Module 5 : A.C. Machines

Walchand College of Engineering, Sangli.

Contents

- Construction and working principle of single and three-phase induction motor
- Types, torque-speed characteristics and applications of induction motor
- Types of starters
- AC generator

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.
- 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" (RMF). In a motor, synchronous speed is the speed at which the magnetic field rotates.
- 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**.
- This action is same as that occurs in transformers, hence induction motors can be called as **rotating transformers**.

- 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.
- 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** of either type, single phase of 3 phase.

- **Synchronous Speed:**

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

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

where, f = frequency of the spply

P = number of poles

- **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 force/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.

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

Construction

- A three phase Induction motor mainly consists of two parts called as the Stator and the Rotor.

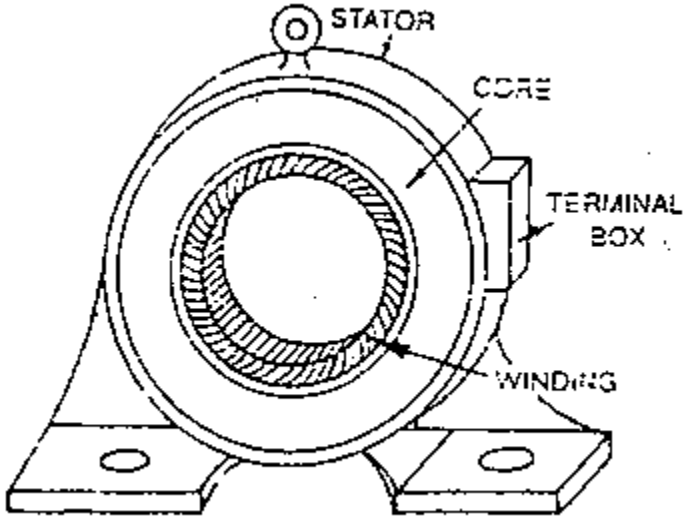
- The stator is the stationary part of the induction motor, and the rotor is the rotating part.

Construction of Stator

The stator is built up of high-grade alloy steel laminations to reduce eddy current losses. It has three main parts, namely outer frame, the stator core and a stator winding.

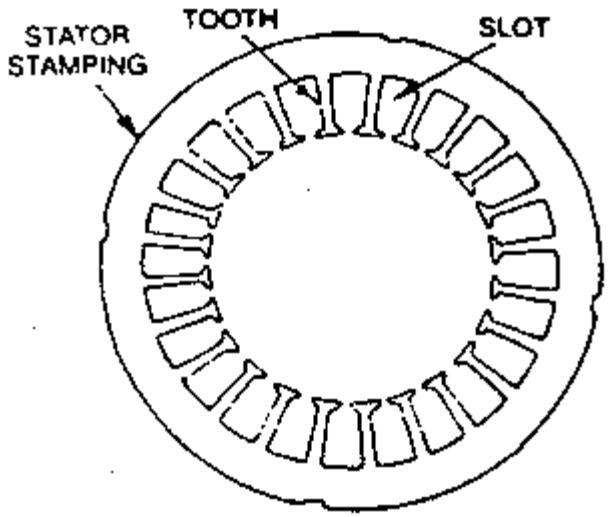
- **Outer frame**

It is the outer body of the motor. Its main function is to support the stator core and to protect the inner parts of the machine. For small machines, the outer frame is casted, but for the large machine, it is fabricated.



- **Stator Core**

The stator core is built of high-grade silicon steel stampings. Its main function is to carry the alternating magnetic field which produces hysteresis and eddy current losses. The stampings are fixed to the stator frame. Each stamping are insulated from the other with a thin varnish layer. The thickness of the stamping usually varies from 0.3 to 0.5 mm. Slots are punched on the inner side of the stampings as shown in the figure below.



- **Stator windings**
- The core of the stator carries three phase windings which are usually supplied from a three-phase supply system. The six terminals of the windings (two of each phase) are connected in the terminal box of the machine.
- The stator of the motor is wound for a definite number of poles, depending on the speed of the motor. If the number of poles is greater, the speed of the motor will be less and if the number of poles is less than the speed will be high.

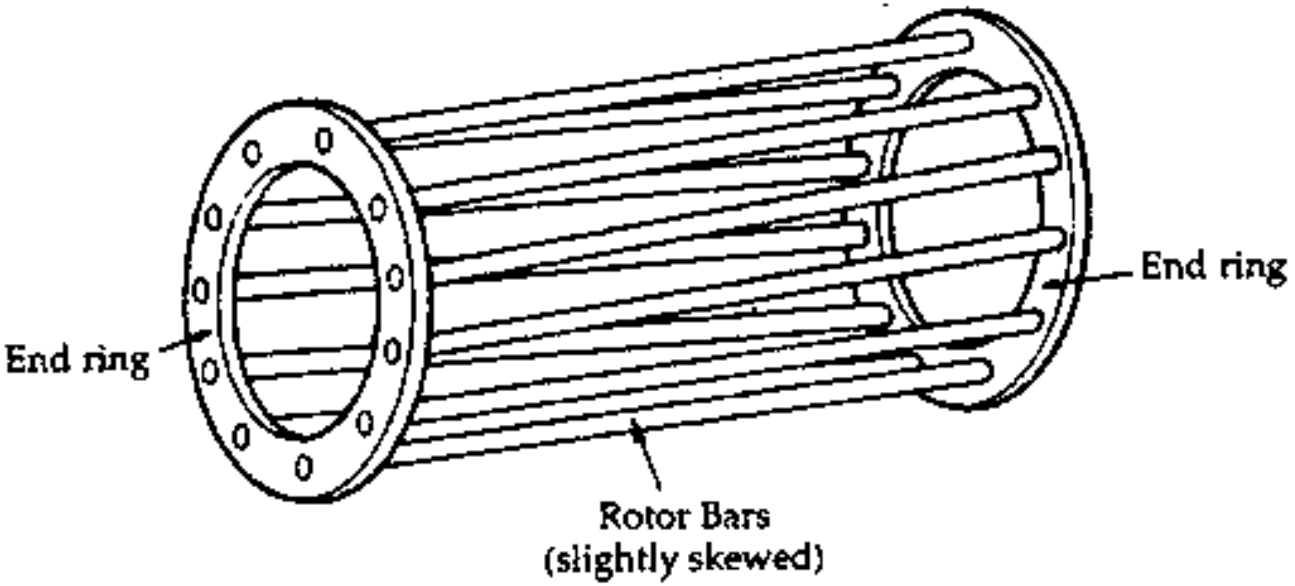
$$N_S \propto \frac{1}{P} \quad \text{or} \quad N_S = \frac{120f}{P}$$

Construction of Rotor

The rotor is also built of thin laminations of the same material as the stator. The laminated cylindrical core is mounted directly on the shaft. These laminations are slotted on the outer side to receive the conductors. There are two types of rotor.

