Summer – 2018 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 why 3 phase induction motor can never run on 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

1 a) (ii) Give the comparison between squirrel cage induction motor and slip ring induction motor on any four parameters.

Ans:

Comparison Between Squirrel Cage Induction Motor and Slip Ring Induction Motor:

Sr. No.	Squirrel Cage Induction Motor	Slip Ring Induction Motor
1	Rotor is in the form of short circuited bars	Rotor is in the form of 3-ph winding
2	No slip-ring and brushes required	3 slip-rings with brushes are present
3	External resistance cannot be inserted in rotor circuit.	External resistance can be inserted in rotor circuit.
4	Small or moderate starting torque is obtained.	High starting torque can be obtained.
5	Starting torque is fixed.	Starting torque can be adjusted by inserting external resistance in rotor circuit.
6	Simple and rugged construction	Comparatively complicated construction
7	Power factor is poor in the range of 0.4 to 0.6 lagging	Power factor is better in the range of 0.8 to 0.9 lagging
8	Size is compact for same HP	Relatively size is larger
9	Speed control by stator control method only	Speed control by stator and rotor control method.
10	High efficiency	Low efficiency
11	Less cost	More cost
12	Less maintenance	Frequent maintenance due to slip-rings and brushes
13	High starting current i.e. about 5 to 6 times full load current.	Starting current can be restricted to 1.2 to 2 times full load current.

Any four points = 4 Marks

14	Used as a constant speed drive e.g. Lathe machine	Used where high starting torque is required.

1 a) (iii) State the necessity of starter in 3 phase induction motor. Draw a neat diagram of auto transformer starter.

Ans:

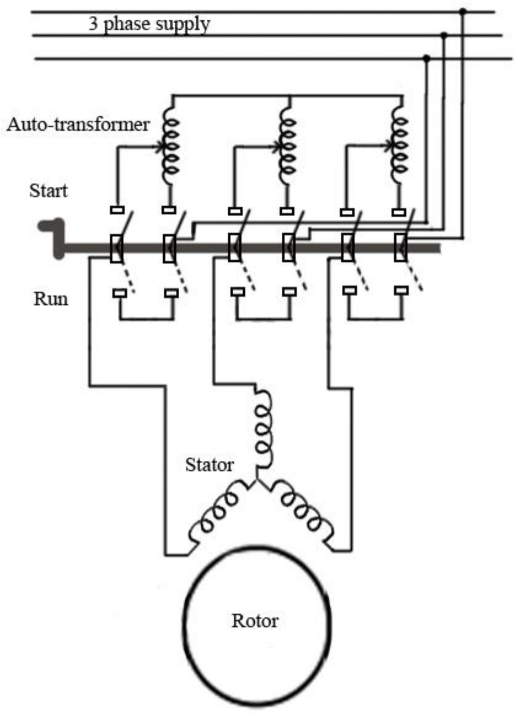
Necessity of Starter for 3 Phase Induction Motor:

Three-phase Induction motor is similar in action to a poly-phase transformer with short-circuited secondary. Therefore when a rated voltage is applied to the stationary motor, it will draw a large current which is about five to seven times the full load current and will develop about 1.5 to 2 times full load torque. 2 Marks for explanation

This heavy inrush current of short duration may not cause harm to the motor since construction of the induction motor is rugged. Also time duration of this heavy current is not that long as to cause excessive temperature rise which may damage the insulation of windings. But, this heavy inrush current will cause a large voltage drop in the line to which the motor is connected. So other equipment connected to the line may receive a reduced voltage that affects their working. In order to avoid these effects starter is required.

Autotransformer Starter:

2 Marks for diagram



1 a) (iv) Give any four advantages of having a stationary armature in case of alternator.

Ans:

Advantages of Stationary Armature in Case of 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. 1 Mark for each of any four advantages = 4 Marks
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 b) Attempt any <u>ONE</u> of the following: 6

1 b) (i) Explain speed control of 3 phase induction motor by the following methods:
i) Pole changing method
ii) Stator voltage control method
iii) Rotor resistance control method.

Ans:

Speed Control of 3 Phase Induction Motor:

i)Pole Changing Method:

Synchronous speed is given by, $N_s = \frac{120f}{P}$ rpm.

From the above equation of synchronous speed, it can be seen that synchronous speed (and hence, running speed) can be changed by changing the number of stator poles. This method is generally used for squirrel cage induction motors as squirrel cage rotor adopts itself for any number of stator poles. Change in stator poles is achieved by two or more independent stator windings wound for different number of poles in same slots.

ii)Stator Voltage Control Method:

As in three phase induction motor, the torque produced, $T \propto sE_2^2$ where E_2 is rotor induced emf and $E_2 \propto V$. Thus, $T \propto sV^2$, which means, if supplied voltage is decreased, the developed torque decreases. Hence, for providing the same load torque, the slip increases with decrease in voltage and consequently the speed decreases and vice versa. Ultimately speed depends on the supply voltage. 2 Marks for each method = 6 Marks

iii)Rotor Resistance Control Method:

This method is only applicable to slip ring motors, as addition of external resistance in the rotor of squirrel cage motors is not possible. The speed of the motor can be decreased by adding external resistance to the rotor. Under normal running condition $T \propto s/R_2$, where R_2 is rotor resistance per phase. Therefore, for same load torque, slip can be increased (i.e. motor speed can be decreased) by increasing the rotor resistance and vice versa.

1 b) (ii) With the help of neat labeled diagram, explain the construction and working of variable reluctance stepper motor (VRSM). Also give any two applications of this motor.

