B.Tech First Year: Regular Course Lecture Plan Session 2022-23

Subject Name	Electrical Engineering

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Name of Subject Head	Mr. Ashok Kumar Rajput

UNIT-4

ELECTRICAL MACHINES

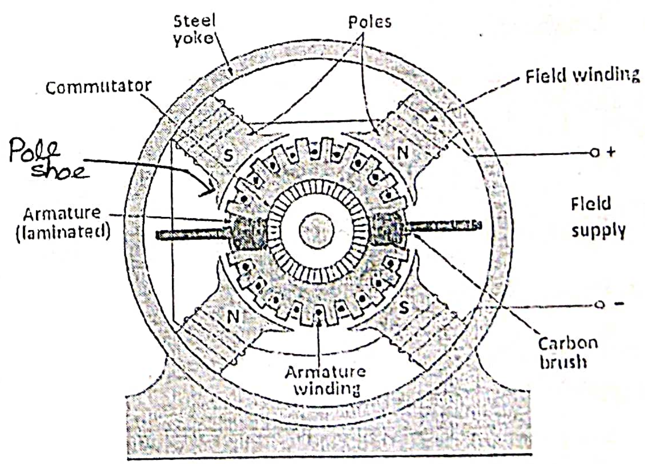
Electrical machines are broadly categorised into two types viz. Generator and Motor.

The device which converts mechanical energy into electrical energy, is known as generator and the device which converts electrical energy into mechanical energy is known as motor.

Mechanical Energy → Generator → Electrical Energy · Electrical Energy → Motor → Mechanical Energy

Imp. Ques ⇒ Discuss the constructional feature of D.C machine. (17-18)

Ans ⇒ Construction of DC machine ⇒ The constructional features of DC generator or a motor is same. A cross section of D.C machine is shown below.



Yoke ⇒ * It is the outermost cover of d.c machine. It protect the inner parts of d.c machine from harmful atmospheric conditions like moisture, dust, fumes etc.

* It provides mechanical support to poles.
* It also provide a path of low reluctance for magnetic flux.

Material used ⇒ It must be made up of some magnetic material. For low rating machines cast iron is used. For large machines rolled steel, cast steel, silicon still are used (High permiablity, low reluctance).

Poles ⇒ They are devided in two parts.

1. Pole Core
2. Pole shoe

⇒ It carries the field winding which is necessary to produce the flux.

⇒ The area of poles are enlarged so that more armature part comes under the flux. It is known as pole shoe.

Material used ⇒ Made up of magnetic material like cast iron or cast steel.

Field winding ⇒

* It is wounded on the pole core with a definite direction. It is excited with D.C supply.
* It carry current due to which pole core behaves as an electromagnet. It is also known as exciting winding.

Material used ⇒ As it has to carry current so made up of some conducting material like aluminium and copper.

Armature ⇒ It is divided in to two parts.

1. Armature Core
2. Armature winding

(1.) Armature Core ⇒ It is cylindrical in shape mounted on shaft, It has slots on its peripheny. It houses the armature winding i.e armature conductors. It also provide a low reluctance path for the flux.

Material used :- Magnetic material like cast iron and silicon steel. It is made up of laminated construction to keep eddy current low.

(2.) Armature winding ⇒ It is nothing but the interconnection of the armature conductors, placed on different-different slots.

* So emf generation takes place in the armature winding in case of generator.
* In case of motor it carry current to play the role of current carrying conductor.

Material used :- Copper

Imp.
Ques ⇒ Why commutator is used in D.C machine? (2019-20)

Ans ⇒ Commutator ⇒ The basic nature of induced emf in the armature conductor is alternating. This needs to be rectified in case of D.C generator, which is possible by a device called commutator.
In case of motor commutator is used to produce unidirectional torque.

Material Used :· It is made up of copper segments. these segments are insulated from each other by thin layer of mica.

Brushes :· It collect the current from commutator and make it available to the stationary external ckt.

Materials ⇒ Made up of soft conducting material like carbon.

Imp. Ques:· What are the various types of Armature winding ?

Ans ⇒ Types of armature winding ⇒

① Lap winding ⇒ In this type of winding connections overlap each other as winding proceeds, till starting point reached again.

For Lap winding

No. of parallel path, A = No of poles, P

ie $\boxed{A=P}$

Large no of parallel path indicate high current carrying capacity. Hence it is used for high current and low voltage rating machines.

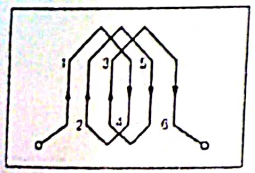
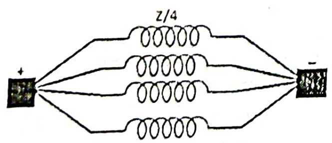


Fig. Lap winding



Lap winding for 4 pole motor

② Wave winding ⇒ In this type of connection, winding always travels ahead avoiding overlapping. It travels like progressive wave hence called wave winding.

* For wave winding

No of parallel path, A = Always 2

i.e $\boxed{A=2}$

As No of parallel path is less therefore this type of connection is used for low current and high voltage rating machines.

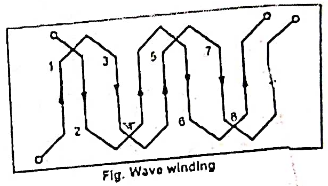
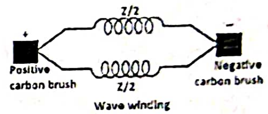


Fig. Wave winding



Wave winding

Winding Terminologies

(A) Conductor ⇒ It is actual armature conductor which is under the influence of magnetic field. It is placed in armature slot.

(b) Turn ⇒ Two conductors placed in different slots when connected together, forms a turn.

So No of conductor Z = 2× No of turns.

Ques ⇒ Discuss the working principle of DC generator.

Ans ⇒ Working principle of DC generator ⇒ All the generator works on the principle of faraday's law.

According to Faraday's law "when ever there is relative motion between magnetic field and conductor, an emf get induced in the conductor (Dynamically - induced emf)."

So for generating operation, we need three things viz.
(i) Magnetic field (ii) Conductor (iii) Relative motion between them

* To produce magnetic field we can use permanent magnet or electro magnet (Pole core & field winding)
* For conductor, many conductors are formed together to form another set of winding which is nothing but armature winding.
* For relative motion between them either conductor is rotating and field is stationary or the field is rotating and conductor is stationary
* But in DC generator Armature winding (conductor) is always placed on rotor (on shaft which is free to rotate).
* In AC generator (Alternator) we may make conductor stationary and field rotating i.e field winding is placed on rotor this time.
* So when armature conductor rotates in a magnetic field, flux linkage with the conductor (Armature winding) changes. Hence according to Faraday's law emf get induced

- in the armature winding.
* The direction of induced emf will be determined with the help of Fleming Right Hand Rule.
* The nature of induced emf is basically alternating which is converted in to DC with the help of commutator.

Note :- A DC generator without commutator will become AC generator (Alternator).

(V.Imp)
Ques ⇒ Derive the emf equation of DC generator

E.M.F Equation of DC generator ⇒ (2018-19, 2017-18, 2013-14)

Let P = No of poles
ϕ = Flux produced by each pole in wb.
N = Speed of armature in r.p.m.
Z = Total No of Armature Conductors
A = No of parallel paths
A = P for lap winding
A = 2 for wave winding

Now the average value of e.m.f induced in each armature conductor is,

$$e = \text{Rate of cutting the flux} = d\phi/dt$$

Now consider one revolution of conductor. In one revolution conductor will cut total flux produced by all the poles i.e $\phi \times P$. While time required to complete one revolution is 60/N seconds as speed is N r.p.m.

$$e = \frac{\phi P}{60/N} = \frac{\phi N P}{60}$$

This is the e.m.f. induced in one conductor. Now we have Z No of conductors with A no of parallel path. So we have total Z/A conductors in series in each parallel path.

∴ Total e.m.f. induced

$$E_g = \frac{\phi NP}{60}\cdot\frac{Z}{A} \quad \text{or} \quad \boxed{E_g = \frac{\phi ZNP}{60A}}$$

Ques ⇒ An 8 Pole lap wound DC generator has 450 armature turns. It operates at 0.02 Wb flux per pole and runs at 1000 r.p.m at no load. find the e.m.f induced by it. (2018-19)

Solution ⇒ Given $P=8$, $A=8$, No of turns $=450$

$\phi = 0.02$ Wb, $N = 1000$ r.p.m

Now No of conductors = 2X no of turns

∴ $Z = 2\times 450$

$= 900$

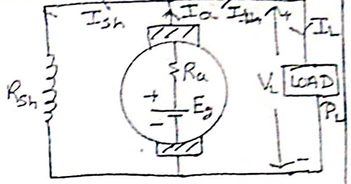
Now $E_g = \frac{\phi NZP}{60A} = \frac{0.02\times 900\times 1000\times 8}{60\times 8}$

$\boxed{E_g = 300 \text{ Volt}}$ Ans

Ques ⇒ Discuss various types of DC generator.

Types of DC generator ⇒ Depending upon the method of excitation used, the DC generator are classified as.

1. Separately excited generator ⇒ Separate DC supply is used to excite the field winding.



Now

$P_L = V_L I_L \Rightarrow 100 = 100 I_L$

$I_L = 1A$

and $I_{sh} = \frac{V_L}{R_{sh}} = \frac{100}{50} = 2A$

Now $I_a = I_L + I_{sh}$

∴ $\boxed{I_a = 3A}$

And $E_g = V_L + I_a R_a + 2V_b$

$= 100 + 3\times 0.1 + 2\times 1$

$\boxed{E_g = 102.3V}$

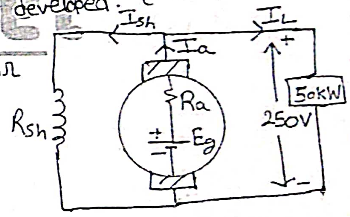
Ans

V.Imp.

