INDUCTION MACHINE

Construction of Three Phase Induction Motor

The three phase induction motor is the most widely used electrical motor. Almost 80% of the mechanical power used by industries is provided by **three phase induction motors** because of its simple and rugged construction, low cost, good operating characteristics, the absence of commutator and good speed regulation. In three phase induction motor, the power is transferred from stator to rotor winding through induction. The induction motor is also called a synchronous motor as it runs at a speed other than the synchronous speed.

3 Phase Induction Motor Construction

Like any other type of electrical motor induction motor, a 3 phase induction motor is constructed from two main parts, namely the rotor and stator:

1. Stator: As its name indicates stator is a stationary part of induction motor. A stator winding is placed in the stator of induction motor and the three phase supply is given to it.
2. Rotor: The rotor is a rotating part of induction motor. The rotor is connected to the mechanical load through the shaft.

he rotor of the three phase induction motor are further classified as

1. Squirrel cage rotor
2. Slip ring rotor or wound rotor or phase wound rotor.

Depending upon the type of rotor construction used the **three phase induction motor** are classified as:

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The construction of a stator for both of the kinds of three phase induction motors is identifcal, and is discussed briefly below. Please ensure you are using the appropriate electrical tools if you're going to be deconstructing a motor yourself.

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The other parts of a 3 phase induction motor are:

1. Shaft for transmitting the torque to the load. This shaft is made up of steel.
2. Bearings for supporting the rotating shaft.
3. One of the problems with electrical motor is the production of heat during its rotation. To overcome this problem, we need a fan for cooling.
4. For receiving external electrical connection Terminal box is needed.
5. There is a small distance between rotor and stator which usually varies from 0.4 mm to 4 mm. Such a distance is called air gap.

You can learn more about induction motors by studying our electrical engineering MCQ.

Stator of Three Phase Induction Motor

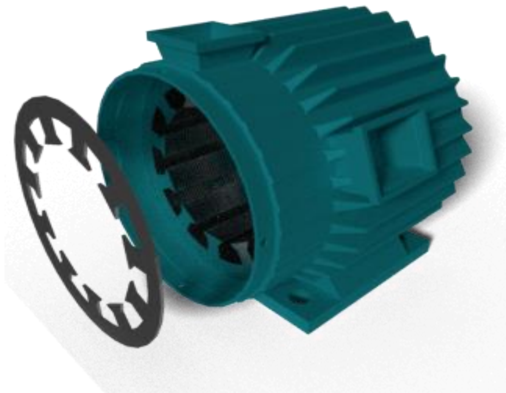
The stator of the three-phase induction motor consists of three main parts :

1. Stator frame,
2. Stator core,
3. Stator winding or field winding.

Stator Frame

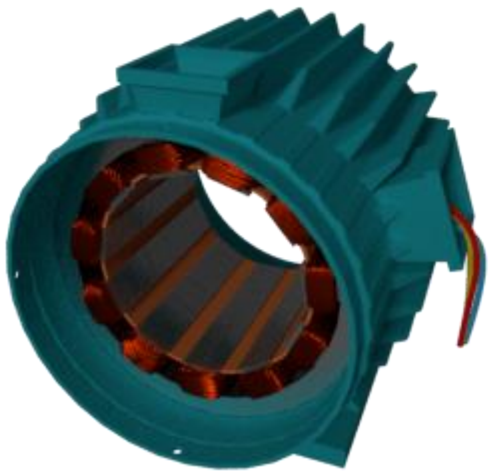
It is the outer part of the **three phase induction motor**. Its main function is to support the stator core and the field winding. It acts as a covering, and it provides protection and mechanical strength to all the inner parts of the induction motor. The frame is either made up of die-cast or fabricated steel. The frame of three phase induction motor should be strong and rigid as the air gap length of three phase induction motor is very small. Otherwise, the rotor will not remain concentric with the stator, which will give rise to an unbalanced magnetic pull.

Stator Core


The main function of the stator core is to carry the alternating flux. In order to reduce the eddy current loss, the stator core is laminated. These laminated types of structure are made up of stamping which is about 0.4 to 0.5 mm thick. All the stamping are stamped together to form stator core, which is then housed in stator frame. The stamping is made up of silicon steel, which helps to reduce the hysteresis loss occurring in the motor.

Stator Winding or Field Winding

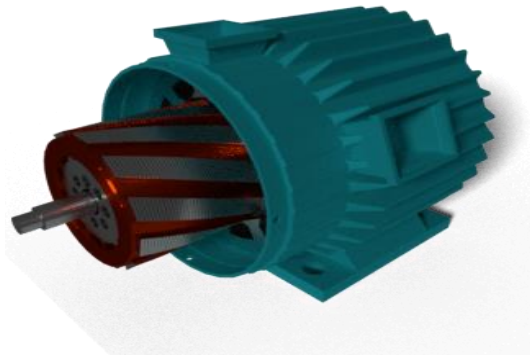
The slots on the periphery of the stator core of the three-phase induction motor carry three phase windings. We apply three phase ac supply to this three-phase winding. The three phases of the winding are connected either in star or delta depending upon which type of starting method we use. We start the squirrel cage motor mostly with star-delta stater and hence the stator of squirrel cage motor is delta connected. We start the slip ring three-phase induction motor by inserting resistances so, the stator winding of slip ring induction motor can be connected either in star or delta. The winding wound on the stator of three phase induction motor is also called field winding, and when this winding is excited by three phase ac supply, it produces a rotating magnetic field.



Types of Three Phase Induction Motor

Squirrel Cage Three Phase Induction Motor

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 (skewing is not shown in the figure of squirrel cage rotor besides) 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, brass or copper bars (copper bras rotor is shown in the figure beside). These aluminum, brass or copper 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. These motors have the advantage of adopting any number of pole pairs. The below diagram shows a squirrel cage induction rotor having aluminum bars short circuit by aluminum end rings.