- **Squirrel Cage Rotor**

A squirrel cage rotor consists of a laminated cylindrical core. The circular slots at the outer periphery are semi-closed. Each slot contains bar conductor of aluminum or copper. At the end of the rotor the conductors the short-circuited by a heavy ring of copper or aluminum. The diagram of the cage rotor is shown below.


End ring
End ring
Rotor Bars
(slightly skewed)

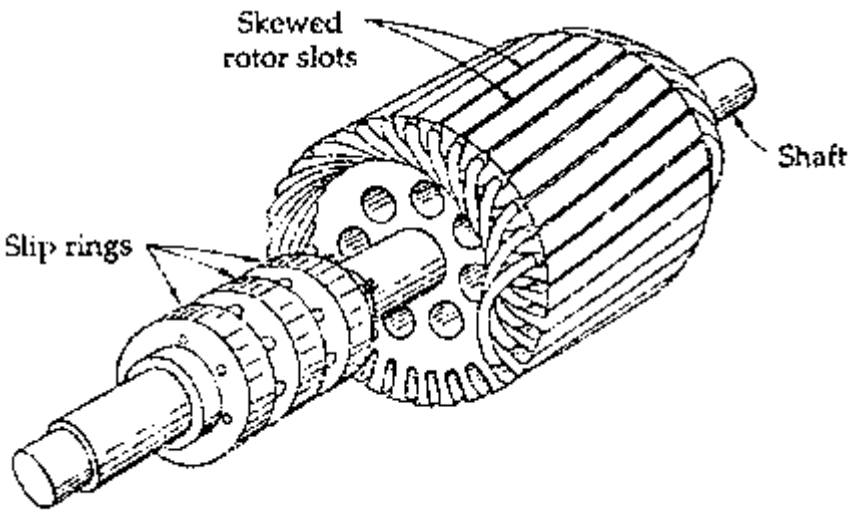
- The rotor slots are usually not parallel to the shaft but are skewed. The skewing of the rotor conductors has the following advantages given below.

1. It reduces humming and provide smooth and noise free operation.
2. It results in a uniform torque curve for different positions of the rotor.
3. The locking tendency of the rotor is reduced. As the teeth of the rotor and the stator attract each other and lock.
4. It increases the rotor resistance due to the increased length of the rotor bar conductors.

Advantages of Squirrel Cage Rotor

- The cage rotor is cheaper, and the construction is robust.
- The absence of the brushes reduces the risk of sparking.
- Its Maintenance is less.
- The power factor is higher
- The efficiency of the cage rotor is higher.

- **Phase Wound Rotor**
- The Phase wound rotor is also called as Slip Ring Rotor. It consists of a cylindrical core which is laminated. The outer periphery of the rotor has a semi-closed slot which carries a 3 phase insulated windings. The rotor windings are connected in star.
- The **slip ring induction motor** is shown in the figure below



- The slip rings are mounted on the shaft with brushes resting on them. The brushes are connected to the variable resistor. The function of the slip rings and the brushes is to provide a means of connecting external resistors in the rotor circuit. The resistor enables the variation of each rotor phase resistance to serve the following purposes given below.

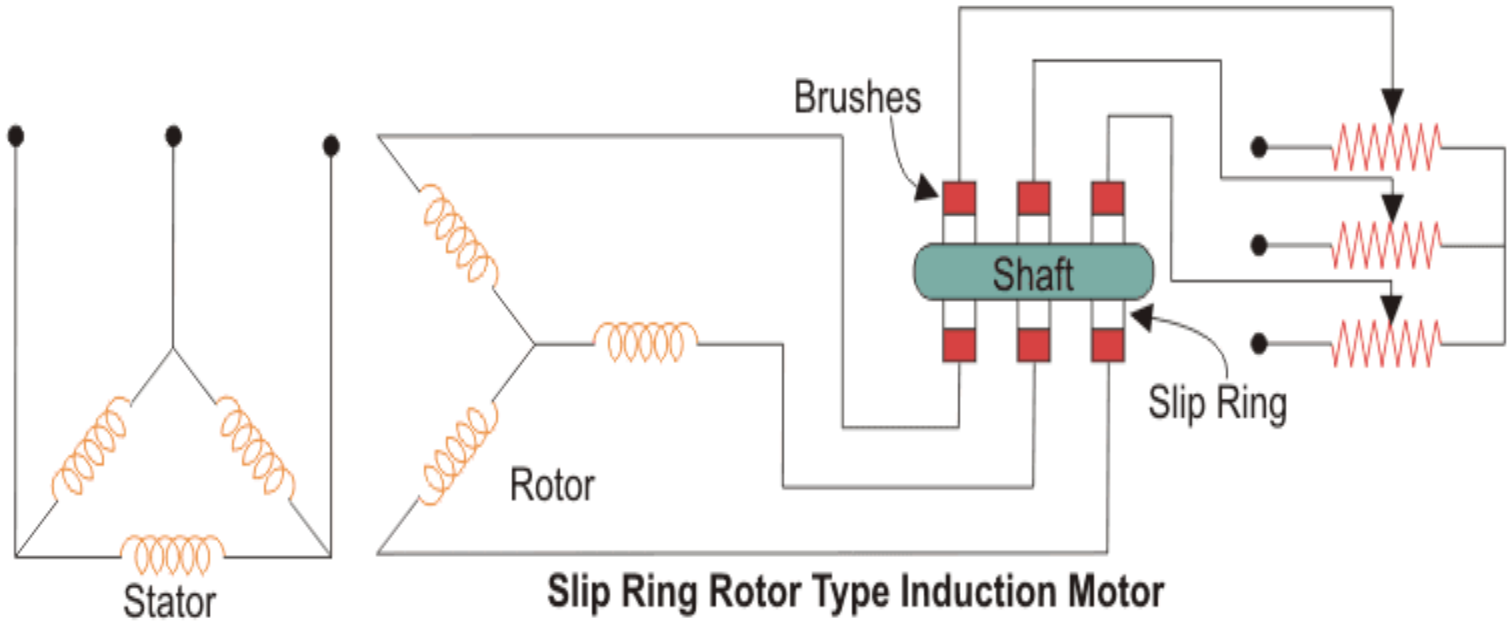
1. It increases the starting torque and decreases the starting current.
2. It is used to control the speed of the motor.
3. In this type also, the rotor is skewed. A mild steel shaft is passed through the center of the rotor and is fixed to it. The purpose of the shaft is to transfer mechanical power.

