MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION
(Autonomous)
(ISO/IEC-27001-2013 Certified)

Winter – 2019 Examinations

Model Answers

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

Important Instructions to examiners:

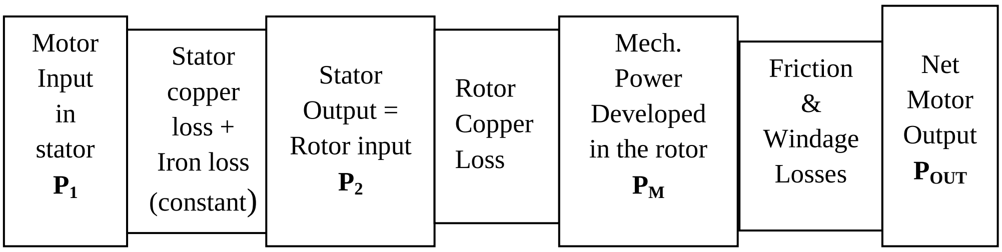
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more 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 may give credit for any equivalent figure drawn.
5) Credits may 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.
6) In case of some questions credit may be given by judgement 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 Attempt any FIVE of the following: 20

1 a) Draw a block diagram showing power stages of 3-ϕ Induction Motor.

Ans:

Power Flow Diagram of 3- Phase Induction Motor:



Correct labeled block diagram 4 Marks

1 b) Compare squirrel cage and slip ring induction motor. (any four points).

Ans:

Comparison Between Squirrel Cage and Slip Ring Induction Motor:

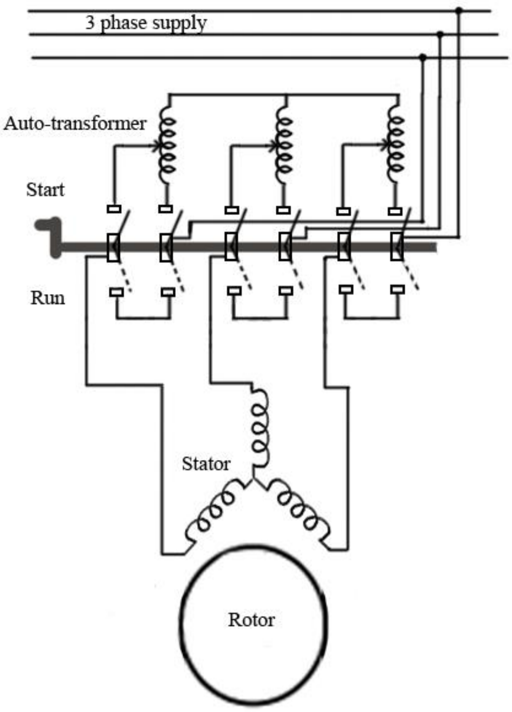
Sr. No.	Squirrel Cage Induction Motor	Slip Ring Induction Motor
1	Rotor is in the form of short circuited bars	Rotor is in the form of 3-ph winding
2	No slip-ring and brushes required	3 slip-rings with brushes are present
3	External resistance cannot be inserted in rotor circuit.	External resistance 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.
14	Used as a constant speed drive e.g. Lathe machine	Used where high starting torque is required.

1 Mark for each of any four points = 4 Marks

1 c) Draw a neat labeled sketch of auto transformer starter for starting of 3 ϕ I. M.

Ans:

Autotransformer Starter:



4 Marks for neat labeled sketch

1 d) Derive the expression for distribution factor.

Ans:

Expression for distribution factor:

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

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

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

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

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

Let 'E' be the emf induced in each coil side.

