CMR INSTITUTE OF TECHNOLOGY

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Internal Assesment Test - 2

Sub:	**Electric Motors**							Code:	**18EE44**
Date:	04.08.2022 (12.00 -1.30PM)	Duration:	90 mins	Max Marks:	50	Sem:	IV	Branch:	EEE

Answer Any FIVE FULL Questions

	Solution	Marks	OBE CO	OBE RBT
1	Explain briefly the Retardation test for determination of efficiency of two shunt machines.	10	CO3	L2

- ✓ This is the best and simplest method to find the efficiency of a constant-speed d.c. machine (e.g., shunt generator and motor).
- ✓ In this method, we find the mechanical (friction and windage) and iron losses (Stray Losses) of the machine.
- ✓ Then knowing the armature and shunt Cu losses at any load, the efficiency of the machine can be calculated at that load.

Consider a d.c. shunt motor running at no-load.

(i) If the supply to the armature is cut off but field remains normally excited, the motor slows down gradually and finally stops. The kinetic energy of the armature is used up to overcome friction, windage and iron losses.

(ii) If the supply to the armature as well as field excitation is cut off, the motor again slows down and finally stops. Now the kinetic energy of the armature is used up to overcome only the friction and windage losses. This is expected because in the absence of flux, there will be no iron losses.

- ✓ By carrying out the first test, we can find out the friction, windage and iron losses and hence the efficiency of the machine.
- ✓ However, if we perform the second test also, we can separate friction and windage losses from the iron losses.
- ✓ **In the retardation test, the d.c. machine is run as a motor at a speed just above the normal.**
- ✓ **Then the supply to the armature is cut off while the field is normally excited.**
- ✓ **The speed is allowed to fall to some value just below normal.**
- ✓ **The time taken for this fall of speed is noted.**
- ✓ **From these observations, the rotational losses (i.e., friction, windage and iron losses) and hence the efficiency of the machine can be determined.**

Let N = normal speed in r.p.m.
ω = normal angular velocity in rad/s = $2\pi N/60$

$\therefore$ Rotational losses, W = Rate of loss of K.E. of armature

or $$W = \frac{d}{dt}\left(\frac{1}{2}I\omega^2\right) = I\omega\frac{d\omega}{dt}$$

Here I is the moment of inertia of the armature. As $\omega = 2\pi N/60$,

$$\therefore \quad W = I \times \frac{2\pi N}{60} \times \frac{d}{dt}\left(\frac{2\pi N}{60}\right) = \left(\frac{2\pi}{60}\right)^2 IN\frac{dN}{dt}$$

or $$W = 0.011\, IN\frac{dN}{dt}$$

In retardation test, the rotational losses are given by;

$$W = 0.011\, IN\frac{dN}{dt}$$

In order to find W, the value of I must be known. It is difficult to determine I directly or by calculation. Therefore, we perform another experiment by which either I is calculated or it is eliminated from the above expression.

(i) First method

- ✓ **It is a fly-wheel method in which the value of I is calculated.**
- ✓ **First, retardation test is performed with armature alone and dN/dt_1 is determined.**
- ✓ **Next, a flywheel of known moment of inertia I1 is keyed on to the shaft of the machine.**
- ✓ **For the same change in speed, dN/dt_2 is noted.**
- ✓ **Since the addition of fly-wheel will not materially affect the rotational losses in the two cases,**

$\therefore$ For the first case, $W = 0.011\, IN\frac{dN}{dt_1}$

For the second case, $W = 0.011\,(I + I_1)N\frac{dN}{dt_2}$

$$\therefore \quad 0.011\, IN\frac{dN}{dt_1} = 0.011\,(I + I_1)N\frac{dN}{dt_2}$$

or $I\frac{dN}{dt_1} = (I + I_1)\frac{dN}{dt_2}$ or $\frac{I + I_1}{I} = \frac{dN/dt_1}{dN/dt_2} = \frac{dt_2}{dt_1}$

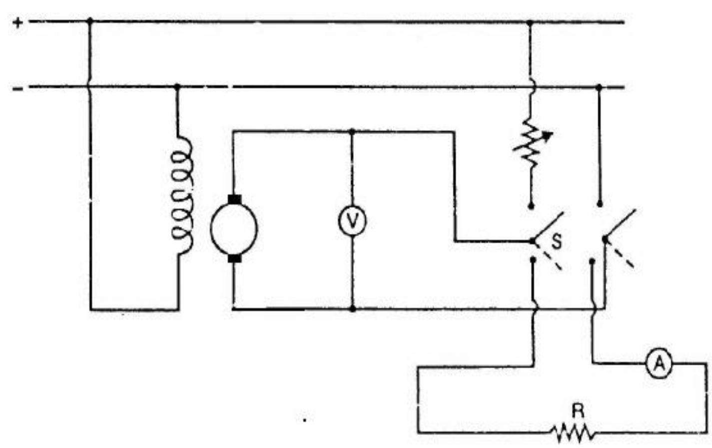
or $\frac{I_1}{I} = \frac{dt_2 - dt_1}{dt_1} = \frac{t_2 - t_1}{t_1}$

