GATE

2019

ELECTRICAL MACHINE

ELECTRICAL MACHINE

ECG Publications

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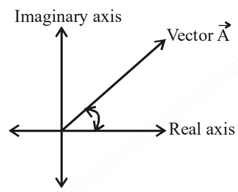
CHAPTER - 1
TRANSFORMERS

1.1 PHASOR DIAGRAMS



Phasor Diagram of vector A

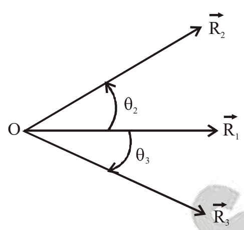
Phasor rotating vector

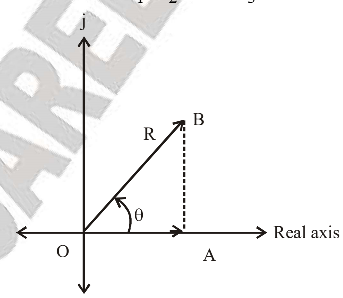
1. If all vectors are rotating at same frequency then only phase difference and amplitude of vector is to be known for vector operation.

2. Angle measured in counter clock- wise (ccw) direction are positive.

3. Angle measured in clock wise (cw) directions are negative.

4. If $\vec{R}_1$ is taken as reference then angle of $\vec{R}_1$ is Zero (0°). $\vec{R}_2$ vector is ahead or leading $\vec{R}_1$ by θ_2° and vector $\vec{R}_3$ is lagging $\vec{R}_1$ by θ_3°. And the vector R_1 R_2 and R_3 will be represented as :





$R_1 \angle 0°$, $R_2 \angle \theta_2°$ and $R_3 \angle -\theta_3°$

5. In phasor form always RMS values of amplitudes are taken.

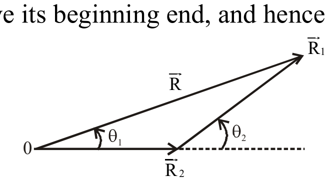
6. Adding or subtracting vectors.

Let $\vec{R} = \vec{R}_1 + \vec{R}_2$ is to be find out.

I. Place or draw $\vec{R}_1$

$$0 \longrightarrow \bar{R}_1$$

II. At the end of $\vec{R}_1$, $\vec{R}_2$ will have its beginning end, and hence join the ends of R_1 and R_2 as:



7. $|R| \angle\theta$ is represented on axis as the length of OB is equal to magnitude of $\vec{R} = |R|$

GATE QUESTIONS

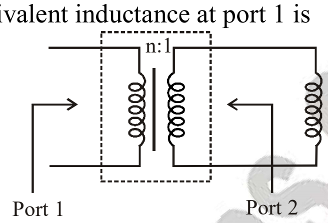
1. A three – phase, three winding Δ/Δ/Y (1.1 kV/6.6kV/400V) transformer is energized from AC mains at the 1.1 kV side. It Supplies 900 kVA load at 0.8 power factor lag from the 6.6 kV winding and 300 kVA load at 0.6 power factor lag from the 400V winding. The RMS line current in ampere drawn by the 1.1 kV winding from the mains is _____.

[GATE - 2017]

2. If the primary line voltage rating is 3.3 kV(Y side) of a 25 kVA, Y-Δ transformer (the per phase turns ratio is 5;1), then the line current rating of the secondary side (in Ampere) is _____.

[GATE - 2017]

3. If an ideal transformer has an inductive load element at port 2 as shown in the figure below, the equivalent inductance at port 1 is



[GATE - 2016]

(a) nL (b) n^2 L
(c) n/L (d) n^2/L

4. A single phase 400V, 50Hz transformer has no iron loss of 5000 W at the rated condition. When operated at 200V, 25Hz, the iron loss is 2000 W. when operated at 416V, 52Hz the value of the hysteresis loss divided by the eddy current loss is ____

[GATE - 2016]

5. A single – phase 22kVA, 220 V/220V, 50Hz, distribution transformer is to be connected as an auto transformer to get an output voltage of 2420V. Its maximum kVA rating as an auto- transformer is

[GATE - 2016]

(a) 22 (b) 24.2
(c) 242 (d) 2420

6. A single phase 2 kVA, 100/200 V transformer is reconnects as an auto – transformer such that its kVA rating is maximum. The new rating, in kVA, is ________.

[GATE - 2016]

7. Three single phase transformers are connected to form a delta – star three - phase transformer of 110 kV/11kV. The transformer supplies at 11 kV a load of 8 MW at 0.8p.f lagging to a nearby plant. Neglect the transformer losses. The ratio phase currents in delta side to star side is

[GATE - 2016]

(a) $1:10\sqrt{3}$ (b) $10\sqrt{3}:1$
(c) 1 : 10 (d) $\sqrt{3}:1$

8. For a specified input voltage and frequency, if the equivalent radius of the core of a transformer is reduced by half, the factor by which the number of turns in the primary should change to maintain the same no load current is

[GATE - 2014]

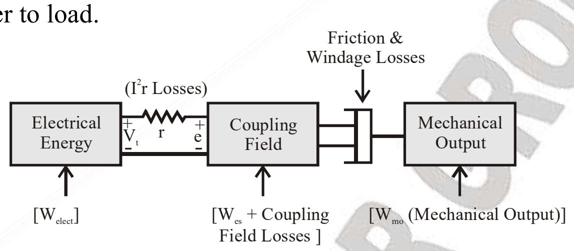
(a) 1/4 (b) 1/2
(c) 2 (d) 4

9. The core loss of a single phase, 230/115V, 50Hz power transformer is measured from 230 V side by feeding the primary (230 V side) from a variable voltage variable frequency source while keeping the secondary open circuit. The core loss is measured to be 1050 W for 230 V, 50 Hz input. The core loss is again measured to be 500W for 138 V, 30 Hz input. The hysteresis and eddy current losses of the transformer for 230 V, 30 Hz input. The hysteresis and eddy current losses of the transformer for 230 V, 50 Hz input are respectively.

