ONLINE GATE COACHING CLASSES

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Lecture 7 of Electrical Machines

Topic: Three phase induction motors

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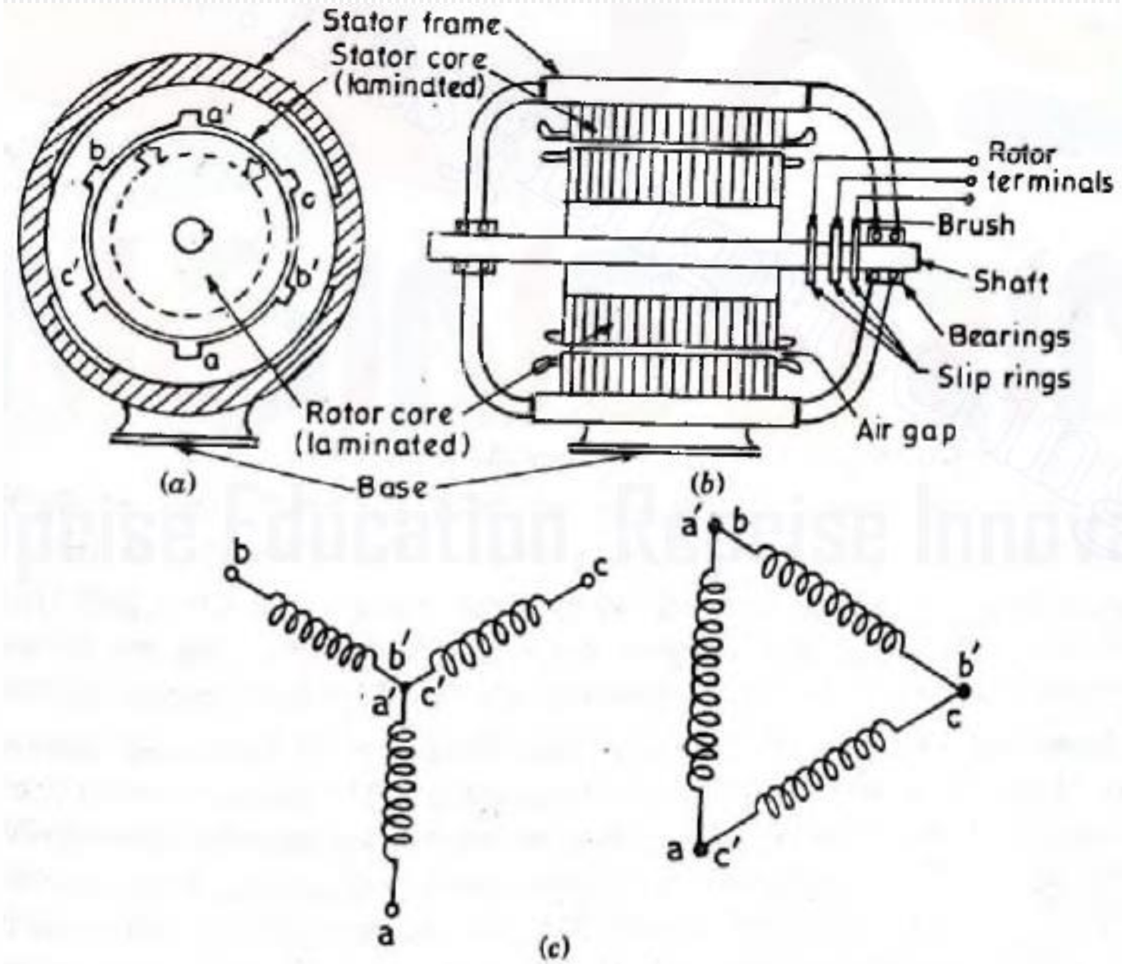
Number	Syllabus	Detailed Syllabus
Lecture VII	Three phase induction motors: principle of operation, types, performance, torque-speed characteristics.	Principle of Operation of Three Phase Induction Motor, Torque Equation, Slip, Condition for maximum Torque.

Constructional details of 3-Phase Induction Motor



Stator

- The stator of induction motor consists of stator frame, stator core, distributed winding, two end covers, bearings etc.
- The stator core is a stack of cylindrical laminations which are slotted along their inner periphery for housing the 3-phase winding.
- The stator core fits closely in the cast iron stator frame.
- The two end convers are made of cast-iron.

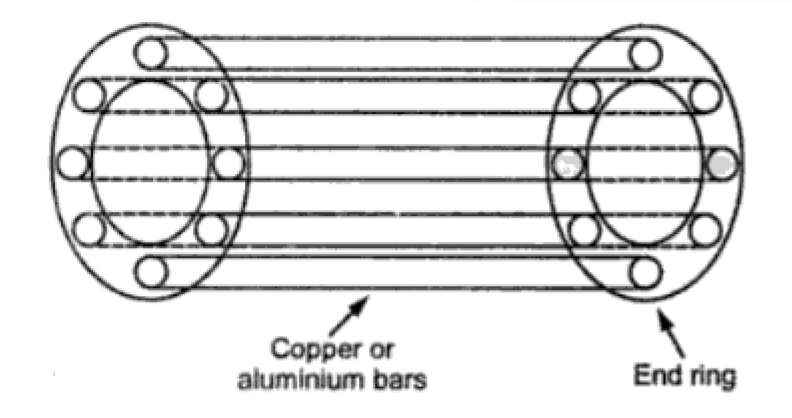
Constructional details of 3-Phase Induction Motor

Rotor

- The induction motor has two types of rotors: Squirrel cage rotor and Slip ring or wound rotor.

Squirrel cage rotor

- The rotor core is cylindrical and slotted on its periphery.
- The rotor consists of uninsulated copper or aluminium bars called rotor conductors.
- The bars are placed in the slots.
- These bars are permanently shorted at each end with the help of conducting copper ring called end ring.



Cage type structure of rotor

Constructional details of 3-Phase Induction Motor

Squirrel cage rotor

- As rotor itself is short circuited, no external resistance can be introduced in the rotor circuit.
- Fan blades are generally provided at the ends of the rotor core.
- This circulates the air through the machine while operation , providing the necessary cooling .
- The air gap between stator and rotor is kept uniform and as small as possible.
- In this type of rotor the slots are not arranged parallel to the shaft axis but are skewed.

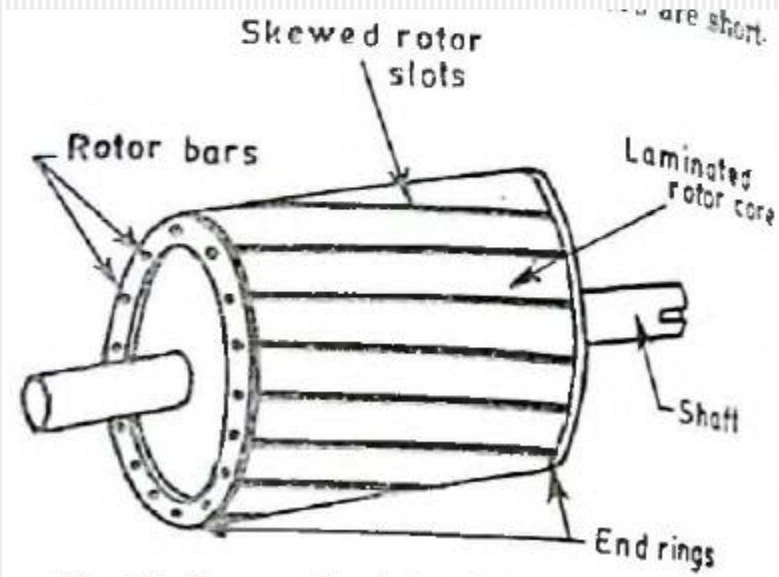


Fig. Skewing in rotor construction

Constructional details of 3-Phase Induction Motor

Squirrel cage rotor

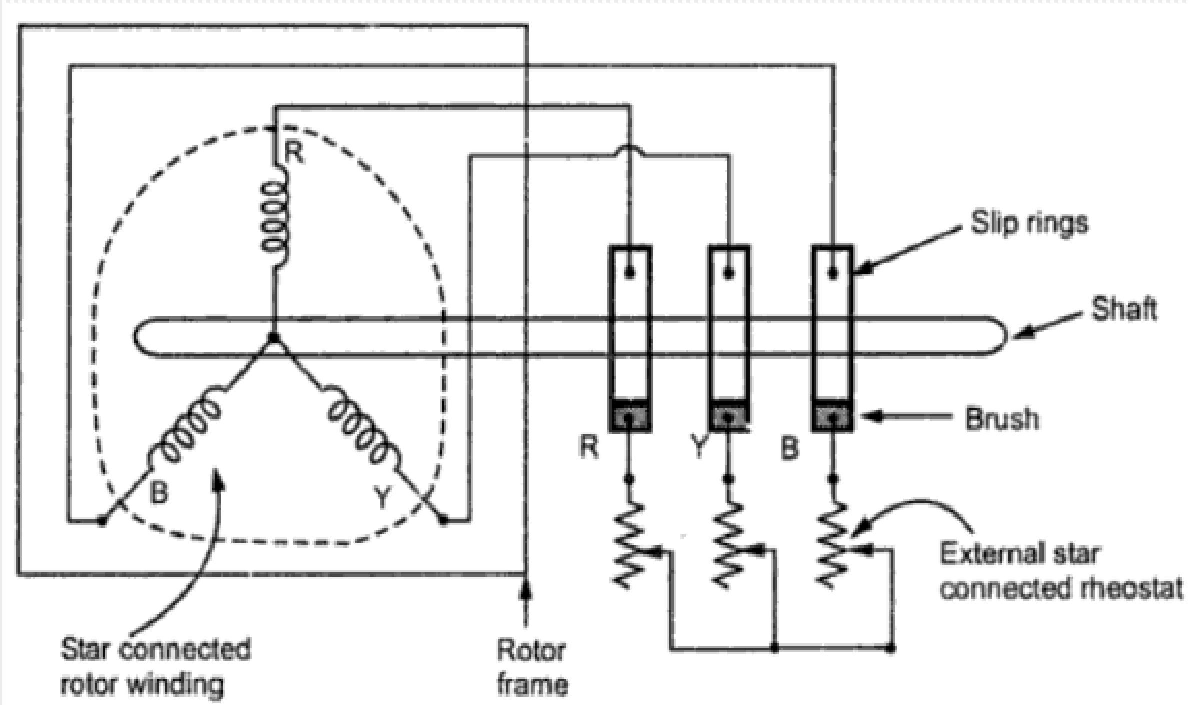
- **The advantages of skewing;**

1. **A magnetic hum gets reduced.**
2. **Smooth motor operation.**
3. **Magnetic locking gets reduced.**

Constructional details of 3-Phase Induction Motor

Slip ring rotor or wound rotor

- In this type of construction, rotor winding is similar to the stator.
- The rotor construction is laminated and slotted. The slots contain the rotor winding.
- The three ends of the three phase winding are permanently connected to the slip rings. The slip rings are mounted on the same shaft.
- The external resistances can be added with the help of brushes and slip ring arrangement in series with each phase of the rotor winding.