or $I = I_1 \times \frac{t_1}{t_2 - t_1}$

(ii) Second method

- ✓ In this method, I is eliminated from the expression by an experiment.
- ✓ First, retardation test is performed with armature alone.
- ✓ The rotational losses are given by;

$$W = 0.011\, IN\frac{dN}{dt_1}$$



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Next the motor is loaded with a known amount of power W' with a brake. For the same change in speed, dN/dt_2 is noted. Then,

$$W + W' = 0.011\,IN\frac{dN}{dt_2}$$

$$\therefore \quad \frac{W + W'}{W} = \frac{dt}{dt_2} = \frac{t_1}{t_2}$$

or $$\frac{W'}{W} = \frac{t_1 - t_2}{t_2}$$

$$\therefore \quad W = W' \times \frac{t_2}{t_1 - t_2}$$

Since the values of W', t_1 and t_2 are known, the value of W can be determined.

2	a. Derive the torque equation of three phase induction motor and obtain Tst/Tm and TFL/Tm. b. Derive the condition to get maximum torque and maximum torque equation.	10	CO1	L2

(6)

Torque Equation of IM.

The torque produced in IM depends on the following factors.

1. The part of rotating magnetic field which reacts with rotor & is responsible to produce induced emf (ϕ)
2. The magnitude of rotor current in running condition.
3. Power factor of the rotor circuit in running condition.

$T \propto \phi \, I_{2r} \cos\phi_{2r}$ — (1)

$\phi \Rightarrow$ flux responsible to produce emf
$I_{2r} \Rightarrow$ Rotor running current
$\phi_{2r} \Rightarrow$ Running PF of rotor.

Flux produced ϕ

$\phi \propto$ stator voltage E_1 —

$\phi \propto E_1$ — (2)

Turns Ratio K $\quad K = \frac{E_2}{E_1}$ — (3) $\qquad K = \frac{E_2}{\phi}$

From (2) & (3) $\qquad E_2 = K\phi$

$\boxed{E_2 \propto \phi}$ $\qquad E_2 \propto \phi$.

From (1) $\phi = E_2$. — (4)

∴ Rotor current I_{2r}

$$I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{S E_2}{\sqrt{R_2^2 + (S X_2)^2}} \quad \text{—(5)}$$

Power Factor $\cos\phi_{2r}$

$$\cos\phi_{2r} = \frac{R_2}{Z_{2r}} = \frac{R_2}{\sqrt{R_2^2 + (S X_2)^2}} \quad \text{—(6)}$$

Sub 4, 5, 6 in (1).

$$T \propto \phi \, I_{2r} \cos\phi_{2r}$$

$$T \propto E_2 \cdot \frac{S E_2}{\sqrt{R_2^2 + (S X_2)^2}} \cdot \frac{R_2}{\sqrt{R_2^2 + (S X_2)^2}}$$

$$T \propto \frac{S E_2^2 R_2}{R_2^2 + (S X_2)^2}$$

$$\boxed{T = K \frac{S E_2^2 R_2}{R_2^2 + (S X_2)^2}}$$

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

$K = \frac{3 \times 60}{2\pi N_s} \Rightarrow \frac{90}{\pi N_s}$

K ⇒ proportionality constant

n_s = Syn. speed in rps

$$\boxed{T = \frac{3}{2\pi n_s} \cdot \frac{S E_2^2 R_2}{R_2^2 + (S X_2)^2}} \text{ Nm.}$$

$$n_s = \frac{N_s}{60}$$

Starting Torque (T_{st})

$S=1$

$$T_{st} = \frac{3}{2\pi n_s} \frac{E_2^2 R_2}{R_2^2 + X_2^2}$$

Condition to Get Maximum Torque.

$$T = \frac{K\, S\, E_2^2 R_2}{R_2^2 + (S X_2)^2} = \frac{K S E_2^2 R_2}{R_2^2 + S^2 X_2^2}$$

Differentiate T WRT slip (s) and equate to zero

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

$$\frac{dT}{dt} = \frac{d}{dt}\left[\frac{K\, S\, E_2^2 R_2}{R_2^2 + S^2 X_2^2}\right] = 0 \quad . \quad \frac{u}{v} = \frac{u'v - v'u}{v^2}$$

$$\Rightarrow \frac{K E_2^2 R_2 (1) \left[R_2^2 + S^2 X_2^2\right] - 2 S X_2^2 K S E_2^2 R_2}{(R_2^2 + S^2 X_2^2)^2} = 0.$$

$$\Rightarrow R_2^2 + S^2 X_2^2 - 2 S^2 X_2^2 = 0$$

$$R_2^2 = S^2 X_2^2$$

$$R_2 = S X_2$$

$$S = \frac{R_2}{X_2}$$

This is the condition to get maximum Torque under running.

Condition to Get Maximum Starting Torque.

$S = 1.$

$$\boxed{R_2 = X_2.}$$ condition for maximum starting torque.

