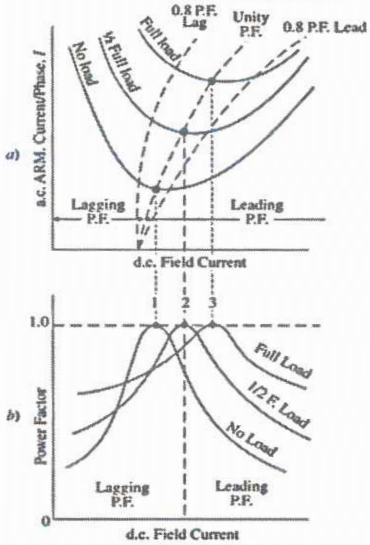
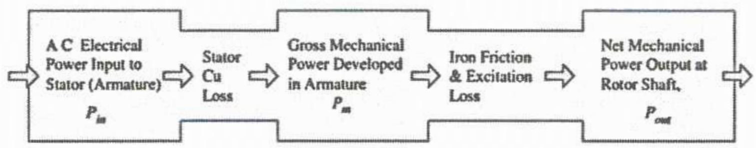
Scoring Indicators

Course Name: Synchronous Machines and FHP Motors

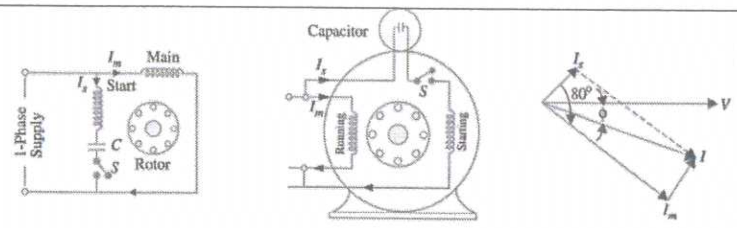
Course Code: 5031

QID: 2109230051A

Q No	Scoring Indicators	Split score	Sub Total	Total Score
	PART A			9
I. 1	a) Cylindrical Rotor b) Salient Pole	0.5m*2	1	
I. 2	$K_p = \cos\frac{\alpha}{2}$	1	1	
I. 3	i-c ii-a iii-b	1	1	
I. 4	Any two: 1. EMF Method / Synchronous impedance method 2. MMF Method / Rotherts Ampere Turn Method 3. ZPF Method/Potier triangle Method 4. ASA Method	1	1	
I. 5	Synchroscope	1	1	
I. 6	The inverted V curve is the plot between **FILED CURRENT (I_f)** in X axis and **POWER FACTOR(Cos Φ)** in Y axis.	0.5m*2	1	
I. 7	Over Excited	1	1	
I. 8	Any two modes: 1. Full Step or 1-phase ON 2. 2-Phase ON 3. Half step 4. Micro Stepping	0.5m*2	1	
I. 9	$\beta = \frac{360°}{No\ of\ stator\ phases\ x\ No.of\ rotor\ teeth}$	1	1	
	PART B			24
II. 1	***Any three*** Advantages of stationary armature windings 1. Current collection is easy. 2. Better insulation for high voltage. 3. Increased armature tooth strength.	1m*3	3	

	4. Reduced armature leakage reactance i.e. better voltage regulation. 5. Only two slip rings are required for dc excitation. 6. The rotor is light in weight, hence higher speeds are possible. 7. Stationary armature can be cooled easily.			
II. 2	For proper synchronization of alternators, the following three conditions must be satisfied : 1. The terminal voltage (effective) of the incoming alternator must be the same as bus-bar voltage. 2. The speed of the incoming machine must be such that its frequency (= PN/120) equals bus-bar frequency. 3. The phase of the alternator voltage must be identical with the phase of the bus-bar voltage. It means that the switch must be closed at (or very near) the instant the two voltages have correct phase relationship.	1m*3	3	
II. 3		1.5 marks each	3	
II. 4		3	3	
II. 5	**Pull-in Torque** The maximum torque at rated voltage and frequency under 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.	1.5*2	3	

