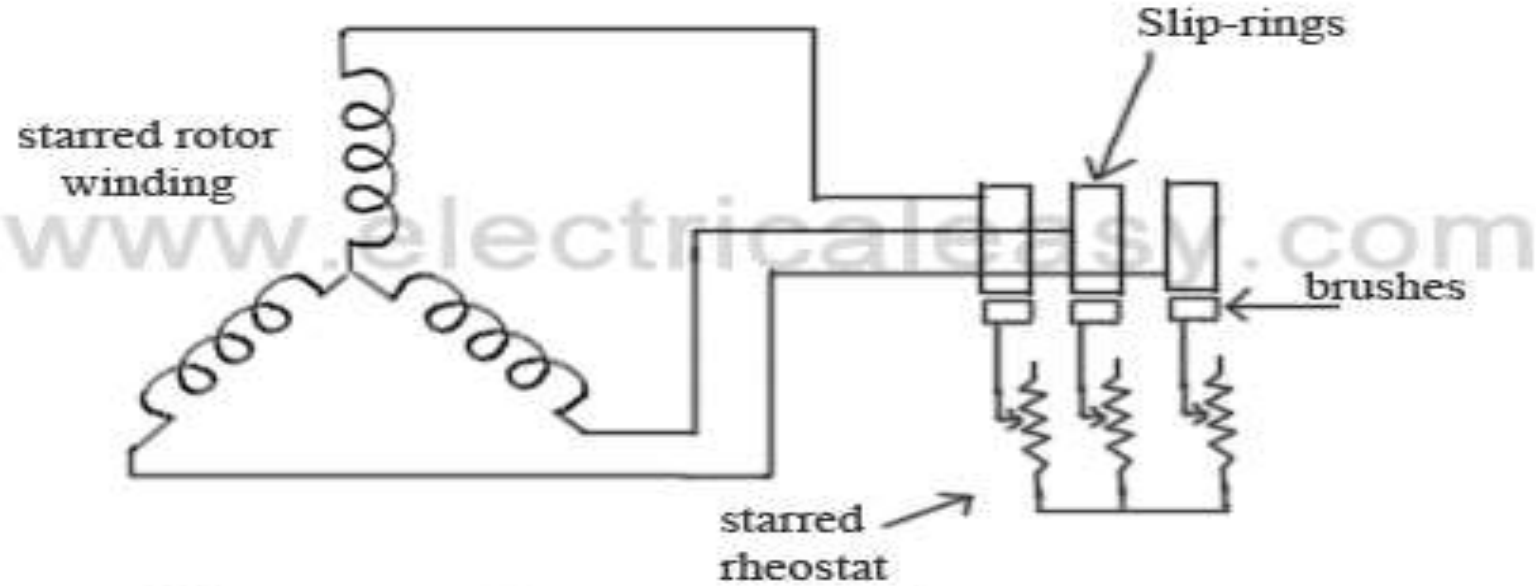
ROTOR: SQUIRREL CAGE ROTOR

Rotor slots are slightly skewed to achieve following advantages -

- 1. it reduces locking tendency of the rotor, i.e. the tendency of rotor teeth to remain under stator teeth due to magnetic attraction.
- 2. increases the effective transformation ratio between stator and rotor
- 3. increases rotor resistance due to increased length of the rotor conductor

- The rotor bars are brazed or electrically welded to short circuiting end rings at both ends.
- Thus this rotor construction looks like a squirrel cage and hence we call it.
- The rotor bars are permanently short circuited, hence it is not possible to add any external resistance to armature circuit.