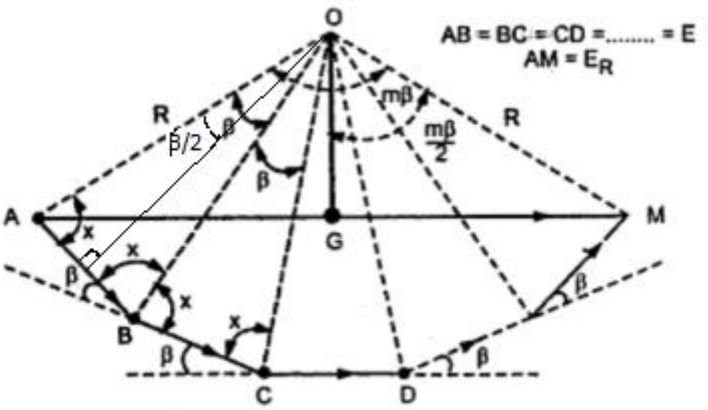
For concentrated winding, the resultant emf E_C is arithmetic sum.

$\therefore E_C = m.E$

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

$\therefore E_D$ = Phasor sum of 'm' emfs each having value 'E'.

4 Marks for stepwise derivation



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

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

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

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

1 e) State the necessity of parallel operation of 3-phase alternators.

Ans:

Necessity of 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.

1 Mark for each of any four points = 4 Marks

1 f) Give the reason why single-phase induction motors are not self-starting.

Ans:

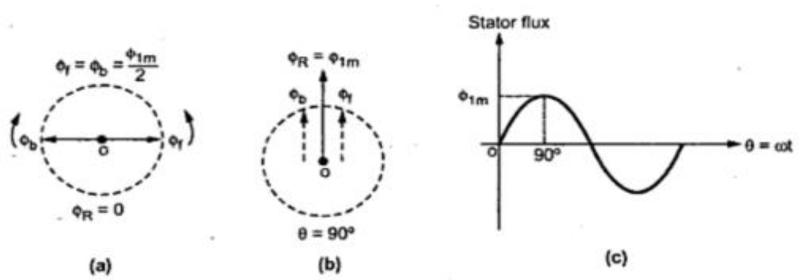
Single Phase Induction Motor is not Self- Starting:

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

4 Marks for correct justification

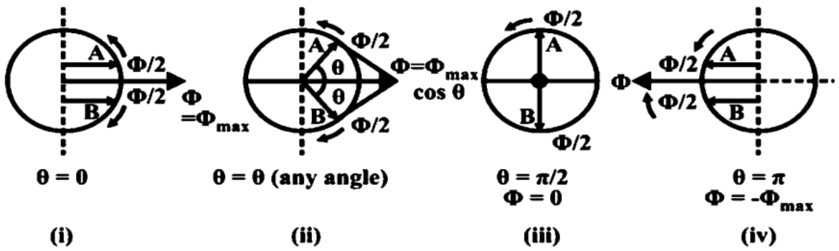
Double Field Revolving Theory:

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



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 Φ_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. The rotor flux also interacts with backward component 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.

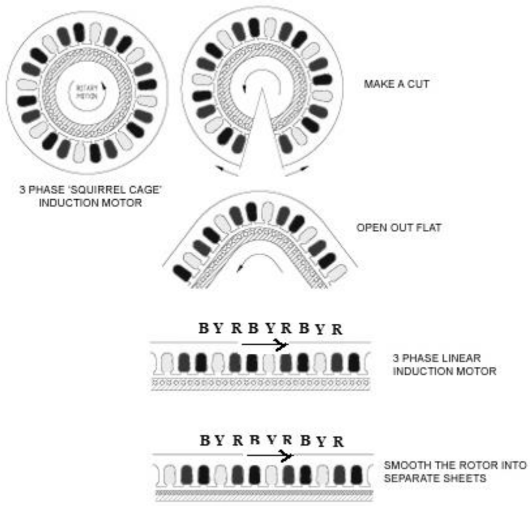
1 g) Explain the principle of operation of linear induction motor.

Ans:

Linear induction motor:

- Linear Induction Motor (LIM) is asynchronous motor, working on the same principle as that of an Induction motor, but is designed to produce the linear motion.

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



2 Marks for diagrams

The linear synchronous speed given by

$$V_s = 2wf$$

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

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

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

2 a) Derive the condition for maximum torque developed by ~~IC~~ IM for any value of slip(s) - 3ϕ I.M. under running condition.