Principle of Operation of 3-Phase Induction Motor

- The stator of three phase induction motor is connected to three phase supply.
- The flow of 3-phase currents in the 3-phase stator winding produces a rotating magnetic field.
- The speed of rotating field is the synchronous speed.
- The rotating flux wave cuts the stationary rotor conductors and therefore emfs are induced in the rotor conductor.
- As the rotor circuit is short circuited, these induced emfs give rise to current in the rotor conductors.
- The interaction of these rotor currents with rotating flux wave produces torque in the rotor of a 3-phase induction motor and as a consequence, rotor begins to rotate.

Principle of Operation of 3-Phase Induction Motor

- According to Lenz' s law the developed torque must oppose the flux cutting action.
- This is possible only if the developed torque forces the rotor to rotate in the direction of rotating field.
- The relative speed between rotating flux and rotor conductors is reduced and therefore flux cutting action also gets reduced.
- This shows that rotor must rotate in the direction of rotating magnetic field.
- If the rotor is assumed to run at synchronous speed in the direction of rotating field, then there would be no flux cutting action, no emf in rotor conductors, no current in rotor bars and therefore no developed torque.
- Thus, the rotor of 3-phase induction motor can never attain synchronous speed.

Slip of induction motor

- **Slip:** It is defined as the difference between the synchronous speed (Ns) and actual speed of rotor (N) expressed as the percentage of the synchronous speed.

$$\therefore s = \frac{N_s - N}{N_s}$$

The percentage slip is expressed as

$$s = \frac{N_s - N}{N_s} \times 100$$

- The actual speed of motor (N) can be expressed as

$$N = N_s(1 - s)$$

Performance parameters

➢ **Rotor Frequency:**

The of rotating magnetic field is

$$N_s = \frac{120f}{P} \qquad (1)$$

Where f is the supply frequency and P is the number of poles.

If f_r is the frequency of rotor induced emf in running condition at slip speed $N_s - N$ then there exists a fixed relation between $(N_s - N)$.

From eqn.(1),

$$(N_s - N) = \frac{120f_r}{P} \qquad (2)$$

Dividing Eqn. (2) by Eqn. (1) we get,

$$\frac{(N_s - N)}{N_s} = s = \frac{\frac{120f_r}{P}}{\frac{120f}{P}}$$

$$s = \frac{f_r}{f}$$

$$\therefore f_r = sf$$

Performance parameters

- **Rotor induced EMF:**

Let,

E_2 = Rotor induced e.m.f. per phase on standstill condition

E_{2r} = Rotor induced e.m.f. per phase in running condition

Now $E_2 \propto N_s$ while $E_{2r} \propto N_s - N$

Dividing the two proportionality equations,

$$\frac{E_{2r}}{E_2} = \frac{N_s - N}{N_s} \quad \text{but} \quad \frac{N_s - N}{N_s} = \text{Slip } s$$

$$\therefore \quad \frac{E_{2r}}{E_2} = s$$

$$\therefore \quad \boxed{E_{2r} = s\,E_2}$$

Performance parameters

- **Rotor resistance and reactance:**

Let,

R_2 = Rotor resistance per phase on standstill.

X_2 = Rotor reactance per phase on standstill.

Now at standstill,

$f_r = f$ hence if L_2 is the inductance of rotor per phase,

$$X_2 = 2\pi f_r L_2 = 2\pi f L_2 \ \Omega/\text{ph.}$$

While R_2 = Rotor resistance in Ω/ph.

Performance parameters

➢ Rotor resistance and reactance:

Now in running condition,

$$f_r = sf \quad \text{hence,}$$

$$X_{2r} = 2\pi f_r L_2 = 2\pi f s L_2 = s \cdot (2\pi f L_2)$$

$$\therefore \quad \boxed{X_{2r} = s X_2}$$

Where X_{2r} = Rotor reactance in running condition.

Thus resistance as independent of frequency remains same at standstill and in running condition. While the rotor reactance decreases by slip times the rotor reactance at standstill.

Hence we can write rotor impedance per phase as :

$$Z_2 = \text{Rotor impedance on standstill } (N = 0) \text{ condition}$$

$$= R_2 + j X_2 \quad \Omega/\text{ph}$$

$$\therefore \quad Z_2 = \sqrt{R_2^2 + X_2^2} \quad \Omega/\text{ph} \qquad \text{... Magnitude}$$

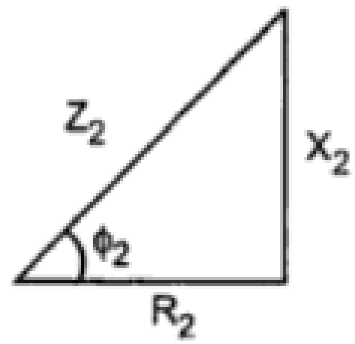
While Z_{2r} = Rotor impedance in running condition.

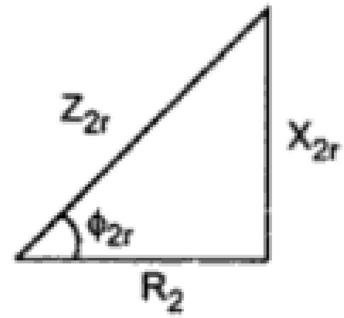
$$= R_2 + j X_{2r} = R_2 + j (s X_2) \quad \Omega/\text{ph}$$

$$\therefore \quad \boxed{Z_{2r} = \sqrt{R_2^2 + (s X_2)^2} \quad \Omega/\text{ph}} \qquad \text{... Magnitude}$$

Performance parameters

➢ **Rotor Power Factor:**





Let,

$\cos\phi_2$ = Rotor power factor on standstill.

$$\therefore \quad \cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + X_2^2}} \quad \text{... At standstill}$$

$\cos\phi_{2r}$ = Rotor power factor in running condition.

$$\therefore \quad \cos\phi_{2r} = \frac{R_2}{Z_{2r}} = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}} \quad \text{... Running}$$

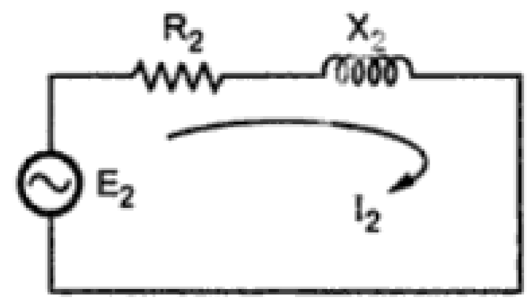
Performance parameters

- **Rotor Current:**

Let I_2 = Rotor current per phase on standstill condition.

The magnitude of I_2 depends on magnitude of E_2 and impedance Z_2 per phase.

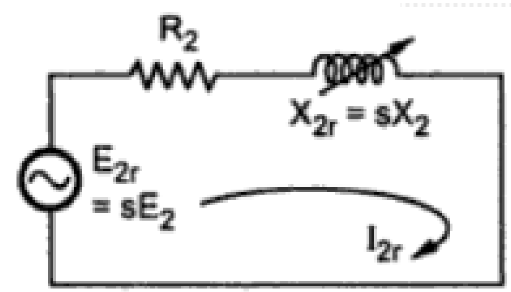
$$I_2 = \frac{E_2 \text{ per phase}}{Z_2 \text{ per phase}} \text{ A}$$



Substituting expression of Z_2 we get,

$$I_2 = \frac{E_2}{\sqrt{R_2^2 + X_2^2}} \text{ A}$$

I_{2r} = Rotor current per phase in running condition



All values are phase

$$I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Torque Equation

➢ **The torque produced in the induction motor can be expressed as**

$$T \propto \emptyset I_{2r} \cos \emptyset_{2r} \quad (1)$$

Where, $\emptyset$ **= Flux,**

I_{2r} **= Rotor current in running condition,**

$\cos \emptyset_{2r}$**= Power factor of rotor in running condition**

$$E_2 \propto \emptyset \quad (2)$$

$$I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{sE_2}{\sqrt{(R_2)^2+(sX_2)^2}} \quad (3)$$

$$\cos \emptyset_{2r} = \frac{R_2}{Z_{2r}} = \frac{R_2}{\sqrt{(R_2)^2+(sX_2)^2}} \quad (4)$$

Substitute equations (2), (3) and (4) in Eqn. (1)

$$T \propto E_2 \times \frac{sE_2}{\sqrt{(R_2)^2+(sX_2)^2}} \times \frac{R_2}{\sqrt{(R_2)^2+(sX_2)^2}} \quad (5)$$

$$T \propto \frac{s.(E_2)^2.R_2}{(R_2)^2+(sX_2)^2} \quad (6)$$

$$T = \frac{ks.(E_2)^2.R_2}{(R_2)^2+(sX_2)^2} \quad (7)$$

Where, k is the proportionality constant = $\frac{3}{2\pi n_s}$

Starting torque

- The torque produced by an induction motor at start is called the starting torque.
- At start, Speed (N) =0 and   Slip (S)=1,
- Substituting S=1 in torque equation, the starting torque is given by

$$T_{st} = \frac{ks.(E_2)^2.R_2}{(R_2)^2+(sX_2)^2}$$

Maximum torque

- Condition for the maximum torque,

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

Where, $T = \frac{ks.(E_2)^2.R_2}{(R_2)^2+(sX_2)^2}$

As both numerator and denominator contains ‘s’ terms, differentiate Torque w.r.t slip using the rule of differentiation (u/v)

Maximum torque

$$\therefore \frac{dT}{ds} = \frac{(k\,s\,E_2^2\,R_2)\frac{d}{ds}(R_2^2 + s^2 X_2^2) - (R_2^2 + s^2 X_2^2)\frac{d}{ds}(k\,s\,E_2^2\,R_2)}{(R_2^2 + s^2 X_2^2)^2} = 0$$

$$\therefore \quad k\,s\,E_2^2\,R_2\,[2s\,X_2^2] - (R_2^2 + s^2 X_2^2)\,(k\,E_2^2\,R_2) = 0$$

$$\therefore \; 2\,s^2\,k\,X_2^2\,E_2^2\,R_2 - R_2^2\,k\,E_2^2\,R_2 - k\,s^2\,X_2^2\,E_2^2\,R_2 = 0$$

$$\therefore \quad k\,s^2\,X_2^2 E_2^2\,R_2 - R_2^2\,k X_2^2\,R_2 = 0$$

$$\therefore \quad s^2 X_2^2 - R_2^2 = 0 \qquad \text{Taking } k\,E_2^2\,R_2 \text{ common.}$$

$$\therefore \quad s^2 = \frac{R_2^2}{X_2^2}$$

$$\therefore \quad \boxed{s = \frac{R_2}{X_2} \qquad \text{Neglecting negative slip}}$$

This is the slip at which the torque is maximum and is denoted as s_m.

$$\therefore \quad \boxed{s_m = \frac{R_2}{X_2}}$$

Maximum torque

- The maximum torque (T_m) can be obtained by substituting $s = \frac{R_2}{X_2}$ in the torque equation,

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

$$\therefore \quad T_m = \frac{k\left(\frac{R_2}{X_2}\right) E_2^2 R_2}{R_2^2 + \left(\frac{R_2}{X_2} X_2\right)^2}$$

$$\therefore \quad \boxed{T_m = \frac{k\, E_2^2}{2X_2} \text{ N-m.}}$$

Torque Ratios

Full load and Maximum torque ratio

In general, $T \propto \dfrac{s E_2^2 R_2}{R_2^2 + (sX_2)^2}$

Let s_f = Full load slip.

$\therefore \quad T_{F.L.} \propto \dfrac{s_f E_2^2 R_2}{R_2^2 + (s_f X_2)^2}$

and s_m = Slip for maximum torque T_m.