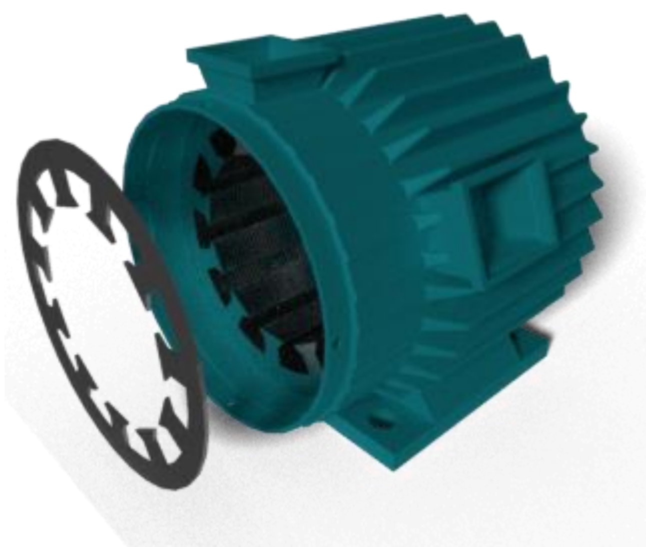


Advantages of Squirrel Cage Induction Rotor

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

Applications of Squirrel Cage Induction Rotor

We use the squirrel cage induction motors in lathes, drilling machine, fan, blower printing machines, etc



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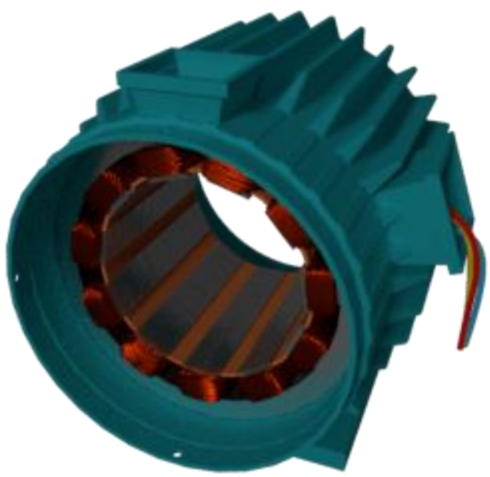

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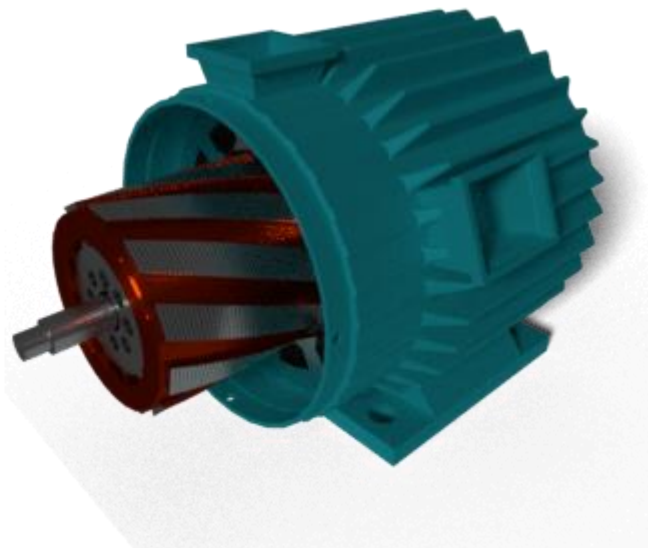

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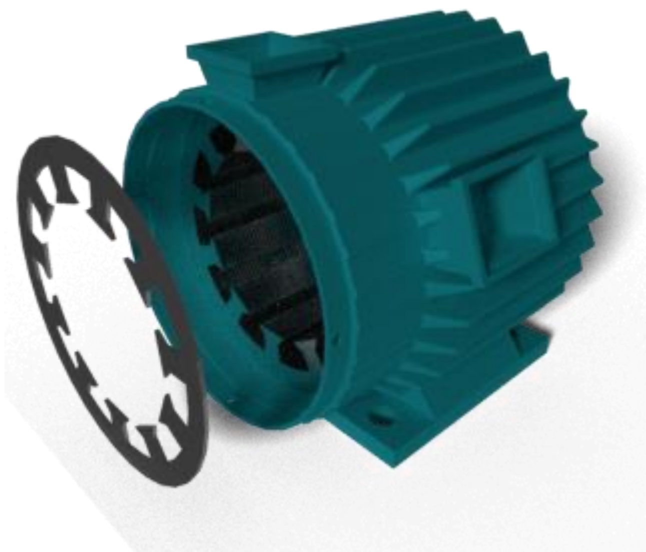
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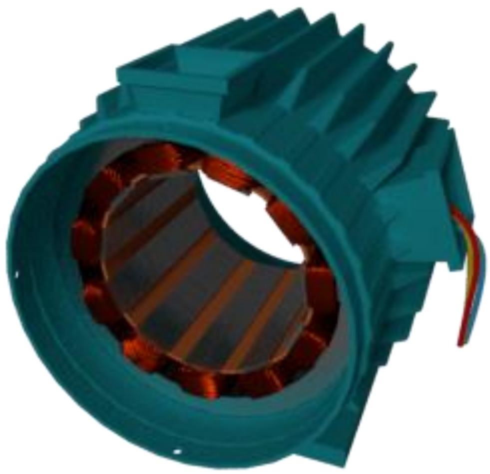

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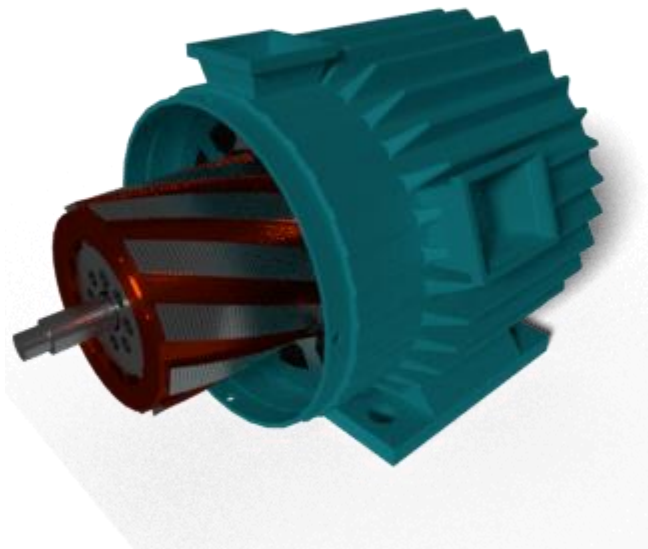

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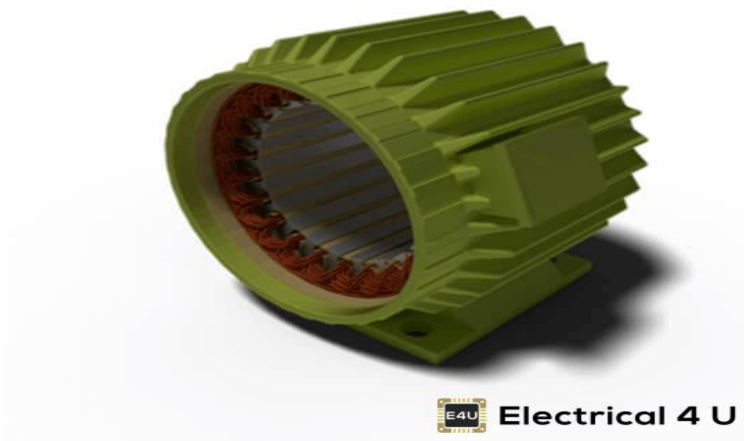
Working Principle