Ques ⇒ A 25 kW, 250 V, DC shunt generator has armature and field resistance of 0.06Ω & 100Ω respectively. Determine the total armature power developed. (2017-18 odd)

Solution ⇒ Given $P_L = 25$ kW

$V_L = 250$ V, $R_a = 0.06\Omega$, $R_{sh} = 100\Omega$



Now, $P_L = V_L I_L \Rightarrow 50\times 1000 = 250 I_L$

$I_L = 200A$

$I_{sh} = \frac{V_L}{R_{sh}} = \frac{250}{100} = 2.5A$

Now, $I_a = I_L + I_{sh} = 200 + 2.5$

$I_a = 202.5A$

And $E_g = V_L + I_a R_a = 250 + 202.5\times 0.06$

$E_g = 262.15V$

Now armature power, $P_a = E_g I_a = 262.15\times 202.5$

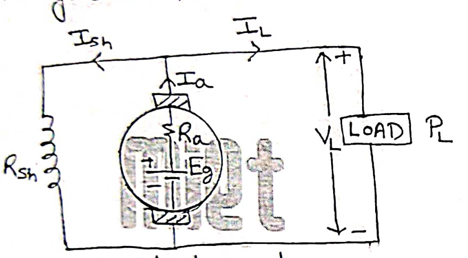
$\boxed{P_a = 53.08 \text{ kW}}$ Ans

2. Self excited ⇒ The generated voltage it self is used to excited the field winding of the same DC generator.

So depending on how field winding is connected to the armature, self excited generators are further divided in to following types.

(i) DC shunt generator
(ii) DC series generator

Imp.
(i) DC shunt generator ⇒



DC shunt generator

from the diagram:

$$\boxed{I_a = I_L + I_{sh}}$$

And $\boxed{I_{sh} = \frac{V_L}{R_{sh}}}$

Now apply KVL in the IInd mesh (Load side)

$$-E_g + I_aR_a + V_L + 2V_b = 0$$

$$\therefore \boxed{E_g = V_L + I_aR_a + 2V_b}$$

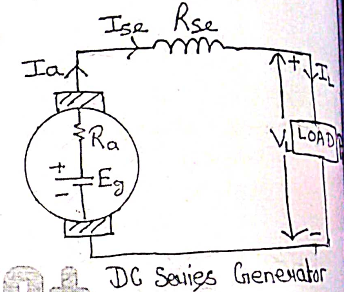
Where V_b is the voltage drop across each brush

Now if we neglect the voltage drop across brushes then $\boxed{E_g = V_L + I_aR_a}$

And

* Power developed by armature $= P_a = E_g I_a$
* Power delivered to the load $= P_L = V_L I_L$

Imp.
(ii) DC Series Generator :



DC Series Generator

From fig.

$$\boxed{I_a = I_L = I_{se}}$$

And

$$-E_g + I_aR_a + I_{se}R_{se} + V_L + 2V_b = 0$$

$$\therefore \boxed{E_g = V_L + I_a(R_a + R_{se}) + 2V_b}$$

Now if we neglect the brush drop then

$$\boxed{E_g = V_L + I_a(R_a + R_{se})}$$

* Power developed in Armature $= P_a = E_g I_a$
* Power delivered to the load $= P_L = V_L I_L$

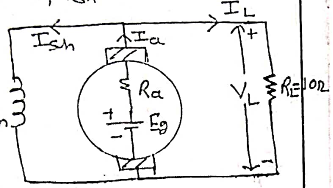
Imp.
Ques ⇒ A 4-Pole shunt generator with lap connected armature has field and armature resistance of 50 Ω and 0.1 Ω respectively. If supply power to 100 W lamp load for 100 V. calculate the armature current and the generated e.m.f. Consider contact drop of 1 V per brush. (2018-19 odd Sem)

Solution ⇒ Given $P=4$, $A=4$, $R_{sh} = 50\,\Omega$, $R_a = 0.1\,\Omega$, $P_L = 100\,W$ and $V_L = 100\,V$, $V_b = 1\,V/\text{Brush}$

Ques ⇒ A 4 pole DC shunt generator with wave connected armature has 41 slots and 12 conductors / slot. Armature resistance and shunt field resistance are 0.5 Ω and 200 Ω. Flux / Pole is 125 mWb speed N = 1000 rpm. Calculate the voltage drop across terminals. The load resistance is 10 Ω. (2013–14)

Solution ⇒ Given $P = 4$, $A = 2$, $Z = 41 \times 12 = 492$, $N = 1000$ rpm

$\phi = 125$ mWb $= 0.125$ Wb, $R_a = 0.5\,\Omega$, $R_{sh} = 200\,\Omega$



Now
$$E_g = \frac{\phi Z N P}{60 A} = \frac{0.125 \times 492 \times 1000 \times 4}{60 \times 2}$$
$$= 2050 \text{ Volt}$$

Now apply KVL in I[st] mesh

$$-E_g + I_a R_a + I_{sh} R_{sh} = 0$$
$$0.5 I_a + (I_a - I_L)\, 200 = 2050 \quad \text{——— (1)}$$

Apply KVL in II[nd] mesh

$$-E_g + I_a R_a + I_L R_L = 0$$
$$0.5 I_a + 10 I_L = 2050 \quad \text{——— (2)}$$

On solving eq[n] (1) and (2)

$I_a = 204.5$ A, $I_L = 194.77$ A

Now voltage drop across the terminal

$$V_L = I_L R_L = 194.77 \times 10$$
$$\boxed{V_L = 1947.7\text{V}}$$ Ans

V.Imp.

Ques ⇒ Write down the principle of operation of DC motor. (2017–18)

Working principle of DC motor ⇒ The basic principle behind motoring action is that "When a current carrying conductor is placed in a magnetic field, It will experience of force"

The magnitude of force is given by

$$\boxed{F = BIL}$$

And the direction of force can be determined by using fleming Left Hand Rule.

So for any motor, we need

(i) Magnetic field (ii) Conductor (iii) Supply to drive current in conductor.

⇒ Similar to DC generator we have pole core and field winding to produce magnetic field.

⇒ We have armature winding which play the role of conductor.

⇒ Now to have current in the conductor we connect armature with DC supply.

⇒ So as armature conductor are placed in a magnetic field and it has also current in it. Therefore it will experience a force.

⇒ As conductor are placed on the periphery of armature core, the individual force experience by the conductor acts as twisting or turning force which is called torque.

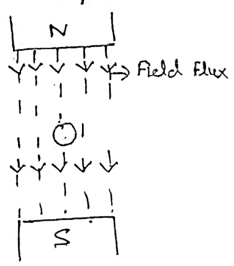


Fig: 6(a)

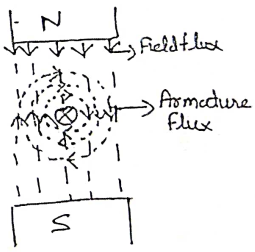


Fig: 6(b)

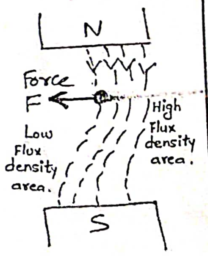


Fig: 6(c)

⇒ Now consider a single conductor placed in a magnetic field as shown in fig. 6(a).

⇒ Let us assume the direction of current flowing in the conductor is such as that it is going inside the paper shown by in fig. 6(b).

⇒ Now this current carrying conductor will also produce its own magnetic field around it. whose direction can be determined by using right hand thumb rule. clockwise in this case (fig. 6(b)).

⇒ Now we have two fluxes i.e field flux and armature flux. These two fluxes interact with each other and motor will run.

⇒ As we can see from the fig. 6(b) that on the right side of conductor, these two fluxes are in same direction. Therefore supporting each other.

⇒ While on the left side of conductor these two fluxes are opposite to each other. Hence try to cancle out each other.

⇒ Due to this the flux distribution around the conductor acts like streched rubber as shown in fig. 6(c).

⇒ Now due to this a force will be exerts on conductor from high flux density area to low flux density area i.e from Right to Left.

Imp.
Ques ⇒ How we will change the direction of DC motor? (2018-19, 13, 14)

Ans ⇒ To reverse the direction of rotation of DC motor, either direction of field flux is reversed or the direction of armature current is reversed.

So by interchanging the terminals of field winding or armature winding we can reverse the direction of rotation of DC motor.

V. Imp.
Ques ⇒ What is back emf ? What is the significance of back emf ? (2016-17, 15-16, 14-15, 13-14)

Back emf ⇒ * In DC motor, after motoring action armature starts rotating and armature conductor cuts the main flux.

* So, there exist a generating action also. Due to which an emf gets induced into the armature conductors.

* This induced emf always opposes the supply voltage (Lenz's law), It is called back emf.

* So according to emf equation back emf is given by

$$\boxed{E_b = \frac{\phi Z N P}{60 A}}$$

Significance of Back E.M.F ⇒ The symbolic representation of motor and back e.m.f is shown in fig.

We can write

$$-V + I_a R_a + E_b = 0$$

or $V = E_b - I_a R_a$

or $\boxed{I_a = \frac{V - E_b}{R_a}}$

Due to presence of back e.m.f DC motor becomes a self regulating machine i.e motor adjust itself to draw the armature current which is enough to supply the load demand.

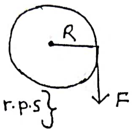
As $E_b \propto N$

So when load increase ↑, motor speed N decrease ↓ and due to this E_b ↓. Now the difference $(V - E_b)$ increase ↑. Therefore I_a increases ↑.

V.Imp.
Ques ⇒ Derive the torque equation of DC motor. (2019-20, 14-15) (2016-17)

Ans ⇒ Torque equation ⇒

Let a wheel having radius R meter.
circumferential force = F Newton
Speed of rotation of wheel = N r.p.m



Now
$\omega = 2\pi n = \frac{2\pi N}{60}$ {where n = speed in r.p.s}

Now the work done is given by
W = F × distance travelled in one revolution = F × 2πR

And
Power developed, $P = \frac{\text{Workdone}}{\text{Time}} = \frac{F \times 2\pi R}{\left(\frac{60}{N}\right)}$

$P = F \times R \cdot \left(\frac{2\pi N}{60}\right)$

$\therefore \boxed{P = T \cdot \omega}$ $\left\{\text{where } \omega = \frac{2\pi N}{60}\right\}$

Now the gross mechanical power developed by the armature is

$\boxed{P = E_b \cdot I_a}$

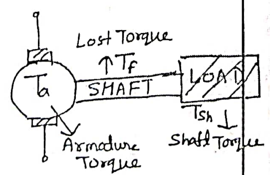
$\therefore E_b \cdot I_a = T_a \cdot \frac{2\pi N}{60}$

$\frac{NP\phi Z}{60A} \cdot I_a = T_a \cdot \frac{2\pi N}{60}$ $\left\{\because E_b = \frac{NP\phi Z}{60A}\right\}$

$\boxed{T_a = \frac{1}{2\pi} \cdot \frac{I_a \cdot P\phi Z}{A}}$ OR $\boxed{T_a = 0.159 \frac{I_a P\phi Z}{A}}$

$\boxed{T_a \propto \phi \cdot I_a}$

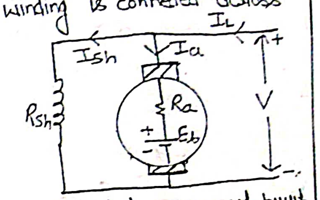
$\boxed{T_a = T_f + T_{sh}}$



Imp.
Q ⇒ What are the different types of DC motor? (2016-17, 14-15)

Types of DC motor ⇒

① DC shunt Motor ⇒ Similar to DC shunt generator, here also field winding is connected across the armature.