CHAPTER - 2
BASICS OF ENERGY CONVERSION & ROTATING MACHINES

2.1 INTRODUTION

For conversion of energy from electrical to mechanical and mechanical to electrical, there must be coupling field, the coupling field must react in such a way that over all conversion draws energy from source and deliver to load.



$W_{elect} = W_{fld} + W_{mech.}$

$dW_{elect} = dW_{fld} + dW_{mech.}$

2.2 COUPLING FIELD

Coupling field is the link between electrical and mechanical system and energy stored in coupling field produces action and reaction on electrical and mechanical system.

This Coupling field may be magnetic or electrostatic field, but capacity of magnetic field to store energy is 25000 times more than electrostatic energy.Thus, magnetic field is used as coupling field.

Electrical input = e i dt

$$dW_{elec.} = i.e.dt\left[\because e = \frac{d\psi}{dt} \Rightarrow edt = d\psi\right]$$

$$dW_{elec.} = id\psi$$

Where ψ is flux linkage

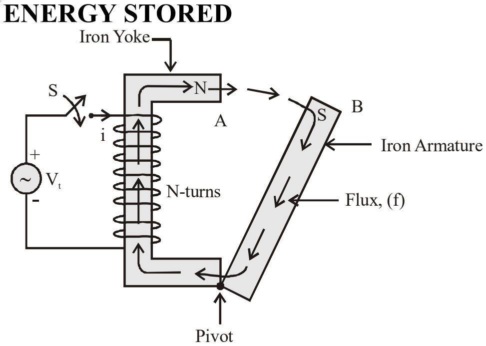
$\psi = Li = N\phi$

$\Rightarrow$ $d\, w_{elec} = I\, d(N\,\phi) = iNd\phi$

$\Rightarrow$ $d\, W_{elec} = F\, d\phi$

Where F is magnetomotive force

2.3 MAGNETIC FIELD ENERGY STORED



GATE QUESTIONS

1. The flux linkage (λ) and current (i) relation for an electromagnetic system is $\lambda = -(\sqrt{i})/g$. When i = 2A and g (air gap length) = 10 cm, the magnitude of mechanical force on the moving part, in N, is_______

[GATE - 2016]

2. Match List-I with List-II and select the correct answer using the code given below the lists

List-I
A. Magnetic flux
B. Magneto motive force
C. Reluctance
D. Permeability

List-II
(i) Resistance
(ii) Electric current
(iii) Conductivity
(iv) Electromotive force

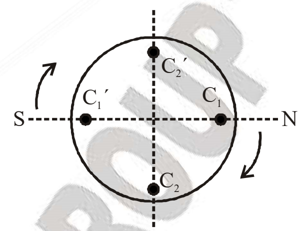
Codes: **[GATE - 2012]**
(a)A-ii, B-i, C-iv, D-iii
(b)A-iii, B-i, C-iv, D-ii
(c)A-ii, B-iv, C-i, D-iii
(d) A-iii, B-iv, C-i, D-ii

3. Distributed winding and short chording employed in AC machines will result in

[GATE - 2009]

(a) Increase in emf and reduction in harmonics
(b) Reduction in emf and increases in harmonics
(c) Increase in both emf and harmonics
(d) Reduction in both emf and harmonics

4. Two magnetic poles revolve around a stationary armature carrying two coil (c_1-c_1'.c_2-c_2') as shown in the figure. Consider the instant when the poles are in a position as shown .Identify the correct statement regarding the polarity of the induced emf at this instant in coil sides c_1 and c_2



[GATE - 2005]

(a) ⊙ in c_1 , no emf in c_2
(b) ⊗in c_1 , no emf in c_2
(c) ⊙ in c_2 , no emf in c_1
(d) ⊗ in c_2 , no emf in c_1

5. For a linear electromagnetic circuit , the following statement is true

[GATE - 2004]

(a) Field energy is equal to the co-energy
(b) Field energy is greater than the co- energy
(c) Field energy is lesser than the co-energy
(d) Co-energy is zero

6. A rotating electrical machine having its self inductances of both the stator and the rotor windings, independent of the rotor position will be definitely not develop.

[GATE - 2004]

(a) Starting torque
(b) Synchronizing torque
(c) Hysteresis torque
(d) Reluctance torque

7. When stator and rotor windings of a 2-pole rotating electrical machine are excited, each would produce a, sinusoidal mmf. Distribution in the air gap with peak value F_s and F_r respectively. The rotor mmf lags the stator