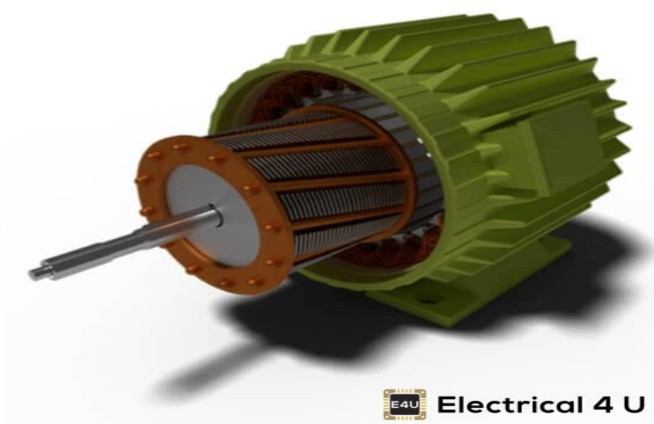
An electrical motor is an electromechanical device which converts electrical energy into mechanical energy. In the case of three phase AC (Alternating Current) operation, the most widely used motor is a **3 phase induction motor**, as this type of motor does not require an additional starting device. These types of motors are known as self-starting induction motors.

To get a good understanding of the working principle of a three phase induction motor, it's essential to understand the construction of a 3 phase induction motor. A 3 phase induction motor consists of two major parts:

- A stator
- A rotor
- The **stator** of three phase induction motor is made up of numbers of slots to construct a 3 phase winding circuit which we connect with 3 phase AC source. We arrange the three-phase winding in such a manner in the slots that they produce one rotating magnetic field when we switch on the three-phase AC supply source.

- 

- ## Rotor of 3 Phase Induction Motor
- The **rotor** of three phase induction motor consists of a cylindrical laminated core with parallel slots that can carry conductors. The conductors are heavy copper or aluminum bars fitted in each slot and short-circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise and can avoid stalling of the motor.

- 

- ## Working of Three Phase Induction Motor
- ## Production of Rotating Magnetic Field
- The stator of the motor consists of overlapping winding offset by an electrical angle of 120°. When we connect the primary winding, or the stator to a 3 phase AC source, it establishes rotating magnetic field which rotates at the synchronous speed.

Secrets Behind the Rotation:

According to Faraday's law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the

stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor.
Here the relative speed between the rotating flux and static rotor conductor is the cause of current generation; hence as per Lenz's law, the rotor will rotate in the same direction to reduce the cause, i.e., the relative velocity.
Thus from the **working principle of three phase induction motor**, it may be observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds become equal, there would be no such relative speed, so no emf induced in the rotor, and no current would be flowing, and therefore no torque would be generated. Consequently, the rotor cannot reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor.
Thus the **three phase induction motor** is:

- Self-starting.
- Less armature reaction and brush sparking because of the absence of commutators and brushes that may cause sparks.
- Robust in construction.
- Economical.
- Easier to maintain.

Squirrel Cage Induction Motor: Working Principle & Applications

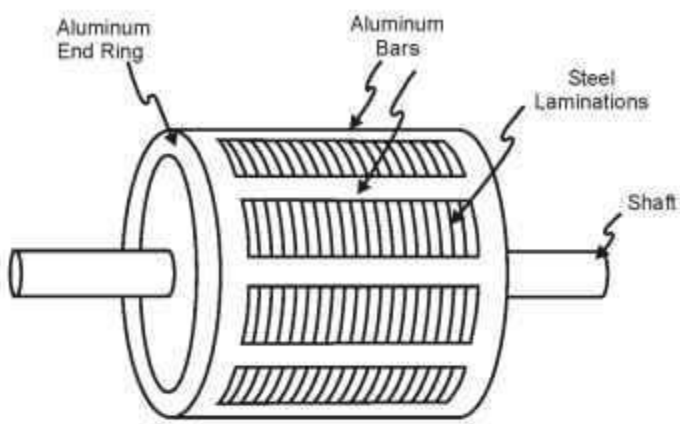
What is Squirrel Cage Induction Motor

A **3 phase squirrel cage induction motor** is a type of three phase induction motor which functions based on the principle of electromagnetism. It is called a 'squirrel cage' motor because the rotor inside of it – known as a 'squirrel cage rotor' – looks like a squirrel cage. This rotor is a cylinder of steel laminations, with highly conductive metal (typically aluminum or copper) embedded into its surface. When an alternating current is run through the stator windings, a rotating magnetic field is produced.
This induces a current in the rotor winding, which produces its own magnetic field. The interaction of the magnetic fields produced by the stator and rotor windings produces a torque on the squirrel cage rotor.

One big advantage of a squirrel cage motor is how easily you can change its speed-torque characteristics. This can be done by simply adjusting the shape of the bars in the rotor. Squirrel cage induction motors are used a lot in industry – as they are reliable, self-starting, and easy to adjust.

Squirrel Cage Induction Motor Working Principle

When a 3 phase supply is given to the stator winding it sets up a rotating magnetic field in space. This rotating magnetic field has a speed which is known as the synchronous speed. This rotating magnetic field induces the voltage in rotor bars and hence short-circuit currents start flowing in the rotor bars. These rotor currents generate their self-magnetic field which will interact with the field of the stator. Now the rotor field will try to oppose its cause, and hence rotor starts following the rotating magnetic field.
The moment rotor catches the rotating magnetic field the rotor current drops to zero as there is no more relative motion between the rotating magnetic field and rotor. Hence, at that moment the rotor experiences zero tangential force hence the rotor decelerates for the moment.



