Model Answers

Summer – 2019 Examination

Subject & Code: A. C. MACHINES (17511)

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.

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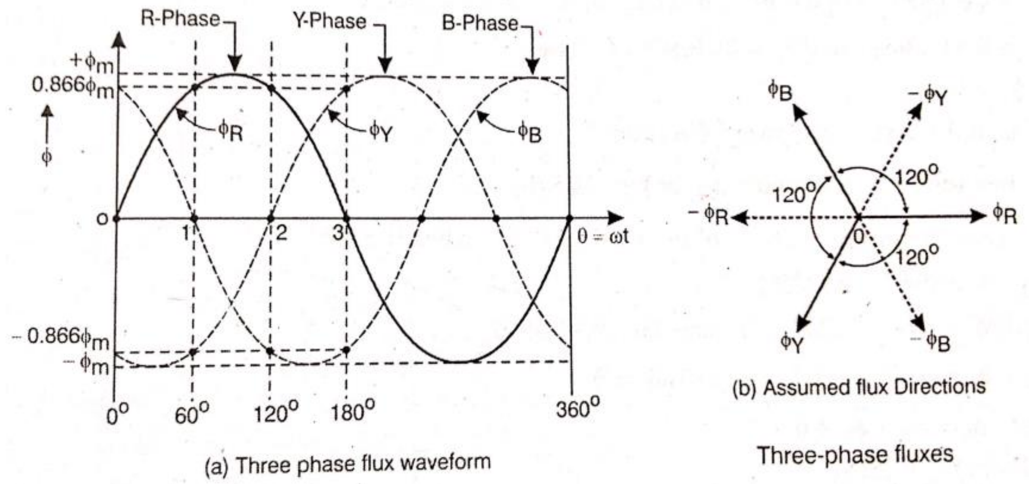
1 a) Attempt any THREE of the following: **12**

1 a) (i) Explain how in a 3 phase induction motor ~~to~~ a rotating magnetic field is developed.

Ans:

Production of Rotating Magnetic Field in Three-phase Induction Motor:

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



(a) Three phase flux waveform

(b) Assumed flux Directions

Three-phase fluxes

1 Mark for flux waveform

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

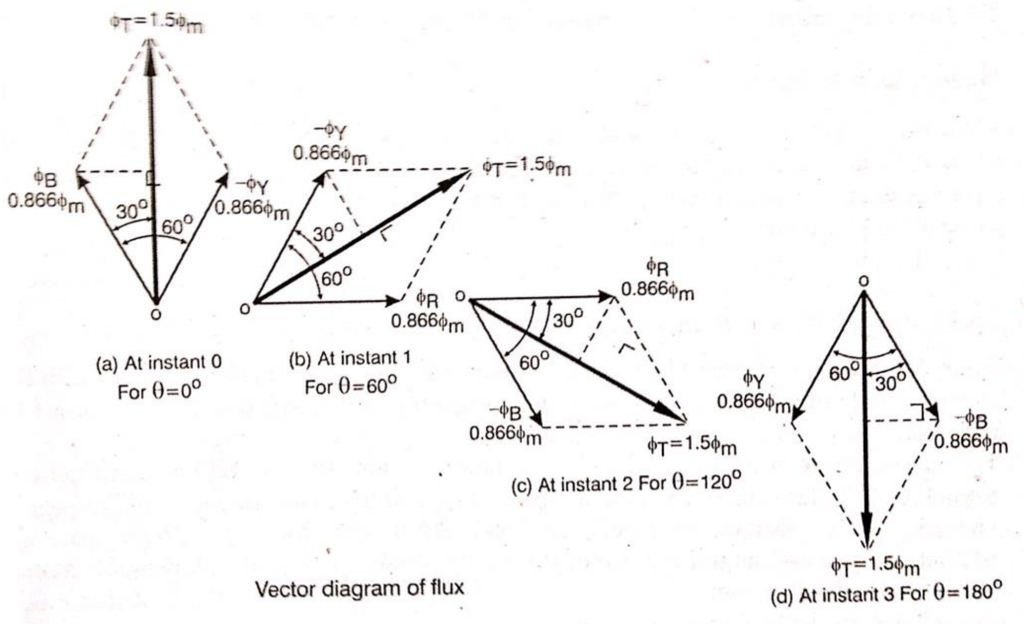
1) **At instant 0 (θ = 0°):**
   $\phi_R = 0$, $\phi_Y = -0.866\ \phi_m$ and $\phi_B = 0.866\ \phi_m$
   With assumed flux directions, the vector diagram for fluxes can be drawn as shown in the figure (a). It is seen that the total flux is $\phi_T = 1.5\ \phi_m$ with direction vertically upward.

1 Mark for explanation

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 $\phi_T = 1.5$

ϕ_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

2 Marks for flux vector diagrams

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) (ii) List any four advantages and two disadvantages of 3 phase induction motor.

Ans: \

Advantages of 3 phase induction motor:

1) Simple in construction.
2) Economical in cost.
3) Requires very less maintenance.
4) High efficiency.
5) Low maintenace cost.
6) Self starting.
7) Robust and mechanically strong.
8) High overload capacity.
9) Small capacity motors, less than 5 HP, don't need a starter.

½ Mark for each of any four advantages = 2 Marks

Disadvantages of 3 phase induction motor:

1) Essentialy a constant speed motor and its speed cannot be changed easily.
2) Medium starting torque.
3) Very sensitive to fluctuations in supply voltage.
4) Separate starter is required for stating for high capacity (more than 5HP) motors.
5) Cause of low system power factor, especially when motors are operated below its full load capacity.
6) It takes a large current from line at instant of starting.

1 Mark for each of any two disadvantages = 2 Marks

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1 a) (iii) Define and explain distribution factor of a winding with neat sketch.

Ans:

Distribution Factor of a Winding:

Distribution factor is defined as;

$$K_d = \frac{Emf\ with\ distribured\ winding}{Emf\ with\ concentrated\ winding} \quad \textbf{OR}$$

1 Mark for definition

$$K_d = \frac{Phasor\ sum\ of\ coil\ emf\ /phase}{Airthmetic\ sum\ of\ coil\ emf\ /phase}$$

Referring to the figure, let β be the value of the angular displacement between the slots. Its value is

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

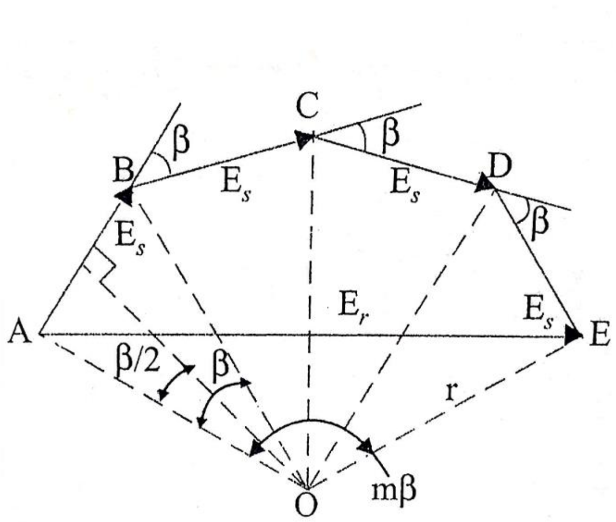
m = No. of slots/pole/phase.

m β = Phase spread angle.

Then the resultant voltage induced in one polar group would be m E_S.

Where Es is the voltage induced in one coil side. The following figure illustrates the method for finding the vector sum of 'm' voltages each of value Es and having a mutual phase difference of β (if m is large, then the curve ABCDE will become part of a circle of radius r).

