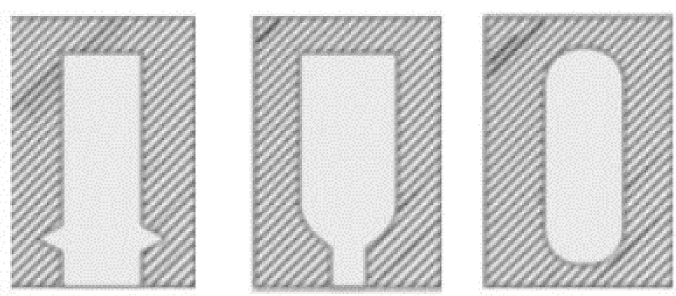
1891

October 2024

Electrical Machines – II

PART – A

1. **List the different types of Armature Slots in an Alternator. (3 marks)**
   - **Wide Open type Slot -** In this type of slots, the windings can be easily done and it is easily removed in the case of repair.
   - **Semi closed type slot**- This type of slots is better than open type but former wound coils are not suitable for this type.
   - **Closed type slot**- The armature winding has to be threaded through the slots. Hence the cost of labour and winding will be increased. Hence, they are rarely used.



2.Define Critical Speed of an Alternator. (3marks)

- When the rotor of an alternator is rotating, at a particular speed of the rotor, considerable amount of vibration is set up in the machine.
- This particular speed at which the rotor rotates with a vibration is called Critical speed.
- Critical Speed Should not exceed than 20% of the rated speed.

3. What is Infinite bus bar? (3 marks)

- A power system with a large number of alternators connected in parallel is called Infinite bus bar.
- When large number of alternators are connected in parallel to an infinite bus-bar, the synchronous impedance of the system is reduced to a very small value.
- The terminal voltage and bus-bar frequency are constant in an infinite bus-bar system.

4.Define synchronous reactance and synchronous impedance. (3 marks)

- The synchronous reactance of an alternator is the combined reactance of Armature reactance (X_a,) and Leakage reactance (X_L).So $X_s = (X_L + X_a)$

- The effective value of armature resistance (Reff) and synchronous reactance(Xs) combined together is called synchronous impedance Zs. it is the vector sum of armature resistance and the synchronous reactance. So Zs = $\sqrt{Reff^2 + Xs^2}$

5.Derive an expression for the starting torque of a three phase induction motor. (3 marks)

Torque of the Induction motor T = $K_1\, E_2\, I_2\, \cos\theta_2$

Where $I_2 = \frac{E2}{\sqrt{R2^2+X2^2}}$ and $\cos\theta_2 = \frac{R2}{\sqrt{R2^2+X2^2}}$

Starting Torque Ts = $K_1\, E_2 \cdot \frac{E2}{\sqrt{R2^2+X2^2}} \cdot \frac{R2}{\sqrt{R2^2+X2^2}}$

$$= \frac{K_1 E_2^2 R_2}{R_2^2+X_2^2}$$

$$T_s = \frac{K_1 E_2^2 R_2}{Z_2^2}$$

When the voltage applied to the motor is constant then ϕ is constant and thereby E_2 is constant.

Hence Starting Torque **Ts =** $\mathbf{\frac{K_1 R_2}{Z_2^2}}$ where $K_1 = K\, E_2^2$ which is another constant.

6.What is cogging? How it is prevented? (3 marks)

- When the number of rotor slots are equal to the number of stator slots magnetic locking occurs between the stator teeth and rotor teeth.
- As the magnetic locking torque is more than the accelerating torque the motor refuses to start. This phenomenon is called cogging.
- Cogging can be prevented by increasing the rotor slots than the number of stator slots or by skewing the rotor slots.

7.Why a Single-Phase induction motor is not self-starting? (3 marks)

- When single phase ac supply is given to the stator winding of single-phase induction motor, the alternating current starts flowing through the stator or main winding.
- This alternating current produces an alternating flux which is pulsating in nature and it will not create rotating magnetic field as three phase induction motor.
- As there is no rotating magnetic field the single-phase induction motor is not self-starting.

8.List the methods for starting a Synchronous motor. (3 marks)

Synchronous motor can be started by using

- DC motor method
- Small Induction motor method or Pony motor method
- Damper winding method
- Starting as a slip ring induction motor method

9.What is the need for BIS codes of practice for induction motors? (3 marks)

- BIS code of Practice for Induction motor serves as a guide for engineers in selection, Installation and maintenance of Induction motors.
- This code also gives additional information regarding selection of various types of drives available for transmission of power from the motor shaft to the driven machine.

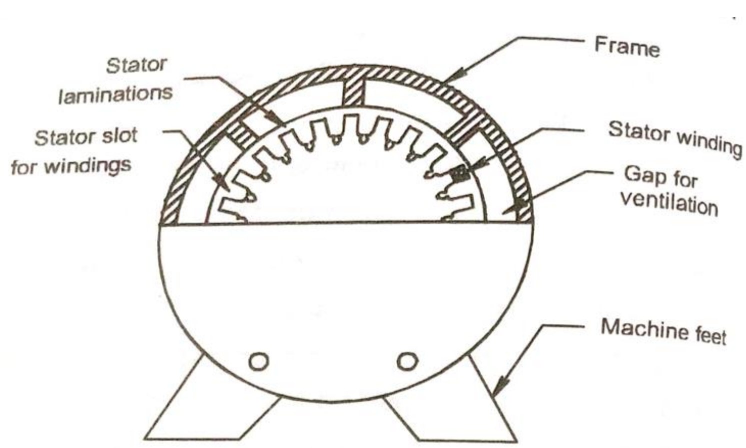
10.What is static balancing? (3 marks)

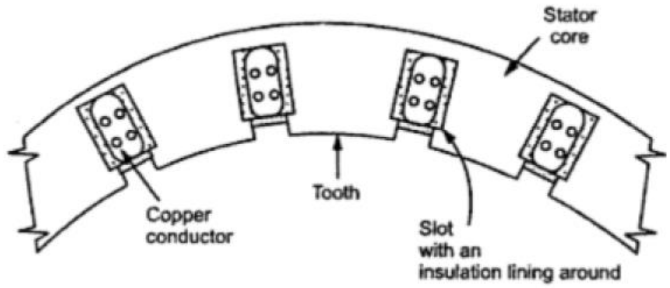
- Rotors should be mechanically balanced for smooth running without vibrations.
- This operation of correcting the weight distribution of the finished rotor assembly is called balancing.
- When the rotor to be balanced is placed on two knife edges of the balancing rig or balancing rollers for balancing is called static balancing. This method is suitable for low speed rotors.