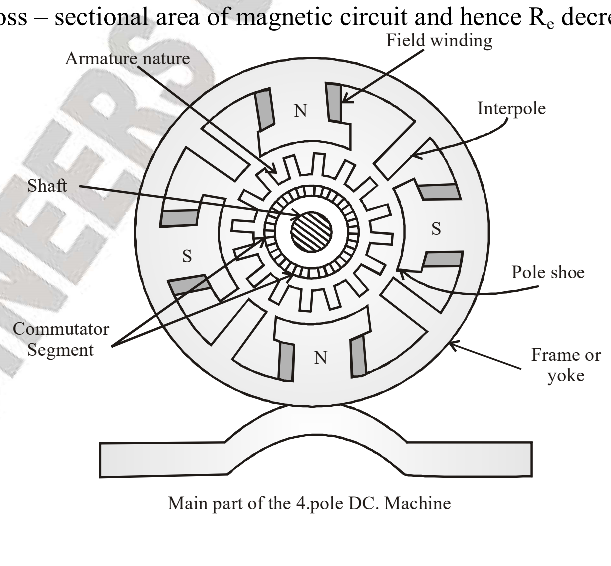
CHAPTER - 3
D.C MACHINE

3.1 BASIC STRUCTURE OF ELECTRIC MACHINE
1. Stator: Stationary part and normally is the outer frame of the machine.
2. Rotor: Rotating part and generally inner part of the machine.
3. Armature Winding: The winding in which voltage is induced.
4. Field Winding: The winding through which a current is passed to produce the main flux.

3.2 TYPES OF D.C MACHINE
1. D.C Generator: It convert mechanical energy into electrical energy.
2. D.C Motor: It converts electrical energy into mechanical energy.

3.3 D.C MACHINE CONSTRUCTION
D.C. Machine consists of three main parts:
1. Magnetic field system
2. Armature
3. Commutator and brush gear.

1. Magnetic Field System
(i) It is the fixed or stationary part of the machine.
(ii) It produces the main magnetic flux.
(iii) The field winding is placed on poles, projected inward and hence they are called salient poles with poles with pole shoes.
(iv) Pole shoe serve two purposes:-
(a) It supports the field coils
(b) It increase the cross – sectional area of magnetic circuit and hence R_e decreases



Main part of the 4.pole DC. Machine

GATE QUESTIONS

1. A separately excited DC generator supplies 150A to a 145 VDC grid. The generator is running at 800 RPM. The armature resistance of the generator is 0.1Ω. If the speed of the generator is increased to 1000 RPM, the current in amperes supplied by the generator to the DC grid is ______.

[GATE - 2017]

2. A 220V DC series motor runs drawing a current of 30A fro mthe supply. Armature and field circuit resistances are 0.4Ω and 0.1Ω, respectively. The load torque varies as the square of the speed. The flux in the motor may be taken as being proportional to the armature current. To reduce the speed of the motor by 50% the resistance in ohms that should eb added in series with the armagure is _____. (Given the answer up to two decimal places)

[GATE - 2017]

3. A 120 V DC shunt motor takes 2 A at no load. It takes 7A on full load while running at 1200 rpm. The armauture resistance is 0.8Ω and the shunt field resistance is 240Ω. The no load speed, in rpm, is ________

[GATE - 2017]

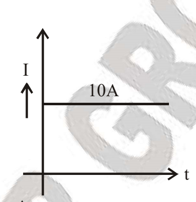
4. A 220V, 10 kW, 900 rpm separately excited DC motor has an armature resistance R_a = 0.02Ω. When the motor operates at rated speed and with rated terminal voltage, the electromagnetic torque developed by the motor is 70Nm. Neglecting the rotational losses of the machine, the current drawn by the motor from the 220V supply is

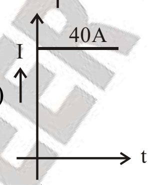
[GATE - 2017]

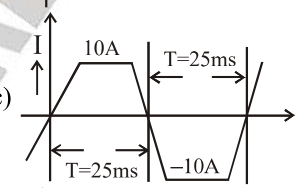
(a) 34.2 A
(b) 30A
(c) 22A
(d) 4.84 A

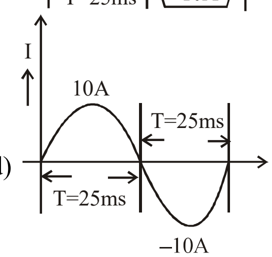
5. A 4-pole, lap – connected separately excited dc motor is drawing a steady current of 40A while running at 600 rpm. A good approximation for the waveshape of the current in an armature conductor of the motor is given by

[GATE - 2016]

(a)


(b)


(c)


(d)


6. A DC shunt generator delivers 45 A at a terminal voltage of 220 V. The armature and the shunt field resistances are 0.01Ω and 44Ω respectively. The stray losses are 375 W. the percentage efficiency of the DC generator is ____.

[GATE - 2016]

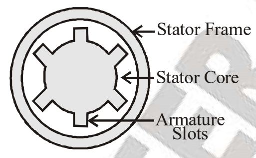
7. A three-phase, 50Hz salient-pole synchronous motor has a per – phase direct-axis reactance (X_d) of 0.8 pu and a per phase

CHAPTER - 4
SYNCHRONOUS MACHINE

4.1 INTRODUCTION
4.1.1 Construction and Working Principle
A synchronous machine essentially consists of two parts.
1. Armature (Rotor)
2. Field Magnet System

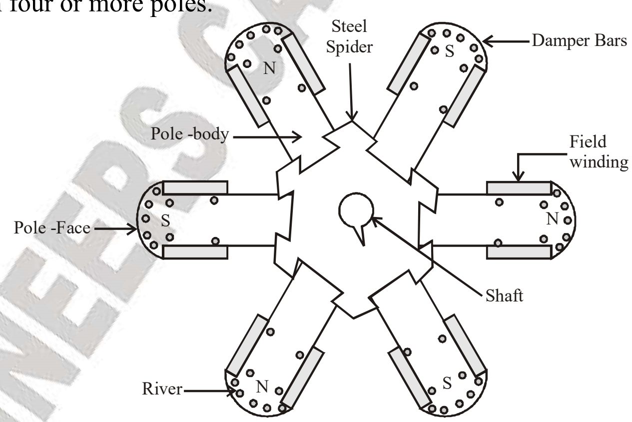
An alternation may be constructed with either the armature or the field structure as the revolving system. Stator is the stationary part of the machine it carries the armature winding in which the voltage is generated and hence output is taken from stator. The rotor is the rotating part of the machine. The rotor produces the main field flux.

