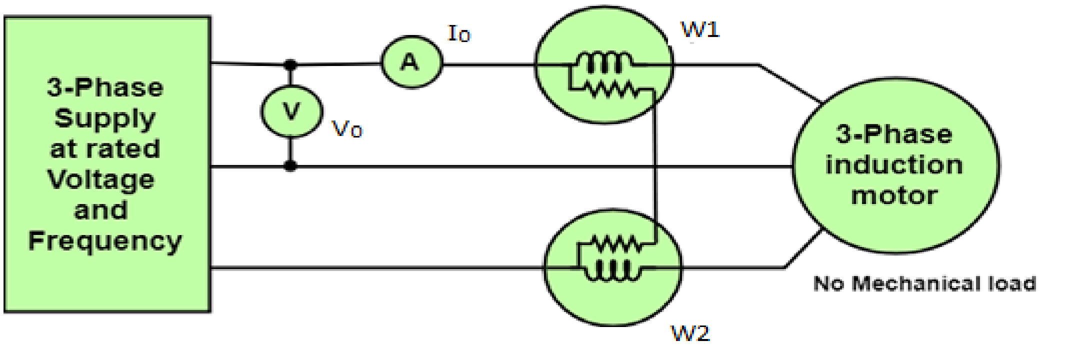
MODULE 4

TESTING AND SPEED CONTROL OF INDUCTION MOTOR

Testing of 3 phase IM

No load Test



- This test is similar to OC test of transformer. It is used to determine constant losses in a IM and core loss component R_0 and magnetising component X_0 of equivalent circuit of IM
- This test is conducted by giving rated voltage at rated frequency to the stator winding at no load condition as per the circuit diagram shown above. The voltmeter measures the rated supply voltage V_0 and an ammeter measures the no-load current I_0. The two-watt meters give reading W1 and W2. Since the no load test is done at no load condition, the power factor of operation will be less than 0.5. So total power input at no load condition (W_0) can be obtained by taking difference of W_1 and W_2.

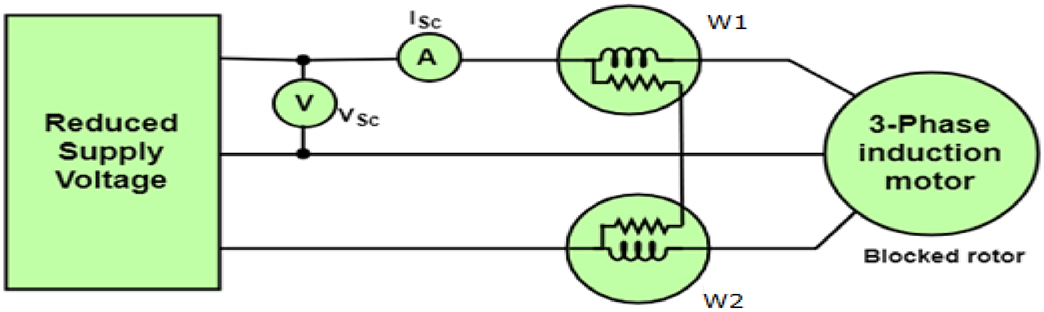
  The no load input, W_0 =core loss in stator+ friction and windage loss +copper loss in the stator (very small= $3I_0^2R_1$)

  Calculations using NO load test values

- $W_0=\sqrt{3}\ V_0\ I_0\ \cos\Phi_0$
- No load power factor, $\cos\Phi_0 = \frac{W_0}{\sqrt{3}V_0 I_0}$
- $I_\mu = I_0 \sin\Phi_0$

  $I_\omega = I_0 \cos\Phi_0$
- $R_0=\frac{V_{ph}}{I_w}$
- $X_0=\frac{V_{ph}}{I_\mu}$ V_{ph} = Input phase voltage

Locked Rotor Test or Blocked Rotor Test



- This test is similar to SC test of a transformer
- This test is used to find
  1. Short circuit current with normal voltage applied to stator
  2. Power-factor on short circuit
  3. Equivalent resistance and reactance of the motor referred to primary
- In this test rotor is locked or blocked and a reduced input voltage is applied to stator (V_{SC}) till rated current is flowing in stator. The value of V_{SC} will be 10 to 20% of rated stator voltage of IM. The ammeter measures value of short circuit current Isc and wattmeter measures total power input Wsc in locked rotor conditions
- Calculations using Blocked rotor test values

Power factor on short circuit, $\cos\Phi_{sc} = \frac{W_{sc}}{\sqrt{3}V_{sc}I_{sc}}$

Equivalent impedance per phase referred to stator, $Z_{01} = \frac{V_{sc(\,per\,phase)}}{I_{sc}}$

Equivalent reactance per phase referred to stator $X_{01} = \sqrt{{Z_{01}}^2 - {R_{01}}^2}$

MEASUREMENT OF SLIP OF IM

Different method of measurement of slip of IM are

1. **Tachometer method**
2. **Galvanometer method**
3. **Stroboscopic method**

1. Tachometer method

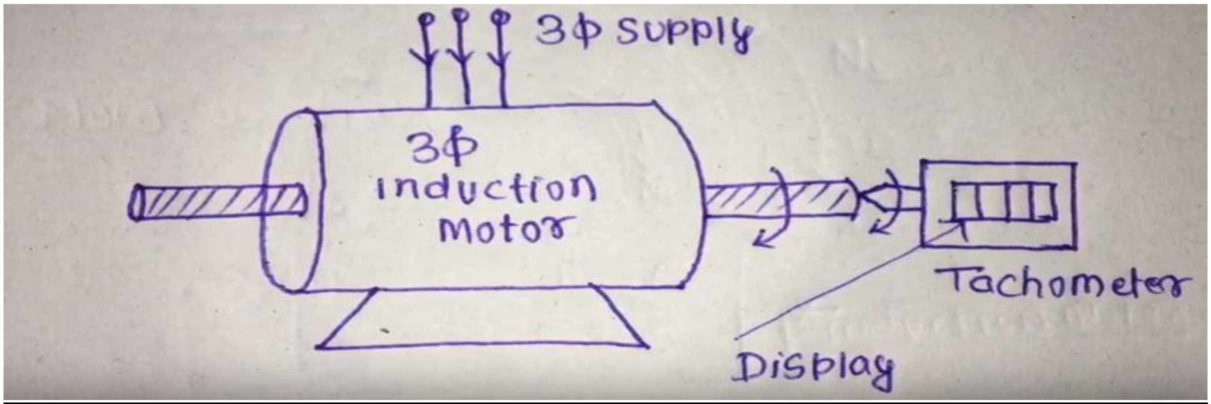


Figure shown the slip measuring method by tachometer. A tachometer is connected to shaft of IM rotor. The tachometer reading gives the actual rotor speed (Nr). If we know synchronous speed (Ns) of IM already, then slip S can be calculated using = Ns-Nr/Ns

