QNO	Scoring Indicators	Split Score	Total Score
I 1	PART - A It is the ratio of vector sum of emf induced in the coil to arithmetic sum of emfs induced in the same coil $K_c = \cos(\alpha/2)$	1 1	2
2	when at sudden the shaft load is increased in an alternator, the speed of the rotor falls out of synchronism with that of the stator mmf speed, thus instability arises in synchronism i.e. rotor speed decreases in order to supply the load. as a result load angle starts rising. During forward swing electrical power of rotor becomes equal to load power, but still now the rotor speed is less than syn. speed. In order to boost the rotor speed, the rotor swings further until power of rotor>load power, now the rotor gets accelerated. This swinging phenomenon of rotor in order to achieve synchronism is called HUNTING.	2	2
3	Remote Indicator or positioned X-Y plotter Machine tool positioning Floppy disk drives Any two applications (any two)	2	2
4	%regulation = $(E_0 - V)/V$ E_0 – No load Voltage, V- Rated Voltage	1 1	2
5	It is the ratio of the open circuit voltage to the short circuit current for particular field current. $Z_s = V_{oc}/I_{sc}$	2	2
II 1	PART –B Z = No. of conductors or coil sides in series/ phase = 2 T Where T is the No of coils or turns/phase P = No. of poles f = frequency of induced emf in Hz Φ = flux/pole in webers $K_d = \frac{\sin\left(\left(\frac{m\beta}{2}\right)\right)}{m\sin\left(\frac{\beta}{2}\right)}$ $K_c = \cos\alpha/2$ K_f = form factor = 1.11 N= rotor rpm Assumptions $d\Phi = \Phi P$ $dt = 60/N$	1	

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<td>$Average\ emf\ per\ conductor, \frac{d\emptyset}{dt} = \frac{\Phi P}{60/N} = \frac{\emptyset N P}{60}$
N= 120f/P
Average emf per conductor $= \frac{\emptyset P}{60} \text{x} \frac{120 f}{P} = 2 f \Phi$
If there are z conductors, average emf = $2f\Phi Z = 4 f \Phi T$
Rms value of emf = K_f x average emf = $4.44 f \Phi T$
Actually available emf $= 4.44 K_c K_d f \Phi .T$</td>
<td>1

1
1
1
1</td>
<td>6</td>
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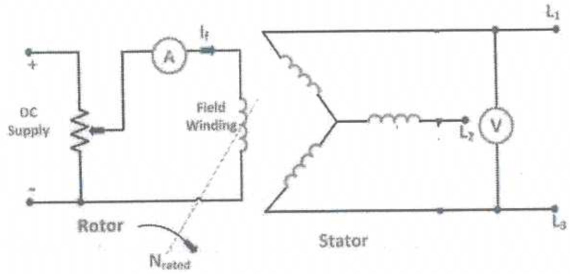
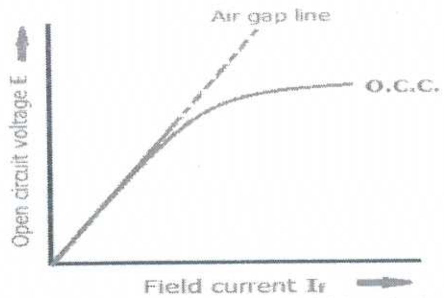
<td>The alternator is run at rated synchronous speed and the load terminals are kept open. That is, all the loads are disconnected. The field current is set to zero, this condition is called open circuit test condition.



The field current is gradually increase in steps, and the terminal voltage Et is measure at each step, The excitation current may be increased to get 25% more than rated voltage of the alternator. A graph is plotted between the open circuit test voltage Ep and field excitation current If.



The characteristic curve so obtain is called open circuit characteristic (O.C.C.). it take the shape of a normal magnetization curve. The extension of linear portion of an O.C.C. is called the air gap line are show in figure.

Circuit Diagram
Explanation
Expected Graph</td>
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3
1</td>
<td>6</td>
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<td>3</td>
<td>1. Starting Torque : It is developed by the rotor when full voltage is applied to its stator winding. It is also called breakaway torque
2. Running Torque : It is the torque developed by the rotor under</td>
<td>1.5</td>
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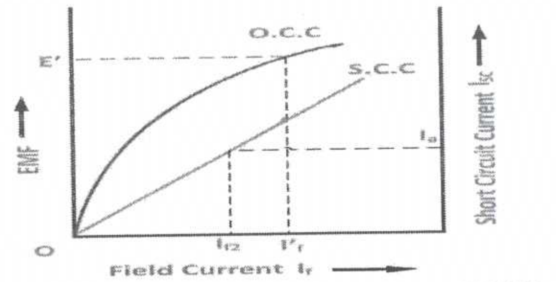
	running conditions. It is determined by rating and speed of the driven machine. 3. Pull in Torque : A synchronous motor started as induction motor till it runs 2 to 5 % below the synchronous speed. Afterwards excitation is switched on and rotor pulls into step with synchronously rotating stator field. The amount of torque at which the motor pull into step is called pull in torque. 4. Pull-out Torque : The maximum torque which can motor develop without pulling out of step or synchronism is called pull out torque	1.5 1.5 1.5	6
4	**MMF Method** is also known as **Ampere Turn** Method. The synchronous impedance method is based on the concept of replacing the effect of armature reaction by an imaginary reactance the Magnetomotive force (MMF). The MMF method replaces the effect of armature leakage reactance by an equivalent additional armature reaction MMF so that this MMF may be combined with the armature reaction MMF. To calculate the voltage regulation by MMF Method, the following information is required. They are as follows: • The resistance of the stator winding per phase • Open circuit characteristics at synchronous speed. • Short circuit characteristic  • Considering the Open Current Characteristics shown above the field current I'_f corresponding to the voltage E' is calculated. • Draw the field current I'_f leading the voltage E' by 90 degrees. It is assumed that on short circuit all the excitation is opposed by the MMF of armature reaction. Thus, $$I_f' = I_f' \angle 90^\circ - \alpha$$ From the Short Circuit Current characteristics (SSC) shown above, determine the field current I_{f2} required to circulate the rated current on short circuit. This is the filed current required to overcome the synchronous reactance drop I_aX_a.		