Maximum Torque. (Running)

$$T = K \frac{S E_2^2 R_2}{R_2^2 + (S X_2)^2}.$$

put $R_2 = S X_2$.

$$T_{max} = \frac{K S E_2^2 S X_2}{(S X_2)^2 + (S X_2)^2} = \frac{K S^2 E_2^2 X_2}{2 S^2 X_2^2}$$

$$\boxed{T_{max} = K \frac{E_2^2}{2 X_2}}$$

→ Maximum Torque independent rotor resistance.

→ T_{max} varies inversely as X_2

→ T_{max} varies as square of E_2 ($E_2 \propto E_1$ supply voltage.)

→ T_{max} at starting occurs when $R_2 = X_2$.

Torque Ratios

• Full load and Maximum Torque Ratio

$$\frac{T_{F.L.}}{T_m} = \frac{s_f}{s_m} \times \frac{[R_2^{\,2} + (s_m X_2)^2]}{[R_2^{\,2} + (s_f X_2)^2]}$$

$$\frac{T_{F.L.}}{T_m} = \frac{s_f}{s_m} \times \frac{\left[\frac{R_2^{\,2}}{X_2^{\,2}} + s_m^2\right]}{\left[\frac{R_2^{\,2}}{X_2^{\,2}} + s_f^2\right]}$$

$R_2/X_2 = s_m$

$T_{F.L.}/T_m = (s_f \times 2\, s_m^2)/(s_m \times (s_m^2 + s^2))$

$T_{F.L.}/T_m = (2\, s_f s_m)/(s_m^2 + s^2)$

Starting Torque and Maximum Torque Ratio

Now for T_{st}, $s = 1$

$T_{st}\, \alpha\, (E_2^2 R_2)/(R_2^2 + (X_2)^2)$

While for T_m, $s = s_m$

$$\therefore \quad T_m \propto \frac{s_m E_2^{\,2} R_2}{R_2^{\,2} + (s_m X_2)^2}$$

$$\boxed{\frac{T_{st}}{T_m} = \frac{2 s_m^{\,2}}{s_m(1 + s_m^{\,2})} = \frac{2 s_m}{1 + s_m^{\,2}}}$$

3	Explain the significance of slip. Discuss the Torque-Slip characteristics of three phase induction motor including motoring, generating and braking operation.	10	CO2	L2

significance of slip

- The induction motor can’t run if there is no slip.
- The torque is produced when the current flows in the rotor conductor. If the slip is zero, no EMF will be induced in the rotor conductor and hence there will be no flow of the current in the rotor circuit.
- The slip plays a very vital role in the operation of an induction motor. At no load, the slip of the induction motor is less and the slip gets increased with increased loading on the motor. The slip of the motor gets self-adjusted according to the torque demands from the load side.

Torque-Slip characteristics of three phase induction motor including motoring, generating and braking operation.

The torque slip curve for an induction motor gives us the information about the variation of torque with the slip.

➢The slip is defined as the ratio of difference of synchronous speed and actual rotor speed to the synchronous speed of the machine.

➢The variation of slip can be obtained with the variation of speed that is when speed varies the slip will also vary and the torque corresponding to that speed will also vary.

Torque Equation

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

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

Torque-Slip characteristics

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

• Low slip region

• High slip region

Three Modes

✓Motoring Mode

✓Generating Mode

✓Braking Mode

Low slip region

- In low slip region, 's' is very very small. Due to this, the term $(s X_2)^2$ is so small as compared to R_2^2 that it can be neglected.

T α S

$$T \propto \frac{s R_2}{R_2^2} \propto s$$ As R_2 is constant.

- Hence in low slip region torque is directly proportional to slip.
- So as load increases, speed decreases, increasing the slip. This increases the torque which satisfies the load demand.
- Hence the graph is straight line in nature.

At Nr = N_s , s = 0 hence T = 0. As no torque is generated at Nr = N_s, motor stops if it tries to achieve the synchronous speed.

Torque increases linearly in this region, of low slip values.

Hence this region is called stable region of operation.

High slip region

- In this region, slip is high i.e. slip value is approaching to 1.
- Here it can be assumed that the term R_2^2 is very very small as compared to $(s X_2)^2$.
- Hence neglecting from the denominator, we get

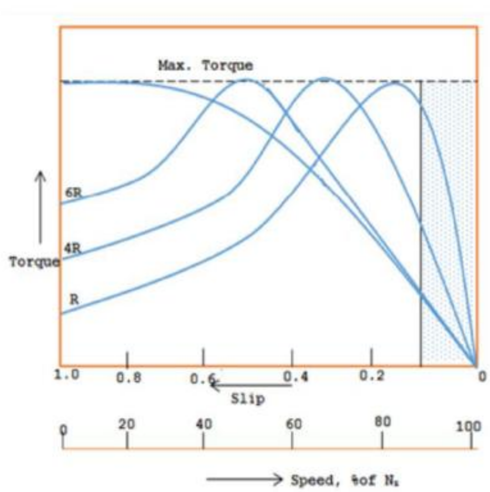
T α 1/S

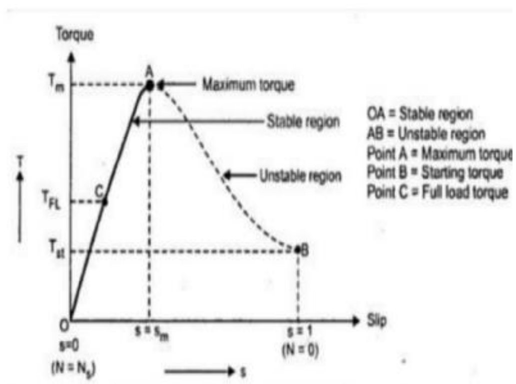
$$T \propto \frac{s R_2}{(sX_2)^2} \propto \frac{1}{s}$$ where R_2 and X_2 are constants