Advantages of Phase Wound Rotor

- High starting torque and low starting current.
- For controlling the speed of the motor, an external resistance can be added in the circuit.

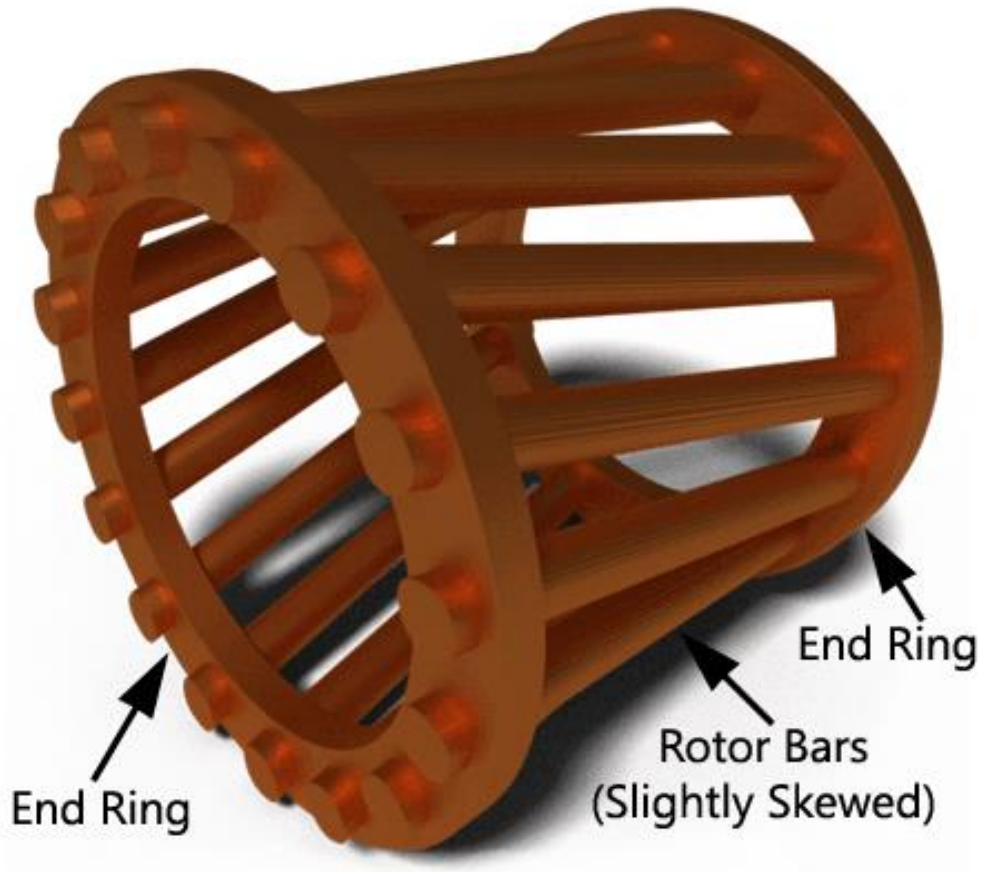
Slip ring or phase wound Induction motor	Squirrel cage induction motor
Construction is complicated due to presence of slip ring and brushes	Construction is very simple
The rotor winding is similar to the stator winding	The rotor consists of rotor bars which are permanently shorted with the help of end rings
We can easily add rotor resistance by using slip ring and brushes	Since the rotor bars are permanently shorted, its not possible to add external resistance
Due to presence of external resistance high starting torque can be obtained	Staring torque is low and cannot be improved
Slip ring and brushes are present	Slip ring and brushes are absent
Frequent maintenance is required due to presence of brushes	Less maintenance is required

The construction is complicated and the presence of brushes and slip ring makes the motor more costly	The construction is simple and robust and it is cheap as compared to slip ring induction motor
This motor is rarely used only 10% industry uses slip ring induction motor	Due to its simple construction and low cost. The squirrel cage induction motor is widely used
Rotor copper losses are high and hence less efficiency	Less rotor copper losses and hence high efficiency
Speed control by rotor resistance method is possible	Speed control by rotor resistance method is not possible
Slip ring induction motor are used where high starting torque is required i.e in hoists, cranes, elevator etc	Squirrel cage induction motor is used in lathes, drilling machine, fan, blower printing machines etc