1. *Stator Construction*
It includes the frame, stator core, stator windings and cooling arrangement, where frame may be of cast iron for small size machines.



2. *Rotor Construction*
There are two types of rotor constructions namely salient-pole type and cylindrical rotor type.

4.2 SALIENT POLE TYPE
Consists of poles projecting out from the surface of rotor core. Salient pole rotors are normally used for rotors with four or more poles.



Six Pole Salient Pole Rotor

4.2.1 Six Pole Salient Pole Rotor
Salient pole rotors have concentrated winding on the poles. And it has generally non-uniform air gap. And hence pole phases are so formed that this non-uniform flux becomes sinusodially which

GATE QUESTIONS

1. Two parallel connected, three - phase, 50Hz, 11kV, star - connected synchronous machines A and B, are operating as synchronous condensers. They together supply 50MVAR to a 11kV grid. Current supplied by both the machines are equal. Synchronous reactance's of machine A and machine B are 1Ω and 3Ω, respectively. Assuming the magnetic circuit to be linear, the ratio of excitation current of m machine A to that of machine B is _____.(given the answer up to two decimal places).

[GATE - 2017]

2. A three - phase, 50hz, star - connected cylindrical - rotor synchronous machine is running as a motor. The machine is operated from a 6.6kV grid and draws current at unity power factor (UPF). The synchronous reactance of the motor is 30Ω per phase. The load angle is 30°. The power delivered to the motor in kW is ________ (Give the answer up to one decimal place)

[GATE - 2017]

3. Two generating units rated 300MW and 400MW have governor speed regulation of 6% and 4% respectively from no load to full load. Both the generating units are operating in parallel to share a load of 600MW. Assuming free governor action, the load shared by the larger units is ____ MW.

[GATE - 2017]

4. A 25 kVA, 400V, Δ - connected, 3-phase, cylindrical rotor synchronous generator requires a field current of 5A to maintain the rated armature current under short – circuit condition. For the same field current, the open – circuit voltage is 360V. Neglecting the armature resistance and magnetic saturation, its voltage regulation (in % with respect to terminal voltage), when the generator delivers the rated load at 0.8 pf leading at rated terminal voltage is _____.

[GATE - 2017]

5. A 3-phase, 2-pole, 50hz, synchronous generator has a rating of 250 MVA, 0.8 pf lagging. The kinetic energy of the machine at synchronous speed is 100MJ. The machine is running steadily at synchronous speed and delivering 60MW power at a power angle of 10 electrical degrees. If the load is suddenly removed, assuming the acceleration is constant for 10 cycles, the value of the power angle after 5 cycles is _____ electrical degrees.

[GATE - 2017]

6. A star connected 400 V, 50 Hz, 4 pole synchronous machine gave the following open circuit and short circuit test results;'

Open circuit test : $V_{\propto}$ = 400V (rms, line –to – line) at field current,

$I_f = 2.3$ A

Short circuit test: $I_{sc} = 10$ A (rms, phase) at field current.

$I_f = 1.5$ A

The value of per phase synchronous impedance in Ω at rated voltage is ____.

[GATE - 2014]

7. A three phase synchronous generator is to be connected to the infinite bus. The lamps are connected as shown in the figure for the synchronization. The phase sequence fo bus voltage is R–Y–B and that of incoming generator voltage is R′ – Y′ – B′.

CHAPTER - 5
INDUCTION MOTOR

5.1 INTRODUCTION
5.1.1 Stator Emf
In general emf induced in coil
$E = K_w N_{phs} \phi_p \omega_r \sin(\omega_r t - \pi/2)$
E is Induced emf
K_w is Winding factor
N_{phs} is Number of seires turns per phase
ϕ_p is Flux per pole
ω_r is Relative angular velocity
$\sin(\omega_r t - \pi/2)$
$\therefore$ Induced emf in stator
$E_s = K_{ws} N_{phs} \phi_p \omega_s$
Induced emf in rotor, at stand still
$E_r = K_{ws} N_{phr} \phi_p \omega_r$
Instantaneous emf induced in rotor
$K_{wr} N_{phs} \phi(\omega_s - \omega_r)\sin[(\omega_s - \omega_r)t - \pi/2]$
Rotating field rotates at synchronous speed cuts the rotor bar conductors which generates emf and as rotor conductors are short circuited hence current will flow in it, which produces its own emf and interaction of these two emf. produces torque. As per Lenzes Law, the effect opposes the cause, here effect is rotation of rotor and causes is relative velocity between fields.
$\therefore$ Rotor rotates in direction as to decrease the relative velocity.
$\omega_s - \omega_r$ is slip speed
Where relative velocity = slip speed ,
$$S(\text{slip}) = \frac{\omega_s - \omega_r}{\omega_s} = \frac{N_s - N_r}{N_s} = \frac{\text{Relative speed}}{\text{Synchronous speed}}$$
$N_r = (1 - S) N_s$
$= K_{wr} N_{phs} \phi S \omega_s \sin[t - \pi/2]$
$\therefore$ Frequency and amplitude of rotor emp. Both becomes S-times the stator amplitude and frequency.
If (At stand still), S = 1, $E_r = E_2$, $f_r = f_2$ then at any slip say S, $E_r = SE_2$, $f_r = Sf_2$

5.2 CONSTRUCTIONAL FEATURES
5.2.1 Stator
Frame made-up of cost iron. Stator core made-up of laminated steel i.e., bearing, slip ring and shaft. 3– phase uniformly distributed winding electrically spread 120°.