II. 6	**Parameters**	**Synchronous Motor**	**Induction Motor**				
	Type of Machine	A synchronous motor is a doubly excitation machine, i.e., its armature winding is connected to an AC source and its field winding is excited from a DC source.	An induction motor is a singly excited machine, that is, its stator winding is energized from an AC source.				
	Speed	Its speed is independent of the load.	Its speed decreases with the increase in load.				
	Starting	It is not self-starting. It requires external means for starting.	Induction motor has self-starting torque.				
	Efficiency	A synchronous motor is more efficient than induction motor of the same rating.	The efficiency of an induction motor is lesser than that of a synchronous motor of same rating.				
	Power Factor	A synchronous motor can operate under a wide range of power factors, both lagging and leading. The power factor of a synchronous motor can be changed by changing its excitation.	An induction motor operates at only lagging power factor. The power factor of induction motor cannot be controlled. It becomes very poor (lagging) at high loads.				
	Relative Motion	No relative motion between the stator rotating magnetic field (RMF) and the rotor is required for the operation of a synchronous motor.	For the operation of an induction motor, there must be a relative motion between the stator RMF and the rotor.		Any 6*0.5	3	
	Cost-effectiveness	For the same rating, a synchronous motor is expensive than an induction motor.	An induction motor is cheaper than a synchronous motor.				
	Construction	A synchronous motor has complicated construction.	An induction motor have simple construction than a synchronous motor.				
	Starting Torque	A synchronous motor has high starting torque as compared to an induction motor.	An induction motor has less starting torque.				
	RPM	Synchronous motors are economical for speeds below 300 RPM.	The induction motors are economical for speeds above 600 RPM.				
	Excitation	Synchronous motors require DC excitation at the rotor.	Induction motors do not require excitation for the rotor.				
	Applications	Driving mechanical loads at constant speed, power factor correction of electrical systems, etc.	Induction motors are used for driving mechanical loads only.				

II. 7	 • In these motors, the necessary phase difference between Is and Im is produced by connecting a capacitor in series with the starting winding. • The capacitor is generally of the electrolytic type and is usually mounted on the outside of the motor as a separate unit. • The capacitor is designed for extremely short-duty service and is guaranteed for not more than 20 periods of operation per hour, each period not to exceed 3 seconds. • When the motor reaches about 75 per cent of full speed, the centrifugal switch S opens and cuts out both the starting winding and the capacitor from the supply, thus leaving only the running winding across the lines. • Since the torque developed by a split-phase motor is proportional to the sine of the angle between Is and Im, it is obvious that the increase in the angle (from 30° to 80°) alone increases the starting torque to nearly twice the value developed by a standard split phase induction motor.	1 2	3	
II. 8	1. Portable drill machines. 2. Used in hairdryers 3. Grinders 4. Table fans. 5. Blowers 6. Polishers 7. Kitchen appliances. 8. vacuum cleaners, 9. sewing machines, etc.	Any 6 0.5m each	3	
II. 9	**Advantages** 1. They are smaller in size. 2. For smaller rating Permanent Magnet reduces the manufacturing cost and thus PMDC motor are cheaper. 3. As these motors do not require field windings, they do not have field circuit copper losses. This increases their efficiency.	1.5	3	
	Disadvantages 1. Permanent magnets cannot produce a high flux density as that as an externally supplied shunt field does.	1.5		