Slip Ring Rotor Type Induction Motor

Squirrel Cage Rotor



Single Phase IM

Working Principle

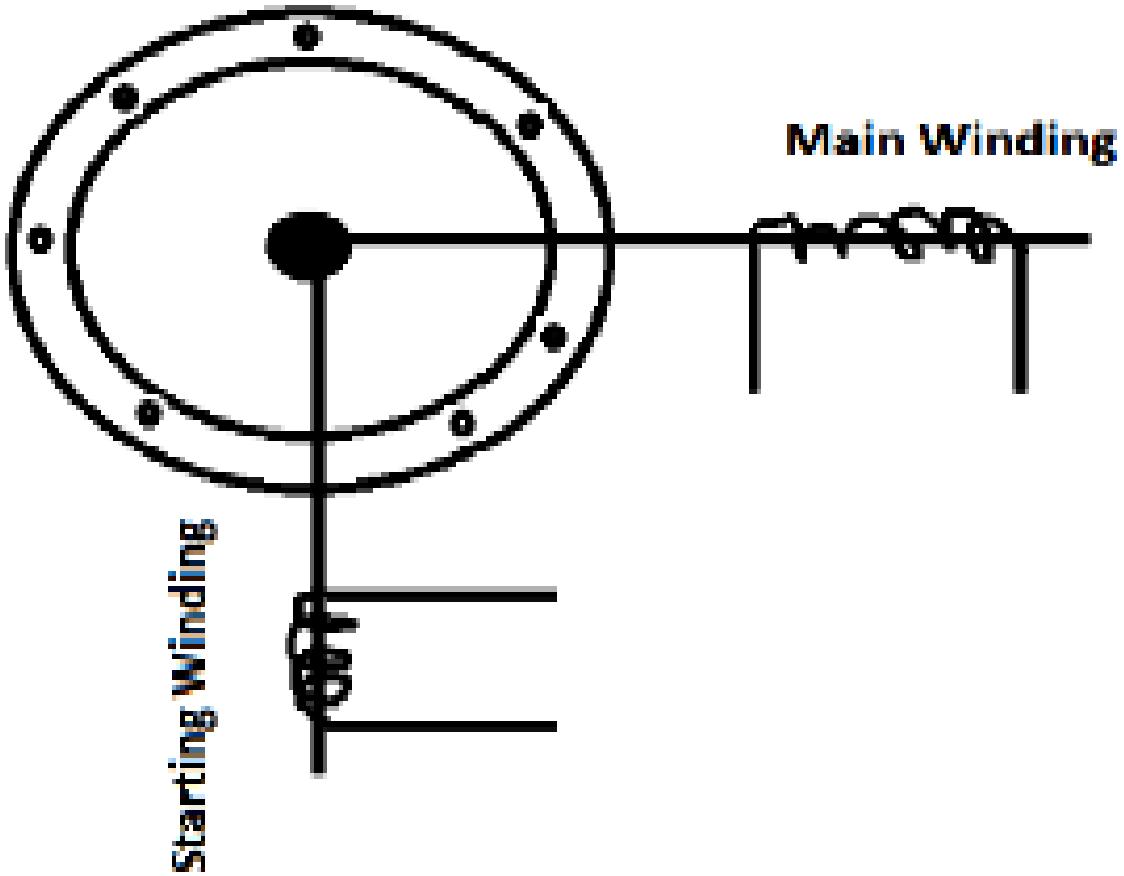
- When ac supply is given, current starts flowing through the stator winding
- This alternating current produces an alternating flux called main flux.
- This flux links with the rotor conductors and hence cut the rotor conductors.
- The EMF gets induced in the rotor and current starts flowing in the rotor (Faraday's Law).
- This rotor current produces its own flux called rotor flux.

- This flux is produced due to induction principle.
- Two fluxes: one is main flux and another is rotor flux.
- The interaction of these two fluxes produces the desired torque which is required by the motor to rotate.
- Good efficiency up to 97%.
- The speed of the motor varies with the load given

Principle of Starting

- Two windings are phase shifted by 90° electrically
- The winding currents are 90° phase shifted with respect to each others
- Two windings produce a rotating magnetic field in air gap between stator & rotor.
- This rotating magnetic field induces EMF in rotor & rotor rotates in the same direction of rotating magnetic field.
- Methods used for Phase shifting the currents:
  1. Resistance split phase
  2. Capacitor Split phase

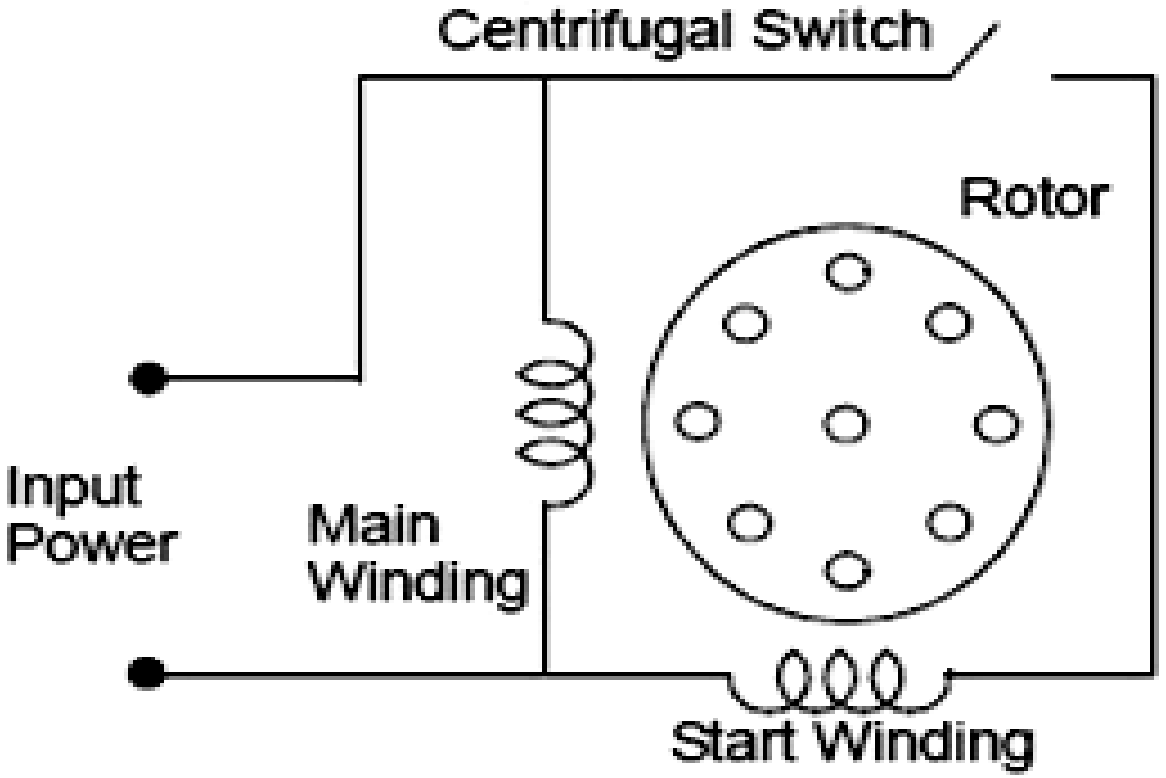
Principle of Starting



Types of Single Phase Induction Motor

1. Split phase induction motor
2. Capacitor start induction motor
3. Capacitor start capacitor run induction motor
4. Shaded pole induction motor