From the fig. 8
$I_L = I_a + I_{sh}$
OR $\boxed{I_a = I_L - I_{sh}}$ also $\boxed{I_{sh} = \frac{V}{R_{sh}}}$

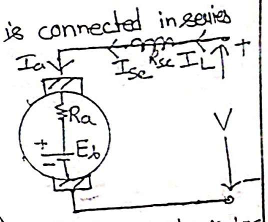
And apply K.V.L
$-V + I_a R_a + E_b + 2V_b = 0$. where V_b = Voltage drop across each brush

$\therefore \boxed{E_b = V - I_a R_a - 2V_b}$

or $\boxed{E_b = V - I_a R_a}$ {Neglecting brush voltage drop}

And power developed in armature
$\boxed{P_a = E_b I_a}$

② DC Series Motor ⇒ Here field winding is connected in series with armature.



So from fig 9 $I_a = I_L = I_{se}$
and $-V + I_{se}R_{se} + I_a R_a + E_b + 2V_b = 0$
or $\boxed{E_b = V - I_a (R_a + R_{se}) - 2V_b}$
Where V_b = brush drop across each brush

Fig 9: DC series Motor

$\boxed{E_b = V - I_a (R_a + R_{se})}$

Here $\phi \propto I_{se} \propto I_a$
So $T \propto \phi I_a$ or $\boxed{T \propto I_a^2}$

So very high torque is available. this is why it is used for heavy loads

Now Armature Power $\boxed{P_a = E_b I_a}$

Ques ⇒ What is speed regulation? (2020-21-17-18)

Ans ⇒ It is defined as the ratio of change in speed corresponding to no load and full load condition to speed corresponding to full load.

$$\boxed{\%\ \text{speed regulation} = \frac{N_{No\ load} - N_{full\ load}}{N_{full\ load}} \times 100}$$

Imp.

Ques ⇒ Why Series motor is never started on no load? (2013-14)

Ans ⇒ We know that

$$E_b = \frac{\phi ZNP}{60A} \quad \text{OR} \quad N \propto \frac{E_b}{\phi} \quad \text{—— (1)}$$

* In DC series motor, at no load the current I_L drawn from supply is very low.
* $\therefore \phi \propto I_{se}$ is also very low ($I_L = I_{se}$).
* Now from the relation eqn (1) $N \propto \frac{1}{\phi}$, ϕ is very low so speed will be dangerously high. which will damage the motor.

Imp.

Ques ⇒ What will happen if the field winding of shunt motor is suddenly open during running condition? (2014-15)

Ans ⇒ $N \propto \frac{E_b}{\phi}$

When field winding open, $I_{sh} = 0$

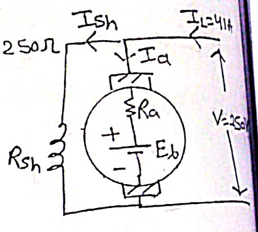
$\therefore \phi \propto I_{sh} = 0$

So speed $N \propto \frac{1}{\phi}$, which is dangerously high and will damage the motor.

V. Imp.

Ques ⇒ A 250V DC shunt motor takes 41A at full load. Armature and shunt field winding resistances are 0.1Ω and 250Ω respectively. find back emf on full load. What will be generated emf, if working as generator and supplying 41A to the load at a voltage of 250V? (2018-19 Even Sem)

Solution ⇒ (i) As a motor



Given $V = 250\,V$, $I_L = 41A$, $R_a = 0.1\Omega$, $R_{sh} = 250\Omega$

. Now $I_{sh} = \frac{V}{R_{sh}} = \frac{250}{250} = 1A$

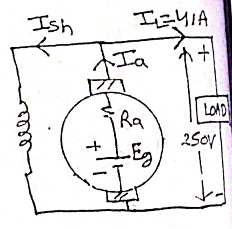
$\therefore I_a = I_L - I_{sh} = 41 - 1 = 40A$

Now $E_b = V - I_a R_a$

$= 250 - 40 \times 0.1$

$\boxed{E_b = 246\,V}$

(ii) As a generator



Again Given $I_L = 41A$, $V_L = 250V$

So $I_{sh} = \frac{V_L}{R_{sh}} = \frac{250}{250} = 1A$

$\therefore I_a = I_L + I_{sh} = 41 + 1$

$= 42A$

Now $E_g = V_L = I_a R_a = 250 + 42 \times 0.1$

$\boxed{E_g = 254.2\,V}$

Imp.

Ques ⇒ A DC shunt generator delivers 50 kW at 250 V running at 500 rpm. The armature and field resistance are 0.05Ω and 125Ω respectively calculate the speed of the same machine and developed torque when running as a shunt motor and taking 50kw at 250V. (2016-17 Even Sem)

Solution ⇒ (i) As a generator

Given $P_L = 50kW$, $V_L = 250V$, $N_g = 500$ rpm $R_a = 0.05\Omega$, $R_{sh} = 125\Omega$

Now $P_L = V_L I_L \Rightarrow 50\times1000 = 250 I_L$

$I_L = 200A$

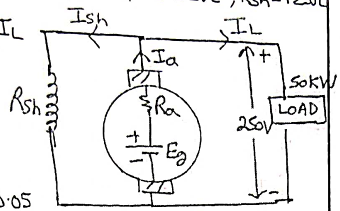
And $I_{sh} = \frac{V_L}{R_{sh}} = \frac{250}{125} = 2A$

∴ $I_a = I_L + I_{sh} = 200 + 2$

$I_a = 202A$

Now $E_g = V_L + I_aR_a = 250 + 202\times0.05$

$\boxed{E_g = 260.1V}$



(ii) As a motor

Again Pin = 50kW at V = 250V

∴ $P_{in} = V I_L \Rightarrow 50\times1000 = 250 I_L$

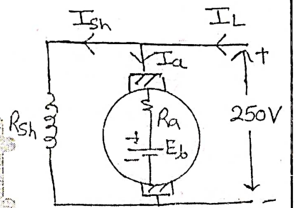
$I_L = 200A$

and $I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125} = 2A$

∴ $I_a = I_L - I_{sh} = 198A$

Now $E_b = V - I_aR_a = 250 - 198\times0.05$

$\boxed{E_b = 240.1V}$



Now we know that

$N \propto \frac{E_b}{\phi}$ or $N \propto E$ $\{\because \phi = $ Constant

∴ $N_g \propto E_g$ and $N_m \propto E_b$ or $\frac{N_m}{N_g} = \frac{E_b}{E_g}$

$N_m = \frac{240.1}{260.1}\times500$ And Torque, $T_a = \frac{P_a}{\omega} = \frac{E_bI_a}{\frac{2\pi N}{60}}$

$\boxed{N_m = 461.55 \text{ rpm}}$ $\boxed{T_a = 984.07 Nm}$

Imp.

Ques ⇒ A 120V DC shunt motor having armature & field resistances of 0.2Ω and 60Ω, draw a line current of 40A at full load. The brush voltage drop is 3V and rated full load speed is 1800 rpm. Calculate ⇒ (1) Speed at half load. (2016-17 odd)
(2) Speed at 125% of full load.

Solution (1) ⇒ Given $V = 120V$, $R_a = 0.2\Omega$, $R_{sh} = 60\Omega$, $(I_L)_{F.L} = 40A$

$V_{brush} = 3V$, $(N)_{F.L} = 1800$ rpm

Now $I_{sh} = \frac{V}{R_{sh}} = \frac{120}{60} = 2A$

∴ $(I_a)_{F.L} = (I_L)_{FL} - I_{sh} = 40 - 2 = 38A$

Now $T \propto \phi I_a$ or $T \propto I_a$ $\{\because \phi = $ constant for shunt motor$\}$

∴ $\frac{T_{FL}}{T_{HL}} = \frac{(I_a)_{FL}}{(I_a)_{HL}}$

Therefore at half load torque is half of the full load torque. Therefore armature current at half load is also half.

∴ $(I_a)_{HL} = \frac{(I_a)_{FL}}{2} = \frac{38}{2} = 19A$

Now $(E_b)_{FL} = V - (I_a)_{FL} R_a - V_b = 120 - 38\times0.2 - 3$

$(E_b)_{FL} = 109.4V$

And $(E_b)_{HL} = V - (I_a)_{HL} R_a - V_b = 120 - 19\times0.2 - 3 = 113.2V$

Now $N \propto E$, ∴ $\frac{N_{HL}}{N_{FL}} = \frac{(E_b)_{HL}}{(E_b)_{FL}}$

∴ $N_{HL} = \frac{113.2}{109.4}\times1800$

$\boxed{N_{HL} = 1862.52 \text{ rpm}}$

(ii) Similarly $(I_a)_{125\%} = 1.25\times(I_a)_{FL} = 1.25\times38 = 47.5A$

∴ $(E_b)_{125\%} = V - (I_a)_{125\%} R_a - V_b$
$= 120 - 47.5\times0.2 - 3$

$(E_b)_{125\%} = 107.5V$

Now $\frac{N_{125\%}}{N_{FL}} = \frac{(E_b)_{125\%}}{(E_b)_{FL}}$ or $N_{125\%} = \frac{107.5}{109.4}\times1800$

$\boxed{N_{125\%} = 1768.73 \text{ rpm}}$

Ans

Ques ⇒ A 6-pole lap wound DC shunt motor has 250 conductors and flux of 0.04 Wb/Pole at 1200 rpm. The armature and field resistances are 1Ω 220Ω. It is connected to 220V DC supply Determine — (2015-16 Even)

① Induced emf in motor
(ii) Armature current
(iii) Input supply current
(iv) Mechanical power developed in the motor
(V) Torque developed

Solution ⇒ (i) Given $P=6$, $A=6$, $Z=250$, $\phi = 0.04$ Wb $N = 1200$ rpm

$R_a = 1\Omega$, $R_{sh} = 220\Omega$

$$\therefore E_b = \frac{\phi Z N P}{60 A} = \frac{0.04 \times 250 \times 1200 \times 6}{60 \times 6}$$

$$\boxed{E_b = 200 \text{ Volt}}$$

(ii) $I_{sh} = \frac{V}{R_{sh}} = \frac{220}{220} = 1A$

Now $V = E_b + I_a R_a$ or $I_a = \frac{V - E_b}{R_a}$

$$= \frac{220-200}{1}$$

$$\therefore \boxed{I_a = 20A}$$

(iii) Input supply current

$I_L = I_a + I_{sh} = 20+1$

$$\boxed{I_L = 21A}$$

(iv) Mechanical power developed

$P_a = E_b I_a$. 200×20

$$\boxed{P_a = 4000W}$$

(v) Torque

$$T = \frac{\phi Z P I_a}{2\pi A} = 0.159 \frac{\phi Z P I_a}{A}$$

$0.159 \times 0.04 \times 250 \times 20$

$$\boxed{T = 31.8 \text{ Nm}}$$

Ans

Ques ⇒ A DC shunt motor develops an open ckt emf of 250V at 1500 rpm. find the developed torque for an armature current of 20A. (2013-14 Even)