1 Mark for diagram



AB = Es = 2r sin(β/2)

The arithmetic sum = m E_S = m× 2r sin(β/2)

The vector sum AE= E_r = 2r sin(mβ/2)

The distribution factor (Kd) is defined as,

2 Marks for explanation

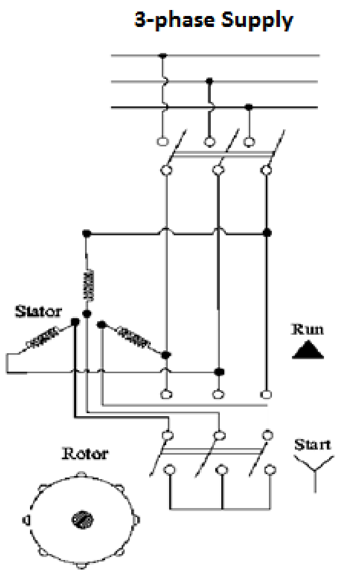
$$K_d = \frac{Vector\ or\ phasor\ sum\ of\ coil\ emfs}{Arithmetic\ sum\ of coil\ emfs} = \frac{2r sin(\frac{m\beta}{2})}{m\times 2r sin(\frac{\beta}{2})}$$

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

1 a) (iv) With the help of diagram explain how star-delta starter used for reducing starting current of 3 phase induction motor.

Ans:

Star Delta Starter for 3 Phase Induction Motor:



2 Marks for diagram

Explanation:

The stator winding of the motor which is designed for delta operation is connected in star during starting period. The arrangement is shown in the above figure; here six leads of the stator windings are connected to change over switch. At the instant of starting the switch is on the "Start" position which connects the stator winding in star connection so that each stator phase gets the reduced voltage $V_L/\sqrt{3}$ volts, where V_L is the line voltage. The application of reduced voltage reduces the starting current and protects the motor from high starting current.

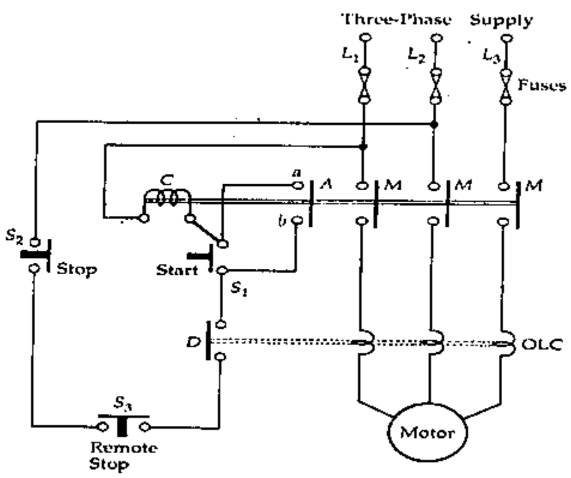
2 Marks for explanation

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

1b) (i) Draw neat sketch of a D.O.L starter and state functions of OLC and NOC.

Ans:

DOL Starter of 3 Phase Induction Motor:



3 Marks for diagram

Function of ~~NOC~~ NVC:

The No-Volt-Coil (NVC) is a contactor coil (coil C) placed on an iron core. When this coil is connected across two lines, it is energized and current flows through it. This current magnetizes the core and therefore either a part of core or some soft iron piece, called armature is attracted to the core against the spring tension. This movement is used to close the contacts. The contacts remain closed so far the core is magnetized. However, when supply fails, supply voltage becomes zero, called no-volt condition, the coil current falls to zero, the core is demagnetized, attractive force becomes zero and the armature is send back to its original position due to spring mechanism. Thus the contacts are opened & motor is disconnected from the supply. On recovery of supply, motor can not start because start push button normally open (NO) contact appears in series with the coil. Thus accidental starting on recovery of supply is prevented and motor, operator, driven machine are protected. 2 Marks

Function of OLC:

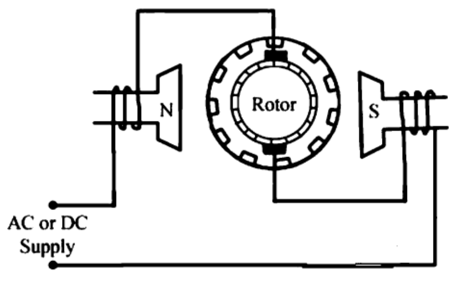
The overload coil (OLC) is a heating coil which carries the motor current & heats up the thermal bimetallic strip. The heat developed by this coil is proportional to the heat developed in the motor by its copper loss. During over-load condition, if the motor heating is about to damage the motor, the bi-metal strip bends and opens its normally closed (NC) contact in series with the contactor coil. Therefore, the contactor coil current is interrupted, contactor is tripped and motor is disconnected from the supply. Thus motor is protected from severe over-load conditions. 1 Mark

1b) (ii) State and explain the main constructional features and principle of operation of universal motor.

Ans:

Construction of Universal Motor:

The construction of universal motor is just similar to DC motor. It consists of a stator on which field poles are mounted. The Field coils are wound on the field poles. However, the whole magnetic path comprising stator field circuit and also rotor or armature is laminated. Lamination is necessary to minimize the eddy currents which induce while operating on AC. The rotary armature is of wound type having straight or skewed slots and commutator with brushes resting on it. The commutation on AC is poorer than that for DC because of the current induced in the armature coils. For that reason brushes used are having high resistance. 2 Marks for constructional features



1 Mark for diagram

Working of Universal Motor:

A universal motor works on either DC or single phase AC supply. When the universal motor is fed with a DC supply, the current flows in the field winding and it produces magnetic field in the air gap. 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. — 3 Marks for working

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 reverse 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.

As motor works on AC or DC supply, it is referred as Universal motor.

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

2 a) Derive the condition for maximum torque developed in a 3 phase induction motor.

Ans:

Condition for Maximum Torque Developed in 3 Phase Induction Motor:

Torque produced by Three-phase induction motor is given by

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

Since synchronous speed N_S is constant and the rotor standstill emf E_2, rotor standstill resistance R_2 & reactance X_2 are constants, the only variable on which torque depends will be the slip 's'.

For maximum torque,

$$\frac{dT}{ds} = \frac{d}{ds}\left[\left(\frac{3\times 60}{2\pi N_S}\right)\frac{sE_2^2R_2}{(R_2^2+s^2X_2^2)}\right] = 0$$ 1 Mark

$$\therefore \left(\frac{3\times 60}{2\pi N_S}\right)\frac{d}{ds}\left[\frac{sE_2^2R_2}{(R_2^2+s^2X_2^2)}\right] = 0$$

$$\therefore \frac{(R_2^2+s^2X_2^2)E_2^2R_2 - sE_2^2R_2(0+2sX_2^2)}{(R_2^2+s^2X_2^2)^2} = 0$$

$$(R_2^3E_2^2 + s^2X_2^2E_2^2R_2) - 2s^2R_2X_2^2E_2^2 = 0$$ 1 Mark

$$(R_2^2E_2^2 + s^2X_2^2E_2^2) - 2s^2X_2^2E_2^2 = 0$$

$$(R_2^2E_2^2 - s^2X_2^2E_2^2) = 0$$

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

$$R_2^2 = s^2X_2^2$$

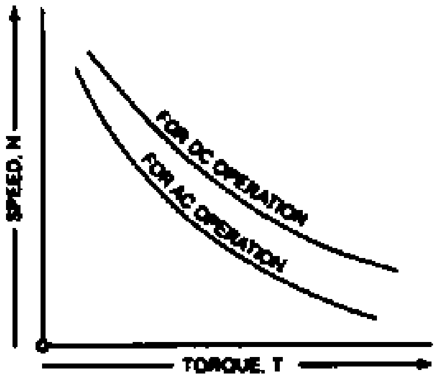
$$R_2 = sX_2$$

Thus the motor under running condition produces maximum torque at speed or slip when rotor resistance is equal to the rotor reactance under running condition. This is the condition for maximum torque produced by motor under running condition. — 1 Mark

2 b) Describe the torque speed characteristics of A.C series motor.