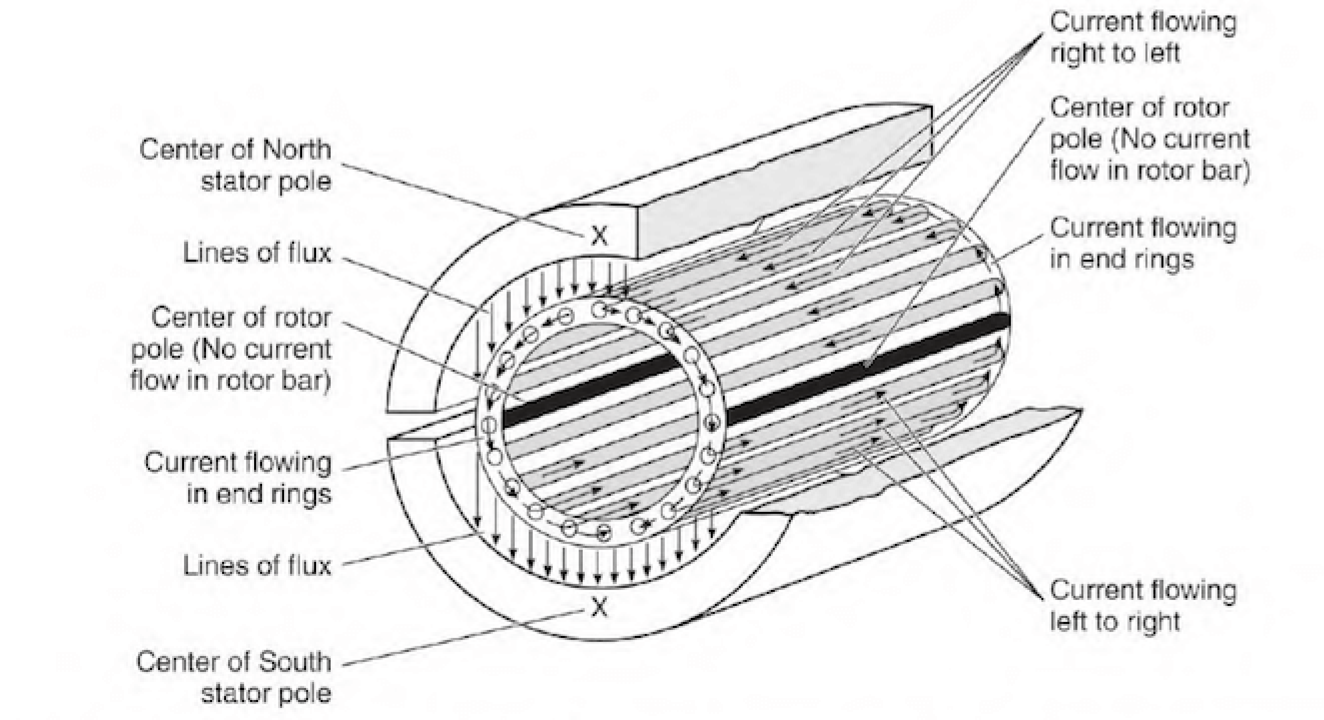
After deceleration of the rotor, the relative motion between the rotor and the rotating magnetic field reestablishes hence rotor current again being induced. So again, the tangential force for rotation of the rotor is restored, and therefore again the rotor starts following rotating magnetic field, and in this way, the rotor maintains a constant speed which is just less than the speed of rotating magnetic field or synchronous speed.

Slip is a measure of the difference between the speed of the rotating magnetic field and rotor speed. The frequency of the rotor current = slip × supply frequency

Squirrel Cage Induction Motor Construction

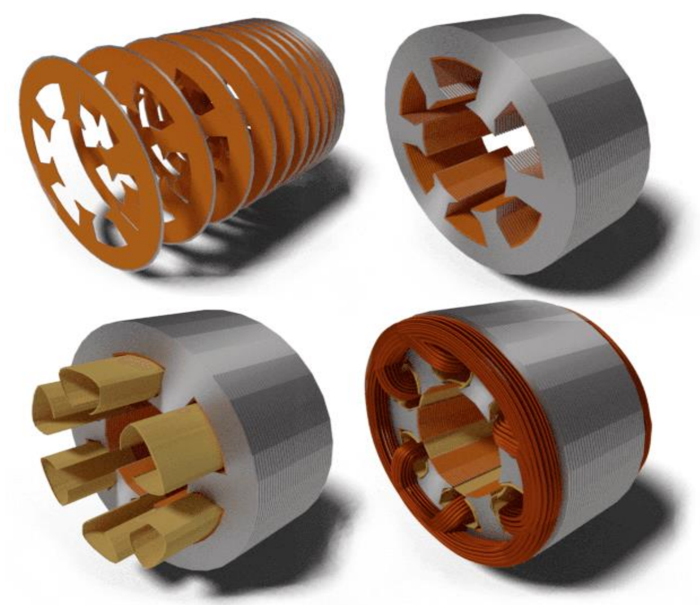
A squirrel cage induction motor consists of the following parts:

- Stator
- Rotor
- Fan
- Bearings



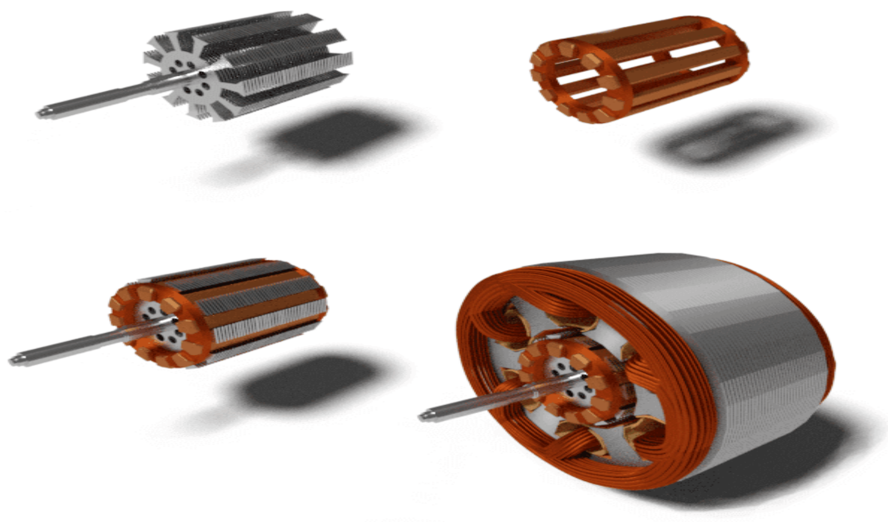
Stator

It consists of a 3 phase winding with a core and metal housing. Windings are such placed that they are electrically and mechanically 120° apart from in space. The winding is mounted on the laminated iron core to provide low reluctance path for generated flux by AC currents.



Rotor

It is the part of the motor which will be in a rotation to give mechanical output for a given amount of electrical energy. The rated output of the motor is mentioned on the nameplate in horsepower. It consists of a shaft, short-circuited copper/aluminum bars, and a core.



The rotor core is laminated to avoid power loss from eddy currents and hysteresis. Conductors are skewed to prevent cogging during starting operation and gives better transformation ratio between stator and rotor.

Fan

A fan is attached to the back side of the rotor to provide heat exchange, and hence it maintains the temperature of the motor under a limit.

Bearings

Bearings are provided as the base for rotor motion, and the bearings keep the smooth rotation of the motor.

Application of Squirrel Cage Induction Motor

Squirrel cage induction motors are commonly used in many industrial applications. They are particularly suited for applications where the motor must maintain a constant speed, be self-starting, or there is a desire for low maintenance.