GATE QUESTIONS

1. A 4 pole induction machine is working as an induction generator. The generator supply frequency is 60Hz. The rotor current frequency is 5Hz. The mechanical speed of the rotor in RPM is

[GATE - 2017]

(a) 1350 (b) 1650
(c) 1950 (d) 2250

2. A 3-phase, 50Hz generator supplies power of 3MW at 17.32 kV to a balanced 3-phae inductive load through an overhead line. The per phase line resistance and reactacne are 0.25Ω and 3.925Ω respectively. If the voltage at the generator terminal is 17.87 kV, the power factor of the load is ______.

[GATE - 2017]

3. A star – connected, 12.5 kW, 208V (line), 3-phase, 60hz squirrel cage induction motor has following equivalent circuit parameters per phase referred to the stator. $R_1 = 0.3\Omega$, $R_2 = 0.3\Omega$, $X_1 = 0.41\ \Omega$, $X_2 = 0.41\Omega$. neglect shunt branch in the equivalent circuit. The starting current (in Ampere) for this motor when connected to an 80V (line), 20Hz, 3-phase, AC source is ______

[GATE - 2017]

4. A 3-Phase, 4-pole, 400V, 50Hz 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

5. The starting line current of a 415 V, 3-phase delta connected induction motor is 120A, when the rated voltage is applied to its stator winding. The starting line current at a reduced voltage of 110V, in ampere, is ____

[GATE - 2016]

6. A 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 - 2016]

7. A 3-Phase , 50 Hz, six pole induction motor has a rotor resistance of 0.1Ω and reactance of 0.92Ω. 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

8. A three – phase , 4 pole, self exited induction generator is feeding power to a load at a frequency f_1. If the load is partially removed, the frequency becomes f_2. If the speed of the generator is maintained at 1500 rpm in both the cases, then

[GATE - 2014]

(a) f_1, f_2 >: 50 Hz and $f_1 > f_2$
(b) $f_1 < 50$ Hz and $f_2 > 50$ Hz
(c) f_1, $f_2 < 50$ Hz and $f_2 > f_1$
(d) $f_1 > 50$ Hz and $f_2 < 50$ Hz

9. In a synchronous machine, hunting is predominantly damped by

[GATE - 2014]

(a) Mechanical losses in the rotor
(b) Iron losses in the rotor
(c) Copper losses in the stator
(d) Copper losses in the rotor

10. Leakage flux in an induction motor is

[GATE - 2013]

(a) Flux that leaks through the machine
(b)Flux that links both stator and rotor windings
(c)Flux that links none of the windings
(d)Flux that links the stator winding or the rotor winding but not both

SOLUTIONS

Sol.1. (c)

Supply frequency (f_1) = 60Hz & Pole = 4

$$\therefore\ N_s = \frac{120f}{P} = \frac{120\times 60}{4} = 1800\text{rpm}$$

Rotor frequency (f_2) = 5hz

We know tht $f_2 = sf_1$

5 = (s) (60) $\Rightarrow$ 0.0833

But in induction generator, slip is a negative value

$$\Rightarrow\ -0.0833 = \frac{1800 - N_r}{1800}$$

$\Rightarrow N_r$ = 1950 rpm

Sol.2. (0.8083)

$|V_s|$ = 17.87 kV

$|V_r|$ = 17.32 kV

R = 0.25Ω

X_L = 3.925 Ω

$$Z = \sqrt{0.25^2 + 3.925^2}$$

= 3.933 Ω

$$P_r = \frac{17.87\times 17.32}{3.933}\cos(\theta-\delta) - \frac{0.25(17.32)^2}{3.933^2}$$

$$3 = \frac{17.87\times 17.32}{3.933}\cos(\theta-\delta) - \frac{0.25(17.32)^2}{3.933^2}$$

$\text{Cos}(\theta - \delta) = 0.0997$

$(\theta - \delta) = 84.276°$

$$Q_r = \frac{|V_s||V_r|}{|Z|}\sin(\theta-8) - \frac{X|V_r|^2}{|Z|^2}$$

$$= \frac{1787\times 17.32}{3.933}\sin(84.276) - \frac{3.925\times 17.32^2}{3.933^2}$$

= 2.18483 VAR

$$pf = \cos\tan^{-1}\left(\frac{Q_r}{P_r}\right)$$

$$= \cos\tan^{-1}\left(\frac{2.18483}{3}\right)$$

= 0.8083 lag

Sol.3. (70.19 A)

Given parameters of star –connected SCIM at 60Hz are

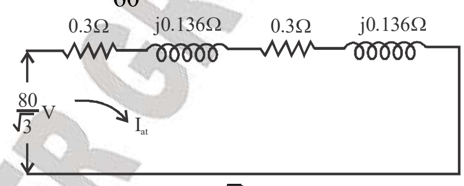
$r_1 = 0.3\Omega$, $r_2 = 0.3\Omega$

$X_1 = 0.41\Omega$, $X_2 = 0.41\ \Omega$

Now, if frequency changed to 20Hz, leakage reactance magnitude will change.

