Unit IV
Three phase Induction Motor-II

Starting of squirrel cage and slip ring motors, power factor control, Cogging & Crawling, Double cage & Deep bar Induction Motor, impact of unbalanced supply and harmonics on performance, speed control, braking, Induction Generator. Applications

Starting Methods for 3 phase Induction Motors

Starting Method for Induction Motors

A 3-phase induction motor is self starting machine. Therefore, 3-phase induction motors employ a starting method not to provide a starting torque at the rotor, but because of the following reasons;

1) Reduce heavy starting currents and prevent motor from overheating.

2) Provide overload and no-load voltage protection.

There are many methods in use to start 3-phase induction motors. Some of the common methods are;

1.Full Voltage Starting Method for Squirrel Cage Induction Motor

- **Direct On-Line Starter (DOL)**

2.Reduced voltage method for starting squirrel cage induction motor as well as slip ring Induction motor

- **Star-Delta Starter**
- **Auto Transformer Starter**
- **Rotor Resistance Starter(only for slip ring Induction motor)**

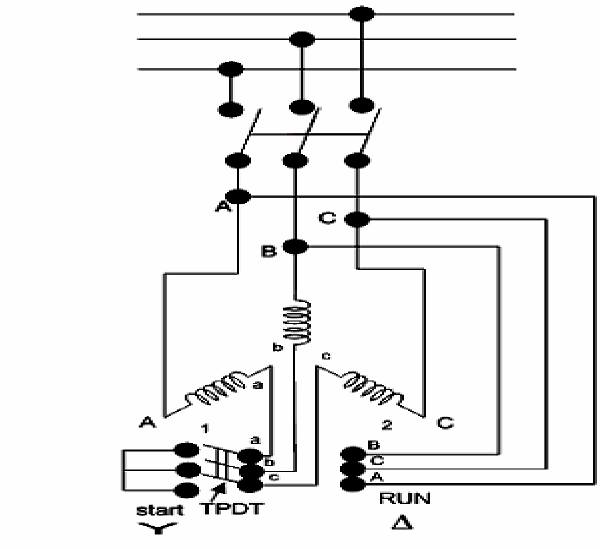
Direct On-Line Starter (DOL)

- In this method we directly switch the stator of the three phase squirrel cage induction motor on to the supply mains. The motor at the time of starting draws very high starting current (about 5 to 7 times the full load current) for the very short duration. The amount of current drawn by the motor depends upon its design and size. But such a high value of current does not harm the motor because of rugged construction of the squirrel cage induction motor.

- The DOL starter is used only for motors with a rating of less than 5KW

Star-Delta Starter

- The star delta starting is a very common type of starter and extensively used, compared to the other types of the starters.
- This method used reduced supply voltage in starting.
- This method is used for the motors designed to operate in delta connected winding.
- 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.
- At the time of starting when the stator windings are star connected, each stator phase gets voltage $V_L / \sqrt{3}$, where V_L is the line voltage.
- Since the torque developed by an induction motor is proportional to the square of the applied voltage, star- delta starting reduced the starting torque to one – third that obtainable by direct delta starting.



➢ **Auto Transformer Starter**

➢ The operation principle of auto transformer method is similar to the star delta starter method. The starting current is limited by using a three phase auto transformer to reduce the initial stator applied voltage.

➢ The auto transformer starter is more expensive, more complicated in operation and bulkier in construction as compared to the star – delta starter method.

➢ But an auto transformer starter is suitable for both star and delta connected motors, and the starting current and torque can be adjusted to a desired value by taking the correct tapping from the auto transformer.

➢ When the star delta method is considered, voltage can be adjusted only by factor of $1/\sqrt{3}$

Cogging & Crawling

Cogging (Magnetic Locking Or Teeth Locking)

➢ When an induction motor refuses to start even if full voltage is applied to it, this phenomenon is called cogging or magnetic locking of induction motor.

➢ This happens when the rotor slots and stator slots are equal in number.

➢ Due to this the opposite poles of stator and rotor face in front of each other and get locked.

Crawling

- Induction motor runs at one seventh of the rated speed is known as crawling .
- When an IM runs at a very low speed (as low as 1/7th of synchronous speed) even if full rated voltage is applied to it, then it is called at crawling.
- This happens due to harmonic torques in which torques due to 7th harmonic overpower the driving torque (fundamental component torque).

Special Rotor Constructions and Applications

Double Cage & Deep Bar Induction Motor

High Starting Torque Motor

- Deep Bar Cage Induction MotorDouble Cage Induction Motor

Drawbacks of Conventional Squirrel Cage Induction Motor

i.e. with Low Rotor Resistance

(1) Low Starting Torque

(2) High Starting Current

(3) Low operating p.f.

