WINTER – 2022 EXAMINATION

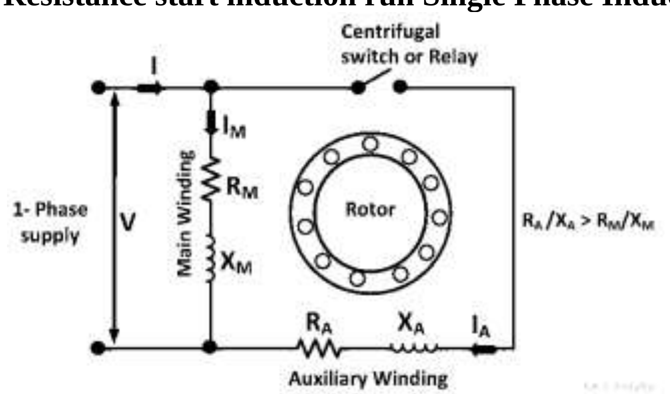
Model Answer

Subject Name: Industrial A. C. Machines

22523: IAM

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills).
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.
8) As per the policy decision of Maharashtra State Government, teaching in English/Marathi and Bilingual (English + Marathi) medium is introduced at first year of AICTE Diploma Programme from academic year 2021-2022. Hence if the students in first year (first and second semesters) write answers in Marathi or bilingual language (English +Marathi), the Examiner shall consider the same and assess the answer based on matching of concepts with model answer.

Q. No.	Sub Q. N.	Answer	Marking Scheme
1.		**Attempt any FIVE of the following:**	**10 Marks**
	a)	Define synchronous speed. Write the relationship between Ns and Nr, where symbols have their usual meaning. **Ans:** **Synchronous speed (Ns):** The synchronous speed is the speed at which rotating magnetic field rotates. It is expressed as $N_s = 120.f/P$, where f is supply frequency and P be the no. of poles. **Relationship between Ns & Nr:** Rotor speed Nr can be expressed in terms of Ns Nr = (1- s) Ns where 's' is the slip.	1 Mark 1 Mark
	b)	Draw diagram of Resistance start induction run Single Phase Induction Motor. **Ans:** **Circuit Diagram of Resistance start induction run Single Phase Induction Motor:**  	2 Marks for labelled diagram

	c)	Compare salient Rotor and cylindrical Rotor for alternator. **Ans:**	

Sr. No.	Salient-Pole rotor	Cylindrical Rotor
1	In salient pole alternator, the rotor poles are projecting out from the surface of the rotor.	In a cylindrical rotor alternator, the poles are non-projecting type.
2	The diameter of the salient-pole rotor alternator is larger than that of cylindrical rotor alternator.	The diameter of the cylindrical rotor alternator is smaller.
3	Salient-pole rotor alternator has large no. of poles.	Cylindrical rotor alternator has less no. of poles
4	The axial length of the salient-pole rotor alternator is small.	Cylindrical rotor alternator has large axial length.
5	Salient pole rotor alternator has non-uniform air gap	In cylindrical rotor alternator, the air-gap between stator and rotor is uniform
6	Salient pole alternator has less mechanical strength.	The mechanical strength of the cylindrical rotor alternator is high.
7	Salient pole rotor alternator is most suitable for low speed applications.	Cylindrical rotor alternator is suitable for high speed applications.
8	The prime movers used for driving the salient pole alternators are hydro turbines and IC engines.	The prime movers used are steam turbines in thermal, gas and nuclear power plants.

1 Mark for each of any two points = 2 Marks

d) Define chording factor and distribution factor for alternator winding.

Ans:

Chording factor:

The chording factor is the ratio of resultant emf of a short-pitched coil to resultant emf of a full pitched coil. (1 Mark)

OR

It is defined as ratio of phasor sum of induced emfs per coil to the arithmetic sum of induced emfs per coil.

Distribution factor

Distribution factor is the ratio of resultant emf of a distributed winding to resultant emf of a concentrated winding. (1 Mark)

OR

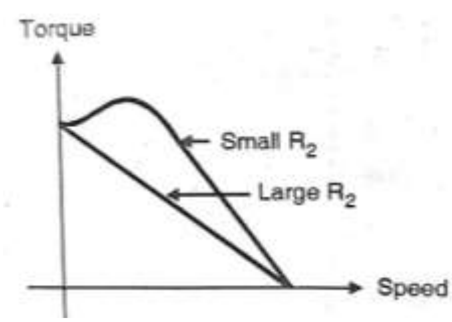
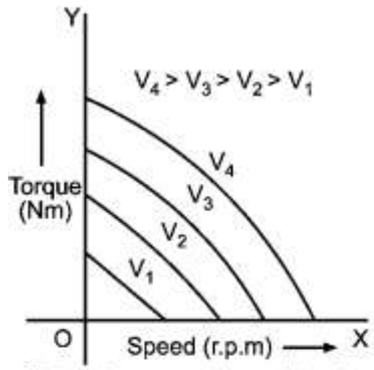
Ratio of the actual voltage obtained to the possible voltage if all the coils of a polar group were concentrated in single slot.

OR

It is defined as the ratio of the phasor sum of the emfs induced in all the coils distributed in some slots under one pole to the arithmetic sum of the emfs induced in those coils.

e) Define -

(i) Pull in Torque

		(ii) Pull out Torque in case of synchronous motor **Ans:** **Pull in torque:** The maximum torque produced at rated voltage and frequency due to which a synchronous motor will pull a connected load into synchronism when the DC excitation is applied to the motor, is known as *pull-in torque*. **Pull out torque:** The maximum value of load torque which a synchronous motor can develop at rated voltage and frequency without losing synchronism is called as *pull-out torque or breakdown torque.*	1 Mark 1 Mark
	f)	State any four applications of BLDC Motor. **Ans:** **Applications of BLDC Motor:** 1. Computer peripheral equipment 2. Spindle drives in hard disc drives in computers, 3. Turn table drives in record players, 4. Instrumentation and control systems, 5. Electric power steering, 6. Air conditioners, 7. Biomedical instrumentation 8. In the field of aerospace 9. Computer hard drives and DVD/CD players 10. Electric vehicles, hybrid vehicles, and electric bicycles 11. Industrial robots, CNC machine tools, and simple belt driven systems 12. Washing machines, compressors and dryers 13. Fans, pumps and blowers 14. Health care equipment	½ Mark for each of any four = 2 Marks
	g)	Draw the torque speed characteristics of A.C. Servo motor. **Ans:** **Torque speed characteristics of A.C. Servo motor:**  **OR**  B) Typical torque-speed characteristics of a servo motor (ac) for various control voltages,	2 Marks for labelled diagram