Ans:

Variable Reluctance Stepper Motor (VRSM):

Construction:

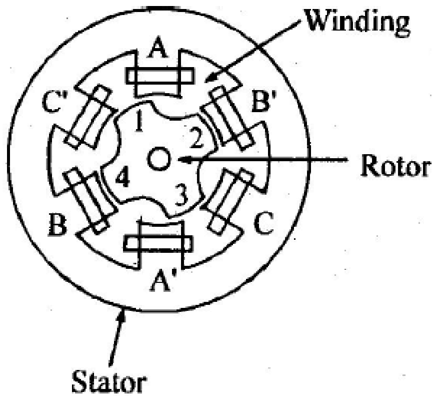
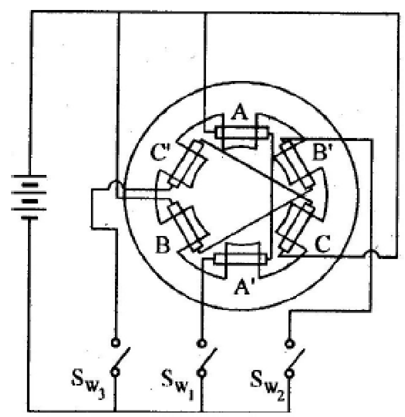


Figure shows schematic representation of variable reluctance stepper motor, the stator is made of laminated silicon steel and generally has six salient poles or teeth, the winding is wound 120 electrical degree electrically apart from one another. Two coils wound around diametrically opposite poles and 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

Working:



The switching is done sequentially to obtain rotation.

When poles A & A’ are excited by closing switch S_{W1}, the rotor teeth nearest to these align to have minimum reluctance between the A-A' stator poles. (poles A and A' are opposite in nature).

Next if poles B & B' are excited by opening S_{W1} and closing switch S_{W2} then the rotor moves anticlockwise by 30° to align with these poles as shown in figure. — 2 Marks for working

Thus if we provide 12 such voltage pulses sequentially by proper opening and closing of switches we get one full rotation in 12 equal steps.

If the sequence of application of these pulses is A / A'- C / C'- B / B' then we obtain clockwise rotation.

By changing the no of rotor teeth proportionally, we can have smaller angular steps.

Applications:

1) Wall Clocks
2) C.D. Drives
3) Robots — 2 Marks for any two applications
4) Printers
5) Scanners
6) C.N.C. Machines
7) Automotive gauges and machine tool
8) Medical scanners
9) Respirators and fluid pumps
10) Digital dental photograph

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

2 a) Draw the necessary flow diagram showing power stages of 3-ϕ Induction Motor.

Ans:

Power Flow Diagram of 3- Phase Induction Motor:

Motor Input in stator **P_1**	Stator copper loss + Iron loss (constant)	Stator Output = Rotor input **P_2**	Rotor Copper Loss	Mech. Power Developed in the rotor **P_M**	Friction & Windage Losses	Net Motor Output **P_{OUT}**

4 Marks

2 b) Draw and explain torque slip characteristics of 3-ϕ Induction Motor.

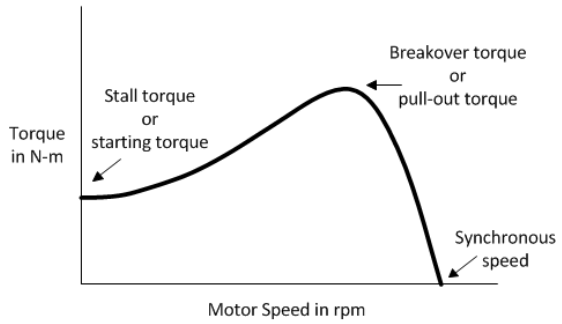
Ans:

Torque-Speed Characteristics of 3-Phase Induction Motor:

- 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.
- For lower values of load, torque is proportional to slip, and characteristic is linear in nature. — 2 Marks for explanation
- 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.



Speed-Torque Curve for a Three-Phase Induction Motor

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

2 c) Derive 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, $d\emptyset = P.\emptyset$ ½ Mark

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 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 Mark

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

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 Mark

The emf induced in a phase winding is given by,

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

= $4\phi fT$ volt ½ Mark

The RMS value of emf per phase is given by,

E_{ph}= Form Factor × (E_{avg}/phase)

$E_{ph}=1.11\times 4f\phi T$ volt

$\mathbf{E_{ph} = 4.44 f\phi T}$ **volt** ½ Mark

This is for full pitched concentrated winding.

If winding is distributed & short pitched then

$\mathbf{E_{ph} = 4.44\, K_p K_d f\phi T}$ **volt** ½ Mark

where, K_p = Pitch factor

K_d = Distribution factor

2 d) State any 3 advantages and any one disadvantage of short pitched coil in case of alternator.

Ans:

Advantages of Short Pitched Coil in Alternator:

1) Short Pitching reduces the amount of copper needed for end Connection when compared with Full Pitched Coil. 3 Marks for any three advantages
2) They improve the waveform of generated EMF i.e. generated EMF can be made approximately to sine wave more easily and the distorting harmonics can be reduced.
3) Due to the elimination of high frequency harmonics, eddy current and hysteresis losses are reduced, thereby increasing the efficiency.
4) The power quality of generated emf is of improved nature. 1 Mark for one disadvantage

Disadvantages of Short Pitched Coil:

1. The disadvantages of using short-pitch winding is that, the total voltage around the coils is somewhat reduced. = 4 Marks
2. Total requirement of copper is more.

2 e) In AC series motor, explain how the construction is modified in order to.

i) Reduce eddy current loss
ii) Improve power factor.

Ans:

i) Reduction of Eddy Current Loss:

In A. C. series motor the eddy current loss is reduced by laminating the entire magnetic circuit & field structure. 2 Marks

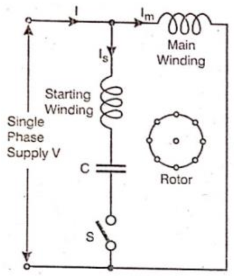
ii) Improvement of Power Factor:

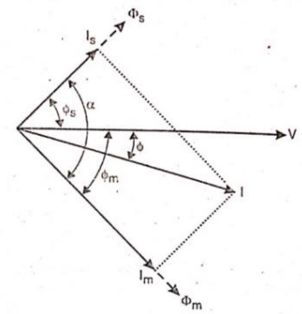
In A. C. series motor the power factor is improved by reducing the reactance of field winding, if possible low frequency supply is used; field winding is wound with fewer numbers of turns, decreasing the air gap. 2 Marks

2 f) With the help of necessary phasor diagram, explain how starting torque is produced in capacitor start induction run 1 ϕ induction motor.

