Winter – 2017 Examinations

Model Answer **Subject Code: 17511 (ACM)**

Important Instructions to examiners:

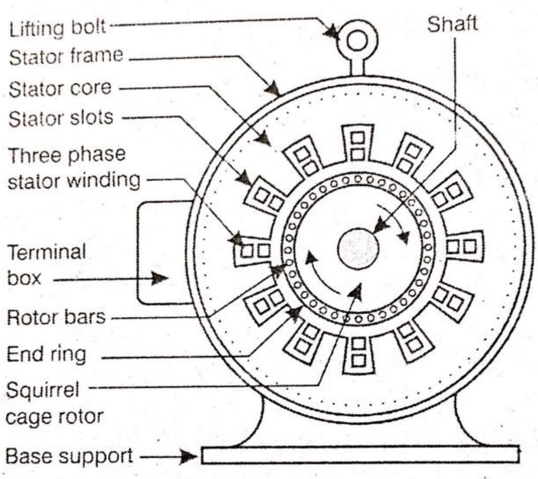
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner should assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given importance (Not applicable for subject English and Communication Skills).
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner should give credit for any equivalent figure/figures drawn.
5) Credits to be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer (as long as the assumptions are not incorrect).
6) In case of some questions credit may be given by judgment on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept

1 a) Attempt any THREE of the following: 12

1 a) (i) Explain the construction of three phase induction motor with neat diagram.

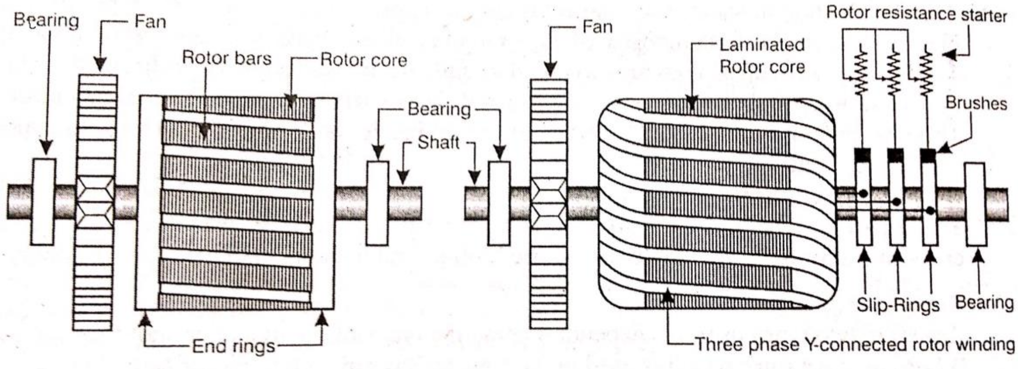
Ans:

Construction of Three-phase Induction Motor:



Sectional view

2 marks for any valid constructional sketch



(a) Squirrel Cage Rotor (b) Wound Rotor (Slip-Ring Rotor)

Rotor construction

There are two main parts of the three phase induction motor:

i) Stator which is the stationary part
ii) Rotor which is the rotating part

1) Stator:

The stator is composed of thin circular, ring-shaped laminations of good quality silicon steel in which slots are provided round the inner periphery. Silicon steel has low hysteresis loss. The laminations are insulated from each other to reduce eddy current loss. These laminations are stacked together and fitted inside the frame of the motor to appear like a hollow cylinder. A three-phase stator winding is uniformly distributed in the slots as shown in the sectional view. The winding is wound for specific number of poles, say 2 or 4 or 6 etc. It is connected either in star or delta and the terminals are brought out to connect to the 3-phase supply.

2 marks for explanation of stator and rotor construction

2) Rotor:

There are two types of rotors:

i) Squirrel cage rotor
ii) Wound rotor or slip-ring rotor

i) Squirrel Cage Rotor: This rotor is formed by a laminated cylindrical core having semi-closed slots provided around its outer periphery. This rotor is mounted on the shaft and placed in the central space of the stator as shown in the sectional view.

Thick copper or aluminium bars are driven through the slots and short-circuited at the two ends by the two thick end rings as shown in the figure (a). These bars are the rotor conductors. They are brazed or welded to the end-rings to produce the short-circuited rotor winding. The appearance of the rotor bars and the end rings is like a squirrel cage and hence the rotor is called by that name. The rotor slots are not exactly parallel to the shaft but skewed slightly to avoid magnetic noise and direct magnetic locking between rotor and stator teeth.

ii) Slip-Ring Rotor (Wound Rotor): This rotor is formed by a cylindrical laminated core having slots on its outer periphery to carry a three-phase uniformly distributed winding, wound for the same number of poles as that of the stator winding. The rotor winding is inherently connected in star and the terminals are connected to the three copper slip-rings mounted on the shaft. External resistance can be inserted in each phase of the rotor winding through brushes and slip-rings. In this rotor also the slots are not exactly parallel to the shaft but slightly skewed.

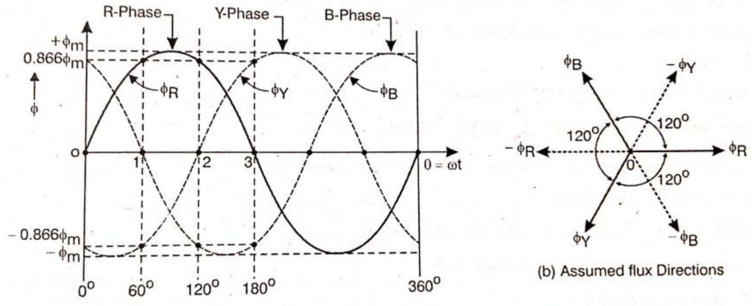
1 a) (ii) Explain with neat sketches the production of rotating magnetic field in three phase Induction Motor.

Ans:

Production of rotating magnetic field in Three-phase Induction Motor:

In three-phase induction motor, the three-phase stator windings are displaced in space by 120° and their three-phase currents are displaced in time by 120°. So they produce the three-phase fluxes which are displaced in space by 120° and also in time by 120°. Such fluxes give rise to the resultant rotating magnetic field.

1 mark for flux waveform



(a) Three phase flux waveform

(b) Assumed flux Directions

Three-phase fluxes

1 mark for explanation

When a three-phase supply is given to the three-phase stator winding, three-phase currents flow and three-phase fluxes, which are displaced in space and also in time by 120° are produced. The waveforms of three-phase fluxes are shown in the figure. The directions of fluxes in the air-gap are assumed as shown in the figure. The resultant total flux ϕ_T at any instant is given by the phasor sum of the three fluxes ϕ_R, ϕ_Y, and ϕ_B. The resultant flux ϕ_T can be obtained mathematically and graphically at instants 0, 1, 2 and 3 when angle θ is 0°, 60°, 120° and 180° as shown in the diagram of flux waveforms.

2 marks for flux vector diagram

1) At instant 0 (θ = 0°):

$\phi_R = 0$, $\phi_Y = -0.866\ \phi_m$ and $\phi_B = 0.866\ \phi_m$

With assumed flux directions, the vector diagram for fluxes can be drawn as shown in the figure (a). It is seen that the total flux is $\phi_T = 1.5\ \phi_m$ with direction vertically upward.

2) At instant 1 (θ = 60°):

$\phi_R = 0.866\ \phi_m$, $\phi_Y = -0.866\ \phi_m$ and $\phi_B = 0$

With assumed flux directions, the vector diagram for fluxes can be drawn as shown in the figure (b). It is seen that the total flux is $\phi_T = 1.5\ \phi_m$ with further clockwise rotation of 60° in the space.

3) At instant 2 (θ = 120°):

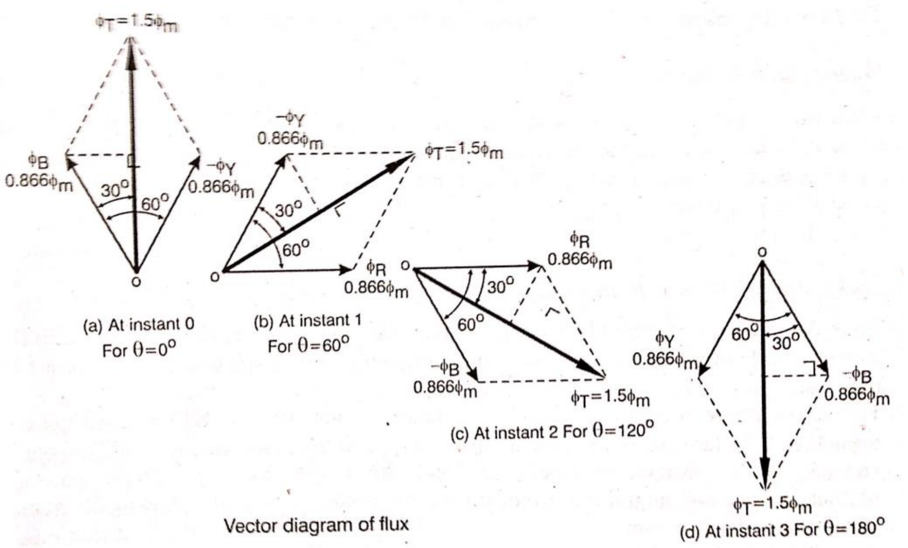
$\phi_R = 0.866\ \phi_m$, $\phi_Y = 0$ and $\phi_B = -0.866\ \phi_m$

With assumed flux directions, the vector diagram for fluxes can be drawn as shown in the figure (c). It is seen that the total flux is $\phi_T = 1.5\ \phi_m$ with further clockwise rotation of 60° in the space.

4) At instant 3 (θ = 180°):

$\phi_R = 0$, $\phi_Y = 0.866\ \phi_m$ and $\phi_B = -0.866\ \phi_m$

With assumed flux directions, the vector diagram for fluxes can be drawn as shown in the figure (d). It is seen that the total flux is $\phi_T = 1.5\ \phi_m$ with further clockwise rotation of 60° in the space.