- So in high slip region torque is inversely proportional to the slip.
- Hence its nature is like rectangular hyperbola.
- Now when load increases, load demand increases but speed decreases. As speed decreases, slip increases. In high slip region as T α1/s, torque decreases as slip increases.
- Hence speed further drops. Eventually motor comes to standstill condition. The motor can not continue to rotate at any point in this high slip region.
- Hence this region is called unstable region of operation.

So torque - slip characteristics has two parts,
1. Straight line called stable region of operation
2. Rectangular hyperbola called unstable region of operation.

Torque – Slip Charateristics – Motoring Mde





Torque speed characteristics

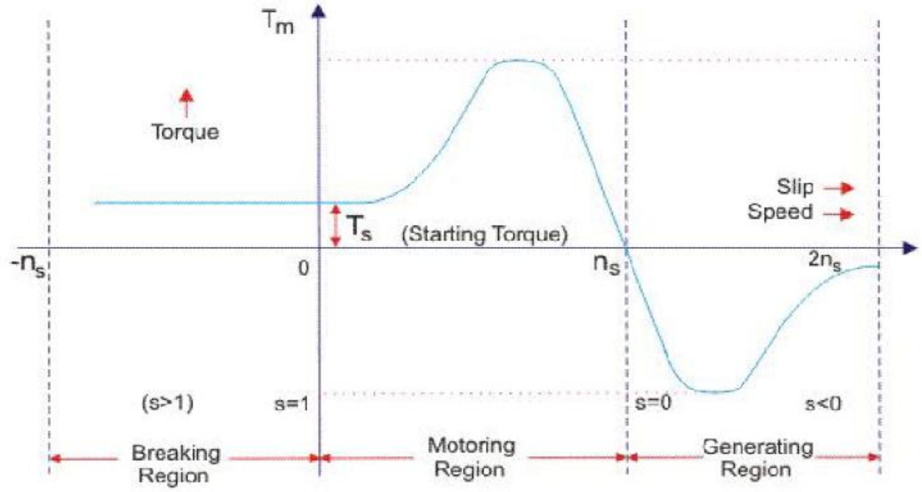
- In low slip region, as load increases, slip increases and torque also increases linearly.
- Every motor has its own limit to produce a torque.
- The maximum torque, the motor can produces as load increases is Tm which occurs at s = sm.
- So linear behavior continues till s = sm.
- If load is increased beyond this limit, motor slip acts dominantly pushing motor into high slip region.
- Due to unstable conditions, motor comes to standstill condition at such a load.
- Maximum torque which motor can produce is also called breakdown torque or pull out torque.
- So range s = 0 to s = sm is called low slip region, known as stable region of operation. Motor always operates at a point in this region.
- And range s = sm to s = 1 is called high slip region which is rectangular hyperbola, called unstable region of operation.
- Motor can not continue to rotate at any point in this region.
- At s = 1, Nr = 0 i.e. start, motor produces a torque called starting torque denoted as Tst.

Full load torque

- The load which motor can drive safely while operating continuously and due to such load, the current drawn is also within safe limits is called full load condition of motor. When current increases, due to heat produced the temperature rises. The safe limit of current is that which when drawn for continuous operation of motor, produces a temperature rise well within the limits. Such a full load point is shown on the torque-slip characteristics torque as TF.L.

$$T_{Full\ load} < T_m$$

Torque-Slip characteristics



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.
- 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

- To run the induction machine as a generator, **its slip must be less than zero i.e. negative.**
- The negative slip indicates that the rotor is running at a speed above the synchronous speed.
- S=(Ns – Nr) / Ns
- If Nr > Ns , then S = -ve
- When running as a generator it takes mechanical energy and supplies electrical energy from the stator.
- **Thus the negative slip, generation action takes place** and nature of torque - slip characteristics reverses in this generating region.

<table>
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Braking Mode

- When the slip is greater than 1, the machine works in the braking mode.
- The motor is rotated in opposite direction to that of rotating field.
- In practice two of the stator terminals are interchanged which changes the phase sequence which in turn reverses the direction of rotation of magnetic field.
- The motor comes to quick stop under the influence of counter torque which produces braking action.
- This method by which the motor comes to rest is known as plugging.
- Only care is taken that the stator must be disconnected from the supply to avoid the rotor to rotate in other direction

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What is necessity of starter in three phase induction motor. Explain with neat diagram about the rotor resistance starter; State the advantages and disadvantages.