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- Draw the field current I_{f2} in phase in opposition to the current armature current I_a. Thus,

$$I_{f2} = I_{f2} \angle 180^\circ - \varphi$$

Determine the phasor sum of the field currents I'_f and I_{f2}. This gives the resultant field current If which would generate a voltage E_0 under no load conditions of the alternator. The open circuit EMF E_0 corresponding to the field current if is found from the open circuit characteristics

The regulation of the alternator is found from the relation shown below.

$$\text{Regulation} = \frac{E_0 - V}{V} \times 100\%$$

Explanation
Characteristics/Graph
</td>
<td>4
2</td>
<td>6</td>
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<td>5</td>
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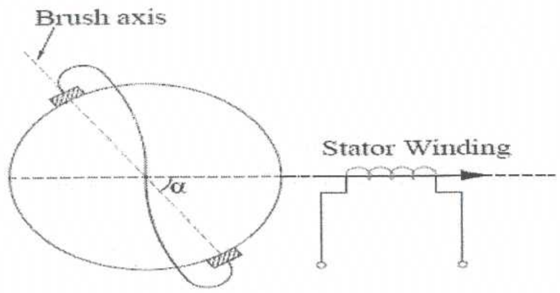
Repulsion Motor is a special kind of single phase AC motor which works due to the repulsion of similar poles. The stator of this motor is supplied with 1 phase AC supply and rotor circuit is shorted through carbon brush.

The main components of repulsion motor are stator, rotor and commutator brush assembly. The stator carries a single phase exciting winding similar to the main winding of single phase induction motor. The rotor has distributed DC winding connected to the commutator at one end just like in DC motor. The carbon brushes are short circuited on themselves.



In the above figure, the stator winding have single phase AC winding which produces the working mmf in the air gap. The brushes on rotor are shown to be shorted. As the rotor circuit is shorted, the rotor receives power from stator by transformer action.
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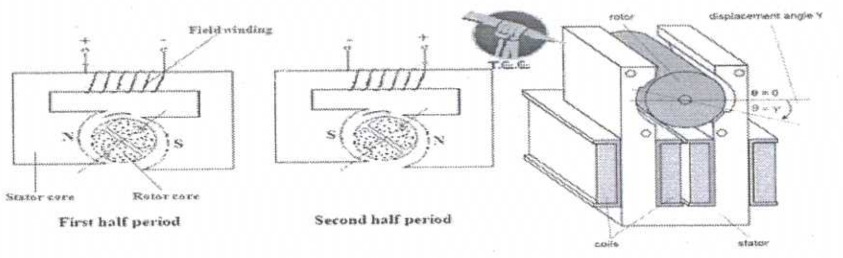
	Working principle of Repulsion Motor: The basic principle behind the working of repulsion motor is that "similar poles repel each other." This means two North poles will repel each other. Similarly, two South poles will repel each other. When the stator winding of repulsion motor is supplied with single phase AC, it produces a magnetic flux along the direct axis as shown in figure above by arrow mark. This magnetic flux when link with the rotor winding, creates an emf. Due to this emf, a rotor current is produced. This rotor current in turn produces a magnetic flux which is directed along the brush axis due to commutator assembly. Due to the interaction of stator and rotor produced fluxes, an electromagnetic torque is produced Diagram Explanation	3 3	6
6	• A universal motor is built like a series d.c. motor with the difference that both its stator and armature are laminated. A universal motor is defined as a motor which can be operated on both a.c. supply and d.c. supply at approximately the same speed and output. • A d.c. series motor (both armature and field windings are in series) can be operated on a single phase a.c. supply. It is then called an a.c. series motor. • <u>**Operation:**</u> When the motor is connected to a.c. supply, the same alternating current flows in the field and armature windings. The field winding produces an alternating flux that reacts with the current flowing in the armature to produce a torque. The flux produced is only alternating not the rotating.  Diagram Explanation	3 3	6

7	**Split phase Motor (Resistive Start)** The auxiliary windings have a higher resistance to reactance ratio. It is also obtained by using thinner wire for auxiliary windings. The Split phase Motor is permissible because the auxiliary winding is in the circuit which only during startup. When the motor reaches about 75% it synchronous speed the centrifugal switch cut it out. The motor has low to moderate starting torque. The starting torque can be increased by melting a series resistance in the auxiliary windings. **Capacitor Start Motor** Higher the starting torque can obtain if a capacitor is connected with the auxiliary windings. It also increases phase angle between the winding currents. Since the capacitor is additional cost normally this motor is expensive rather than other types of motors. Typical capacitors values for half horsepower motor is 300 uf . AC electrolytic type can sued for this type of motor. As the capacitor is in the circuit only during the startup the electrolytic type can be used. The high starting torque is the out of the starting torque. **Capacitor Start-Capacitor Run Motor** Normally two capacitors on in this circuit and one capacitor is used for a start the motor while the other is used to run the motor. Normally it optimized the starting and running performances. The starting capacitor is normally contained larger values electrolytic type of motor. The running capacitor is smaller than the starting capacitor. **Shaded Pole Motors** Those shaded pole motors got the salient pole construction. The shaded band consisting of a short-circuited copper which is used on one portion of each pole. The short-circuited coil is known as shading coil. The result is that the current induced in the shading band causes the flux in the shaded pole portion to lag the flux in the unshaded portion. The flux of the shaded portion is reached its maximum after unshaded portion flux reaches its maximum. This normally creates a progressive shift of flux which the result is similar to rotating field. The last expensive motor in the fractional horsepower motor built for low horsepower rating. Mention any three motor	3 x 2	6

III Part –III

a Salient pole rotor

Salient pole type of rotor consist of large number of projected poles (salient poles) mounted on a magnetic wheel. Construction of a salient pole rotor is as shown in the figure at left. The projected poles are made up from laminations of steel. The rotor winding is provided on these poles and it is supported by pole shoes.