These motors are commonly used in:

- Centrifugal pumps
- Industrial drives (e.g. to run conveyor belts)

- Large blowers and fans
- Machine tools
- Lathes and other turning equipment

Advantages of Squirrel Cage Induction Motor

Some advantages of squirrel cage induction motors are:

- They are low cost
- Require less maintenance (as there are no slip rings or brushes)
- Good speed regulation (they are able to maintain a constant speed)
- High efficiency in converting electrical energy to mechanical energy (while running, not during startup)
- Have better heat regulation (i.e. don’t get as hot)
- Small and lightweight
- Explosion proof (as there are no brushes which eliminate the risks of sparking)

Disadvantages of Squirrel Cage Induction Motor

Although squirrel cage motors are very popular and have many advantages – they also have some downsides. Some disadvantages of squirrel cage induction motors are:

- Very poor speed control
- Although they are energy efficient while running at full load current, they consume a lot of energy on startup
- They are more sensitive to fluctuations in the supply voltage. When the supply voltage is reduced, induction motor draws more current. During voltage surges, increase in voltage saturates the magnetic components of the squirrel cage induction motor
- They have high starting current and poor starting torque (the starting current can be 5-9 times the full load current; the starting torque can be 1.5-2 times the full load torque)

Difference Between Squirrel Cage and Slip Ring Induction Motor

While slip ring induction motors (also known as wound-rotor motor) aren’t as popular as squirrel cage induction motors, they do have a few advantages.

Below is a comparison table of squirrel cage vs wound rotor type motors:

	Squirrel Cage Motor	Slip Ring Motor
Cost	Low	High

Maintenance	Low	High
Speed Control	Poor	Good
Efficiency on startup	Poor	Good
Efficiency during operation	Good	Poor
Heat regulation	Good	Poor
In rush current & torque	High	Low

Classification of Squirrel Cage Induction Motor

NEMA (National Electrical Manufacturer's Association) in United States and IEC in Europe has classified the design of the squirrel cage induction motors based on their speed-torque characteristics into some classes. These classes are Class A, Class B, Class C, Class D, Class E and Class F.

Class A Design

1. A normal starting torque.
2. A normal starting current.
3. Low slip.
4. In this Class, pullout torque is always of 200 to 300 percent of the full-load torque and it occurs at a low slip (it is less than 20 percent).
5. For this Class, the starting torque is equal to rated torque for larger motors and is about 200 percent or more of the rated torque for the smaller motors.

Class B Design

1. Normal starting torque,
2. Lower starting current,
3. Low slip.
4. Induction Motor of this class produces about the same starting torque as the class A induction motor.
5. Pullout torque is always greater than or equal to 200 percent of the rated load torque. But it is less than that of the class A design because it has increased rotor reactance.
6. Again Rotor slip is still relatively low (less than 5 percent) at full load.

7. Applications of Class B design are similar to those for design A. But design B is preferred more because of its lower starting-current requirements.

Class C Design

1. High starting torque.
2. Low starting currents.
3. Low slip at the full load (less than 5 %).
4. Up to 250 percent of the full-load torque, the starting torque is in this class of design.
5. The pullout torque is lower than that for Class A induction motors.
6. In this design the motors are built from double-cage rotors. They are more expensive than motors of Class A and B classes.
7. Class C Designs are used for high-starting-torque loads (loaded pumps, compressors, and conveyors).

Class D Design

1. In this Design of Class motors has very high starting torque (275 percent or more of the rated torque).
2. A low starting current.
3. A high slip at full load.
4. Again in this class of design the high rotor resistance shifts the peak torque to a very low speed.
5. It is even possible at zero speed (100 percent slip) for the highest torque to occur in this class of design.
6. Full-load slip (It is typically 7 to 11 percent, but may go as high as 17 percent or more) in this class of design is quite high because of the high rotor resistance always.

Class E Design

1. Very Low Starting Torque.
2. Normal Starting Current.
3. Low Slip.
4. Compensator or resistance starter are used to control starting current.

Class F Design

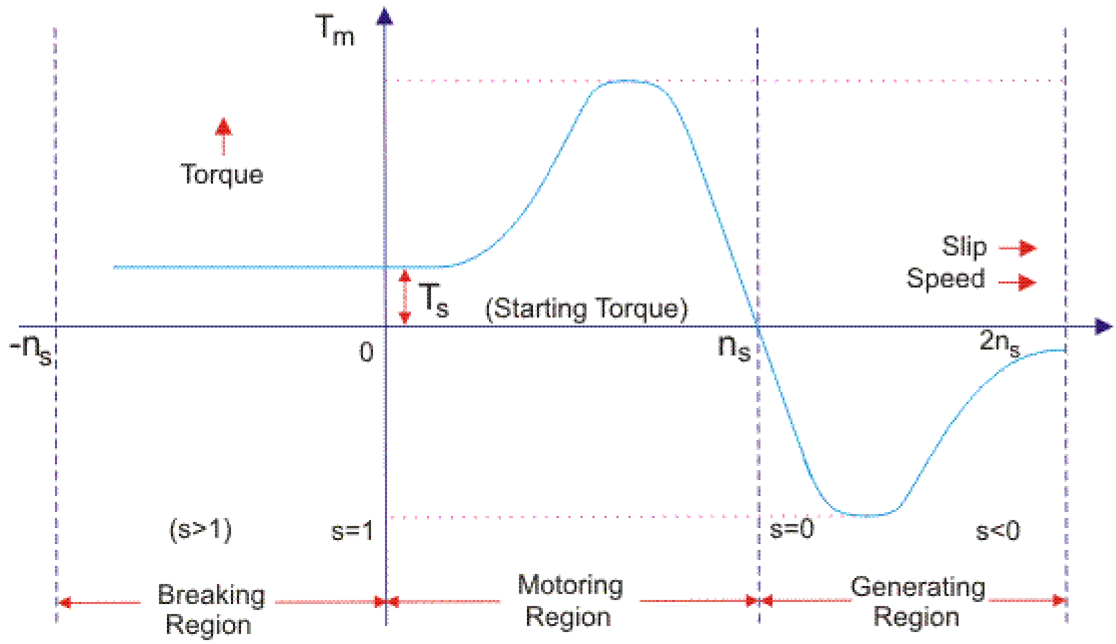
1. Low Starting Torque, 1.25 times of full load torque when full voltage is applied.
2. Low Starting Current.
3. Normal Slip.