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

$$\therefore \quad \frac{T_{F.L.}}{T_m} = \frac{s_f E_2^2 R_2}{[R_2^2 + (s_f X_2)^2]} \times \frac{[R_2^2 + (s_m X_2)^2]}{s_m E_2^2 R_2}$$

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

Dividing both numerator and denominator by X_2^2 we get,

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

But $\dfrac{R_2}{X_2} = s_m$

$$\therefore \quad \frac{T_{F.L.}}{T_m} = \frac{s_f \times 2 s_m^2}{s_m \times [s_m^2 + s_f^2]}$$

$$\therefore \quad \boxed{\frac{T_{F.L.}}{T_m} = \frac{2 s_f s_m}{[s_m^2 + s_f^2]}}$$

Torque Ratios

Starting and Maximum torque ratio

$$T \propto \frac{s E_2^2 R_2}{R_2^2 + (sX_2)^2}$$

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

$$\therefore \quad T_{st} \propto \frac{E_2^2 R_2}{R_2^2 + X_2^2}$$

While for T_m, $s = s_m$

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

$$\therefore \quad \frac{T_{st}}{T_m} = \frac{E_2^2 R_2}{[R_2^2 + X_2^2]} \times \frac{[R_2^2 + (s_m X_2)^2]}{s_m E_2^2 R_2}$$

$$\therefore \quad \frac{T_{st}}{T_m} = \frac{[R_2^2 + (s_m X_2)^2]}{s_m [R_2^2 + X_2^2]}$$

Dividing both numerator and denominator by X_2^2 we get,

$$\therefore \quad \frac{T_{st}}{T_m} = \frac{\left[\frac{R_2^2}{X_2^2} + s_m^2\right]}{s_m \left[\frac{R_2^2}{X_2^2} + 1\right]}$$

Substituting $\frac{R_2}{X_2} = s_m$

Torque Ratios

Starting and Maximum torque ratio

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

Infact using the same method, ratio of any two torques at two different slip values can be obtained.

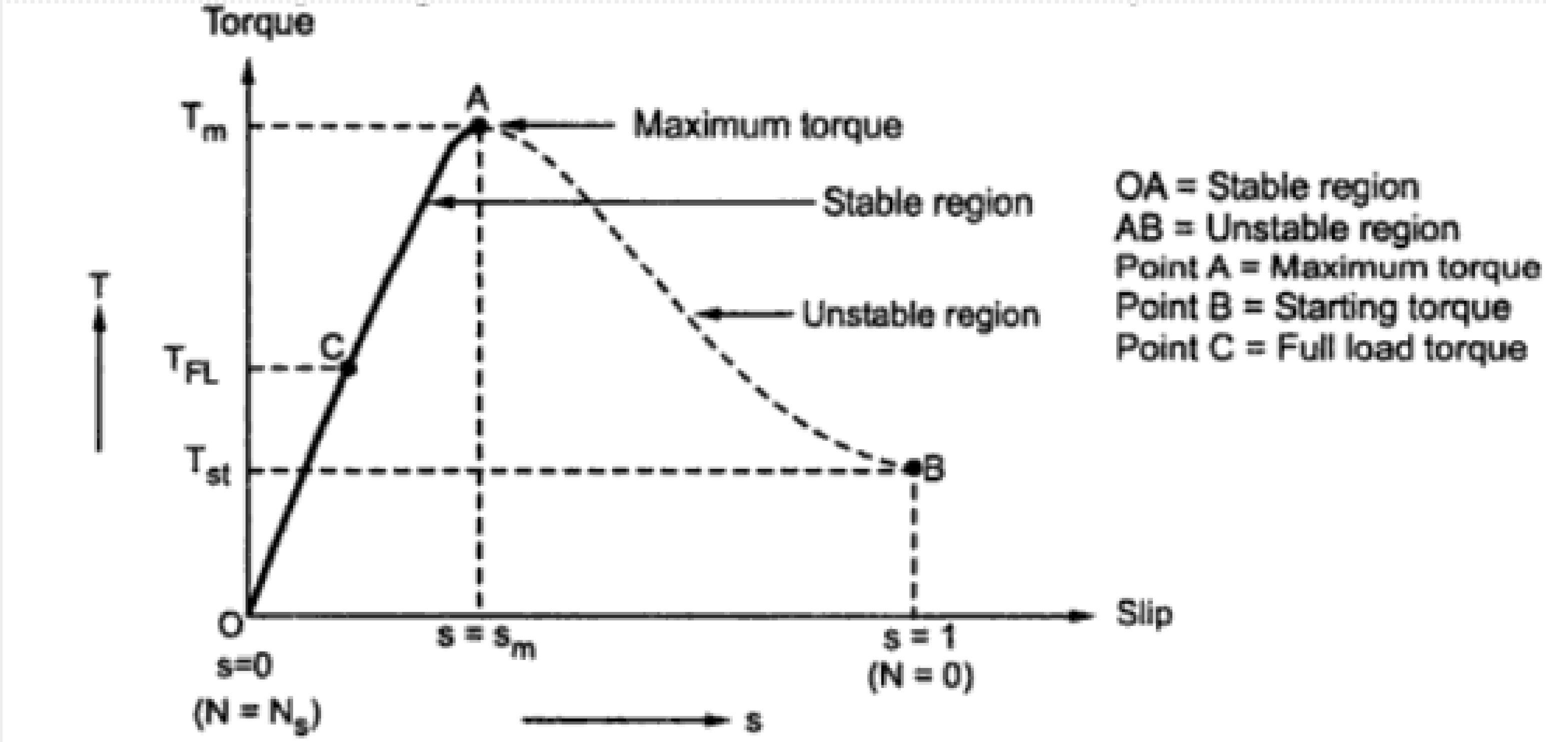
Sometimes using the relation, $R_2 = aX_2$ the torque ratios are expressed interms of constant a as,

$$\frac{T_{F.L.}}{T_m} = \frac{2\,a\,s_f}{a^2 + s_f^2}$$

and $$\frac{T_{st}}{T_m} = \frac{2a}{1+a^2}$$

where $$a = \frac{R_2}{X_2} = s_m$$

Torque-Slip Characteristics



- **Torque-Slip characteristics has two parts,**

1. **Straight line called stable region of operation.**
2. **Rectangular hyperbola called unstable region of operation.**

- **There are two slip regions;**

1. **Low slip region**
2. **High slip region**

Torque-Slip Characteristics

➢ **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.

$$\therefore \quad T \propto \frac{s R_2}{R_2^2} \propto s \quad \text{as } R_2 \text{ is constant.}$$

At $N = N_s$, $s = 0$ hence $T = 0$. As no torque is generated at $N = N_s$, motor stops if it tries to achieve the synchronous speed. Torque increases linearly in this region, of low slip values.

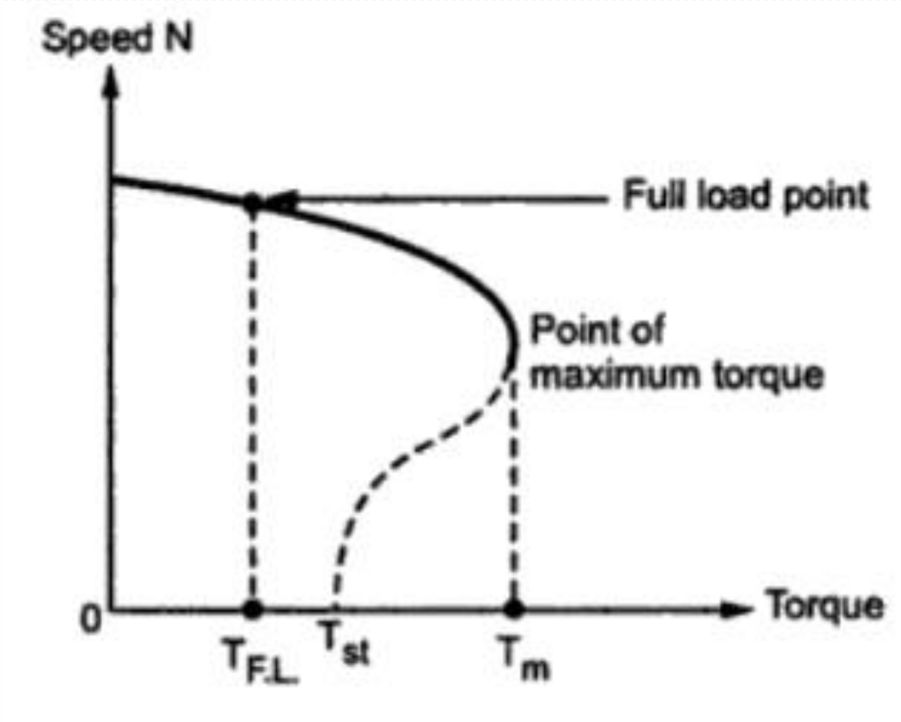
➢ **High slip region:**

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 R_2^2 from the denominator, we get

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

So in high slip region torque is inversely proportional to the slip. Hence its nature is like rectangular hyperbola.

Torque-Speed Characteristics



- At N=Ns, the motor stops as it cannot produce any torque.
- At N=0, the starting condition, motor produces a torque called starting torque.
- For low slip region, i.e speeds near Ns the region is stable and the characteristics is straight line in nature.
- Fall in speed from no-load to full load is about 4 to 6%.

Multiple Choice Questions

1. A 3-phase 440 V, 50 Hz induction motor has 4% slip. The frequency of rotor current will be

   (a) 50 Hz   (b) 25 Hz

   (c) 5 Hz   (d) 2 Hz

Ans: (d)

Explanation:

Frequency of the rotor current is given as $f_r = sf$,

$$f_r = 0.4 \times 50$$

$$= 2\ Hz$$

2. In which of the following region, induction motor operation is stable?

(a) Low Slip region **(b) High slip region**

(c) Any of the two **(d) None of the above**

Ans: (a)

Explanation:

- **For Low slip region "S" is very small therefore the term $S.X_2$ can be neglected and R_2 is constant therefore $T \propto S$.**
- **Hence the graph is in the straight line in nature and this reason is a stable region.**

3. A 4 pole 50 Hz induction motor is running at 1300 rpm. Find the speed of stator magnetic field with respect to the rotor?

(a) 1500 rpm (b)200 rpm

(c) 1300 rpm (d)3000 rpm

Ans: (b)

Explanation:

- The relative speed of an induction motor stator magnetic field with respect to rotor is given as Ns – Nr.

  Ns = 120f/p=120 x 50 / 4 =1500.

- Hence speed of stator magnetic field with respect to rotor is

  Ns – Nr =1500-1300 = 200 rpm

4. If the applied rated voltage per phase is reduced to one-half, then the starting torque of squirrel cage induction motor becomes

(a) 4 times the initial value (b) 2 times the initial value

(c) 1/4 of the initial value (d) 1/2 times the initial value

Ans: (c)

Explanation:

- In an induction, motor torque is proportional to square of the applied voltage, $T \propto V^2$, $T = (V/2)^2$,

  $T = 1/4 \times V^2$

⇒ 1/4 of the initial value

5. **An 8 pole, three phase induction motor is supplied from 50 Hz, a.c. supply. On full load, the frequency of induced EMF in the rotor is 2 Hz. Then the full load slip and the corresponding speed.**

(a) 4% & 750 **(b) 4% & 720**

(c) 5% & 1000 **(d) 5% & 1500**

Ans: (b)

Explanation:

- **Rotor frequency is given as $f_r = sf$, $s = 2/50$, s = 0.04,**

  %s = 0.04 x 100 = 4%

- **Now the corresponding speed i.e rotor speed, N = Ns(1 – s),**

Where Ns = 120f/P = 120 x 50/8 = 750 R.P.M, N = 750(1 – 0.04),

N = 720 R.P.M

6. A 4 pole, 3 phase, 50 Hz induction motor runs at a speed of 1470 r.p.m. speed. Then the frequency of the induced e.m.f. in the rotor under this condition.