Necessity of starter in three phase induction motor

- The starter is a device which is basically used to limit high starting current by supplying reduced voltage to the motor at the time of starting.
- Over load protection
- Low voltage protection
- Protection against single phasing

Rotor Resistance Starter

- To limit the rotor current which consequently reduces the current drawn by the motor from the supply, the resistance can be inserted in the rotor circuit at start.
- This addition of the resistance in rotor in the form of 3 phase star connected rheostat.
- The external resistance is inserted in each phase of the rotor winding through slip ring and brush assembly.
- Initially maximum resistance is in the circuit. As motor gather speed, the resistance is gradually cut-off. The operation may be manual or automatic.

Advantages

- The starting torque is proportional to the rotor resistance.
- Hence important advantage of this method is not only the starting current is limited but starting torque of the motor also gets improved.

Disadvantages

- It can be used only for slip ring induction motors as in squirrel cage motors, the rotor is permanently short circuited.

</td><td>10</td><td>CO5</td><td>L2</td></tr>
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Rotor Resistance Starter:

To limit the rotor current which consequently reduces the current drawn by the motor from the supply, the resistance can be inserted in the rotor circuit at start. This addition of the resistance in rotor in the form of 3 phase star connected rheostat. The arrangement is shown in the Fig. 1.

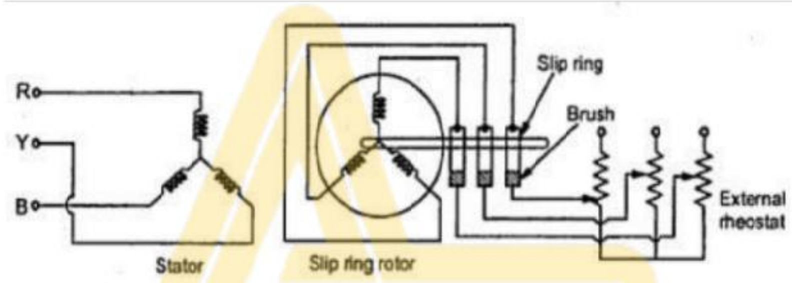


Fig. 1 Rotor resistance starter

The external resistance is inserted in each phase of the rotor winding through slip ring and brush assembly. Initially maximum resistance is in the circuit. As motor gather speed, the resistance is gradually cut-off. The operation may be manual or automatic.

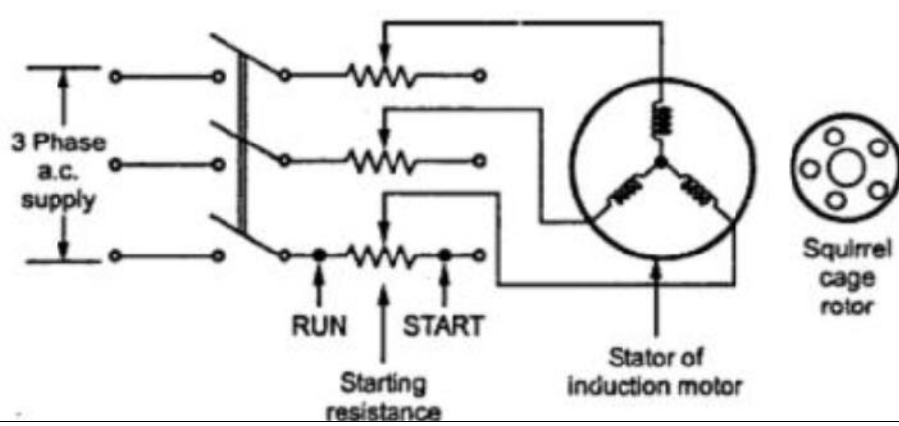
We have seen that the starting torque is proportional to the rotor resistance. Hence important advantage of this method is not only the starting current is limited but starting torque of the motor also gets improved.

Note : The only limitation of the starter that it can be used only for slip ring induction motors as in squirrel cage motors, the rotor is permanently short circuited.

5	Explain with neat diagram about the stator resistance starter; derive the expression for Tst/TFL. State the advantages and disadvantages.	10	CO5	L2

Stator Resistance Starter

- In order to apply the reduced voltage to the stator of the induction motor, three resistances are added in series with each phase of the stator winding. Initially the resistances are kept maximum in the circuit. Due to its large voltage gets dropped across the resistances. Hence a reduced voltage gets applied to the stator which reduces the high starting current.



- When the motor starts running, the resistances are gradually cut-off from the stator circuit. When the resistances are entirely removed from the stator circuit i.e. rheostats in RUN position then rated voltage gets applied to the stator. Motor runs with normal speed.

Advantages

- The starter is simple in construction
- cheap.
- It can be used for both star and delta connected stator.

Disadvantages

- There are large power losses due to resistances.
- Also the starting torque of the motor reduces due to reduced voltage applied to the stator.

Relation between T_{st} and $T_{F.L.}$

- We know, $P_2 = T \times \omega_s = 2\pi N_s T / 60$
- where T is torque produced and P_2 is the rotor input at N_s.