Vector diagram of flux

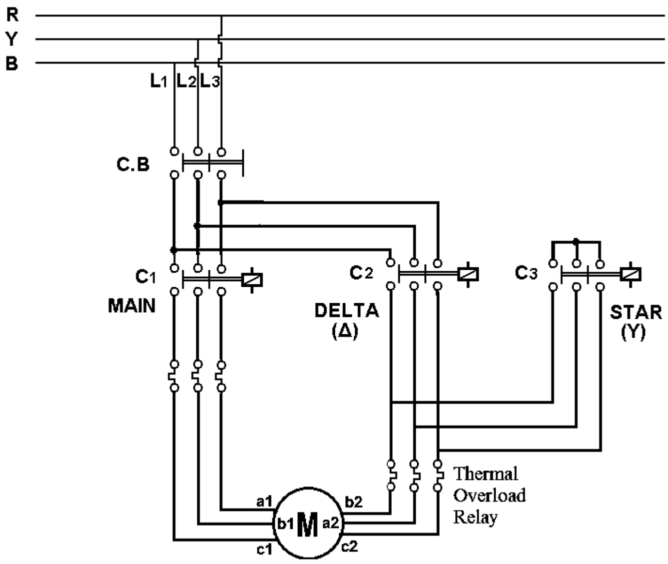
Thus it seen that the rotating magnetic field of constant magnitude (1.5 ϕ_m) is produced in the air-gap or central space of the stator.

1 a) (iii) Draw a neat labeled sketch of Star Delta Starter. Can we use star delta starter for starting a DC servo motor?

Ans:

Power Circuit of Star Delta Starter:

(NOTE: Examiner is requested to award marks for any valid circuit diagram of manual, semi-automatic or fully-automatic Star-Delta Starter.)



3 marks for labeled circuit diagram

2 marks for partially labeled diagram

1 mark for unlabeled diagram

or Equivalent figure

No. We cannot use star delta starter for starting a DC servo motor. 1 mark

1 a) (iv) Give any four advantages of rotating magnetic field alternator.

Ans:

Advantages of Stationary Armature and Rotating Field type 3-phase alternator:

1) For high-voltage alternator, large space is required to accommodate conductors with insulation, as high voltage is induced in them. If field poles are placed on rotor and armature winding is placed on stator, large space can be provided to accommodate large number of conductors and the insulation.
2) It is always better to protect high voltage winding from the centrifugal forces caused due to the rotation. So high voltage armature is generally kept stationary. This avoids the interaction of mechanical and electrical stresses.
3) It is easier to collect larger currents at very high voltage from a stationary member than from the slip ring and brush assembly. The voltage required to be supplied to the field is very low (110 V to 220 V d.c.) and hence can be easily supplied with the help of slip ring and brush assembly by keeping it rotating.
4) Due to low voltage level on the field side, the insulation required is less and hence field system has very low inertia. It is always better to rotate low inertia system than high inertia, as efforts required to rotate low inertia system are always less.
5) Rotating field makes the overall construction very simple. With simple, robust mechanical construction and low inertia of rotor, it can be driven at high speeds. So greater output can be obtained from an alternator of given size.
6) If field is rotating, to excite it from external dc supply two slip rings are enough. One each for positive and negative terminals. As against this, in three phase rotating armature, the minimum number of slip rings required is three and cannot be easily insulated due to high voltage levels.
7) The ventilation arrangement for high voltage side can be improved if it is kept stationary.

1 mark for each of any four advantages = 4 marks

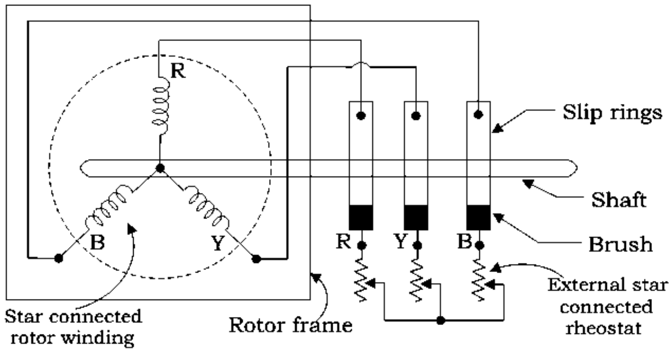
8) Rotating field is comparatively light and can run with high speed.

1 b) Attempt any ONE of the following: **6**

1 b) (i) Explain the method of speed control of Slip Ring Induction Motor with a neat circuit diagram.

Ans:

Speed control of 3 phase Slip Ring Induction Motor:



Slip Ring Three Phase Induction Motor

3 marks for neat diagram

The torque produced by three-phase induction motor is given by,

$$T = \left(\frac{3\times 60}{2\pi N_s}\right)\frac{sR_2E_2^2}{(R_2^2+s^2X_2^2)} \text{ N-m}$$

1 mark for mathematical treatment

For low slip region, $(sX_2)^2 \ll R_2$ and can be neglected and for constant supply voltage, E_2 is also constant.

$$\therefore T \propto \left(\frac{sR_2}{R_2^2}\right) \propto \frac{s}{R_2}$$

2 marks for explanation

where, R_2 is rotor resistance per phase in ohms,

Thus if the rotor resistance is increased, the torque produced decreases. But when the load on the motor is same, motor has to supply same torque as load demands. So motor reacts by increasing its slip to compensate decrease in T due to R_2 and maintains the load torque constant. So due to additional rotor resistance R_2, motor slip increases i.e the speed of the motor decreases. Thus by increasing the rotor resistance R_2, speed below normal value can be achieved.

1 b) (ii) A 500V, 3 phase, 50 Hz Induction motor develops an output of 15 kW at 950 rpm. If input power factor is 0.86 lagging, Mechanical losses are 730W and stator losses 1500W, find:

1) The slip
2) The rotor copper loss
3) Motor Input
4) The line current

Ans:

Given: V_L =500V, P_{out} =15 kW, Speed N = 950 rpm

P.F. = cosØ= 0.86 lag

Mechanical loss = 730W, Stator losses = 1500 W.

(NOTE: Since data regarding number of poles is not specified, Examiners are requested to award the marks appropriately to the examinee who has attempted to solve the problem)

Step 1: Find N_s and s : 1 mark for N_s

Assuming the synchronous speed as 1000 rpm, which is close to 950 rpm OR assuming number of poles as 6, 1 mark for *slip*

$$N_S = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000\ rpm$$

$$s = \frac{Ns - N}{Ns} = \frac{1000 - 950}{1000} = 0.05\ or\ 5\%$$

Step 2 : Find Rotor output: 1 mark

Rotor output = P_{out} + Mechanical losses

= 15 kW + 730W = 15.73 kW

Step3 : Find Rotor copper loss:

$$\frac{\text{Rotor copper loss}}{\text{Rotor output}} = \frac{s}{1-s}$$

1 mark

$$\therefore \text{Rotor copper loss} = \left(\frac{s}{1-s}\right)\text{Rotor output}$$

$$= \left(\frac{0.05}{1-0.05}\right)15730 = 827.89\ \text{W}$$

Step 4: Find motor input: 1 mark

Motor input = P_{in} = Motor o/p + stator losses + Rotor losses+ Mech. losses

= 15000 +1500 +730 +827.89

= 18057.89 W

Step 5: Find line current: 1 mark

$$P_{in} = \sqrt{3} \times V_L I_L \cos\phi$$

$$\therefore I_L = \frac{P_{in}}{\sqrt{3}V_L\cos\phi} = \frac{18057.89}{\sqrt{3}\times 500 \times 0.86} = 24.25\ \text{amp}$$

2 **Attempt any <u>FOUR</u> of the following:** 16

2 a) Explain the working principle of three phase Induction Motor.

Ans:

Working principle of 3 phase Induction Motor:

Three-phase induction motor works on the principle of electromagnetic induction. The motor is supplied only from stator side. When 3-phase AC supply is given to three-phase stator winding, three phase currents displaced in time phase by 120° flows through three windings displaced in space by 120°. Therefore three fluxes displaced in time phase and also in space by 120° are produced in the air-gap. This results in the production of rotating magnetic field (RMF) of constant magnitude in the air-gap. The rotating magnetic field rotates at synchronous speed (Ns = 120f/P). This RMF is cut by stationary rotor conductors. According to Faraday's laws of electromagnetic induction, emf is induced in the rotor conductors. As the rotor conductors are short-circuited on either sides by end rings, current flows through it. According to basic motor principle, whenever a current carrying conductor is placed in a magnetic field, force is exerted on it. The direction of force depends upon the direction of rotor current. According to Lenz's law the induced rotor current direction is such that it always opposes the cause which produces it. Here the cause is relative speed between rotating magnetic field and rotor conductors. So the rotor currents cause force on rotor conductors such that rotor rotates so as to reduce the relative speed between RMF and rotor. Therefore rotor rotates in the same direction as that of rotating magnetic field, to reduce the relative speed. The power is transferred from stator to rotor through electromagnetic induction,

4 marks for stepwise working

hence the motor is named as Induction motor.

2 b) Derive the condition for maximum starting torque of three phase I.M.

Ans:

(NOTE: Examiner is requested to award marks for equivalent alternate derivation)

Condition for Maximum Starting Torque of Three-phase Induction Motor:

Torque produced by Three-phase induction motor is given by,

$T = \left(\frac{3\times 60}{2\pi N_S}\right)\frac{sE_2^2R_2}{(R_2^2+s^2X_2^2)}$ N-m 1 mark

At the instant of starting, motor speed N = 0 and slip s = 1

∴ Starting torque is given by,

$T_{st} = \left(\frac{3\times 60}{2\pi N_S}\right)\frac{E_2^2R_2}{(R_2^2+X_2^2)}$ N-m $= k\,\frac{E_2^2R_2}{(R_2^2+X_2^2)}$ N-m 1 mark

(Since synchronous speed N_S is constant)

The rotor standstill emf E_2 and rotor standstill reactance X_2 are constants, but the external resistance can be inserted in rotor circuit through slip-ring and brush arrangement. So the rotor resistance R_2 is considered variable. Thus starting torque depends upon rotor resistance R_2 only.