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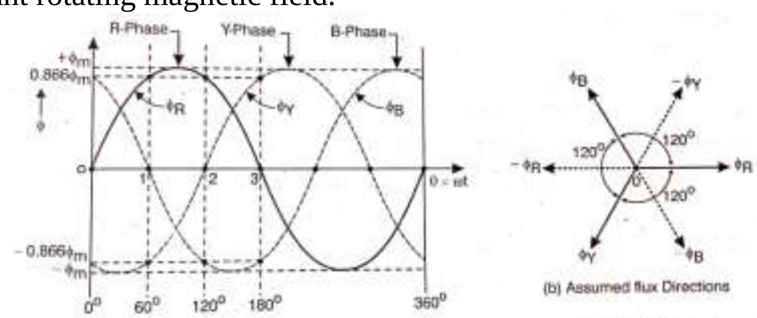
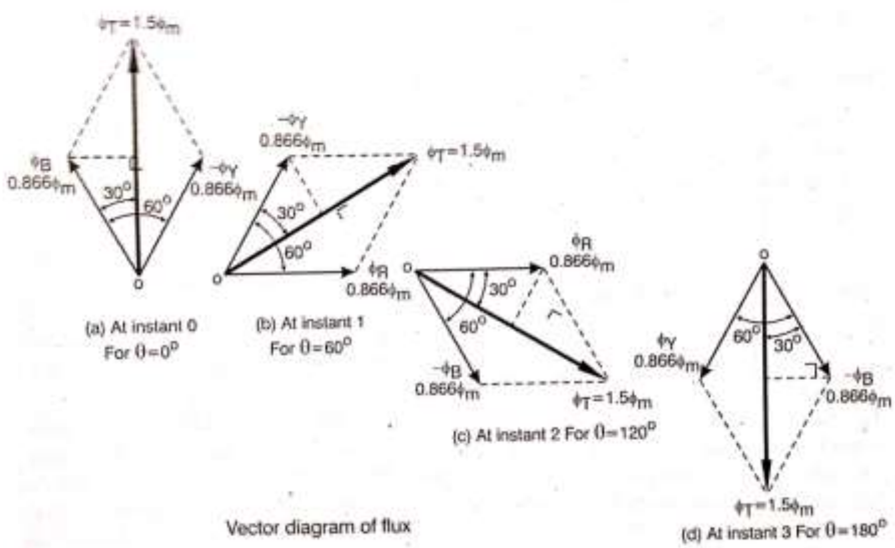
2.		**Attempt any THREE of the following:**	**12 Marks**
	a)	State any four advantages of squirrel cage induction motor over slip ring induction motor. **Ans:** **Advantages of squirrel cage induction motor over slip ring induction motor:** 1. Squirrel Cage Induction motors have rugged and robust rotor construction than slip ring induction motor. 2. Squirrel Cage induction motors are cheaper in cost compared to Slip Ring induction motors. 3. Because of the absence of slip rings and brushes, maintenance duration and maintenance cost associated with Squirrel Cage Induction motor is less than slip ring induction motor. 4. Squirrel Cage Induction Motors requires less conductor material than slip ring motor. 5. Hence copper losses in squirrel cage motors are less, resulting in higher efficiency compared to slip ring induction motor. 6. Squirrel cage motors are explosion proof due to the absence of brushes and slip rings, which eliminates the risks of sparking. 7. Squirrel Cage motors are better cooled compared to slip ring induction motors. 8. The squirrel cage rotor automatically adjust itself for same number of poles as that of stator, but the slip-ring rotor must be wound for same number of poles as that of stator.	1 Mark for each of any four advantages = 4 Marks
	b)	Explain production of Rotating Magnetic field in case of 3 phase Induction motor using vectors. **Ans:** **Production of rotating magnetic field in Three-phase Induction Motor:** In three-phase induction motor, the three-phase stator windings are displaced in space by 120° and their three-phase currents are displaced in time by 120°. So they produce the three-phase fluxes which are displaced in space by 120° and also in time by 120°. Such fluxes give rise to the resultant rotating magnetic field.  (a) Three phase flux waveform (b) Assumed flux Directions Three-phase fluxes When a three-phase supply is given to the three-phase stator winding, three-phase currents flow and three-phase fluxes, which are displaced in space and also in time by 120° are produced. The waveforms of three-phase fluxes are shown in the figure. The directions of fluxes in the air-gap are assumed as shown in the figure. The resultant total flux ϕ_T at any instant is given by the phasor sum of the three fluxes ϕ_R, ϕ_Y, and ϕ_B. The resultant flux ϕ_T can be obtained mathematically and graphically at instants 0, 1, 2 and 3 when angle θ is 0°, 60°, 120° and 180° as shown in the diagram of flux waveforms. **1) At instant 0 (θ = 0°):** $\phi_R = 0$, $\phi_Y = -0.866\ \phi_m$ and $\phi_B = 0.866\ \phi_m$ With assumed flux directions, the vector diagram for fluxes can be drawn as shown in	1 mark for flux waveform 1 mark for explanation

the figure (a). It is seen that the total flux is $\phi_T = 1.5\ \phi_m$ with direction vertically upward.

2) **At instant 1 (θ = 60°):**
$\phi_R = 0.866\ \phi_m$, $\phi_Y = -0.866\ \phi_m$ and $\phi_B = 0$
With assumed flux directions, the vector diagram for fluxes can be drawn as shown in the figure (b). It is seen that the total flux is $\phi_T = 1.5\ \phi_m$ with further clockwise rotation of 60° in the space.

3) **At instant 2 (θ = 120°):**
$\phi_R = 0.866\ \phi_m$, $\phi_Y = 0$ and $\phi_B = -0.866\ \phi_m$
With assumed flux directions, the vector diagram for fluxes can be drawn as shown in the figure (c). It is seen that the total flux is $\phi_T = 1.5\ \phi_m$ with further clockwise rotation of 60° in the space.

4) **At instant 3 (θ = 180°):**
$\phi_R = 0$, $\phi_Y = 0.866\ \phi_m$ and $\phi_B = -0.866\ \phi_m$
With assumed flux directions, the vector diagram for fluxes can be drawn as shown in the figure (d). It is seen that the total flux is $\phi_T = 1.5\ \phi_m$ with further clockwise rotation of 60° in the space.



2 Marks for flux vector diagram

Thus it seen that the rotating magnetic field of constant magnitude (1.5 ϕ_m) is produced in the air-gap or central space of the stator.

c) Explain working of synchronous motor. Explain any one method of starting.