  $T \alpha P_2$
- But $P_2 = P_c/s$ where P_c = Total copper loss (P2:Pc:Pm = 1:S:(1-S)
- $= (3I_{2r}^2R_2)/s$
- $T \alpha I_{2r}^2/s$
- But rotor current I_{2r} and stator current are related to each other through transformer action.
- $T \alpha I_1^2/s$ where I_1 = Stator current
- At start, $s = 1$, $T = T_{st}$ and $I_1 = I_{st}$
- $T_{st} \alpha I_{st}^2$ ....(1)
- When stator resistance starter is used, the factor by which stator voltage reduces is say $x < 1$. The starting current is proportional to to this factor x. So if **I_{sc} is the normal current drawn under full rated voltage condition at start** then,
- $I_{st} = x I_{sc}$ ....(2)
- $T_{st} \alpha (xI_{sc})^2$ ....(3)
- But $T_{F.L.} \alpha (I_{F.L.})^2/s_f$ where s_f = Full load slip ....(4)

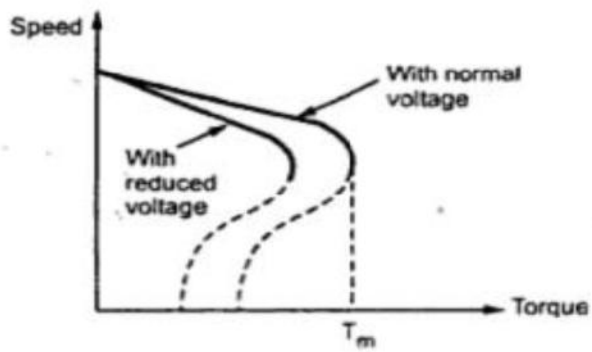
$$\frac{T_{st}}{T_{F.L.}} = x^2\left(\frac{I_{sc}}{I_{F.L.}}\right)^2 s_f$$

6	Explain speed control methods of 3 phase induction motor by voltage, V/f and rotor resistance control. • A three phase induction motor is practically a constant speed motor like a d.c. shunt motor. • But the speed of d.c. shunt motor can be varied smoothly just by using simple rheostats. This maintains the speed regulation and efficiency of d.c. shunt motor. • But in case of three phase induction motors it is very difficult to achieve smooth speed control. • And if the speed control is achieved by some means, the performance of the induction motor in terms of its power factor, efficiency etc. gets adversely affected. • For the induction motor we know that, $N_r = N_s(1 - s)$ • From this expression it can be seen that the speed of induction motor can be changed either by changing its synchronous speed or by changing the slip s. • Similarly torque produced in case of three phase induction motor is given by, • $T \propto \frac{sE_2^2 R_2}{R_2^2 + (s X_2)^2}$ • So as the parameters like R_2, E_2 are changed then to keep the torque constant for constant load condition, motor reacts by change in its slip. Effectively its speed changes. **Speed Control Methods** 1. Supply voltage control. 2. Supply frequency control, called V / f control. 3. Rotor Resistance control / Adding external resistance in the rotor circuit.	10	CO4	L2

Supply Voltage Control

- We know that, $T \ \alpha \ (k\, s\, E_2^2\, R_2)/(R_2^2 + (s\, X_2)^2)$
- Now E_2, the rotor induced e.m.f. at standstill depends on the supply voltage V.
- $E_2 \ \alpha \ V$
- Also for low slip region, which is operating region of the induction motor, $(s\, X_2)^2 << R_2$ and hence can be neglected.
- $T \ \alpha \ (s\, E_2^2\, R_2)/R_2^2) \ \alpha \ sV^2$ for constant R_2
- Now if supply voltage is reduced below rated value, as per above equation torque produced also decreases.
- But to supply the same load it is necessary to develop same torque hence value of slip increases so that torque produced remains same.
- Slip increases means motor reacts by running at lower speed, to decrease in supply voltage. S=(Ns – Nr) / Ns
- So motor produces the required load torque at a lower speed.

Speed-torque curves for motor with voltage control



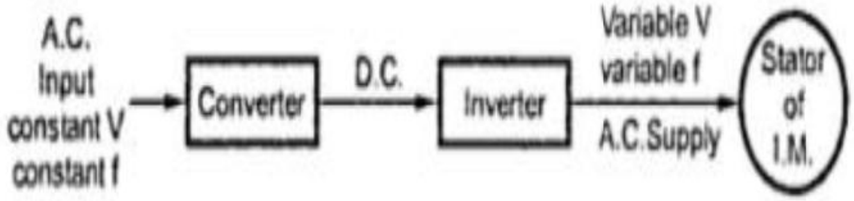
Disadvantages

- In this method, due to reduction in voltage, current drawn by the motor increases.
- Large change in voltage for small change in speed is required is the biggest disadvantage.
- Due to increased current, the motor may get overheated.
- Additional voltage changing equipment is necessary.
- Hence this method is rarely used in practice.
- Motors driving fan type of loads use this method of speed control. Due to reduced voltage, E_2 decreases, decreasing the value of maximum torque too.