Ans:

Capacitor Start Induction Run Motor:





Circuit diagram **Phasor diagram**

2 Marks for phasor diagram

This motor consists two windings in stator, first is main winding which is inductive and hence current drawn by this winding I_m is lagging behind the applied voltage V by an angle ϕ_m. Second is the starting winding connected in series with a capacitor and centrifugal switch which is in ON position at the time of starting, so draws leading current I_S by an angle ϕ_s with respect to applied voltage as shown in phasor diagram. The main winding and starting winding are connected in parallel with each other. Value of capacitor is so chosen that I_S should lead I_m by almost 90°. Consequently, the starting torque, $T \alpha k.I_S.I_m.\sin\alpha$ obtained is very much sufficient to accelerate the motor and motor starts rotating. After acquiring 75% of rated speed the starting winding is cut out of circuit with opening of centrifugal switch. Then motor continues to run with only main winding in the circuit & its pulsating magnetic field. 2 Marks for explanation

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

3 a) Derive the condition for maximum torque under running conditions for a three phase induction motor.

Ans:

Condition for Maximum Torque Under Running Conditions:

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

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,

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

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

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

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

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

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

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

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

$$R_2 = sX_2$$ 1 Mark

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.

OR Equivalent Derivation

3 b) A 4 pole, 50 Hz, 7.46 kW motor has at rated voltage and frequency, a starting torque of 160 % and maximum torque 200% of full load. Determine:
i) Full load speed
ii) Speed at maximum torque.

Ans:

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

Given $T_{max}/T_{fl} = 2$ 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 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. 1 Mark

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

s_{fl} = 0.933 and 0.067 of which 0.067 is acceptable. 1 Mark

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

3 c) From the following test results, determine the voltage regulation of a 2000 V, single phase alternator delivering a current of 100 Amp. at
i) Unity pf
ii) 0.8 leading pf.

Test results:

1) Full load current of 100 A is produced on short circuit by field excitation of 2.5A.
2) An emf of 500V is produced on open circuit by same excitation.

Armature resistance is 0.8 ohm.

Ans:

V = rated voltage = 2000V,

Synchronous impedance Z_S = 500/100 = 5 Ω, Armature resistance R = 0.8 Ω,

Synchronous reactance $X_S = \sqrt{(Z_S^2 - R^2)} = 4.94\ \Omega$. 1 Mark

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

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

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

i) At UPF:
$E = \sqrt{[(2000 \times 1 + 100 \times 0.8)^2 + (2000 \times 0 + 100 \times 4.94)^2]}$ 1 Mark
= 2137.85 V
% regulation = [(2137.85 – 2000)/2000] x 100 = 0.0689 OR 6.89%
ii) At 0.8 pf lead:
cosØ= 0.8 and sinØ=0.6 and –ve sign to be taken in expression.
$E = \sqrt{[(2000 \times 0.8 + 100 \times 0.8)^2 + (2000 \times 0.6 - 100 \times 4.94)^2]}$ 1 Mark
= 1822 V.
% regulation = [(1822 – 2000)/2000] x 100 = – 8.9%

3 d) The stator of a three phase, 16 pole alternator has 144 slots and there are 4 conductors per slot connected in two layers and the conductors of each phase are connected in series. If the speed of the alternator is 375 rpm, calculate the emf induced per phase. Resultant flux in the air gap is 5×10^{-2}wb per pole sinusoidally distributed. Assume the coil span as 150° electrical.

Ans:
Total number of conductors Z = 144 x 4 = 576.
Conductors per phase Z_{ph} = Z/3 = 192.
Flux per pole = Ø = 5×10^{-2} wb.
Frequency of generated emf = NP/120 = 375 x 16 / 120 = 50 Hz. 1 Mark

Distribution factor K_d:
m = Number of slots per pole per phase = 144/(16 x 3) = 3.
α = angle between adjacent slots = 180 x 16/144 = 20°.
distribution factor = $K_d = \frac{\sin(m\,\alpha/2)}{m\sin(\alpha/2)} = \frac{\sin(3 \times 20/2)}{3\sin(20/2)}$ = 0.9598. ½ Mark
Pitch factor K_p:
Angle of short pitching β = 180 – 150 = 30°. ½ Mark
K_p = cos (β/2) = cos 15 = 0.9659.
Winding factor $K_w = K_d \times K_p$ = 0.9598 x 0.9659 = 0.927 1 Mark
Induced emf per phase
$E_{ph} = 2.22 \times K_w \times Z_{ph} \times f \times Ø$ (V)
= $2.22 \times 0.927 \times 192 \times 50 \times 5 \times 10^{-2}$ 1 Mark
= 987.811 V.

3 e) Discuss the construction and working principle of linear induction motor.

Ans:
Linear Induction Motor:
Construction:

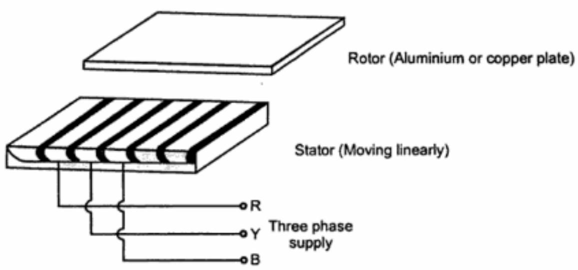


Figure or other equivalent one = 2 Marks

The stator and rotor are flat. The stator winding is placed on the linear stator slots as shown and the three phase supply is given to it. The rotor is in the form of a plate of aluminium or copper. Normally the stator is the moving member while the rotor is the stationary member.