(a) 1 Hz **(b) 2 Hz**

(c) 5 Hz **(d) 6 Hz**

Ans: (a)

Explanation:

- **Ns = 120f/P = 120 x 50/4 = 1500 RPM,**
- **Slip of an induction motor,**

  s = (Ns – Nr)/Ns = (1500 – 1470)/1500 = 0.02
- **Now Rotor frequency f_r = sf = 0.02 x 50 = 1 Hz**

7. The rotor current in a 3-phase induction motor is ……. slip.

(a) Directly proportional to

(b) Inversely Proportional to

(c) Independent

(d) None of the above

Ans: (a)

Explanation:

- At normal speed, close to synchronism, sX_2 is very small and may be neglected. Since E_2 and R_2 are fixed, $I_{2r} \propto s$.

8. If the slip of a 3-phase induction motor increases, the p.f. of the rotor circuit is

(a) Decreased

(b) Remain unchanged

(c) Increased

(d) None of the above

Ans: (a)

Explanation:

- **Rotor reactance is a function of rotor frequency an increase in slip causes an increase in rotor frequency and hence the total reactance.**
- **This in turn increases the total impedance Z_2.**
- **Since rotor resistance (R_2) is constant, rotor p.f. is decreased.**

9. If the supply voltage of a 3-phase induction motor is increased two times, then, torque is

(a) Increased 4 times (b) Decreased 4 Times

(c) Increased twice (d) Remain the same

Ans: (a)

Explanation:

- **The torque of the induction motor is directly proportional to the square of the voltage $T \propto V^{2}$.**
- **If the supply voltage is increased by two times then the torque will increase four times $T = 2^2$ or $T = 4$.**

10. For a slip of 0.05, find the ratio of rotor speeds with the motor operating with 4 and 6 poles respectively.

(a) 2.8 (b) 1.5 (c) 3.2 (d) 4.5

Ans: (b)

Explanation:

- **Rotor speed with 4 poles and slip of 0.05 is**

  $N_{r4} = (1 - 0.05) \times 1500 = 1425$ **RPM**

- **Rotor speed with 6 poles and slip of 0.05 is**

  $N_{r6} = (1 - 0.05) \times 1000 = 950$ **RPM**

- **The ratio of rotor speeds of motor operating with 4 and 6 poles is** $N_{r4}/N_{r6} = 1425/950 = 1.5$

11. If the stator voltage of an induction motor is reduced to 50% of its rated value, the torque developed is reduced by ______% of its full load value.

(a) 50 **(b) 25**

(c) 75 **(d) 57.7**

Ans: (c)

Explanation:

- **In an induction, motor torque is proportional to square of the applied voltage , $T \propto V^2$, $T = (0.5V)^2$, $T = 0.25\ V^2$**
  $\Rightarrow$ 1/4 of the initial value or it is reduced by 75% of its full load value

12. **A three phase, 50Hz, 8-pole squirrel cage induction motor run at a speed**

(a) <750rpm

(b) >750 rpm but < 1000rpm

(c) >1000rpm but <1500rpm

(d) >1500rpm

Ans: (a)

Explanation:

- $N_s=120f/P$, $N_s=(120*50)/8=750$ rpm
- Induction motor speed is always less than synchronous speed.

13. The slip ring or wound rotor induction motor find its applications in

(a) lifts, cranes (b) lathes

(c) drilling machines (d) printing machines

Ans: (a)

Explanation:

- High braking torque can also be obtained (slip > 1) easily. Its application therefore is where high starting and braking torque are required as in lifts and cranes. Slip ring motor induction motor can deliver higher starting torque as compared to squirrel cage induction motor.

14. Slip speed of the motor decides the magnitude of the induced emf and the rotor current, which in turn decides the torque produced. If Ns is the synchronous speed and N is the motor speed in rpm, then the slip speed is given by

(a) Ns **(b) Ns – N** **(c) Ns + N** **(d) N – Ns**

Ans: (b)

Explanation:

- **Slip speed is defined as the difference between the synchronous speed (Ns) and actual speed (N).**

15. At start, the slip of the induction motor is

(a) 1 (b) 0

(c) 0.5 (d) None of these

Ans: (a)

Explanation:

- At start, Speed (N) =0
- Slip, $s = \frac{N_s - N}{N_s} = \frac{N_s - 0}{N_s}$
- $\therefore s = 1$

16. A 50 Hz, 3 phase slip ring induction motor, has 6 poles on stator and 4 poles on rotor. Then the machine will run at

(a) 1000 rpm (b) 1500 rpm

(c) 1400 rpm (d) Machine will not run at all

Ans: (d)

Explanation:

- If stator poles and rotor poles are not equal then resultant torque will be zero and motor will not run.

17. Nature of the rotor power factor in running condition is always

(a) Leading

(b) Lagging

(c) Both (a) and (b)

(d) None of these

Ans: (b)

Explanation:

- **The power factor of the induction motor is always lagging because the rotor and the stator winding have inductive impedance.**

18. If a voltmeter when connected to the rotor of an induction motor gives 150 oscillations per minute and stator frequency is 50 Hz. Then the slip of induction motor will be

(a) 3% **(b) 4.5%**

(c) 5% **(d) 5.5%**

Ans: (c)

Explanation:

- **Rotor frequency, *fr =150/60=2.5Hz***
- ***fr=sf, s=fr/f=2.5/50=0.05***
- ***The slip of induction motor is 0.05*100=5%***

19. The nature of the graph in the low slip region and in the high slip region is

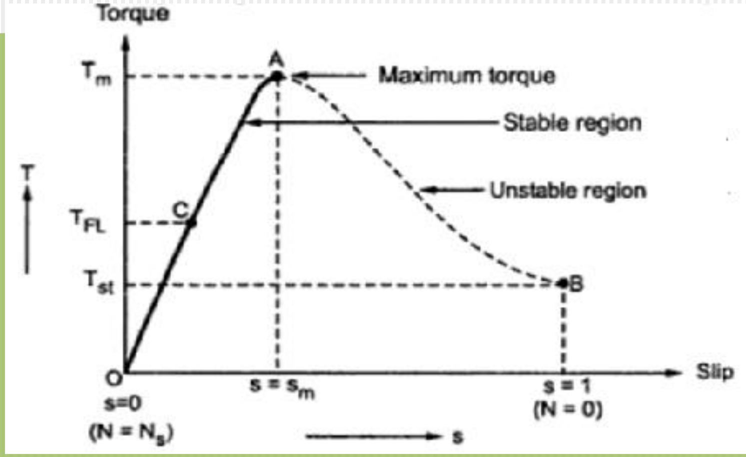
(a) Rising exponential, decaying exponential
(b) Both will be straight line
(c) Straight line, rectangular hyperbola
(d) Straight line, decaying exponential

Ans: (c)

Explanation:

- 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.

- In high slip region torque is inversely proportional to the slip. Hence its nature is like rectangular hyperbola.



20. If an induction motor is operating at a point in the high slip region, then the motor will be

(a) Stable
(b) Unstable
(c) Either stable or unstable depending on the torque
(d) None of these

Ans: (b)

Explanation:

- **In high slip region as T α1/s, torque decreases as slip increases.**
- **But torque must increases to satisfy the load demand. As torque decreases, due to extra loading effect, speed further decreases and slip further 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.**

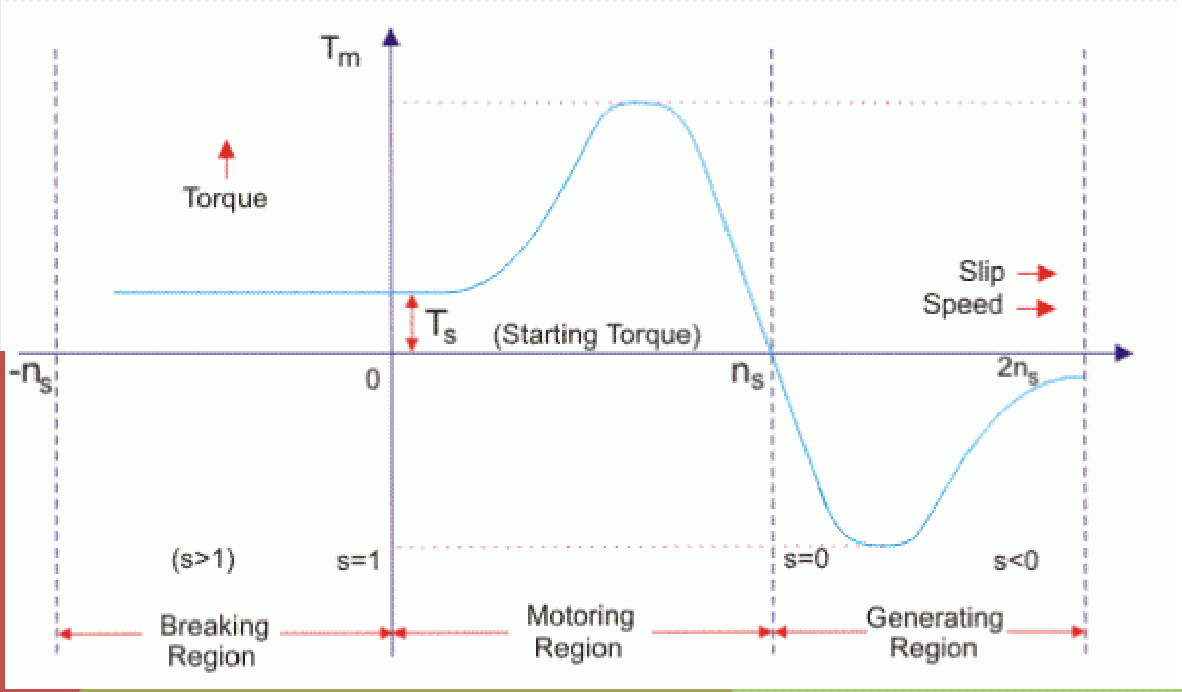
21. The value of slip for motoring, generating and braking region respectively are

(a) S > 1, 0 = s = 1, s < 0 (b) S < 0, 0 = s = 1, s > 1

(c) 0 = s = 1, s > 1, s < 1 (d) 0 = s = 1, s < 0, s > 1

Ans: (d)

Explanation:



Range s = 0 to s = 1 is called motoring region and s<0 is called generating region. The slip s>1 is called the braking region.