- Salient pole rotors have large diameter and shorter axial length.
- They are generally used in lower speed electrical machines, say 100 RPM to 1500 RPM.
- As the rotor speed is lower, more number of poles are required to attain the required frequency. ($Ns = 120f / P$ therefore, $f = Ns*p/120$ i.e. frequency is proportional to number of poles). Typically number of salient poles is between 4 to 60.
- Flux distribution is relatively poor than non-salient pole rotor, hence the generated emf waveform is not as good as cylindrical rotor.
- Salient pole rotors generally need damper windings to prevent rotor oscillations during operation.
- Salient pole synchronous generators are mostly used in hydro power plants.

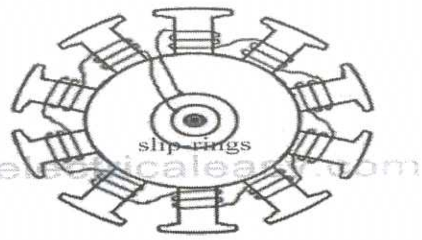


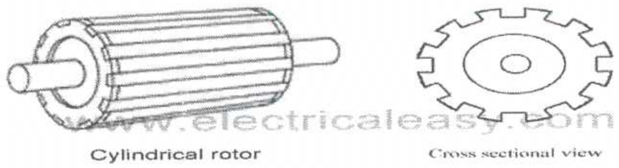
Figure 2

Explanation 2

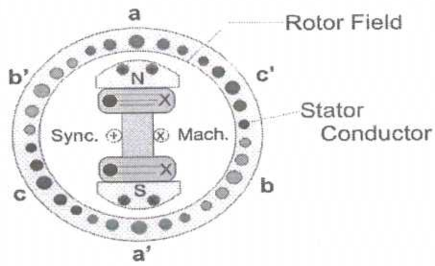
Non-salient pole (cylindrical) rotor

Non-salient pole rotors are cylindrical in shape having parallel slots on it to place rotor windings. It is made up of solid steel. The construction of non-salient pole rotor (cylindrical rotor) is as shown in figure above. Sometimes, they are also called as drum rotor.

- They are smaller in diameter but having longer axial length.
- Cylindrical rotors are used in high speed electrical machines, usually 1500 RPM to 3000 RPM.
- Windage loss as well as noise is less as compared to salient pole rotors.

	• Their construction is robust as compared to salient pole rotors. • Number of poles is usually 2 or 4. • Damper windings are not needed in non-salient pole rotors. • Flux distribution is sinusoidal and hence gives better emf waveform. • Non-salient pole rotors are used in nuclear, gas and thermal power plants.  Figure Explanation	2 2	8
b	**Armature Reaction in Alternator** In an alternator like all other synchronous machines, the effect of armature reaction depends on the power factor i.e the phase relationship between the terminal voltage and armature current Hence, the armature reaction is demagnetizing. Similarly, the armature reaction has magnetizing effect when the generator supplies a leading load (as leading load takes the leading VAR) and in return gives lagging VAR (magnetic energy) to the generator. In case of purely resistive load, the armature reaction is cross magnetizing only.	1	
	Armature Reaction of Alternator at Unity Power Factor At unity power factor, the angle between armature current I and induced emf E, is zero. That means, armature current and induced emf are in same phase. But we know theoretically that emf induced in the armature is due to changing main field flux, linked with the armature conductor. As the field is excited by DC, the main field flux is constant in respect to field magnets, but it would be alternating in respect of armature as there is a relative motion between field and armature in the alternator. If main field flux of the alternator in respect of armature can be represented as $\phi_f = \phi_{fm} sin\omega t \cdots\cdots\cdots (1)$ Then induced emf E across the armature is proportional to, dφf/dt. $Now, \frac{d\phi_f}{dt} = -\omega\phi_{fm} cos\omega t \cdots\cdots\cdots (2)$ Hence, from these above equations (1) and (2) it is clear that the angle between, φf and induced emf E will be 90o. Now, armature flux φa is proportional to armature current I. Hence, armature flux φa is in phase with armature current I. Again at unity electrical power factor I and E are in same phase. So, at unity power factor, φa is phase with E. So at this	2	

	condition, armature flux is in phase with induced emf E and field flux is in quadrature with E. Hence, armature flux φa is in quadrature with main field flux φf. As this two fluxes are perpendicular to each other, the armature reaction of the alternator at unity power factor is purely distorting or cross-magnetising type. As the armature flux pushes the main field flux perpendicularly, distribution of main field flux under a pole face does not remain uniformly distributed. The flux density under the trailing pole tips increases somewhat while under the leading pole tips it decreases. **Armature Reaction of Alternator at Lagging Zero Power Factor** At lagging zero electrical power factor, the armature current lags by 90o to induced emf in the armature. As the emf induced in the armature coil due to main field flux thus the emf leads the main field flux by 90o. From equation (1) we get, the field flux, $\phi_f = \phi_{fm} sin\omega t$ $Therefore,\ induced\ emf\ E \propto -\frac{d\phi_f}{dt}$ $\Rightarrow E \propto -\omega\phi_{fm}cos\omega t$ Hence, at ωt = 0, E is maximum and φf is zero. At ωt = 90o, E is zero and φf has maximum value. At ωt = 180o, E is maximum and φf zero. At ωt = 270o, E is zero and φf has negative maximum value. Here, φf got maximum value 90o before E. Hence φf leads E by 90o. Now, armature current I is proportional to armature flux φa, and I lags E by 90o. Hence, φa lags E by 90o. So, it can be concluded that, field flux φf leads E by 90o. Therefore, armature flux and field flux act directly opposite to each other. Thus, armature reaction of the alternator at lagging zero power factor is a purely demagnetising type. That means, armature flux directly weakens main field flux. **Armature Reaction of Alternator at Leading Power Factor** At leading power factor condition, armature current "I" leads induced emf E by an angle 90o. Again, we have shown just, field flux φf leads, induced emf E by 90o. Again, armature flux φa is proportional to armature current I. Hence, φa is in phase with I. Hence, armature flux φa also leads E, by 90o as I leads E by 90o. As in this case both armature flux and field flux lead, induced emf E by 90o, it can be said, field flux and armature flux are in the same direction. Hence, the resultant flux is simply arithmetic sum of field flux and armature flux. Hence, at last, it can be said that armature reaction of alternator due to a purely leading electrical power factor is the magnetizing type.	2 2	7
IV a	Construction wise, an alternator consists of field poles placed on the rotating fixture of the machine i.e. rotor as shown in the figure above. The rotor rotates in the stator. The field poles get projected on the rotor body. The armature conductors are housed on the stator. An alternating three-phase voltage represented by aa', bb', cc' is induced in the armature conductors thus resulting in the generation of three-phase electrical power.		