Ans:

Working of Synchronous motor:

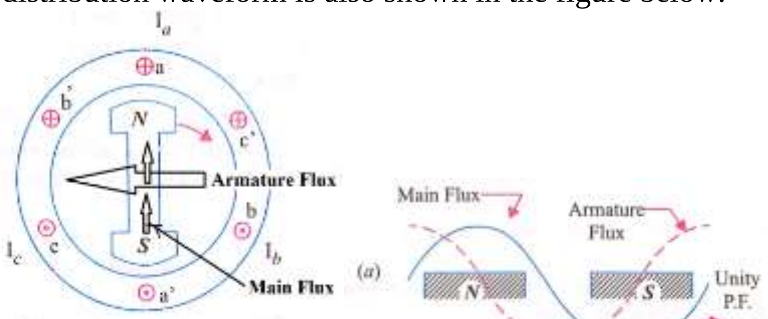
1) When 3-ϕ supply is given to 3-ϕ stator winding, 3-ϕ currents flow and Rotating magnetic field (RMF) is produced in the air-gap between stator and rotor. Rotating magnetic poles are created in stator core.
2) When DC supply is given to the field winding on rotor, magnetic poles are created on rotor.
3) Opposite magnetic poles on stator and rotor get locked due to force of attraction and rotor rotates with same speed as that of rotating magnetic field produced by stator i.e

2 Marks for working

		synchronous speed. 4) **As soon as 3-ph supply is given to stator winding, immediately stator magnetic field starts rotating at synchronous speed. Every time stator pole sweeps over rotor poles, rotor pole experiences pull and push. So rotor poles can not pick up speed. Thus motor is NOT SELF-STARTING.** 5) In fact, rotor is rotated by some means near to synchronous speed and then field winding is excited, so that rotor is pulled into synchronism and further rotates at constant synchronous speed. **Different Starting Methods of Three Phase Synchronous Motor:** As synchronous motor is not self starting, different methods of starting are as follows: 1) By using an Induction (Pony) motor 2) By using a DC Machine / Source 3) By using Damper windings **1) By using an Induction (Pony) motor:** A small induction motor (pony motor) is directly coupled with the synchronous motor. The number of poles of the induction motor should be less than the synchronous motor. First supply is given to the pony motor, when it rotates the rotor of the synchronous motor near to the synchronous speed, the main switch and DC switch of synchronous motor are closed. The rotor poles of synchronous motor are pulled into synchronism. After that, supply to the pony motor is disconnected and it can be de-coupled from the synchronous motor shaft. **2) By using a DC Machine / Source:** A DC machine is coupled to the synchronous motor. The DC machine works like a DC motor initially and brings the synchronous motor near to synchronous speed. The main switch and DC switch of synchronous motor are closed. The rotor poles of synchronous motor are pulled into synchronism. Once it is achieved, the DC machine can be operated like a DC generator and DC power generated can be supplied to the rotor of the synchronous motor. **3) By using Damper Windings:** In this method, the motor is first started as an induction motor and then starts running as a synchronous motor after achieving synchronous speed. For this, damper windings are used. Damper windings are additional windings consisting of copper bars placed in the slots in the pole faces. The ends of the copper bars are short-circuited. These windings behave as the rotor of an induction motor. When 3 phase power is supplied to the motor, the motor starts running as an induction motor at a speed below synchronous speed. After some time DC supply is given to the field winding. The rotor gets pulled into synchronism and starts running at constant speed as a synchronous motor.	2 Marks for any one method of starting
	d)	Explain the effect of armature reaction on main field flux of alternator with load of – (i) Unity pf (ii) Zero pf leading **Ans:** **Armature reaction:** The effect of armature flux on main flux is called as armature reaction. When the armature conductors of alternator carry current, they produce their own flux, called armature flux. This flux affects the main pole flux and resultant flux in the air-gap is modified. This affects the terminal voltage of alternator. The power factor of the load has a considerable effect on the armature reaction.	

I) Armature Reaction when the load is Purely Resistive (Unity pf):

Consider a 2 pole, 3-phase simple alternator supplying purely resistive load. Referring to fig. (a), for shown pole positions, the phase-a conductors lie exactly under the poles. So phase-a emf is maximum. Since load is purely resistive, the current is in phase with voltage, resulting the currents is all phases as shown in the figure. These currents produce their own magnetic field, whose direction can be obtained using grip-rule. It is seen that the armature flux appears to be crossing the main flux. Therefore, the armature reaction is termed as cross-magnetizing. With reference to the rotation, we can say that the armature flux is lagging the main flux by 90°. Since the magnetic flux lines never cross each other, the net effect of cross-magnetization is to disturb the main flux, resulting reduction in the terminal voltage to some extent. The flux distribution waveform is also shown in the figure below. — 1 Mark for explanation

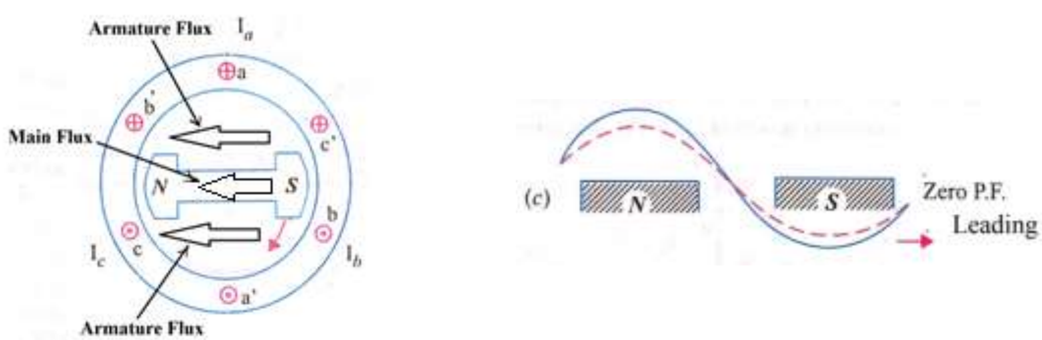


(a) Purely Resistive Load (UPF)

1 Mark for diagram

II) Armature Reaction when the load is Purely Capacitive (Zero pf leading):

Referring to fig. (c), for shown pole positions, let the phase-a conductors lie exactly on magnetic neutral axis, so phase-a emf is zero. Since load is purely capacitive, the current leads the voltage by 90°, resulting the current in phase-a as positive maximum with zero voltage induced in it. Thus the current pattern in all phases remains same as shown in the figure. It is seen that the armature flux appears to be aiding the main flux. Therefore, the armature reaction is wholly magnetizing, resulting greater induced emf. With reference to the rotation, we can say that the armature flux is in-phase with the main flux. Therefore, the net effect of magnetization is to increase the main flux, resulting rise in the terminal voltage. The flux distribution waveform is also shown in the figure. — 1 Mark for explanation



(c) Purely Capacitive Load
(Zero pf leading)

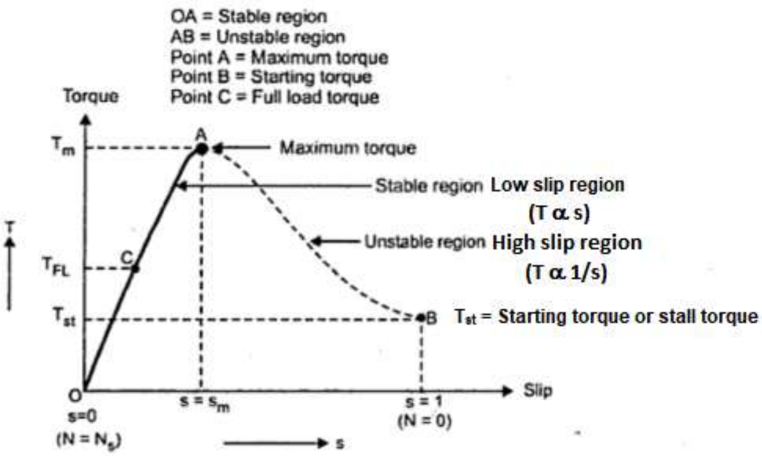
1 Mark for diagram

3.		Attempt any THREE of the following:	12 Marks

a) Draw and explain Torque Slip characteristic of 3 phase Induction motor.