Part – B

11.a Explain the stator and rotor constructional details of a salient pole alternator (Diagram – 7 marks, Explanation - 7 marks)

Salient pole Alternator - Stator

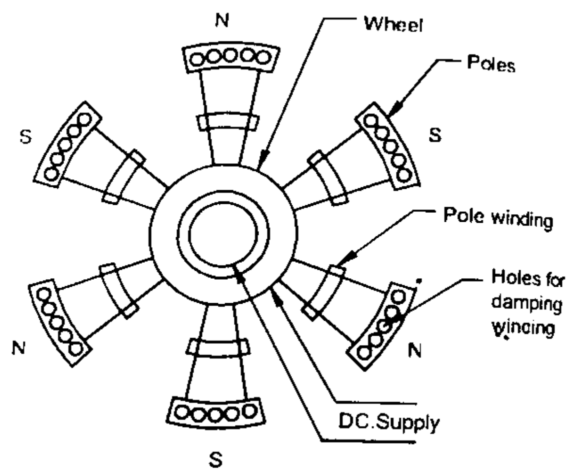




The stator is a stationary armature. This consists of a core and the slots to hold the armature winding similar to the armature of a dc generator. The stator core uses a laminated construction. It is built up of special steel stampings insulated from each other with varnish or paper. The laminated construction is basically to keep down eddy current losses. Generally, choice of material is steel to keep down hysteresis losses.

Rotor

It is used in low-and medium-speed alternators. It has a large number of projecting poles called salient poles having their cores bolted or dovetailed onto a heavy magnetic wheel of cast-iron, or steel of good magnetic quality. These rotors are characterized by their large diameters and short axial lengths. The poles and pole-shoes are laminated to minimize heating due to eddy currents. In large machines, field windings consist of rectangular copper strip wound on edge.

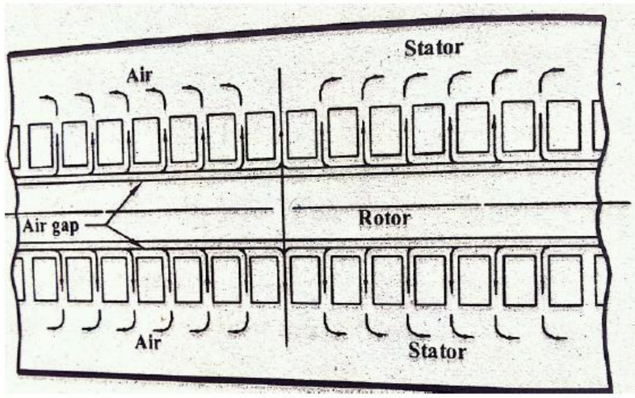


11.b Explain the methods of Ventilation in turbo alternators. (Diagram – 7 marks Explanation – 7 marks)

Types of ventilation in turbo alternators are
1. Radial Ventilation
2. Axial Ventilation
3. Radial Axial Ventilation
4. Multiple inlet system of ventilation

5. Closed Circuit Ventilation System

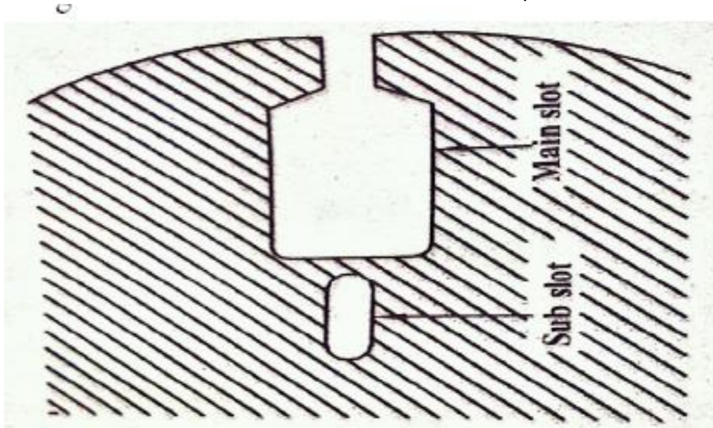
1. Radial Ventilation:



In case of small size turbo alternators, the length of the machine is so short. In such machines, cold air is allowed to flow inside the machine, by providing fans at the ends of the rotor. This cold air passes over the winding surface of the rotor and then reaches the air cap. Then it passes through the radial vent ducts of the stator core. This method of providing ventilation is called radial ventilation

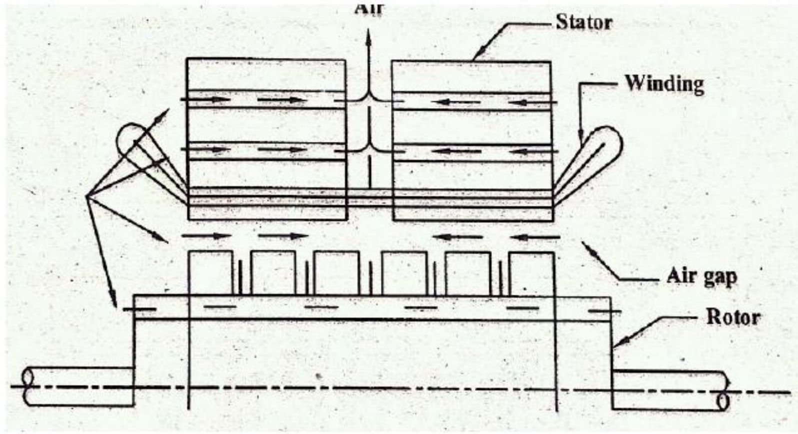
2. Axial Ventilation:

In this method, large quantity of air is passed through narrow sub slots which are just below the main slots in the stator core. For larger size turbo alternators, the air allowed for the purpose of circulation through the rotor and stator should be with higher pressure. Excessive amount of air is also needed. For effective circulation of air, radial and axial ducts are provided.