Advantages of Slip Ring Induction Motor

(1) High Staring Torque

(2) Low Starting Current

(3) High Operating p.f.

DOUBLE CAGE INDUCTION MOTOR

Constructional details:

Stator – Exactly similar to Three phase Induction Motor

Rotor – Squirrel Cage type, but with 2 cages

(i) Outer Cage – High T_{st} & Low I_{st}

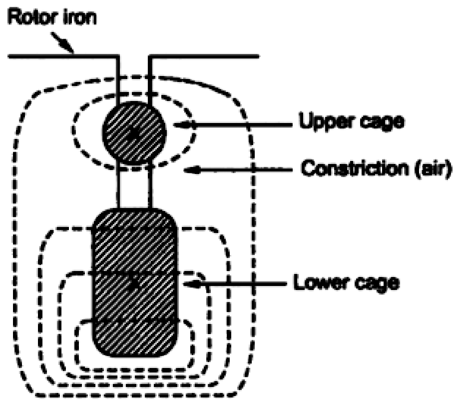
Designed with High Resistance & Low Reactance Rotor bars made of Brass, Aluminium or Bronze

(ii) Inner Cage – for obtaining good running condition

Designed with Low Resistance & High Reactance

Rotor bars made of Copper

Cage windings are embedded in two rows of slots separated by narrow slit. Staggered slots are also available.

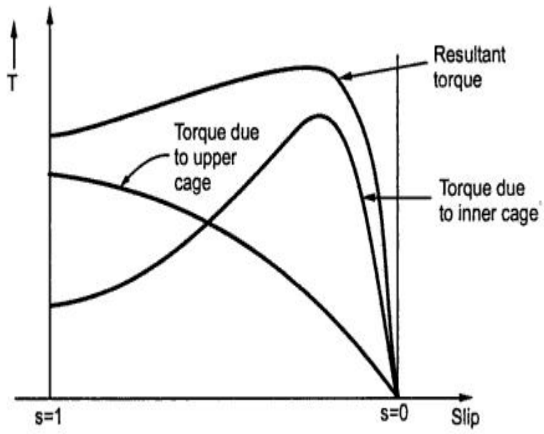


At Starting:

- Leakage Reactance of INNER CAGE is HIGH. Impedance is also HIGH.
- Most of the Starting Current is confined to OUTER CAGE.
- High Resistance OUTER CAGE develops HIGH Starting Torque and LOW Starting Current

When Motor Picks up speed:

- Impedance of inner cage lowers.
- Most of the rotor current now flows through inner cage
- Inner cage develops greater portion of the Running Torque



DEEP BAR INDUCTION MOTOR

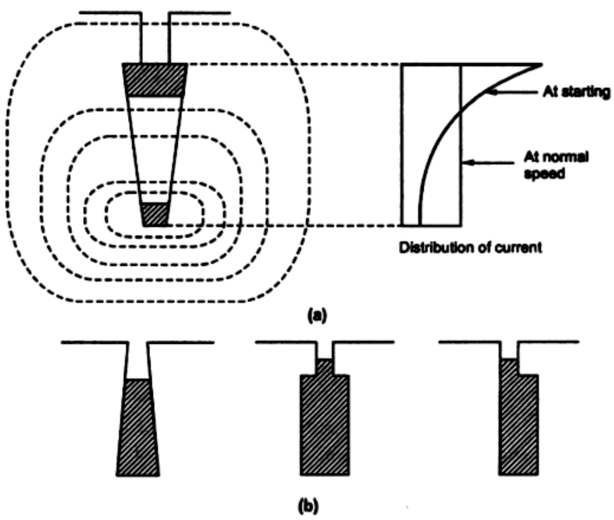
Constructional details

Stator – Exactly similar to Three phase Induction Motor

Rotor – Squirrel Cage Rotor, with deep and narrow bars.

Bars of narrow width are laid down in deep semi-closed slots.