Solution ⇒ Given $E_b = 250V$, $I_a = 20A$

We know that $E_b = \frac{\phi Z N P}{60 A} = \frac{\phi Z P}{A} \cdot \frac{N}{60}$

or $\frac{\phi Z P}{A} = \frac{E_b \times 60}{N} = \frac{250 \times 60}{1500} = 10$

Now $T = 0.159 \left(\frac{\phi Z P}{A}\right) I_a$

$T = 0.159 \times 10 \times 20$

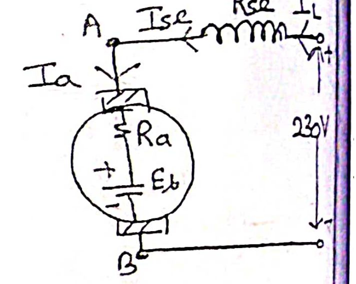
$$\boxed{T = 31.8 \text{ Nm}}$$

Ans

V. Imp.

Ques ⇒ A 230V DC Series motor is taking 50A. Resistance of armature and series field winding is 0.2Ω and 0.1Ω. Calculate (1) Brush Voltage ② Back emf (2013-14 Even)

Solution ⇒ Given $V = 230V$, $I_L = 50A$, $R_a = 0.2$, $R_{se} = 0.1\Omega$



① Brush voltage = Voltage b/n AB

$= 230 - I_L R_{se}$

$= 230 - 50 \times 0.1$

$$\boxed{V_{brush} = 225V}$$

② Back emf

$E_b = V - I_a (R_a + R_{se})$

$= 230 - 50 (0.2 + 0.1)$

$$\boxed{E_b = 215V}$$

$\{\because I_a = I_L\}$

Imp.

Ques ⇒ Sketch and explain the operating characteristics of DC shunt and series motor. (2014-15 odd, 14-15 Even)

DC Motor characteristics : . The performance of DC motor under various conditions can be judge by the following characteristics.

(i) Torque - Armature current characteristics
(ii) Speed - Armature current characteristics
(iii) Speed - Torque characteristics.

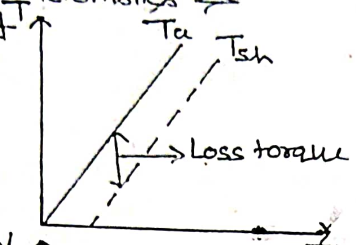
Characteristics of D.C Shunt Motor :

(i) Torque - Armature current characteristics ⇒

We know that $T \propto \phi I_a$, But ϕ = constant

∴ So $\boxed{T \propto I_a}$

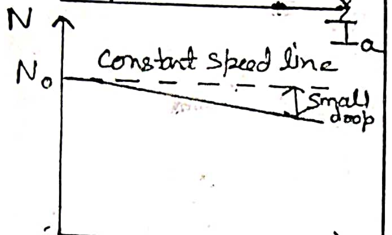
Above relation represent a straight line passing through origin.



(ii) Speed - Armature current :

We know that $N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi}$

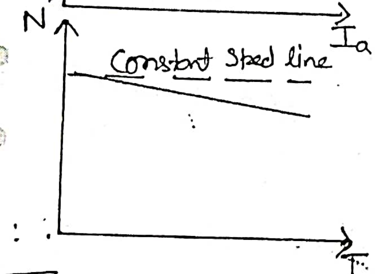
Now if load increase, I_a increase Hence speed reduces. But R_a is very small hence drop in speed from no load to full load is also very low.



(iii) Speed - torque characteristic

As for shunt motor $T \propto I_a$.

Therefore speed torque characteristic is same as speed - Armature current characteristics.



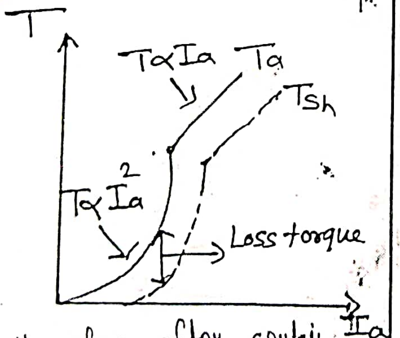
(2) Characteristics of DC Series motor :

(i) Torque - Armature current :

We know that $T \propto \phi I_a$ and

$\phi \propto I_a$

∴ $\boxed{T \propto I_a^2}$



⇒ This relation is parabolic in nature.

⇒ As load increase I_a increases and hence torque produced increases proportional to square of I_a

⇒ As I_a passes through field winding. therefore after certain value of I_a saturation occur and ϕ will be constant after saturation.

∴ After saturation $\boxed{T \propto I_a}$

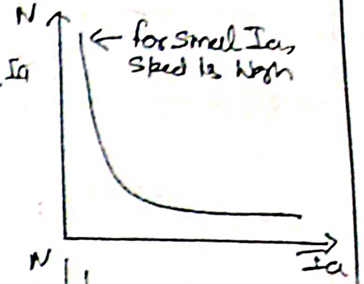
(ii) Speed Armature Current :

$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a (R_a + R_{se})}{I_a}$, as $\phi \propto I_a$

But R_a and R_{se} are very small and V is constant

∴ $\boxed{N \propto \frac{1}{I_a}}$

It represent rectangular hyperbola

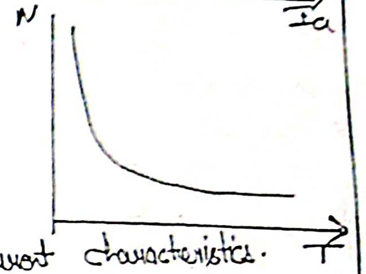


(iii) Speed - Torque characteristics :

$T \propto I_a^2$

and $N \propto \frac{1}{I_a}$

∴ $N \propto \frac{1}{\sqrt{T}}$



It is similar to speed - Armature current characteristics.

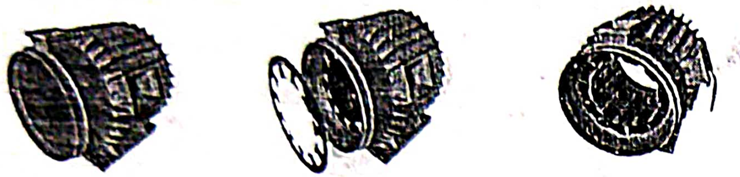
Qus ⇒ Write down the applications of DC Series & shunt motor (2020-21, 19-20, 18-19, 17-18, 15-16)

Ans ⇒ Series Motor ⇒
1. Crane
2. Hoists
3. Elevators
4. Trolley's
5. Conveyors
6. Electric locomotive

Shunt Motor ⇒
1. Fans and blowers
2. Centrifugal pumps
3. Lathe machines
4. Machine tools
5. Milling Machines
6. Drilling Machines

Three phase Induction Motor

Ques ⇒ Discuss Constructional feature of 3-ϕ induction motor. (2015-16)



* The 3-ϕ induction motor consist of two main parts, namely.

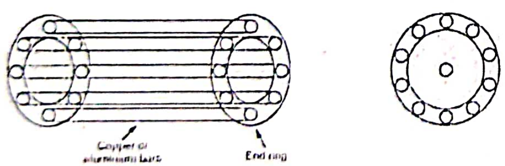
Stator ⇒ The part carrying 3-ϕ winding, and which is stationary called stator.

Rotor ⇒ The part which rotates and connected to the mechanical load through shaft called rotor.

Two types of rotor are used in induction motor.

① Squirrel cage rotor ⇒

* Cylindrical rotor core having slots on its periphery.
* Rotor consist of copper or aluminium bars, which is placed in the slots of rotor core.
* These bars are permanently shorted at each end with the help of copper end rings.

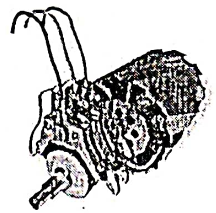


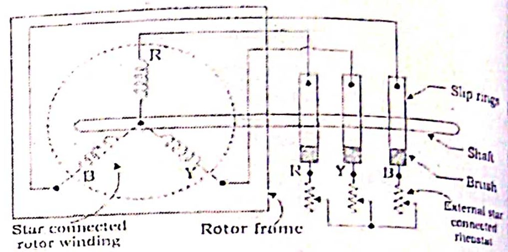
(a) Cage type structure of rotor

(b) Symbolic representation

② Slip ring rotor or Wound rotor :-

* In this type of rotor there is another winding which is placed on rotor slots called rotor winding.
* The three ends of rotor windings are permanently connect-ed to slip-rings.
* Now these slip-rings are short ckted with the help of carbon brush and external resistance. So external resistance can be added in series with each phase of rotor winding to increase the torque.





Imp.

Ques ⇒ What are the advantage of wound rotor over squirrel cage? OR Write down the difference b/n slip-rings and squirrel cage rotor.

Slip-ring wound rotor	Squirrel cage rotor (2015-16)
1. Construction is complicated.	1. Construction is very simple.
2. There is 3-ϕ winding on rotor	2. It has rotor bars, shorted by end-rings.
3. Rotor resistance can be added.	3. It is not possible to add rotor resistance.
4. Due to presence of external resistance, high starting torque can be obtained.	4. Starting torque is low and can not be improved.
5. Slip-ring and brushes are pre-sent. due to this high main-tance required.	5. Slip ring in brushes are absent So low maintance required.
6. Used where high starting torque is required.	6. Used for low starting torque applications.

V.Imp.
Ques ⇒ Explain the working principle of 3-ϕ induction motor (2016-17)

⇒ Induction motor works on the principle of electro magnetic induction.