Ans:

Torque-Slip characteristics of 3-phase Induction Motor:



(OR equivalent diagram)

2 Marks for labelled diagram (Equivalent diagram may please be considered)

- When slip (s) ≈ 0, the rotor speed is equal to synchronous speed (i.e N≈ Ns) and torque is almost zero at no load.
- As load on motor increases, slip increases and therefore torques increases.
- For lower values of load, the speed is close to synchronous speed and slip is low. In low slip region (stable region), torque is proportional to slip (T α s), and characteristic is linear in nature.
- At a particular value of slip, maximum torque will be obtained at condition $R_2 = sX_2$. On the characteristic, the maximum torque is indicated by breakover torque or pull-out torque. If load torque exceeds this breakover torque, the motor is pulled out and simply comes to rest.
- For higher values of slip i.e high slip region which is unstable region, torque is inversely proportional to slip (T α 1/s) and characteristics will be hyperbolic in nature.
- The maximum torque condition can be obtained at any required slip by changing rotor resistance.
- At the time of starting (N = 0 and s = 1), the motor produces starting torque, called stall torque, which must be greater than the load torque, otherwise the motor will not pick up the speed and simply stalled.

2 Marks for explanation

b) A 4 pole, 3 phase Induction motor operates from a supply whose frequency is 50 Hz. Calculate:

(i) Speed at which the magnetic field of the stator is rotating.
(ii) Speed of the Rotor when slip is 0.04.
(iii) Frequency of the Rotor current when the slip is 0.03.
(iv) Frequency of the Rotor currents at standstill.

Ans:

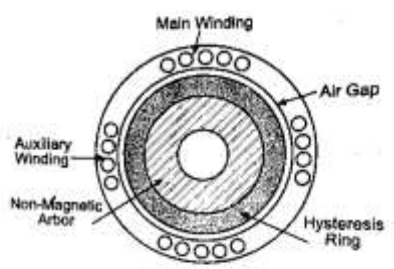
Data Given:
Frequency f = 50 Hz
No. of poles P = 4

1 Mark for each bit = 4 Marks

I) Speed at which the magnetic field of the stator is rotating:

It is the synchronous speed (N_s) given by,

		$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = \mathbf{1500\ rpm}$ **II) Speed of the Rotor when slip is 0.04:** Rotor speed (N) is given by, $N = (1 - s)\,N_s = (1 - 0.04)1500 =$ **1440 rpm** **III) Frequency of the Rotor current when the slip is 0.03:** Rotor frequency (f_r) is given by, $f_r = s.f = (0.03)50 =$ **1.5 Hz** **IV) Frequency of the Rotor currents at standstill:** At standstill, rotor speed N = 0 and slip s = 1 Rotor frequency $f_r = s.f = (1)50 =$ **50 Hz**	
	c)	Explain with neat sketches working of Hysteresis motor. **Ans:** **Hysteresis motor:**	



(OR any equivalent diagram)

2 Marks for diagram

Working:

When stator is energized with single phase ac supply, rotating magnetic field is produced because of starting (auxiliary) and main windings, which remain in circuit permanently. The rotor, which is hysteresis ring, cuts this flux, emf is induced and eddy currents start circulating in rotor as it is a shorted ring. Thus eddy current torque is developed along with the hysteresis torque in the rotor. Hysteresis torque in the rotor is developed because the rotor magnetic material has high hysteresis loss property and high retentivity. Now the rotor starts rotating initially as induction motor with speed somewhat less than synchronous speed and rotor pole axis lagging behind the axis of rotating stator field.

When the speed of the rotor reaches near about the synchronous speed, then rotor poles are locked with stator field poles and then rotor starts rotating with synchronous speed. At the condition of synchronism, the relative motion between stator rotating magnetic field and rotor vanishes, hence no eddy current are induced & no eddy current torque is produced on rotor. In this condition the rotor continues to rotate because of hysteresis torque only. This torque is constant at all speeds and motor runs with perfect synchronous speed. Due to the principle of magnetic locking this motor rotates at synchronous speed. However if due to some reason the rotor falls out of synchronism, the relative speed appears between stator rotating magnetic field and rotor, so eddy currents are induced, eddy current torque is produced and rotor is speed up.

2 Marks for explanation

	d)	Derive the EMF equation of Alternator. State the meaning of each term ~~and~~ used therein. **Ans:**	

<table>
<tr><td></td><td></td><td>
EMF Equation of alternator:-
Let P = No. of poles
$\emptyset$ = Flux per pole
N= Speed in rpm
Z= Number of stator conductors per phase
$\therefore$ Turns per phase $T = \frac{Z}{2}$
The flux cut by a conductor in one revolution, $d\emptyset = P.\emptyset$
Time in seconds required for one revolution, $dt = \frac{1}{(\frac{N}{60})} = \frac{60}{N}\ sec$
By Faraday's law of electromagnetic induction, the average emf induced in a conductor is given by,
$\therefore$ Average emf /conductor $= \frac{Flux\ cut}{Time\ required} = \frac{d\emptyset}{dt}$
$\therefore E_{avg}$/conductor $= \frac{P.\emptyset}{(\frac{60}{N})} = \frac{P.\emptyset.N}{60}$ volts
In one revolution, conductor cuts the flux produced by all the 'P' poles and emf completes (P/2) cycles. If rotor is rotating at N rpm, the revolutions completed in one second are (N/60). Therefore, the cycles completed by emf in one second are (P/2)(N/60) i.e (PN)/120. Thus the frequency of the induced emf is,
$$f = (\frac{P.N}{120})$$
$$\therefore N = (\frac{120f}{P})$$
Substituting this value of N in above equation,
$\therefore E_{avg}$/conductor $=\frac{P.\emptyset}{60} \times \frac{120f}{P} = 2\emptyset f$ volt
Since each turn has two conductors,
E_{avg} /turn = 2 × E_{avg}/conductor = $4\emptyset f$ volt
The emf induced in a phase winding is given by,
E_{avg}/phase = (E_{avg} /turn) × Turns/phase
= $4\emptyset f T$ volt
The Rms value of emf per phase is given by,
E_{ph}= (E_{avg}/phase) × Form Factor
E_{ph}=1.11× $4f\emptyset T$ volt
$E_{ph} = 4.44 f\emptyset T$ volt
This is for full pitched concentrated winding.
If winding is distributed & short pitched then
$E_{ph} = 4.44\ K_p K_d f\emptyset T$ volt
where, K_p = Pitch factor
K_d = Distribution factor
</td><td>½ mark