Supply frequency control - V / f control

- The synchronous speed is given by,
- $N_s = 120f / P$
- Thus by controlling the supply frequency smoothly, the synchronous speed can be controlled over a wide range. This gives smooth speed control of an induction motor.
- But the expression for the air gap flux is given by,
- $$\phi_g = \frac{1}{4.44 K_1 T_{ph1}} \left(\frac{V}{f}\right)$$
- This is according to the e.m.f. equation of a transformer where,
- K_1 = Stator winding constant
- T_{ph1} = Stator turns per phase
- V = Supply voltage
- f = Supply frequency
- It can be seen from this expression that if the supply frequency f is changed, the value of air gap flux also gets affected.
- This may result into saturation of stator and rotor cores.
- Such a saturation leads to the sharp increase in the (magnetisation) no load current of the motor.
- Hence it is necessary to maintain air gap flux constant when supply frequency f is changed.
- To achieve this, it can be seen from the above expression that along with f, V also must be changed so as to keep (V/f) ratio constant.
- This ensures constant air gap flux giving speed control without affecting the performance of the motor.
- Hence this method is called V / f control.

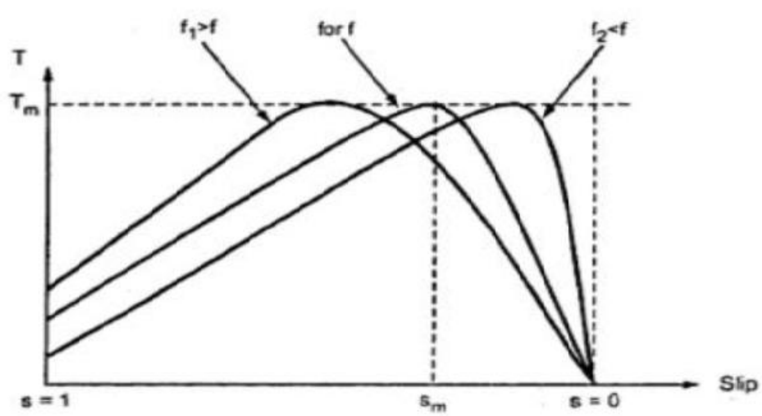
Electronic scheme for V/f control



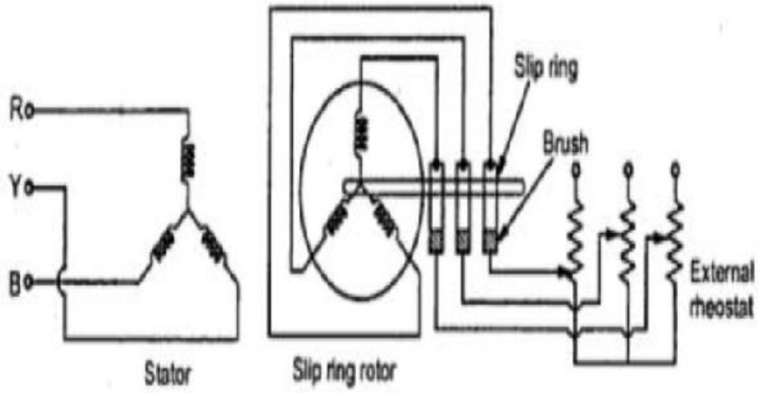
- Hence in this method, the supply to the induction motor required is variable voltage variable frequency supply and can be achieved by an electronic scheme using converter and inverter circuitry.
- The normal supply available is constant voltage constant frequency a.c. supply.
- The converter converts this supply into a d.c. supply.
- This d.c. supply is then given to the inverter.
- The inverter is a device which converts d.c. supply, to variable voltage variable frequency a.c. supply which is required to keep V / f ratio constant.
- By selecting the proper frequency and maintaining V / f constant, smooth speed control of the induction motor is possible.

Torque-slip characteristics with variable f and constant (V/f)

- If f is the normal working frequency then the Fig. shows the torque-slip characteristics for the frequency $f_{1>}$ f and $f_{2<}$ f i.e. for frequencies above and below the normal frequency.
- Another disadvantages of this method is that the supply obtained can not be used to supply other devices which require constant voltage.
- Hence an individual scheme for a separate motor is required which makes it costly. Ns = 120f / P; Nr = Ns(1-s)



Rotor Resistance Control



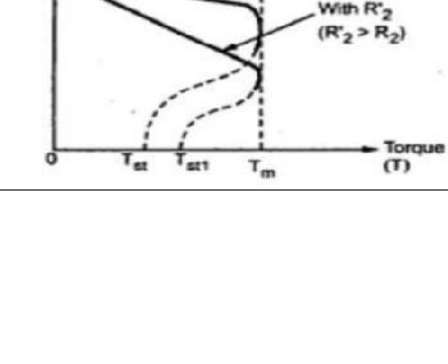
Rotor Resistance Control
Adding External Resistance in Rotor Circuit

- We know, $T \propto (s E_2^2 R_2)/(R_2^2 + (s X_2)^2)$
- For low slip region $(s X_2)^2 << R_2$ and can be neglected and for constant supply voltage is also constant.
- $T \propto (s R_2)/R_2^2 \propto s/R_2$
- Thus if the rotor resistance is increased, the torque produced decreases.
- But when the load on the motor is same, motor has to supply same torque as load demands.
- So motor reacts by increasing its slip to compensate decreases in T due to R_2 and maintains the load torque constant.
- So due to additional rotor resistance R_2, motor slip increases i.e. the speed of the motor decreases. $Nr = Ns(1-S)$
- Thus by increasing the rotor resistance R_2, speeds below normal value can be achieved.
- Another advantage of this method is that the starting torque of the motor increases proportional to rotor resistance.