Working Principle:

The working principle is same as the normal rotary induction motor. The flux produced by the combined effect of the three phase fluxes due to the three phase supply given to the three phase stator winding moves linearly at synchronous speed given by 1 Mark

$v_s = 2\,W f$ *(metres/second)*

where v_s *is the speed in metres/sec,*

W = pole pitch in metres and

f = frequency of the supply in hertz.

The linear moving flux produces induced emf in the rotor (secondary) that has induced currents that have such a direction so as to reduce the cause of them (i.e the relative motion). Thus the rotor follows the stator produced moving flux at a speed slightly lower than the synchronous speed. 1 Mark

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

4 a) i) The power input to a 500V, 50 Hz, 6 pole, 3 phase induction motor running at 975 rpm is 40kW. The stator losses are 1 kW and friction and windage losses are 2kW, calculate:

1) Slip
2) Rotor copper loss
3) Shaft power
4) Efficiency

Ans:

Synchronous speed $N_S = 120f/P = 1000$ RPM.

1) Slip 's' = $(N_S – N_R)/N_S = (1000-975)/1000 = 0.025$ or 2.5%. 1 Mark

2) Rotor input power P_i = Motor input power – stator losses
= 40 kW – 1 kW = 39 kW.

Rotor copper losses = slip x rotor input power = $s.P_i$
= 0.025 x 39 = 0.975 kW = 975 W. 1 Mark

3) Shaft power = (mechanical power in rotor – friction & windage losses)
= $P_i(1-s)$ – friction and windage losses
= 39(1 – 0.025) – 2 = 36.025 kW 1 Mark

4) %Efficiency η = [(output power)/(input power)] x100

The output power is same as the shaft power.

%Efficiency η = (36.025/40) x 100 = 90.06 % 1 Mark

4 a) ii) Explain how each of the following can reduce starting current of a three phase induction motor:

1) By star-delta starter

2) By inserting resistance in rotor winding.

Ans:

The general expression for magnitude of current induced in the rotor is

$$I_2 = sE_2/\sqrt{(R_2^2 + s^2 X_2^2)}$$

which is very high at start as the slip s = 1 resulting in

$I_2 = E_2/\sqrt{(R_2^2 + X_2^2)}$ (about 4 to 7 times the rated current). This high current leads to high voltage drops in supply lines that lead to severe fall in line voltages affecting other machines on the lines.

1) **Star – Delta Starter**:

The rotor induced emf E_2 is proportional to the flux created in the air gap by the applied voltage to the stator. In the star delta starter this applied voltage to the stator phase winding of the normally delta connected motor (stator) is kept at ($1/\sqrt{3}$) times the normal value by connecting the stator windings in star across the supply lines at start that leads to proportional reduction in the stator current drawn (as the rotor induced emf also gets reduced by the same proportion). Once the motor (rotor) picks up speed (the slip falls appreciably) the rotor current drops to values depending on the load and the stator windings are then connected in delta to run normally. 2 Marks

2) By Inserting Resistance in Rotor Winding:

The inserted resistance is in series with the rotor resistance thus increasing the total rotor circuit resistance leading to the control of the current drawn by the motor [$I_2 = E_2/\sqrt{(r_2 + R_{ex})^2 + X_2^2)}$] from the supply where R_{ex} is the inserted resistance in rotor circuit through the slip rings of the wound rotor motor. 2 Mark

4 a) iii) Discuss the different factor affecting the terminal voltage of an alternator.

Ans:

Factors Affecting the Terminal Voltage of an Alternator:

Terminal voltage of an alternator per phase is given by:

$\mathbf{V_{ph}} = \mathbf{E_{ph}} - \mathbf{I_a}$ ($\mathbf{R_a}$ + j $\mathbf{X_s}$) (where all quantities are per phase) 1 Mark

Factors on which it depends:

1) Load current (armature current) and its power factor which depends on the load nature.
2) The armature resistance R_a whose higher values lead to higher drops and lower terminal voltage.
3) The synchronous reactance X_s (which covers the effect of leakage reactance and armature reaction) which is kept higher for alternators. The terminal voltage falls as the alternators synchronous reactance is increased.
4) The induced emf E_{ph} which is function of the excitation of the alternator. Increase in the excitation current leads to increased induced emf and hence higher terminal voltage and lower terminal voltages for reduced excitations.

1 Mark each of any three = 3 Marks

4 a) iv) State the need for parallel operation of Alternators. Also give the three essential conditions which must be satisfied for proper synchronization of alternators.

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

1 Mark each point any two = 2 Marks

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.

Essential Conditions for Proper Synchronization of Alternators:
1) The terminal voltage between the corresponding lines of the alternators must be identical in magnitude and phase.
2) The frequencies of the two alternators must be equal.
3) The phase sequence of the two alternators must be same.

1 point = ½ Mark
2 points = 1 Mark
3 points = 2 Marks

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

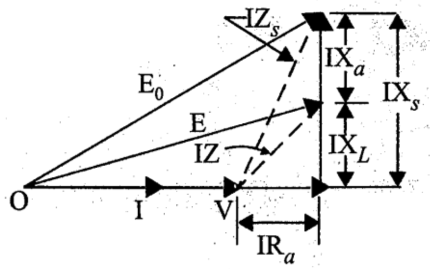
4 b) i) Draw the vector diagram of a loaded alternator when load is:
1) unity pf
2) 0.8 pf lagging
3) 0.8 pf leading

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.