	Therefore, a PMDC motor has a lower induced torque per ampere turns of armature current then a shunt motor of the same rating. 2. There is a risk of demagnetization of the poles which may be caused by large armature currents. Demagnetization can also occur due to excessive heating and also when the motor is overloaded for a long period of time. 3. The magnetic field of PMDC motor is present at all time, even when the motor is not being used. 4. Extra ampere turns cannot be added to reduce the armature reaction.			
II. 10	There are three main types of stepper motors: **Permanent Magnet Stepper.** PM steppers have rotors that are constructed with permanent magnets, which interact with the electromagnets of the stator to create rotation and torque. PM steppers usually have comparatively low power requirements and can produce more torque per unit of input power. **Variable Reluctance Stepper.** VR stepper rotors are not built with permanent magnets. Rather, they are constructed with plain iron and resemble a gear, with protrusions or "teeth" around the circumference of the rotor. The teeth lead to VR steppers that have a very high degree of angular resolution; however, this accuracy usually comes at the expense of torque. **Hybrid Synchronous Stepper.** HS stepper rotors use the best features of both PM and VR steppers. The rotor in an HS motor has a permanent magnet core, while the circumference is built from plain iron and has teeth. A hybrid synchronous motor, therefore, has both high angular resolution and high torque.	1 1 1	3	
	PART C			42
III	<u>**Problem**</u> $3\varphi, P = 16, Star\ Connected, Slots = 144$ $Conductors\ per\ slot = 10$ $Flux, \varphi_m = 0.03Wb, Speed\ N = 375\ rpm$ $f = ?, E_{ph} = ?, E_{line} = ?$ $Full\ pitched\ coil\ \therefore\ k_p = 1$ $slots\ per\ pole\ , n = \frac{144}{16} = 9$ $slots\ per\ pole\ per\ phase, m = \frac{9}{3} = 3$ $slot\ angle, \gamma = \frac{180}{n} = 20°$	2	7	

	$k_d = \frac{\sin\frac{m\gamma}{2}}{m * \sin\frac{\gamma}{2}} = \frac{\sin\frac{3*20}{2}}{3*\sin\frac{20}{2}} = 0.96$ $f = \frac{PN}{120} = \frac{16*375}{120} = \mathbf{50Hz}$ $Total\ conductors, Z = 144 * 10 = 1440$ $Total\ turns = \frac{Z}{2} = 720$ $Turn\ per\ phase, T_{ph} = 240$ $E_{ph} = 4.44 * \varphi_m * f * T_{ph} * k_p * k_d$ $= 4.44 * 0.03 * 50 * 240 * 1 * 0.96 = \mathbf{1534.464\ V}$ $E_{line} = \sqrt{3} * E_{ph} = \sqrt{3} * 1534 = \mathbf{2657.691\ V}$	2 2 1		
IV	**Problem** $3\varphi, Star\ Connected$ $Load\ power, P_{load} = 10\ MW\ at\ 0.85\ pf\ lag$ $V_l = 11kV = 11000\ V\ \therefore\ V_{ph} = \frac{V_{line}}{\sqrt{3}} = 6350\ V$ $R_a = 0.1\ \Omega, X_s = 0.66\ \Omega$ $E_{line} = ?$ $\cos\phi = 0.85, \sin\phi = 0.527$ $Load\ current, I_l = ?$ $Load\ Power, P_{load} = 10\ MW$ $\therefore\ P_{load} = \sqrt{3}\, V_l I_l \cos\phi = 10MW\ \therefore\ I_l = 618\ A$ $E_{ph} = \sqrt{(V_{ph}\cos\phi + I_a R_a)^2 + (V_{ph}\sin\phi + I_a X_s)^2}$ $E_{ph} = \mathbf{6,625\ V}$ $E_{line} = \sqrt{3} * E_{ph} = \sqrt{3} * 6625 = \mathbf{11,486\ V}$	1 2 2 1	7	
V	The main parts of an alternators are: 1. Stator 2. Rotor 3. Windings 1. Stator: *Explanation* 2. Rotor: Based on rotor construction, alternator rotors are classified as: a) Salient Pole Rotor *Explanation* b) Cylindrical Rotor *Explanation* 3. Windings a) Single Layer b) Double layer	1 2 2 2	7	

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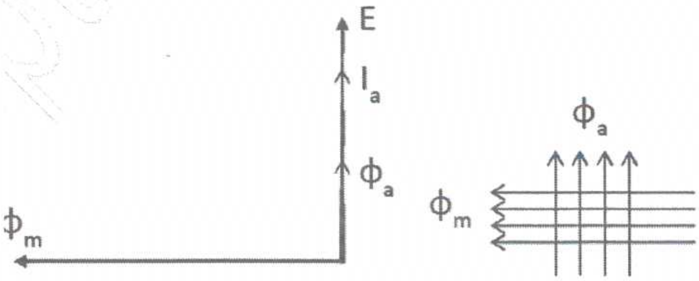
<td>VI</td>
<td>UPF