- The rotor bar can be imagined to be composed of elementary strips in parallel – topmost and bottom-most strips.
- Magnetic leakage flux pattern set up by the bar current is shown.
- Less on top part and more on bottom part



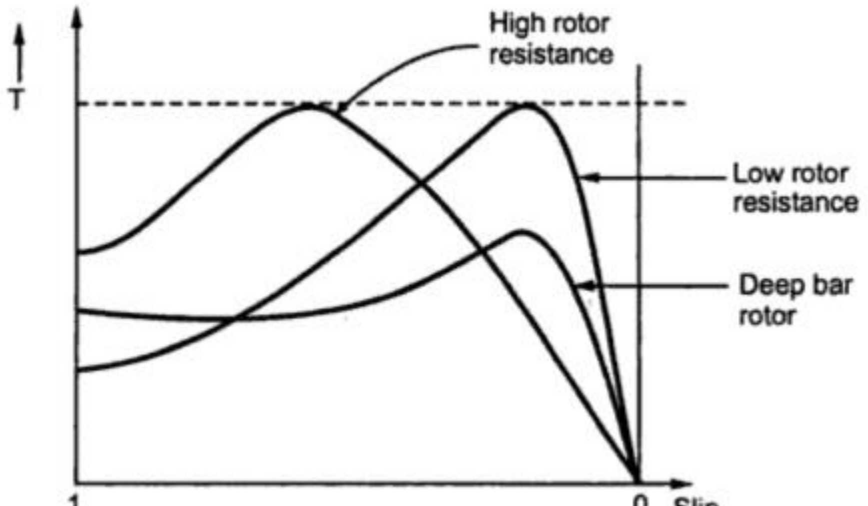
At Starting:

- Bottom Part offers more impedance to the current than Top Part.
- Maximum current flows through the top layers and minimum through bottom layers.
- Unequal distribution of current.
- Effective resistance of the bar increases.
- High Rotor Resistance develops HIGH Starting Torque and LOW Starting Current.

When Motor Picks up speed:

- Reactance of all the layers of the bar are reduced.
- Impedances of all the layers of the bar are nearly equal.
- Almost equal distribution of current.
- Effective resistance of the bar decreases.
- Low Rotor Resistance develops Good Running Torque and provides good efficiency at low slips.

Torque slip characteristics of deep bar rotor



Speed Control of Three Phase Induction Motor

- A 3-phase induction motor is basically a constant speed motor so it's somewhat difficult to control its speed.
- The speed control of induction motor is done at the cost of decrease in efficiency and low power factor.
- We know that induction motor cannot run at synchronous speed, its speed is always less than that of synchronous speed.
- The difference between the synchronous speed N_s and actual rotor speed N_r is called slip.

Slip (s) = $(N_s – N_r) / N_s$
$N_r = (1-s) N_s$
$N_s = 120f /P$

$N_r = (1-s) 120f /P$ ……………… (i)

From the above equation (i) it is observed that there are three factors which controls the speed of induction motor. These factors are: Supply frequency f, Number of poles P & Slip s.

The speed of induction motor is changed from both stator and rotor side.

Various methods of speed control from stator side are:
a) Variation of supply frequency
b) Variation of applied voltage
c) Changing the number of pole

Various methods of speed control from rotor side are:

i. Adding external resistance on rotor side.

ii. Cascade control method.

iii. Injecting slip frequency emf into rotor side.

- **Speed Control from Stator Side**

1. V / f control or frequency control

In 3 phase induction motor emf is induced by induction similar to that of transformer which is given by:

E or V = 4.44fØKT or Ø = V/4.44KTf

Where ,

K is the winding constant,

T is the number of turns per phase and

f is frequency

- Now if we change the frequency synchronous speed changes but with decrease in frequency flux will increase and this change in value of flux causes saturation of rotor and stator cores which will further cause increase in no load current of the motor.
- So, it's important to maintain flux, ϕ constant and it is only possible if we change voltage i.e if we decrease frequency flux increases but at the same time if we decrease voltage flux will also decrease causing no change in flux and hence it remains constant.
- So, here we are keeping the ratio of V/ f as constant. Hence its name is V/ f method.
- For controlling the speed of 3 phase induction motor by V/ f method we have to supply variable voltage and frequency which is easily obtained by using converter and inverter set.

2. Speed control by variation of supply /stator voltage

- By varying the supply voltage (V) i,e the voltage supplied to the stator we can vary the speed of an induction motor.
- This is a slip control method with constant frequency variable supply voltage.
- The torque produced by running 3 phase IM is given by:

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

- In low slip region $(sX_2)^2$ is very very small as compared to R_2 . So, it can be neglected. So torque becomes

$$T \propto \frac{sE_2^2}{R_2}$$

- Since rotor resistance , R_2 is constant so the equation of torque further reduces to

$$T \propto sE_2^2$$

- We know that rotor induced emf

$$\mathbf{E_2 \propto V \;\; \& \;\; T \propto sV^2}$$

- From the equation above it is clear that if we decrease supply voltage torque will also decrease.
- But for supplying the same load, the torque must remains the same and it is only possible if we increase the slip and if the slip increases the motor will run at reduced speed .
- This method of speed control is rarely used because small change in speed requires large reduction in voltage, and hence the current drawn by motor increases, which cause over heating of induction motor.