Torque Slip Characteristics of Induction Motor

Torque Slip Characteristics of Three Phase 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.
The curve can be described in three modes of operation-



Torque Slip Curve for Three Phase Induction Motor

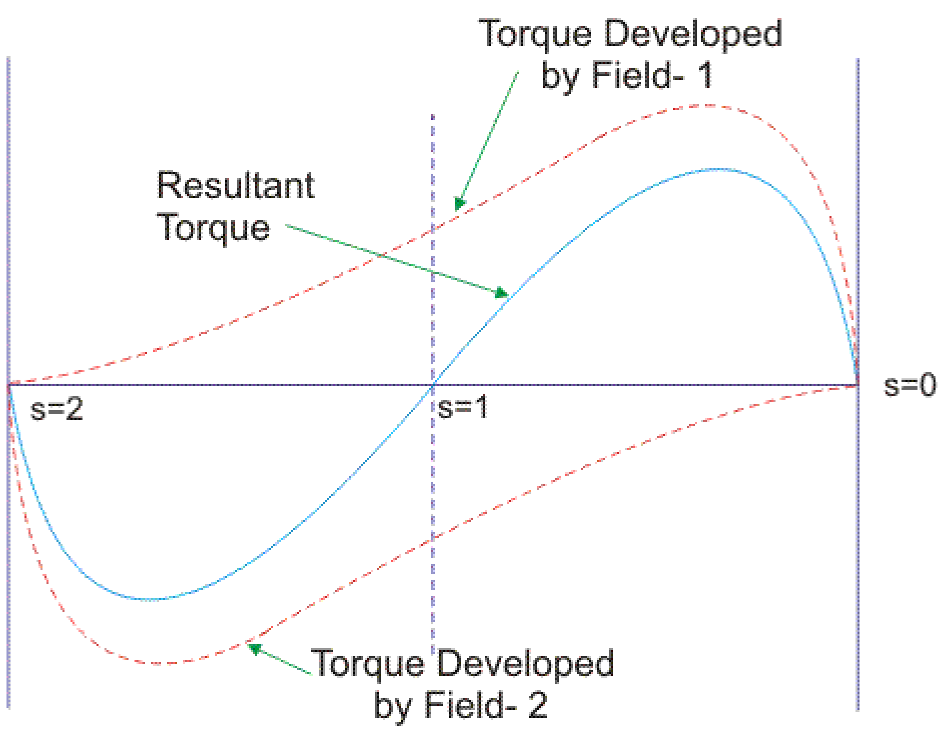
The torque-slip characteristic curve can be divided roughly into three regions:

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

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. The linear relationship simplifies the calculation of motor parameter to great extent.
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.
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.
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.

Torque Slip Characteristics of Single Phase Induction Motor



Torque Slip Characteristics of Single Phase Induction Motor

From the figure, we see that at a slip of unity, both forward and backward field develops equal torque but the direction of which are opposite to each other so the net torque produced is zero hence the motor fails to start. From here we can say that these motors are not self starting unlike the case of three phase induction motor. There must be some means to provide the starting torque. If by some means, we can increase the forward speed of the

machine due to which the forward slip decreases the forward torque will increase and the reverse torque will decrease as a result of which motor will start.
From here we can conclude that for starting of single phase induction motor, there should be a production of difference of torque between the forward and backward field. If the forward field torque is larger than the backward field than the motor rotates in forward or anti clockwise direction. If the torque due to backward field is larger compared to other, then the motor rotates in backward or clockwise direction.

Losses and Efficiency of Induction Motor

There are two types of losses occur in three phase induction motor. These losses are,

1. Constant or fixed losses,
2. Variable losses.

Constant or Fixed Losses

Constant losses are those losses which are considered to remain constant over normal working range of induction motor. The fixed losses can be easily obtained by performing no-load test on the three phase induction motor. These losses are further classified as-

1. Iron or core losses,
2. Mechanical losses,
3. Brush friction losses.

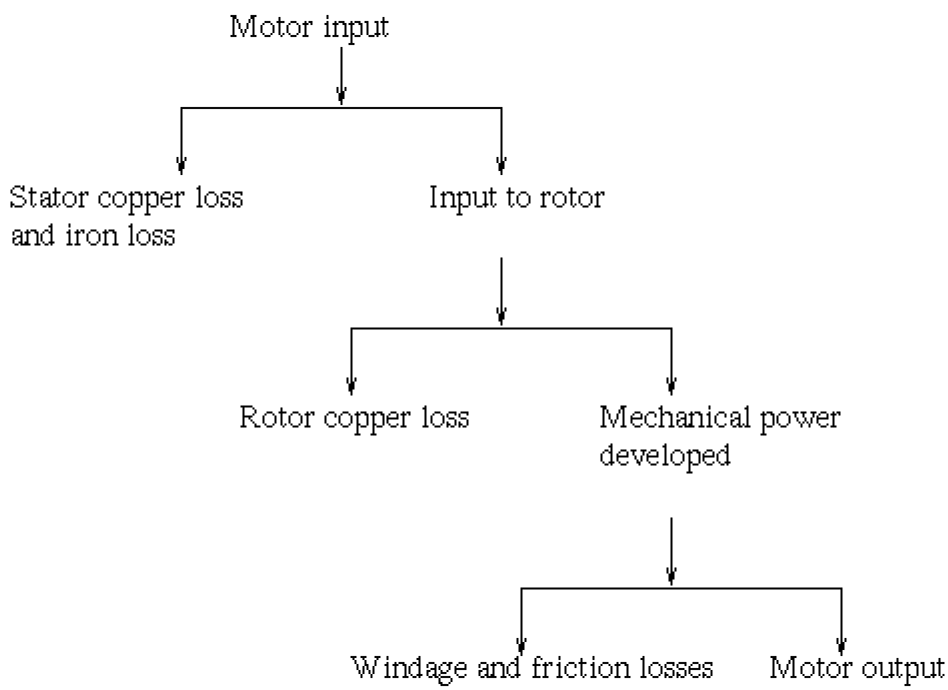
Iron or Core Losses

Iron or core losses are further divided into hysteresis and eddy current losses. Eddy current losses are minimized by using lamination on core. Since by laminating the core, area decreases and hence resistance increases, which results in decrease in eddy currents. Hysteresis losses are minimized by using high grade silicon steel. The core losses depend upon frequency of the supply voltage. The frequency of stator is always supply frequency, f and the frequency of rotor is slip times the supply frequency, (sf) which is always less than the stator frequency. For stator frequency of 50 Hz, rotor frequency is about 1.5 Hz because under normal running condition slip is of the order of 3 %. Hence the rotor core loss is very small as compared to stator core loss and is usually neglected in running conditions.

Mechanical and Brush Friction Losses

Mechanical losses occur at the bearing and brush friction loss occurs in wound rotor induction motor. These losses are zero at start and with increase in speed these losses increases. In three phase induction motor the speed usually remains constant. Hence these losses almost remains constant.

Variable Losses



These losses are also called copper losses. These losses occur due to current flowing in stator and rotor windings. As the load changes, the current flowing in rotor and stator winding also changes and hence these losses also changes. Therefore these losses are called variable losses. The copper losses are obtained by performing blocked rotor test on three phase induction motor. The main function of induction motor is to convert an electrical power into mechanical power. During this conversion of electrical energy into mechanical energy the power flows through different stages.