Ans:

Torque Speed Characteristics of A.C series motor:



Speed-Torque Characteristics of Series Motors

2 Marks for diagram

The torque speed characteristics of ac series motor is shown in figure. It is clear that AC series motor develops high torque at low speed and vice versa. It is because an increase in torque requires an increasing armature current which is also the field current in series motor. The result is that the flux is strengthened and hence speed drops (as N α 1/ ϕ). The main features of the torque-speed characteristics of A.C series motor are as below:

2 Marks for explanation

1) It has high starting torque because initially T α $(I_a)^2$.
2) It is variable speed motor and automatically adjusts speed as load changes.
3) For DC series motor the torque obtained is somewhat high than AC series motor.

2 c) What are the special features of servo motor? State their types.

Ans:

Special Features of Servo Motor:

1) The servo motor is specialized for high-response applications.
2) The servo motor is used for high-precision positioning.
3) The servo motor is capable of accurate rotation angle and speed control.
4) The automatic control of physical quantity is done with servo motor.
5) They are not used for continuous energy conversion but only for precise speed and precise position control at high torque.
6) Their power rating varied from a fraction of watt up to few 100 watts.
7) They produce high torque at all speeds including zero speed.
8) They do not overheat at standstill or lower speed.
9) Due to low inertia they are able to reverse direction quickly.
10) They are able to accelerate and decelerate quickly.
11) They are able to return to a given position without any drift.

2 Marks for any four features

Types of Servo Motor:

1) DC servo motor
   a) Field controlled DC servo motor.
   b) Armature controlled DC servo motor.
   c) Permanent magnet armature controlled DC servo motor.
2) AC servo motor
   a) 2 Phase AC servo motor.
   b) 3 Phase AC servo motor.

2 Marks for types

2 d) List the advantages of having stationary armature and rotating field for 3 phase alternator.

Ans:

Advantages of Stationary Armature and rotating field for Three 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 on rotor.
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.
8) Rotating field is comparatively light and can run with high speed.

1 Mark for each of any four advantages = 4 Marks

2 e) If frequency of the supply voltage to the stator is 50 Hz, while the frequency of the induced emf in the rotor is observed to be 90 cycles per min. Calculate the slip and speed of the motor. Stator is wound for 6 poles.

Ans:

Data Given: f = 50 Hz, P = 6

f_r = 90 cycles/min = $\frac{90}{60}$ cycles/sec = **1.5 Hz** — 1 Mark

Synchronous speed (N_s):

$$N_s = \frac{120\,f}{P}$$

$$N_s = \frac{120 \times 50}{6} = \mathbf{1000\ rpm}$$ — 1 Mark

Slip (s):

$$f_r = s \times f$$

$$1.5 = s \times 50$$

$$s = \frac{1.5}{50} = \mathbf{0.03\ or\ 3\%}$$ — 1 Mark

Motor Speed (N): 1 Mark

$N = N_s(1 – s) = 1000\ (1 - 0.03) =$ **970 rpm**

2 f) A 3 phase, 50 Hz, 4 pole, star connected alternator has 72 slots with 4 conductors per slot. The coil span is 2 slots less than pole pitch. If machine gives 6600 V between lines on O.C determine the useful flux per pole.

Ans:

Data Given: P = 4, No of Slots = 72, No of conductors per slot = 4,
E_L = 6600V and Coil span is 2 slots less than pole pitch.

Phase Voltage (E_{ph}):

$$\text{Eph} = \frac{\text{Line Voltage}}{\sqrt{3}}$$

$$\text{Eph} = \frac{6600}{\sqrt{3}} = 3810.512\text{V}$$

No. of conductors Z = 72 x 4 = 288

∴ No. of turns N = Z/2 = 288/2 = 144 turns

m = No. of slots / pole / phase = $\frac{72}{4 \times 3} = 6$

Slots / pole = $\frac{72}{4}$ = 18

$\beta = \frac{180}{slot/pole} = \frac{180}{18} = 10^0$ 1 Mark

Distribution factor:

$$K_d = \frac{sin(\frac{m\beta}{2})}{m \times sin(\frac{\beta}{2})} = \frac{sin(\frac{6 \times 10}{2})}{6 \times sin(\frac{10}{2})} = \frac{sin30}{6 \times sin5} = \frac{0.5}{0.523} = 0.956$$ 1 Mark

The coil span is 2 slots less than pole pitch therefore,

$\alpha = 2\beta = 2 \times 10^0 = 20^0$

Pitch factor:

$K_p = \cos(\frac{\alpha}{2}) = \cos(\frac{20}{2}) = \cos 10^0 = 0.985$ 1 Mark

$E_{ph} = 4.44\ K_p\ K_d\ Nf\ \phi$

$3810.512 = 4.44 \times 0.985 \times 0.956 \times 144 \times 50 \times \phi$

$\Phi = \frac{3810.512}{4.44 \times 0.985 \times 0.956 \times 144 \times 50}$ = **0.1266 wb** 1 Mark

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

3 a) Explain double field revolving theory for 1 phase induction motor.

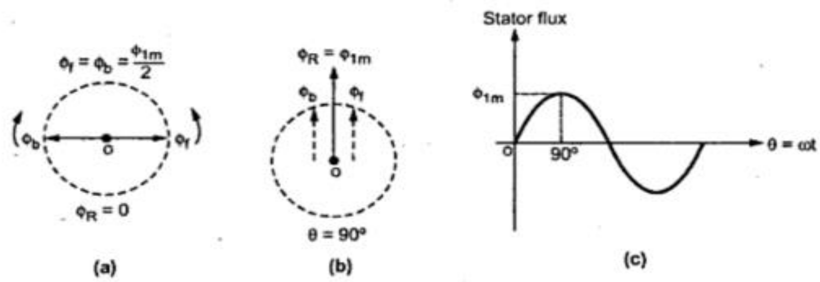
Ans:

Double Field Revolving Theory:

The sinusoidally alternating single phase supply given to the winding of the single phase motor produces an alternating magnetic field in the air gap around the rotor. But a sinusoidally alternating single phase field, having oscillating nature, can be expressed as the sum of two oppositely rotating fields (ϕ_f forward rotating field & ϕ_b backward rotating field) having the same angular speed as the alternating field but having constant magnitude of half the amplitude of the alternating field (Ferrari's principle). 2 Marks for explanation

The fields ϕ_f and ϕ_b are the forward and backward rotating components each of constant magnitude of $\phi_{1m}/2$. The speed of rotation is 'ω' radians per second. Hence the resultant of the addition of these two fields is given by taking and adding the components along the vertical and horizontal axis. The horizontal component sum is zero as they are equal and opposite in direction at all times. The resultant is along the vertical axis always for the given configuration but varies sinusoisally as seen below.

$\phi_R = 2(\phi_{1m}/2)\cos\theta = \phi_{1m}\cos\theta$ (where $\theta = \omega t$).



2 Marks for diagram

Thus representation of an alternating magnetic field in terms of two oppositely rotating fields is the concept of Double revolving field theory.

Both the rotating fields are cut by rotor conductors, emfs are induced, rotor currents flow and according to basic motor principle torques are produced on the rotor. However, since the fields are oppositely rotating, the torques produced on the rotor are also opposite to each other. At start, ($\omega t = 0°$) (Fig. a) these two torques are equal in magnitude but opposite in direction. Each torque tries to rotate the rotor in its own direction. Thus the net torque experienced by the rotor is zero at start, hence the single phase induction motors are not self- starting.