2. **Galvanometer method**

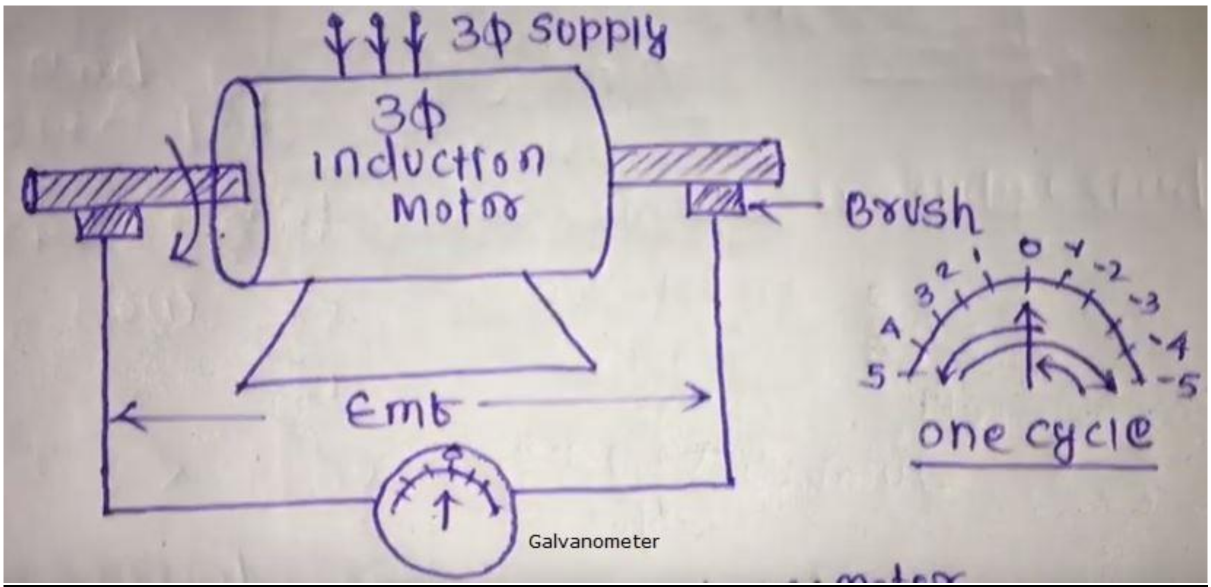
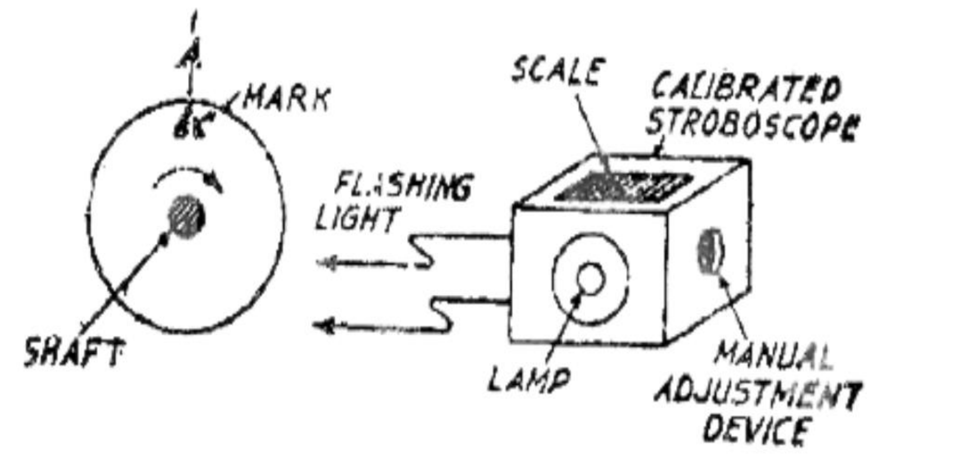


Figure shows the slip measuring method by Galvanometer method. A galvanometer is connected to shaft via brushes as per the diagram. When rotor rotates an emf is induced across the shaft with frequency same as rotor frequency. The needle on galvanometer oscillate around mean its mean position based on shaft induced emf frequency. The number of cycles of movement of galvanometer pointer in one second gives the frequency of shaft induced emf. Since frequency of shaft induced emf is same as rotor induced emf frequency, the Slip Can be calculated as

Slip, S= $\frac{\text{number of cycles of movement of galvanometer pointer in one second}}{Stator\ supply\ frequency}$

3. **Stroboscopic method**



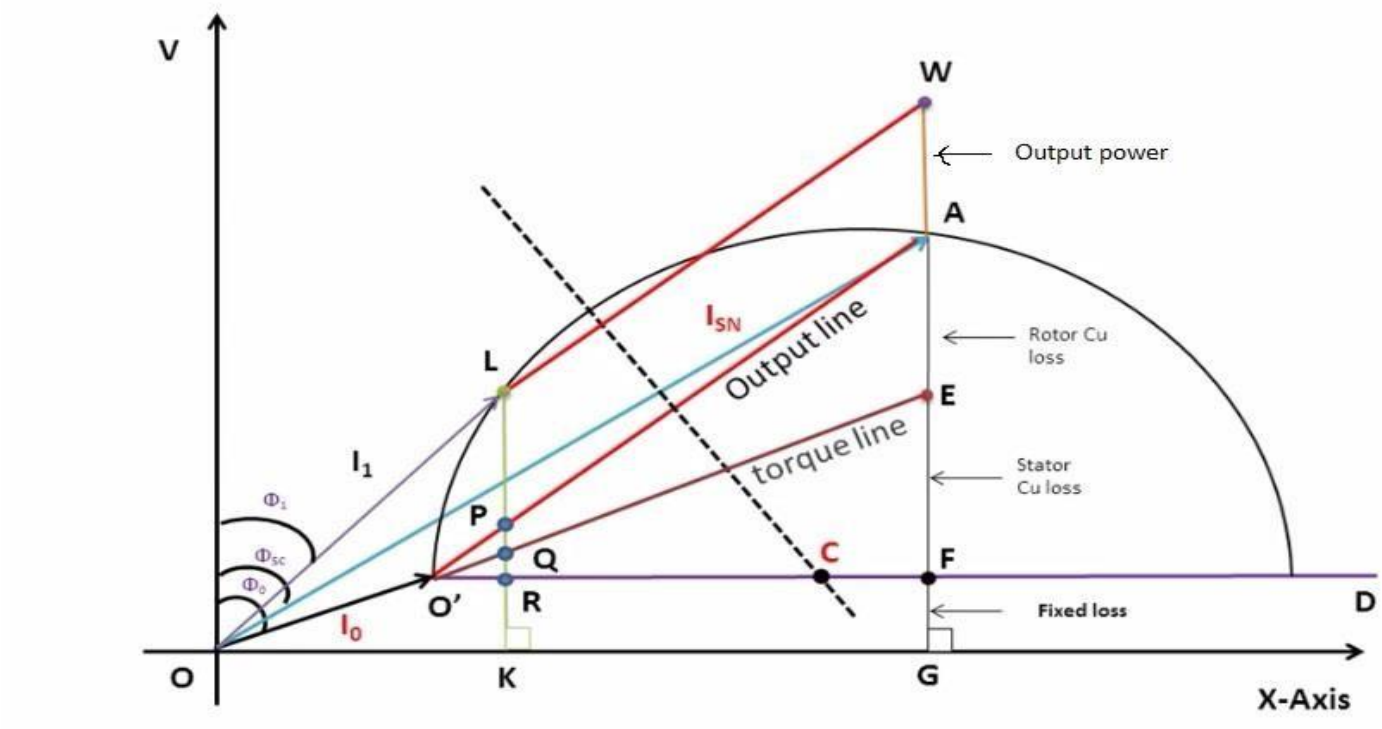
- Stroboscopic method of measurement of slip is shown.
- In this method of measurement of slip a stroboscopic instrument is used. Basically, a stroboscopic instrument is a source of flashing light whose flashing frequency can be varied. A disk is attached to the shaft of the induction motor. On the disk a marking is provided. a stroboscope is arranged in such a way that flashing light will directly strike on disc attached on the rotating shaft of IM. The frequency of flashing light is adjusted and at a particular flashing frequency the mark provided on the disc attached to rotating shaft appears stationery. In this condition Flashing frequency speed will be equal to speed of the shaft. This flashing frequency is calibrated with slip and stroboscope gives slip of the IM