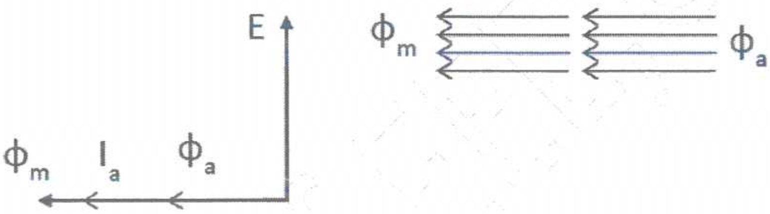
Phasor diagram



Explanation

The armature flux is in quadrature with main filed flux, so the air gap flux is distorted. So the effect of armature reaction under upf condition is purely cross magnetization.
ZPF Lead

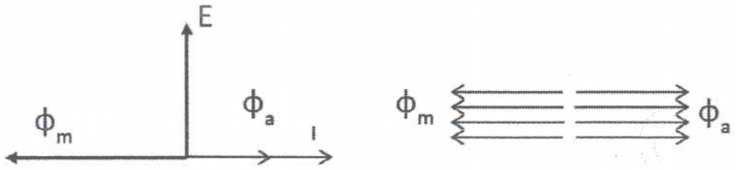
Phasor diagram



Explanation

The armature flux aids the main filed flux, so the resultant flux is increased.So the effect of armature reaction under upf condition is purely magnetization.
ZPF lag

Phasor diagram



Explanation

The armature flux opposes the main filed flux, so the resultant flux is reduced. So the effect of armature reaction under upf condition is purely demagnetization.</td>
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3

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<td>VII</td>
<td>**Problem**
$3\varphi, Star\ Connected$
$Load\ power, P_{load} = 1280\ kW\ at\ 0.8\ pf\ lead$
$V_l = 13500\ V \ \therefore\ V_{ph} = \frac{V_{line}}{\sqrt{3}} = 7795\ V$</td>
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<td>7</td>
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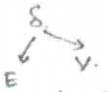
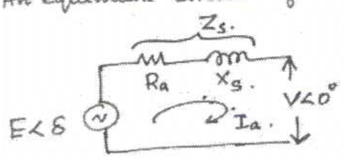
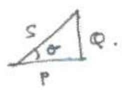
	$R_a = 1.5\,\Omega\,, X_s = 30\,\Omega$ $\%\ Regulation = ?$ $\cos\phi = 0.85\,, \sin\phi = 0.527$ $Load\ current, I_l = ?$ $Load\ Power, P_{load} = 1280\ kW$ $\therefore\ P_{load} = \sqrt{3}\,V_l I_l \cos\phi = 1280\ kW\ \ \therefore\ I_l = \ 68.4\ A$ $E_{ph} = \sqrt{(V_{ph}\cos\phi + I_a R_a)^2 + (V_{ph}\sin\phi - I_a X_s)^2}$ $E_{ph} = \mathbf{6,663\ V}$ $\%\ Regulation\ Up = \frac{E_{ph} - V_{ph}}{V_{ph}} * 100\ \%$ $= \frac{6663 - 7795}{7795} * 100\% = \mathbf{-14.11\%}$	2 3 2		
VIII	**Derivation** *Steps- 3.5 marks* *Final Results- 3.5 marks*	3.5+3.5	7	
	Power flow in a synchronous machine. Consider a machine with induced emf 'E' terminal voltage 'V', synchronous impedance 'Zs' Let 'δ' be the load angle or power angle.  'θ' be the angle of 'Zs' (ie) $Z_s = R_a + j\,X_s$  An equivalent circuit of an alternator is  Consider 'V' as reference ∴ $V\angle 0^\circ$ and $E\angle\delta$. Applying KVL to the above equation. $\vec{E}\angle\delta = \vec{V}\angle 0^\circ + \vec{I_a} \cdot \vec{Z_s}\angle\theta$ $\therefore\ \vec{I_a} = \frac{\vec{E}\angle\delta - \vec{V}\angle 0^\circ}{Z_s\angle\theta}$			

$$\therefore \quad I_a = \frac{E}{Z_s}\angle(\delta-\theta) - \frac{V}{Z_s}\angle-\theta$$