3b) Derive the expression for torque under running condition of 3 phase induction motor.

Ans:

Expression for torque under running condition of 3 phase induction motor:

The following expression gives the power relations in the rotor of the motor.

Power input to rotor from stator

P_{in} = Mechanical power developed in rotor + Rotor copper loss.

Power input to rotor from stator is in the form of the torque 'T' exerted at synchronous speed 'ω_S' in radians per second. ($\omega_S = 2\pi N_S/60$)

4 Marks for stepwise derivation

$\therefore P_{in} = T\,\omega_S$

Mechanical power developed in rotor $P_m = T\,\omega_R$, at rotor speed of ω_R.

Rotor copper losses = $3\,I_2^2R_2$, where I_2 = rotor current per phase and R_2 = rotor resistance per phase.

$\therefore P_{in} = T\,\omega_S = T\,\omega_R + 3\,I_2^2R_2$

Total rotor copper losses = $3\,I_2^2R_2 = T(\omega_S - \omega_R)$
$= T\,s\,\omega_S$ watt,

where 's' is the slip, $s = (\omega_S - \omega_R)/\omega_S$

$$\text{Hence } T = \frac{3I_2^2\,R_2}{s\,\omega_S}, \qquad (\text{ but } I_2 = \frac{sE_2}{\sqrt{(R_2^2+s^2X_2^2)}})$$

$$T = \frac{3s^2E_2^2\,R_2}{s\,\omega_S(R_2^2+s^2X_2^2)} = \frac{3sE_2^2\,R_2}{\omega_S(R_2^2+s^2X_2^2)}$$

$$T = \frac{KsE_2^2\,R_2}{(R_2^2+s^2X_2^2)} \quad \text{where } K = 90/(2\pi N_S)$$

3c) Describe the Z method to find regulation of the alternator.

Ans:

Voltage Regulation of 3-phase Alternator by Synchronous Impedance Method:

Model Answers

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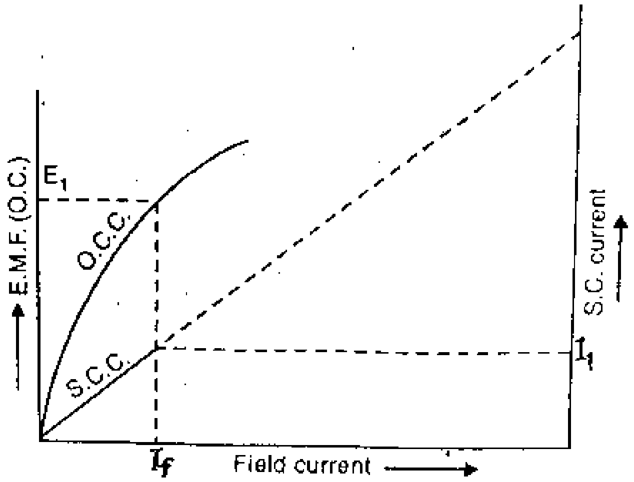
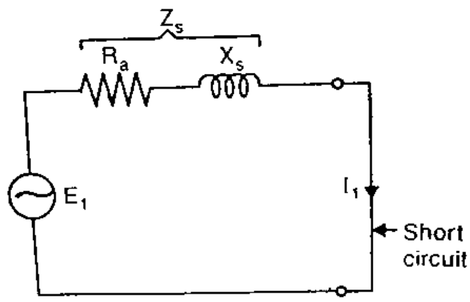
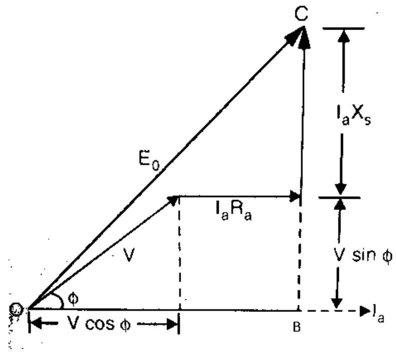
1) Plot the OCC and SSC on the same field current base as shown in following figure:



1 Mark

2) Consider field current I_f. The open circuit voltage corresponding to this field current is E_1.The short circuit armature current corresponding to field current I_f is I_1.On the short circuit P.d.=0 and voltage E_1 is being used to circulate short circuit armature current I_1 against the synchronous impedance Z_s, this is illustrated in following figure:





1 Mark

Now $E_1 = I_1 Z_S$

$$Zs = \frac{E_{1\text{ per phase(open circuit)}}}{I_{1\text{ per phase(short circuit)}}}$$

3) By performing resistance test the effective armature resistance Ra can be calculated.
4) The synchronous reactance can be calculated as

$$X_S = \sqrt{\left(Z_S^2 - {R_a}^2\right)}$$

1 Mark for syn. Impedance parameters

5) Once we know R_a and X_s the phasor diagram can be drawn for any load and any p.f. The phasor diagram for usual case of inductive load is shown above. Here current I_a has been taken as reference phasor.
6) The E0 can be found out as: $E_0 = \sqrt{(OB^2 + BC^2)}$
But, OB = $Vcos\emptyset + I_a\,R_a$ and BC = $Vsin\emptyset + I_a\,X_s$

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

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

1 Mark

3 d) A 4 pole, 50 Hz, 7.46 kW induction motor has a starting torque of 160% of full load torque and maximum torque of 200% of full load torque. Determine:

(i) Full load speed

(ii) Speed at maximum torque

Ans:

Data Given: Synchronous speed $N_S = 120f/P = 1500$ rpm and $T = \frac{k\,s\propto}{(s^2+\propto^2)}$

$T_{max} = \frac{k}{2}$ as s = α at max torque and $T_{st} = \frac{k\propto}{(1+\propto^2)}$ as at start s = 1

Since $T_{max}/T_{fl} = 2$ and $T_{st}/T_{fl} = 1.6$,

$T_{max}/T_{st} = 2/1.6 = 1.25$,

but $T_{max}/T_{st} = (\alpha^2+1)/(2\alpha) = 1.25$, which gives $\alpha^2 - 2.5\alpha + 1 = 0$ from which 1 Mark

α = 2 or 0.25.

α = 2 is not a possible value of slip (for motor) and hence α = 0.25 is acceptable as slip at which maximum torque occurs and hence motor speed at maximum torque is 1 Mark

$N_R = N_S(1 - \alpha) = 1500(1 - 0.25) =$ **1125 rpm**

Now using

$T_{max}/T_{fl} = 2$ we have

$$\frac{T_{fl}}{T_{max}} = \frac{2\,s_{fl}\propto}{({s_{fl}}^2 + \propto^2)} = \frac{1}{2}$$ 1 Mark

From which $({s_{fl}}^2 - 4s_{fl}\alpha + \alpha^2 = 0)$ But α = 0.25

hence the equation becomes $({s_{fl}}^2 - s_{fl} + 0.0625 = 0)$ that gives 1 Mark

$s_{fl} = 0.933$ and 0.067 of which 0.067 is acceptable.

Hence the full load speed = 1500(1- 0.067) = **1399.5 rpm.**

3 e) Draw a phasor diagram of an alternator at unity and lagging power factor.

Ans:

Vector Diagram of a Loaded Alternator:

For the phasor diagrams drawn the legends are as follows:

E = induced emf per phase on load,

E_0 = induced emf per phase on no-load,

V = terminal voltage per phase,

I = load/ armature current per phase,

R_a = armature winding resistance per phase,

X_L = Armature leakage reactance per phase,

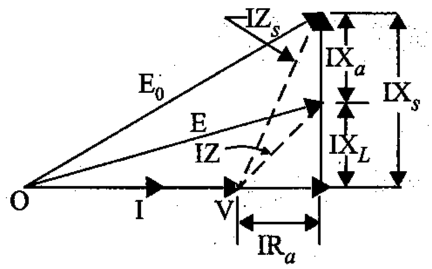
X_a = Armature reaction reactance per phase,

X_s = synchronous reactance per phase,

Z_s = synchronous impedance per phase.