An alternator is basically a type of AC generator which also known as synchronous generator. The field poles are made to rotate at synchronous speed $N_s = 120\ f/P$ for effective power generation. Where, f signifies the alternating current frequency and the P represents the number of poles.

In most practical **construction of alternator**, it is installed with a stationary armature winding and a rotating field unlike in the case of DC generator where the arrangement is exactly opposite. This modification is made to cope with the very high power of the order of few 100 Megawatts produced in an AC generator contrary to that of a DC generator. To accommodate such high power the conductor weighs and dimensions naturally have to be increased for optimum performance. For this reason is it beneficial to replace these high power armature windings by low power field windings, which is also consequently of much lighter weight, thus reducing the centrifugal force required to turn the rotor and permitting higher speed limits.

Stator:

- Stator is the stationary part of the alternator and contains 3-phase armature windings. Stator core is built up of silicon steel laminations to reduce eddy current losses. The laminations are provided with slots on its inner periphery and are packed tightly together by cast iron frame.
- Open slots are used allowing easy installation of stator coils and easy removal in case of repair. Coils are insulated before inserting in the slots and are further protected by fiber.
- The three phase windings are placed in these slots and serves as the armature windings of the alternator. The armature windings are always connected in star and the neutral is connected to ground.

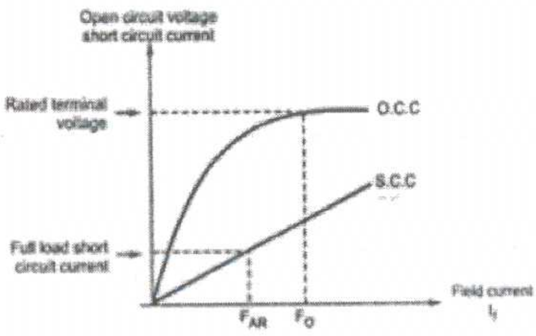
Rotor

There are mainly two types of rotor used in **construction of alternator,**

1. Salient pole type.
2. Cylindrical rotor type.

	Salient Pole Type The term salient means protruding or projecting. The salient pole type of rotor is generally used for slow speed machines having large diameters and relatively small axial lengths. The poles, in this case, are made of thick laminated steel sections riveted together and attached to a rotor with the help of joint. **Cylindrical Rotor Type** The cylindrical rotor is generally used for very high speed operation and employed in steam turbine driven alternators like turbogenerators. The machines are built in a number of ratings from 10 MVA to over 1500 MVA. The cylindrical rotor type machine has a uniform length in all directions, giving a cylindrical shape to the rotor thus providing uniform flux cutting in all directions. The rotor, in this case, consists of a smooth solid steel cylinder, having a number of slots along its outer periphery for hosting the field coils. Explanation Diagram	5 4	9
b	P=10; f= 50 Hz; Z_{ph} = (60 x 4)/3 = 80; Coil span =150°; Φ = 0.12 Wb; K_f =1.11 No. Of. Slots/pole = 60/10 = 6; α = 180-150 = 30° K_c = cos 30/2) = 0.966 β = (180/ No.Of. Slots/pole)= 180/6 =30^0 m= no.of slots/pole/phase = 6/3 =2 $K_d = \frac{\sin(\frac{m\beta}{2})}{m.\sin(\frac{\beta}{2})} = 0.966$ T= Z/2 = 80/2 =40 E_{ph} = 4.44. K_c. K_d.f Φ.T = 4.44 x 0.966x 0.966 x 50 x 0.12 x 40x = 994.4 V E_L = 1.732 * 994.4 = 1722 V	3 2 1	6
V a	The Synchronous Impedance Method or Emf Method is based on the concept of replacing the effect of armature reaction by an imaginary reactance. The method requires following data to calculate the regulation. 1. **The open -circuit characteristic (O.C.C) :** • The O.C.C is a plot of the armature terminal voltage as a function of field current with a symmetrical three phase short-circuits applied across the armature terminals with the machine running at rated speed.		

- At any value of field current, if E is the open circuit voltage and Isc is the short circuit current then for this value of excitation
  - Zs = Eoc/Isc
- At higher values of field current, saturation increases and the synchronous impedance decreases.
- The value of Zs calculated for the unsaturated region.
- The O.C.C is called the unsaturated value of the synchronous impedance.



2. **The short-circuit characteristic (S.C.C)**

- The S.C.C is a plot of short-circuit armature current versus the field current.
- The current range of the instrument should be about 25-50 % more than the full load current of the alternator.
- Starting with zero field current, increase the field current gradually and cautiously till rated current flows in the armature.
- The speed of the set in this test also is tom be maintained at the rated speed of the alternator.

3. **Resistance of the armature winding.**

- Measure the D.C. resistance of he armature circuit of the alternator.
- The effective a.c resistance may be taken to be 1.2 times the D.C. resistance.

Regulation Calculation

- From O.C.C. and S.C.C., Zs can be determined for any load condition.