For maximum starting torque,

$$\frac{dT_{st}}{dR_2} = \frac{d}{dR_2}\left[k\,\frac{E_2^2R_2}{(R_2^2+X_2^2)}\right] = 0$$

$$\therefore \frac{(R_2^2+X_2^2)kE_2^2 - kE_2^2R_2(2R_2+0)}{(R_2^2+X_2^2)^2} = 0$$

$$(R_2^2kE_2^2 + X_2^2kE_2^2) - 2{R_2}^2kE_2^2 = 0$$

$$(X_2^2 - R_2^2)kE_2^2 = 0$$

$$\therefore X_2^2 = R_2^2 \quad \text{or} \quad R_2 = X_2$$

2 marks for Stepwise derivation

Thus if the rotor resistance per phase i.e R_2 is equal to the rotor reactance per phase at standstill i.e X_2, then the motor produces maximum torque at start.

2 c) Derive the expression for distribution factor.

Ans:

Expression for distribution factor:

Let β be the slot angle i.e the angular displacement between the slots.

$$\therefore \beta = \frac{180°}{\text{No. of slots/pole}} = \frac{180°}{n}$$

1 mark for slot angle β

Let m = No. of slots/pole/phase i.e there are m coil-sides/pole/phase.

For distributed winding, the rms value of emf induced in each coil-side is equal but displaced from neighbouring coil-side by slot angle β. Thus total emf induced in ‘m’ coil-sides is obtained by phasor sum of ‘m’ emfs.

For concentrated winding, these ‘m’ coil-sides would have been accommodated in one big slot. Therefore, the total emf induced in ‘m’ coil-sides placed in one slot is given by the arithmetic sum of the ‘m’ emfs. 1 mark for explanation

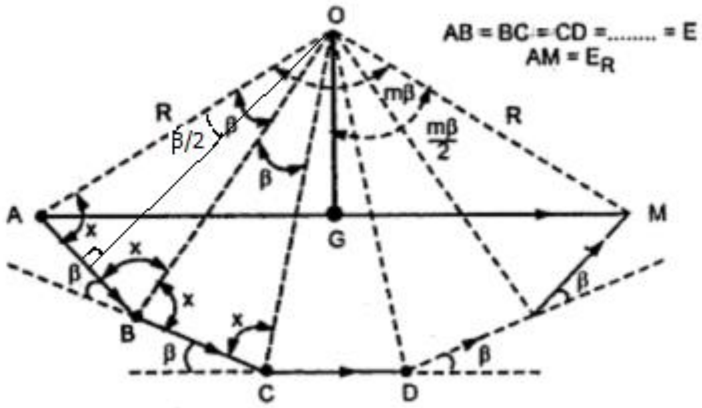
Let ‘E’ be the emf induced in each coil side.

For concentrated winding, the resultant emf E_C is arithmetic sum.

∴ E_C = m.E

For distributed winding, the resultant emf E_D is the vector or phasor sum.

∴ E_D = Phasor sum of ‘m’ emfs each having value ‘E’.



1 mark for relevant phasor diagram

Referring to the phasor diagram showing 'm' emfs each having value 'E', we can write, E = AB = 2[OA]sin(β/2) = = 2Rsin(β/2)
The arithmetic sum of 'm' emfs is given by E_C = m×E = m× 2Rsin(β/2)
The phasor sum of 'm' emfs is given by E_D = E_R = AM = 2Rsin(mβ/2)
The distribution factor (Kd) is defined as,

$$K_d = \frac{Emf\ with\ distributed\ winding}{Emf\ with\ concentrated\ winding}$$

$$= \frac{Vector\ or\ phasor\ sum\ of\ emfs}{Arithmetic\ sum\ of\ emfs} = \frac{E_D}{E_C} = \frac{2Rsin(\frac{m\beta}{2})}{m\times 2Rsin(\frac{\beta}{2})}$$

$$\therefore K_d = \frac{sin(\frac{m\beta}{2})}{m\times sin(\frac{\beta}{2})}$$

1 mark for stepwise derivation

2 d) Calculate the pitch factor for three phase winding of alternator having 72 stator slots and 6 poles. The coil span is 1 to 10 slot.

Ans:

Given: Number of slots = 72
No. of poles = 6
∴ No. of slots /pole = 72/6 = 12
Since One pole pitch = 180°,
Slot angle β = One pole pitch/(No. of slots per pole) = 180°/12 = 15°

1 mark for slots per pole

1 mark for slot angle

The coil is placed in the slots such that when one coil-side comes under north pole, the other coil-side should come under south pole. If the angular distance between the coil-sides (called coil-pitch) of a coil is equal to pole pitch, the coil is said to be full-pitched coil. Here, for full-pitched coil, if one coil-side is placed in slot no. 1, then other coil-side must be placed in slot no. 13, making coil pitch equal to pole pitch. However, here coil span is specified as 1 to 10 slot, i.e one coil-side in slot no. 1 and other coil-side in slot no. 10. Thus the coil is short pitched by (13-10) = 3 slots.
∴The short-pitching angle α = 3×slot angle = 3 × 15° = 45°
∴ Pitch factor Kp = cos(α/2) = cos(45°/2) = 0.924

1 mark for short-pitching angle α

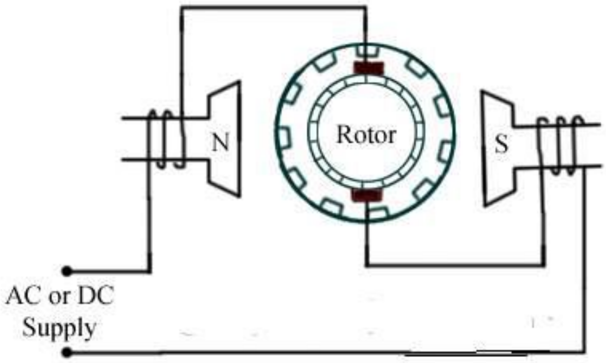
1 mark for Kp

2 e) Explain with neat diagram working of universal motor.

Ans:

Universal Motor:

The motor which operates on both AC and DC supply, is called as Universal Motor.



2 marks for diagram

A universal motor works on either DC or single phase AC supply. When the universal motor is fed with a DC supply, it works as a DC series motor. When current flows in the field winding, it produces an electromagnetic field. The same current also flows through the armature conductors. According to basic motor principle, when a current carrying conductor is placed in the magnetic field, it experiences a mechanical force. Thus mechanical force is exerted on the current carrying armature conductors and torque is produced on rotor. Therefore the rotor starts to rotate.

2 marks for explanation

When fed with AC supply, it still produces unidirectional torque. Because armature winding and field winding are connected in series, they carry same current. Hence, as polarity of AC voltage changes and current reverses its direction, the direction of current in armature conductors and magnetic field in the air-gap reverses at the same time. The direction of magnetic field and the direction of armature current reverses in such a way that the direction of force experienced by armature conductors remains same. Thus unidirectional torque is produced and motor continues to run in the same direction.

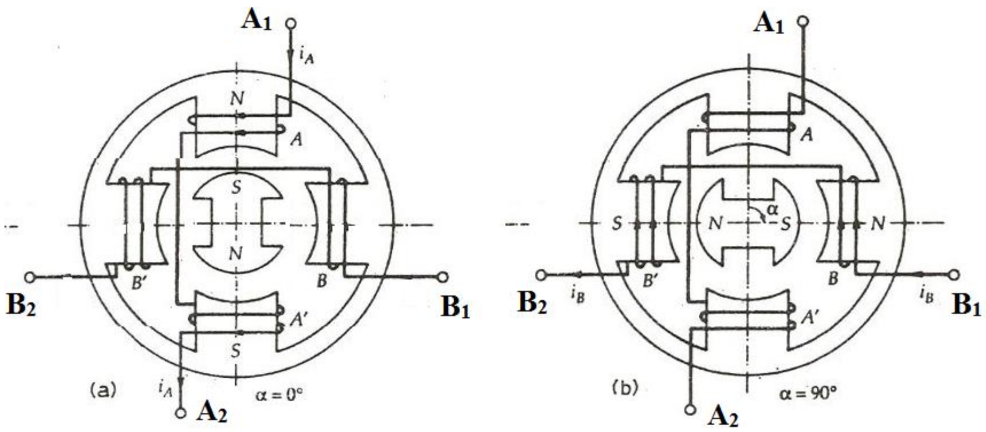
Thus, regardless of AC or DC supply, universal motor works on the same principle as that of DC series motor.

Since motor works on both the type of supply: AC or DC, it is referred as Universal motor.

2 f) Explain construction and working of permanent magnet stepper motor.

Ans:

Permanent Magnet Stepper Motor:



2 marks for diagrams

OR any other equivalent figure

The constructional sketch of Permanent Magnet Stepper Motor is shown in the figure. The rotor consists of permanent magnet poles of high retentivity steel and is cylindrical in shape. The concentrating windings on diametrically opposite poles are connected in series to form a two phase winding on the stator. The rotor poles align with the stator teeth depending on the excitation of the winding. The two coils AA' connected in series to form a winding of Phase A with terminals A_1 and A_2. Similarly the two coil BB' is connected in series forming a phase B windings with terminals B_1 and B_2. 2 marks for explanation

In figure (a) the phase A is excited, causing current i_A flowing from A_1 to A_2 of phase A, whereas phase B is not excited. Due to the current i_A the poles are created on stator as shown. The south pole of the rotor is attracted by the north pole of stator phase A. Thus, the magnetic axis of the stator and rotor coincide and $\alpha = 0^o$.