⇒ When 3-ϕ supply is given to the three phase stator winding, a rotating magnetic field (R.M.F) of constant magnitude is produced. The speed of (R.M.F) is synchronous speed, N_s r.p.m

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

where f = Supply frequency
P = No of Stator or Rotor poles

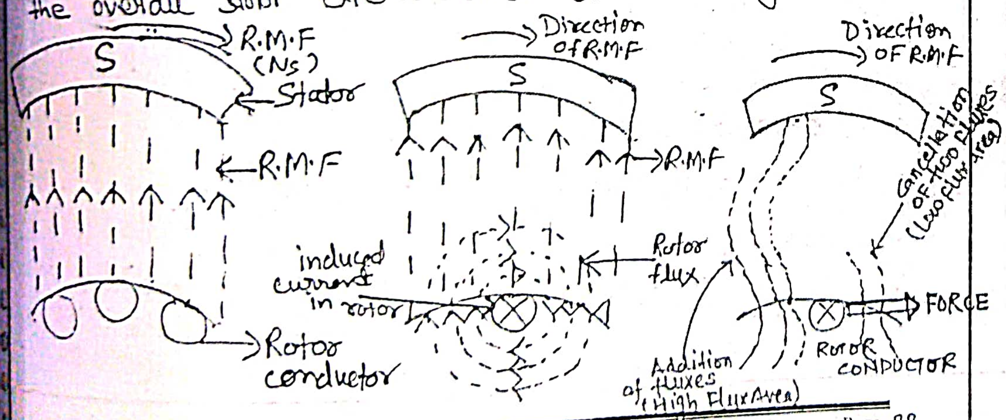
⇒ Now rotor is stationary and stator flux R.M.F is rotating. So there exists relative motion b/n R.M.F & rotor conductor.

⇒ Due to this an emf get induced in the rotor conductor.

⇒ As rotor ckt is closed, the induced emf derives a current in the rotor conductor.

⇒ Now any current carrying conductor produces its own flux. So rotor produces it own flux called rotor flux.

⇒ The two fluxes stator flux & rotor flux interact with each other and due to interaction of the two fluxes. rotor conductor will experiance a force, the overall rotor experiences torque and start rotating. with N_R speed.



⇒ The direction of rotation of rotor will be such that it will oppose the cause (Lenz's law).

⇒ Here the cause is relative motion b/n R.M.F & rotor conductor. Hence to reduce this relative motion rotor rotates in the same direction as that of R.M.F and tries to catch up the speed of R.M.F.

V.Imp.
Ques ⇒ Why induction motor can't run at synchronous speed
OR
Can $N_r = N_s$? explain it. (2019-20, 16-17)

* If $N_r = N_s$. Then the relative motion b/n R.M.F and rotor conductor hence no emf induced. Therefore there will be no rotor current. Hence no rotor flux and therefore no torque. So motor will stop.

* The inducation motor never rotates at synchronous speed ($N_r < N_s$).

Ques ⇒ Imp. Define Slip and Slip-speed. (2020-21, 19-20, 18-19, 17-18)

Ans ⇒ Slip-speed ⇒ As we know that N_r is less than N_s. So it can be said the rotor slip behind the R.M.F. The difference b/n these two is called slip-speed.

$$\boxed{\text{Slip-Speed} = N_s - N_r}$$

Slip ⇒ Slip of induction motor is defined as the difference b/n synchronous speed N_s and actual speed N_r of rotor and it is expressed as percentage of synchronous speed N_s.

$$\boxed{S = \frac{N_s - N_r}{N_s}} \quad \text{OR} \quad \boxed{\%S = \frac{N_s - N_R}{N_s} \times 100}$$

$\therefore$ ~~$N_r = N_s(1-S)$~~ $\boxed{N_r = N_s(1-S)}$

Note ⇒ * At starting $N_r = 0$, therefore $s = 1$

* When $N_r = N_s$, then $s = 0$

* So $0 < s < 1$

* Practically the value of slip is between 1% to 5%.

Effect of slip on rotor frequency : (18-19)

—x—x—x—

⇒ At starting $N_r = 0$. So the stator frequency (supply frequency) and rotor frequency is same at starting.

⇒ But when rotor rotates, the relative motion b/n rotor and r.m.f decreases and become equal to slip speed i.e. $N_s - N_r$

⇒ Due to this rotor frequency is no longer same as that of stator frequency (supply).

⇒ As we know that there is fix relation between speed and frequency.

$$\boxed{N_s = \frac{120f}{P}} \quad \text{—— (1)}$$

Now for rotor, speed will be relative speed $N_s - N_r$.
Let f_r be the rotor frequency
So for rotor

$$N_s - N_r = \frac{120 f_r}{P} \quad \text{—— (2)}$$

equation (2) ÷ (1)

$$\frac{N_s - N_r}{N_s} = \frac{f_r}{F} \quad \text{OR} \quad \boxed{f_r = sf}$$

effect on rotor induced emf : (18-19)

⇒ Let E_2 = induced emf at stand still

and E_{2r} = induced emf at running

Now we know that

$$E_2 = 4.44 f \phi_m N_2$$

and during running condition, rotor frequency is f_r.

$$\therefore E_{2r} = 4.44 f_r \phi_m N_2$$

$$= 4.44 sf \phi_m N_2 \qquad \{\because f_r = sf\}$$

$$\therefore \boxed{E_{2r} = sE_2}$$

* **Important Note :** (20-21, 19-20, 18-19, 17-18, 16-17, 14-15)

(1) Speed of stator frame or stator structure = 0

(2) Speed of stator flux or stator field = Speed of r.m.f = N_s

(3) Speed of rotor frame or rotor structure = N_r

(4) Speed of rotor flux or rotor field = N_s

* All above speed are w.r.t stationary observer.

Ques ⇒ Give the expression for speed in terms of pole and frequency. (2019-20 odd)

Ans ⇒

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

Where N_s = Synchronous speed
f = Supply frequency
P = No of poles on stator or rotor.

Ques ⇒ What is the relation between frequency of stator & rotor currents? A 3-phase, 50Hz induction motor has 6 poles and operates with a slip of 5% at a certain load. Determine (i) The speed of rotor with respect to the stator. (ii) The frequency of the rotor current. (iii) The speed of the rotor magnetic field with respect to the stator. (2018-19 odd)

Ans ⇒ $\boxed{F_r = sf}$

Given, $f = 50Hz$, $P = 6$, $s = 5\% = 0.05$

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

And $N_r = N_s(1-s) = 1000(1-0.05) = 950$ r.p.m

Now (1) Speed of rotor w.r.t stator ⇒ $N_r - 0 = 950$ rpm

(2) $F_r = Sf = 0.05 \times 50 = \boxed{f_r = 2.5\,Hz}$

(3) Speed of rotor magnetic field with respect to stator $= N_s - 0 = 1000$ r.p.m. Ans

Imp.

Ques ⇒ A 12-Pole, 3 phase alternator is coupled to an engine running at 500 rpm. This alternator supplies an induction motor running at 1450 rpm. Find slip and number of poles of the induction motor. (2017-18. odd)

Ans ⇒ Given $P_A = 12$, $N_A = 500$ rpm, $N_r = 1450$ rpm

Now for alternator

$$N_s = \frac{120f}{P} \Rightarrow 500 = \frac{120 \times f}{12} \text{ or } \boxed{f = 50Hz}$$

Now for motor given $N_r = 1450$ rpm

We know that $N_r = N_s$

$$\therefore N_r = \frac{120f}{P} = 1450 = \frac{120 \times 50}{P}$$

$$P = 4.13$$

No of pole will be alway even

$$\therefore \boxed{P = 4}$$

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

$$\therefore \% s = \frac{N_s - N_r}{N_s} \times 100 = \frac{1500 - 1450}{1500} \times 1000$$

$$\boxed{s = 3.3\%} \quad \underline{\text{Ans}}$$

Ques ⇒ Explain the term slip and slip speed. The rotor speed of 6 pole, 50 HZ induction motor is 940 rpm. Determine the percentage slip. (18-19)

Ans ⇒ Given $f = 50HZ$, $P = 6$, $N_r = 940$

$$\text{Now } N_s = \frac{120f}{P} = \frac{120 \times 50}{6}$$

$$= 1000 \text{ rpm.}$$

$$\therefore \% s = \frac{N_s - N_r}{N_s} \times 100 \Rightarrow \frac{1000 - 940}{1000} \times 100$$

$$\boxed{s = 6\%} \quad \underline{\text{Ans}}$$

Slip speed $= (N_s - N_r)$

$= (1000 - 940)$

$= 60$ r.p.m.

Ques ⇒ A three-phase 50Hz, induction motor has a full-load speed of 1460 rpm. Calculate slip, number of poles and frequency of rotor induced emf. (2013-14 Even)

Ans ⇒ Given $N_r = 1460$ rpm, $f = 50Hz$

We know that $N_r = N_s$

$$\therefore N_r = \frac{120f}{P} \Rightarrow 1440 = \frac{120 \times 50}{P}$$

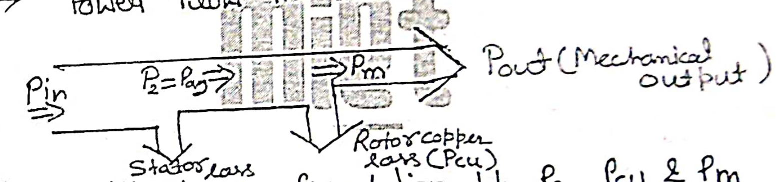
$$P = \frac{120 \times 50}{1440} = 4.16$$

$$\therefore \boxed{P = 4}$$

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

$$\therefore \% s = \frac{N_s - N_r}{N_s} \times 100 = \boxed{4\%} \quad \underline{\text{Ans}}$$

Note ⇒ Power flow in induction motor



∴ There will be a fix relation b/n P_2, P_{cu} & P_m

$$P_2 : P_{cu} : P_m = 1 : s : (1-s)$$

Where $P_2 = P_{ag}$ = Rotor input power or air gap power

P_{cu} = rotor cu loss

P_m = Gross mech power developed

Ques ⇒ A 4 pole, 3 phase induction motor runs at 1440 rpm. supply voltage is 500 V at 50 Hz. Mechanical power output is 20.3 Hp and mechanical loss is 2.23 Hp. Calculate (i) Mechanical Power developed. (ii) Rotor Cu loss (iii) Efficiency (2020-21 odd)

Ans ⇒ Given $P = 4$, $N_r = 1440$ rpm, $V_L = 500V$, $f = 5Hz$

$P_{out} = 20.3$ H.P, Mechanical loss $= 2.23$ H.P

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

and $\%s = \frac{N_s - N_r}{N_s} = \frac{1500 - 1440}{1500} \times 100$

$= 4\%$

Now

(i) Mechanical power developed $P_m = P_{out} +$ losses

$= 20.3 + 2.23 = 22.53$ HP

$\boxed{P_m = 22.53HP}$

(ii) Rotor Cu loss, P_{cu}

$$\frac{P_{cu}}{P_m} = \frac{s}{1-s}$$

$$P_{cu} = \frac{0.04}{(1-0.04)} \times 22.53 \Rightarrow \boxed{P_{cu} = 0.938 H.P}$$

(iii) Now $\frac{P}{P_{cu}} = \frac{1}{s} = P_2 = \frac{0.938}{0.04} = 23.46$ H.P.