1) **Unity pf Load Phasor Diagram:**

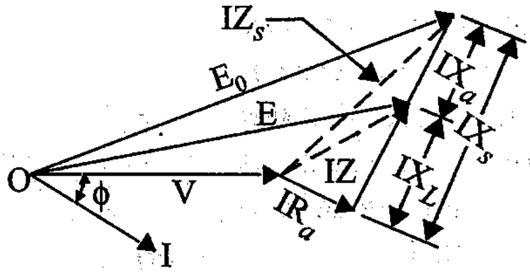
Labeled diagrams
2 Marks each



(*a*)

Partial labeled diagrams 1 Mark each

2) Lagging pf load Phasor Diagram:



(*b*)

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

4 a) i) The useful torque of a 3 phase, 50 Hz, 8 pole induction motor is 190 N.M the rotor frequency is 1.5 Hz. Calculate the rotor Cu loss if mechanical losses are 700 watts.

Ans:

The synchronous speed N_S = 120f/P = (120 x 50)/8 = 750 rpm

Slip 's' = (rotor frequency)/(stator frequency) = 1.5/50 = 0.03

Rotor speed N_R = (1-s) N_S = (1- 0.03)x 750 = 727.5 rpm

Hence rotor speed in radians per sec ω_R = 727.6 x 2 x π/60 = 76.18 rad/s. 1 Mark

Rotor output power or shaft power

= useful torque x ω_R = 190 x 76.18 = 14475 W. 1 Mark

Now if rotor input power = P_i, mechanical power developed in rotor = P_i(1-s) and rotor copper loss = s P_i.

Shaft power = (mechanical power in rotor – mechanical losses)

= P_i(1-s) – mechanical losses, 1 Mark

Substituting in this relation we get,

14475 = P_i(1-0.03) – 700,

P_i = 15644 W.

Copper losses = s P_i = 0.03 x 15644 — 1 Mark
= 469 W

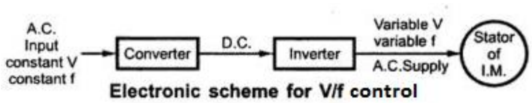
4 a) ii) Explain speed control by changing frequency of 3 phase induction motor. State disadvantage of this method.

Ans:

Speed Control by Changing Frequency of 3 Phase Induction Motor:

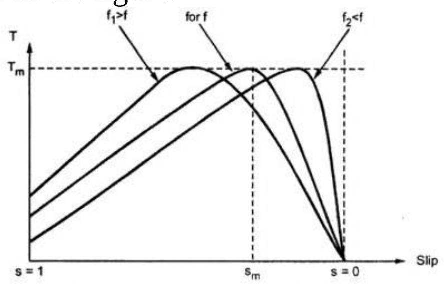
Synchronous speed is given by, $N_S = 120f/P$, hence by varying the frequency we can change the synchronous speed and hence the rotor speed which is given by
$N_R = (1- s)N_S$. — 1 Mark

We need a frequency changer equipment between the supply and the motor input terminals.
Now the emf equation for the motor is
$E = 4.44\ \phi_g\ f\ K_W T_{PH}$ volts.
(It is to be noted that the applied voltage V is approximately equal to the induced emf E).
Hence $V \doteqdot 4.44\ \phi_g\ f\ K_W T_{PH}$ volts
To maintain a constant flux $\phi_g = E/(4.44\ f\ T_{PH})$ the ratio E/f (or approximately V/f) must be maintained constant so that the air gap flux does not change and affect the performance as changing only frequency will change the air gap flux ϕ_g leading to saturation of both (stator and rotor) cores due to which the magnetization current increases. Hence changing frequency will need to be accompanied by proportionally changing the supply voltage V. — 1 Mark



Electronic scheme for V/f control — 1 Mark figure

The torque variation for frequencies above and below normal (f_1 and f_2 respectively) is shown in the figure.



Torque-slip characteristics with variable f and constant (V/f)

The **disadvantages** of this method are;

- The supply obtained cannot be used for other equipment. Hence every motor will need an independent speed control unit.
- The high iron and mechanical losses at higher speeds will lead to overheating and hence need elaborate cooling arrangements.

Any one disadvantage = 1 Mark

4 a) iii) Describe the effect of armature reaction on the performance of alternator.

Ans:

Effect of Armature Reaction on the Performance of Alternator:

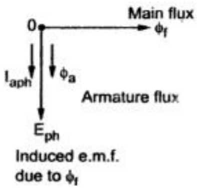
Armature reaction is the effect of the armature current flux on the main flux and hence the induced emf and further the terminal voltage.

The armature reaction affects the alternator terminal voltage by influencing the main flux due to which the terminal voltage changes as the load pf changes. This leads to variation in the alternator voltage regulation even though the armature (load) current is constant. The flux due to the armature current affects the main flux depending on the nature of the load current (that is the pf).

2 Marks

At unity pf loads:

The armature current being in phase with the voltage while the main flux is differing in phase by 90^0 with the voltage. Thus the effect of the armature reaction is to cross magnetize and distort the main flux.



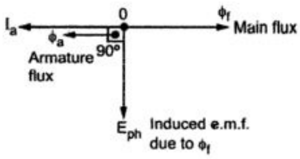
1 Mark each figure = 3 Marks

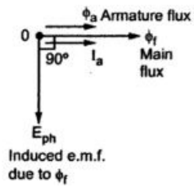
At zero pf loads:

This effect is either opposing or adding directly to the main flux.

Zero pf lag: (demagnetizing effect)

Zero pf lead: (magnetizing effect: increase in magnetism)





For all other PF the effect is the combination of cross and (demagnetization or magnetization)

4 a) iv) Why it is necessary to run alternators in parallel? State condition for parallel operation.

Ans:

Need for parallel operation of alternators:

1) Share the electric load on the power system.
2) Reduce the size of the standby unit (reserve unit).
3) Operate the generator units near or at their maximum efficiencies.
4) Increase the reliability of the electric power system as in case of any problem with one of the units, the remaining units can take up the load.
5) Maintain the cost of generation per unit of energy to the optimum.

Need: ½ Mark each any four = 2 Marks

Conditions for proper synchronization of alternators:

1) The terminal voltage between the corresponding lines of the two alternators must be identical in magnitude and phase.

Conditions: 2 points =1 Mark, All points = 2 Marks

2) The frequencies of the emfs of two alternators must be equal.
3) The phase sequence of the phases RYB of two alternators must be identical.

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

4 b) i) State the difference between single layer and double layer armature winding related to alternator. State two merits of both.

Ans:

Difference Between Single Layer and Double Layer Armature Winding Related to Alternator:

No	Single layer winding	Double layer winding
1	One coil side occupies whole slot	Two coil sides occupy whole slot
2	Number of coils = half the number of slots	Number of coils = number of slots
2	Used for small AC machines only (below few kW or below 4 kW)	Used for medium and large machines (from few kW or 5 kW onwards)
3	Low noise operation as narrow slot opening	Noisier operation due to larger slot opening
4	Higher efficiency due to narrow slot opening	Lower efficiency due to larger slot opening
5	Higher space factor due to absence of inter layer separators	Lower space factor due to presence of inter layer separators
6	Requires large space for end connections	Requires lower space for end connections
7	Short pitching is less advantages	Short pitching is more advantageous as end connections require less copper
8	Emf waveform is not as good as the double layer winding	Emf waveform is better than single layer winding.
9	Easy to repair due to single layer	Difficult to repair due to 2 coil sides inserted in each slot
10	Lower number of harmonics	More harmonics.