PHASE WOUND ROTOR:SLIPRING ROTOR

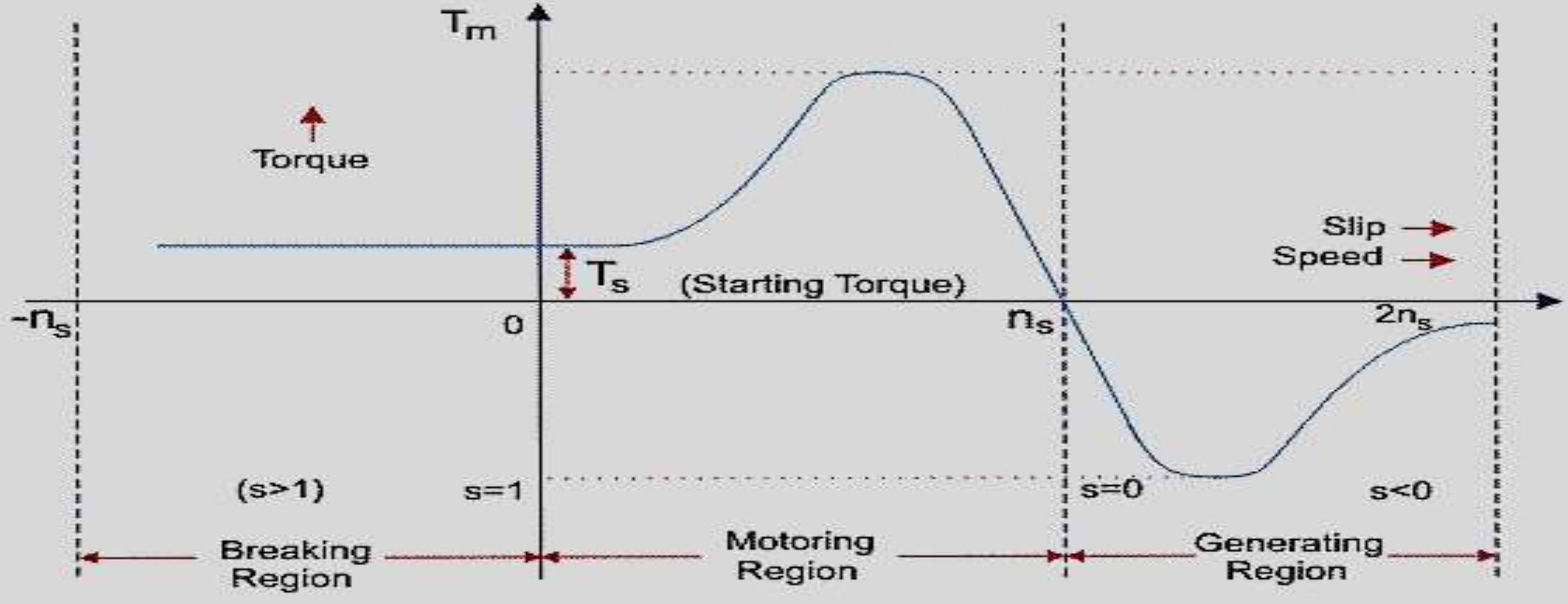


Phase wound rotor connections

PHASE WOUND ROTOR:SLIPRING ROTOR

- Phase wound rotor is wound with 3 phase, double layer, distributed winding. The number of poles of rotor are kept same to the number of poles of the stator.
- The three phase rotor winding is internally star connected.
- The other three terminals of the winding are taken out via three insulated sleep rings mounted on the shaft and the brushes resting on them.
- These three brushes are connected to an external star connected rheostat.
- This arrangement is done to introduce an external resistance in rotor circuit for **starting purposes** and for **changing the speed / torque characteristics**.

TORQUE SLIP[P CHARACTERISTICS OF 3PHASE INDUCTION MOTOR



Torque Slip Curve for Three Phase Induction Motor

TORQUE SLIP[P CHARACTERISTICS OF 3PHASE INDUCTION MOTOR

- The torque slip curve for an induction motor gives us the information about the variation of torque with the slip. The slip is defined as the ratio of difference of synchronous speed and actual rotor speed to the synchronous speed of the machine. The variation of slip can be obtained with the variation of speed that is when speed varies the slip will also vary and the torque corresponding to that speed will also vary.

TORQUE SLIP[P CHARACTERISTICS OF 3PHASE INDUCTION MOTOR

Motoring Mode: In this mode of operation, supply is given to the stator sides and the motor always rotates below the synchronous speed.

- The induction motor torque varies from zero to full load torque as the slip varies.
- The slip varies from zero to one.
- It is zero at no load and one at standstill.
- From the curve it is seen that the torque is directly proportional to the slip.
- That is, more is the slip, more will be the torque produced and vice-versa.

TORQUE SLIP[P CHARACTERISTICS OF 3PHASE INDUCTION MOTOR

Generating Mode:

- In this mode of operation induction motor runs above the synchronous speed and it should be driven by a prime mover. The stator winding is connected to a three phase supply in which it supplies electrical energy.
- Actually, in this case, the torque and slip both are negative so the motor receives mechanical energy and delivers electrical energy.
- **Induction motor is not much used as generator because it requires reactive power for its operation.**
- That is, reactive power should be supplied from outside and if it runs below the synchronous speed by any means, it consumes electrical energy rather than giving it at the output. So, as far as possible, induction generators are generally avoided.

TORQUE SLIP[P CHARACTERISTICS OF 3PHASE INDUCTION MOTOR

Braking Mode: In the Braking mode, the two leads or the polarity of the supply voltage is changed so that the motor starts to rotate in the reverse direction and as a result the motor stops. This method of braking is known as plugging.

- This method is used when it is required to stop the motor within a very short period of time.
- The kinetic energy stored in the revolving load is dissipated as heat.
- Also, motor is still receiving power from the stator which is also dissipated as heat.
- So as a result of which motor develops enormous heat energy.
- For this stator is disconnected from the supply before motor enters the braking mode.

GENERATIVE BRAKING

- If load which the motor drives accelerates the motor in the same direction as the motor is rotating, the speed of the motor may increase more than synchronous speed.
- In this case, it acts as an induction generator which supplies electrical energy to the mains which tends to slow down the motor to its synchronous speed,
- in this case the motor stops. This type of breaking principle is called dynamic or regenerative breaking.

3 PHASE INDUCTION MACHINE

- Torque equation
- Slip and its significance
- Torque slip characteristics
- various losses that occur in an induction motor and vary with frequency, voltage and load