This power flowing through different stages is shown by power flow diagram. As we all know the input to the three phase induction motor is three phase supply. So, the three phase supply is given to the stator of three phase induction motor.

Let, P_{in} = electrical power supplied to the stator of three phase induction motor,

V_L = line voltage supplied to the stator of three phase induction motor,

I_L = line current,

$\cos\varphi$ = power factor of the three phase induction motor.

Electrical power input to the stator, $P_{in} = \sqrt{3}V_L I_L \cos\varphi$

A part of this power input is used to supply stator losses which are stator iron loss and stator copper loss. The remaining power i.e (input electrical power – stator losses) are supplied to rotor as rotor input.

So, rotor input $P_2 = P_{in}$ – stator losses (stator copper loss and stator iron loss).

Now, the rotor has to convert this rotor input into mechanical energy but this complete input cannot be converted into mechanical output as it has to supply rotor losses. As explained earlier the rotor losses are of two types rotor iron loss and rotor copper loss. Since the iron loss depends upon the rotor frequency, which is very small when the rotor rotates, so it is usually neglected. So, the rotor has only rotor copper loss. Therefore the rotor input has to supply these rotor copper losses. After supplying the rotor copper losses, the remaining part of Rotor input, P_2 is converted into mechanical power, P_m.

Let P_c be the rotor copper loss,

I_2 be the rotor current under running condition,

R_2 is the rotor resistance,

P_m is the gross mechanical power developed.

$P_c = 3I_2^2R_2$

$P_m = P_2 - P_c$

Now this mechanical power developed is given to the load by the shaft but there occur some mechanical losses like friction and windage losses. So, the gross mechanical power developed has to be supplied to these losses. Therefore the net output power developed at the shaft, which is finally given to the load is P_{out}.

$P_{out} = P_m$ – Mechanical losses (friction and windage losses).

P_{out} is called the shaft power or useful power.

Efficiency of Three Phase Induction Motor

Efficiency is defined as the ratio of the output to that of input,

$$Efficiency,\ \eta = \frac{output}{input}$$

Rotor efficiency of the three phase induction motor ,

$$= \frac{rotor\ output}{rotor\ input}$$

= Gross mechanical power developed / rotor input

$$= \frac{P_m}{P_2}$$

Three phase induction motor efficiency,

$$= \frac{power\ developed\ at\ shaft}{electrical\ input\ to\ the\ motor}$$

Three phase induction motor efficiency

$$\eta = \frac{P_{out}}{P_{in}}$$

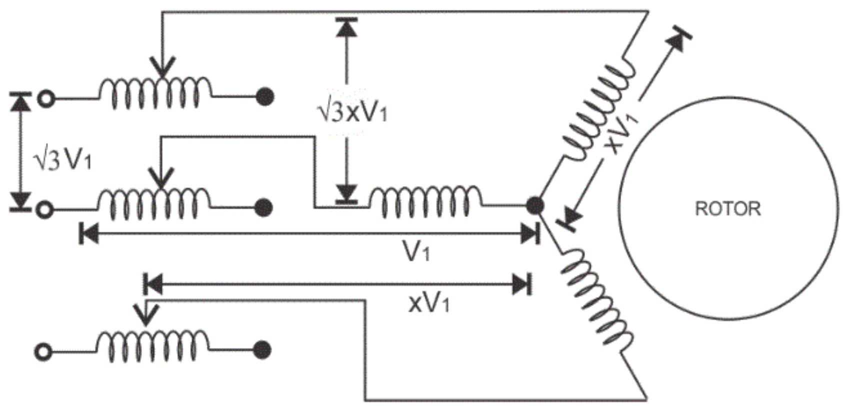
STARTING METHODS OF INDUCTION MOTOR

1. Stator resistor starting method
2. Auto transformer staring method
3. Star delta starting method

Now let us discuss each of these methods in detail.

Stator Resistor Starting Method

Given below is the figure for the starting resistor method:



In this method we add resistor or a reactor in each phase as shown in the diagram (between the motor terminal and the supply mains).Thus by adding resistor we can control the supply voltage. Only a fraction of the voltage (x) of the supply voltage is applied at the time of starting of the induction motor. The value of x is always less than one. Due to the drop in the voltage the starting torque also decreases. We will derive the expression for the starting torque in terms of the voltage fraction x in order to show the variation of the starting torque with the value of x. As the motor speeds up the reactor or resistor is cut out from the circuit and finally the resistors are short circuited when the motor reaches to its operating speed. Now let us derive the expression for starting torque in terms of full load torque for the stator resistor starting method. We have various quantities that involved in the expression for the starting torque are written below: we define T_s as starting torque
T_f as full load torque
I_f as per phase rotor current at full load
I_s as per phase rotor current at the time of starting
s_f as full load slip
s_s as starting slip
R_2 as rotor resistance
W_s as synchronous speed of the motor
Now we can directly write the expression for torque of the induction motor as

$$T = \frac{1}{W_s} \times I^2 \frac{r}{s}$$

From the help of the above expression we write the ratio of starting torque to full load torque as

$$\frac{T_s}{T_f} = \left(\frac{I_s}{I_f}\right)^2 \times s_f \cdots\cdots(i)$$

Here we have assumed that the rotor resistance is constant and it does not vary with the frequency of the rotor current. From the above equation we can have the expression for the starting torque in terms of the full load torque. Now at the time of starting the per phase voltage is reduced to xV_1, the per phase starting current is also reduced to xI_s. On substituting the value of I_s as xI_s in equation 1. We have

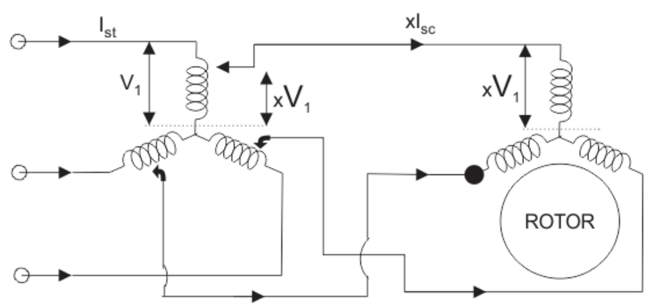
$$\frac{T_s}{T_f} = \left(\frac{xI_s}{I_f}\right)^2 \times s_f$$

$$\frac{T_s}{T_f} = \left(\frac{I_s}{I_f}\right)^2 \times s_f \times x^2$$

This shows the variation of the starting torque with the value of x. Now there are some considerations regarding this method. If we add series resistor then the energy losses are increased so it's better to use series reactor in place of resistor because it is more effective in reducing the voltage however series reactor is more costly than the series resistance.