1 Mark each point any four = 4 Marks

(other valid points or expressed in other ways to be assessed and awarded Marks)

Merits:

Single layer:

1) Very suitable for small sized machines.
2) Easy to repair.
3) Lower harmonics
4) Low noise.
5) Higher slot space factor.
6) Higher efficiency

Merits: 1 Mark each for two points of each = 2 Marks

Double layer:

1) Highly suitable for medium and large capacity machines.
2) Better emf waveform.
3) Length of end connections less due to short pitch hence saving in

copper.

4) All coils are identical hence fewer difficulties and tools for windings

4 b) ii) A 750 KVA, 2300 V, delta connected alternator has had open and short circuit tests performed and the following data were obtained.
S.C test: Field current = 31.5 Amp line current rated
O.C test: Field current = 31.50 Amp line voltage = 1050 V
The dc resistance across the terminals was measured at 0.38 Ω. Calculate the voltage regulation at 0.8 p.f. lag.

Ans:

DC resistance per phase = 1.5 x 0.38 = 0.57 Ω. (as delta terminal DC resistance is given).

AC resistance (skin effect) R_a = 1.5 x DC resistance = 0.855 Ω. — 1 Mark

V = rated phase voltage = 2300V,
I = rated phase current = 750000/(3 x 2300) = 109 A — 1 Mark
Synchronous impedance Z_S = (OC emf)/(rated phase current)
= 1050/109 = 9.63 Ω,
Armature resistance R = 0.855 Ω,
Synchronous reactance $X_S = \sqrt{(Z_S^2 - R^2)}$ = 9.59 Ω. — 1 Mark

Expression for no load emf or induced emf 'E' for any load current 'I' is

$E = \sqrt{[(V\cos\varnothing + IR)^2 + (V\sin\varnothing \pm IX_S)^2]}$, — 1 Mark

Hence $E = \sqrt{[(2300 \times 0.8 + 109 \times 0.855)^2 + (2300 \times 0.6 + 109 \times 9.59)^2]}$

= 3102 V — 1 Mark

%regulation = [(E-V)/V] x100

= [(3102-2300)/2300] x 100

= 34.87 % — 1 Mark

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

5 a) Describe the slip measurement by comparing rotor frequency and stator frequency.

Ans:

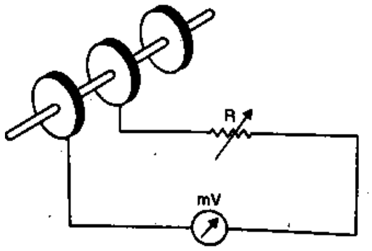
Slip measurement by Compairing Rotor frequency and Stator Frequency:

There are two methods of slip measurement by comparing rotor frequency and stator frequency.

(a) For Slip ring Induction Motor:

The folowing figure shows the arrangement for measuring the rotor frequency of a slip-ring motor. The leads of the millivoltmeter are lightly pressed across the adjacent slip rings as they revolve.The current in the millivoltmeter follows the variations of the rotor current and hence the pointer oscillates about the zero position.The number of oscillations (cycles) completed by the pointer over a given period can be counted.Hence the rotor frequency f_r can be determined.

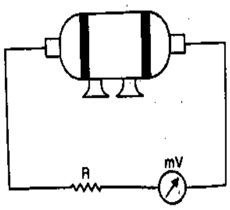
$$\therefore \text{Slip, s} = \frac{Rotor\ current\ frequency}{Stator\ current\ frequency} = \frac{f_r}{f}$$



4 Marks for any one method

(b) For Squirrel cage Induction Motor:

Since a squirrel-cage motor does not have slip-rings, it is not possible to employ the millivoltmeter in the rotor circuit. In this case,it is sometimes possible to obtain an induction by connecting the millivoltmeter across the ends of the motor shaft as shown in following figure. We can use another method to find the slip of the motor. A large flat search coil of many turns is placed centrally against the end plate on the driving end of the motor. It is possible to pick up sufficient voltage by induction from the leakage fluxes to obtain the reading on the millivoltmeter.Althrough a large 50 Hz voltage will also be induced in the search coil,but this is too rapid to affect the millivoltmeter.

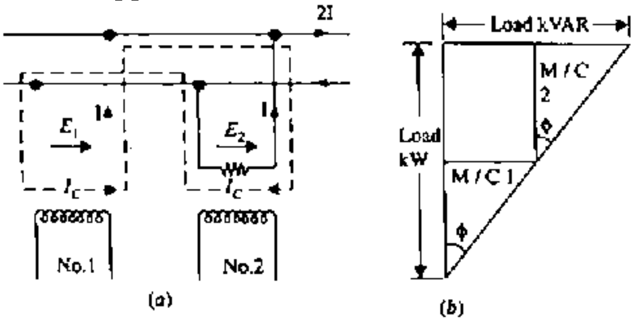


5b) Explain the effect of change of steam supply to one alternator when they are running in parallel.

Ans:

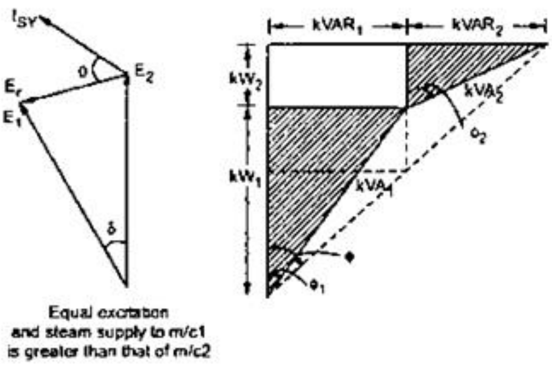
Effect of Change of Steam Supply to One Alternator When they are Running in Parallel:

Consider two alternators running in parallel with each alternator supplying one half of active power (kW) and one half of reactive power (kVAR), the operating power factor thus being equal to the load p.f. thereby giving equal apparent power triangles for the two machines as shown in figure. Here it is assumed that $E_1 = E_2$ and alternator supplies load current I such that total load current is 2I.



2 Marks for diagrams

Now the excitations for the two alternators are kept constant but steam supply i.e. power input to prime mover of alternator 1 is increased. The two alternators are running in synchronism. So machine 1 cannot over run machine 2. The increased power input for alternator 1 makes it possible for carrying more load than 2. This will make rotor for machine 1 advancing its angular position by an angle δ. The resultant e.m.f. E_r is produced in the local circuit which will setup a circulating current I_{SY} which lags E_r by 90^o and almost in phase with E_1. The power per phase for alternator 1 is increased by an amount $E_1 I_{SY}$ whereas it is decreased by same amount for alternator 2. This current I_{SY} has no appreciable reactive component and it will not disturb the reactive power distribution but active power output of alternator 1 will increase and that of 2 will decrease. This is shown in Figure (c) and (d). 2 Marks for explanations



(c) (d)

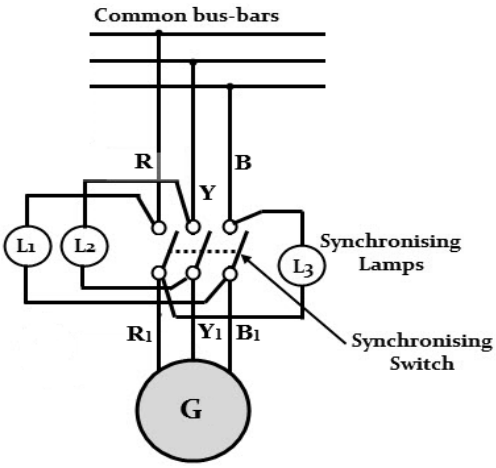
5 c) State the procedure of any one method of synchronization alternator to a bus bar.