Ans:

Condition for Maximum Torque Under Running Conditions:

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

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

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'.

4 Marks for step-wise derivation

For maximum torque,

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

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

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

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

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

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

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

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

$$R_2 = sX_2$$

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.

OR Equivalent Derivation

2 b) Explain the necessity of starters in 3 phase induction motor.

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.

4 Mark for correct justified answer

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.

2 c) Derive EMF equation of 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 — 1 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,

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

$$\therefore N = (\frac{120f}{P})$$ 1 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 — 1 Mark

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
= $4\emptyset f T$ volt

The RMS value of emf per phase is given by,

E_{ph}= Form Factor × (E_{avg}/phase)
E_{ph}=1.11× $4f\emptyset T$ volt — 1 Mark
$E_{ph} = 4.44 f\emptyset T$ volt

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

$E_{ph} = 4.44\ K_p K_d f\emptyset T$ volt

where, K_p = Pitch factor
K_d = Distribution factor

2 d) Explain the concept of load sharing.

Ans:

Concept of load sharing:

Consider two machines operating in parallel with a common terminal voltage of V volts and load impedance Z, as shown in the figure. Let the generated emfs of the machines 1 and 2 be E_1 and E_2 respectively and synchronous impedances per phase be Z_1 and Z_2 respectively. — 1 Mark for explanation

The total load current I is shared by two machines by supplying currents I_1 and I_2 respectively. Thus the load sharing can be expressed as,

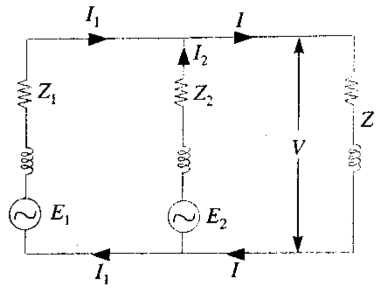
$$\mathbf{I = I_1 + I_2} \quad \textbf{(phasor sum)}$$

The common terminal voltage can be obtained as,

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

The load sharing can be then given by,

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



2 Marks for circuit diagram

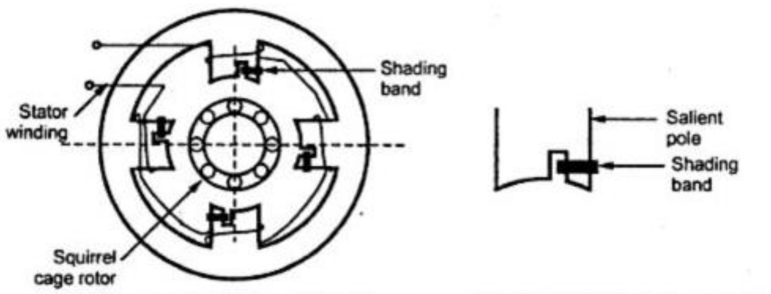
1 Mark for equations

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

2 e) Explain working of shaded pole induction motor with suitable sketch.

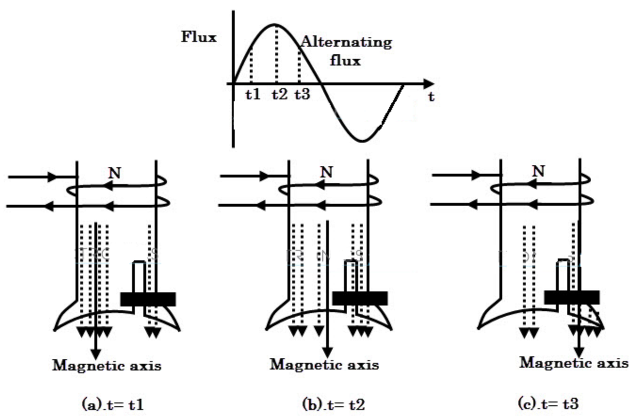
Ans:

Shaded Pole Induction Motor :



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

2 Marks for diagram



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.