In figure (b) the phase B is excited, causing current i_B flowing from B_1 to B_2 of phase B, whereas phase A is not excited. Due to the current i_B the poles are created on stator as shown. The south pole of the rotor is attracted by the north pole of stator phase B and the rotor moves by 90° in the clockwise direction. Thus, the magnetic axis of the stator and rotor coincide and $\alpha = 90^o$.

Similary, if phase A alone is excited with reversed current i_A, the rotor moves further by 90° and when the magnetic axis of the stator and rotor coincide, we get $\alpha = 180^o$. Further if only B phase is excited with reversed current i_B, the rotor moves further by 90° and when the magnetic axis of the stator and rotor coincide, we get $\alpha = 270^o$.

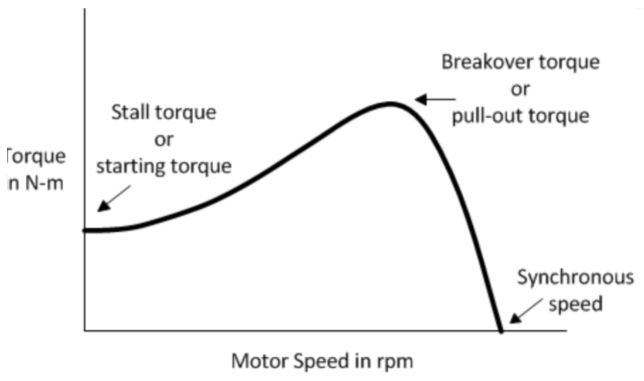
In this way, the sequential excitation of phases A and B with forward and reverse current, the rotor movements in steps of 90° can be obtained. It is also possible to obtain steps of 45° by exciting both the phases simultaneously.

3 Attempt any <u>FOUR</u> of the following: 16

3 a) Draw and explain the torque speed characteristic of three phase induction motor.

Ans:

Torque-Speed characteristics of 3-phase Induction Motor:



Speed-Torque Curve for a Three-Phase Induction Motor

2 marks for diagram (Equivalent diagram may please be considered)

- When slip (s) ≈ 0, the rotor speed is equal to synchronous speed (i.e N≈ Ns) and torque is almost zero at no load.
- As load on motor increases, slip increases and therefore torques increases.

2 marks for explanation

- For lower values of load, torque is proportional to slip, and characteristic is linear in nature.
- At a particular value of slip, maximum torque will be obtained at condition $R_2 = sX_2$. On the characteristic, the maximum torque is indicated by breakover torque or pull-out torque. If load torque exceeds this breakover torque, the motor is pulled out and simply comes to rest.
- For higher values of slip, torque is inversely proportional to slip and characteristics will be hyperbolic in nature.
- The maximum torque condition can be obtained at any required slip by changing rotor resistance.
- At the time of starting, the motor produces starting torque, called stall torque, which must be greater than the load torque, otherwise the motor will not pick up the speed and simply stalled.

3 b) The power input to a 500 V, 50 Hz, 6-pole, 3 phase induction motor running at 975 rpm is 40 kW. The stator losses are 1 kW and the friction and windage losses are 2 kW. Calculate:
i) Slip, ii) Rotor copper loss, iii) Shaft power, iv)Efficiency

Ans:

Given: 3-phase induction motor, f = 50 Hz, P = 6 , Actual Speed N = 975 rpm
Line voltage V_L = 500V
Stator input Power P_{in} = 40kW = 40×10^3 W
Stator losses = Ps_{loss} = 1kW = 1000W
Friction & windage losses = Rotational losses $P_{Rot\text{-}loss}$ = 2kW = 2000W
Synchronous speed $N_S = \frac{120f}{P} = \frac{120\times50}{6} = 1000\ rpm$

1) **Slip:**

Slip = $\frac{N_S-N}{N_S} = \frac{1000-975}{1000} = \mathbf{0.025}$ **or 2.5%**

1 mark for each bit = 4 marks

2) **Rotor Copper Loss:**

Rotor input power = Stator input power - Stator losses
= (40 kW-1 kW)= 39 kW = 39000W

Rotor Cu-loss = s × Rotor input power
= (0.025) (39kW)
= **975 W**

3) **Shaft Power:**

Gross Rotor output power = (1- s) Rotor input power
= (1- 0.025)39000 = 38025W

OR

Gross Rotor output power = Rotor input power – Rotor Cu losses
= 39000 – 975 = 38025W

Shaft Power = Gross rotor output – Mechanical losses
= 38025 – 2000 = **36025W**

4) **Efficiency :**

$$\text{Efficiency} = \frac{Output\ Power}{Input\ Power}\times 100 = \frac{Shaft\ Power\ Output}{Motor\ stator\ input}\times 100$$

$$= \frac{36025}{40000}\times 100 = \mathbf{90.06}\%$$

3 c) Derive EMF equation of alternator.

Ans:

EMF Equation of alternator:-

Let P = No. of poles
$\emptyset$ = Flux per pole
N= Speed in rpm
Z= Number of stator conductors per phase
$\therefore$ Turns per phase $T = \frac{Z}{2}$

The flux cut by a conductor in one revolution, $d\emptyset = P.\emptyset$

Time in seconds required for one revolution, $dt = \frac{1}{(\frac{N}{60})} = \frac{60}{N}\ sec$ ½ mark

By Faraday's law of electromagnetic induction, the average emf induced in a conductor is given by,

$\therefore$ Average emf /conductor $= \frac{Flux\ cut}{Time\ required} = \frac{d\emptyset}{dt}$

$\therefore E_{avg}$/conductor $= \frac{P.\emptyset}{(\frac{60}{N})} = \frac{P.\emptyset.N}{60}$ volts ½ mark

In one revolution, conductor cuts the flux produced by all the 'P' poles and emf completes (P/2) cycles. If rotor is rotating at N rpm, the revolutions completed in one second are (N/60). Therefore, the cycles completed by emf in one second are (P/2)(N/60) i.e (PN)/120. Thus the frequency of the induced emf is,

$$f = (\frac{P.N}{120})$$ ½ marks

$$\therefore N = (\frac{120f}{P})$$ ½ marks

Substituting this value of N in above equation,

$\therefore E_{avg}$/conductor $= \frac{P.\emptyset}{60} \times \frac{120f}{P} = 2\emptyset f$ volt

Since each turn has two conductors,

E_{avg} /turn = 2 × E_{avg}/conductor = $4\emptyset f$ volt ½ marks

The emf induced in a phase winding is given by,

E_{avg}/phase = (E_{avg} /turn) × Turns/phase
= $4\emptyset fT$ volt ½ marks

The Rms value of emf per phase is given by,

E_{ph}= (E_{avg}/phase) × Form Factor
E_{ph}=1.11× $4f\emptyset T$ volt
$\mathbf{E_{ph} = 4.44 f\emptyset T}$ **volt** ½ marks

This is for full pitched concentrated winding.

If winding is distributed & short pitched then

$\mathbf{E_{ph} = 4.44\ K_p K_d f\emptyset T}$ **volt** ½ marks

where, K_p = Pitch factor
K_d = Distribution factor

3 d) State the essential steps to conduct the open circuit test and short circuit test on alternator. Which precaution has to be taken while conducting the short circuit test on alternator?

Ans:

Assumptions:

i) DC Shunt Motor – Alternator set

ii) Alternator field winding is excited from DC supply using potential divider arrangement.

Steps to conduct Open Circuit test on Alternator:

i) Connect the circuit as per the circuit diagram, alternator terminals kept open.
ii) Set the alternator field potential divider to zero position.
iii) Set field rheostat of DC shunt motor to the minimum value. 1 ½ marks for OC Test
iv) Switch on the DC supply and start the motor with the help of starter.
v) Adjust the speed of the motor (prime mover) to the synchronous speed of the alternator with the help of field rheostat of motor.
vi) Switch on the DC supply to the alternator field and increase excitation in steps.
vii) Note the readings of alternator field winding current I_f and generated open-circuit phase voltage up to 10% more than rated voltage of alternator.

Steps to conduct short circuit test on alternator:

i) Connect the circuit as per the circuit diagram, alternator terminals shorted through ammeter.
ii) Set the alternator field potential divider to zero position. 1 ½ marks for S.C. test
iii) Set the field rheostat of DC shunt motor to the minimum value.
iv) Switch on the DC supply and start the motor with the help of starter.
v) Adjust the speed of motor to the synchronous speed of the alternator with help of field rheostat of motor.
vi) Switch on the DC supply to the alternator field and increase excitation in steps.
vii) Note the readings of alternator field winding current I_f and short-circuit phase current up to rated current of alternator.

Precautions should be taken during short circuit test on alternator.

i) DC supply provided to the field winding of the alternator should be initially kept zero. 1 mark for Precaution
ii) After adjusting the speed, vary the field current of alternator carefully in smaller steps, because large change in alternator field current causes large change in induced emf and due to short-circuit, very large change in armature current will be observed.
iii) Maintain constant speed throughout the experiment.
iv) Take precaution that the alternator will not be overloaded for longer duration.

3 e) Write any two applications of each of the following single phase induction motor.

i) Capacitor Start Induction Run Motor
ii) Resistance Start Induction Run Motor
iii) Capacitor Start Capacitor Run Motor
iv) Shaded pole I. M.