Disadvantages :

1. The large speed changes are not possible. This is because for large speed change, large resistance is required to be introduced in rotor which causes large rotor copper loss due to reduce the efficiency.
2. The method can not be used for the squirrel cage induction motors.
3. The speeds above the normal values can not be obtained.
4. Large power losses occur due to large resistance.
5. Sufficient cooling arrangements are required which make the external rheostats bulky, and expensive.
6. Due to large power losses, efficiency is low.

Thus the method is rarely used in the practice.



7	A 400 V, 4 pole, 3 phase, 50 Hz star connected induction motor has a rotor resistance and reactance per phase equal to 0.01 Ω and 0.1 Ω respectively. Determine i) Starting torque ii) slip at which maximum torque will occur iii) speed at which maximum torque will occur iv) maximum torque v) full load torque if full load slip is 4 %. Assume ratio of stator to rotor turns as 4.	10	CO2	L4

Solution : The given values are,

P = 4, f = 50 Hz, stator turns/ rotor turns = 4, R2 = 0.01 Ω, X2 = 0.1 Ω

E1line = stator line voltage = 400 V

E1ph = E1line/√3 = 400/√3 = 230.94 V……………………… star connection

K = E2ph/E1ph = Rotor turns/ Stator turns = 1/4

E2 = (1/4) x E1ph = 230.94/4 = 57.735 V

Ns = 120f/P = 120x50 / 4 = 1500 r.p.m.

i) At start, s =1

∴ $T_{st} = (k\ E_2^2\ R_2)/(R_2^2 + (X_2)^2)$ where $k = 3/(2\ \pi\ n_s)$

$n_s = N_s/60 = 1500/60 = 25$ r.p.s.

∴ $k = 3/(2\pi \times 25) = 0.01909$

∴ $T_{st} = (0.01909 \times 57.735^2 \times 0.01)/(0.01^2 + 0.1^2) = 63.031$ N-m

ii) Slip at which maximum torque occurs is,

$s_m = R_2/X_2 = 0.01/0.1 = 0.1$

$\% s_m = 0.1 \times 100 = 10\%$

iii) Speed at which maximum torque occurs is speed corresponding to,

$N = N_s(1 - s_m) = 1500\ (1 - 0.1) = 1350$ r.p.m.

iv) The maximum torque is,

$T_m = (k\ E_2^2)/(2\ X_2) = (0.01909 \times 57.735^2)/(2 \times 0.1) = 318.16$ N-m

v) Full load slip, $s_f = 0.04$ as % $s_f = 4$ %

∴ $T_{f.l.} = (k\ s_f\ E_2^2\ R_2)/(R_2^2 + (s_f\ X_2)^2) = (0.01909 \times 0.04 \times 57.735^2 \times 0.01)/(0.01^2 + (0.04 \times 0.1)^2)$

$= 219.52$ N-m

8a	An 8 pole, 50Hz induction motor has an emf in the rotor frequency 1.5Hz. Determine the slip and speed of the motor. **Given Data** **P=8, f = 50Hz, fr = 1.5Hz** **Slip = ?** fr = s*f s = fr/f = 1.5/50 = 0.03 **Speed of motor:** Nr = Ns (1-s) Ns = 120 f / p = 120*50 / 8 = 750rpm Nr = Ns (1-s) = 750 * (1-.03) = 727.5 rpm.	4	CO1	L3
8b	A 24 pole, 50 Hz, star connected induction motor has rotor resistance of 0.016 Ω per phase and rotor reactance of 0.265 Ω per phase at standstill. It is achieving its full load torque at a speed of 247 r.p.m. Calculate the ratio of i) Full load torque to maximum torque ii) starting torque to maximum torque. Solution : Given values are, P = 24, f = 50 Hz, R2 = 0.016 Ω, X2 = 0.265 Ω, N = 247 r.p.m. Ns = 120f / P = (120x50)/24 = 250 r.p.m. sf = (Ns - N)/Ns = (250-247)/250 = 0.012 = Full load slip sm = R2/X2 = 0.016/0.265 = 0.06037 i) $T_{F.L.}/T_m = (2 s_m s_f)/(s_m^2 + s_f^2) = (2 \times 0.06037 \times 0.012)/(0.06037^2 + 0.012^2)$ ii) $T_{st}/T_m = (2 s_m)/(1 + s_m^2) = (2 \times 0.06037)/(1 + 0.06037^2) = 0.1203$	6	CO2	L3