½ mark

½ marks

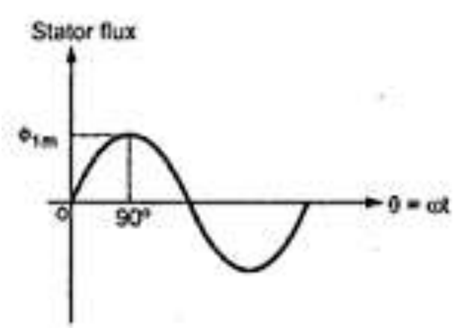
½ marks

½ marks

½ marks

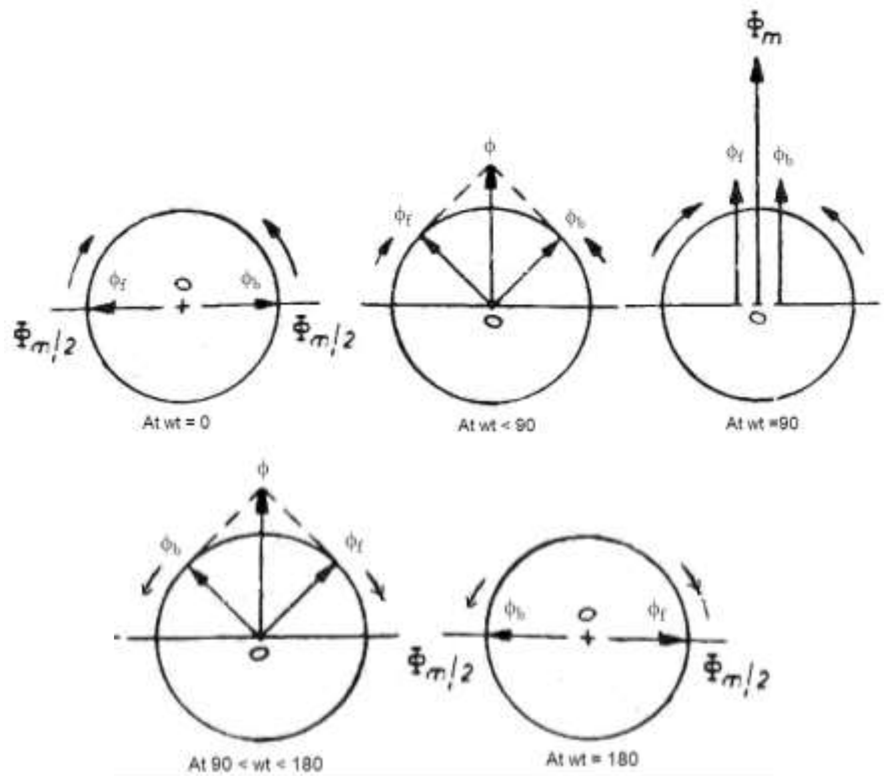
½ marks

½ marks</td></tr>
<tr><td>4.</td><td></td><td>Attempt any <u>THREE</u> of the following:</td><td>12 Marks</td></tr>
<tr><td></td><td>a)</td><td>The power input to the rotor of a 400V, 50Hz, 6 pole, 3ϕ Induction motor is 75 KW. The rotor electromotive force is observed to make 100 complete alteration per minute. Calculate
(i) Slip
(ii) Rotor speed
(iii) Rotor Copper Loss per phase
(iv) Mechanical Power developed</td><td></td></tr>
</table>

		Ans: **Data Given:** Supply line voltage V_L = 400V Frequency f = 50 Hz No. of poles P = 6 Rotor Input Power Pr_i = 75 kW = 75000W Rotor emf frequency f_r = 100 complete alterations per minute = 100 cycles per minute = (100/60) cycles per second = 1.67 Hz **1) Slip:** $f_r = s.\ f$ $s = \frac{fr}{f} = \frac{1.67}{50}$ = **0.0334 = 3.34%** **2) Rotor speed:** $Ns = \frac{120f}{p} = \frac{120*50}{6}$ = 1000 rpm N = Ns (1 – s) = 1000 (1- 0.0334) = **966.6 rpm** **3) Rotor copper loss per phase:** Rotor copper losses Pr_{Cu} = slip x rotor input power = $s.Pr_i$ = 0.0334 × 75 KW = 2.505 KW Rotor copper loss per phase = P_c = 2.505/3 = **0.835 KW = 835 W** **4) Mechanical power developed:** Mechanical power developed = rotor input – rotor Cu loss = $Pr_i - Pr_{Cu}$ = 75 – 2.505 = **72.495 KW = 72495 W**	3 Marks for Steps + 1 Mark for final answers = 4 Marks
	b)	Explain why single phase Induction Motor not self-starting with the help of double field Revolving Theory. **Ans:** **Single phase induction motors are not self-starting:** • When single phase AC supply is given to main winding it produces alternating flux. • According to the double field revolving theory, the stator alternating flux, ϕ is divided into two components each of magnitude ϕm/2. • Each of these components rotates at synchronous speed N_s in the opposite direction i. e if one ϕm/2 is rotating in a clockwise (forward) direction then the other ϕm/2 rotates in an anticlockwise 	2 Marks for double-field revolving theory explanation + 2 Marks for diagram = 4 Marks

(backward) direction.

- The resultant of these two components of flux at any instant of time gives the value of instantaneous stator flux at that particular instant.
- At starting condition, both the forward and backward components of flux produce equal but exactly opposite torques on rotor. So, they cancel each other, and hence the net torque experienced by the rotor at the starting condition is zero.
- So, the single-phase induction motor is not self-starting motor.



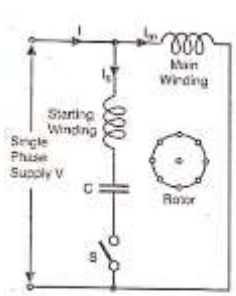
c) Explain working of capacitor start Induction run single phase Induction motor. Draw Phasor diagram.