CIRCLE DIAGRAM

A **circle diagram** is a graphical representation of the performance of an electrical machine. It is commonly used to illustrate the performance of transformers, alternators, synchronous motors, and induction motors.. The diagrammatic representation of a circle diagram makes it much easier to understand and remember compared to theoretical and mathematical descriptions.

Tests to be conducted to Plot Circle Diagram of IM

1. **No Load Test**
2. **Blocked Rotor Test**
3. **Stator Resistance Test**


V
W
Output power
A
I_{SN}
Output line
Rotor Cu loss
L
E
torque line
I_1
Stator Cu loss
Φ_1
P
Φ_{sc}
Q
C
F
Φ_0
O'
R
Fixed loss
D
I_0
O
K
G
X-Axis

Steps to draw circle diagram:

1. Take V as reference line in Y axis.
2. Draw X axis.
3. From no load test calculate φ_0 and from blocked rotor test φ_{sc}
   $\varphi_{sc} = \cos^{-1}$ [$W_{sc}/\sqrt{3}$ Vsc Isc]., $\varphi_o = \cos^{-1}$ [$W_o/\sqrt{3}$ Vo Io]
4. Draw by selecting suitable current scale vector I_0 lagging V by an angle φ_0. Mark the vector as $OO^{|}$.
5. Draw a horizontal line $O^{|}D$ passing through $O^{|}$ and parallel to X axis.
6. Calculate short circuit current with normal voltage applied I_{SN} and draw I_{SN} at an angle φ_{sc} behind voltage vector V. Mark the vector OA.
   $I_{SN} = I_{SC} * [V_0 / V_{SC}]$
7. Join $O^{|}A$ (Output line).
8. Draw a perpendicular bisector of line $O^{|}A$ that bisector meet line $O^{|}D$ mark that point as C which is centre of circle.
9. Take C as centre and radius line $O^{|}A$ draw a semicircle passing through $O^{|}$ and A.
10. Draw a perpendicular from point A to X axis, mark end point as G. Mark point F where line AG meet the line $O^{|}D$.
11. Line AF shows sum of rotor copper loss and stator copper loss. EF= $3 I_{sc}^2 R_1$, AE= $W_{SC} - 3 I_{sc}^2 R_1$. AE = rotor cu loss, EF= stator cu loss .
12. The line which separate stator copper loss and rotor copper loss is called torque line. Mark the point E and join $O^{|}E$ (torque line).
13. Calculate power scale and Full load output in cm. Extend line AG vertically upward of length equal to FL output in cm and mark W at the end. WA= output power.
14. Draw a parallel to output line starting from point W which will pass semicircle 2 times. Take nearest point to origin and mark the point L.
15. Draw a perpendicular on x axis starting from L. Mark the point P ,Q and R
16. Join OL which represent FL current of motor.
17. To find Max torque, draw tangent to circle which is parallel to torque line. From the point at which tangent meets the circle, draw perpendicular to the torque line. This perpendicular length gives maximum torque
18. To find maximum out put draw tangent to circle which is parallel to output line. From the point at which tangent meets the circle, draw perpendicular to the output line. This perpendicular length gives maximum output
19. Maximum input occurs at highest point of the circle. From the highest point, draw perpendicular to output line. This line length gives the maximum input.