Ans:

Procedure of any One Method of Synchronization of Alternator to a Bus bar:

There are two methods of synchronization alternator to a bus bar as:

a) **Lamp Method of Synchronizing an Alternator to Bus bar:**



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

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

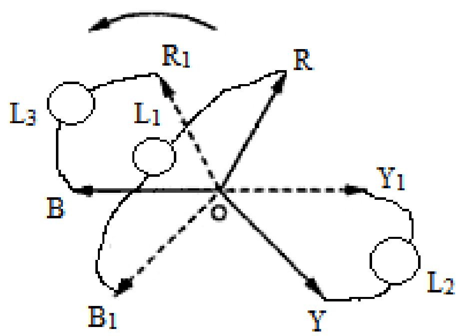
If the above conditions are satisfied, then it is necessary to synchronize one phase of alternator (say phase R) to corresponding phase R of bus bar. The other two phases will then synchronized automatically.

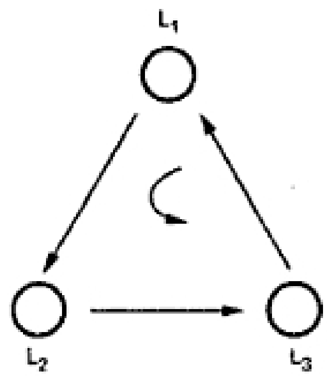
In Lamp method, three lamps are connected across synchronizing triple pole switch between bus-bar and alternator. Depending upon the lamp connections and their indication at the instant of synchronizing, there are three methods:

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

The synchronizing triple pole switch is provided to connect three phase terminals of alternator to corresponding phase terminals of bus bar. 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 bus bar 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





The above diagram shows the voltage phasor group $R_1Y_1B_1$ of alternator and RYB of bus bar. 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.

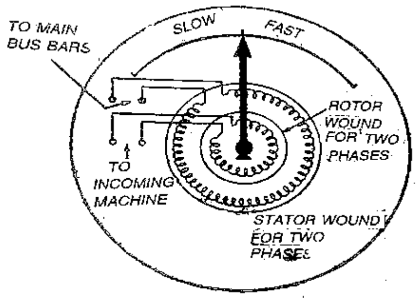
(ii) The voltage across L_2 i.e $V_{Y\text{-}Y1}$ is increasing towards maximum, the lamp L_2 glows with brightness increasing towards maximum.

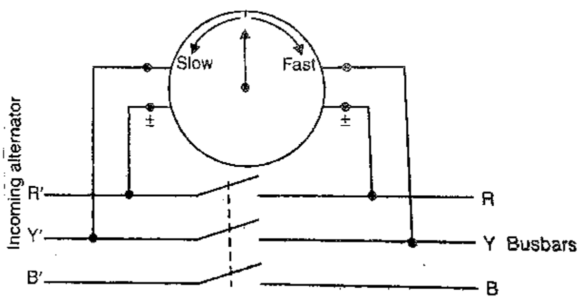
(iii) The voltage across L_3 i.e $V_{B\text{-}R1}$ is decreasing and will become zero when R_1 phasor coincides with B phasor. Thus the lamp L_3 glows with brightness decreasing towards dark.

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 gets connected to the bus bar.

4 Marks for any one method

b) Synchroscope Method of Synchronizing an Alternator to Bus bar:





A synchroscope is an instrument that indicates by means of a revolving pointer the phase difference and frequency difference between the voltages of the incoming alternator and the bus bars. A synchroscope is a small motor having stator and rotor wound for two phases, its stator is supplied from bus bars through P.T and rotor is supplied from the incoming alternator through another P.T. A pointer is attached to the rotor. When incoming alternator is running fast (i.e. frequency of incoming alternator is higher than that of bus bars) the rotor and hence the pointer moves in clockwise direction. When the incoming alternator running slow (i.e. frequency of incoming alternator is lower than that of bus bars) the pointer moves in anticlockwise direction. When the frequency of incoming alternator is equal to that of the bus bars, no torque acts on the rotor and pointer points vertically upward (“12” O’ clock position). It indicates the correct instant for connecting the incoming alternator to the bus bars.

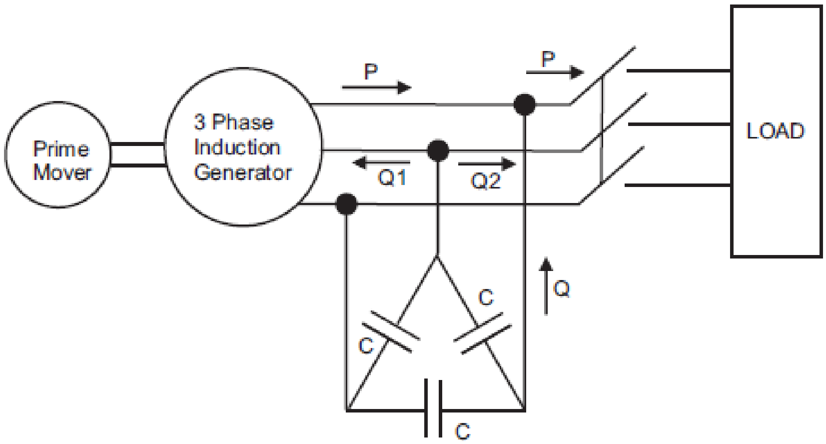
5 d) What is an induction generator? State its principle of operation.

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 diagram

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.

2 Marks for explanation

5e) State the principle of operation of linear induction motor. List its two applications.

Ans:

Principle of Operation of Linear Induction Motor:

When three phase supply is given to the three phase stator winding the flux moves linearly at synchronous speed.The linear moving flux produces induced emf in the rotor (secondary) that has induced currents in such a direction so as to reduce the cause producing them (i.e the relative motion). Thus the rotor follows the stator produced moving flux at a speed slightly lower than the synchronous speed.

2 Marks for principle

Applications of Linear Induction Motor:

1. Automatic sliding doors
2. Metallic belt conveyer
3. Propulsion of a train
4. Shuttle-propelling application
5. High speed ground transportation
6. Curtain pullers
7. Travelling crane motor

2 Marks for any two applications

5f) A phase wound 3 phase induction motor has an induced emf of 135 volts between slip rings of rotor at standstill with rated voltage applied to stator. The rotor winding has a resistance per phase of 0.25 Ω and standstill leakage reactance per phase of 1.6 Ω. Calculate:

(i) Rotor current / phase when running short circuited with 5 % slip.
(ii) The slip and ~~rotar~~ rotor current per phase when the rotor is developing max torque.

Ans:

Given: Standstill line emf of rotor = 135V, $R_2 = 0.25\Omega$, $X_2 = 1.6\Omega$

Standstill emf of rotor / phase = $\frac{135}{\sqrt{3}}$ = 77.9422V

At 5% slip

$X_r = s\,X_2 = 0.05 \times 1.6 = 0.08\Omega$

$R_2 = 0.25\Omega$

$Z_r = \sqrt{(0.25)^2 + (0.08)^2}$

$= \sqrt{0.0625 + 0.0064}$

$= 0.2624\Omega$ — 1 Mark

$E_r = s\,E_2 = 0.05 \times 77.9422$

$= 3.8971V$

Rotor current per phase $I_r = \frac{E_r}{Z_r} = \frac{3.8971}{0.2624} = 14.851A$ — 1 Mark

At maximum torque

$R_2 = sX_2$

$s = \frac{R_2}{X_2} = \frac{0.25}{1.6}$

$= 0.1562$ — 1 Mark

$X_r = 0.1562 \times 1.6 = 0.25$

$R_2 = 0.25$

$Z_r = \sqrt{(0.25)^2 + (0.25)^2}$ $Z_r = \sqrt{0.0625 + 0.0625}$ $= 0.3535\Omega$

$E_r = s\,E_2 = 0.1562 \times 77.9422$

$= 12.1745V$

$I_r = \frac{E_r}{Z_r} = \frac{12.1745}{0.3535}$ — 1 Mark

Rotor current per phase = 34.4398A

6 Attempt any FOUR of the following: 16

6 a) Compare resistance split phase and capacitor start 1 phase induction motor (any four points)

Ans:

Comparison between Resistance Split Phase and Capacitor Start 1 Phase Induction Motor:

Sr. No.	Resistance Split Phase Single Phase Induction Motor	Capacitor start Single Phase Induction Motor
1	Resistor is connected in series with the starting winding.	Capacitor is connected in series with the starting winding.
2	The angle between starting current and main current is in the range of 20^0 to 30^0.	The angle between starting current and main current is in the range of 80^0 to 90^0.