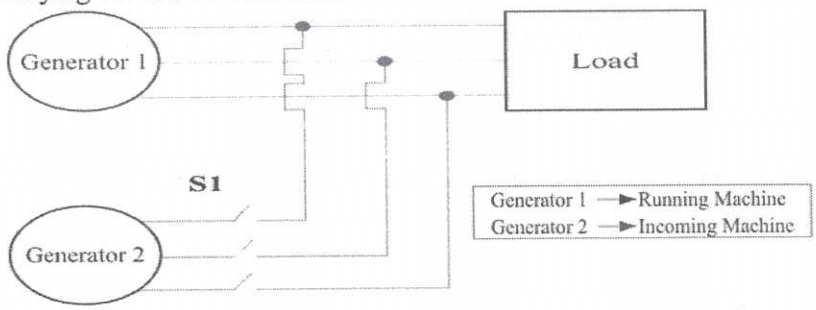
- The armature resistance per phase can be measured by different

	methods. • One of the method is applying d.c. known voltage across the two terminals and measuring current. So value of Ra per phase is known. $$\mathbf{Xs = \sqrt{Zs^2 - Ra^2}}$$ So synchronous reactance per phase can be determined. • No load induced e.m.f. per phase, Eph can be determined by the mathematical expression derived earlier. $Eph = [\ (V \cos\varphi + IRa)^2 + (V \sin\varphi \pm IXs)^2\ ]^{0.5}$ where Vph = Phase value of rated voltage Ia = Phase value of current depending on the load condition $\cos\Phi$ = p.f. of load • Positive sign for lagging power factor while negative sign for leading power factor, Ra and Xs values are known from the various tests performed. The regulation then can be determined by using formula, $$\text{Percentage Voltage Regulation} = \left(\frac{\lvert E_0 \rvert - \lvert V \rvert}{\lvert V \rvert}\right)$$ Different methods/Experiments to obtain the data Calculation	 4 4	 8
b	$Z_s = \frac{O.C\ Voltage}{S.C.Current} = 500/200 = 2.5\Omega$ $X_s = \sqrt{Z_s^2 - R_s^2} = 2.488\ \Omega$ Full load Current I = (55 x 1000)/ 550 = 100 A $Cos\Phi = 0.8$; $Sin\ \Phi = 0.6$; $E_o = \sqrt{(V \cos \emptyset + I R_a)^2 + (V \sin \emptyset + I X_s)^2}$ = 742.5 V % reg = (E_0- V)/V = 35%	 3 2 2	 7
VI a	**Synchronization of alternator** means **connecting an alternator into grid** in parallel with many other alternators that is in a live system of constant voltage and constant frequency. Many alternators and loads are connected into a grid, and all the alternators in grid are having same output voltage and frequency (whatever may be the power). It is also said that the		

alternator is connected to infinite bus-bar.
A stationary alternator is never connected to live bus-bars, because it will result in short circuit in the stator winding (since there is no generated emf yet). Before **connecting an alternator into grid**, following conditions must be satisfied:

1. Equal voltage: The terminal voltage of incoming alternator must be equal to the bus-bar voltage.
2. Similar frequency: The frequency of generated voltage must be equal to the frequency of the bus-bar voltage.
3. Phase sequence: The phase sequence of the three phases of alternator must be similar to that of the grid or bus-bars.
4. Phase angle: The phase angle between the generated voltage and the voltage of grid must be zero.

The figure below shows an alternator (generator 2) being paralleled with a running power system (generator 1). These two machines are about to synchronize for supplying power to a load. Generator 2 is about to parallel with the help of a switch, S1. This switch should never be closed without satisfying the above conditions.



1. To make the terminal voltages equal. This can be done by adjusting the terminal voltage of incoming machine by changing the field current and make it equal to the line voltage of running system using voltmeters.
2. There are two methods to check the phase sequence of the machines. They are as follows
   - First one is using a Synchroscope. It is not actually check the phase sequence but it is used to measure the difference in phase angles.
   - Second method is three lamp method (Figure 2). Here we can see three light bulbs are connected to the terminals of the switch, S1. Bulbs become bright if the phase difference is large. Bulbs become dim if the phase difference is small. The bulbs will show dim and bright all together if phase sequence is the same. The bulbs will get bright in progression if the phase sequence is opposite. This phase sequence can be made equal by swapping the connections

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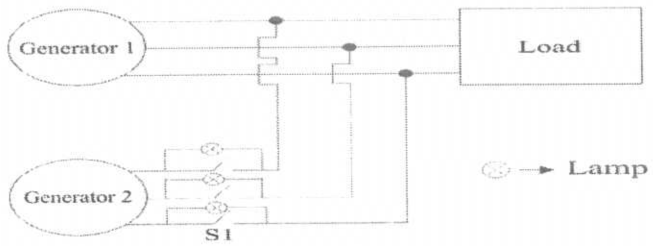
on any two phases on one of the generators.



3. The frequency should be nearly the same. This can be done by inspecting the frequency of dimming and brightening of lamps.
4. When the frequencies are nearly equal, the two voltages (incoming alternator and running system) will alter the phase gradually. These changes can be observed and the switch, S1 can be made closed when the phase angles are equal.

Conditions

Explanations

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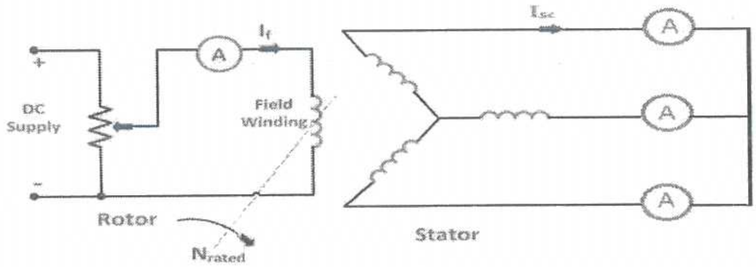
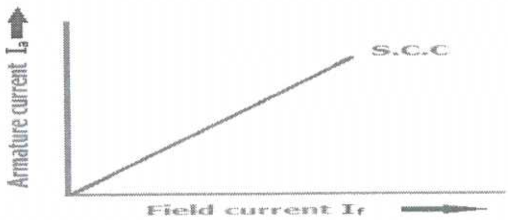
<tr><td>b</td><td>

The armature terminals are shorted through three ammeters. Care should we taken performing this test, and the field current should first decreased to zero before starting the alternator. Each ammeter should have range greater than the full rated value. the alternator run at synchronous speed. then the field current gradually increased in step, and the armature current is measured at each step.