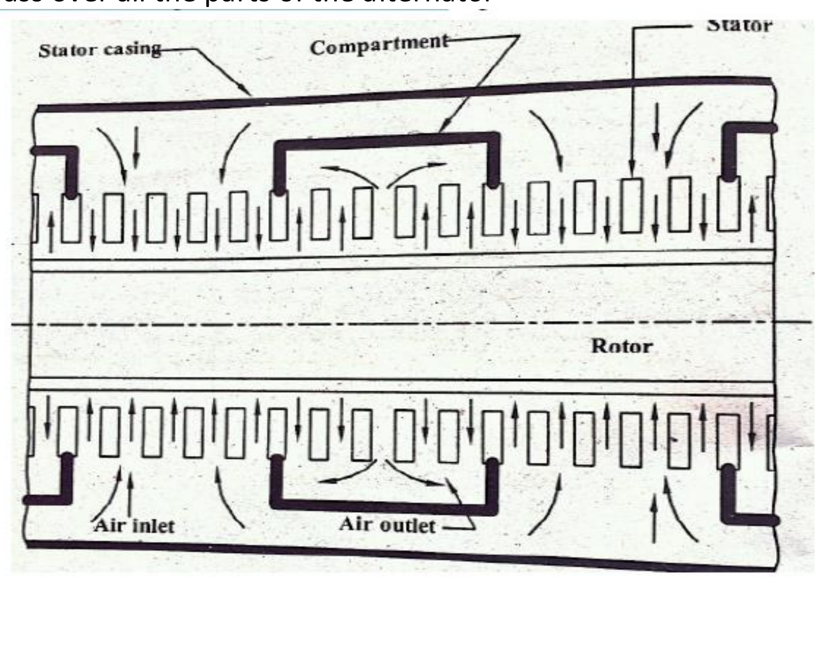
3. Radial axial Ventilation:

The cold air is allowed through the axial holes of the rotor. Then it is allowed to escape through the radial vent ducts and moves across the air gap. Then this air is allowed to pass through the radial ducts in the stator core. Special care and provision should be made to cool the rotor end windings by directly allowing the air over these portions. This air is again allowed to pass through the axial holes that are provided in the stator stampings. Now the air that is passing through the axial holes and also through the radial ducts is totally discharged from the alternator. In these method radial and axial ventilating ducts are provided for ventilation purposes. Hence this method is called radial axial method



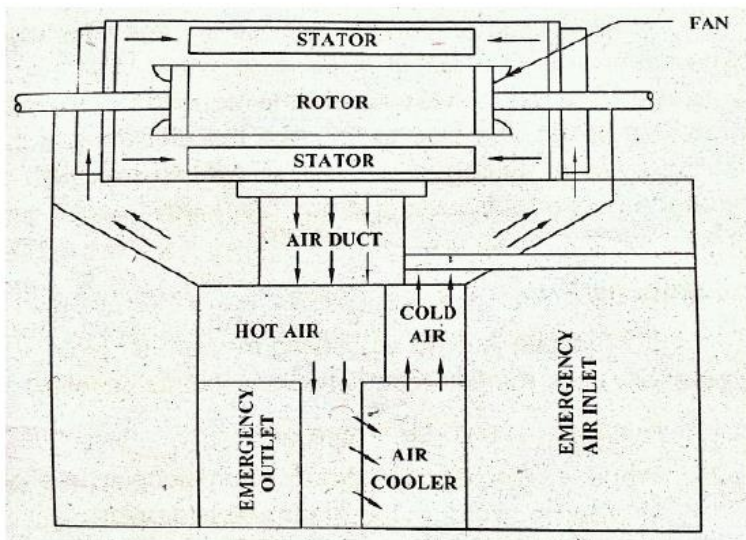
4. Multiple inlet system:

This method is adopted in case of turbo alternators having very long rotors. In such alternators there is difficulty in circulating cool air with certain pressure in all parts. To eliminate this difficulty, multiple inlet system of ventilation is adopted. In this method, the outer stator frame is fabricated with two compartments and provisions as inlet and outlet chambers. These inlet and outlet chambers are provided alternately. The air is allowed to pass through the inlet chambers. This air passes through radially inside the stator ventilating ducts. A portion of this air passes through the axial ducts and the remaining air flows through the air gap. From the air gap this air leaves out, through the outlet chambers. In addition to this provision airs also allowed to pass through the two ends of the rotor. This air passes through the axial ventilating ducts of the rotor and also over the stator windings. In this multiple inlet system of ventilation, the cold
air is allowed to pass over all the parts of the alternator