Ans:

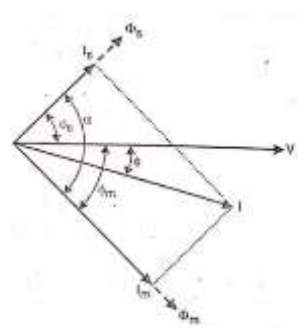
Capacitor Start Induction Run Motor:

1 Mark for circuit diagram

2 Marks for phasor diagram

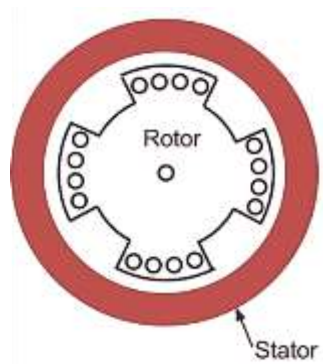


Circuit diagram

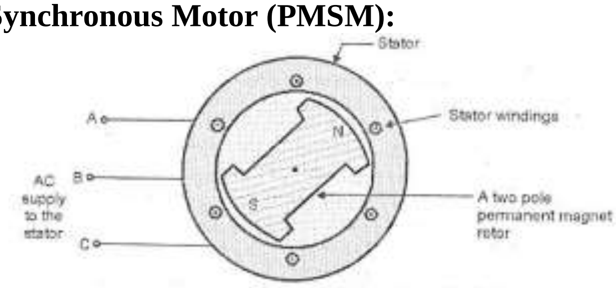


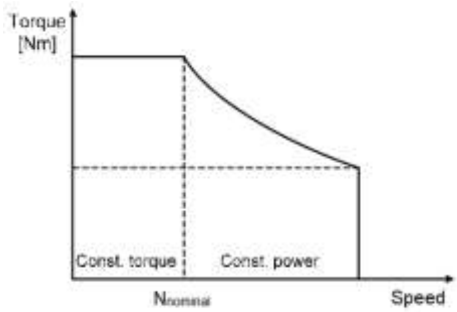
Phasor diagram

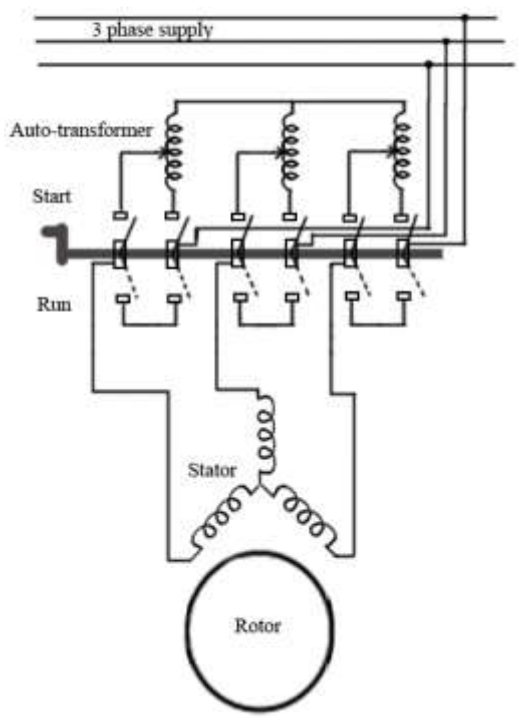
This motor consists two windings in stator, first is main winding which is inductive and hence current drawn by this winding I_m is lagging behind the applied voltage V by an angle

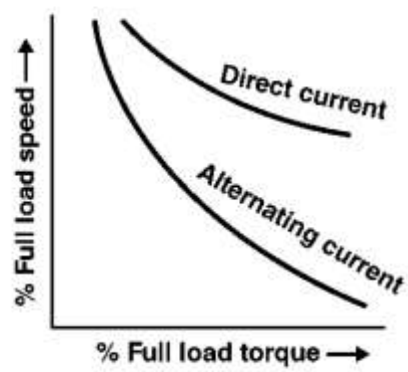
		ϕ_m. Second is the starting winding, also called auxiliary winding, connected in series with a capacitor and centrifugal switch which is in ON position at the time of starting, so draws leading current I_S by an angle ϕ_s with respect to applied voltage as shown in phasor diagram. The main winding and starting winding are connected in parallel with each other. Value of capacitor is so chosen that I_S should lead I_m by almost 90°. Consequently, the starting torque, $T \propto k.I_S.I_m.\sin\alpha$ obtained is very much sufficient to accelerate the motor and motor starts rotating. After acquiring 75% of rated speed the starting winding is cut out of circuit with opening of centrifugal switch. Then motor continues to run with only main winding in the circuit. The pulsating magnetic field produced by main winding can be represented by two equal but oppositely rotating magnetic field components as per double field revolving theory. The component which rotates in the same direction as that of rotor produces torque sufficient to rotate the rotor with load. Thus rotor continues its rotation.	1 Mark for explanation of working
	d)	Explain construction and working of Synchronous Reluctance motor. **Ans:** **Synchronous Reluctance motor:** **Construction:** 1. Reluctance motor is basically same as 3-ph or 1-ph Induction motor with modification in rotor design. 2. It consists of a slotted stator carrying uniformly distributed 3-ph winding (for 3-ph motor) or both the main & starting winding (for 1-ph motor). 3. The rotor in this motor does not include any field winding but the rotor core presents unsymmetrical reluctance to stator rotating magnetic field.. 4. Many rotor designs are available to offer unsymmetrical reluctance. 5. Typical rotor is cage type having poles projecting out (just like big tooth), as shown in the figure. 6. The rotor bars are kept intact even in the spaces from where teeth are removed, the two end rings short circuit these bars as in a cage rotor.  **Working:** 1. When the stator windings (1-ph or 3-ph) are connected to AC supply, the rotating magnetic field is produced. This rotating magnetic field is cut by rotor conductors (bars), emf is induced and currents are produced in rotor bars as they are shorted. According to basic motor principle, force is exerted on current carrying rotor conductors (bars) placed in rotating magnetic field. Thus the motor starts as an induction motor. 2. The rotating magnetic field experiences unsymmetrical reluctance as it sweeps over the rotor surface (toothed and non-toothed portion). 3. Since the magnetic flux always follow the path of minimum reluctance, the induced magnetic field in rotor core creates magnetic poles in toothed portion of the rotor. 4. The rotating magnetic field poles attract the rotor induced opposite poles. The torque	1 Mark for diagram 1 Mark for construction 2 Marks for working

		so produced is called reluctance torque. 5. During starting period, when motor is started as induction motor and the speed reaches close to the synchronous speed, reluctance torque produced causes tendency of the rotor to align itself in the minimum reluctance position with respect to the synchronously rotating magnetic field of stator. As a result, rotor is pulled into synchronism and then rotates at synchronous speed with rotating magnetic field of stator. 6. Once rotor starts rotating with synchronous speed, the relative motion between rotor and rotating magnetic field of stator becomes zero, so no induced emf, no rotor currents and no induction motor torque. The rotor continues constant synchronous speed operation due to reluctance torque only, hence it is called “Synchronous Reluctance Motor”. OR **Equivalent Answer**	

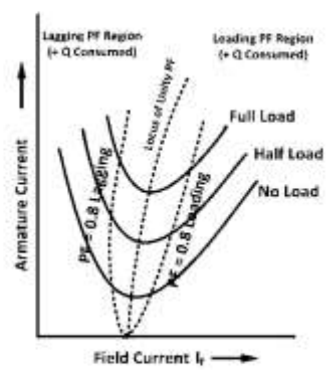
	e)	Explain the construction of PMSM motor. Also draw the Torque speed characteristic of this motor.
		Ans:
		Permanent Magnet Synchronous Motor (PMSM):
		