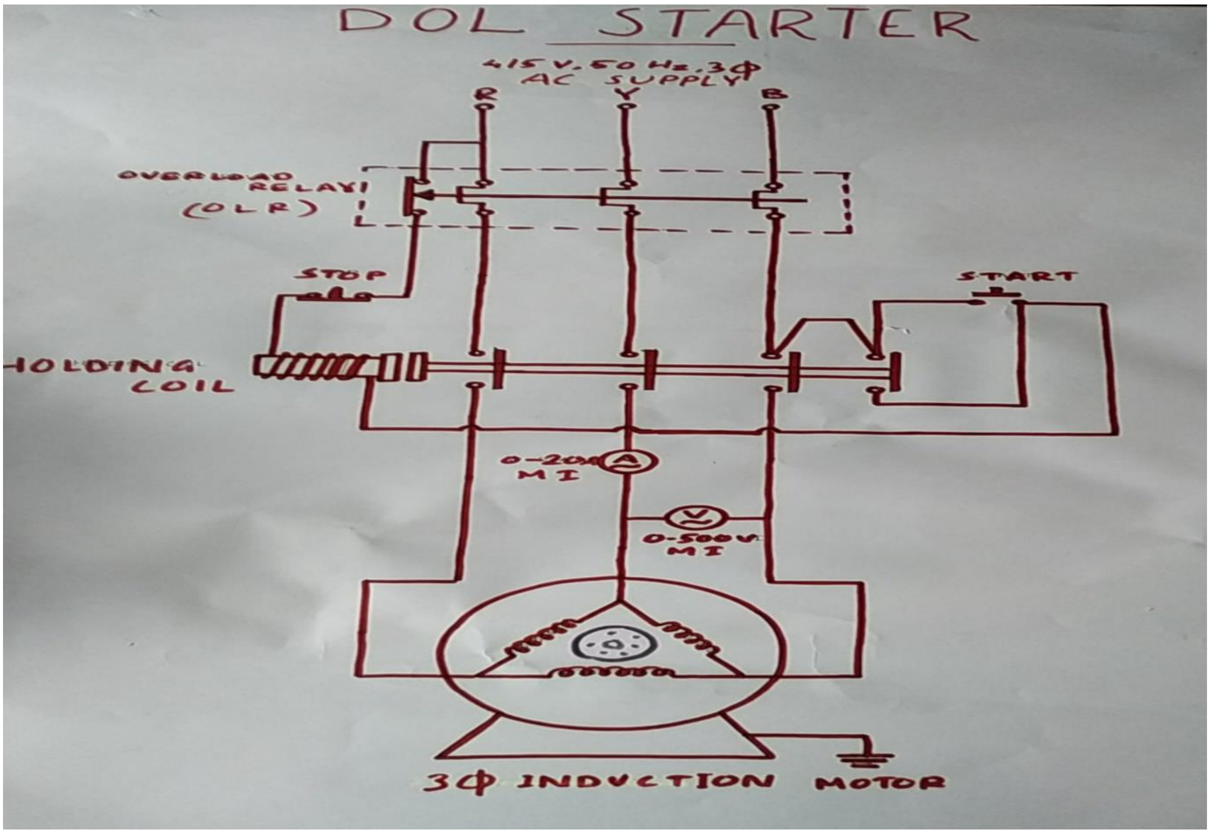
STARTERS USED FOR IM

WHY STARTERS ARE NEEDED: When IM started directly, it takes a huge current. This starting current value is around six to ten times of rated current of IM. If this huge current flows through winding of the motor, the motor burns. large current is taken by the motor for starting also causes voltage dip in the system.it affects the working of other machines connected to that system. Therefore, starting current of the IM must be reduced. To reduce it we use starters.

Starters used for squirrel cage IM starting

1. DOL STARTER (Direct online starter)

It is a simple and inexpensive starter.it is very easy to install and maintain. So, it is very commonly used. In this starter, full line voltage is applied directly across the IM. So, it takes a huge current. This starting current value is around six to ten times of rated current of IM. If this huge current flows through winding of the motor, the motor burns. large current is taken by the motor for starting also causes voltage dip in the system.it affects the working of other machines connected to that system. So the use of DOL starter is used for starting of 3 phase induction motors having capacity less than 5hp. It is a simple and inexpensive starter.it is very easy to install and maintain. So it is very commonly used



It consists of

1. 2 Nos of push button switches. one is Start button switch which is normally open and other is Stop button switch, which is normally closed.
2. holding coil used for holding contacts
3. overload relay (OLR) to disconnect motor supply when motor is overloaded.
4. main contact- 3 nos of main contacts are present..
5. Auxilary contact-it help to keep holding coil energised after ON push button is pressed

Working of DOL Starter

(draw figure)

When start button is pressed (which is normally open), the current flows through holding coil. It energises Holding coil. This energised holding coil closes the three main contacts. Now the supply will come across motor winding terminals. The auxiliary contact helps to energize the hold on coil after the start button is released. Therefor motor gets supply even when start button is released.

When stop button (which is normally closed) is pressed, the supply through holding coil will break. So holding coil is de-energised. So main contact will open. So the supply to motor winding terminal is disconnected.

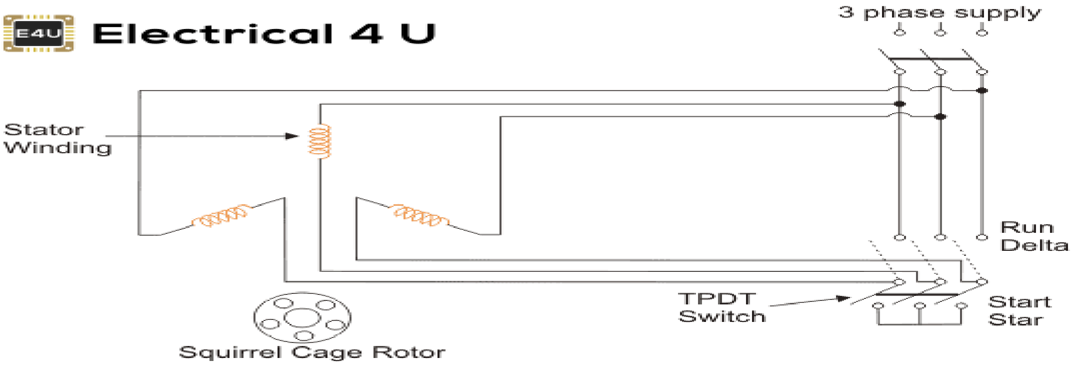
When overload is happened during motor working condition, OLR operates and disconnect the supply through holding coil. This makes main contacts to open. Thus, the supply to motor winding terminal is disconnected.

If supply voltage fails or supply voltage reduces below certain value, the main contacts will open and the motor stops. Therefor it provides under voltage also.

2. STAR-DELTA STARTER

- It is a widely used reduced voltage starter
- This starter is used for squirrel cage IM having delta connected stator winding. . It consist of one TPDT(Triple pole Double throw)switch.