The field current may be increased to get armature current upto 150% of the rated value.The field current If and the average of three ammeter reading at each step is taken.



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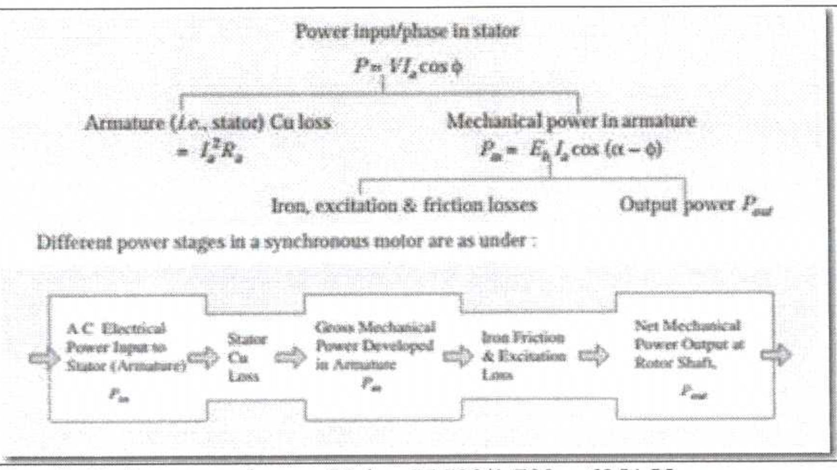
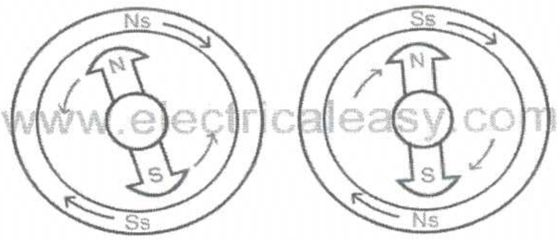
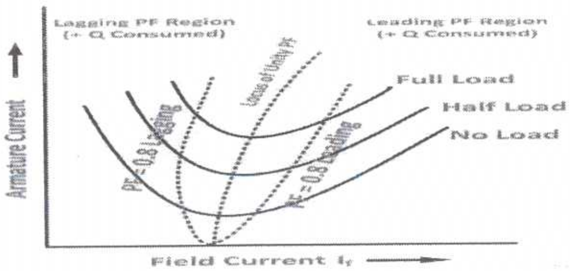
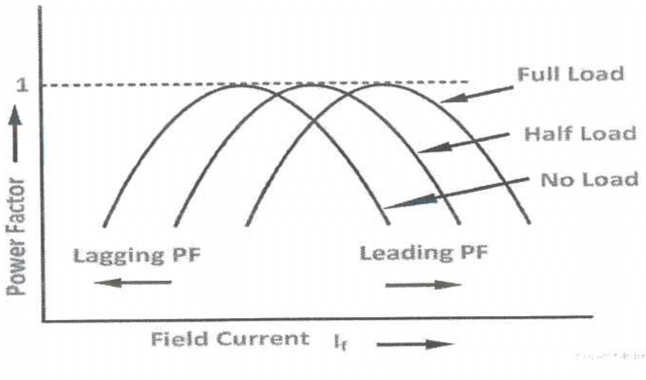
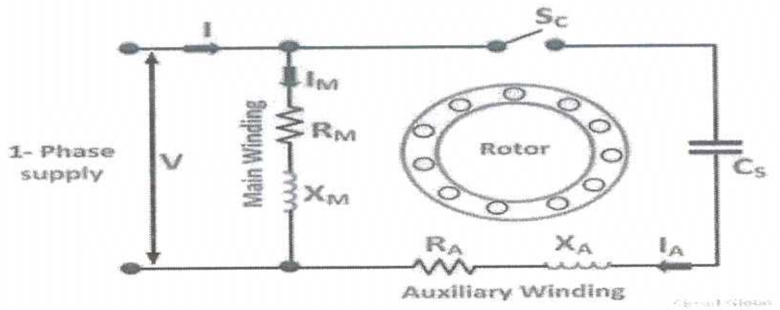
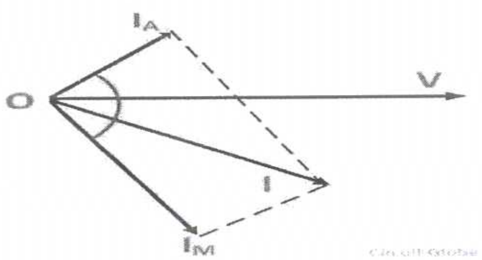
</table>

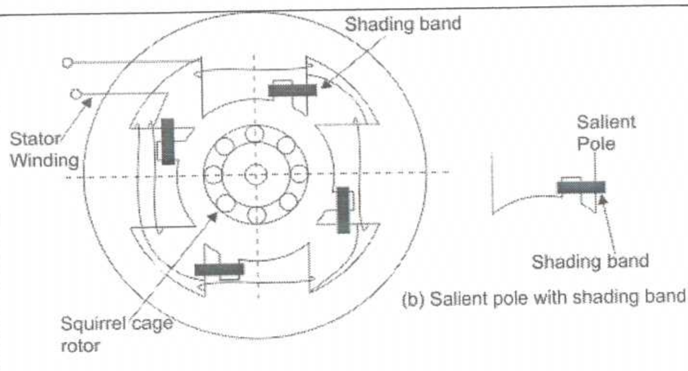
	A graph is plotted between the armature current Ia and field current If. The characteristic so obtained is called short-circuit characteristic (SCC). the characteristic is a straight line as shown in figure. Diagrams+Graph Explanations	3 4	7
VII a	 	3 4	7
b	Supply Voltage per phase = Vph = 11000/1.732 = 6351 V Internal angle q = $\tan^{-1}$ (Xs/Rs)= 88.1^0 Power factor angle $\Phi = \text{Cos}^{-1}\ 0.8 = 36.9°$ Synchronous impedance Zs = $\sqrt{R_a{}^2 + X_s{}^2} = 30.01\ \Omega$ Impedance drop = IZs= 60 x 30.01 = 1800.6 V ✓ When pf = 0.8 lead Power supplied to motor P= 1.73 x V_L x I_L x cos Φ = 914523 W Induced emf per phase = $\sqrt{V^2 + E_r{}^2 - 2VE_r\,(\cos(\theta + \emptyset)}$ = 7529.7 V Line E_b= 1.732 x 7529.7 = 13042 V 2.When pf = 0.8 lag Induced emf per phase = $\sqrt{V^2 + E_r{}^2 - 2VE_r\,(\cos(\theta - \emptyset)}$ = 5408 V Line E_b= 1.732 x 5408 = 9376 V	3 3 2	8
VIII a	The stator is wound for the similar number of poles as that of rotor, and fed with three phase AC supply. The 3 phase AC supply produces rotating magnetic field in stator. The rotor winding is fed with DC supply which magnetizes the rotor. Consider a two pole **synchronous machine** as shown		