$$\therefore\ X_{1(new)} = \frac{20}{60}(0.41) = 0.136\Omega$$

$$\therefore\ X_{2(new)} = \frac{20}{60}(0.41) = 0.136\Omega$$



$$I_{st} = \frac{80/\sqrt{3}}{\sqrt{(0.3+0.3)^2 + (0.136+0+36)^2}}$$

= 70.19A

Sol.4. (c)

A 3–ϕ, 4 pole, 50Hz squirrel cage induction motor operating at a slip of 0.02

$$\text{Synchronous speed} = \frac{120F}{P}\text{rpm}$$

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

$\therefore$ rotor speed = $(1 - s)N_s$

= (1 – 0.02)(1500)

= 1470 rpm

The speed of rotor field with respect to rotor is

$$= \frac{120\times sF}{P} = 30\text{rpm}$$

The speed of rotor field with respect to stator is 1470 + 30 = 1500 rpm

$$= \frac{2\pi(1500)}{60}\text{rad/sec}$$

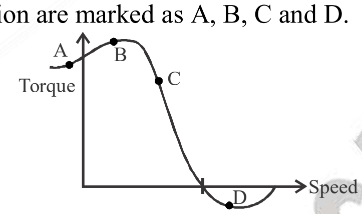
= 157.07 rad/sec

Sol.5. (31.8)

ESE OBJ QUESTIONS

1. Statement(I): A 3-phase induction motor is a self-starting machine.
Statement (II): A star-delta starter is used to produce starting torque for the induction motor.
[ESE - 2017]
(a)Both Statement (I) and Statements(II) are individually true and Statements (II) is the correct explanation of Statement (I)
(b)Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
(c)Statement (I) is true but Statement (II) is false.
(d)Statement (I) is false but Statement (II) is true

2. 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?
[ESE - 2017]
(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

3. A 3-phase, 460 v, 6 pole, 60 Hz cylindrical rotor synchronous motor has a synchronous reactance of 2.5Ω and negligible armature resistance. The load torque, proportional to the square of the speed, is 398N.m at 1200 rpm. Unity power factor is maintained by excitation control. Keeping the V/f constant, the frequency is reduced to 36 Hz. The torque angle δ is
[ESE - 2017]
(a) 9.5° (b) 12.5°
(c) 25.5° (d) 30°

4. A 3-phase, induction motor operating at a slip of 5% develop 20 kW rotor power output. What is the corresponding rotor copper loss in this operating condition?
[ESE - 2016]
(a) 750 VV (b) 900 W
(c) 1050W (d) 1200W

5. Increasing the air gap of a squirrel-cage induction motor would result in
[ESE - 2016]
(a) Increasing in no-load speed
(b) Increase in full-load power factor
(c) Increase in magnetizing current
(d) Maximum available torque

6. For a 3-phase induction motor, what fraction/multiple of supply voltage is required for a direct on line starting method such that starting current is limited to 5 times the full load current and motor develops 1.5 times full load torque at starting time?
[ESE - 2016]
(a) 1.632 (b) 1.226
(c) 0.816 (d) 0.456

7. What is the material of slip rings in an induction machine?
[ESE - 2016]
(a) Carbon (b) Nickel
(c) Phosphor bronze (d) Manganese

8. The stator loss of a 3-phase induction motor is 2 kW. If the motor is running with a slip of 4% and power input of 90 kW, then what is the rotor mechanical power developed?
[ESE - 2016]
(a) 84.48 kW (b) 86.35 kW
(c) 89.72 kW (d) 90.52 kW

9. If a 3-phase slip ring induction motor is fed from the rotor side with stator winding short

CHAPTER - 6
SINGLE – PHASE INDUCTION MOTOR

6.1 SINGLE PHASE INDUCTION MOTOR

Alike 3 - ϕ I_M, 1 - ϕ IM is not self starting, and operates on poor p.f., lower capacity and reduced efficiency. It has pulsating air gap field.

For starting purposes an auxiliary winding is used and hence stator of a 1 - ϕ IM carries two windings:

1. Main or Running winding(S_M)   2. Auxiliary or starting winding(S_A)

In these motors, both main and auxiliary windings are in the circuit at the time of starting and a centrifugal switch is provided to disconnect the Auxiliary windings when rotor attains 70 to 80% of synchronous speed.

It must be noted that the space angle between (S_M) and (S_A) should be near about 90°.

6.2 REVOLVING FIELD THEORY OF SINGLE PHASE INDUCTION MOTOR

It is also called – double – revolving field theory of 1 - ϕ IM, basically states that a stationary pulsating magnetic field can be resolved into two rotating magnetic field, each of equal magnitude but rotating in opposite direction. And IM responds to each magnetic field separately, and net torque in motor is sum of the torques due to each the two magnetic fields.

Assume the stator mmf wave to be sinusoidally distributed in space and varying sinusoudally with time then,

$\therefore$ $F_S = F_{s.max} \sin \omega t.\cos\alpha$

Where $\cos\alpha$ is Distribution in space along the a is gap periphery

Where $\sin\omega t$ is Distribution in space alogn the a is gap periphery

Where $F_{s.max}$ is Peak maximum instantaneous altesnating M.M.F

Since, $\sin a \cos b = \frac{1}{2}\left[\sin(a-b) + \sin(a+b)\right]$

$$F_s = \frac{1}{2}F_{s.max.} \sin(\omega t - \alpha) + \frac{1}{2}F_{s.max.} \sin(\omega t + \alpha)$$

$\Rightarrow$ This shows that the pulsating stationary mmf wave of amplitude $F_{s.max.}$ can be resolved into, two counter rotating mmf. components of equal magnitudes as shown in figure.