Ans: 1 mark for any two applications of each motor = 4 marks

Sr. No.	Name of Motor	Applications
1	Capacitor Start Induction Run Motor	Fans, Blowers, Grinder, Drilling Machine, Washing Machine, Refrigerator, Air conditioner, Domestic Water Pumps, Compressor.
2	Resistance Start Induction Run Motor	Washing Machine, Fans, Blowers, Domestic Refrigerator, Centrifugal Pump, Small electrical Tools, Saw machine
3	Capacitor Start Capacitor Run Motor	Fans, Blowers, Grinder, Drilling Machine, Washing Machine, Refrigerator, Air conditioner, Domestic Water Pumps, compressors.
4	Shaded pole I. M.	Recording Instruments, Record Player, Gramophones, toy Motors, Hair dryers, Photo copy machine, Advertising display , Table Fan

4 a) Attempt any <u>THREE</u> of the following: 12

4 a) i) A 746 kW, 3 phase, 50 Hz, 6 pole Induction Motor has a rotor impedance of (0.02+j0.15) Ω at standstill. Full load torque is obtained at 360 rpm. Calculate:

1) The ratio of maximum to full load torque.
2) The speed at maximum torque
3) Rotor resistance to be added to get maximum starting torque.

Ans:

Data Given: 3 phase, Slip-ring Induction motor,

Rated Output Power P_{out} = 746 kW, Pole P = 6, Frequency f =50hz,
Speed at full load torque = N_f = 360 rpm
Rotor impedance at standstill, $Z_2 = R_2 + jX_2$ = (0.02+j0.15) Ω

i) Synchronous Speed (N_S):

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000rpm$$ 1 mark

ii) Speed at Maximum Torque (N_m):

The maximum torque occurs at the condition

$$R_2 = s_m(X_2)$$

where, s_m is the slip at which the maximum torque occurs.

$$\therefore s_m = \frac{R_2}{X_2} = \frac{0.02}{0.15} = 0.133$$

Speed at maximum torque or at slip=0.133 is obtained as,

$$N_m = N_s(1 - S_m) = 1000(1 - 0.133) = \mathbf{867\ rpm}$$ 1 mark

iii) Slip at Full-load Torque (s_f):

$$S_f = \frac{N_s - N_f}{N_s} = \frac{1000 - 360}{1000} = 0.64$$

iv) Ratio of Maximum Torque to Full- load Torque:

Ratio of full-load torque to maximum torque is given by,

$$\frac{T_{full}}{T_{max}} = \frac{2S_m S_f}{S_m{}^2 + S_f{}^2} = \frac{2 \times 0.133 \times 0.64}{0.133^2 + 0.64^2} = 0.398$$

$$\therefore \frac{T_{max}}{T_{Full}} = \mathbf{2.51}$$ 1 mark

v) Resistance to be added to obtain Maximum Starting Torque:

At start, slip s = 1. The condition for maximum starting torque is,

$$R_2 + R_{ext} = X_2$$

where, R_{ext} is the external resistance to be added in rotor circuit to get maximum torque at start. 1 mark

$$R_{ext} = X_2 - R_2 = 0.15 - 0.02 = \mathbf{0.13\ \Omega}$$

4 a) ii) Suggest the three phase induction motor for the following applications with reason.

1) Fans and blowers
2) Lift
3) Lathe machines
4) Centrifugal pumps

Ans:

Sr. No.	Application	Type of 3-phase Induction Motor	Reason for selection
1	Fans and Blowers	Squirrel cage I.M.	Moderate starting torque. Constant speed operation.
2	Lift	Slip Ring Induction motor with Rotor resistance starter	High starting torque can be obtained with addition of external resistance in rotor circuit $[(R_2+R_{ext}) = X_2]$
3	Lathe machine	Squirrel cage I.M.	Almost constant speed operation with Variable load torque and speed can be adjusted with mechanical (gears) arrangement.
4	Centrifugal Pumps	Squirrel cage I.M.	Moderate starting torque. Constant speed operation.

1 mark for each point = 4 marks

4 a) iii) A 4 pole three phase star connected alternator armature has 12 slots with 24 conductors per slot and the flux per pole is 0.1Wb sinusoidaly distributed. Calculate the line emf generated at 50 Hz. Assume full pitch coils.

Ans:

Data Given: Star connected alternator
No. of Poles P = 4
Total no. of slots = 12
Conductors per slot = 24
Flux per pole ϕ = 0.1 Wb

Frequency f = 50Hz

Full-pitched coils, Pitch factor = $K_p = 1$ ½ mark for K_p

A) Distribution-factor (K_d):

Slots/pole/phase: m = 12/4/3 = 1 ½ mark for m

Slots/pole: n = 12/4 = 3

Slot angle: $\beta = \frac{180°}{n} = \frac{180°}{3} = 60°$ ½ mark for β

$\therefore$ Distribution factor, $K_d = \frac{sin(\frac{m\beta}{2})}{m \times sin(\frac{\beta}{2})} = \frac{sin(\frac{1\times 60°}{2})}{1 \times sin(\frac{60°}{2})} = \frac{sin(30°)}{sin(30°)} = 1$ ½ mark for K_d

B) Phase value of Emf (E_{ph}):

Total no. of conductors Z = 12×24 = 288

No. of conductors/phase = 288/3 = 96

No. of turns/phase T = 96/2 = 48 ½ mark for T

The rms value of emf induced in each phase winding is given by,

$E_{ph} = 4.44\, K_p K_d f \emptyset T$ volt ½ mark for emf equation

$= 4.44\,(1)(1)(50)(0.1)(48)$

$= 1065.6\ volt$ ½ mark

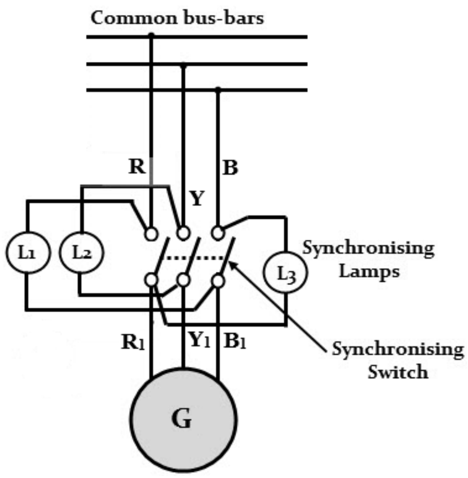
For star connected alternator,

Line emf $E_L = \sqrt{3}E_{ph} = \sqrt{3}(1065.6) = \mathbf{1845.67\ volt}$ ½ mark

4 a) iv) Explain ~~Lump~~ **Lamp** method of synchronizing alternator to bus bar.

Ans:

Lamp Method of Synchronizing an Alternator to Busbar:



1 mark for circuit diagram of any one method

To synchronize an alternator to busbar, following conditions must be satisfied:

1) Alternator voltage is equal to the busbar voltage.
2) Frequency of alternator voltage is equal to the busbar voltage frequency.
3) Alternator phase voltage is in phase with the respective busbar phase voltage.
4) Phase sequence of alternator should be same as that of busbar.

If the above conditions are satisfied, then it is necessary to synchronize one phase of alternator (say phase R) to corresponding phase R of busbar. The other two phases will then synchronized automatically.

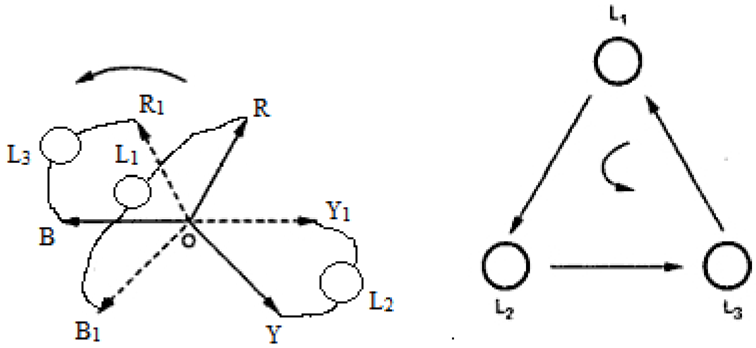
In Lamp method, three lamps are connected across synchronizing triple pole switch between bus-bar and alternator. Depending upon the lamp connections and their indication at the instant of synchronizing, there are three methods:

1) Two Bright, One Dark Lamp Method (refer circuit shown above)
2) Three (All) Dark Lamp Method
3) Three (All) Bright Lamp Method

2 marks for explanation of any one method

The synchronizing triple pole switch is provided to connect three phase terminals of alternator to corresponding phase terminals of busbar. The synchronizing triple pole switch is closed only when it is ensured that the instantaneous phase voltages of alternator are equal to corresponding phase voltages of busbar and are varying in the same fashion. The following table shows the details about the connections and indication of lamps at the instant of synchronization.

Method	Connection of lamps			Indication at the instant of synchronization
	L_1	L_2	L_3	
Two Bright, One Dark	R & B_1	Y & Y_1	B & R_1	L_1 & L_3 bright L_2 dark
Three Dark	R & R_1	Y & Y_1	B & B_1	All dark
Three Bright	R & Y_1	Y & B_1	B & R_1	All bright



1 mark for Phasor Diagram

The above diagram shows the voltage phasor group $R_1Y_1B_1$ of alternator and RYB of busbar. The connections of lamps L_1, L_2, and L_3 are shown for two-bright, one-dark lamp method. If the voltages are assumed equal but the frequencies are slightly different with alternator assumed faster, then the phasors $R_1Y_1B_1$ will rotate faster than phasors RYB in anticlockwise direction. At the shown positions of phasors, it is seen that:

(i) The voltage across L_1 i.e $V_{R\text{-}B1}$ is about to become maximum, the lamp L_1 is about to glow maximum bright.

(ii) The voltage across L_2 i.e $V_{Y\text{-}Y1}$ is increasing towards maximum, the lamp L_2 glows with brightness increasing towards maximum.

(iii) The voltage across L_3 i.e $V_{B\text{-}R1}$ is decreasing and will become zero when R_1 phasor coincides with B phasor. Thus the lamp L_3 glows with brightness decreasing towards dark.