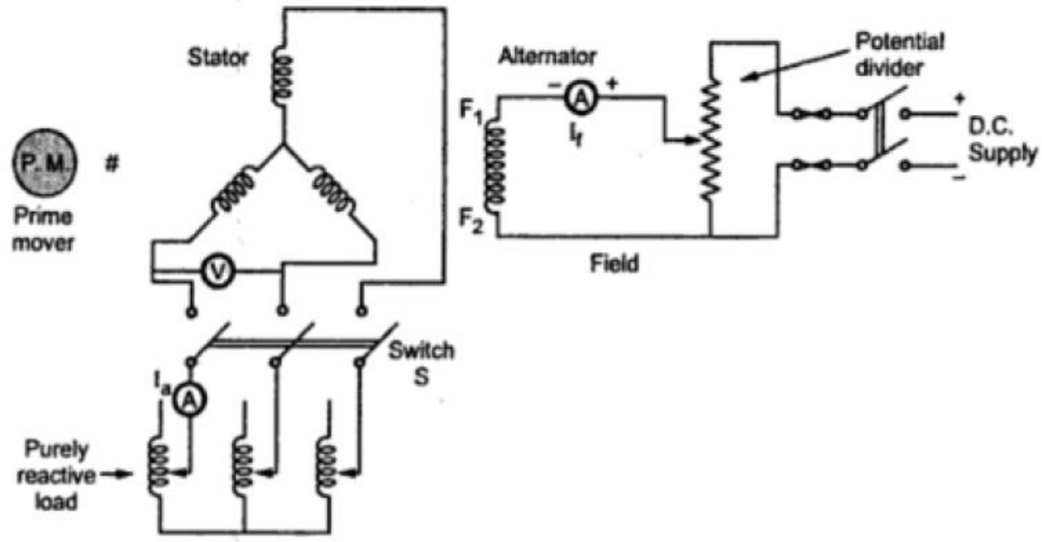
5. Closed Circuit Ventilation system:

In closed circuit ventilation system, the coolers are mounted at the bottom of the alternators in the space provided in the foundations. The arrangement should be such that the installation of the entire unites an air tight one. The air is replaced by hydrogen to increase the efficiency of the cooling system. If hydrogen is used for cooling medium, the coolers and the whole alternator are designed with a gas tight casing. The special sealing device is also provided at the shaft in order to prevent the leakage of the hydrogen. The hydrogen pressure should be maintained at certain pressure higher than that of the atmosphere in order to prevent the leakage of air into the cooling system.



12.a How Voltage regulation of an alternator can be predetermined by using ZPF method? Explain.(Diagram – 7 marks , Explanation - 7 marks)

To conduct zero power factor test, the switch ‘S’ is kept closed. Due to this, a purely inductive load is connected to the alternator through an ammeter. A purely inductive load has zero power factor lagging (i.e. cos90°). The machine speed is maintained constant at synchronous speed. Then by adjusting the field current such that the voltmeter reads rated voltage and by varying the inductance of the load, such that ammeter reads rated full load current. In this test there is no need to obtain number of points to obtain the curve. Only two points are enough to construct the zero-power factor curve. This is the graph of terminal voltage against excitation when delivering full load zero power factor current.



Zero power factor, full-load voltage excitation characteristics can be drawn by knowing two points A and P. point A is obtained from a short circuit test with full –load armature current. Hence OA represents field current (Excitation) required to overcome demagnetizing effect of armature reaction and to balance leakage reactance drop at full –load. Point P is obtained when full –load current flows through the armature and wattmeter reading is zero. Zero power factor curve may be drawn as follows:

(i) From P draw line PQ equal and parallel to OA.

(ii) Through point Q draw a line parallel to initial straight part of O.C.C (parallel to OB),cutting the
O.C.C at R.

(iii) Join RQ and draw a perpendicular Line RS on PQ.

(iv) Impose the triangle PRS at various –points of O.C.C to obtain corresponding points on the zero-power factor curve.

In triangle PRS Length RS represents leakage reactance drop (IXL) and Length PS represents armature reaction excitation.

Following is the procedure to draw potier regulation diagram:

(i) Draw OA horizontally to represent terminal voltage V on full load and OB to represent full load current (I) at a given power factor

(ii) Draw AC (=IRa), voltage drop due to resistance (Ra) (if resistance is given)parallel to OB

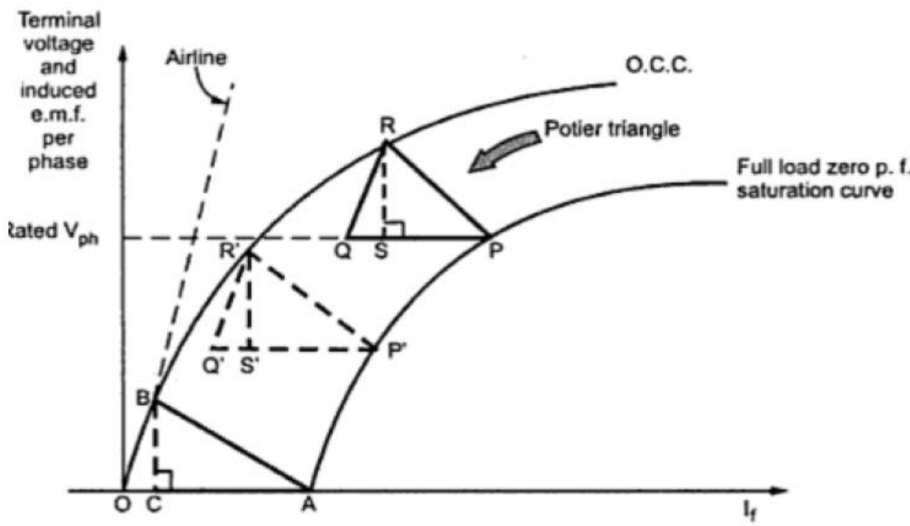
(iii) Draw CD perpendicular to AC and equal to reactance drop IXL. Now OD represents generated e.m.f E.

(iv) From O.C.C, find the field current I1 corresponding to this generated e.m.f E and draw OF (equal to I1) perpendicular to OD. Draw FG parallel to load current OB (i.e . I) to represent excitation (field current) equivalent to full load armature reaction.

OG gives total field current required.

(v) If the load is thrown off, then terminal voltage will be equal to generated e.m.fcorresponding tofield excitation OG. Hence e.m.f Eo may be obtained from O.C.C corresponding to field excitation OG. Vector OJ will lag behind vector OG by 90° DJ represents voltage drop due to armature reaction.