When P_2 = rotor i/p power

Now if we neglect stator loss then input power, $P_{in} = P_2$

$\therefore \% \eta = \frac{P_{out}}{P_{in}} \times 100$

$\frac{20.3}{23.46} \times 100 = 86.5\%$. Ans

V.Imp.

Ques ⇒ Derive torque equation of 3-ϕ inducation motor. (2019-20)

Torque equation ⇒ Let ϕ = flux responsible to produce e.m.f.

E_2 = EMF induced in rotor and start-still.

E_{2r} = EMF induced in rotor at running.

I_{2r} = Rotor current at running.

$\cos\phi_{2r}$ = running p.f of rotor.

Now $T \propto \phi I_{2r} \cos\phi_{2r}$ ——— ①

Flux ϕ produced by stator $\propto$ $E_2 \propto \phi$

and $I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{sE_2}{\sqrt{R_2^2 + (sx_2)^2}}$

While $\cos\phi_{2r} = \frac{R_2}{Z_{2r}} = \frac{R_2}{\sqrt{R_2^2 + (sx_2)^2}}$

Now from eqn ①

$$T \propto E_2 \cdot \frac{sE_2}{\sqrt{R_2^2 + (sx_2)^2}} \cdot \frac{R_2}{\sqrt{R_2^2 + (sx_2)^2}}$$

or $\boxed{T = K \frac{sE_2^2 R_2}{R_2^2 + (sx_2)^2}}$, where k is constant

The value of k is given by

$\boxed{K = \frac{3}{2\pi n_s}}$ where $n_s = \frac{N_s}{60}$

Condition for maximum torque ⇒

for maximum torque

$\frac{dT}{ds} = 0$ where $T = K \frac{sE_2^2 R_2}{R_2^2 + (sx_2)^2}$

on solving $\boxed{s = \frac{R_2}{x_2}}$

$\therefore$ This is slip at which the torque is maximum and is denotated by s_m $\therefore \boxed{s_m = \frac{R_2}{x_2}}$

Now if we need max. torque at starting then, $s_m = 1$

i.e $\boxed{R_2 = x_2}$

V.Imp.

Ques ⇒ Draw the torque - slip characteristics of 3-ϕ induction motor. (2020-21, 19-20, 18-19, 17-18, 16-17, 14-15, 13-14)

Ans ⇒ We know that, Torque

$$T = K \frac{s E_2^2 R_2}{R_2^2 + (s x_2)^2} \quad \text{OR} \quad T \propto \frac{s R_2}{R_2^2 + (s x_2)^2}$$

∵ for constant supply E_2 is constant.

⇒ Now we know that the slip lies between 0 to 1. So the graph obtained by plotting torque against the slip between $s = 0$, to $s = 1$ is called torque slip characteristics.

⇒ Now this whole slip region is divided in to two parts.

① Low slip region ⇒ 's' is very very small. Therefore $(s x_2)^2$ is also very small as compare to $(R_2)^2$ and that can be neglected.

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

So torque is directly proportional to slip. It is the graph showing straight line passing through origin. this region of operation is know as stable region.

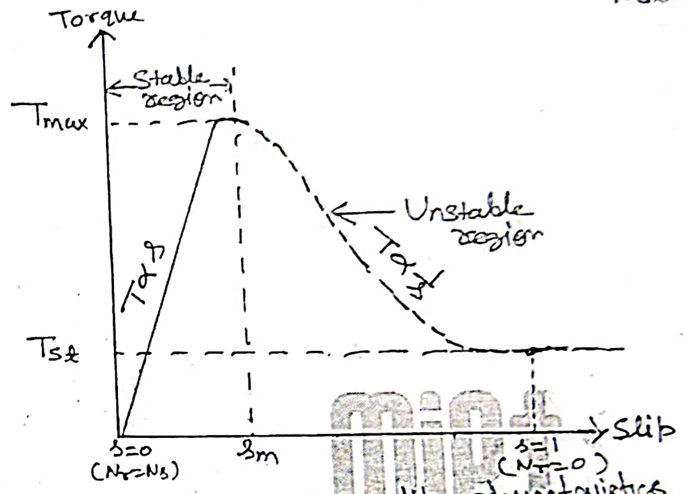
② High slip region ⇒ When slip is high i.e approaching to 1, $(s x_2)^2$ can't be neglected but $(R_2)^2$ is very small as compare to $(s x_2)^2$

$$\therefore T \propto \frac{s R_2}{(s x_2)^2} \propto \frac{1}{s} \Rightarrow \boxed{T \propto \frac{1}{s}}$$

So, in high slip region torque is inversely proportional to the slip. Hence its nature is like rectangular hyperbola. This region is known as unstable region of operation.

* At starting, $N_r = 0$ and $s = 1$, Therefore torque corresponding to slip, $s = 1$ is known as starting Torque T_{st}

T_m = maximum torque. and s_m = slip corresponding to maximum torque.



Ques ⇒ Draw the torque-slip characteristics of induction motor and show ① Motoring region ② generating region ③ Braking region (2015-16 Even)

① Motoring region ⇒ * Slip lies between 0 to 1, the machine runs as a motor

* The direction of rotor is same as that of E.M.F and $N_r < N_s$.

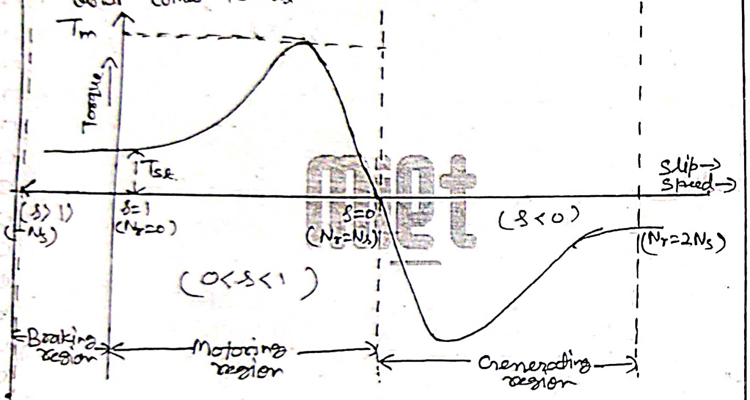
② generating region ⇒ * To run the induction machine as a generator, its slip must be negative i.e ($N_r > N_s$)

* When running as a generator it takes mechanical energy and supply electrical energy.

* The torque slip characteristics is reversed in this region.

③ Braking region ⇒ * When the slip is greater than 1, the machine works in the braking mode.

* To have slip > 1, it is obvious that the direction of rotor is opposite to R.M.F.
* In practice, two of the stator terminals are interchanged, which changes the direction of R.M.F.
* So due to this the rotor will now experience a torque which is opposite to its rotation. therefore rotor comes to rest.



Ques ⇒ A 3-phase, 440V, induction motor is wound for 4 poles and is supplied from 50Hz supply system. calculate the speed of the motor when slip is 5% (2018-19 Even)

Ans ⇒ Given $V_L = 440V$, $P = 4$, $f = 50Hz$, $s = 5\% = 0.05$, $N_r = ?$

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

$$\therefore N_r = N_s(1-s) = 1500\,(1-0.05)$$

$$\boxed{N_r = 1425 \text{ rpm}}$$ Ans

Ques ⇒ The induced emf between the slip-ring terminals of a 3-phase induction motor, when the rotor is stand still is 100V, The rotor winding are star connected and have resistance and stand still reactance of 0.05Ω and 0.1Ω per phase respectively. calculate the rotor current and phase difference between rotor voltage and current at 4% slip. (2016-17 odd)

Solution ⇒ Given $(E_2)_L = 100V$, Y conneted, $R_2 = 0.05\Omega/Ph$

$x_2 = 0.1\Omega/Ph$, $s = 4\% = 0.04$

Now $(E_2)_{Ph} = \frac{100}{\sqrt{3}} = 57.73V$

and $E_{2r} = sE_2 = 0.04 \times 57.73 = 2.31V$

Now $Z_{2r} = \sqrt{R_2^2 + (sx_2)^2} = \sqrt{(0.05)^2 + (0.04 \times 0.1)^2}$

$= 0.0516$

$\therefore I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{2.31}{0.0516}$

$I_{2r} = 45.83A$

Now $\cos\phi_{2r} = \frac{R_2}{Z_{2r}} = \frac{0.05}{0.0516} = 0.99$

$\therefore \boxed{\phi_{2r} = 4.57^\circ}$

Ques ⇒ A 6.6kV, 20-poles, 50Hz, 3 phase star connected induction motor has rotor resistance of 0.12Ω and a stand still reactance of 1.12Ω. the motor has speed of 292.5 rpm at full load. Calculate the slip at maximum torque. (2014-15 odd)

Solution ⇒ $V_L = 6.6kV$, Star connected, $P = 20$, $f = 50Hz$

$R_2 = 0.12\Omega$, $x_2 = 1.12\Omega$, $N_r = 292.5$ rpm $s_m = ?$

at maximum torque slip $s_m = \frac{R_2}{x_2} = \frac{0.12}{1.12}$

$s_m = 0.107$

$\boxed{\% s_m = 10.71\%}$ Ans

V.Imp.

Ques ⇒ A 3-phase 4 pole induction motor is supplied from 3-phase 50 Hz supply. calculate : (a) N_s (b) Rotor speed when slip is 4%. (c) Rotor frequency when rotor runs at 60 rpm. (2013-14 Even)

Solution ⇒ Given $P = 4$, $f = 50Hz$, $s = 4\%$.

(1) Now $N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500\ rpm$.

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

(2) $N_r = N_s(1-s)$

$1500(1-0.04)$

$$\boxed{N_r = 1440\ rpm}$$

(3) $N_r = 60\ rpm$

$\therefore s = \frac{N_s - N_r}{N_s} = \frac{1500-600}{1500}$

$= 0.96$

$\therefore$ rotor frequency

$f_r = sf$

0.96×50

$\therefore \boxed{f_r = 48 Hz}$

Imp.

Ques ⇒ How to reverse of rotation of 3-ϕ Im (Induction motor). (2018-19)

Ans ⇒ By interchanging any two terminals of stator winding which is connected to 3ϕ AC supply, the direction of RMF get reversed. Due to this the direction of rotation of 3-ϕ induction motor gets reversed.