If the lamps are arranged at the vortex of triangle, we can see that the glowing brightness of the lamp follow the sequence $L_1 – L_2 – L_3$ and so on. Thus if the alternator is faster, the lamps glow up and become dark in the sequence $L_1 – L_2 – L_3$. If the alternator is slower, the sequence get reversed i.e $L_1 – L_3 – L_2$. However, if slowly the corresponding phasors coincide i.e R with R_1, Y with Y_1

and B with B_1, that particular instant is the synchronization instant. At this instant, the lamps L_1 and L_3 glow equally bright, whereas the lamp L_2 becomes dark. At this instant the synchronizing switch is closed and the alternator get connected to the busbar.

4 b) Attempt any ONE of the following. **6**

4 b) i) A 100 KVA, 3000V, 50 Hz, 3 phase star connected alternator has effective armature resistance of 6.2 ohm. The field current of 40 A produces short circuit current of 200A and an open circuit emf of 1040 V. Calculate the full load voltage regulation at 0.8 pf lagging and 0.8 pf leading. Draw phasor diagrams.

Ans:

(NOTE: The Examiners are requested to award the marks appropriately to the examinee who has attempted to solve the problem)

Data Given:

Alternator power rating = P = 100kVA = 100×10^3 VA
Rated line voltage V_L = 3000V
Frequency f = 50Hz
Star connected alternator

Armature resistance per phase R = 0.2Ω (Assumption instead of 6.2Ω)

A) Determination of Synchronous Impedance (Z_S):

For a field current of I_f = 40A, the OC and SC test results are:
Short-circuit current I_{SC} = 200A (phase current = line current= 200A)
Open-circuit line voltage V_{OCline} = 1040V
∴ Open-circuit phase voltage $V_{OCphase}$ = 1040/√3 = 600.44V
Synchronous impedance is given by,

$$Z_S = \frac{V_{OCphase}}{I_{SC}} = \frac{600.44}{200} = 3.00\Omega$$

1 mark for Z_S

B) Determination of Synchronous Reactance (X_S):

Since $Z_S = R + jX_S$ and $(Z_S)^2 = R^2 + X_S^2$

∴ Synchronous reactance $X_S = \sqrt{(Z_S^2 - R^2)} = \sqrt{(3.00^2 - 0.2^2)}$

$$X_S = 2.999\Omega$$

1 mark for X_S

C) Determination of Full-load Current (I):

Alternator power rating $P = \sqrt{3}V_L I_L = 100 \times 10^3 VA$

∴ Full-load current $I = \frac{P}{\sqrt{3}V_L} = \frac{100\times10^3}{\sqrt{3}(3000)} = 19.25 amp$

Phase voltage V = V_L/√3 = 3000/√3 = 1732.05V

1 mark for V and I

D) Voltage regulation at 0.8 lagging:

$cos\emptyset = 0.8$ $sin\emptyset = 0.6$

The emf is given by,

$$E_0 = \sqrt{[(Vcos\emptyset + IR)^2 + (Vsin\emptyset + IX_S)^2]}$$

$= \sqrt{[(1732.05 \times 0.8 + 19.25 \times 0.2)^2 + (1732.05 \times 0.6 + 19.25 \times 2.999)^2]}$

$= \sqrt{[1930682.46 + 1203322.887]} = \sqrt{3134005.347}$

$\boldsymbol{E_0 = 1770.31\ volt}$

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

1 mark for regulation for lagging pf

$= \frac{1770.31-1732.05}{1732.05} \times 100$

= 2.21 %

E) Voltage regulation at 0.8 leading:

$cos\emptyset = 0.8 \qquad sin\emptyset = 0.6$

The emf is given by,

$$E_0 = \sqrt{[(Vcos\emptyset + IR)^2 + (Vsin\emptyset - IX_S)^2]}$$

$= \sqrt{[(1732.05 \times 0.8 + 19.25 \times 0.2)^2 + (1732.05 \times 0.6 - 19.25 \times 2.999)^2]}$

$= \sqrt{[1930682.46 + 963340.78]} = \sqrt{2894023.24}$

$\boldsymbol{E_0 = 1701.18\ volt}$

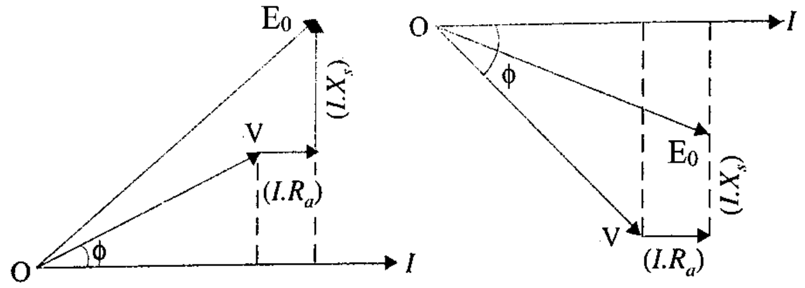
1 mark for regulation for leading pf

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

$= \frac{1701.18-1732.05}{1732.05} \times 100$

= - 1.78 %

F) Phasor diagram:



(a) 0.8 lagging pf (b) 0.8 leading pf

1 mark for phasor diagram

4 b) ii) What is armature reaction? Describe armature reaction with flux distribution waveform of three phase alternator when the nature of load on the alternator is resistive, purely inductive.

Ans:

Armature reaction:

The effect of armature flux on main flux is called as armature reaction. When the armature conductors of alternator carry current, they produce their own flux, called armature flux. This flux affects the main pole flux and resultant flux in the air-gap is modified. This affects the terminal voltage of alternator. The power factor of the load has a considerable effect on the armature reaction.

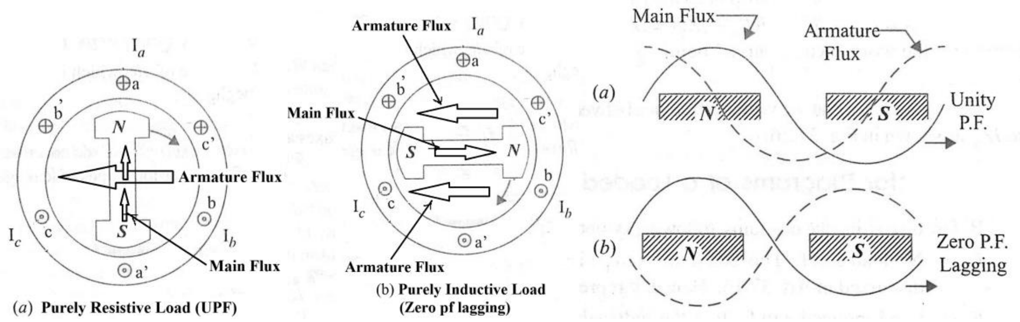
1 mark

Armature Reaction when the load is Purely Resistive:

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

1 Mark

reduction in the terminal voltage to some extent. The flux distribution waveform is also shown in the figure below.



(a) Purely Resistive Load (UPF) (b) Purely Inductive Load (Zero pf lagging)

1 Mark for each of 3 diagrams = 3 marks

Armature Reaction when the load is Purely Inductive:

Referring to fig. (b), for shown pole positions, the phase-a conductors lie exactly on magnetic neutral axis, so phase-a emf is zero. Since load is purely inductive, the current lags behind the voltage by 90°, resulting the current in phase-a as positive maximum with zero voltage induced in it. Thus the current pattern in all phases remains same as shown in the figure. It is seen that the armature flux appears to be opposing the main flux. Therefore, the armature reaction is termed as de-magnetizing. With reference to the rotation, we can say that the armature flux is out-of phase of the main flux by 180°. Since the magnetic flux lines never cross each other, the net effect of de-magnetization is to reduce the main flux, resulting considerable reduction in the terminal voltage. The flux distribution waveform is also shown in the figure. 1 mark

5 Attempt any FOUR of the following: **16**

5 a) Explain why induction motor can never run with the synchronous speed.

Ans:

In induction motor, the force on rotor conductors, causing motion, is produced due to the interaction between rotor currents and rotating magnetic field (RMF) of stator. The rotor currents are due to the rotor emfs. The rotor emfs are due to the cutting of RMF by rotor conductors. The rotor conductors cut the RMF due to the relative motion between rotor and the RMF. Thus the root cause of the force or torque acting on the rotor is the relative motion between the rotor and RMF.

When the rotor catches the synchronous speed of the RMF, the relative speed between rotor and RMF becomes zero. Then rotor conductors cannot cut the RMF. Therefore no rotor emf and no rotor currents. Thus the force or torque acting on the rotor becomes zero. With no driving torque, this condition cannot be maintained because the friction is always present to oppose the speed and the speed falls below the synchronous speed. Thus the induction motor can never run at synchronous speed.

4 marks for logical correct answer

5 b) Explain the effect of resistance of rotor winding on starting torque of three phase induction motor.

Ans:

Effect of Rotor Resistance on Starting Torque:

Torque produced by Three-phase induction motor is given by,

$$T = \left(\frac{3\times 60}{2\pi N_S}\right)\frac{sE_2^2R_2}{(R_2^2+s^2X_2^2)} \text{ N-m}$$

At the instant of starting, motor speed N = 0 and slip s = 1 — 2 marks for explanation

$\therefore$ Starting torque is given by,

$$T_{st} = \left(\frac{3\times 60}{2\pi N_S}\right)\frac{E_2^2 R_2}{(R_2^2+X_2^2)}\text{ N-m} = k\,\frac{E_2^2 R_2}{(R_2^2+X_2^2)}\text{ N-m}$$

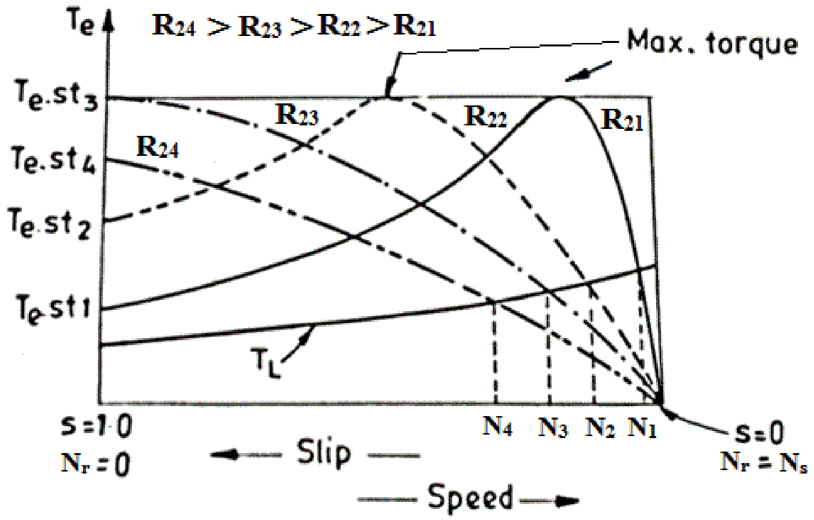
(Since synchronous speed N_S is constant)

The rotor standstill emf E_2 and rotor standstill reactance X_2 are constants, but the external resistance can be inserted in rotor circuit through slip-ring and brush arrangement. So the rotor resistance R_2 is considered variable. Thus starting torque depends upon rotor resistance R_2 only. If rotor resistance is increased, the starting torque get increased.