Working principle

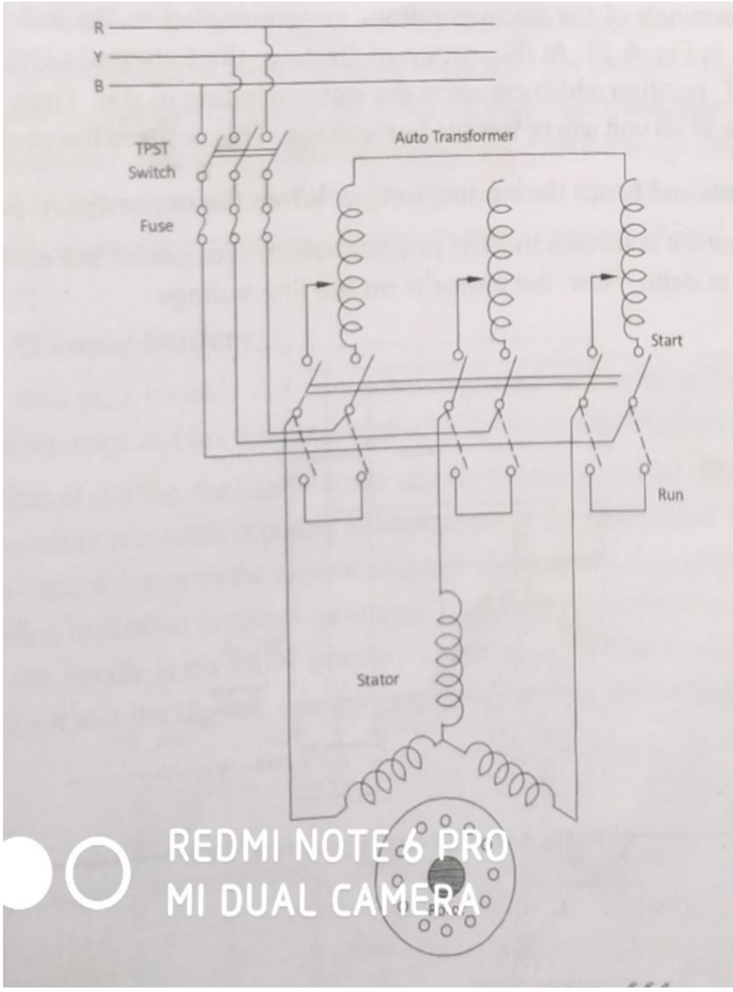


- For starting of IM, star delta starter TPDT switch is placed in the star side. Now the windings will become in star connected. When winding is in star, the voltage across each winding will be $1/\sqrt{3}$ times the line voltage. So the starting current will reduced to 1/3 times. When motor is attaines a sufficient speed, the TPDT switch will be changed to delta side. Now the winding become delta connected.
- This starter is commonly used for IM having rating between 5hp and 20 hp

3. Auto transformer starter

- It is a widely used reduced voltage starter

- This starter is used for squirrel cage IM having star and delta connected stator winding.



- It consists of auto transformer with suitable tapping points and a TPDT switch.
- During starting, TPDT switch is placed in start side. Now the voltage input to the motor at starting is reduced by X times. So the starting current taken by the motor reduces X^2 times.
- After motor attained sufficient speed, TPDT switch is placed in the run position. Now the auto transformer is cut out of the circuit and full supply voltage comes across the IM

4. **Stator resistance starter or Stator Rheostatic starter**
    - It is a reduced voltage starter
    - In this method we add resistor in each phase between the motor terminal and the supply mains as in diagram. Thus, by adding resistor we can control the supply voltage to motor x times the full supply voltage (x is less than 1). so, the starting current taken by the motor reduced by x times.
    - After motor attains the sufficient speed, this stator starting resistance is cut out from the circuit.

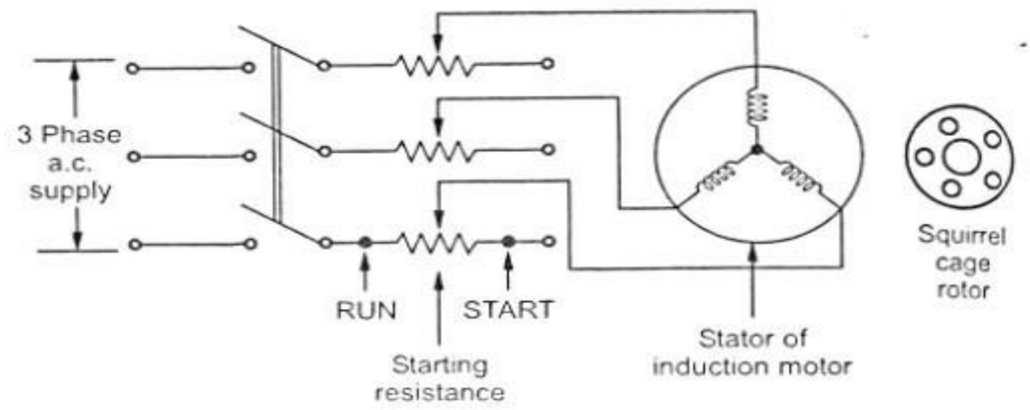
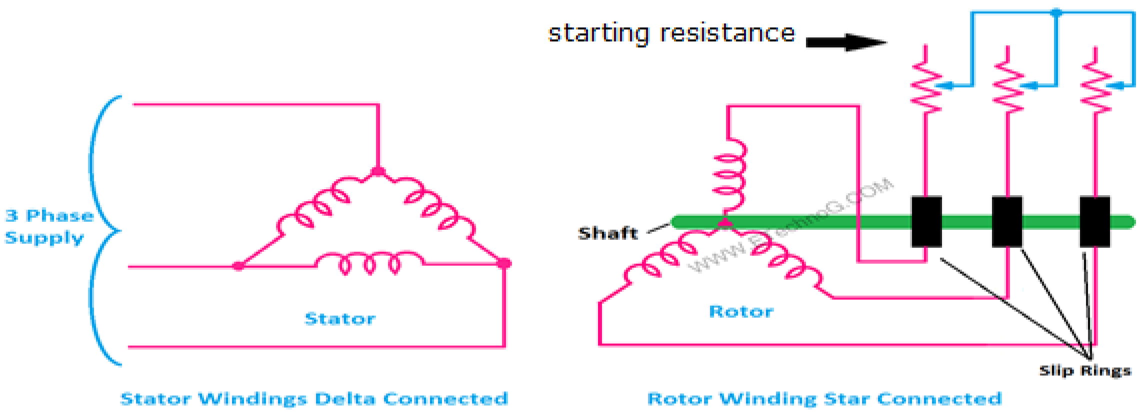


Fig. 7.3.1 Stator resistance starter

- This method is limited for small rated squirrel cage IM

<u>Starters used for Slip Ring IM starting</u>

1. **Rotor Rheostatic Starter**



- This starter is used for slipring IM starting
- In this starter a variable star connected rheostat is connected to the rotor winding through slipring.this rheostat is called starting resistance
- At the time of starting, the rheostats are placed at maximum resistance position. So the starting current will be less.
- When the motor gains sufficient speed, the rheostat is cut out from the rotor circuit
- This methos not only limit the starting current, butr also increases the starting torque.

Electrical Breaking

Stoping or reducing the speed of motor by electrical methods is called electrical breaking.Thre are3 main type of electrical breaking.

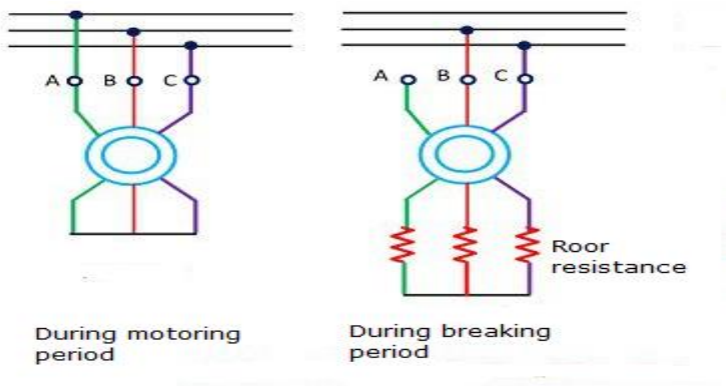
1. **Pluggging**

It is done by interchanging any two phases of IM. This leads to development of torque in opposite to direction of rotation of the IM.This torque acts as breaking torque and using this torque breaking action takes place.After breaking operation is completed, interchanged phases are taken back to old position