The equation for complex power is

$$S = P + jQ$$



$$= V \cdot I_a^*$$

where I_a^* is the complex conjugate of I_a.

$$I_a^* = \frac{E}{Z_s}\angle\theta-\delta - \frac{V}{Z_s}\angle\theta$$

$$\therefore \quad S = V \cdot I_a^* = (\overrightarrow{V\angle 0^\circ}) \cdot \overrightarrow{I_a^*}$$

$$= V\angle 0^\circ \left[\frac{E}{Z_s}\angle\theta-\delta - \frac{V}{Z_s}\angle\theta \right]$$

$$S = \frac{EV}{Z_s}\angle\theta-\delta - \frac{V^2}{Z_s}\angle\theta$$

$$\therefore \text{ Active Power} = \frac{EV}{Z_s}\cos(\theta-\delta) - \frac{V^2}{Z_s}\cos\theta$$

$$\text{Reactive Power} = \frac{EV}{Z_s}\sin(\theta-\delta) - \frac{V^2}{Z_s}\sin(\theta)$$

If $R_a = 0 \Rightarrow Z_s = jX_s = X_s\angle 90^\circ$

$\therefore \theta = 90^\circ$

$Z_s = X_s$.

$$\therefore \quad P = \frac{EV}{X_s}\sin(\delta)$$

$$Q = \frac{V}{X_s}\left[E\cos\delta - V\right]$$

Condition for maximum power

$$\frac{dP}{d\delta} = 0$$

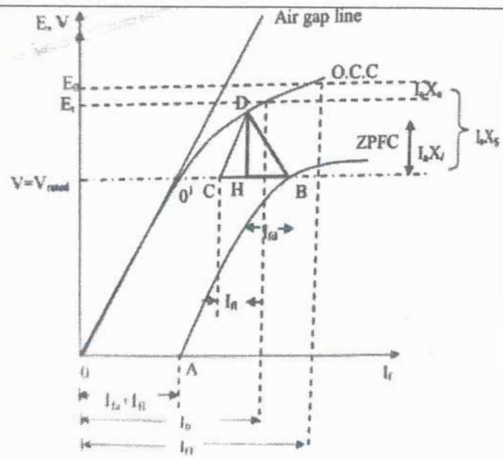
$$\Rightarrow \sin(\theta-\delta) = 0$$

$$\therefore \theta = \delta$$

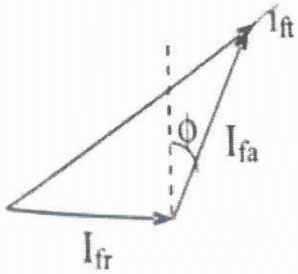
For $\theta = \delta$,

$$P_{max} = \frac{EV}{Z_s} - \frac{V^2}{Z_s}\cos\theta$$

IX	*OC, ZPF characteristics: 2 marks* *Steps:4 marks* *Resultant current phasor diagram: 1mark*	2+4+1	7	



1. Draw OCC,ZPFC and Air gap line
2. At $V=V_{rated}$, draw a horizontal line on the ZPFC to meet at a point B
3. Draw BC=OA
4. Draw CD parallel to air gap line
5. Join BD
6. Draw DH perpendicular to BC
7. The right angle triangle BHD is called Potier Triangle
8. Base of the Potier triangle BH=$\mathbf{I_{fa}}$ is the filed current to compensate the drop duet to armature reaction
9. Height of the potier triangle DH=$\mathbf{I_a X_L}$ is the drop due to leakage reactance.
10. The base of the triangle CH= $\mathbf{I_{fL}}$ is the filed current required to compensate the drop due to leakage reactance.
11. With DH= $\mathbf{I_a X_L}$ calculate the air gap voltage $E_r = \sqrt{(V\cos\varphi + I_aR_a)^2 + (V\sin\varphi \pm I_aX_L)^2}$
12. After finding Er, meaure the filed current $\mathbf{I_{fr}}$ corresponding to Er from OCC
    Add $\mathbf{I_{fa}}$ to $\mathbf{I_{fr}}$ to obtain $\mathbf{I_{fT}}$