1. Split phase induction motor

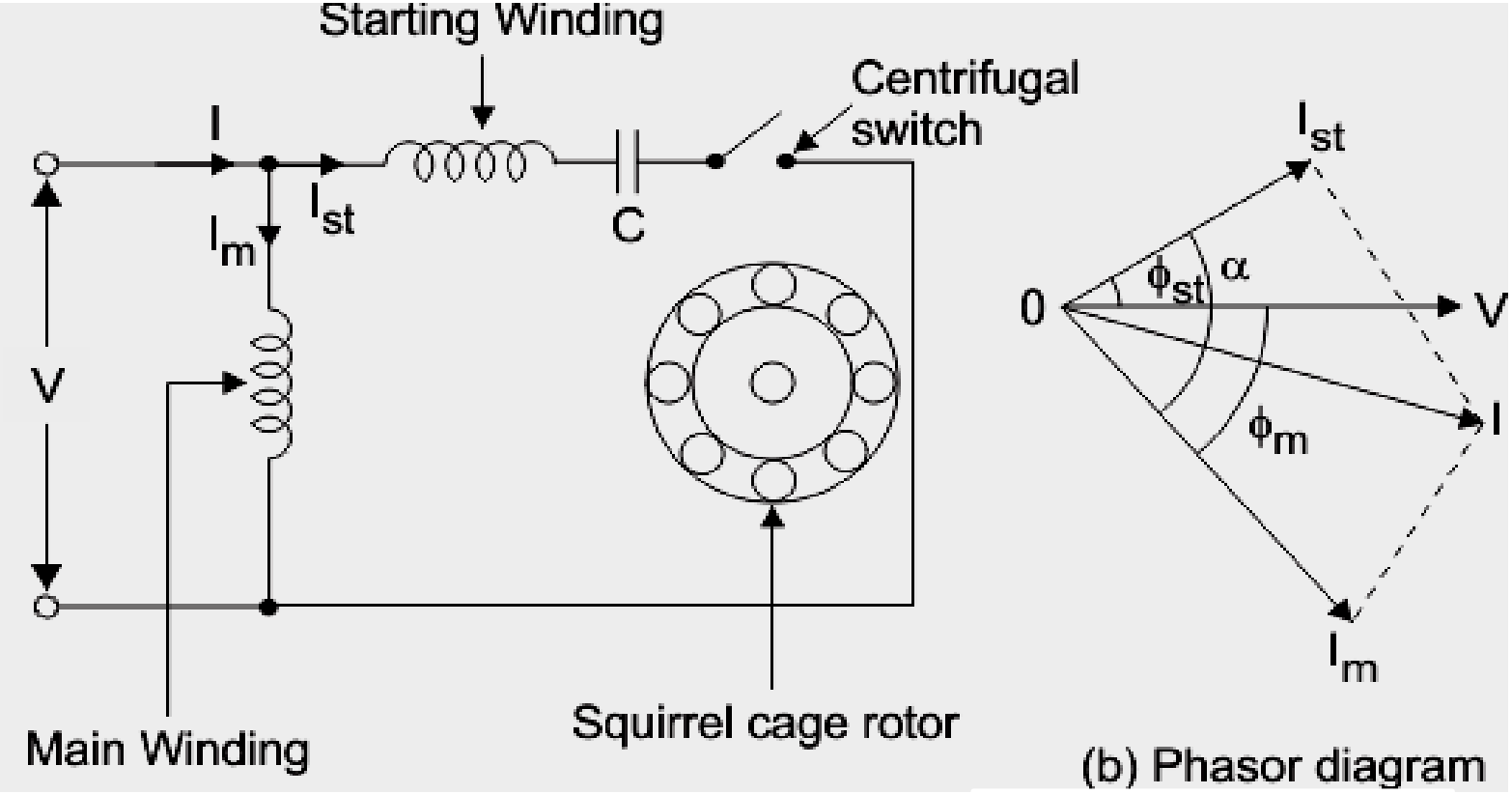


Split phase induction motor

- In addition to the main winding **(inductive)** ,the stator carries another winding called auxiliary winding or starting winding **(resistive).**
- Centrifugal switch: to disconnect the auxiliary winding from the main circuit at speed up to 75 to 80% of the synchronous speed.
- Aim is to create the phase difference between the two winding
- This is possible if the starting winding carries high resistance.

- For highly resistive winding the current is almost in phase with the voltage and for highly inductive winding the current lag behind the voltage by large angle.
- The current flowing in the starting winding lags behind the applied voltage by very small angle and the current flowing in running winding lags behind applied voltage by large angle.
- The resultant of these two current produce rotating magnetic field which rotates in one direction