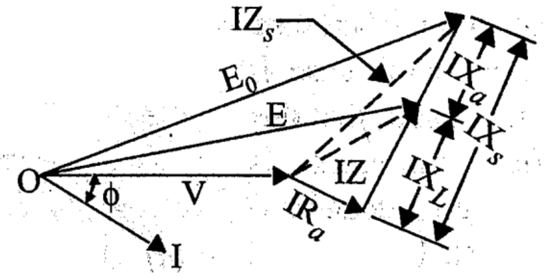
1) Unity pf Load Phasor Diagram:

Labeled diagrams 2 Marks each and partial ones 1 Mark each = maximum 6 Marks



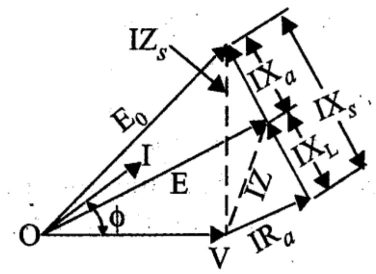
(a)

2) 0.8 pf Lag Phasor Diagram: $Ø = \cos^{-1}(0.8) = 36.86^o$:



(b)

3) 0.8 pf Lead Phasor Diagram: Ø = $\cos^{-1}(0.8) = 36.86^o$:



(c)

4 b) ii) With the help of necessary graphs and vector diagram, describe in details the ampere turn method of determining regulation of a 3 phase alternator.

Ans:

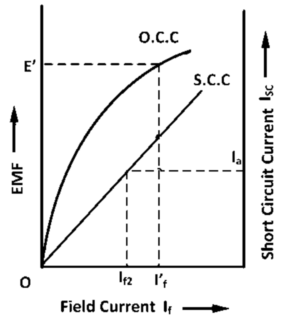
Ampere Turn Method (also called as MMF method):

To calculate the voltage regulation the following information is required.

R_a = the resistance of the stator winding per phase.

OCC: Open circuit characteristics at synchronous speed.

SCC: Short circuit characteristic.



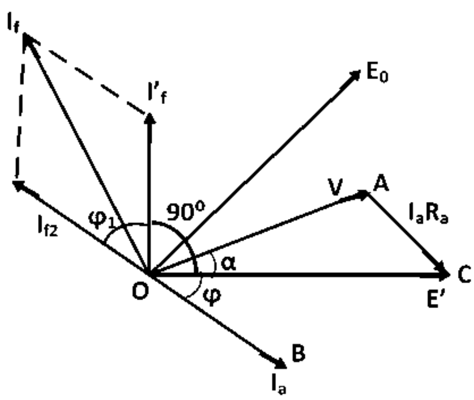
1 Mark

For the phasor diagram:

The armature terminal voltage per phase (V) is taken as the reference phasor along OA and hence all angles are with respect to the line OA.

The armature current phasor I_a is drawn lagging the phasor voltage for lagging power factor angle ϕ (= $\alpha+\varphi$) for which the regulation is to be calculated. 1 Mark

The armature resistance drop phasor I_aR_a is drawn in phase with I_a along the line AC. Join O and C. OC represents the emf E'.



1 Mark

Considering the Open Current Characteristics shown above the field current

I'_f corresponding to the voltage E' is read.
Draw the field current I'_f leading the voltage E' by 90 degrees. It is assumed that on short circuit all the excitation is opposed by the MMF of armature reaction. Thus,

$\mathbf{I'_f} = I'_f\angle(90-\alpha)^o$

1 Mark

From the Short Circuit Current characteristics (SSC) shown above, determine the field current I_{f2} required to circulate the rated current on short circuit. This is the field current required to overcome the synchronous reactance drop I_aX_s.
Draw the field current I_{f2} in phase in opposition to the current armature current I_a. Thus,

$\mathbf{I_{f2}} = I_{f2}\angle(180-\varphi)^o$

1 Mark

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

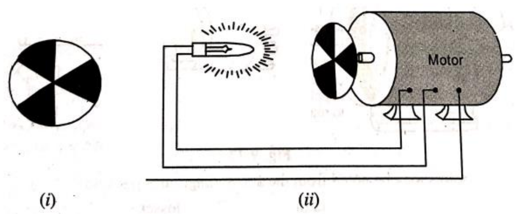
1 Mark

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

5 a) Discuss the stroboscopic method of measurement of slip in 3-ϕ induction motor.

Ans:

Stroboscopic Method of Measurement of Slip in 3 Phase Induction Motor:



1 Mark for Diagram

In this method a circular disc painted with alternately black and white segments is rigidly attached to the shaft of the motor. The no of segments (both black and white)is equal to the poles of the motor. For a six pole motor there will be six segments three black and three white as shown in figure. A neon glow lamp supplied from the motor line is arranged to illuminate the stroboscopic disc, such lamp glows twice in a circle. If the disc were ti rotate at synchronous speed it would appear to be stationery. Since the speed of rotor and hence the disc is less than synchronous speed, the disc appeared to rotate slowly backward in a direction opposite to the rotation of the motor. Counting the no of apparent revolutions of the disc in one minute gives the slip speed (Ns-N) in rpm. Hence slip s of motor can be found from the relation

3 Marks for explanation

$$s = \frac{\text{Ns}-\text{N}}{\text{Ns}}$$

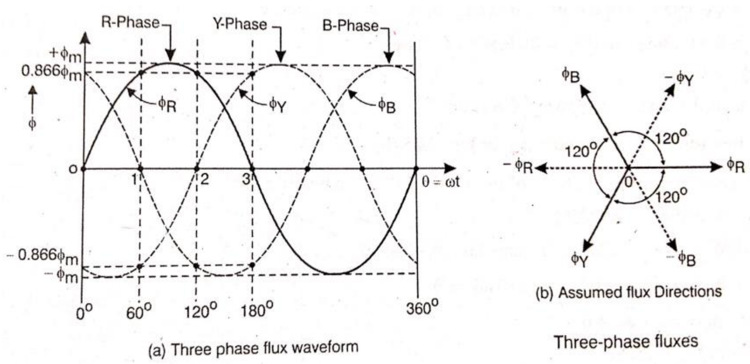
where, (Ns-N) = apparent revolutions of the disc in one minute
Ns = Synchronous speed.