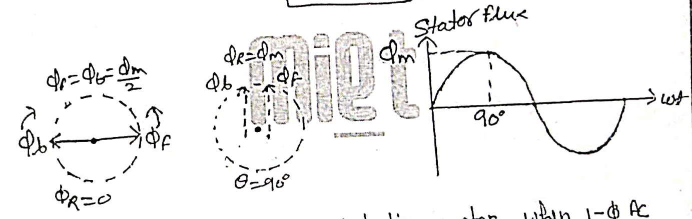
SINGLE PHASE INDUCTION MOTOR

Imp.

Ques ⇒ With the help of double revolving field theory explain that single phase induction motor is not self-starting. List the various methods of starting. (2020-21, 19-20, 18-19, 16-17, 14-15, 13-14)

Ans ⇒ Double revolving field theory ⇒ According to this theory, any alternating quantity can be resolved into two rotating components which rotates in opposite direction with same speed (N_s) and each having magnitude as half of the maximum magnitude of alternating quantity.

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



⇒ In case of single phase induction motor, when 1-ϕ AC supply is given to stator winding, it produces an alternating magnetic field having maximum magnitude of ϕ_m.

⇒ Now according to double revolving field theory, this alternating flux can be imagined as of two rotating fluxes each having magnitude $\phi_m/2$ and rotates in opposite direction with a speed N_s.

⇒ Let ϕ_f is the forward component rotating anticlockwise direction and ϕ_b is backward component rotating in anti-clock wise direction.

⇒ Now, as we have two rotating fluxes ϕ_f & ϕ_b. Hence get cut by rotor. Due to this an emf induced in the rotor which circulate rotor current.

⇒ Now we know that every current carrying conductor will experience a force if it is placed in magnetic field.

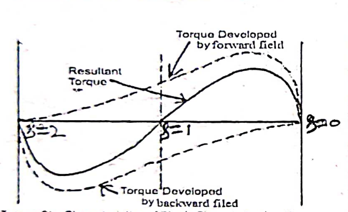
⇒ So due to ϕ_f rotor will experience a torque in anti-clockwise direction and due to ϕ_b it will experience some amount of torque in clockwise

⇒ Thus the net torque experienced by the rotor is zero at start and hence the single phase IM is not self stator.

Torque slip characteristics ⇒

⇒ The two torque which are opposite to each other and their resultat can be shown effectively with the help of torque slip characteristics.

Ques ⇒



Torque Slip Characteristics of Single Phase Induction Motor

V. Imp.

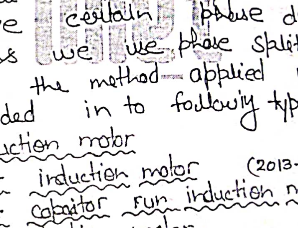
Ques ⇒ List the various methods of starting/ types of 1-ϕ induction motor. (2018-19, 16-17, 14-15, 13-14)

⇒ As we have see that 1-ϕ induction motor have zero starting torque. So it is not self starting.

So at start if rotor get some bursh in direction then it will start rotation.

⇒ So, to produce starting torque we need atleast two fluxes having some phase difference between them.

$\boxed{T_{st} \propto I_0 \sin \alpha}$ $\boxed{I_{st} = I_a}$

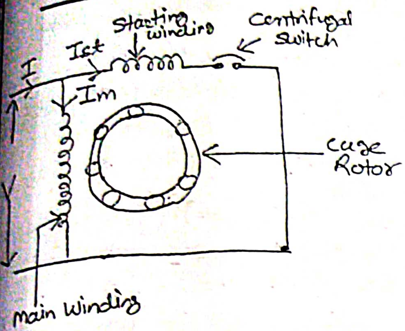


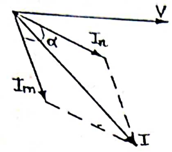
⇒ So attempt is made in single phase induction motor. To produce additional flux along with the stator flux, which must have certain phase difference between them. for this we use phase splitting technique. So according to the method applied 1-ϕ induction motor are divided in to following types.

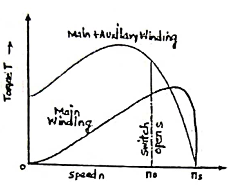
1. Split phase induction motor
2. Capacitor start induction motor (2013-14)
3. Capacitor start capacitor run induction motor
4. Shaded pole induction motor.

(1) Split Phase induction motor ⇒ * This type of motor has single phase stator winding called main winding and one more winding called auxiliary winding or starting winding.

* The starting winding is highly resistive while the main winding is highly inductive.







Let I_m = Current in main winding
I_{st} = Current in starting winding

* Now from phasor diagram, we have two current I_m & I_{st} and there exists a phase difference α b/n them

And $\boxed{I_{st} \propto I_a \sin\alpha}$

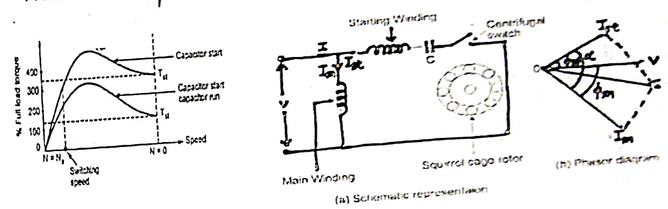
* So due to this starting torque is produced and motor runs in one particular direction.
* The auxiliary winding has a centrifugal switch in series with it. So when motor gain speed up to 70 to 80% of synchronous speed, centrifugal switch gets open. and starting winding is disconnected.

V. Imp.

② Capacitor start induction motor ⇒ * It is similar to the resistance split phase

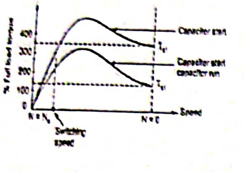
The only difference is, there is capacitor in series with auxiliary winding.

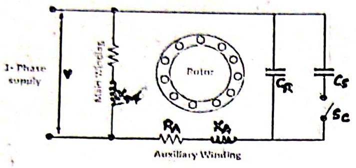
* As capacitor draws a leading current. So due to this angle between I_m and I_{st} (α) increases. Hence torque also increases.



③ Capacitor start - capacitor run induction motor ⇒

* It is similar to capacitor start induction motor. The only difference is here capacitor remains in the ckt during running condition. this will improved the P.f of motor.
* In some motors two different - 2 capacitor are use for starting & running.
* The starting capacitor along with starting winding is disconnected with the help of centrifugal switch when motor gain 70 to 80% speed.





(2020-21, 14-15).

Applications ⇒ Fans, Blowers, Compressors, grinders, refrigerators, Ac etc.

SYNCHRONOUS MOTOR

Imp.

Ques ⇒ Explain the principle of operation of 3-ϕ synchronous motor. (2020-21, 19-20, 18-19, 17-18, 16-17, 14-15, 13-14)

Ans ⇒ Working principle of synchronous motor :—

* Synchronous motor works on the principle of magnetic locking. When two magnets are brought together, the opposite poles attract each other, and the magnets are magnetically locked.
* Now if one of the magnet is rotated the other magnet also rotates in same direction, with the same speed.
* In synchronous motor, 3-ϕ supply is given to 3-ϕ stator winding of stator. So it produces R.M.F (Rotating pole) which rotates at synchronous speed N_s where $\boxed{N_s = \frac{120f}{P}}$

* Now the other magnet (electromagnet) is produced by rotor winding. So when dc supply is given to rotor winding, it magnetise the rotor core and produces rotor pole.
* Now if some how unlike poles of stator and rotor are brought near each other, the magnetic locking established between them.
* Now as stator poles are rotating with N_s speed. So rotor will also starts rotation with same speed N_s and in same direction as that of R.M.F

V. Imp.

Ques ⇒ Why synchronous motor is not self starting? Discuss various method used for starting a synchronous motor. (2020-21, 17-18, 15-16, 14-15, 13-14)

Ans ⇒ Consider a two pole synchronous motor having stator poles N_1 and S_1 and poles on rotor is N_2 and S_2

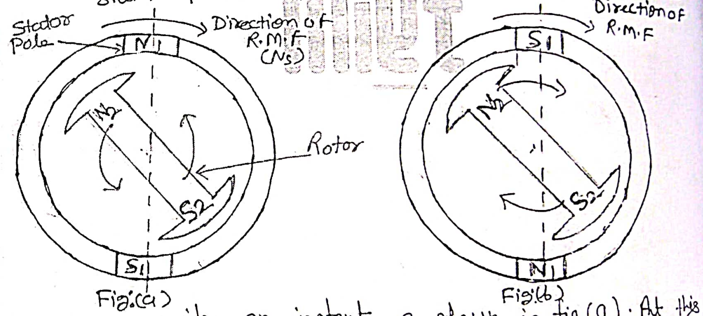


Fig.(a) Fig.(b)

* Now consider an instant as shown in fig (a). At this instant rotor is stationary and unlike poles will try to attract each other. So due to this rotor will experience a torque in anti clock wise direction.

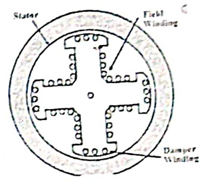
* Now stator poles are rotating very fast (at N_s rpm). So due to inertia of rotor, before rotor hardly rotates in the direction of anti-clockwise torque, stator poles changes its position as shown in fig (b)
* Now again at this instant (fig(b)) opposite poles will try to attract each other and rotor will now experience a clock-wise torque as shown in fig (b).
* Due to this the net torque acting on rotor will be zero and synchronous motor fail to start.

Methods of Starting ⇒
(A) Using pony motors
(b) Using Damper winding
(c) As a slip-ring induction motor

(a). By using pony motors ⇒ * Give 3-ϕ supply to stator winding, R.M.F will be produced.
* Now rotate the rotor with the help of external means (Pony motor) at a speed near or equal to synchronous speed.
* Now give the DC supply to rotor winding, it will produce poles on rotor.
* As rotor is also rotating with a speed nearly equal to synchronous speed. So the relative speed between stator and rotor poles is very less. Hence at some instant they will get magnetically locked.

* Now the external device used to rotate rotor can be removed. But rotor will still continue rotates at synchronous speed.

(B) By using Damper winding ⇒
* There is another winding which is placed on the tip of rotor, is used to start the synchronous motor know as damper winding.
* The ends of damper winding is short ckted with the help of end ring.
* So due to relative motor between damper winding and R.M.F emf gets induced in the damper winding which drives a current in it.



* So at starting it runs like squirrel cage induction motor and rotates with Nr speed.
* Now DC supply is given to rotor and magnetic locking stablished. There fore rotor also rotates at Ns speed Now.
* After magnetic locking the relative speed between Damper winding and R.M.F is zero. ($N_r = N_s$) So there is no emf in damper winding Now.