Auto Transformer Starting Method

As the name suggests in this method we connect auto transformer in between the three phase power supply and the induction motor as shown in the given diagram:



Pertaining to Auto-Transfer Starting

The auto transformer is a step down transformer hence it reduces the per phase supply voltage from V_1 to xV_1.The reduction in voltage reduces current from I_s to xI_s. After the motor reaches to its normal operating speed, the auto transformer is disconnected and then full line voltage is applied. Now let us derive the expression for starting torque in terms of full load torque for the auto transformer starting method. We have various quantities that involved in the expression for the starting torque are written below:

We define T_s as starting torque

T_f as full load torque

I_f as per phase rotor current at full load

I_s as per phase rotor current at the time of starting

s_f as full load slip

s_s as starting slip

R_2 as rotor resistance

W_s as synchronous speed of the motor

Now we can directly write the expression for torque of the induction motor as

$$T = \frac{1}{W_s} \times I^2 \frac{r}{s}$$

From the help of the above expression we write the ratio of starting torque to full load torque as

$$\frac{T_s}{T_f} = \left(\frac{I_s}{I_f}\right)^2 \times s_f \cdots\cdots (i)$$

Here we have assumed that the rotor resistance is constant and it does not vary with the frequency of the rotor current. From the above equation we can have the expression for the starting torque in terms of the full load torque. Now at the time of starting the per phase voltage is reduced to xV_1, the per phase starting current is also reduced to xI_s. On substituting the value of I_s as xI_s in equation 1. We have

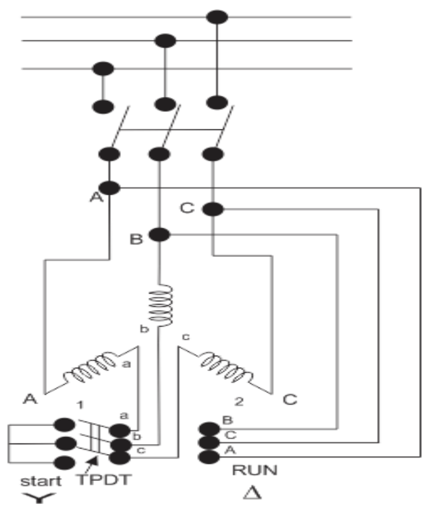
$$\frac{T_s}{T_f} = \left(\frac{xI_s}{I_f}\right)^2 \times s_f$$

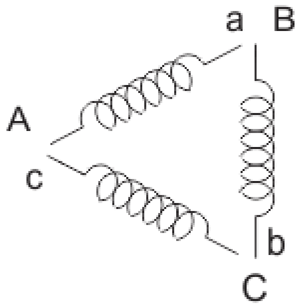
$$\frac{T_s}{T_f} = \left(\frac{I_s}{I_f}\right)^2 \times s_f \times x^2$$

This shows the variation of the starting torque with the value of x.

Star-Delta Starting Method

Connection diagram is shown below for star delta method,





Star Delta

This method is used for the motors designed to operate in delta connected winding. The terminals are marked for the phases of the stator are shown above. Now let us see this method works. The stator phases are first connected to the star by the help of triple pole double throw switch (TPDT switch) in the diagram the position is marked as 1 then after this when the steady state speed is reached the switch is thrown to position 2 as shown in the above diagram.

Now let analyse the working of the above circuit. In the first position the terminals of the motor are short circuited and in the second position from the diagram the terminal a, b and c are respectively connected to B, C and A. Now let us derive the expression for starting torque in terms of full load torque for the star delta starting method. We have various quantities that involved in the expression for the starting torque are written below

T_f as full load torque

T_s as starting torque

I_f as per phase rotor current at full load

I_s as per phase rotor current at the time of starting

s_f as full load slip

s_s as starting slip

R_2 as rotor resistance

W_s as synchronous speed of the motor

Now we can directly write the expression for torque of the induction motor as

$$T = \frac{1}{W_s} \times I^2 \frac{r}{s}$$

From the help of the above expression we write the ratio of starting torque to full load torque as

$$\frac{T_s}{T_f} = \left(\frac{I_s}{I_f}\right)^2 \times s_f \cdots\cdots (ii)$$

Here we have assumed that the rotor resistance is constant and it does not vary with the frequency of the rotor current. Let us assume the line voltage to be V_l then the per phase starting current when connected in star position is I_{ss} which is given by

$$I_{ss} = \frac{V_l}{\sqrt{3} \times Z}$$

When stator is in delta connected position we have starting current

$$I_{sd} = \frac{V_l}{Z}\ clearly,\ I_{sd} = \sqrt{3} \times I_{ss}\ and\ I_{fd} = I_{ss}$$

From the above equation we have

$$\frac{T_s}{T_f} = \frac{1}{3}\left(\frac{I_{sd}}{I_{fd}}\right)^2 \times s_f \cdots\cdots(iii)$$

This shows that the reduced voltage method has an advantage of reducing the starting current but the disadvantage is that all these methods of reduced voltage causes the objectionable reduction in the starting torque.

Starting Methods of Wound Rotor Motors

We can employ all the methods that we have discussed for starting of the squirrel cage induction motor in order to start the wound rotor motors. We will discuss the cheapest method of starting the wound rotors motor here.

Addition of External Resistances in Rotor Circuit

This will decrease the starting current, increases the starting torque and also improves the power factor. The circuit diagram is shown below: In the circuit diagram, the three slip rings shown are connected to the rotor terminals of the wound rotor motor. At the time of starting of the motor, the entire externalresistance is added in the rotor circuit. Then the external rotor resistance is decreased in steps as the rotor speeds up, however the motor torque remain maximum during the acceleration period of the motor. Under normal condition when the motor develops load torque the external resistance is removed.
After completing this article, we are able to compare induction motor with synchronous motor. Point wise comparison between the induction motor and synchronous motor is written below,
(a) Induction motor always operates at lagging power factor while the synchronous motor can operate at both lagging and leading power factor.
(b) In an induction motor the value of maximum torque is directly proportional to the square of the supply voltage while in case of synchronous machine the maximum torque is directly proportional to the supply voltage.
(c) In an induction motor we can easily control speed while with synchronous motor, in normal condition we cannot control speed of the motor.
(d) Induction motor has inherent self starting torque while the synchronous motor has no inherent self starting torque.
(e) We cannot use induction motor to improve the power factor of the supply system while with the use of synchronous motor we can improve the power factor of the supply system.
(f) It is a singly excited machine means there is no requirement of dc excitation while the synchronous motor is doubly excited motor means there is requirement of separate dc excitation.

(g) In case of induction motor on increasing the load the speed of the motor decreases while with the speed of the synchronous motor remains constant.