		
		1. The permanent magnet synchronous motor (PMSM) is basically a synchronous motor in which field excitation is provided by permanent magnets.
		2. The stator is similar to that of an induction motor. It has slotted stator core construction & 3-ph or 2-ph winding is accommodated in the slots.
		3. A PMSM uses permanent magnets embedded in the steel rotor to create a constant magnetic field. These motor do not have rotor winding instead they have PM rotor so no external DC excitation is needed.
		1) Stator Construction:
		• The **stator** consists of an outer frame and a core with windings.
		• The most common design comes with two-phase winding (1-ph motor) and three-phase winding (3-ph motor).
		• Depending on the stator design, a permanent magnet synchronous motor can be:
		  • PMSM with distributed winding
		  • PMSM with concentrated winding.
		2) Stator Windings:
		• **Distributed** winding has the number of slots per pole and phase
		  • Q = 2, 3, ..., k.
			1 Mark for diagram
			
			2 Marks for construction

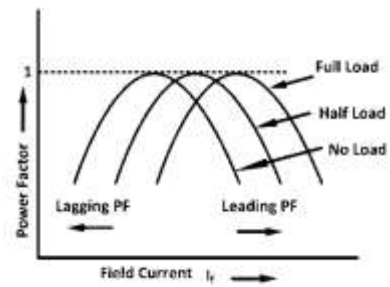
		• **Concentrated** winding has the number of slots per pole and phase
		  ◦ Q = 1.
		3) Rotor Construction:
		• The **rotor** consists of permanent magnets.
		• Materials with high coercive force are used as permanent magnets.
		• According to the rotor design, synchronous motors are divided into:
		  ◦ PMSM with salient pole rotor
		  ◦ PMSM with non-salient pole rotor
		
		Torque speed characteristic of PMSM:
		
			1 Mark for torque-speed characteristic

5		**Attempt any TWO of the following:**	**12 Marks**
5	a)	Explain with neat sketch the operation of Auto transformer starter for 3ϕ induction motor. **Ans:** **Working of Autotramsformer Starter for a 3 Phase Induction Motor:**  A three phase star connected autotransformer along with suitable change over switch forms	3 Marks for circuit diagram (Equivalent diagram may please be considered)

		an autotransformer starter.When the switch is in the starting position, the stator of an induction motor is supplied with reduced voltage through the autotransformer using suitable tap.This limits the starting current to a safe value.Usually 3 tappings per phase are provided to give 50,65 or 80% of the normal line voltage across the motor terminals.When the motor attains about 80% of its normal speed, the switch is thrown to 'RUN' position which connects the motor directly across the supply and cuts out the autotransformer from the circuit.These actions may be carried out automatically by time-delay operated magnetic contactors. The provision of required taps on the autotransformer makes the adjustment possible to suit the local conditions. Hence the motor is started safely by reducing the starting supply voltage to limit the heavy starting inrush current.	3 Marks for explanation
5	b)	Draw and explain torque speed characteristics of Universal motor and state applications of the same. **Ans:** **Torque-Speed characteristics:** • In electric motor, the torque is produced due to interaction between conductor current (armature current, I_a) and magnetic flux ϕ. Therefore $T \alpha \phi.I_a$ • Universal motor is basically series motor i.e armature winding and field winding are in series, so field current $I_f = I_a$. Therefore, the magnetic flux ϕ produced by field winding is proportional to field current i.e armature current. $\therefore \phi \alpha I_a$  • Thus $T \alpha \phi^2 \alpha I_a^2$ • Speed is inversely proportional to flux, $N \alpha (1/\phi)$. • Comparing dependence of torque and speed on flux, it is clear that $N \alpha \sqrt{T}$. • Therefore torque-speed characteristics of universal motors for both AC and DC are inverse characteristics as shown in the figure. • The speed of the universal motor is the lowest at full load and the highest at no load. **Applications of Universal Motor:** 1) Mixer and Food processor 2) Heavy duty machine tools 3) Grinder 4) Vacuum cleaners 5) Drills 6) Sewing machines 7) Electric Shavers 8) Hair dryers 9) Cloth washing machine	2 Marks for labelled diagram 2 Marks for explanation 2 Marks for any four applications
5	c)	(i) Define – (1) Synchronous Reactance (2) Synchronous Impedance **Ans:** **(1) Synchronous Reactance (X_s):** It is the imaginary reactance of armature winding considered to account for the voltage effects in the armature circuit produced by:	1 Mark

		(i) the actual armature leakage reactance (X_l) and (ii) the change in the air gap flux caused by the armature reaction (X_a) **OR** Synchronous reactance (X_s) is the combination of two inductive reactances representing the effect of leakage flux (called armature leakage reactance)(X_l) and the effect of armature reaction (called armature reaction reactance) (X_a). i.e $X_s = X_l + X_a$ **(2) Synchronous Impedance (Z_s):** **Synchronous Impedance** Z_S is a fictitious impedance of armature winding considered to account for the voltage effects in the armature circuit produced by the actual armature resistance (R_a), the actual armature leakage reactance (X_l) and the change in the air gap flux produced by the armature reaction (X_a). i.e $Z_s = (R_a + j X_s) = R_a + j (X_l + X_a)$	1 Mark
5	c)	ii) From the following test results, determine the Voltage Regulation of a 2000V, 1-ϕ alternator, delivering a current of 100A at – 1) Unity pf 2) 0.8 leading pf Test Results: Full load current of 100A is produced on short circuit by a field excitation of 2.5 A. An emf of 500V is produced on open circuit by the same excitation. The armature resistance is 0.8 Ω. **Ans:** V = Rated voltage = 2000V, Synchronous impedance $Z_S = 500/100 = 5\ \Omega$, Armature resistance R = 0.8 Ω, Synchronous reactance $X_S = \sqrt{(Z_S^2 - R^2)} = 4.94\ \Omega$. Expression for no load emf or induced emf 'E' for any load current 'I' is $E = \sqrt{[(V\cos\varnothing + IR)^2 + (V\sin\varnothing \pm IX_S)^2]}$, % Regulation = [(E-V)/V] x100 **i) At UPF:** $E = \sqrt{[(2000 \times 1 + 100 \times 0.8)^2 + (2000 \times 0 + 100 \times 4.94)^2]}$ = 2137.85 V % Regulation = [(2137.85 – 2000)/2000] x 100 = 0.0689 OR **6.89%** **ii) At 0.8 pf lead:** cosØ= 0.8 and sinØ=0.6 and –ve sign to be taken in expression. $E = \sqrt{[(2000 \times 0.8 + 100 \times 0.8)^2 + (2000 \times 0.6 - 100 \times 4.94)^2]}$ = 1822.32 V. % Regulation = [(1822.32 – 2000)/2000] x 100 = **– 8.88%**	1 Mark for Zs 1 Mark for Xs 1 Mark 1 Mark
6		**Attempt any TWO of the following:**	**12 Marks**
6	a)	Explain the concept of Hunting and phase swinging in synchronous motor. **Ans:** **Concept of Hunting and phase swinging in synchronous motor:** • The phenomenon of oscillation of the rotor of a synchronous motor about its final	