2. **Regenerative Breaking**
    - This breaking is achieved by running the IM at a speed heigher than synchronus speed of the motor. Now the slip of induction motor becomes negative. So IM acts as induction generator. Now the direction of torque in Induction generator will be opposite to direction of torque in Induction motor. So this opposite torque acts as breaking torque and using this opposite torque breaking action takes place
    - The main advatange of this breaking is during breaking period electrical power developed by induction generator is fedback to supply source
    - The main condition needed for this is rotor speed should be greater than synchronus speed of the motor. It can be achieved either by running rotor at very high speed by external means or by reducing synchronus speed of the motor using variable frequency drives.
    - This breaking is called regenerative because, during breking period electrical power developed by induction generator is fedback to supply source.
3. **Dynamic Breaking**

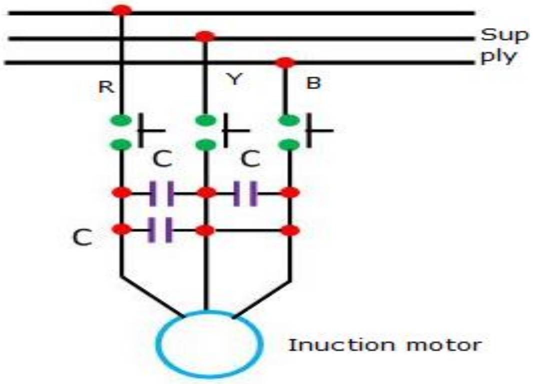
    Dynamic breaking are different types

    A. **AC dynamic breaking**



- In this method the supply to the one of the phase is cut off. So the motor is working with unbalanced supply. So positive sequence torque and negative sequence topques are developed in the Induction motor
- At high rotor resistance condition, the negative sequence torque develeped in the motor will be more than positive sequence torque. So the breaking action takes place

B. **Capacitive breaking**



- In this method three capacitors are kept permanently connected across the supply terminals of the motor as in figure (1)
- For breaking action, we are disconnecting supply to the Induction motor.
- when the motor terminals are disconnected from the supply source the motor works as a self-excited generator and the developed torque will be in the opposite direction and the induction motor breaking action occurs.

SPEED CONTROL OF INDUCTION MOTOR

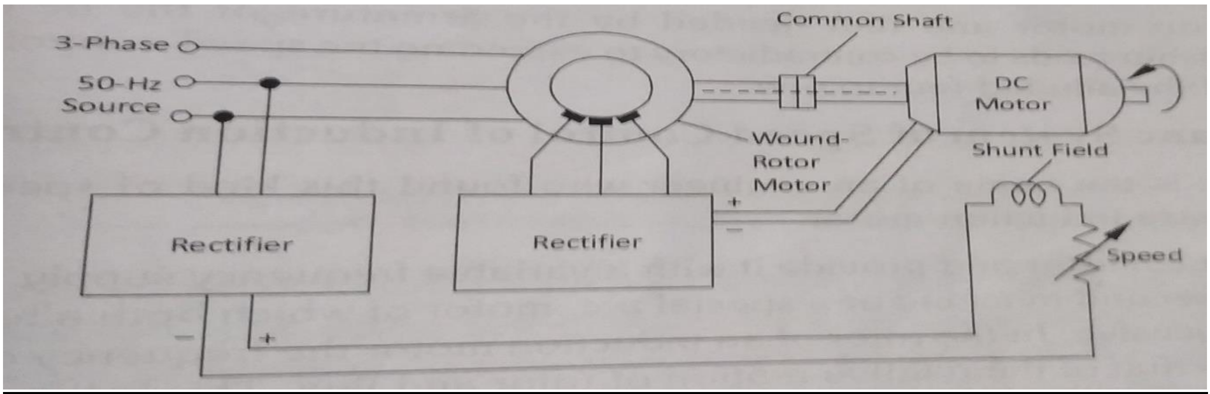
Speed of induction motor can be controlled from stator side and rotor side. From stator side speed can be controlled by

1. By changing supply voltage- As Supply voltage is reduced, speed reduces and viceversa
2. By changing supply frequency- As supply frequency is increased, speed increses and vice versa
3. By changing number of stator poles- As sator poles are increased, speed reduces

From rotor side, speed control of IM can be done by

1. kramer system of speed control
2. Scherbius system of speed control
3. Leblanc system of speed control

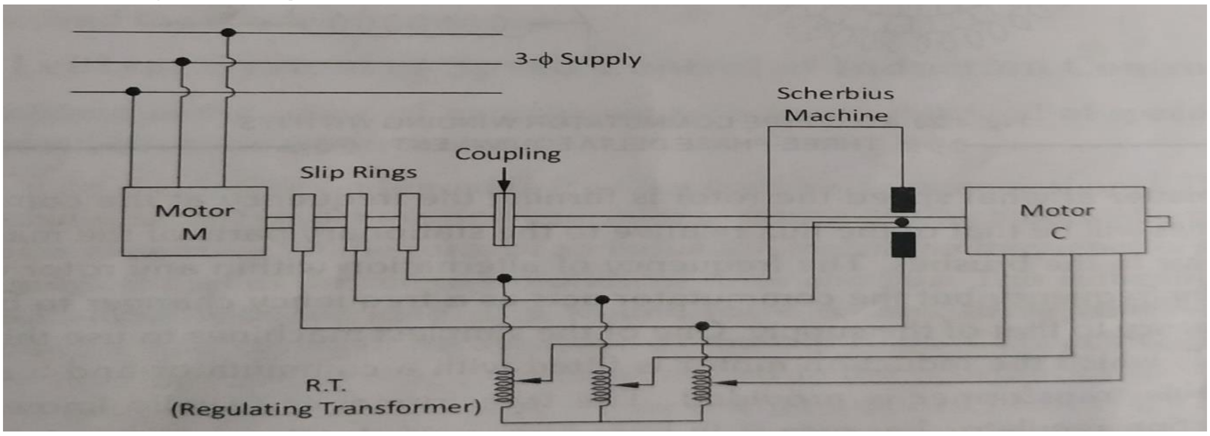
1. **Kramer system of speed control**



- Figure shows the kramer system of speed control of IM.This method of speed control is used for speed control of slip ring induction motor only.
- In kramer system of speed control, a DC motor is coupled to the shaft of the IM. The low frequency AC slip power from rotor of Induction motor is rectiied using a rectifier and given to armature of DC motor.