Now regulation may be obtained from the following relation: % regulation $= \frac{Eo-V}{V}$ x 100

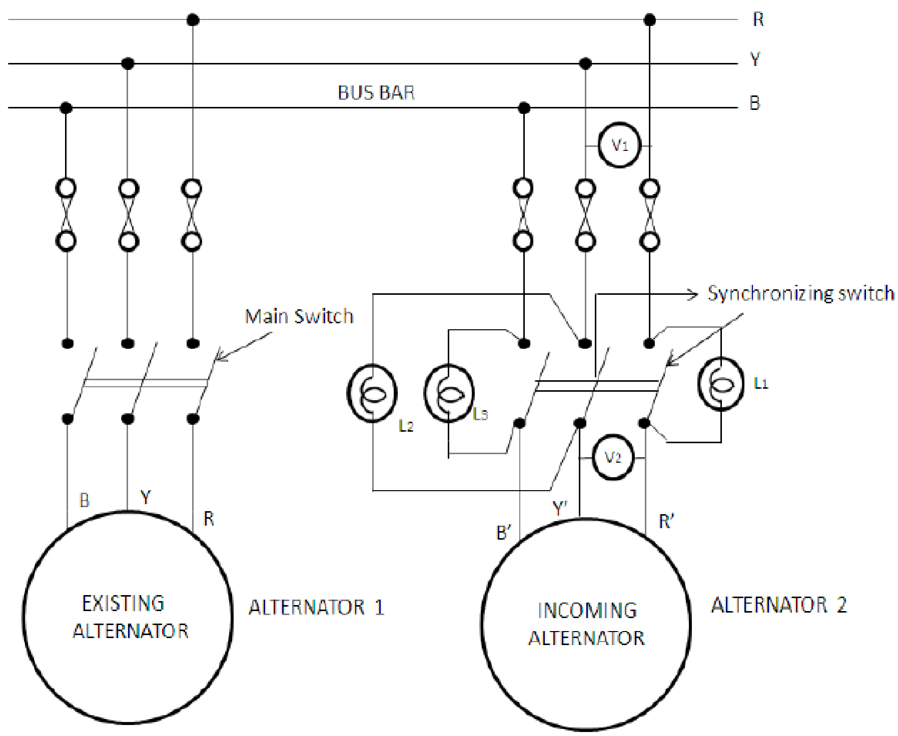


12.b Describe the synchronizing of two alternators by dark lamp method. (Diagram – 7 marks, Explanation - 7 marks)

The alternator 1 is already connected with the bus-bar and is supplying power factor to the external circuit. The alternator 2 is the incoming alternator. The incoming alternator started and its speed is adjusted to its rated value. Its excitation is also adjusted to generate its rated voltage. Voltmeter V2 will indicate its voltage and voltmeter V1 will indicate the bus-bar voltage. When the voltage V1 and V2 are equal, the condition 1 is satisfied.

The frequency of the incoming machine is adjusted to the bus-bar frequency by controlling the speed of the alternator 2. This fulfills the condition 2. The phase sequence also checked as mentioned above.

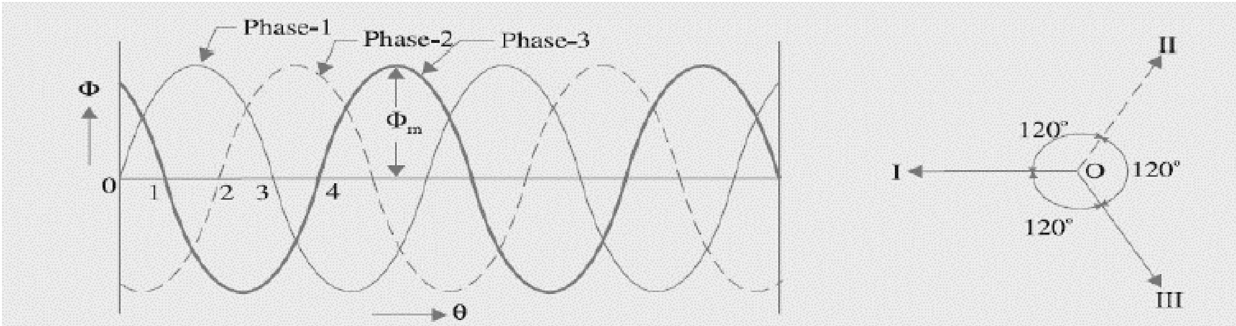
The synchronizing switch is closed at the middle of the lamps dark period. Now the incoming machine is connected to the bus-bar. At this stage, the generated emf of the incoming machine is just equal to the bus-bar voltage. It neither supply power nor receive power from the bus-bar, and the alternator 2 is said to be “floating on the bus-bar”.

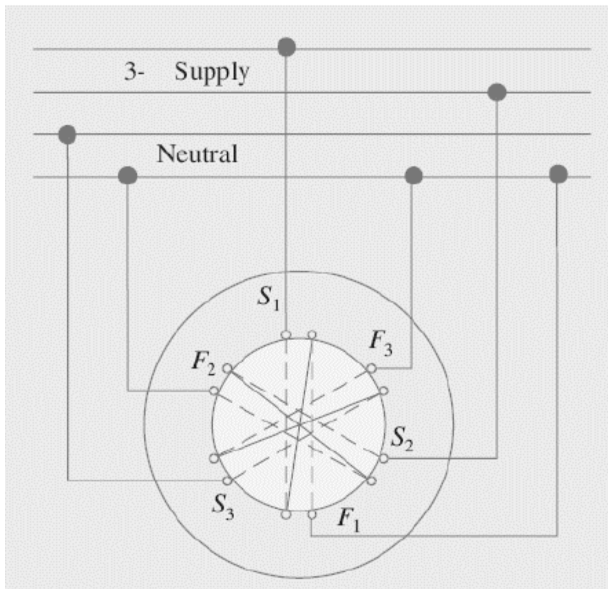


In dark lamp method, it is not possible to judge whether the incoming alternator is fast or slow. Also, the lamp can be dark even though a small value of voltage may present across its terminals. These are the disadvantages of dark lamp method. These disadvantages may not cause much in case of slow speed alternators or small capacity alternators. But it may cause harm and disturbance in case of high speed and large capacity alternators. The bright lamp method eliminates these difficulties.