(c) As a slip ring induction motor ⇒ * This method is similar to damper winding method. But we can add external resistance in rotor ckt (like in slip-ring induction motor).
* So it starts just like slip ring induction motor and runs at Nr speed.
* After magnetic locking it runs at Ns speed.

Applications ⇒ (2020-21, 18-19, 15-16, 14-15)
① Power factor improvement
② Motor - generator set
③ Synchronous clock
④ Textile mills, paper mills, rolling mills etc.

5 Years AKTU University Examination Questions		Unit-4	
S. No	Questions	Session	Lecture No
1	Why commutator is needed?	2019-20 (ODD)	27-36
2	A 4-pole shunt generator with lap-connected armature has field and armature resistance of 50 Ω and 0.1 Ω respectively. If supplying power to 100W lamp load for 100 V. Calculate the armature current and the generated e.m.f. Consider a contact drop of 1V per brush.	2018-19 (ODD)	27-36
3	Write the e.m.f. equation of a DC generator.	2013-14 (EVEN)	27-36
4	Derive the expression of torque for dc motor. Also discuss the applications of it.	2019-20 (ODD)	27-36
5	How can we change the direction of rotation of DC motor?	2018-19 (ODD)	27-36
6	Derive the E.M.F. equation of D.C. Generator. An 8 pole lap wound dc generator has 450 armature turns. It operates at 0.02 Wb flux per pole and runs at 1000 r.p.m. at no load. Find the emf induced by it.	2018-19 (ODD)	27-36
7	Draw and discuss the construction and principle of operation of a D.C.motor and also give some of its applications.	2017-18 (ODD)	27-36
8	Derive e.m.f. equation of D.C. machine. Also deduce the expression for torque of a dc machine.	2016-17 (EVEN)	27-36
9	What do you mean by back e.m.f in dc motor?	2016-17 (ODD)	27-36
10	Derive the expression for generated emf in DC machine. Explain the term Back E.M.F. when applied to DC motor. Briefly explain what role Back E.M.F plays in starting and running of motor.	2015-16 (ODD)	27-36
11	Derive the torque equation of a DC motor.	2014-15 (EVEN)	27-36
12	Write the expression for the induced e.m.f. and torque of DC machine. What is the value of constant relating ω and n ?	2014-15 (ODD)	27-36
13	How will you change the direction of rotation of DC motor?	2013-14 (ODD) 19-20	27-36
14	What is meant by the term speed regulation	2020-21 (ODD)	27-36

15	A 250V dc shunt motor takes 41A at full load. Resistances of motor armature and shunt field winding are 0.1 Ω and 250 Ω respectively. Find the back e.m.f. on full load. What will be generated emf, if working as generator and supplying 41A to a load at terminal voltage of 250V?	2018-19 (EVEN)	27-36
16	What is meant by the term speed regulation?	2017-18 (EVEN)	27-36
17	Give the E.M.F. equation of a D.C. generator and draw the characteristics of a D.C. series motor A 25kw, 250V, dc shunt generator has armature and field resistances of 0.06ohm and100ohm respectively. Determine the total armature power developed.	2017-18 (ODD)	27-36
18	A dc shunt generator delivers 50 kW at 250 V when running at 500 rpm. The armature and field resistances are 0.05 Ω and 125 Ω respectively. Calculate the speed of the same machine and developed torque when running as a shunt motor and taking 50 kW at 250 V.	2016-17 (EVEN)	27-36
19	Explain the speed-torque characteristics of dc shunt and series motors.	2016-17 (ODD)	27-36
20	A 120 V dc shunt motor having an armature resistance of 0.2 Ω and field resistance of 60 Ω, draw a line current 0f 40 A at full load. The brush voltage drop is 3V and rated full load speed is 1800 rpm. Calculate: (i) The speed at half load (ii) The speed at 125% of full load.	2016-17 (ODD)	27-36
21	Draw the torque v/s speed characteristics of a DC series motor and explain why motor should not be started at no load.	2015-16 (EVEN)	27-36
22	A 6-pole lap wound dc shunt motor has 250 armature conductors, a flux of 0.04 wb/pole and at 1200 rpm. The armature and field winding resistances are 1Ω and 220Ω respectively. It is connected to a 220 V DC supply. Determine: (i) Induced emf in the motor (ii) Armature current (iii) Input supply current (iv) Mechanical power developed in the motor (v) Torque developed	2015-16 (EVEN)	27-36
23	Draw speed-torque characteristics of DC series motor.	2014-15 (EVEN)	27-36
24	Classify DC motors and write current and voltage equation for each type.	2014-15 (EVEN)	27-36
25	Sketch and explain the operating characteristics of DC shunt motor.	2014-15 (ODD)	27-36
26	Why is dc series motor preferred in elevators ?	2013-14 (EVEN)	27-36
27	A dc shunt motor develops an open-ckt e.m.f. of 250 V at 1500 rpm. Find its developed torque for an armature current of 20 A.	2013-14 (EVEN)	27-36

28	A 230 V dc series motor is taking 50 A. Resistance of armature and series field winding is 0.2 Ω and 0.1 Ω respectively. Calculate :a) Brush voltage b) Back emf.	2013-14 (EVEN)	27-36
29	A 4-pole DC generator with wave connectedd armature has 41 slots and 12 conductors /slots. Armature resistaance and shunt field resistance are 0.5Ω and 200 Ω respectively. Flux/pole is 125 mWb. Speed N= 1000 r.p.m. Calculate the voltage drop across terminals. The load resistance is 10 Ω.	2013-14 (ODD)	27-36
30	Give the expression of speed in terms of poles and frequency of supply.	2019-20 (ODD)	27-36
31	Explain the working principle of three phase Induction motor.	2016-17 (ODD)	27-36
32	What are the advantages of wound rotor motors over squirrel cage motors?	2015-16 (ODD)	27-36
33	Define the term slip	2020-21 (ODD)	27-36
34	What is the relation between frequencies of stator & rotor currents? A 3-phase, 50Hz induction motor has 6 poles and operates with a slip of 5% at a certain load. Determine (i) The speed of rotor with respect to the stator. (ii) The frequency of the rotor current. (iii) The speed of the rotor magnetic field with respect to the stator.	2018-19 (ODD)	27-36
35	A 12-pole, 3-phase alternator is coupled to an engine running at 500 rpm. This alternator supplies an induction motor running at 1450 r.p.m. Find slip and number of poles of the induction motor.	2017-18 (EVEN)	27-36
36	Explain the term slip and slip speed.	2017-18 (ODD)	27-36
37	The rotor speed of 6 pole, 50 HZ induction motor is 940 rpm. Determine the percentage slip.	2014-15(ODD)	27-36
38	Define the term slip.	2013-14 (EVEN)	27-36
39	A three-phase 50 Hz, induction motor has a full-load speed of 1460 r.p.m. Calculate slip, number of poles and frequency of rotor induced e.m.f.	2013-14 (EVEN)	27-36
40	A 4-Pole , 3 phase Induction motor runs at 1440 r.p.m. Supply voltage is 500 V at 50 Hz. Mechanical power output is 20.3 Hp and mechanical loss is 2.23 H.P. Calculate: (i) Mechanical Power Developed (ii) Rotor Cu Loss (iii) Efficiency	2020-21 (ODD)	27-36
41	Draw and explain the Torque-Slip Characteristics of Three Phase Induction Motor.	2020-21 (ODD)	27-36

42	Draw the slip-torque characteristics of three phase induction motor. A 3-phase, 50 Hz induction motor has 6 poles and operates with a slip of 5 % at a certain load. Determine (i) the speed of the rotor with respect to the stator (ii) the frequency of rotor current (iii) the speed of the rotor magnetic field with respect to rotor.	2019-20 (ODD)	27-36
43	A 3-phase, 440V, induction motor is wound for 4 poles and is supplied from50Hz supply system. Calculate the speed of the motor when slip is 5%.	2018-19 (EVEN)	27-36
44	Derive and explain torque-slip Characteristics of 3-phase Induction motor.	2018-19 (EVEN)	27-36
45	Draw torque slip characteristic of 3 phase induction motor. A12 pole alternator is coupled to an engine running at 500 rpm. It supplies a 3 phase induction motor having full load speed at 1440 rpm. Find % slip and number of poles of the motor.	2017-18 (ODD)	27-36
46	The induced e.m.f between the slip-ring terminals od a 3-phase induction motor, when the rotor is stand still is 100V. The rotor winding are star connected and have resistance and stand still reactance of 0.05Ω and 0.1Ω per phase respectively. Calculate the rotor current and phase difference between rotor voltage and current at 4% slip.	2016-17 (ODD)	27-36
47	Draw slip v/s torque characteristics of a three phase induction motor and indicate: (i) Stable operating zone (ii) Induction generator operating zone.	2015-16 (EVEN)	27-36
48	Explain the working of 3 phase induction motor. What is meant by slip? Explain Torque-Slip characteristics of 3-phase induction motor	2015-16 (ODD)	27-36
49	Draw and explain the torque-slip characteristics of a three phase induction motor.	2014-15 (EVEN)	27-36
50	A 6.6 kV, 20-poles, 50Hz, 3 phase star connected induction motor has rotor resistance of 0.12 Ω and a stand still reactance of 1.12Ω. The motor has speed of 292.5 rpm at full load. Calculate the slip at maximum torque.	2014-15 (ODD)	27-36
51	A 3-phase 4 pole induction motor is supplied from 3-phase 50 Hz supply. Calculate: (a) Ns (b) Rotor speed when slip is 4 % (c) Rotor frequency when rotor runs at 60 r.p.m.	2013-14 (EVEN)	27-36
52	Explain working of 3-phase induction motor. Also draw torque-slip characteristics showing operating regions.	2013-14 (ODD)	27-36
53	Write applications of Single Phase Induction Motor.	2020-21 (ODD),14-15	27-36
54	Why Single Phase induction motor is not self starting. What are different methods to make self starting. Explain one of them.	2020-21(ODD),19-20,18-19,16-17,14-15,13-14	27-36

55	Write down the application of Synchronous Motor.	2020-21 (ODD), 18-19,15-16, 14-15	27-
56	Why Synchronous motor is not self starting?	2019-20 (ODD) 14-15	27
57	Explain the principle of operation of a 3-phase synchronous motor.	2017-18 (EVEN) 14-15, 13-14	2
58	Explain why a synchronous motor does not develop starting torque.	2016-17 (ODD)	2
59	Why a three phase synchronous motor is not self-starting? Discuss use of damper winding for starting a synchronous motor.	2015-16 (EVEN)	
60	Write a short note on synchronous condenser.	2013-14 (EVEN)	
61	Name two motors used for constant speed operation.	2013-14 (EVEN)	