		steady-state position is known as **hunting**. Since during the rotor oscillations, the phase of emf phasor (E) varies with respect to the phasor V, the hunting is also known **phase swinging**. • Hunting means momentary fluctuations in the rotor speed of a synchronous motor. • In a synchronous motor, when the electromagnetic torque developed is equal and opposite to the load torque, such a condition is known as "condition of equilibrium" or "steady state condition". • In the steady-state, the rotor of the synchronous motor runs at synchronous speed, thereby maintaining a constant value of torque angle (δ). If there is a sudden change in the load torque, then the equilibrium of the motor is disturbed and there is a difference between the electromagnetic torque (τ_e) and load torque (τ_l) which changes the speed of the motor. • The electromagnetic torque of synchronous motor is given by, $T_e = (3VE_f/\omega s X_S)\text{Sin}\delta$ • When the load on synchronous motor is suddenly increased, the motor retardation (backward movement of rotor) starts. During backward movement of rotor, the torque angle (δ) is increased, hence the electromagnetic torque increases opposing the backward movement of rotor. • Due to this, the backward movement of rotor stops and the rotor reaches to synchronous speed. • At this state, the torque angle (δ) is greater than the new required value (δ)' for the new steady state condition. As a result, the motor is accelerated. • Consequently, the torque angle (δ) decreases due to the acceleration of the rotor above synchronous speed. At the point where the electromagnetic torque becomes equal to the load torque, the steady-state condition is not restored, because at this point the speed of the rotor is more than the synchronous speed. • Therefore, the rotor continues to move forward and the torque angle goes on decreasing. • When the torque angle (δ) becomes less than the new required value (δ)', the load torque becomes greater than the electromagnetic torque. • Therefore, the motor starts to slow down. The torque angle (δ) is increased again. Hence, the rotor oscillates around the synchronous speed and the new required value (δ)'of the torque angle before reaching the new state of equilibrium.	1 Mark for hunting 1 Mark for phase swinging 1 Mark for steady-state condition 3 Marks for stepwise explanation
6	b)	Draw and explain V and inverted V curves of synchronous motor. **Ans:** **'V curves' and 'inverted V curves' for Synchronous Motor:** **V curve:** V curve is a plot of the stator current versus field current for different constant loads. The graph is plotted between the armature current I_a and field current I_f at no load. This curve is known as V curve because the shape of this curve is similar to the letter "V". For higher values of field current the power factor is leading whereas for lower values of field current the power factor is lagging. Similar curves are plotted for various constant loading conditions. When such number of V-curves are plotted, the unity power factor line is locus of minimum  	1 Mark for explanation of V curves 2 Mark for diagram

		armature current. The family of V- curves for different loads is as shown in the figure. **Inverted V Curve:** When the power factor is plotted against field current for any constant load, the shape of the graph looks like an inverted V. Such curves obtained by plotting p.f. against field current at various constant load conditions, are called Inverted V-curves of synchronous motor. The highest point on each of these curves indicates unity power factor.  	1 Mark for explanation of inverted V curves 2 Mark for diagram
6	c)	(i) Explain in brief the effect of harmonics on Pitch and Distribution factor. **Ans:** **Effect of harmonics on Pitch factor:** Let α = Angle of the short pitch or chording angle for fundamental flux wave. Pitch factor is given by $K_P = \cos(\alpha/2)$ For various n^{th} order harmonic component of flux, the short pitching angle or chording angle changes to "n.α". 3α = For 3rd harmonic component 5α = For 5th harmonic component nα = For n^{th} harmonic component Therefore, for n^{th} harmonic component**,** the pitch factor is expressed as, $\mathbf{K_p = \cos(n\alpha/2)}$ **Effect of harmonics on Distribution factor:** Let β be the value of the angular displacement between the slots. Its value is $\beta = \dfrac{180°}{\text{No. of slots/pole}} = \dfrac{180°}{n}$ m = No. of slots/pole/phase. m β = Phase spread angle The distribution factor is given by, $K_d = \dfrac{\sin(\frac{m\beta}{2})}{m \times \sin(\frac{\beta}{2})}$ Similar to the pitch factor, the distribution factor is also different for various harmonic components. The general expression of distribution factor for n^{th} harmonic component is given by, $\mathbf{K_{dn} = \dfrac{\sin(\frac{mn\beta}{2})}{m \times \sin(\frac{n\beta}{2})}}$	1½ Mark 1½ Mark
6	c)	(ii) A 3 phase, 16 pole alternator has a star connected winding with 144 slots and 10 conductors per slot. The flux per pole is 0.03 Wb, sinusoidally distributed and the speed is 375 rpm. Find: 1) Frequency ~~rpm~~ 2) Phase Emf 3) Line emf Assume full pitched coil. **Ans:**	**3 Marks**

		Data Given: Star connected alternator No. of Poles P = 16 Total no. of slots = 144 Conductors per slot = 10 Flux per pole ϕ = 0.03 Wb Speed N = 375 rpm Full-pitched coils, therefore **Pitch factor = K_p = 1** **(1) Frequency f** $= \frac{PN}{120} = \frac{16\times375}{120}$ = **50Hz**	1 Mark for f
		(2) Distribution-factor (Kd): Slots/pole/phase: m = 144/16/3 = 3 Slots/pole: n = 144/16 = 9 Slot angle: $\beta = \frac{180°}{n} = \frac{180°}{9} = 20°$ $\therefore$ Distribution factor, $K_d = \frac{sin(\frac{m\beta}{2})}{m\times sin(\frac{\beta}{2})} = \frac{sin(\frac{3\times20°}{2})}{3\times sin(\frac{20°}{2})} = \frac{sin(30°)}{3\times sin(10°)} = \mathbf{0.96}$	
		(3) Phase value of Emf (E_{ph}): Total no. of conductors Z = 144×10 = 1440 No. of conductors/phase = 1440/3 = 480 No. of turns/phase T = 480/2 = 240 The rms value of emf induced in each phase winding is given by, $E_{ph} = 4.44\ K_p K_d f \emptyset T$ volt $= 4.44\,(1)(0.96)(50)(0.03)(240)$ $= \mathbf{1534.5\ volt}$	1 Mark for E_{ph}
		(4) Line value of Emf (E_L): For star connected alternator, Line emf $E_L = \sqrt{3}E_{ph} = \sqrt{3}(1534.5)$ $= \mathbf{2657.8\ volts}$	1 Mark for E_L