3.By injecting EMF in rotor circuit

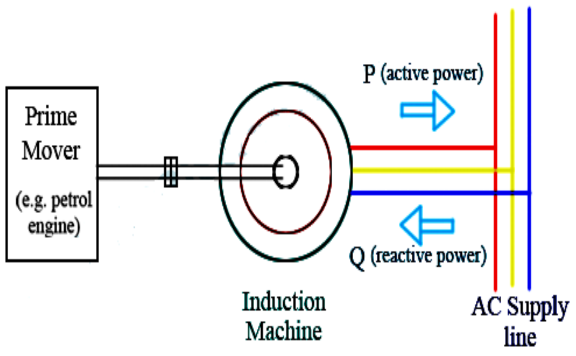
- In this method, speed of induction motor is controlled by injecting a voltage in rotor circuit.
- It is necessary that voltage (emf) being injected must have same frequency as of slip frequency.
- However, there is no restriction to the phase of injected emf.
- If we inject emf which is in opposite phase with the rotor induced emf, rotor resistance will be increased.
- If we inject emf which is in phase with rotor induced emf, rotor resistance will decrease
- Thus, by changing the phase of injected emf, speed can be controlled.
- The main advantage of this method is a wide rage of speed control (above normal as well as below normal) can be achieved.

- The emf can be injected by various methods such as Kramer system, Scherbius system etc.

Induction Generator

When a squirrel cage induction motor is energized from a three phase power system and is mechanically driven above its synchronous speed it will deliver power to the system.

- An induction generator receives its excitation (magnetizing current) from the system to which it is connected.
- It consumes reactive power (KVAR) and supplies only real power (KW) to the system.
- Working of induction generator
- Consider, an AC supply is connected to the stator terminals of an induction machine. Rotating magnetic field produced in the stator pulls the rotor to run behind it (the machine is acting as a motor).
- If the rotor is made to rotate at a speed more than the synchronous speed by means of prime mover, the slip becomes negative.
- A rotor current is generated in the opposite direction, due to the rotor conductors cutting stator magnetic field.
- This generated rotor current produces a rotating magnetic field in the rotor which pushes (forces in opposite way) onto the stator field.
- This causes a stator voltage which pushes current flowing out of the stator winding against the applied voltage.
- Thus, the machine is now **working as an induction generator (asynchronous generator)**.



Application of Induction Generator

Used in wind mills. Thus this type of generator helps in converting the unconventional sources of energy into electrical energy.

- **advantages**

1. It is less expensive and more readily available than a synchronous generator.
2. It does not require a DC field excitation voltage.
3. It automatically synchronizes with the power system, so its controls are simpler and less expensive.

- **disadvantages**
- It is not suitable for separate, isolated operation.
- It consumes rather than supplies magnetizing KVAR
- It cannot contribute to the maintenance of system voltage levels
- It has a lower efficiency.

Braking of Induction Motors

Braking of 3 phase Induction Motors

- **It is the process of reducing speed of any rotating machine.**

- **The process of applying brakes can be termed as braking.**
- **Braking of induction motors can be classified mainly in three types:**

1. **Regenerative Braking**
2. **Plugging or reverse voltage braking**
3. **Dynamic braking.**

1.Regenerative Braking

- It takes place whenever the speed of the motor exceeds the synchronous speed. This braking method is called regenerative baking.
- The main criteria for regenerative braking is that the rotor has to rotate at a speed higher than synchronous speed, only then the motor will act as a generator and the direction of current flow through the circuit and direction of the torque reverses and braking takes place.
- The only disadvantage of this type of braking is that the motor has to run at super synchronous speed which may damage the motor mechanically and electrically.
- Regenerative braking can be done at sub synchronous speed if the variable frequency source is available.

2. Plugging Type Braking

- Plugging of induction motors is done by interchanging any two of the supply terminals as a result the generator torque also reverses which resists the normal rotation of the motor and as a result the speed decreases.
- When the terminals are reversed the operation of the machine changes from motoring to plugging.

3. Dynamic Braking

- In this method the stator of running induction motor drives is connected to dc supply.
- There is a stationary magnetic field generated due to the DC current flow and as the rotor of the motor rotates in that field, there is a field induces in the rotor winding, and as a result

the machine works as a generator and the generated energy dissipates in the rotor circuit resistance and dynamic braking of induction motor occurs.