At = 90° , $F_s = F_{s.max}$– At instant A and two components are = $\frac{1}{2}F_{s.max.}$

At instant B, $\omega t = \omega t_1$ from instant A

$$F_s = F_{s.max.} \sin(\omega t_1 + 90^o) = F_{s.max.} \cos\omega t_1$$

And pulsating mmf wave resolved into sinusoidal mmF. waves marked f and b, both mmf wave travelled through an angle wts to right and left respectively as :

GATE QUESTIONS

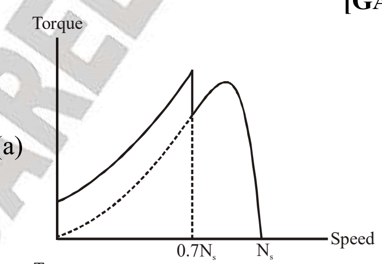
1. A 375 W, 230V, 50Hz, capacitor start single-phase induction motor has the following constants for the main and auxiliary windings (at starting): z_m = (12.50 + j15.75)Ω (main winding), Z_a = (24.50 + j12.75)Ω 9auxiliary winding). Neglecting the magnetizing branch, the value of the capacitance (in μF) to be added in series with the auxiliary winding to obtain maximum torque at staring is ____.
[GATE - 2017]

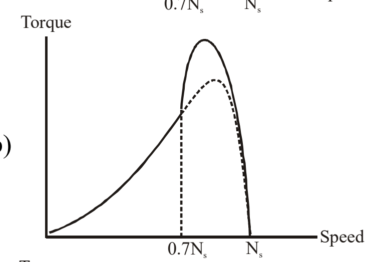
2. In a constant V/f induction motor drive, the slip at the maximum torque
[GATE - 2016]
(a)Is directly proportional to the synchronous speed.
(b)Remains constant with respect to the synchronous speed.
(c)Has an inverse relation with the synchronous speed.
(d)Has no relation with the synchronous speed.

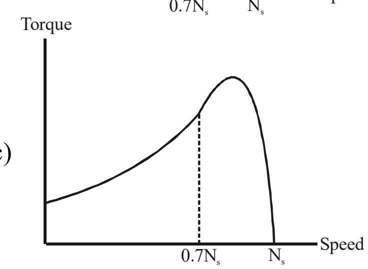
3. The direction of rotation of a single – phase capacitor run induction motor is reversed by
[GATE - 2016]
(a)Interchanging the terminals of the AC supply.
(b)Interchanging the terminals of the capacitor.
(c)Interchanging the terminal of the auxiliary winding.
(d)Interchanging the terminals of both the windings.

4. In a constant V/f control of induction motor, the ratio V/f is maintained constant from 0 to base frequency, where V is the voltage applied to the motor at fundamental frequency f. Which of the following statements relating to low frequency operation of the motor is TRUE?
[GATE - 2014]
(a)At low frequency, the stator flux increases from its rated value.
(b)At low frequency, the stator flux decrease from its rated value.
(c)At low frequency, the motor saturates.
(d)At low frequency, the stator flux remains unchanged at its rated value.

5. A single phase induction motor is provided with capacitor and centrifugal switch in series with auxiliary winding. The switch is expected to operate at a speed of 0.7 ns, but due to malfunctioning the switch fails to operate. The torque speed characteristic of the motor is represented by
[GATE - 2014]

(a)


(b)


(c)


ESE OBJ QUESTIONS

1. In a single-phase capacitor start induction motor, the direction of rotation

[ESE - 2016]

(a)Can be changed by reversing the main winding terminals.
(b)Cannot be changed.
(c)Is dependent on the size of the capacitor.
(d)Can be changed only in large capacitor motors.

2. For a given applied voltage and current , the speed of a universal motor will be

[ESE - 2015]

(a) Higher in dc excitation than in ac excitation
(b) Higher in ac excitation than in dc excitation
(c) Same in both dc and ac excitations
(d) Dangerously high in dc excitation

3. Consider the following statements :
1. Asynchronous motor has no starting torque but when started it always runs at a fixed speed
2. A single –phase reluctance motor is not self starting even if paths for eddy currents are provided in the rotor
3. A single –phase hysteresis motor is self –starting
Which of these statement(s) is /are correct ?

[ESE - 2013]

(a) 1, 2 and 3 (b) 1 only
(c) 1 and 2 only (d) 2 and 3 only

4. Why is centrifugal switch used in a $1-\phi$ induction motor?

[ESE - 2008]

(a)To protect the motor from overloading
(b)To improve the starting performance of the motor.
(c)To cut off the starting winding at an appropriate instant.
(d)To cut in the capacitor during running condition.

5. An 8-pole, $1 - \phi$ induction motor is running at 690 rpm. What is its slip w.r.t forward and backward fields, respectively.

[ESE - 2007]

(a) 0.08, 2.0
(b) 0.08, 1.92
(c) 1.92, 0.08
(d) 2.0, 0.08

6. Match List-I with List-II and select the correct answer using the code given below the lists :

List-I
A. General purpose split phase FHP motor
B. General purpose capacitor start FHP motor
C. Permanent split capacitor start FHP motor
D. Shaded pole FHP motor

List-II
(i) Refrigerator
(ii) Hair dryers
(iii) Unit Heaters
(iv) Fans, blowers

[ESE - 2007]

Codes:
(a) A-i, B-ii,C-iv, D-iii
(b) A-i, B-ii, C-iii, D-iv
(c) A-iv, B-i, C-ii, D-iii
(d) A-iv, B-i, C-iii, D-ii

7. A $1 - \phi$ induction motor is running at N r.p.m. Its synchronous speed is N_s. If its slip with respect to forward field is S, what is the slip with respect to the backward field.