22. A 16 pole, 50 Hz, star connected three phase induction motor has rotor resistance of 0.012 ohm per phase and rotor reactance of 0.220 ohm per phase at standstill. Its full load torque is at speed of 220 rpm. Ratio of its starting torque to maximum torque is

(a) 0.1208 (b) 0.1087 (c) 0.1102 (d) 0.1012

Ans: (b)

Explanation:

- $\frac{T_{st}}{T_m} = \frac{2s_m}{1+(s_m)^2}$, Where s_m is the slip at maximum torque, $s_m = \frac{R_2}{X_2} = \frac{0.012}{0.220} = 0.0545$
- $\frac{T_{st}}{T_m} = \frac{2\times 0.0545}{1+(0.0545)^2} = 0.108677$

23. The torque developed in three phase induction motor depends on

(a) stator flux and rotor current
(b) stator flux and stator current
(c) stator current and rotor flux
(d) rotor current and rotor flux

Ans: (a)

Explanation:

- $T \propto \emptyset I_{2r} \cos \emptyset_{2r}$
- **Torque of a three phase induction motor is proportional to flux per stator pole, rotor current and the power factor of the rotor.**

24. An induction motor when loaded from no load to full load, its slip also varies from s = 1 to s = 0. Then the torques in the low slip region and in high slip region is

(a) Both are directly proportional to the slip

(b) Both are inversely proportional to the slip

(c) Directly proportional to the slip, inversely proportional to the slip

(d) Independent of slip, proportional to the slip

Ans: (c)

Explanation:

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.

$$\therefore \quad T \propto \frac{s R_2}{R_2^2} \propto s \quad \text{as } R_2 \text{ is constant.}$$

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 R_2^2 from the denominator, we get

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

25. A 400V, 4 pole, 3 phase, 50 Hz star connected induction motor has a rotor resistance and reactance per phase equal to 0.02 ohm and 0.2 ohm respectively. Then the slip at which maximum torque occurs is

(a) 10% **(b) 20%** **(c) 12.5%** **(d) 15%**

Ans: (a)

Explanation:

$$S_m = \frac{R_2}{X_2} = \frac{0.02}{0.2} = 0.1 = 0.1 * 100 = 10\%$$

26. **When the torque produced by the induction motor is at its maximum, the slip is given by**

(a) X_2 / R_2

(b) $(R_2 + X_2) / X_2$

(c) R_2 / X_2

(d) $R_2 / (R_2 + X_2)$

Ans: (c)

Explanation:

$$\therefore \frac{dT}{ds} = \frac{(k\,s\,E_2^2\,R_2)\,\frac{d}{ds}(R_2^2 + s^2 X_2^2) - (R_2^2 + s^2 X_2^2)\,\frac{d}{ds}(k\,s\,E_2^2\,R_2)}{(R_2^2 + s^2 X_2^2)^2} = 0$$

$$\therefore \quad k\,s\,E_2^2\,R_2\,[2s\,X_2^2] - (R_2^2 + s^2 X_2^2)\,(k\,E_2^2\,R_2) = 0$$

$$\therefore \; 2\,s^2\,k\,X_2^2\,E_2^2\,R_2 - R_2^2\,k\,E_2^2\,R_2 - k\,s^2\,X_2^2\,E_2^2\,R_2 = 0$$

$$\therefore \quad k\,s^2\,X_2^2 E_2^2\,R_2 - R_2^2\,k X_2^2\,R_2 = 0$$

$$\therefore \quad s^2 X_2^2 - R_2^2 = 0 \qquad \text{Taking } k\,E_2^2\,R_2 \text{ common.}$$

$$\therefore \quad s^2 = \frac{R_2^2}{X_2^2}$$

$$\therefore \quad \boxed{s = \frac{R_2}{X_2} \qquad \text{Neglecting negative slip}} \qquad \boxed{s_m = \frac{R_2}{X_2}}$$

27. Stable operation of induction motor can be expected between

(a) 0 to 100% slip

(b) 0 to 50% slip

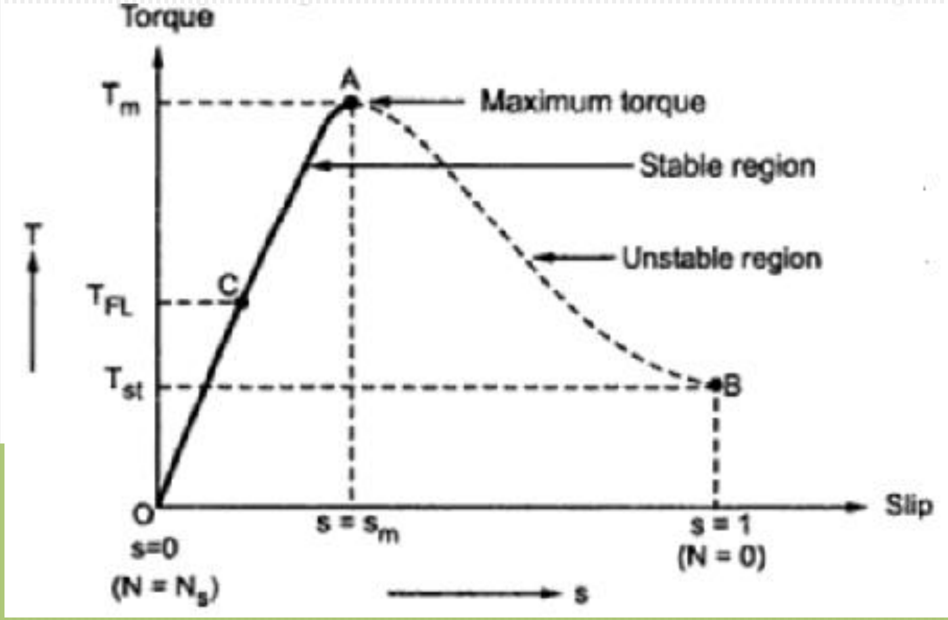
(c) 0 to maximum torque slip

(d) 0 to 1% slip

Ans: (c)

Explanation:

Slip range s = 0 to s = sm is known as stable region of operation. Motor always operates at a point in this region.



28. The rotor of an induction motor cannot run with synchronous speed because

(a) rotor torque would then become zero

(b) Lenz's law would be violated

(c) induction motor would then become synchronous

(d) air friction prevents it from doing so

Ans: (a)

Explanation:

- The torque developed in the rotor is proportional to the Slip.
- If the rotor run at synchronous speed then there will be no difference between the synchronous speed and rotor speed, so the slip will be zero, hence no torque will be developed and the rotor will slow down.

29. A 6-pole induction motor is running from 50Hz supply. The emf in its rotor is of frequency 2.5 Hz. The speed of the motor is

(a) 50 rpm (b) 1000 rpm

(c) 950 rpm (d) 1050 rpm

Ans: (c)

Explanation:

$$N_s = \frac{120 * f}{P} = \frac{120 \times 50}{6} = 1000rpm$$

- *fr=sf, Slip, s=fr/f=2.5/50=0.05*
- $N = N_s(1 - s), N = 1000(1 - 0.05) = 950rpm$

30. **For a three phase, 50Hz, squirrel cage induction motor, rotor leakage reactance at standstill is twice of its resistance. The frequency of the supply at which maximum torque is obtained at starting is**

(a) 50 Hz (b) 25 Hz (c) 100 Hz (d) 75 Hz

Ans: (b)

Explanation:

- Slip at maximum torque $S_m = R_2/X_2$, rotor leakage reactance at standstill is twice of its resistance i.e $X_2 = 2R_2$
- $S_m = R_2/2R_2 = 1/2 = 0.5$, $f = 50*0.5 = 25Hz$

31. **A three-phase, 50 Hz, 4-pole induction motor runs at no-load with a slip of 1%. With full load, the slip increases to 5%. The % speed regulation of the motor (rounded off to 2 decimal places) is____**

GATE 2020

Ans: (4.20 – 4.22)

Explanation:

Sol. Synchronous speed, $N_s = \frac{120f}{P}$

$$N_s = \frac{120 \times 50}{4} \text{rpm}$$

$$N_s = 1500 \text{ rpm}$$

Speed at no-load = $N_s (1 - S_{nL})$

$= 1500 (1 - 0.01)$ rpm

$= 1485$ rpm

Speed at full-load = $N_s (1 - S_{fL})$

$= 1500 (1 - 0.05)$ rpm

$= 1425$ rpm

$$\% \text{ speed regulation} = \frac{N_{NL} - N_{FL}}{N_{FL}} \times 100$$

$$= \frac{1485 - 1425}{1425} \times 100$$

$= 4.21\%$.

32. **The parameter of an equivalent circuit of a three-phase induction motor affected by reducing the rms value of the supply voltage at the rate frequency is**

GATE 2019

(a) magnetizing reactance **(b) rotor leakage reactance**

(c) rotor resistance **(d) stator resistance**

Ans: (b)

Explanation:

$$\downarrow I = \frac{V\downarrow}{z}$$

When voltage alone reduces, the current drawn by Induction Motor reduces, Torque reduces

$$\downarrow \boxed{T_{em} \propto V^2} \downarrow$$

As the torque reduces, slip increases to get steady state operation.

$$\uparrow T_{em} \propto \frac{\uparrow sV^2}{R_2}$$

The change in slip causes change in reactance of rotor

$$\because X_{2r} = sX_2$$

33. A 3-phase, 4-pole, 400 V, 50 Hz squirrel-cage induction motor is operating at a slip of 0.02. The speed of the rotor flux in mechanical rad/sec, sensed by a stationary observer, is closest to

GATE 2017

(a) 1500 (b) 1470 (c) 157 (d) 154

Ans: (c)

Explanation:

$3-\phi$ S.C.I.M

$4-P$ $s = 0.02$

$400V$ $\phi_r \Rightarrow N_r$

Rotor flux speed is same as stator flux speed.

$$N_s = \frac{120 \times 50}{4} = 1500$$

$$W_s = \frac{2\pi N}{60} = \frac{2\pi \times 1500}{60} = 157.08 \text{ rad/sec}$$

34. **A 220 V, 3-phase, 4-pole, 50 Hz inductor motor of wound rotor type is supplied at rated voltage and frequency. The stator resistance, magnetizing reactance, and core loss are negligible. The maximum torque produced by the rotor is 225% of full load torque and it occurs at 15% slip. The actual rotor resistance is 0.03 /phase. The value of external resistance (in Ohm) which must be inserted in a rotor phase If the maximum torque is to occur at start is ______**

Ans: 0.17Ω

GATE 2015

Explanation:

Maximum torque is produced at 15% slip. So, we have

$$s_m = \frac{r_2}{x_2}$$

$$0.15 = \frac{r_2}{x_2}$$

$$0.15 = \frac{0.03}{x_2}$$

$$x_2 = 0.2\,\Omega$$

Now, it is required to have maximum torque at starting, i.e.

$$T_{st} = T_{max}$$

Since,

$$\frac{T_{st}}{T_m} = \frac{2s_m}{s_m^2+1}$$

So, $$s_m^2 + 1 = 2s_m \qquad (T_{st}/T_m = 1)$$

$$(s_m - 1)^2 = 0$$

$$s_m = 1$$

or $$\frac{r_2'}{x_2} = 1$$

Hence, $$r_2' = x_2 = 0.2\,\Omega$$

Thus, the value of external resistance, to be added, is

$$r_2' - r_2 = 0.2 - 0.03 = 0.17\,\Omega$$

35. An 8-pole, 3-phase, 50 Hz induction motor is operating at a speed of 700 rpm. The frequency of the rotor current of the motor in Hz is ______. **GATE 2014**

Ans: 3.33Hz

Explanation:

For the given induction motor, we have

$$P = 8,\ f = 50\,\text{Hz},\ N_r = 700\ \text{rpm}$$

So, we obtain

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{8} = 750\ \text{rpm}$$

Therefore, the slip

$$s = \frac{N_s - N_r}{N_s} = \frac{750 - 700}{750}$$

$$= \frac{1}{15}$$

Thus, the frequency of rotor current of the motor is obtained as

$$\text{Frequency of rotor current} = s \times f$$

$$= \frac{1}{15} \times 50 = 3.33\ \text{Hz}$$

36. **A 3-phase, 50 Hz, six pole induction motor has a rotor resistance of 0.1W and reactance of 0.92W . Neglect the voltage drop in stator and assume that the rotor resistance is constant. Given that the full load slip is 3%, the ratio of maximum torque to full load torque is** **GATE 2014**

(a) 1.567 **(b) 1.712** **(c) 1.948** **(d) 2.134**

Ans: (c)

Explanation:

For the induction motor, we have

$$T_f \text{ (Full load torque)} \propto \frac{s_f R_2}{R_2^2 + (s_f X_2)^2}$$

or $$T_{max} (\text{max}^m \text{ torque}) \propto \frac{1}{2X_2}$$

So, we get

$$\frac{T_f}{T_{max}} = \frac{2 s_f R_2 X_2}{R_2^2 + (s_f X_2)^2}$$

or $$\frac{T_f}{T_{max}} = \frac{2}{\frac{s_{max}}{s_f} + \frac{s_f}{s_{max}}}$$

Now, the slip at full load is 3%, i.e.

$$s_f = 0.003$$

and $$s_{max} = \frac{R_2}{X_2} = \frac{0.1}{0.92} = 0.108$$

Substituting these values in equation (i), we get

$$\frac{T_f}{T_{max}} = \frac{2}{\frac{0.108}{0.03} + \frac{0.03}{0.108}}$$

or $$\frac{T_{max}}{T_f} = \frac{3.623 + 0.276}{2}$$

or $$\frac{T_{max}}{T_f} = 1.948$$

37. A 4-pole induction motor, supplied by a slightly unbalanced three-phase 50 Hz source, is rotating at 1440 rpm. The electrical frequency in Hz of the induced negative sequence current in the rotor is **GATE 2013**

(a) 100 **(b) 98** **(c) 52** **(d) 48**

Explanation:

Ans: (b)

Given,

frequency of source, $f = 50\text{ Hz}$

no. of poles $P = 4$

rotating speed $N = 1440\text{ rpm}$

Now, the synchronous speed is determined as

$$N_s = \frac{120f}{P}$$

$$= \frac{120}{4}(50) = 1500\text{ rpm}$$

So, the slip in the motor is

$$S = \frac{N_s - N}{N_s}$$

$$= \frac{1500 - 1440}{1500} = 0.04$$

Now, the electrical frequency of the induced negative sequence current in rotor is obtained as

$$f_b = (2 - 5)f$$

where f is stator frequency given as $f = 50\text{ Hz}$.

Therefore, $f_b = (2 - 0.04)50 = 98\text{ Hz}$

38. The slip of an induction motor normally does not depend on

(a) rotor speed **(b) synchronous speed**

(c) shaft torque **(d) core-loss component**

GATE 2012

Ans: (d)

Explanation:

Slip is given as

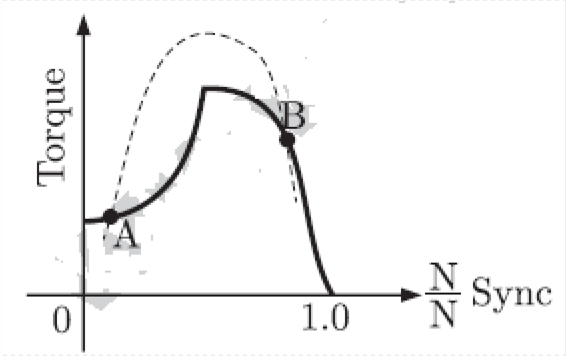
$$S = \frac{n_s - n}{n_s}$$

where, n_s = synchronous speed

n = rotor speed

Thus, slip depend on synchronous speed and the rotor speed. Also, torque increases with increasing slip up to a maximum value and then decreases. Slip does not depend on core loss component.

39. **A 3-phase squirrel cage induction motor supplied from a balanced 3-phase source drives a mechanical load. The torque-speed characteristics of the motor(solid curve) and of the load(dotted curve) are shown. Of the two equilibrium points A and B, which of the following options correctly describes the stability of A and B ?** **GATE 2009**



(a) A is stable, B is unstable **(b) A is unstable, B is stable**
(c) Both are stable **(d) Both are unstable**

Explanation:

Ans: (a)

At point A if speed ↑, Torque ↑
speed ↓, Torque ↓
So A is stable.
At point B if speed ↑ Load torque ↓
So B is un-stable.
Hence (A) is correct option.

40. A three-phase squirrel cage induction motor has a starting torque of 150% and a maximum torque of 300% with respect to rated torque at rated voltage and rated frequency. Neglect the stator resistance and rotational losses. The value of slip for maximum torque is

(a) 13.48% (b) 16.42% (c) 18.92% (d) 26.79%

GATE 2007

Ans: (d)

Explanation:

Given a 3-ϕ squirrel cage induction motor starting torque is 150% and maximum torque 300%

So

$$T_{Start} = 1.5\,T_{FL}$$
$$T_{max} = 3\,T_{FL}$$

Then

$$\frac{T_{Start}}{T_{max}} = \frac{1}{2} \qquad \ldots(1)$$

$$\frac{T_{Start}}{T_{max}} = \frac{2S_{max}}{S^2_{max} + 1^2} \qquad \ldots(2)$$

from equation (1) and (2)

$$\frac{2S_{max}}{S^2_{max} + 1} = \frac{1}{2}$$

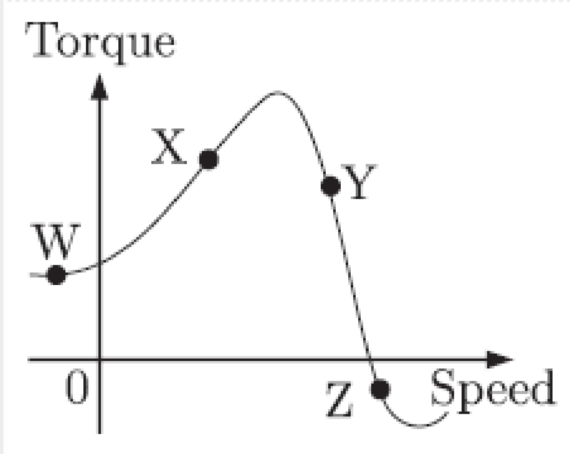
$$S_{max}{}^2 - 4S_{max} + 1 = 0$$

So

$$S_{max} = 26.786\%$$

41. On the torque/speed curve of the induction motor shown in the figure four points of operation are marked as W, X, Y and Z. Which one of them represents the operation at a slip greater than 1 ?

GATE 2005



(a) W **(b) X**
(c) Y **(d) Z**

Ans: (a)

Explanation:

When the speed of the motor is in forward direction then slip varies from 0 to 1 but when speed of motor is in reverse direction or negative then slip is greater then 1. So at point W slip is greater than 1.

42. The direction of rotation of a 3-phase induction motor is clockwise when it is supplied with 3-phase sinusoidal voltage having phase sequence A-B-C. For counter clockwise rotation of the motor, the phase sequence of the power supply should be GATE 2004

(a) B-C-A (b) C-A-B

(c) A-C-B (d) B-C-A or C-A-B

Ans: (c)

Explanation:

- Given that if 3-f induction motor is rotated in clockwise then the phase sequence of supply voltage is A-B-C. In counter clock wise rotation of the motor the phase sequence is change so in the counter clockwise rotation the phase sequence is A-C-B.

43. A 400 V, 15 kW, 4-pole, 50Hz, Y-connected induction motor has full load slip of 4%. The output torque of the machine at full load is

GATE 2004

(a) 1.66 Nm **(b) 95.50 Nm**

(c) 99.47 Nm **(d) 624.73 Nm**

Ans: (c)

Explanation:

Given $V = 400$ V, 15 kW power and $P = 4$

$$f = 50 \text{ Hz, Full load slip } (S) = 4\%$$

So

$$N_s = \frac{120f}{P}$$

$$= \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

$$\text{Actual speed} = \text{synchronous speed} - \text{slip}$$

$$N = 1500 - \frac{4}{100} \times 1500$$

$$= 1440 \text{ rpm}$$

Torque developed

$$T = \frac{P}{\omega_s(1-S)}, \qquad \text{where } \omega_s(1-S) = \frac{2\pi N}{60}$$

$$= \frac{15 \times 10^3 \times 60}{2\pi \times 1440}$$

$$= 99.47 \text{ Nm}$$

44. If a 400V, 50Hz, star connected, 3-phase squirrel cage induction motor is operated from a 400V, 75Hz, the torque that the motor can now provide while drawing rated current from the supply?

(a) reduces (b) increases (c) remains the same

(d) increase or reduces depending upon the rotor resistance

Ans: (a) **GATE 2002**

Explanation:

The given induction motor is designed for 400 V, 50 Hz. When it is connected to 400, 75 Hz supply, then speed of motor increases, as it's clear from

$\left[n = \frac{2f}{P}\right]$, then the slip of the rotor increased

Torque, $T_e = \frac{3}{w_s} \cdot I_2^2 \frac{r_2}{s}$

As the slip increases, T_e decreases

45. If an induction machine is run at above synchronous speed it acts as

(a) a synchronous motor

(b) an induction generator

(c) an induction motor

(d) none of the above

GATE 1997

Ans: (b)

Explanation:

- **When an induction machine is made to run above synchronous speed by using a prime mover, it can works as induction generator.**

46. Induction motor can be regarded as a generalized transformer due to certain similarities except rated **IES/ESE 2020**

(a) Frequency **(b) Flux**

(c) Speed **(d) Induced e.m.f**

Ans: (c)

- Induction motor is a generalized transformer. Difference is that transformer is an alternating flux machine while induction motor is rotating flux machine.

47. A 3-phase, 400/200 V, Y-Y connected wound-rotor induction motor has 0.06 Ω rotor resistance and 0.3 Ω standstill reactance per phase. To make the starting torque equal to the maximum torque, the additional resistance required in the rotor circuit will be **IES/ESE 2020**

(a) 0.24 Ω/phase **(b) 0.34 Ω/phase**

(c) 0.42 Ω/phase **(d) 0.52 Ω/phase**

Ans: (a)

Explanation:

For, max starting torque, $R_2 = X_2$, $R_2 + R_{ext} = X_2$, $\therefore R_{ext} = 0.3 - 0.06 = 0.24$ **Ω/phase**

48. A 500hp, 6-pole, 3-phase, 440V, 50Hz induction motor has a speed of 950 rpm on full load. The full load slip and the number of cycles the rotor voltage makes per minutes will be respectively

IES/ESE 2019

(a) 10% and 150
(b) 10% and 125
(c) 5% and 150
(d) 5% and 125

Ans: (c)

Explanation:

$$N_s = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

Full load speed given as 950 rpm

$$\therefore \quad \% \text{ slip} = \frac{N_s - N}{N_s} \times 100 = \left(\frac{1000 - 950}{1000}\right) \times 100$$

$$= 0.05 \times 100 = 5\%$$

Rotor voltage frequency:

$$s \times f = 0.05 \times 50 = 2.5 \text{ Hz}$$

2.5 cycles/sec.