13.a How a rotating magnetic field is established in a three-phase induction motor? Explain with necessary diagrams. (Diagram – 7 marks, Explanation – 7marks)

The fundamental principle of operation of AC machines is the generation of a rotating magnetic field, which causes the rotor to turn at a speed that depends on the speed of rotation of the magnetic field. The stator of the motor consists of overlapping winding offset by an electrical angle of120°. When the primary winding or the stator is connected to a 3 phase AC source, it establishes a rotating magnetic field which rotates at the synchronous speed.





The assumed positive directions of the fluxes are shown in Figure above. Let the maximum value of flux due to any one of the three phases be Φ_m. Resultant flux Φ_r is the vector sum of Φ_1 Φ_2 Φ_3 and Φ_4.

i) At point 0, θ= 0°;

$\Phi_R = 0$, $\Phi_Y = \frac{-\sqrt{3}}{2}\Phi_m$, $\Phi_B = \frac{\sqrt{3}}{2}\Phi_m$

$\Phi_R = 2 \times \frac{\sqrt{3}}{2}\Phi_m . cos\frac{60°}{2}$

$= 2 \times \frac{\sqrt{3}}{2}\Phi_m\frac{\sqrt{3}}{2}$

$\Phi_R = \frac{3}{2}\Phi_m = 1.5\ \Phi_m$

ii) At point 1, θ= 60°;

$$\Phi_R = \frac{\sqrt{3}}{2}\Phi_m\ ,\ \Phi_Y = \frac{-\sqrt{3}}{2}\Phi_m,\ \Phi_B = 0$$
$$\Phi_R = 2 \text{ x } \frac{\sqrt{3}}{2}\Phi_m . cos\frac{60°}{2}$$
$$\Phi_R = \frac{3}{2}\Phi_m = 1.5\ \Phi_m$$

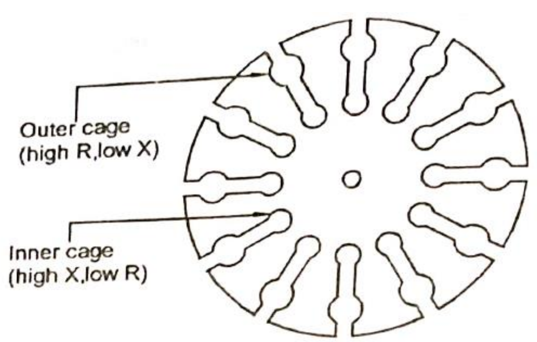
iii) At point 2, θ= 120°;

$$\Phi_R = \frac{\sqrt{3}}{2}\Phi_m\ ,\ \Phi_Y = 0,\ \Phi_B = \frac{-\sqrt{3}}{2}\Phi_m$$
$$\Phi_R = 2 \text{ x } \frac{\sqrt{3}}{2}\Phi_m . cos\frac{60°}{2}$$
$$\Phi_R = \frac{3}{2}\Phi_m = 1.5\ \Phi_m$$

So the resultant flux is 1.5 Φm at each position and the direction of the flux is moving 60° forward at every position. So it can be observed that the flux is rotating and thus the rotating magnetic field is produced in three phase induction motor.

13.b Write notes on (i) Double cage Induction motor (ii) Induction generator.

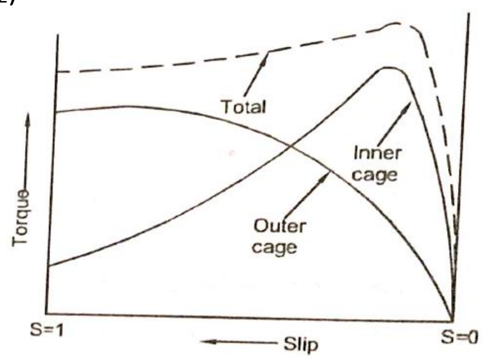
(i) Double cage Induction motor (Explanation- 4 marks, Diagram – 3 marks)



The rotor of a squirrel cage Induction motor has low resistance. So the starting torque is low in such motors (since T$\propto$ r_2). By Increasing the rotor resistance starting torque can be increased. In order to design a rotor with high resistance, the efficiency will become poor under normal working conditions. We can't add external resistance in squirrel cage type rotors as slip ring type.

To eliminate these drawbacks in squirrel cage type rotors a rotor with two independent cages is used. So, a rotor with two cages is designed called double cage rotor. In this type the inner cage is placed deeply in the rotor and it is high in inductance and low in resistance. The outer cage is placed near the outer surface which is high in resistance and low in Inductance.

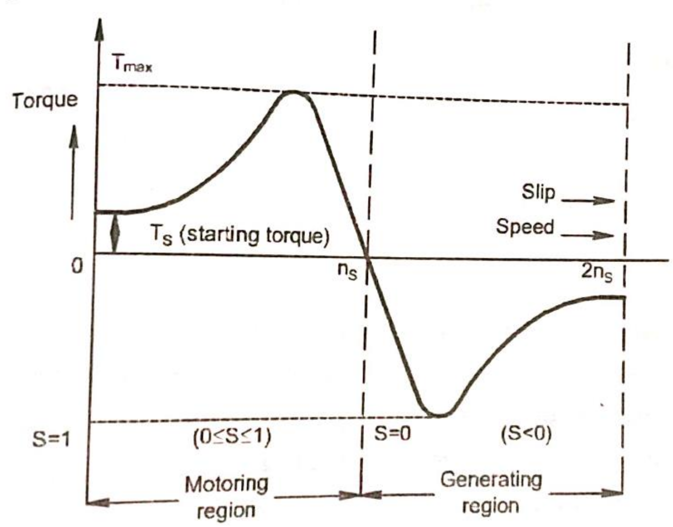
While starting most of the starting current flows through the outer cage and and a small current flow through the inner cage. Since the resistance at this stage is high, high starting torque is developed. (since $T \propto r_2$)



When the speed increases, frequency of the rotor current decreases. Since the slip value is decreased and hence the reactance of the inner cage is also decreased, so larger part of current flows through the inner cage. When the speed is normal, frequency of rotor current (f') is very small, so the reactance of the cage is negligible. Hence under running condition most of the current flows through the inner cage. So the running torque is low and efficiency is high.