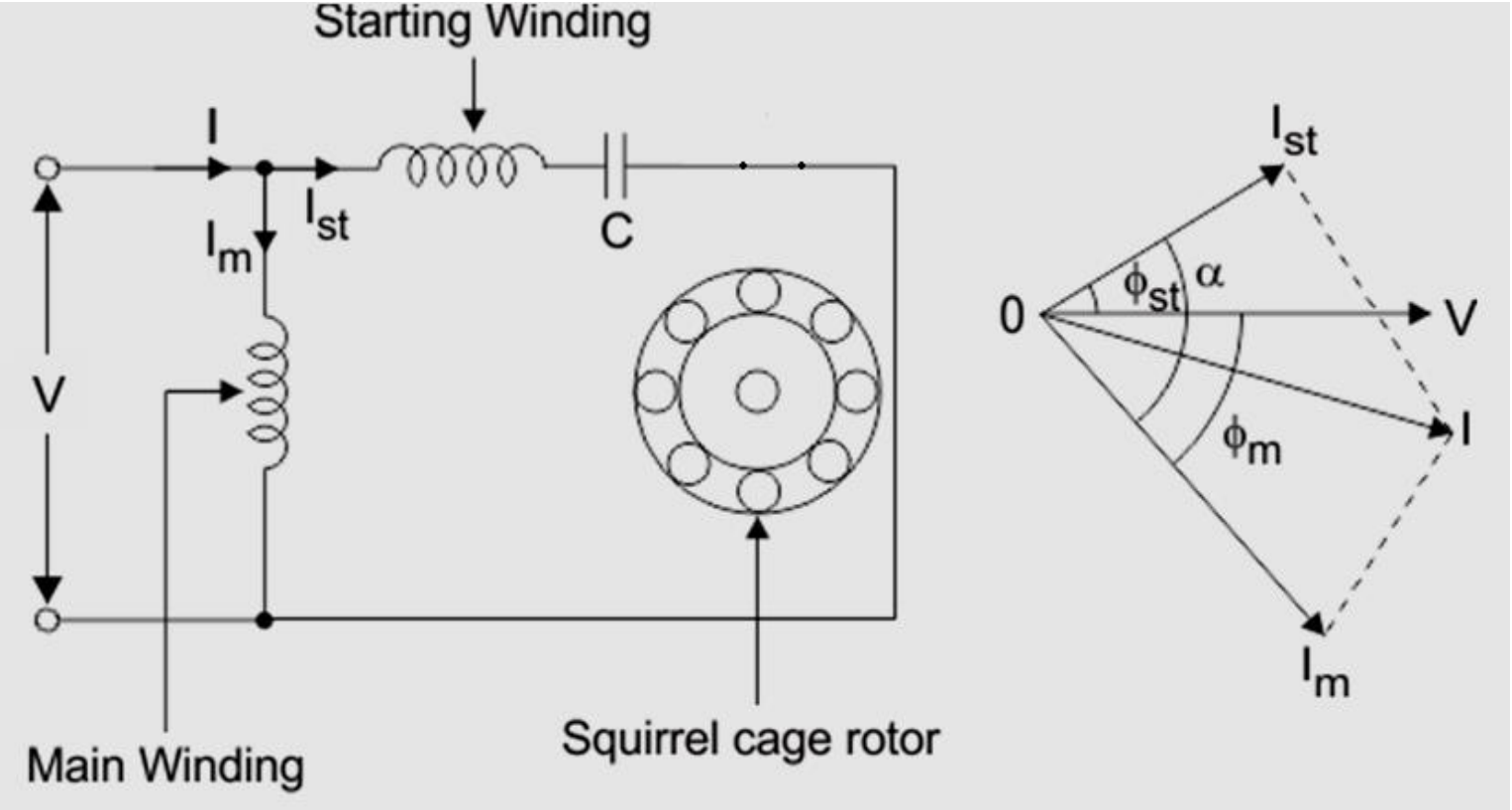
2. Capacitor Start Induction Run Motor



- For producing rotating magnetic field, the phase difference is provided by capacitor in series with starting winding.
- Current flowing through the capacitor leads the voltage.
- With starting winding, we connect a capacitor so the current flowing in the capacitor leads the applied voltage by some angle.
- The current flowing in main winding (inductive) lags behind applied voltage.

- There occur large phase angle differences between two currents which produce a resultant current and produce a rotating magnetic field.
- Phase angle difference is almost 90°
- Very high starting torque
- Centrifugal switch is provided so as to disconnect the starting winding afterwards.

3. Capacitor Start Capacitor Run Induction Motor



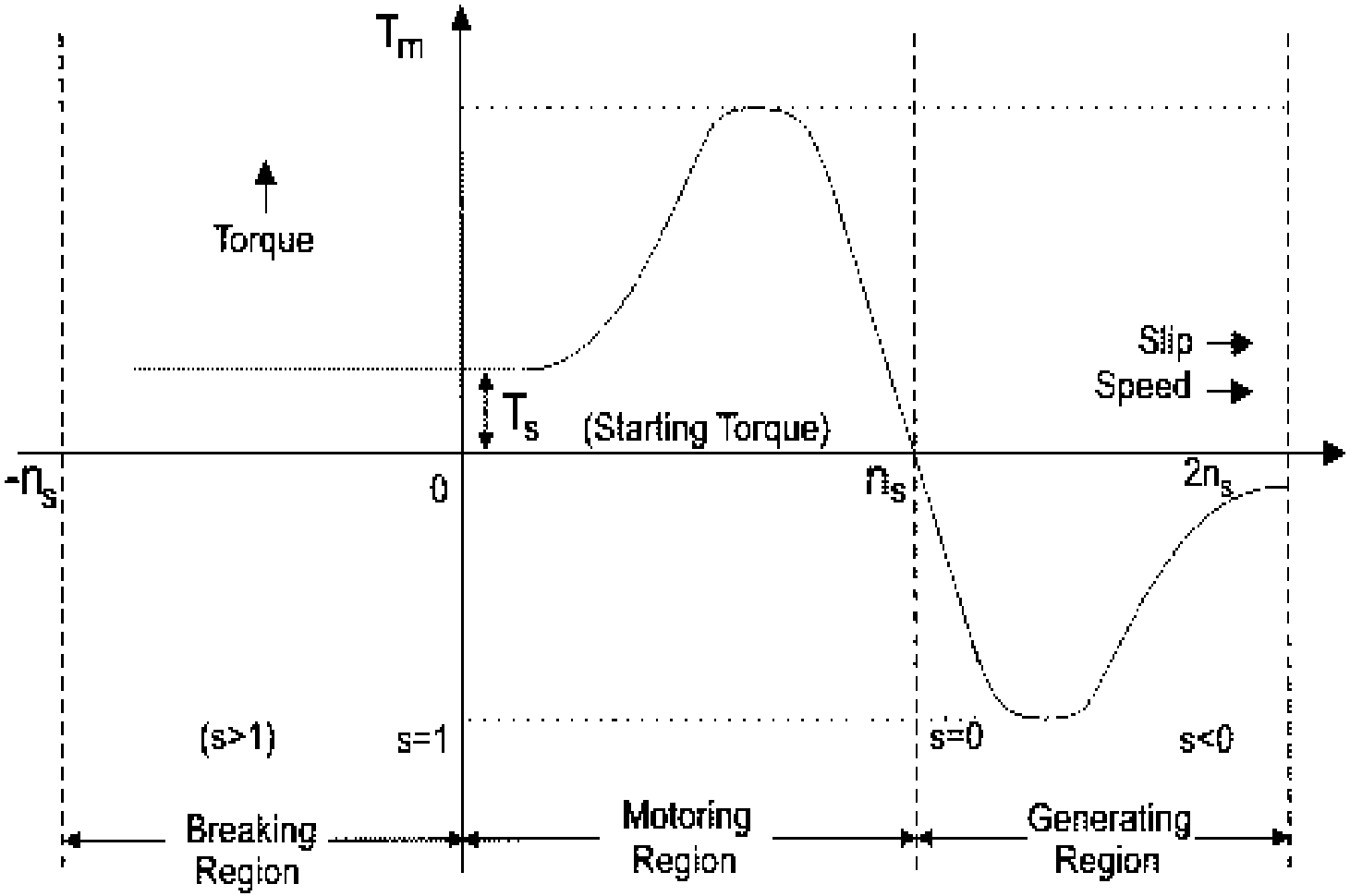
- The working principle & construction of Capacitor start inductor motors & capacitor start capacitor run induction motors are almost the same.
- Two windings: main winding and the starting winding
- No centrifugal switch
- Capacitor remains in the circuit
- It helps to improve the power factor at the running conditions

Torque Slip Characteristics of Induction Motor

The torque slip curve for an induction motor gives us the information about the variation of torque with the slip. 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. The torque-slip characteristic curve can be divided roughly into three regions:

- Low slip region
- Medium slip region
- High slip region

The curve can be described in three modes of operation-



Torque Slip Curve for Three Phase 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.