5 b) Describe the production of rotating magnetic field in case of 3-ϕ induction motor with aid of vector diagram.

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

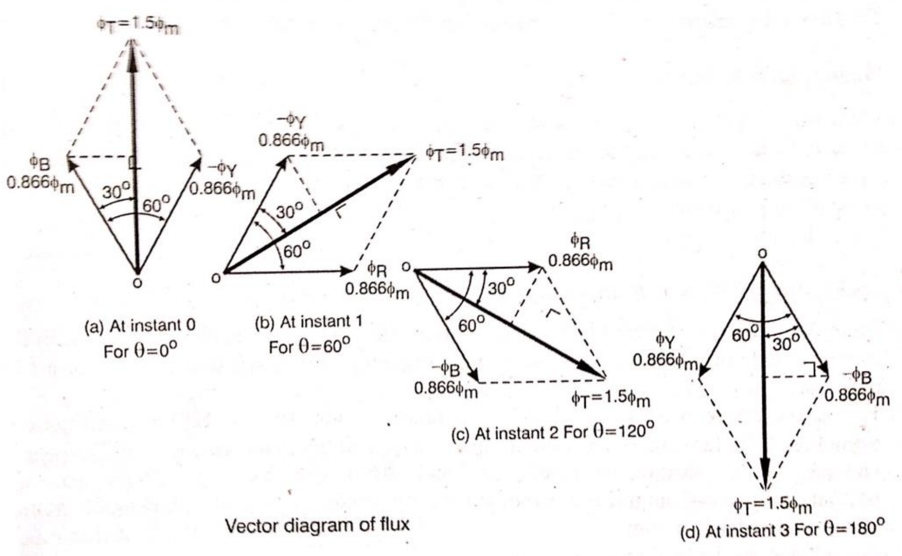


1 Mark for flux waveform

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.

1Mark for explanation

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

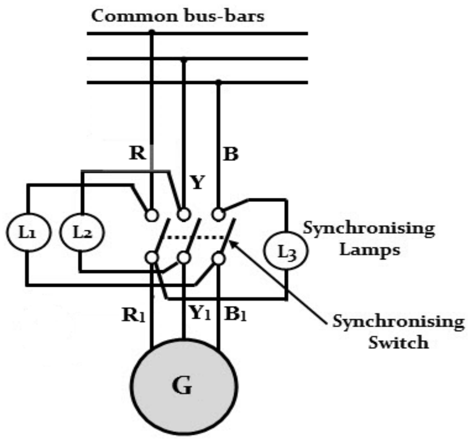
2 Marks for flux vector diagrams

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.

5 c) Explain the lamp method of synchronizing alternator to the 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.

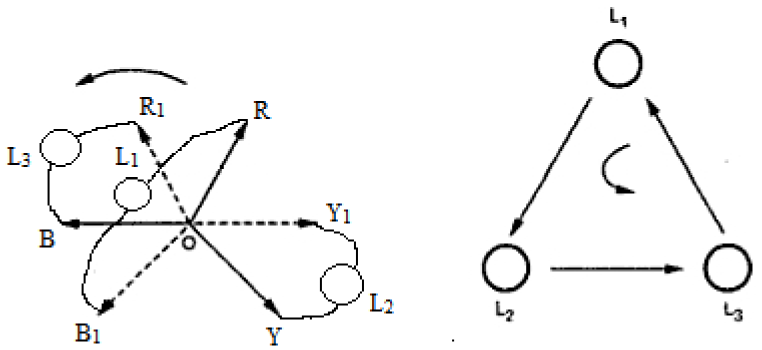
In Lamp method, three lamps are connected across synchronizing triple pole switch between bus-bar and alternator. Depending upon the lamp connections and their indication at the instant of synchronizing, there are three methods:

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

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

2 Marks for explanation of any one method

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 bus bar.

5 d) Discuss how will the change in excitation effect load sharing between two alternators connected in parallel.

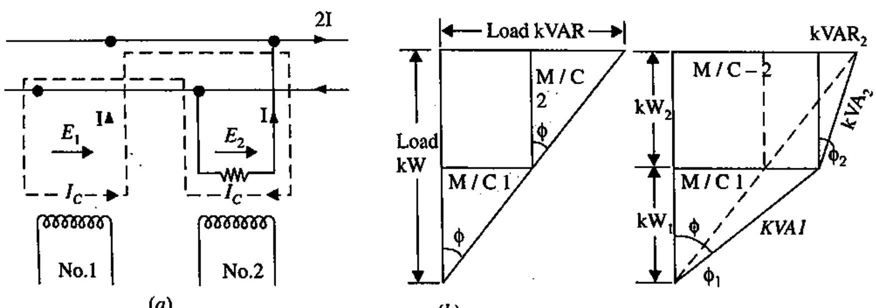
Ans:

Load Sharing Between Two Alternators Connected in Parallel Because of Change in Excitation:

When two alternators are working in parallel, any change in excitation merely changes its kVA output, but not its kW output.

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 a load current of I such that total load current is 2I.

Now let excitation of alternator No.1 be increased, so that E_1 becomes greater than E_2. The difference between these two emfs sets up a circulating current $I_C = (E_1 – E_2) / 2Z_S$ which is confined to the local path through the armature and round the bus-bars. This current is superimposed on the original current distribution. As seen I_C vectorially added to the load current of alternator No.1 and subtracted from that of No.2.The two machines now deliver load currents I_1 and I_2 at respective power factors of $\cos\phi_1$ and $\cos\phi_2$. Then changes in load currents lead to changes in power factors, such that $\cos\phi_1$ is reduced, whereas $\cos\phi_2$ is increased. However, effect on the kW loading of the two alternators is negligible but $kVAR_1$ supplied by alternator No.1 is increased, whereas $kVAR_2$ supplied by alternator No.2 is correspondingly decreased, as shown by the kVA triangles. 3 Marks for explanation



(a) (b) (c) 1 Mark for Diagram

5 e) Describe the construction and working principle of A.C servo motor.