(ii) Induction generator (Explanation- 4 marks, Diagram – 3 marks)

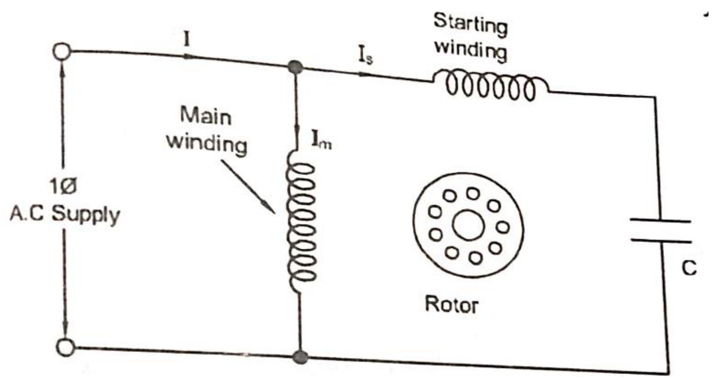
The Construction of Induction generator is same as that of Induction motor. But the difference is that the direction of rotation of the motor and generator is opposite for the same current direction. When the induction motor runs above the synchronous speed, the induction motor runs as a generator called Induction generator. The induction motor is mechanically coupled to a prime mover for driving the motor at a speed higher than the synchronous speed. The Induction generator will generate power only when it is connected to the supply lines.



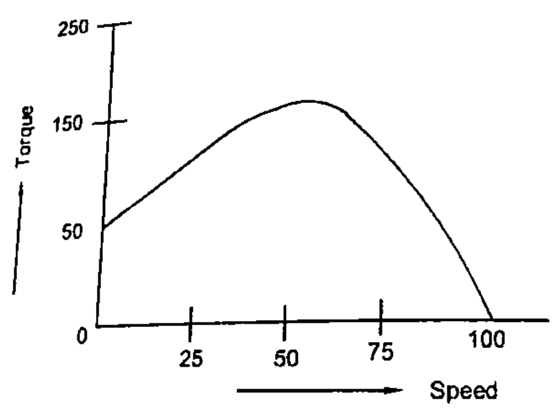
Since the rotor speed is higher than the synchronous speed, the value of slip becomes negative. When the slip lies in the region 0 to 1, the machine runs as a motor. When the slip lies in the region less than zero the motor acts as a generator.

14.aExplain the construction and working of a permanent capacitor induction motor. Also draw its speed torque characteristics.(Diagram – 7 marks, Explanation – 7marks)

Permanent capacitor motor has two windings in the stator called Main winding and auxiliary winding. The main winding has low resistance and high reactance and the auxiliary winding has high resistance and low reactance. The centrifugal switch need not be used in this type of motor. A capacitor C is connected in series with the auxiliary winding.



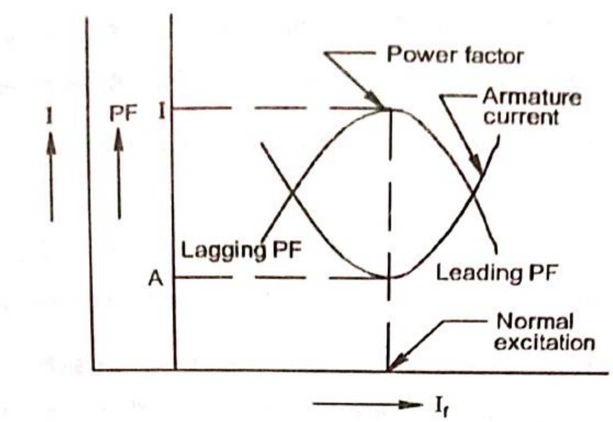
The auxiliary winding and capacitor are permanently in the circuit during starting and running. Since the capacitor remains in the circuit permanently, the motor is called Permanent Capacitor motor. When the single-phase supply is given to the windings, a rotating magnetic field cuts the short-circuited conductors, and hence a magnetic field is set up in the rotor and a torque is developed to rotate it.



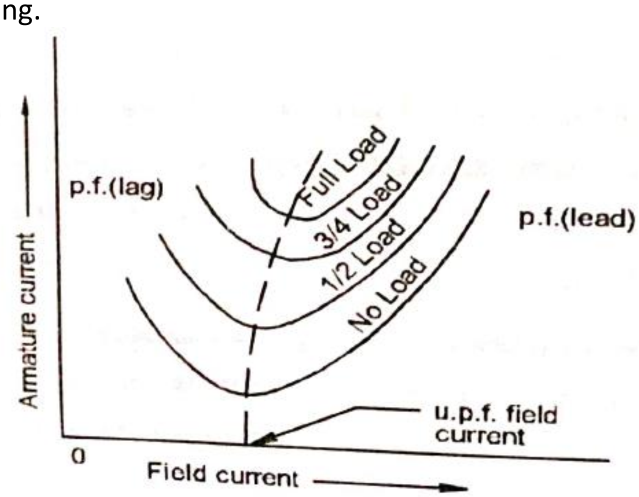
The value of capacitance used in this type of motor is very low. Because of less capacitance in the auxiliary circuit, the motor has lower starting torque than the Capacitor start motors. These Permanent capacitor Induction motors are used in oil burners, blowers, fans, induction regulators, arc welding control and furnace control. It is also used in loads which require low starting torque.