$\Rightarrow$ 2.5 × 60 cycles/min. = 150 cycles/min.

49. A 3-phase induction motor drives a blower where load torque is directly proportional to speed squared. If the motor operates at 1450 rpm, the maximum current in terms of rated current will be nearly

(a) 2.2 (b) 3.4

(c) 4.6 (d) 6.8

IES/ESE 2019

Ans: (a)

Explanation:

$$T_{em} = KI_2^2 \frac{R_2}{s}$$

$$T_L \propto N_r^2 \propto N_s(1-s)^2 \propto (1-s)^2$$

$$\frac{I_2^2 R_2}{s} \propto (1-s)^2$$

$$I_2 = \sqrt{s}\,(1-s)$$

$$I_1 \propto I_2 \quad [\because \text{ Not considering stator impedance and no load current}]$$

$$I_1 \propto \sqrt{s}\,(1-s)$$

For slip at maximum current, $\frac{dI_1}{ds} = 0$

$$\Rightarrow \quad \frac{d}{ds}[\sqrt{s}\,(1-s)] = 0$$

$$= \frac{d}{ds}(\sqrt{s} - s^{3/2}) = \frac{1}{2}\sqrt{s} - \frac{3}{2}\sqrt{s} = 0$$

$$\frac{1}{2}\sqrt{s} = \frac{3}{2}\sqrt{s}$$

Slip at maximum current,

$$s = \frac{1}{3}$$

$$s = \frac{1500-1450}{1500} = 0.0333$$

$$\therefore \quad \frac{I_{max}}{I_{1fl}} = \frac{\sqrt{\frac{1}{3}}\left(1-\frac{1}{3}\right)}{\sqrt{0.0333}\,(1-0.0333)} = 2.2$$

50. When the value of slip of an induction motor approaches zero, the effective resistance

IES/ESE 2018

(a) is very low and the motor is under no-load

(b) of the rotor circuit is very high and the motor is under no-load

(c) is zero

(d) of the rotor circuit is infinity and the motor is equivalent to short-circuited two-winding transformer

Explanation:

Ans: (b)

Effective resistance of rotor is given as $\frac{R_{20}}{s}$

Where R_{20} = standstill rotor resistance

s = slip

Under no load, slip $\approx$ 0

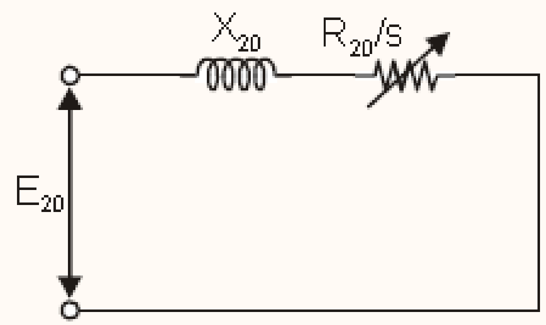
As the load on motor increases, rotor speed decreases, hence slip increases,.

Therefore,

As s approaches to zero, $\frac{R_{20}}{s} \approx \infty$

and motor is under no load

By observing the rotor equivalent circuit at line frequency.



as slip approaches zero, $\frac{R_{20}}{s} \simeq \infty$ and secondary i.e. rotor winding acts as open circuit.

51. A 4-pole, 50 Hz, 3-phase induction motor with a rotor resistance of 0.25Ω develops a maximum torque of 25 N.m at 1400 rpm. The rotor reactance X_2 and slip at maximum torque $S_{max,T}$ respectively would be

(a) 2.0 *and* $\frac{1}{15}$ (b) 3.75 *and* $\frac{1}{12}$

(c) 2.0 *and* $\frac{1}{12}$ (d) 3.75 *and* $\frac{1}{15}$

Ans: (d) **IES/ESE 2018**

Explanation:

For given $3-\phi$ IM

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

Given that, at maximum torque condition,

N_r (rotor speed) = 1400 rpm

$$s_m = \frac{N_s - N_r}{N_s} = \frac{1500 - 1400}{1500} = \frac{1}{15}$$

Also, at maximum torque condition.

$$R_2 = s_m X_2$$

$$\therefore\ 0.25 = \frac{1}{15} X_2$$

or $X_2 = 15 \times 0.25 = 3.75\,\Omega$

or $\boxed{X_2 = 3.75\,\Omega}$

52. In an induction motor for a fixed speed at constant frequency

(a) Both line current and torque are proportional to voltage
(b) Both line current and torque are proportional to the square of voltage
(c) Line current is proportional to voltage and torque is proportional to the square of voltage
(d) Line current is constant and torque is proportional to voltage

IES/ESE 2018

Ans: (c)

Explanation:

In induction motor

$$I_2 = \frac{sE_{20}}{R_{20} + jsX_{20}} = s\left(\frac{Te_2}{Te_1}\right)E_1 \times \frac{1}{R_{20} + jsX_{20}}$$

$$\left(\because E_{20} = \frac{Te_2}{Te_1}E_1\right)$$

or $I_2 \propto E_1$

$$\tau_d = \frac{kE_1^2 sR_2}{R_2^2 + s^2X_{20}^2}$$

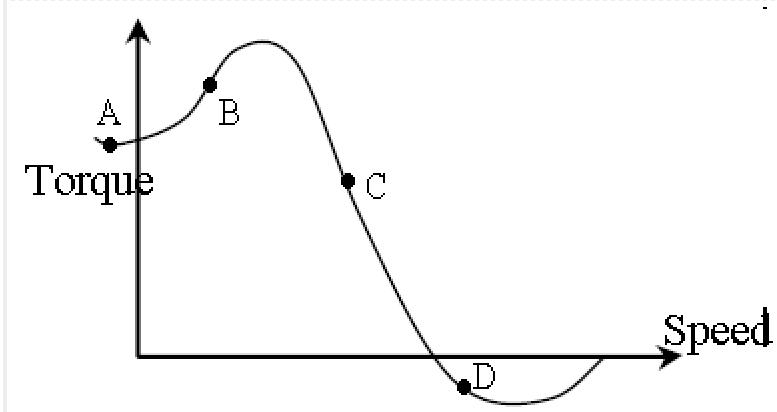
where $K = \frac{3}{2\pi n_s}\left(\frac{Te_2}{Te_1}\right)^2$ = constant for fixed speed.

$\therefore \tau_d \propto E_1^2$

Note : At constant frequency, value of X remains constant.

53. On the Torque/speed curve of an induction motor shown in the figure, four points of operation are marked as A,B,C and D. Which one of them represents the operation at a slip greater than 1?

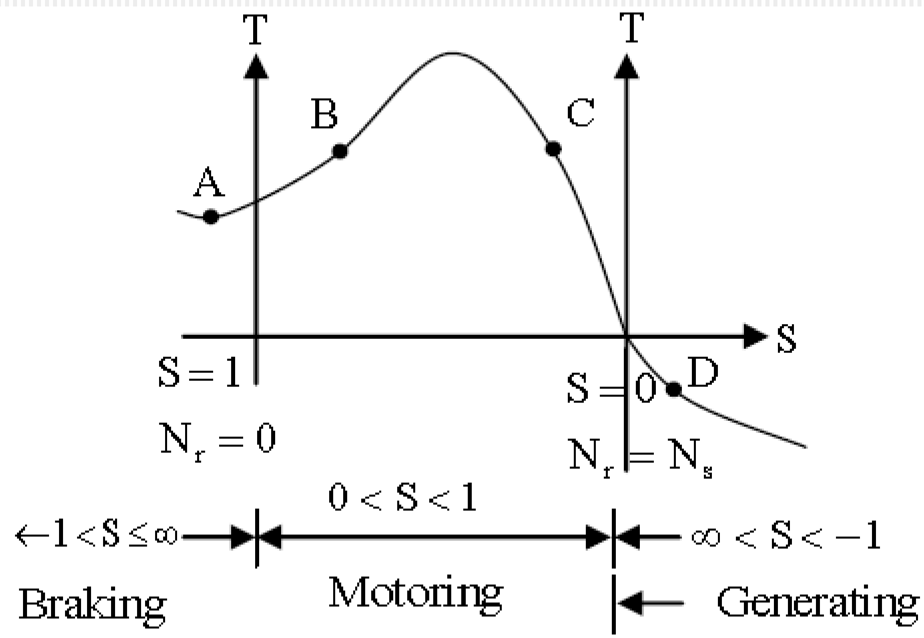
IES/ESE 2017



(a) A **(b) B** **(c) C** **(d) D**

Ans: (a)

Explanation:



At point 'A' Rotor rotates in opposite to R.M.F. Therefore the Relative speed is

$$S = \frac{N_S - (-N_r)}{N_s} = \frac{N_S + N_r}{N_r} > 1$$

54. Increasing the air-gap of a squirrel-cage induction motor would result in

IES/ESE 2017

(a) Increase in no-load speed

(b) Increase in full-load power-factor

(c) Increase in magnetizing current

(d) Maximum available torque

Ans: (c)

Explanation:

- **Increase in air gap results in more reluctance and hence the motor draws large Magnetising current to set up a constant Rotating Magnetic field.**

55. What is the material of slip-rings in an induction machine?

IES/ESE 2016

(a) Carbon **(b) Nickel**

(c) Phosphor bronze **(d) Manganese**

Ans: (c)

Explanation:

'Phosphor bronze' is used to make slip rings. Slip rings will provide the path for current from stationary device to dynamic device and Vice – Versa.

56. If a 3-phase slip ring induction motor is fed from the rotor side with stator winding short circuited, then frequency of currents flowing in the short circuited stator is **IES/ESE 2016**

(a) Slip x frequency **(b) Supply frequency**

(c) Frequency corresponding to rotor speed **(d) Zero**

Ans: (a)

Explanation:

By means of Mutual induction and to satisfy lenz's law the frequency of e.m.f. in stator will be $s \times frequency$.

57. The frequency of rotor emf of an 8-pole induction motor is 2 Hz. If the supply frequency is 50 Hz, then the motor speed is

IES/ESE 2015

(a) 1500 rpm **(b) 750 rpm**

(c) 375 rpm **(d) 720 rpm**

Ans: (d)

Explanation:

$$N_s = \frac{120f}{p} = \frac{120 \times 50}{8} = 750 \text{ rpm}$$

$$s = \frac{N_s - N}{N_s} \Rightarrow \frac{2}{50} = \frac{750 - N}{750} \Rightarrow N = 720 \text{ rpm}$$

58. A 15 kW, 400 V, 4-pole, 50Hz, star connected 3-phase induction motor has full load slip of 4%. The output torque of the machine at full load is IES/ESE 2012

(a) 1.66 Nm (b) 95.5 Nm (c) 99.47 Nm (d) 624.73 Nm

Ans: (c)

Explanation:

$$\text{Power output (P)} = \frac{2\pi NT}{60}$$

$$T = \frac{P \times 60}{2\pi N}$$

$$T = \frac{P \times 60}{2\pi N}$$

$$N_S = \frac{120 \times 50}{4} = 1500\text{rpm}$$

$$N = N_S(1-s) = 1500(1-0.04) = 1440 \text{ rpm}$$

$$T = \frac{15 \times 10^3 \times 60}{2\pi \times 1440} = 99.47 \text{ N} - \text{m}$$

59. The rotor frequency of a 3-phase, 5 kW, 400V, 50Hz, 4-pole slip ring induction motor is 25 Hz. The speed of the motor when connected to a 400 volt, 50 Hz supply will be

IES/ESE 2012

(a) 1500 rpm (b) 1000 rpm

(c) 750 rpm (d) zero

Ans: (c)

Explanation:

- $N_s = \frac{120 \times f}{P} = \frac{120 \times 50}{4} = 1500 rpm$
- S=fr/f=25/50=0.5, $N = N_s(1 - s), N = 1500(1 - 0.5) = 750 rpm$

60. The power factor of an induction motor operating at no load wi11 have a value around **IES/ESE 2010**

(a) 0.9 lag (b) 0.2 lead

(c) 0.2 lag (d) 0.9 lead

Ans: (c)

Explanation:

- At no load, an induction motor draws a large magnetizing current and a small active component to meet the no-load losses. Therefore, the induction motor takes a high no-load current lagging the applied voltage by a large angle. Hence the power factor of an induction motor on no load is low i.e., from 0.1 to 0.2 lagging

61. What is the ratio of starting torque and maximum torque of a 3 phase, 50 Hz, 4 pole induction motor for a maximum torque at 1200 rpm?