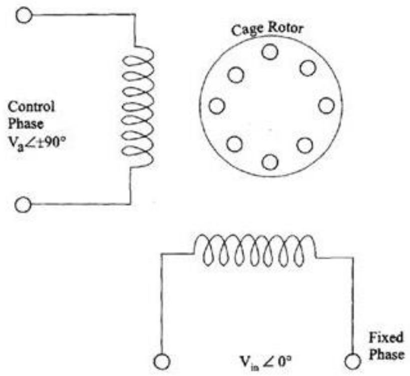
Ans:

Construction of AC Servo Motor:

AC servo motor is mainly composed of a stator and a rotor. Laminated stator core is usually made of silicon. Two phase windings are placed in the stator slots at 90 degree electrically apart from each other. One phase winding is the field winding, and the other is the control winding. Field winding and control winding are excited as shown in figure. 1 Mark for construction

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.



1 Mark for diagram

2 Marks for working

5 f) Give any two applications each of following:
i)Universal motor
ii)Linear induction motor
iii)DC/AC servomotor
iv)Permanent magnet stepper motor(PMSM)

Ans:

Sr. No	Types of Induction Motor	Applications (Any Two expected)
1	Universal motor	1) Mixer and Food processor 2) Heavy duty machine tools 3) Grinder 4) Vacuum cleaners 5) Drills 6) Sewing machines 7) Electric Shavers 8) Hair dryers 9) Cloth washing machine
2	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

1 Mark any two applications

1 Mark for any two applications

		6. Curtain pullers 7. Travelling crane motor	
3	DC/AC servomotor	1. Computers 2. Robotics and toys 3. CD/DVD players 4. Textile industries 5. Instrument servos 6. Tracking and guidance system 7. Self-balancing recorders 8. Remote positioning devices 9. Process controllers 10.Electromechanical actuators 11.Aiacraft control system 12.Programming device	1 Mark for any two applications
4	Permanent magnet stepper motor(PMSM)	1. Use with computer controlled system 2. Used in numerical control of machine tools 3. Tape drives 4. Floppy disc drives 5. Computer printers 6. X-Y plotters 7. Robotics 8. Textile industries 9. Integrated circuit fabrication 10.Electric watches 11.CNC system 12.Milling machines 13.X-Ray table positing system 14. Cameras	1 Mark for any two applications

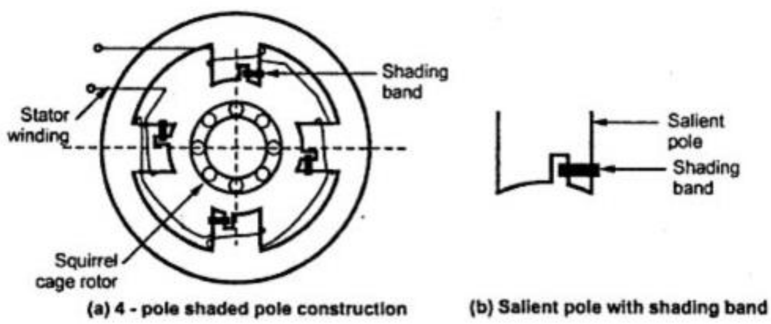
6 Attempt any FOUR of the following: 16

6 a) Describe the construction and working of shaded pole induction motor.

Ans:

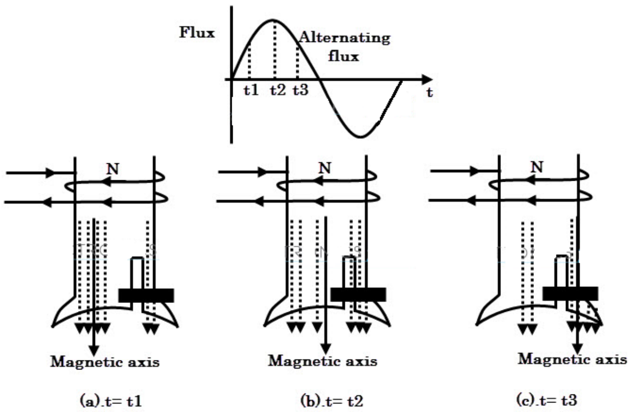
Shaded Pole Induction Motor :

Construction:



2 Marks for construction

It has salient pole on the stator exited by single phase supply and a squirrel cage rotor. The stator consists poles and each pole is splitted into two parts with one portion is surrounded by a short circuited copper band.



Working:

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.

2 Marks for working

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 b) Explain the construction of universal motor and draw its torque-speed characteristics.

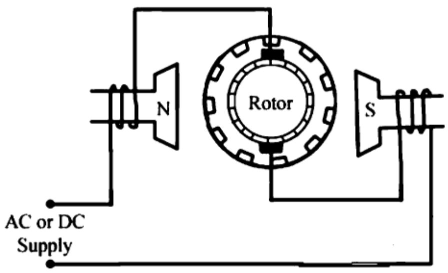
Ans:

Construction of Universal Motor:

In this motor the entire magnetic circuit i.e. stator and rotor is made up of laminated silicon steel stampings. The series field winding, which is housed in the rotor slot are of thick and few turns. The stator field winding and rotor winding are connected in series each other. There is a commutator with sets of

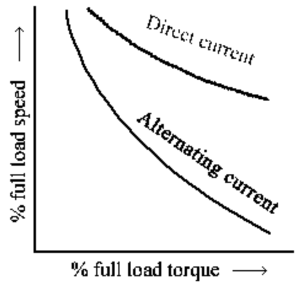
2 Marks for explanation of construction

brushes are available for providing path to flow of current in rotor conductors.



1 Mark for diagram

Torque-Speed characteristics:



1 Mark

6 c) Enlist two types of rotors used in alternator. Give any three differences between them.