2 Marks for explanation

- At instant t_1: The flux is positive and rising, hence the shading band current produces its own flux to oppose the rising main flux. Due to this opposition, the net flux in shaded portion of pole is lesser than that in unshaded portion. Thus the magnetic axis lies in the unshaded portion and away from shaded portion.

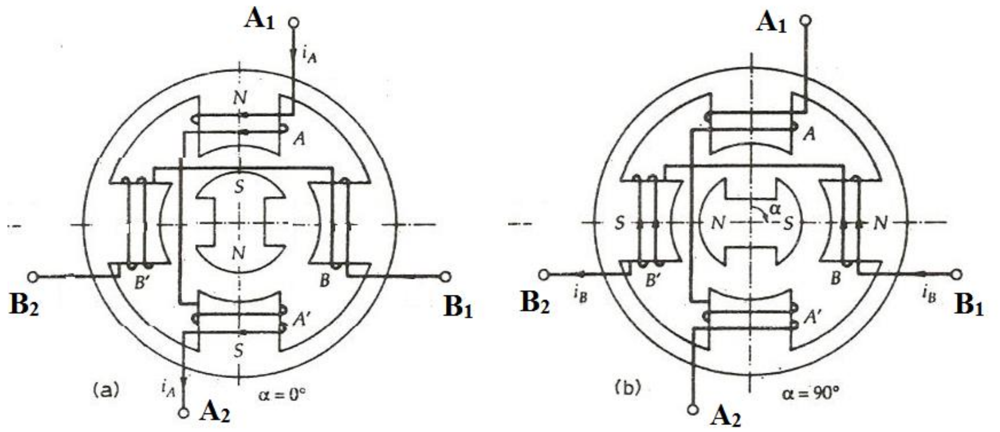
- At instant t_2: The flux is maximum, the rate of change of flux is zero. So the shading band emf and current are zero. Thus the flux distribution among shaded and unshaded portion is equal. The magnetic axis lies in the centre of the pole.
- At instant t_3: The flux is positive but decreasing, hence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

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

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

Ans:

Permanent Magnet Stepper Motor:



2 Marks for construction diagram

OR any other equivalent figure

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

2 Marks for explanation

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

In figure (b) the phase B is excited, causing current i_B flowing from B_1 to B_2 of phase B, whereas phase A is not excited. Due to the current i_B the poles are created on stator

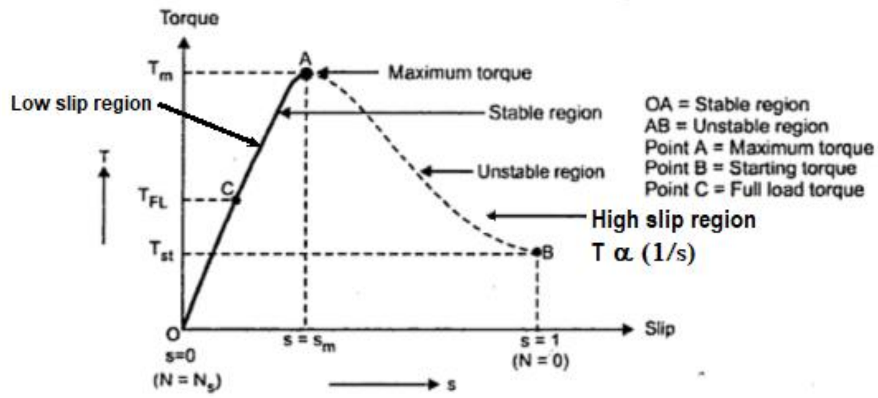
as shown. The south pole of the rotor is attracted by the north pole of stator phase B and the rotor moves by 90° in the clockwise direction. Thus, the magnetic axis of the stator and rotor coincide and $\alpha = 90^o$.
Similary, if phase A alone is excited with reversed current i_A, the rotor moves further by 90° and when the magnetic axis of the stator and rotor coincide, we get $\alpha = 180^o$. Further if only B phase is excited with reversed current i_B, the rotor moves further by 90° and when the magnetic axis of the stator and rotor coincide, we get $\alpha = 270^o$.
In this way, the sequential excitation of phases A and B with forward and reverse current, the rotor movements in steps of 90° can be obtained. It is also possible to obtain steps of 45° by exciting both the phases simultaneously.