IES/ESE 2009

(a) 0.421 (b) 0.384 (c) 0.6 (d) 0.5

Ans: (b)

Explanation:

- $N_s = \frac{120 \times f}{P} = \frac{120 \times 50}{4} = 1500 rpm$, $s = \frac{N_s - N}{N_s} = \frac{1500 - 1200}{1500} = 0.2$
- $\frac{T_{st}}{T_m} = \frac{2 \times s}{1 + (s)^2} = \frac{2 \times 0.2}{1 + (0.2)^2} = 0.3846$

62. An induction motor having 8-poles runs at 727.5 rpm. If the supply frequency is 50 Hz, the emf in the rotor will have a frequency **IES/ESE 2003**

(a) 1.5Hz (b) 48.5 Hz (c) 51.5 Hz (d) 75 Hz

Ans: (a)

Explanation:

- $N_s = \frac{120 \times 50}{8} = 750 rpm, \quad s = \frac{N_s - N}{N_s} = \frac{750 - 727.5}{750} = 0.03$
- $f_r = sf = 0.03 * 50 = 1.5\ Hz$

63. The absolute speed of the magnetic field in space of 3-phase rotor fed induction motor is **IES/ESE 1996**

(a) synchronous speed, Ns (b) rotor speed, Nr

(c) (Ns-Nr) (d) Ns+Nr

Ans: (c)

Explanation:

- Slip speed = Ns-Nr

64. A voltmeter gives 120 oscillations per minute when connected to the rotor of an induction motor. The stator frequency is 50Hz. The slip of the motor is **IES/ESE 1995**

(a) 2% (b) 2.5%

(c) 4% (d) 5%

Ans: (c)

Explanation:

- $f_r = \frac{120}{60} = 2Hz, \quad f_r = sf, \; s = \frac{f_r}{f} = \frac{2}{50} = 0.04$
- The slip of the motor is 0.04*100=4%

Assignment problems

1. In a 3-phase induction machine, motoring, generating and braking operations takes place in the range of slip “S” is

    (a) 1>S>0, 0>S>-2 and S>1

    (b) S>1, 1>S>-1 and 0>S>-1

    (c) S>1, 0>S>-1 and 1>S>0

    (d) 0>S>-1, S>1 and 1>S>0

2. **A 4-pole, 3-phase induction motor is supplied from 50Hz supply. Determine its synchronous speed. On full load, its speed is observed to be 1440 rpm. Its full load slip is.**

   (a) 0.01 **(b) 0.04**

   (c) 0.02 **(d) 0.15**

3. A 4-pole, 3-phase, 50Hz, star connected induction motor has full load slip of 5%. Full load speed of the motor is

(a) 1440 rpm (b) 1425 rpm

(c) 1500 rpm (d) 950 rpm

4. A 4-pole, 3-phase, 50Hz, induction motor runs at a speed of 1440rpm. The frequency of the induced e.m.f in the rotor under this condition is

(a) 2 Hz (b) 1.5Hz

(c) 50Hz (d) 1Hz

5. A 24 pole, 50Hz, star connected induction motor has rotor resistance of 0.016Ω per phase and rotor reactance of 0.265Ω per phase at standstill. It is achieving its full load torque at speed of 247 rpm. The ratio of full load torque to maximum torque is

(a) 0.3824 **(b) 0.1203**

(c) 0.7648 **(d) 0.2406**

6. **Rotor resistance and standstill reactance per phase of a 3-phase induction motor are 0.04Ω and 0.2Ω respectively. What would be the external resistance required at start in rotor circuit to obtain maximum torque at start**

(a) 0.16Ω (b) 1.6Ω

(c) 0.0135Ω (d) 0.008Ω

Thank You
For Your Attention

For any queries/clarifications/suggestions...feel free to contact through...

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Solutions for Assignment problems

1. In a 3-phase induction machine, motoring, generating and braking operations takes place in the range of slip "S" is

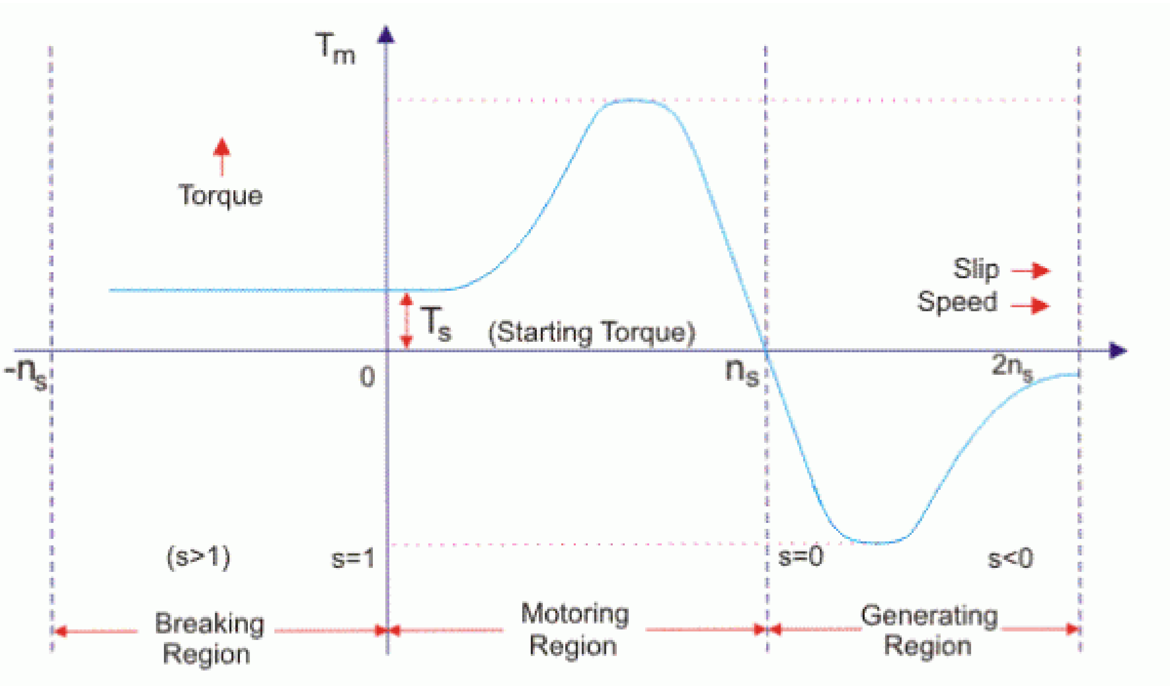
(a) 1>S>0, 0>S>-2 and S>1

(b) S>1, 1>S>-1 and 0>S>-1

(c) S>1, 0>S>-1 and 1>S>0

(d) 0>S>-1, S>1 and 1>S>0

Ans: (a)



Range s = 0 to s = 1 is called motoring region and s<0 is called generating region. The slip s>1 is called the braking region.

2. A 4-pole, 3-phase induction motor is supplied from 50Hz supply. Determine its synchronous speed. On full load, its speed is observed to be 1440 rpm. Its full load slip is.

(a) 0.01 (b) 0.04 (c) 0.02 (d) 0.15

Ans: (b)

Solution:

- **Given values: P=4, f=50Hz, N=1440rpm**
- $N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500rpm$
- **Full load slip,** $s = \frac{N_s - N}{N_s} = \frac{1500 - 1440}{1500} = 0.04$

3. A 4-pole, 3-phase, 50Hz, star connected induction motor has full load slip of 5%. Full load speed of the motor is

(a) 1440 rpm (b) 1425 rpm

(c) 1500 rpm (d) 950 rpm

Ans: (b)

Solution:

Given values: P=4, f=50Hz, slip=5%

$$N_s = \frac{120f}{P} = \frac{120\times50}{4} = 1500rpm$$

Full load speed, $N = N_s(-s)$, $N = 1500(1 - 0.05)$

$$N = 1425rpm$$

4. A 4-pole, 3-phase, 50Hz, induction motor runs at a speed of 1440rpm. The frequency of the induced e.m.f in the rotor under this condition is

(a) 2 Hz (b) 1.5Hz (c) 50Hz (d) 1Hz

Ans: (a)

Solution:

$$N_s = \frac{120f}{P} = \frac{120\times50}{4} = 1500rpm$$

$$s = \frac{N_s - N}{N_s} = \frac{1500-1440}{1500} = 0.04 \quad \therefore f_r = sf = 0.04\times 50 = 2Hz$$

5. **A 24 pole, 50Hz, star connected induction motor has rotor resistance of 0.016Ω per phase and rotor reactance of 0.265Ω per phase at standstill. It is achieving its full load torque at speed of 247 rpm. The ratio of full load torque to maximum torque is**

(a) 0.3824 (b) 0.1203 (c) 0.7648 (d) 0.2406

Ans: (a)

Solution:

$P = 24$, $f = 50$ Hz, $R_2 = 0.016\ \Omega$, $X_2 = 0.265\ \Omega$, $N = 247$ r.p.m.

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{24} = 250 \text{ r.p.m.}$$

$$s_f = \frac{N_s - N}{N_s} = \frac{250 - 247}{250} = 0.012 = \text{Full load slip}$$

$$s_m = \frac{R_2}{X_2} = \frac{0.016}{0.265} = 0.06037$$

$$\frac{T_{F.L.}}{T_m} = \frac{2\, s_m\, s_f}{{s_m}^2 + {s_f}^2} = \frac{2 \times 0.06037 \times 0.012}{(0.06037)^2 + (0.012)^2} = 0.3824$$

6. **Rotor resistance and standstill reactance per phase of a 3-phase induction motor are 0.04Ω and 0.2Ω respectively. What would be the external resistance required at start in rotor circuit to obtain maximum torque at start**

(a) 0.16Ω **(b) 1.6Ω** **(c) 0.0135Ω** **(d) 0.008Ω**

Ans: (a)

Solution:

For $T_m = T_{st}$, $s_m = \frac{R_2'}{X_2} = 1$

$\therefore$ $R_2' = X_2 = 0.2\ \Omega$

Let R_{ex} = External resistance required in rotor.

$R_2' = R_2 + R_{ex}$

$\therefore$ $R_{ex} = R_2' - R_2 = 0.2 - 0.04 = 0.16\ \Omega$ per phase.