4 Marks for any four points

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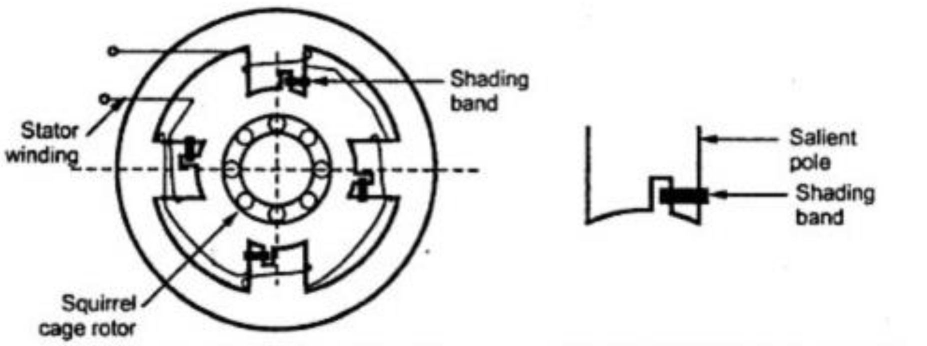
3	The starting torque is 1.5 to 2 times that of full load torque.	The starting torque is 3.5 to 4 times that of full load torque.
4	The speed drops from no load to full load is in the range of 2 to 5%.	The speed of the motor varies 10% to 100% from no load to full load.
5	It is a constant speed motor.	It is a variable speed motor.
6	Generally the wattage rating of such motors is in the range of 40 W to 250 W.	Generally the wattage rating of such motors is in the range of 125 W to 2250 W.
7	General applications are Fans, Blowers, Small machine tools, Duplicating machines etc.	General applications are Compressors, Large fans, Elevators, Conveyors etc.

6b) Describe the working of shaded pole induction motor.

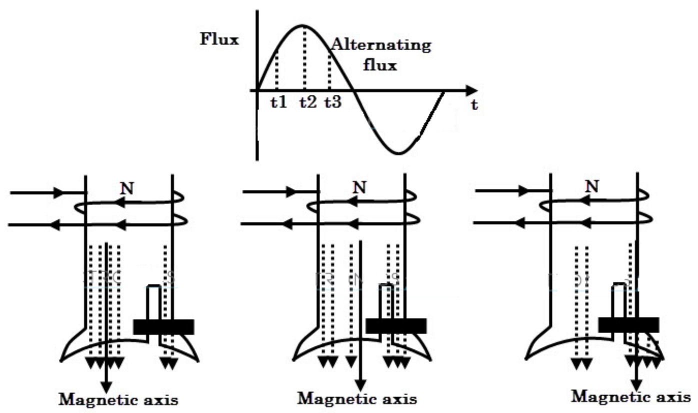
Ans:

Working of Shaded Pole Induction Motor :



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

2 Marks for diagram



(a) t= t1 (b) t= t2 (c) t= t3

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. — 2 Marks for description
- 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 center 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 c) Derive the emf equation of an alternator.

Ans:

EMF Equation of an Alternator:

Let P = No. of poles

$\emptyset$ = Flux per pole in Wb

N= Speed in rpm

Z= Number of stator conductors per phase

$\therefore$ Turns per phase $T = \frac{Z}{2}$

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

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

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

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

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

In one revolution, conductor cuts the flux produced by all the 'P' poles and emf completes (P/2) cycles. If rotor is rotating at N rpm, the revolutions completed in one second are (N/60). Therefore, the cycles completed by emf in one second are (P/2)(N/60) i.e (PN)/120. Thus the frequency of the induced emf is, — 4 Marks for stepwise derivation

$$f = (\frac{P.N}{120}) \quad \therefore N = (\frac{120f}{P})$$

Substituting this value of N in above equation,

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

Since each turn has two conductors,

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

The emf induced in a phase winding is given by,

E_{avg} / phase = (E_{avg} / turn) × Turns/phase

= $4\emptyset fT$ volt

The RMS value of emf per phase is given by,

E_{ph}= Form Factor × (E_{avg} / phase) or E_{ph}=1.11× $4f\emptyset T$ volt

$$\mathbf{E_{ph} = 4.44 f\emptyset T \text{ volt}}$$

This is for full pitched concentrated winding. If winding is distributed & short pitched then

$$\mathbf{E_{ph} = 4.44\, K_p K_d f\emptyset T \quad \text{volt}}$$

where, K_p = Pitch factor

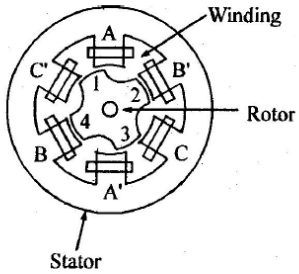
K_d = Distribution factor

6d) Describe the construction of stepper motor (variable reluctance type)

Ans:

Variable Reluctance Stepper Motor (VRSM):

Construction:



2 Marks for diagram

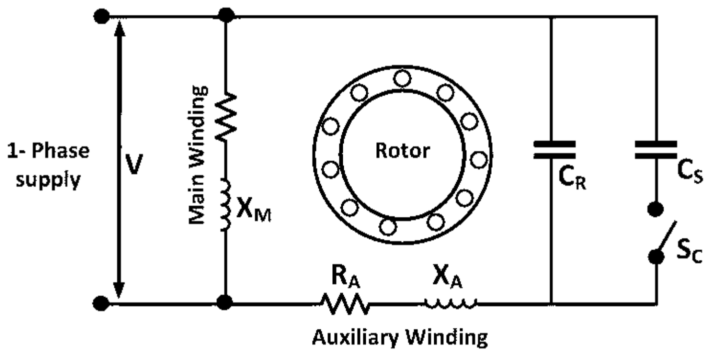
Figure shows schematic representation of variable reluctance stepper motor, the stator is made of laminated silicon steel and generally has six salient poles or teeth, the winding is wound 120 electrical degree electrically apart from one another. Two coils wound around diametrically opposite poles and connected in series, thus three circuits are formed which are energized from a d. c. source in a specified sequence through an electronic switching device. The rotor is also made of laminated silicon steel which has four salient poles without any exciting winding.

2 Marks for construction

6e) Explain the working of capacitor start capacitor run induction motor with the help of circuit diagram.

Ans:

Circuit Diagram:



Capacitor-start, Capacitor-run Induction Motor

2 Marks for Circuit diagram

Working:

The figure shows the circuit diagram of the capacitor-start, capacitor-run induction motor. 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. Another capacitor C_R is known as running capacitor. It remains in the circuit continuously during starting and running of the motor. 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.

2 Marks for working

When single phase supply is given to the motor, two currents having phase displacement of about 90° flow through two windings. 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.