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.

- **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.

- **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.

Applications of IM

- Fan, Blowers, Machine tools
- Compressor, Crushers, Conveyors
- Bulldozers
- Cranes, Elevators, Hoist

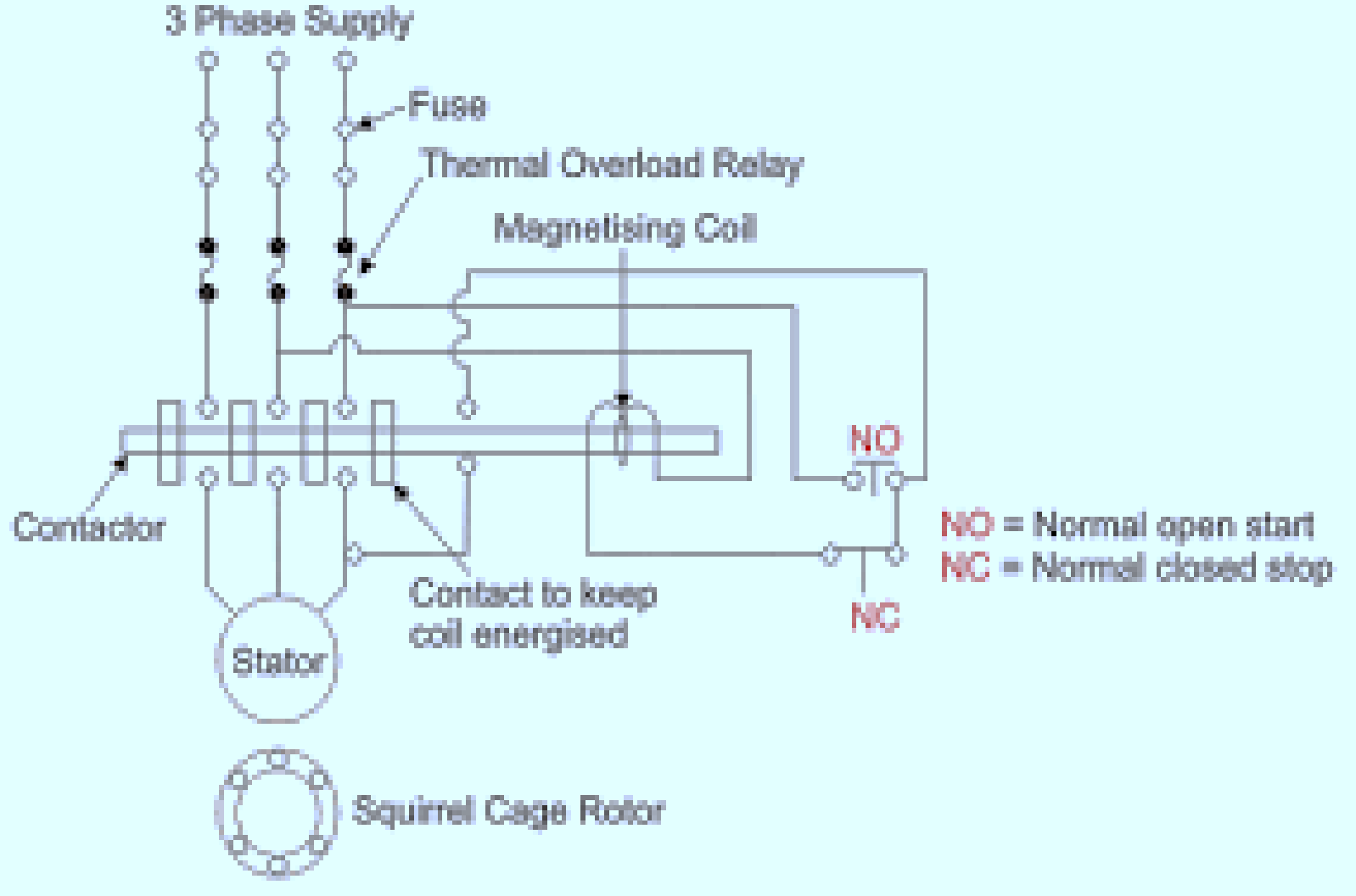
Types of starters

Need of starters

- Large current flowing initially just after switching ON the supply causes large voltage drops across various elements of motor which greatly affects the functioning of motor. This can cause heating up of the motor, eventually damaging it. To prevent this, motor starters are needed.
- It is the device connected in series with the motor **to decrease its starting current** and then increase it as the motor starts rotating gradually.