The motor produces maximum torque at slip $s_m = \frac{R_2}{X_2}$

When the rotor resistance is increased, the slip at which maximum torque occurs also gets increased (speed at which maximum torque occurs get decreased). Thus by increasing the rotor resistance, it is possible to achieve the maximum torque at start. For maximum starting torque, $R_2 = X_2$.Thus if the rotor resistance per phase i.e R_2 is equal to the rotor reactance per phase at standstill i.e X_2, then the motor produces maximum torque at start.

The following graph shows the variation in the starting torque with change in the rotor resistance. It is seen that when the rotor resistance R_2 is increased from its initial value R_{21} to $R_{22} \to R_{23} \to R_{24}$, for given load torque characteristic T_L, the speed of motor drops down from N_1 to $N_2 \to N_3 \to N_4$. The maximum torque occurs subsequently at lower speeds. The starting torque gets increased from its initial value $T_e$st1 to $T_e$st2 $\to$ $T_e$st3. However it must be noted that if the rotor resistance exceeds X_2, the starting torque get reduced, which is shown by $T_e$st4.



2 marks for graph

5 c) Explain why synchronising of alternator is necessary? Also state conditions for synchronization of alternators.

Ans:

Necessity of Synchronization of Alternators :

The alternators generate AC voltage whose magnitude and direction continuously changes with respect to time. So the alternators cannot be just directly connected to operate them in parallel to share common large load. Some conditions need to be satisfied before the parallel connection of alternators.

The process of verifying the operating conditions of alternators and connecting them in parallel after fulfilment of the necessary conditions is called Synchronization. 2 marks for necessity

If the alternators are directly connected without observing the operating conditions, the large circulating currents can damage the whole system of alternators. So synchronization of alternators is necessary. The synchronization and subsequent parallel operation of alternators offer following advantages:

1. Supply continuity can be maintained in the event of breakdown of one alternator, others being functional.
2. Alternators are loaded such that they exhibit higher efficiency.
3. Saving in fuel.
4. Maintenance and repair becomes easy without disturbing supply continuity.
5. Small capacity of reserved units.
6. Easy future expansion.

Conditions of synchronization of Alternators: ½ mark for each of 4 conditions

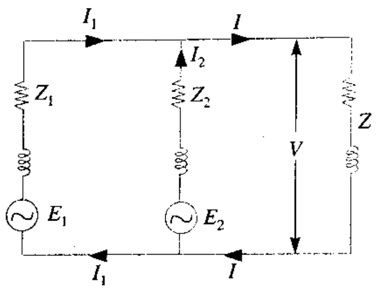
1. The phase sequence of both alternators must be same.
2. The AC voltages of both alternators should be equal.
3. The frequencies of both alternators must be equal.
4. Respective Phase voltages of both alternators must be in phase.

5 d) Explain the concept of load sharing.

Ans:

Concept of load sharing:

Consider two machines operating in parallel with a common terminal voltage of V volts and load impedance Z, as shown in the figure. Let the generated emfs of the machines 1 and 2 be E_1 and E_2 respectively and synchronous impedances per phase be Z_1 and Z_2 respectively. The total load current I is shared by two machines by supplying currents I_1 and I_2 respectively. Thus the load sharing can be expressed as,



$$\mathbf{I = I_1 + I_2} \quad \textbf{(phasor sum)}$$ 2 marks

The common terminal voltage can be obtained as,

$$\mathbf{V = E_1 - I_1Z_1 = E_2 - I_2Z_2}$$

The load sharing can be then given by,

$$\therefore\ \boldsymbol{I_1 = \frac{E_1 - V}{Z_1}} \quad \text{and} \quad \boldsymbol{I_2 = \frac{E_2 - V}{Z_2}}$$

It is seen that for equal emfs (i.e $E_1 = E_2 = E$) the load shared by a machine is inversely proportional to its internal synchronous impedance.

For every alternator, two inputs are available:

i) Shaft power input from prime mover
ii) Excitation input from DC supply

A) Effect of change in shaft power input:

When shaft power input to a machine is increased, its active power input is increased. Since the machines are synchronized, their speed cannot change, but the emf of the machine which receives additional active power through shaft get advanced due to the angular advancement of its rotor. Consequently, the active power output of the machine is increased. Thus by changing the shaft power input of the alternator, the load (active power output) taken up by the alternator can be modified, but the reactive power sharing remains same. 1 mark

B) Effect of change in excitation:

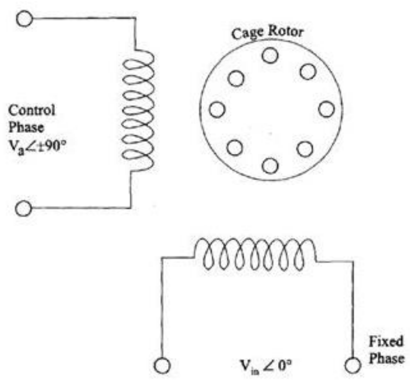
When the excitation of the alternator is increased, the emf of that alternator is increased. Consequently, the current shared by that alternator is increased. But the power factor of the current is so changed that the active power output remains unchanged. However, the reactive power output of the alternator is increased. Thus by changing the excitation, the power factor and reactive power sharing can be modified, but the active power sharing remains same. 1 mark

5 e) Describe the working of AC servo motor.

Ans:

Working of AC servo motor:

There are some special applications of electrical motor where rotation of the motor is required for just a certain angle not continuously for long period of time. For these applications some special types of motor are required with some special arrangement which makes the motor to rotate a certain angle for a given electrical input (signal). Such motors can be ac or dc motors. These motors are used for position control or in servo mechanisms, hence are termed as servomotors. The AC servomotor consists of main and control winding and squirrel cage / drag cup type rotor. V_r is the voltage applied to the main or reference winding while V_c is the voltage applied to control winding which controls the torque-speed characteristics. The 90° space displacement of the two coils/windings and the 90° phase difference between the voltages applied to them result in production of rotating magnetic field in the air gap. This rotating magnetic field is cut by rotor conductors and emf is induced in them. Since rotor is short-circuited, the rotor currents flow. The interaction between rotor currents and rotating magnetic field results in force (or torque) acting on rotor. Due to the force or torque acting on the rotor, it is set in motion.



2 marks for diagram

2 marks for explanation

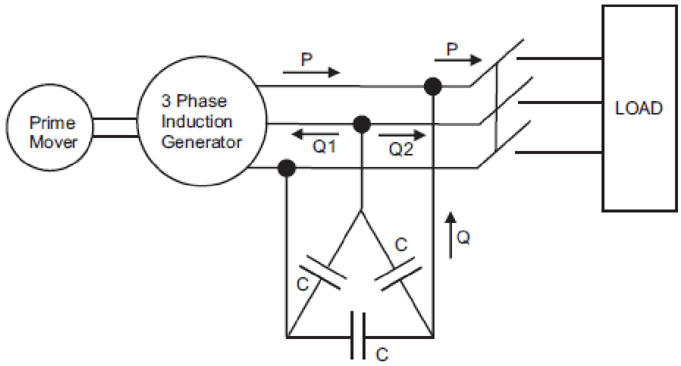
5 f) What is induction generator? State the principle of operation and any two applications of I.G.

Ans:

Induction Generator:

When an induction motor is driven from shaft side by prime mover at speed above synchronous speed, the motor acts as generator and supplies active power output at stator terminals. This is called induction generator. 1 mark

Principle of Operation of Induction Generator:



1 mark for sketch or equivalent

When the rotor of induction motor is driven by prime mover, say wind turbine, at speed faster than synchronous speed, induction motor acts as generator. It converts mechanical energy it receives from the shaft into electrical energy which is released by stator. Since induction motor does not have separate field winding for producing magnetic field, the stator has to produce it. Therefore, for creating the magnetic field, the stator needs to absorb reactive power Q from the line to which it is connected. The reactive power may be supplied by a capacitor bank connected at the stator output terminals of induction generator. Thus while working as an induction generator, it takes mechanical power as input via the shaft from prime mover, reactive power input to produce the magnetic field from the line or capacitor bank connected to stator terminals and gives out active electrical power to the line connected to stator terminals.

1 mark for explanation

Applications of Induction Generator:

1) It is used in wind mills.
2) It is used to assist the power received from weak transmission lines in the remote areas.
3) To compensate reactive power from the supply.
4) Regenerative breaking of hoists driven by the three phase induction motors with energy recovery systems in industrial processes.

½ mark for each of any two applications = 1 mark

6 Attempt any <u>FOUR</u> of the following: 16

6 a) Explain why single phase induction motor is not self-starting.