Ans:

Types of Rotor Used in Alternator:

i) Salient pole type rotor

ii) Smooth cylindrical type rotor.

1 Mark

Sr. No.	Parameter	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 three points = 3 Marks

6 d) Why single phase induction motor is not self-starting? Justify with the help of double field revolving theory.

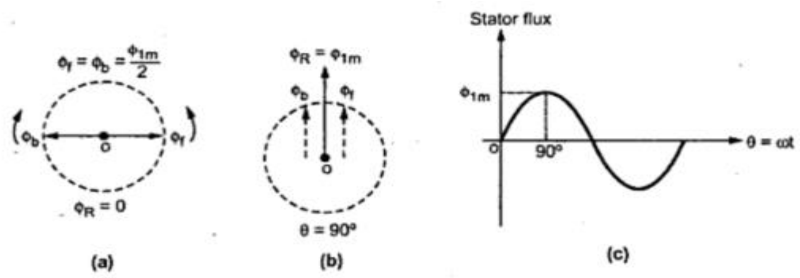
Ans:

Single Phase Induction Motor is not Self- Starting:

When single phase supply is given to the stator of single phase motor it produces pulsating torque which is not of rotating type hence could not produce rotational torque in the rotor of the motor so these motors are not self-starting. 1 Mark

Double Field Revolving Theory:

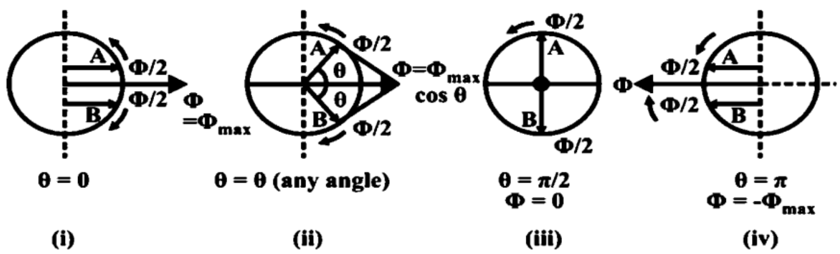
According to this theory, any alternating quantity can be resolved into two rotating components which rotate in opposite directions and each having magnitude as half of the maximum magnitude of the alternating quantity. According to double revolving field theory, consider the two components of the stator flux, each having magnitude half of maximum magnitude of stator flux i.e. $(\Phi_{1m}/2)$. Both these components are rotating in opposite directions at the synchronous speed N_s which is dependent on frequency and stator poles



1 Mark for diagrams

OR

Double field revolving theory



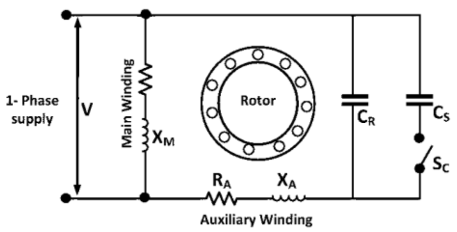
The Fig. shows the stator flux and its two components Φ_f and Φ_b. At start both the components are shown opposite to each other in the Fig.1(a). Thus the resultant $\Phi_R = 0$. This is the instantaneous value of the stator flux at start. After 90^o, as shown in the Fig. 1(b), the two components are rotated in such a way that both are pointing in the same direction. Hence the resultant Φ_R is the algebraic sum of the magnitudes of the two components. So $\Phi_R = (\Phi_{1m}/2) + (\Phi_{1m}/2) = \Phi_{1m}$. This is the instantaneous value of the stator flux at $\theta = 90^o$ as shown in the Fig 1(c). Thus continuous rotation of the two components gives the original alternating stator flux. Both the components are rotating and hence get cut by the motor conductors. Due to cutting of flux, e.m.f. gets induced in rotor which circulates rotor current. The rotor current produces rotor flux. This flux interacts with forward component Φ_f to produce a torque in one particular direction say anticlockwise direction. While rotor flux interacts with backward component

2 Marks for explanation

Φ_b to produce a torque in the clockwise direction. So if anticlockwise torque is positive then clockwise torque is negative.
At start, 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.

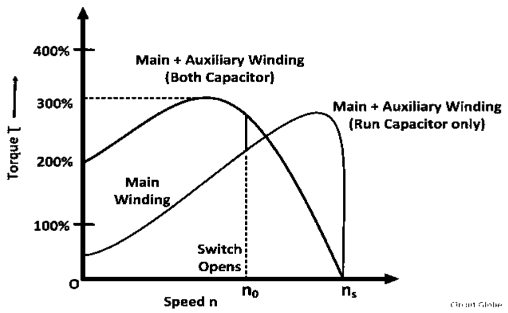
6 e) For capacitor start, capacitor run 1-ϕ IM:
i)Explain construction
ii)Draw torque-speed characteristics
iii) Any two applications.
Ans:
Capacitor-Start, Capacitor- Run Induction Motor:
Construction:
The capacitor start, capacitor run induction motor has stator and rotor which are made up of silicon steel stamping. The stator is provided with an auxiliary or starting winding with main or running winding in the stator slots and rotor is of squirrel cage type. The starting winding is located 90 degree electrically apart from main winding and operates only for starting period. The main winding is inductive in nature and the starting winding is capacitive in nature having two capacitors C_R and C_S with centrifugal type mechanical switch which operates automatically when motor picks 75% of rated speed. The capacitor C_R remains in the circuit but capacitor C_S is disconnected by centrifugal switch.

1 Mark for explanation



Capacitor-start, Capacitor-run Induction Motor

1 Mark diagram



Torque-Speed Characteristics:

1 Mark for characteristics

Applications:
i) Air-conditioning compressors
ii) Centrifugal pumps
iii) Grinders
iv) Conveyors
v) Pumps
vi) Refrigerators
vii) Ceiling fans
viii) Table fans

1 Mark for two applications