	in figure below.  • Now, the stator poles are revolving with synchronous speed (lets say clockwise). If the rotor position is such that, N pole of the rotor is near the N pole of the stator (as shown in first schematic of above figure), then the poles of the stator and rotor will repel each other, and the *torque produced will be anticlockwise*. • The stator poles are rotating with synchronous speed, and they rotate around very fast and interchange their position. But at this very soon, rotor cannot rotate with the same angle (due to inertia), and the next position will be likely the second schematic in above figure. In this case, poles of the stator will attract the poles of rotor, and *the torque produced will be clockwise.* • Hence, the rotor will undergo to a rapidly reversing torque, and the motor will not start. But, if the rotor is rotated up to the synchronous speed of the stator by means of an external force (in the direction of revolving field of the stator), and the rotor field is excited near the synchronous speed, the poles of stator will keep attracting the opposite poles of the rotor (as the rotor is also, now, rotating with it and the position of the poles will be similar throughout the cycle). Now, the rotor will undergo unidirectional torque. The opposite poles of the stator and rotor will get locked with each other, and the rotor will rotate at the synchronous speed. Diagram Explanation	3 4	7
b	**V curve** is a plot of the stator current versus field current for different constant loads. The Graph plotted between the **armature current Ia** and **field current If** at no load the curve is obtained known as **V Curve**. Since the shape of these curves is similar to the letter "V", thus they are called V curve of synchronous motor. The power factor of the synchronous motor can be controlled by varying the field current I_f. As we know that the armature current I_a changes with the change in the field current I_f. Let us assume that the motor is running at No load. If the field current is increased from this small value, the armature current Ia decreases until the armature current becomes minimum. At this minimum point, the motor is operating at unity power		

	factor. The motor operates at lagging power factor until it reaches up to this point of operation. If now, the field current is increased further, the armature current increases and the motor start operating as a leading power factor. The graph drawn between armature current and field current is known as V curve. If this procedure is repeated for various increased loads, a family of curves is obtained. The **V curves** of a synchronous motor are shown below.  The figure below shows the graph between power factor and field current at the different loads. And it is known as **inverted V curve.**  It is clear from the above figure that, if the synchronous motor at full load is operating at unity power factor, then removal of the shaft load causes the motor to operate at a leading power factor. V curve- Graph +Explanation Inverted V curve- Graph +Explanation	 2+2 2+2	 8
IX a	A **Capacitor Start Motors** are a single phase Induction Motor that employs a capacitor in the auxiliary winding circuit to produce a greater phase difference between the current in the main and the auxiliary		

	windings. The name capacitor starts itself shows that the motor uses a capacitor for the purpose of the starting. The figure below shows the connection diagram of a Capacitor Start Motor.  The capacitor start motor has a cage rotor and has two windings on the stator. They are known as the main winding and the auxiliary or the starting winding. The two windings are placed 90 degrees apart. A capacitor C_S is connected in series with the starting winding. A centrifugal switch S_C is also connected in the circuit. The **Phasor Diagram** of the Capacitor Start motor is shown below.  I_M is the current in the main winding which is lagging the auxiliary current I_A by 90 degrees as shown in the phasor diagram above. Thus, a single phase supply current is split into two phases. The two windings are displaced apart by 90 degrees electrical, and their MMF's are equal in magnitude but 90 degrees apart in time phase. The motor acts as a balanced two-phase motor. As the motor approaches its rated speed, the auxiliary winding and the starting capacitor is disconnected automatically by the centrifugal switch provided on the shaft of the motor. Diagram Explanation	 4 3	 7

b



(b) Salient pole with shading band

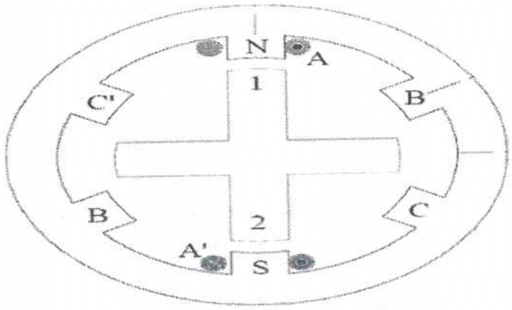
(a) 4-pole shaded pole construction

The stator of the **shaded pole single phase induction motor** has salient or projected poles. These poles are shaded by copper band or ring which is inductive in nature. The poles are divided into two unequal halves. The smaller portion carries the copper band and is called as shaded portion of the pole.