- Another rectifier is provided to rectify AC input supply and this rectified output is given to shunt field winding of DC motor via variable resistance.
- Speed control of IM can be done by adjusting field current of DC motor by adjusting variable resistor. If field current of DC motor changes, the speed of DC motor changes. Since shaft of both IM and DC motor is coupled, speed of IM also changes

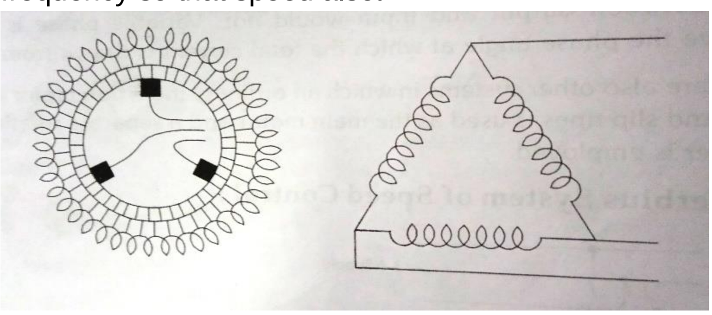
2. **Scherbius system of speed control**



- Figure shows the scherbius system of speed control of IM.This method of speed control is used for speed control of slip ring induction motor only
- In scherbius system of speed control, a three phase or six phase AC commutator motor is coupled to the shaft of the IM. This three phase or six phase AC commutator motor is called scherbius machine
- The AC slip power from rotor of Induction motor direcltly given to scherbius machine armature winding without any rectification via regulating transformer
- Speed control of above system can be achieved by adjusting tapping of the regulating transformer

3. **Leblanc system of speed control**

Leblanc system is used to speed control for three phase induction motor. It can be done with the help of ac motor and which is costly and energy can be wasted as heat in resistance. As we know speed and frequency is proportional, if we could control frequency speed can be controlled. The speed control in Leblanc system can be achieved by varying frequency. The commutator in a DC motor is act as frequency changer. We place a rotor wound for DC motor use with a commutator in a stator connected to three phase AC supply. The figure shows a DC type commutator winding and its three phase delta equivalent. This arrangement will help to achieve different frequency so that speed also.



Types of Enclosures Of Three Phase IM

The main purpose of motor enclosure is to provide protection from environmental impacts such as rain,corrosion,rusting etc. major types of enclosures are

1. **Open Drip Proof(ODP**)

- This enclosure allows movement of air through enclosure for cooing of windings between outside and inside of motor
- It can prevents water entering to the motor within an 15 degree angle from vertrical
- This enclosure is used for indoor applications only

2. Totally Enclosed Fan Cooled(TEFC)

- This enclosure doesnot allows the movement of air though enclosure between outside and inside of motor. That is this enclosure is tottaly enclosedhis
- For cooling of machine enclosed by this enclosure, a fan is provided and which is attached to shaft of the motor

3. Totally Enclosed Non Ventillated(TENV)

- This enclosure is totally enclosed and non ventillated
- Cooing of motor in this types of enclosure is by natural convection cooling method
- This type of enclosure is not suitable in wet environment and explosive environments

4. Totally Enclosed Wash Down (TEWD)

- This enclosure can protect motor from high pressure wash down, wet envirionement and humidity.
- This type of enclosure is used in extremely moist or chemical environments. It is not suitable for explosive areas

5. Explosion Proof Enclosure(EXPL)

- It is also totally enclosed type of enclosure. It can withstand explosion from inside and outside of the motor
- This types o enclosure is preffered for motors operating at hazardous locations

6. Totally Enclosed Air Over(TEAO)

- It is also totally enclosed type of enclosure

Factors Governing The Perfomance of IM

Various factors governing the perfomance of IM are

1.Power supply quality:- a motor should be capable to deliver its rated output with a voltage variation of +/- 6% and frequency variation of +/- 3%. Fluctuation of frequency and voltage severly affect the prfomance of IM. The voltage fluctuation mainly due unbalanced electric supply. So voltage of three phases are not equal. It affect the perfomance of IM.

2.Environment:-Environmental conditions like Temperature, humidity etc affect the peromance of IM

Application of IM

IM are seen in very small power to large power application. For very small power applications single phase IM are used and for large power applications, three phase IM are used. Applications of various types of squirrel cage and wound rotor IM are listed below

A. Squirrel cage IM

1. Squirrel cage IM having normal starting torque and normal starting current-

Applications: 1. Used in Fan 2. Blowers 3.Centrifugal pump 4. Flour mills 5

2. Squirrel cage IM having high starting torque and low starting current

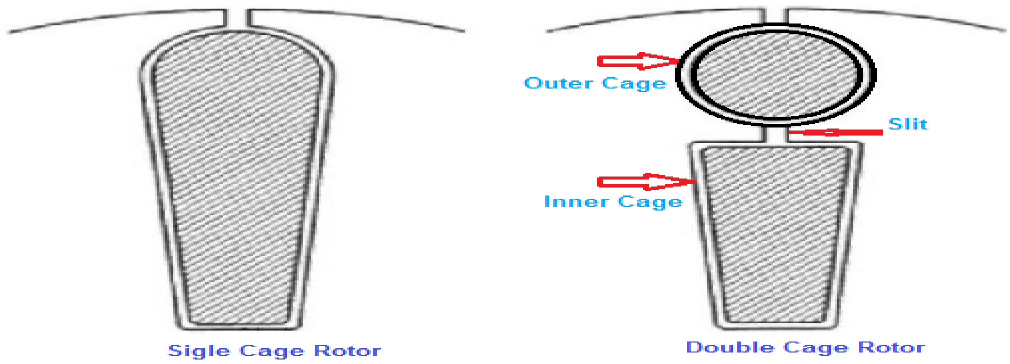
Applications:-1. Conveyors 2. Compressors 3. Crushers 4. Reciprocating pumps

B. Wound rotor IM

It is used where high starting torque and low starting currents are needed

Applications: 1. Conveyors 2. Compressors 3. Pumps 4. Crushers 5. Hoists 6. Cranes 7. Lift 8. Escalator

Double Cage Rotor IM



- The main drawback of squirrel cage IM is, it has very low starting torque. In order to achieve high starting torque a double cage induction motor is introduced.

- A **Double Cage Induction motor** is a type of squirrel cage induction motor in which a **double cage** or **two rotor windings** are used. This arrangement is used for obtaining high starting torque and low value of starting current. The stator of a double cage rotor of an induction motor is same as that of a normal induction motor. In the rotor two cage windings are present. One is outer cage winding and other is inner cage winding.

- The outer cage has high resistance and low inductance. Normally outer cage winding is made up of brass bars. Inner cage has low resistance and high inductance. Normally inner cage is made up of copper bars.