[ESE - 2007]

(a) s (b) -S
(c) (1-S) (d) (2-S)

8. Which one of the following is the type of $1 - \phi$ induction motor having the highest power factor at full load?

CHAPTER - 7
SERVO AND STEPPER MOTOR

7.1 INTRODUCTION

A servo system mainly consists of three basic components - a controlled device, a output sensor, a feedback system. This is an automatic closed loop control system. Here instead of controlling a device by applying the variable input signal, the device is controlled by a feedback signal generated by comparing output signal and reference input signal. When reference input signal or command signal is applied to the system, it is compared with output reference signal of the system produced by output sensor, and a third signal produced by a feedback system. This third signal acts as an input signal of controlled device.
This input signal to the device presents as long as there is a logical difference between reference input signal and the output signal of the system. After the device achieves its desired output, there will be no longer the logical difference between reference input signal and reference output signal of the system. Then, the third signal produced by comparing theses above said signals will not remain enough to operate the device further and to produce a further output of the system until the next reference input signal or command signal is applied to the system. Hence, the primary task of a servomechanism is to maintain the output of a system at the desired value in the presence of disturbances.

7.1.1 Working Principle of Servo Motor

A servo motor is basically a DC motor(in some special cases it is AC motor) along with some other special purpose components that make a DC motor a servo. In a servo unit, you will find a small DC motor, a potentiometer, gear arrangement and an intelligent circuitry. The intelligent circuitry along with the potentiometer makes the servo to rotate according to our wishes. As we know, a small DC motor will rotate with high speed but the torque generated by its rotation will not be enough to move even a light load. This is where the gear system inside a servomechanism comes into the picture. The gear mechanism will take high input speed of the motor (fast) and at the output, we will get an output speed which is slower than original input speed but more practical and widely applicable.
Say at initial position of servo motor shaft, the position of the potentiometer knob is such that there is no electrical signal generated at the output port of the potentiometer. This output port of the potentiometer is connected with one of the input terminals of the error detector amplifier. Now an electrical signal is given to another input terminal of the error detector amplifier. Now difference between these two signals, one comes from potentiometer and another comes from external source, will be amplified in the error detector amplifier and feeds the DC motor. This amplified error signal acts as the input power of the DC motor and the motor starts rotating in desired direction. As the motor shaft progresses the potentiometer knob also rotates as it is coupled with motor shaft with help of gear arrangement. As the position of the potentiometer knob changes there will be an electrical signal produced at the potentiometer port. As the angular position of the potentiometer knob progresses the output or feedback signal increases. After desired angular position of motor shaft the potentiometer knob is reaches at such position the electrical signal generated in the potentiometer becomes same as of external electrical signal given to amplifier. At this condition, there will be no output signal from the amplifier to the motor input

GATE QUESTIONS

1. In a steeper motor , the detent torque means **[GATE - 2009]**

(a) Minimum of the static torque with the phase winding excited
(b) Maximum of the static torque with the phase winding excited
(c) Minimum of the static torque with the phase winding unexcited
(d) Maximum of the static torque with the phase winding unexcited

2. A three-phase, three stack, variable reluctance step motor has 20 poles on each rotor and stator stack .The step angle of this motor is **[GATE - 2007]**

(a) 3° (b) 6°
(c) 9° (d) 18°

3. For a given stepper motor , the following torque has the highest numerical value **[GATE - 2004]**

(a) Detent torque (b) Pull in torque
(c) Pull- out torque (d) Holding torque

4. The following motor definitely has a permanent magnet rotor **[GATE - 2004]**

(a) DC commulator motor
(b) Brushless dc motor
(c) Stepper motor
(d) Reluctance motor

5. For a 1.8°, 2-phase bipolar stepper motor, the stepping rate is 100 steps /second. The rotational speed of the motor in rpm is **[GATE - 2004]**

(a) 15 (b) 30
(c) 60 (d) 90

ESE OBJ QUESTIONS

1. A permanent magnet steeper motor with 8 poles in stator and 6 poles in rotor will have a step angle of

[ESE - 2017]

(a) 7.5° (b) 15°
(c) 30° (d) 60°

2. Which one of the following types of motors is most suitable for a computer printer drive

[ESE - 2004]

(a) Reluctance motor
(b) Hysteresis motor
(c) Shaded pole motor
(d) stepper motor

3. A certain R-L series combination is connected across a 50Hz single phase a.c supply. If the instantaneous power drawn was found to be negative for 2 milliseconds in one cycle, the 'power factor angle' of the current must be

[ESE - 2002]

(a) 9° (b) 18°
(c) 36° (d) 45°

SOUTIONS

Sol.1. (b)

Given $N_s = 8, N_r = 6$

Then step angle (β) = $\frac{(N_s - N_r)}{N_s.N_r} \times 360°$

$= \frac{(8-6)}{8\times 6}\times 360°$

$= \frac{2}{48}\times 360° = \frac{1}{24}\times 360$

$= \beta = 15°$

Sol.2. (d)

Sol.3. (c)

$\phi = \omega t = 2\times\pi\times 50\times 2\times 10^{-3} = \frac{\pi}{5} = 36°$