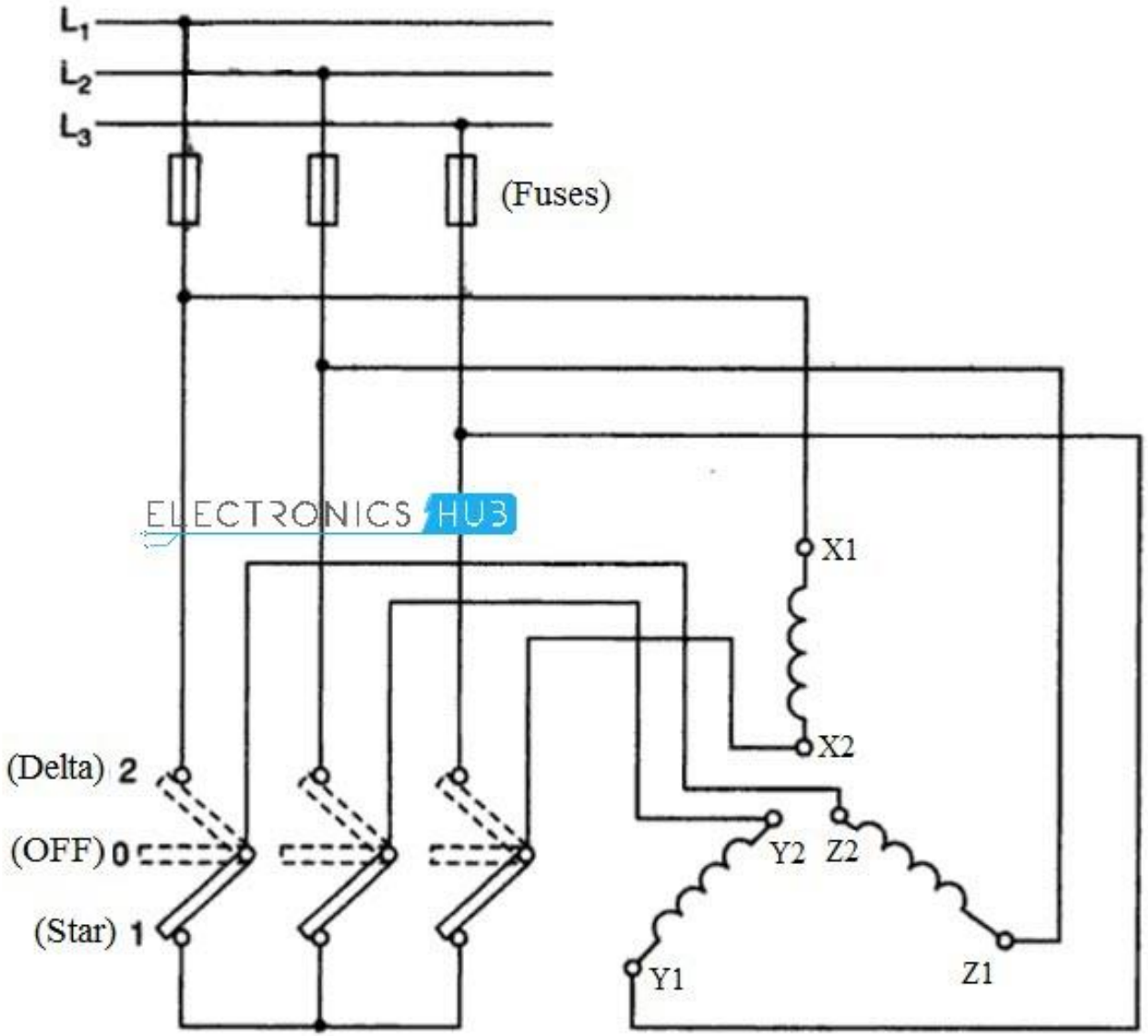
Direct-On-Line (DOL) Starters

- Small three phase induction motors can be started direct-on-line, which means that the rated supply is directly applied to the motor.
- Induction motors can be started directly on-line using a DOL starter which generally consists of a contactor and a motor protection equipment such as a circuit breaker. A DOL starter consists of a coil operated contactor which can be controlled by start and stop push buttons. When the start push button is pressed, the contactor gets energized and it closes all the three phases of the motor to the supply phases at a time. The stop push button de-energizes the contactor and disconnects all the three phases to stop the motor.
- In order to avoid excessive voltage drop in the supply line due to large starting current, a DOL starter is generally used for motors that are rated below 5kW.

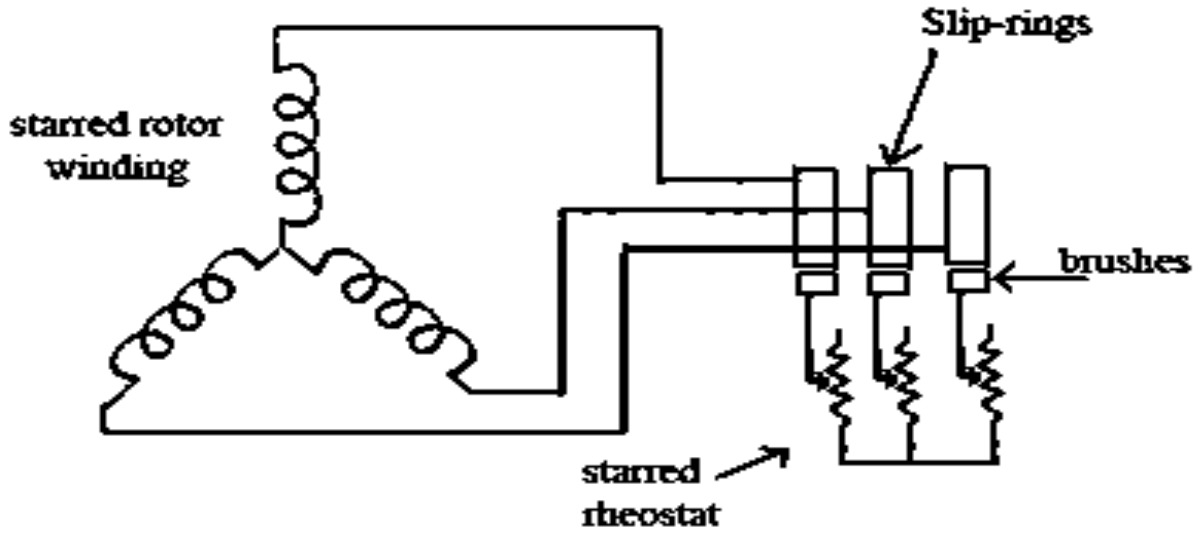

3 Phase Supply
Fuse
Thermal Overload Relay
Magnetising Coil
NO
Contactor
NO = Normal open start
NC = Normal closed stop
Contact to keep
coil energised
NC
Stator
Squirrel Cage Rotor

Star-Delta Starter:

- This method is used in the motors, which are designed to run on delta connected stator. A two way switch is used to connect the stator winding in star while starting and in delta while running at normal speed.
- The stator winding is connected in star fashion so that voltage at each phase is $V_L/\sqrt{3}$ Where, V_L is line voltage. Therefore voltage is reduced at each phase at starting and hence current is reduced. As soon as motor achieves certain speed, motor winding is connected in delta fashion such that line voltage is equal to phase voltage with the help of two way switch.
- A star-delta starter is equivalent to an auto-transformer of ratio $\frac{1}{\sqrt{3}}$ or 58% reduced voltage. The star delta starter is used for starting of induction motor above 5 H.P.


L1
L2
L3
(Fuses)
ELECTRONICS HUB
X1
X2
(Delta) 2
(OFF) 0
(Star) 1
Y2
Z2
Y1
Z1

Starting Of Slip-Ring Motors



Phase wound rotor connections

- Slip-Ring IM are started with full line voltage, as external resistance can be easily added in the rotor circuit with the help of slip-rings. A star connected rheostat is connected in series with the rotor via slip-rings as shown in the fig. Introducing resistance in rotor current will decrease the starting current in rotor (and, hence, in stator). Also, it improves power factor as the torque is increased.

- The connected rheostat may be hand-operated or automatic.
- As, introduction of additional resistance in rotor improves the starting torque, slip-ring motors can be started on load. The external resistance introduced is only for starting purposes, and is gradually cut out as the motor gathers the speed.

THANK YOU