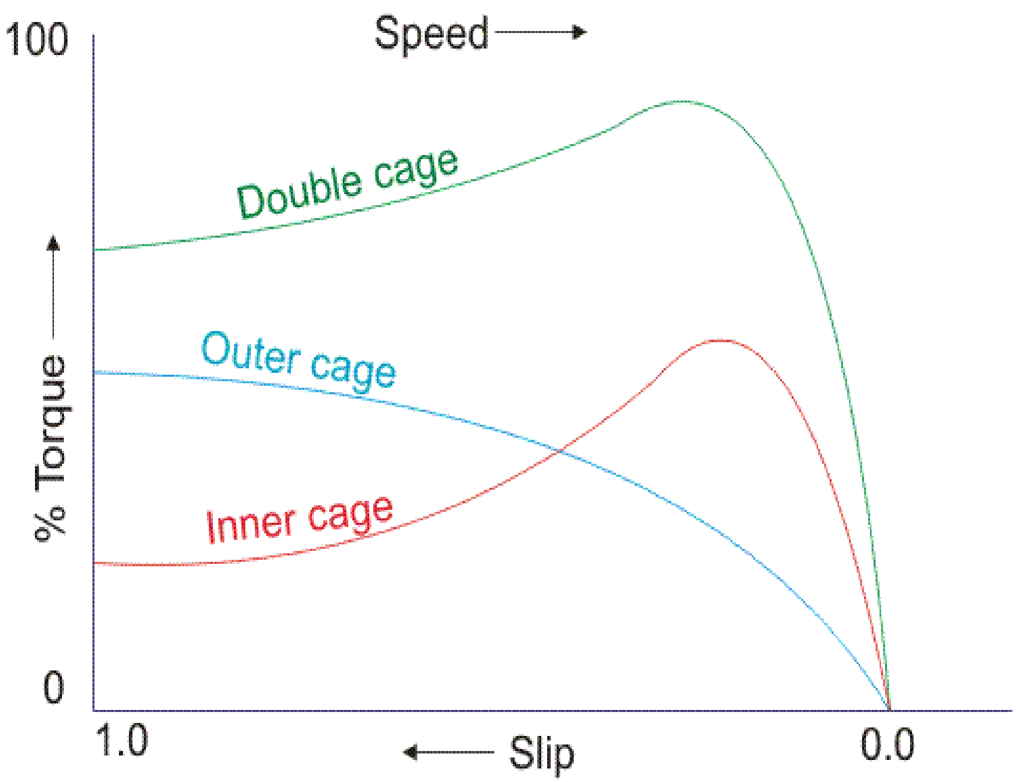
- At the time of starting, frequency of rotor induced emf will be equal to supply frequency. So recatence of innner cage windings will be higher than reactence of higher cage windings. Thus the impidence offered by inner cage winding will be more than outer cage winding. So at starting, most of the current will flow through outer cage winding than inner cage winding. Hence the motor develop high starting torque due to high resistance of the outer cage.
- At normal running condition, frequency of rotor induced emf will be very small. So reactence of inner cage winding very low. So the impidence offred by the inner cage will be less than impidence offered by outer cage . Hence more current will be flow through inner cage winding. So at running condition torque mainly produced due to the flow of currrent through inner cage winding . since inner cage has low resistance, copper loss at running condition will be very small

Torque Slip Curve of Double cage IM

- Torque in a double cage induction motor will be equal to sum of torque produced by inner cage winding(have low resistance and high inductance) and torque produced by outer cage winding(have high resistance and low inductance)
- At starting inner cage winding will have high impidence. So most of the starting current will flow through outer cage having high resistance. So at starting starting torque produced by outer cage will be morethan starting torque produced by inner

cage winding. So from torque slip characteristics we can see that at starting,torque produced by outer cage is more than torque produced by inner cage

- At normal running condition, impidence of inner cage winding will be small compare to outer cage winding. So most of the current will flow through inner cage winding having low resistance. So at normal running condition torque produced by inner cage will be more than torque produced by outer cage.



Equivalent circuit of Double cage IM

R_1 → stator winding Resistance, X_1 → stator winding reactance

R_0 → core loss ~~component~~ Resistance representing core loss in Double cage IM

X_0 → magnetising Reactance

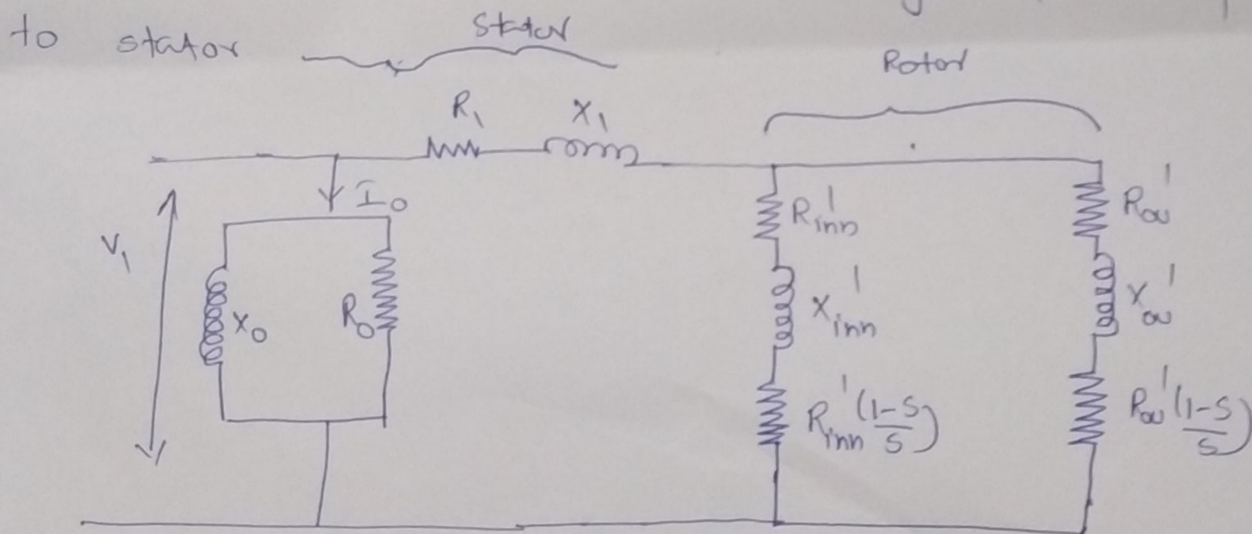
X_{ou} → outer cage winding reactance at stand still

X_{inn} → inner cage winding " " "

R_{ou} → outer cage winding Resistance

R_{inn} → inner cage winding Resistance

Simplified equivalent circuit of Double cage IM reffered to stator



R_{inn}' → inner ~~outer~~ cage winding Resistance reffered to stator

R_{ou}' → outer " " " " " "

X_{inn}' → inner " " Reactance " " "

X_{ou}' → outer " " " " " "

$R_{inn}'\left(\frac{1-S}{S}\right)$ → Electrical equivalent of mechanical Load on inner cage winding

$R_{ou}'\left(\frac{1-S}{S}\right)$ → " " " " " " outer cage winding

V_1 → stator i/p voltage

I_0 → No load input current