13. Measure E_0 corresponding to $\mathbf{I_{fT}}$

$$\%\,Regulation\,(up) = \frac{E_0 - V}{V} x\, 100$$

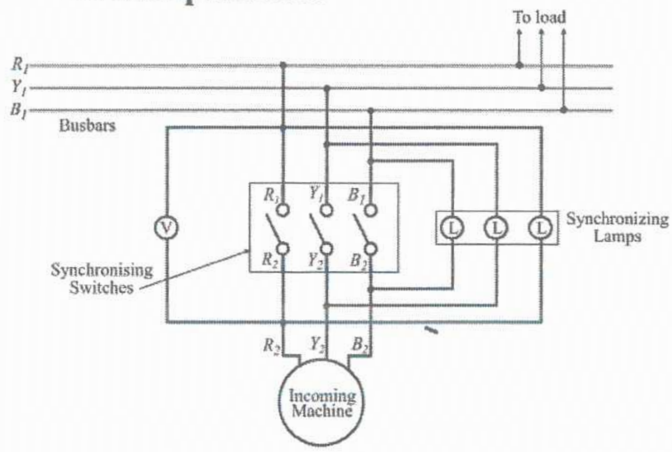
X	*Dark Lamp Method- 3 marks*	3+2+2	7	

Bright lamp Method:2 marks

Synchroscope:2 marks

Three Dark Lamp Method:

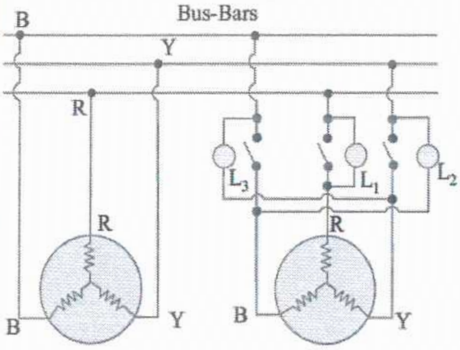
3



The three lamps flicker at a rate equal to the difference in the frequencies of the incoming machine and the busbar. The frequency of the incoming machine is adjusted until the lamps flicker at a very slow rate.

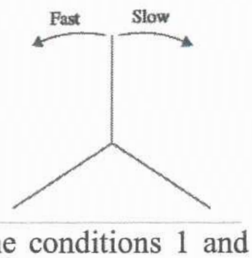
The right moment to close the synchronising switches is obtained at the instant when the straight-connected lamp is dark and the cross-connected lamps are equally bright. If the phase sequence is incorrect, then all the lamps will be dark simultaneously.

2 dark 1 bright lamp method



2

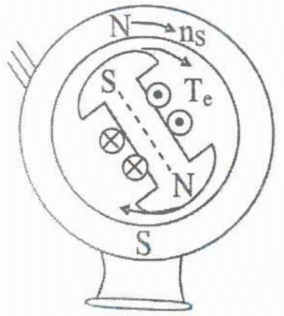
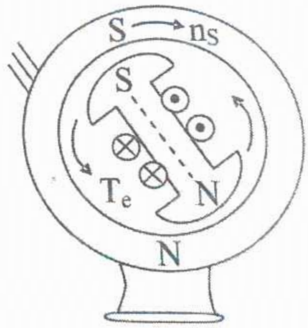
Synchroscope