Ans:

Single phase induction motors are not self-starting:

- When single phase AC supply is given to main winding it produces alternating flux.
- According to double field revolving theory, alternating flux can be represented by two oppositely rotating fluxes of half magnitude.
- These oppositely rotating fluxes induce current in rotor & there interaction produces two opposite torques, hence the net torque is Zero and the rotor remains standstill.
- Hence Single-phase induction motor does not have starting torque and is not self-starting.

4 marks for answer with logical reasoning

OR

Single phase induction motor has distributed stator winding and a squirrel-cage

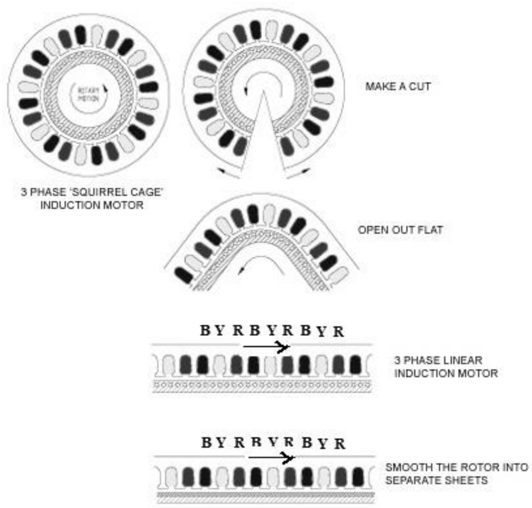
Rotor. When fed from a single-phase supply, its stator winding produces a flux (or field) which is only alternating i.e. one which alternates along one space axis only. It is not a synchronously revolving (or rotating) flux as in the case of a two or a three phase stator winding fed from a 2 or 3-phase supply. Now, alternating or pulsating flux acting on a stationary squirrel-cage rotor cannot produce rotation (only a revolving flux can produce rotation). That is why a single phase motor does not have starting torque and is not self-starting.

6 b) Explain the principle of operation of linear induction motor.

Ans:

Linear induction motor:

- Linear Induction Motor (LIM) is asynchronous motor, working on the same principle as that of an Induction motor, but is designed to produce the linear motion.
- Referring to the figure, if the stator and rotor of conventional induction motor is cut and laid down flat, we get basic linear induction motor. The stator coils appear in sequence RYB. The rotor appears like a flat bed of bars. The rotor further can be modified to have flat sheets of conductor only, no bars needed.
- When the stator of conventional induction motor is excited by 3 phase supply, rotating magnetic field is produced, which causes torque on rotor to rotate it. But in linear induction motor, excitation with three phase supply induces a 'travelling flux', a travelling magnetic field, which would linearly travel along the stator. 1 mark for construction
- This travelling magnetic field induces emfs in the rotor sheets and so the currents. The interaction between rotor currents and travelling magnetic field produces a forward thrust force on rotor, making it to move. However, if the rotor sheets are fixed to ground and not allowed to move, then the stator can move in the opposite direction and travel across the length of the rotor sheets (tracks) linearly with synchronous speed. 2 mark for explanation of working



1 mark for sketch or equivalent diagram

The linear synchronous speed given by

$$V_s = 2wf$$

where, V_s = linear synchronous speed in m/sec
w = width of one pitch in m.
f = supply frequency (Hz)

The speed does not depend on number of poles but depends only on the pole-pitch and supply frequency.

6 c) Compare the salient pole type and smooth cylindrical type rotor used in three phase alternator.(Any four points)

Ans:

Sr. No.	**Parameter/ Machine**	**Salient pole type rotor**	**Smooth cylindrical type rotor**
1	Operating speed	Low, medium	High
2	Number of poles	Large	Less (2 or 4)
3	Rotor construction	• Non-uniform airgap • Projected type or salient poles • Bulky & heavy weight	• Cylindrical with smooth surface so uniform airgap • poles are not projected out, • comparatively moderate weight
4	Axial length	Short	Large
5	Diameter	Large	Small
6	Operation	Noisy	Very smooth
7	Centrifugal stresses	Non uniform	Uniform
8	Application	Hydro power station	Thermal power stations

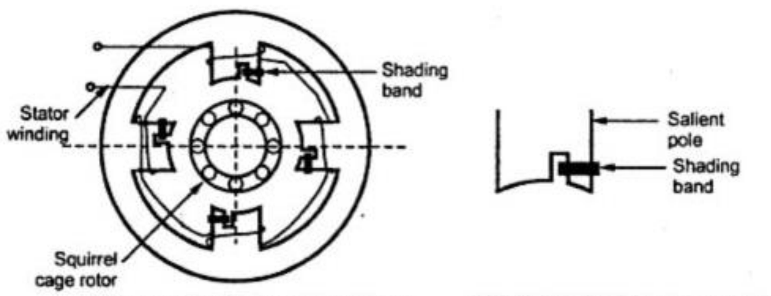
1 mark for each of any four points = 4 marks

6 d) Explain working of shaded pole induction motor with suitable sketch.

Ans:

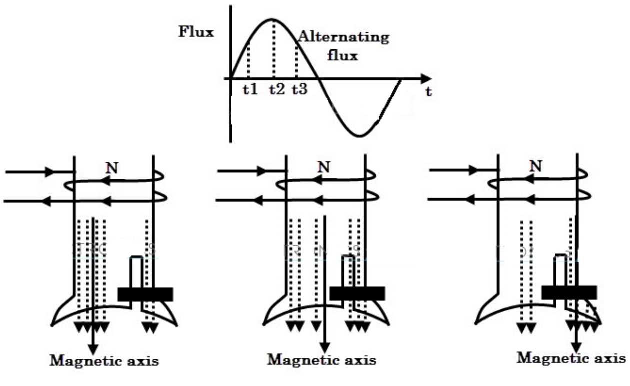
Shaded Pole Induction Motor :

1 mark



(a) 4 - pole shaded pole construction (b) Salient pole with shading band

1 mark



2 marks for explanation

When single phase supply is applied across the stator winding, an alternating field is created. The flux distribution is non uniform due to shading bands on the poles. The shading band acts as a single turn coil and when links with alternating flux, emf is induced in it. The emf circulates current as it is simply a short circuit. The current produces the magnetic flux in the shaded part of pole to oppose the cause of its production which is the change in the alternating flux produced by the winding of motor. Now consider three different instants of time t_1, t_2, t_3 of the flux wave to examine the effect of shading band as shown in the figure.

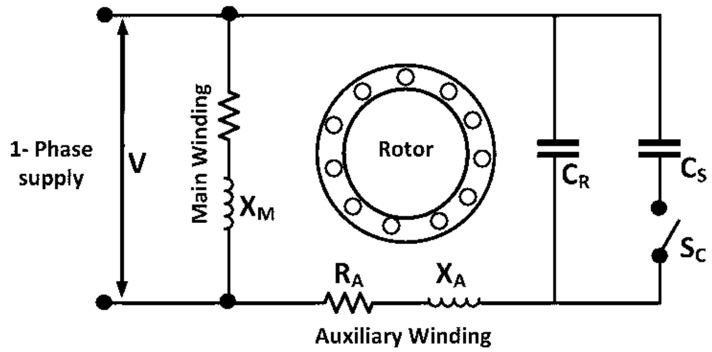
- At instant t_1: The flux is positive and rising, hence the shading band current produces its own flux to oppose the rising main flux. Due to this opposition, the net flux in shaded portion of pole is lesser than that in unshaded portion. Thus the magnetic axis lies in the unshaded portion and away from shaded portion.
- At instant t_2: The flux is maximum, the rate of change of flux is zero. So the shading band emf and current are zero. Thus the flux distribution among shaded and unshaded portion is equal. The magnetic axis lies in the centre of the pole.
- At instant t_3: The flux is positive but decreasing, hence according to Lenz's rule, the shading band emf and current try to oppose the fall in the main flux. So the shading band current produces its own flux which aids the main flux. Since shading band produces aiding flux in shaded portion, the strength of flux in shaded portion increases and the magnetic axis lies in the shaded portion.

Thus it is seen that as time passes, the magnetic neutral axis shifts from left to right in every half cycle, from non-shaded area of pole to the shaded area of the pole. This gives to some extent a rotating field effect which is sufficient to provide starting torque to squirrel cage rotor and rotor rotates.

6 e) Explain working of capacitor start capacitor run single phase induction motor.

Ans:

Capacitor-start, Capacitor- run Induction Motor:



Capacitor-start, Capacitor-run Induction Motor

2 marks for circuit diagram

The figure shows the circuit diagram of the capacitor-start, capacitor-run induction motor. Both the main and auxiliary windings remain permanently in the circuit during the starting and running condition.

2 marks for explanation

There are two capacitors in the auxiliary winding circuit. A capacitor C_S is known as the starting capacitor. It is connected in series with the centrifugal switch S_C. So C_S remains in the circuit only at start and it is switched out during normal running. Hence C_S is of electrolytic type, has high value but short duty. Another capacitor C_R is known as running capacitor. It remains in the circuit continuously during starting and running of the motor. It is an oil capacitor having low value and continuous duty. Thus the motor is a two-value capacitor motor.

Capacitor serves the purpose of obtaining necessary phase displacement (about 90°) at the time of starting and also improves the power factor of the motor. Due to capacitor motor operation becomes salient.

When single phase supply is given to the motor, two currents having phase displacement of about 90° flow through two windings which are 90° displaced in the space. This results in the production of rotating magnetic field (RMF). The RMF is cut by stationary rotor conductors, emf is induced in it, current flows and force is exerted on rotor conductors. The torque is developed and rotor starts rotating. When a particular speed is attained, the centrifugal switch is opened and the capacitor C_S gets disconnected from the circuit. The motor continues to run with both windings in the circuit, the auxiliary winding in series with reduced capacitor. Due to the presence of both the windings in the circuit, this motor is superior at all speed to capacitor-start, induction-run motor.