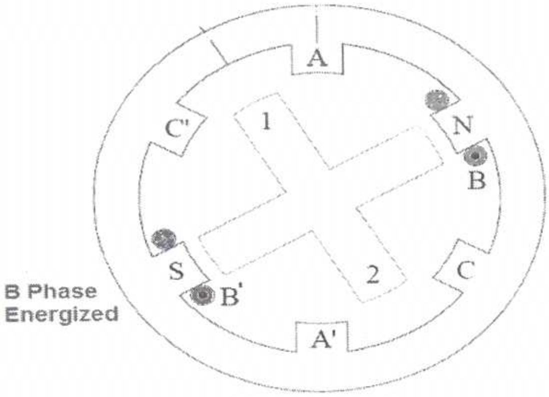
Working : When a single phase supply is given to the stator of shaded pole induction motor an alternating flux is produced. This change of flux induces emf in the shaded coil. Since this shaded portion is short circuited, the current is produced in it in such a direction to oppose the main flux. The flux in shaded pole lags behind the flux in the unshaded pole. The phase difference between these two fluxes produces resultant rotating flux. We know that the stator winding current is alternating in nature and so is the flux produced by the stator current. In order to clearly understand the working of shaded pole induction motor consider three regions-

REGION 1: When the flux changes its value from zero to nearly maximum positive value – In this region the rate of rise of flux and hence current is very high. According to Faraday's law whenever there is change in flux emf gets induced. Since the copper band is short circuit the current starts flowing in the copper band due to this induced emf. This current in copper band produces its own flux. Now according to Lenz's law the direction of this current in copper band is such that it opposes its own cause i.e rise in current. So the shaded ring flux opposes the main flux, which leads to the crowding of flux in non shaded part of stator and the flux weaken in shaded part. This non uniform distribution of flux causes magnetic axis to shift in the middle of the non shaded part.

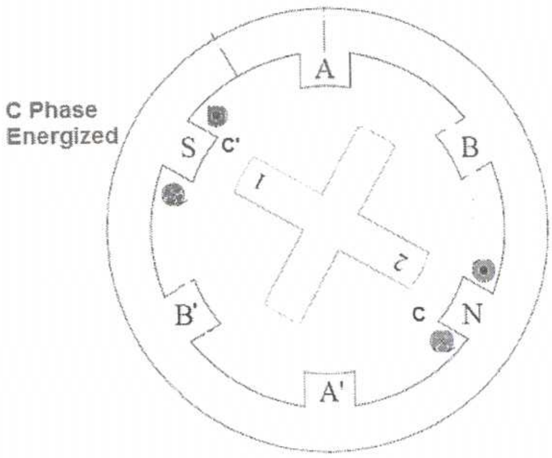
REGION 2: When the flux remains almost constant at its maximum value- In this region the rate of rise of current and hence flux remains almost constant. Hence there is very little induced emf in the shaded portion. The flux produced by this induced emf has no effect on the main flux and hence distribution of flux remains uniform and the magnetic axis

	lies at the center of the pole. REGION 3: When the flux decreases from maximum positive value to zero - In this region the rate of decrease in the flux and hence current is very high. According to Faraday's law whenever there is change in flux emf gets induced. Since the copper band is short circuit the current starts flowing in the copper band due to this induced emf. This current in copper band produces its own flux. Now according to Lenz's law the direction of the current in copper band is such that it opposes its own cause i.e decrease in current. So the shaded ring flux aids the main flux, which leads to the crowding of flux in shaded part of stator and the flux weaken in non shaded part. This non uniform distribution of flux causes magnetic axis to shift in the middle of the shaded part of the pole. This shifting of magnetic axis continues for negative cycle also and leads to the production of rotating magnetic field. The direction of this field is from non shaded part of the pole to the shaded part of the pole. Diagram Explanation	4 4	8
X a	Switched Reluctance Motor (SRM) is also known as Variable Reluctance Motor. This motor works on the principle of variable reluctance. This means, the rotor always tries to align along the lowest reluctance path. As the name suggests, a switching inverter is required for the operation of Switched Reluctance Motor. As we know that magnetic flux have a tendency to flow through lowest reluctance path, therefore rotor always tends to align along the minimum reluctance path. This is the basic working principle of Switched Reluctance Motor or Variable Reluctance Motor. Therefore, when stator phase winding A is energized, the rotor align along this phase as shown in figure below.  A Phase Energized		

When stator phase winding A is de-energized and winding B is energized, the rotor align itself along B phase as shown in figure below.



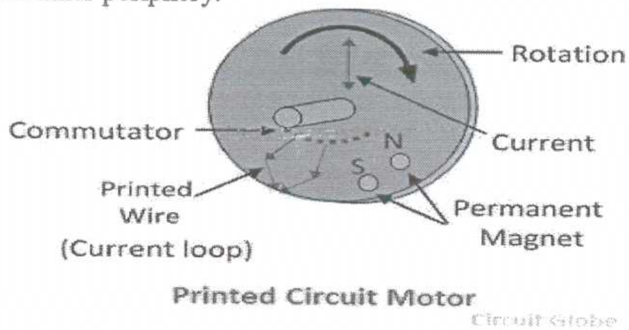
Similarly, the rotor occupies a position along phase winding C when this phase is energized.



Thus rotor rotation in clockwise direction is achieved by energizing the phase winding in a ABC sequence. If rotor rotation in anti-clockwise direction is require, stator phase winding must be energized in ACB sequence.

It must also be noted that, a particular phase winding must be energized / de-energized in synchronism with rotor position. This means as soon as the rotor align along the A phase, B phase must be energized and A phase must be de-energized if clockwise rotor rotation is required.

Diagram	4	8
Explanation	4	

b	A **Printed Circuit Board** or a **Disc Armature motor** consists of a rotor disc made of non-magnetic and non-conducting material. The armature winding and the commutator are printed with copper on both the sides of the disc. The disc armature is placed between two sets of permanent magnets mounted on the ferromagnetic plates. Brushes are placed around the inner periphery.  Working:Traditional electric motors have a radial magnetic field or flux with the rotor current flowing axially along the length of the rotor. In typical printed circuit motors the construction is reversed. The magnetic field is axial (oriented along the axis of the machine) and the current flows radially from the axis to the edge of the disc and back again. A tangential force on the disk is created by the current passing through the magnetic fields in the air gaps between the pole pairs of the permanent magnets. So that the return current does not cancel out the effect of the outgoing current, the return wire is physically separated or displaced to one side from the outgoing wire by the width of the magnet. In this way it interacts with the magnetic field of the adjacent magnet which is in the opposite direction and thus reinforces the tangential force on the disk. Diagram Explanation	 3 4	7