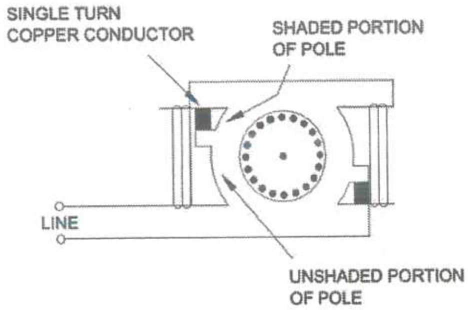
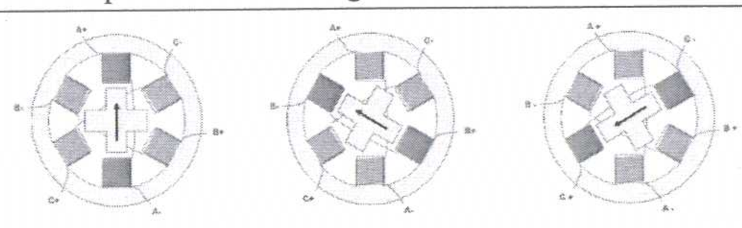


The conditions 1 and 2 required for the synchronization are assured by means of the Synchroscope (shown in the figure). The Synchroscope compares the voltage from one phase of the incoming alternator with that of the corresponding phase of the 3-phase system.

The position of the pointer of the Synchroscope indicates the phase difference between the voltages of the incoming alternator and the infinite busbar.

2

	When the frequencies of the two voltages are equal, the pointer remains stationary. When the frequencies differ, the pointer rotates in one direction or the other. The direction of the rotation of the pointer shows whether the incoming alternator is running too fast or too slow, i.e., whether the frequency of the incoming alternator is higher or lower than that of the infinite busbar. The speed of the rotation of the pointer is equal to the difference between the frequency of the incoming alternator and the frequency of the infinite busbar.			
XI	Consider a two pole synchronous motor as shown in figure. With the three currents in the three phase armature winding, stator N, S poles rotate at synchronous speed. • At the instant, stator N, S poles thus producing a clock wise torque on the rotor as shown. • After a half cycle, stator poles occupy the position as shown in the second figure. • Now the torque direction is counter-clockwise. Thus the rotor is required to rotate counter clockwise from its earlier clockwise direction. • Due to the rotor inertia, the rotor will not be able to respond to the fast reversals of torque. Hence the rotor remains stand still because of the net torque being zero. • Hence the synchronous motor is not self-starting.  Fig. 1  Fig. 2	Figure: 2m Explanation: 5 m	7	
XII	Hunting is the phenomenon of oscillation of the rotor about its steady state position or equilibrium state in a synchronous motor. Hence, hunting means a momentary fluctuation 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 torques which changes the speed of the motor. Methods to reduce hunting:	4 3	7	

	a) Hunting may be reduced by using damper windings. b) It can be decreased by using flywheel. A large and heavy flywheel is to be connected to the rotor. This increases the inertia of the rotor and helps in maintaining the rotor speed constant. c) Hunting can also be decreased by designing the synchronous machine with suitable synchronizing power coefficients.			
XIII	 In the core, when a single phase is applied an alternating flux is generated. This flux links with the shaded coil in fraction amounts. Then voltage gets induced in the coil due to the variation in the flux linking. Hence, the shaded portion is short-circuited due to which it produces the circulating current in it. In such a way, the direction is opposing the main flux. The main core flux is opposed by the flux in the ring that is developed by the circulating current. Hence, flux is induced in the shaded portion of the motor along with the unshaded portion with a phase difference, which is lagging behind the unshaded pole flux. There is also a space displacement that is less than 90 degrees between a shaded ring flux and the main motor flux. Due to this space displacement, a rotating magnetic field is produced which leads to a torque on the cage motor. In order to obtain reversal in the direction of rotation, we have to provide two shading coils.	Figure: 3 marks Explnat ion: 4 marks	7	
XIV	 The basic working principle of the stepper motor is the following: By energizing one or more of the stator phases, a magnetic field is generated by the current flowing in the coil and the rotor aligns with this field. By supplying different phases in sequence, the rotor can be rotated by a specific amount to reach the desired final position. Figure 2 shows a representation of the working principle. At the beginning, coil A is energized and the rotor is aligned with the magnetic field it produces. When coil B is energized, the rotor rotates	Figure: 3 marks Explnat ion: 4 marks	7	

	clockwise by 60° to align with the new magnetic field. The same happens when coil C is energized. In the pictures, the colors of the stator teeth indicate the direction of the magnetic field generated by the stator winding.			

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