14.b How V curves and Inverted V curves are obtained in a synchronous motor? Explain. (Diagram – 7 marks, Explanation – 7marks)

When the armature current of the synchronous motor is plotted against the exciting current, the curve formed is called V curve.



The above graph shows the relation between the excitation current and armature current at a particular load on a synchronous motor. At normal excitation the power factor is unity . The value of armature current for this excitation is minimum and is equal to OA. For excitation greater than the normal excitation, the value of armature current increases and the power factor is leading. At excitation less than the normal, the armature current increases, but the power factor is lagging.



If the load on the motor is changed, to half full load, full load etc., a number of V curves can be plotted for a particular constant load. For the same input power, the armature current changes and hence the power factor also varies. If over excited, the synchronous motor runs with leading power factor and if under excited it runs with lagging power factor. When the power factor is plotted against the exciting current, the curve formed is called Inverted V curve. At unity power factor motor draws minimum armature current.

15.a Explain the factors to be considered while selecting the size of the cables. (Explanation – 14 marks)

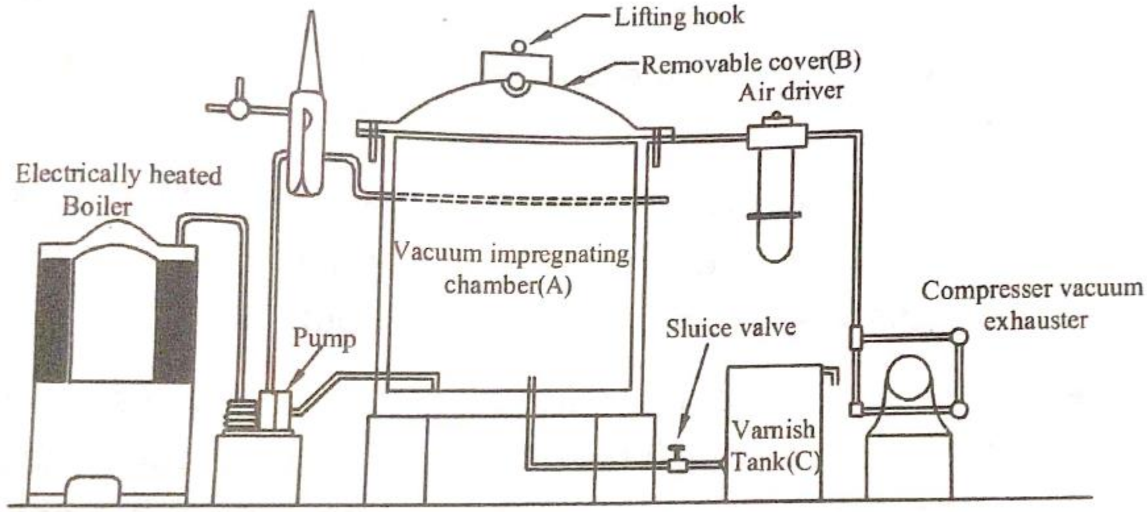
The cable connected to the motor carries the full load current and the heavy starting current. The size of the cable is selected depending upon the starting method and the full load current of the motor. While selecting the size of cables, the following are the key factors should be considered.

1. Current Rating: The amount of current the cable could carry safely without overheating.
2. Voltage drop: The reduction in voltage as electricity moves along the cable, which should remain within acceptable limits.
3. Length of the Cable: The distance the cable will run, as longer cables may require larger sizes to minimize voltage drop.
4. Type of Load: The nature of the electrical load used (resistive, inductive, etc.) must be considered in selection.
5. Installation Environment: Considerations regarding temperature, moisture, and potential mechanical damage.
6. Conductive Material: Copper and aluminum are common materials; copper has lower resistance but is more expensive.
7. Regulatory Standards: Compliance with local electrical codes and standards, such as NEC in the U.S.
8. Future Expansion: Anticipating potential increases in load can influence the size chosen.
9. Insulation type: The insulation's heat rating and resistance to environmental factors can affect performance.
10. Grouping of cables: Cables installed together can produce heat, influencing the required size.

    For short time rated motors, the size of the cable may be 0.85 to 0.9 times the rated current. For continuously rated motors, cable rating must be at least 1.4 times the rated current. These factors help to ensure safety, efficiency, and functionality in electrical installations.

15.b Discuss about how vacuum impregnation process is carried out for induction motors. (Explanation – 7marks, Diagram – 7 marks)

Vacuum impregnation is a process used in the manufacturing of induction motors to enhance their insulation and durability. The Impregnation plant consists of a large air-tight double jacketed vacuum chamber A with a removable cover B. The interior of the tank can be heated up by circulating steam or hot oil through the jacket. The insulating varnish is stored in another storage tank C. A motor driven compressor cum vacuum exhauster is provided with suitable valves to create either vacuum or pressure for the tank A.



This technique involves the placement of the motor armature inside the tank. Close the top cover and heat up the chamber A to 100° C for at least 2 to 4 hours by circulating steam or hot oil through the jacket. During this period, the air inside the tank is pumped out and vacuum is maintained. Now allow insulating varnish by opening the valve to flow into chamber A, until the armature is fully immersed. During this time no air is allowed in contact with the windings. After closing the varnish outlet valve, apply pressurized air into the space above the varnish level in tank A. Now the varnish will be forced into the spaces in the interior of the coil. After half an hour, allow all the varnish to flow back into the storage tank C under air pressure and the excess varnish in the coil to drain out. The armature is heated for 4 to 8 hours at a temperature of 100° C to 110°C. This will cause the varnish in all portions of the coil to set and become dry. The temperature should not exceed 110°C because it will damage the insulation.

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