3 Attempt any FOUR of the following: 16

3 a) Draw and explain the torque-slip characteristics of 3 phase I. M.

Ans:

Torque-Slip characteristics of 3-phase Induction Motor:



2 Marks for curve

- 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.
- 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.

2 Marks for explanation

At the time of starting, the motor produces starting torque, called stall torque, which must be greater than the load torque, otherwise the motor will not pick up the speed and simply stalled.

3 b) List the different method of speed control of 3 phase induction motor and explain any one method in detail.

Ans:

Methods of Speed Control of 3 Phase Induction Motor:

i)Pole Changing Method:
ii)Stator Voltage Control Method:
iii)Rotor Resistance Control Method:

1 Mark for methods

i)Pole Changing Method:

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

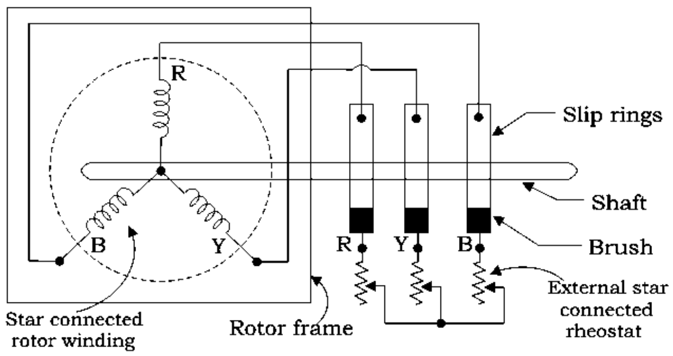
From the above equation of synchronous speed, it can be seen that synchronous speed (and hence, running speed) can be changed by changing the number of stator poles. This method is generally used for squirrel cage induction motors as squirrel cage rotor adopts itself for any number of stator poles. Change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

3 Marks for explanation of any one method

ii)Stator Voltage Control Method:

As in three phase induction motor, the torque produced, T ∝ sE_2^2 where E_2 is rotor induced emf and $E_2 \propto V$. Thus, T ∝ 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.

iii)Rotor Resistance Control Method:



Slip Ring Three Phase Induction Motor

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

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

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

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

where, R_2 is rotor resistance per phase in ohms,

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

3 c) Compare salient pole type and smooth cylindrical type alternator.(Any four points)

Ans:

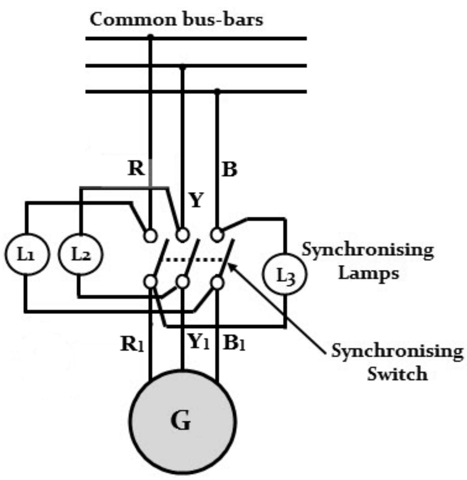
Sr. No.	Parameter/ Machine	Salient pole type rotor	Smooth cylindrical type rotor
1	Operating speed	Low, medium	High
2	Number of poles	Large	Less (2 or 4)
3	Rotor construction	• Non-uniform airgap • Projected type or salient poles • Bulky & heavy weight	• Cylindrical with smooth surface so uniform airgap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

1 Mark for each of any four points = 4 Marks

3 d) Explain various methods of synchronizing of 3-phase alternators. Explain any one method in detail.

Ans:

Synchronizing an Alternator to Busbar:



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 or another alternator. The other two phases will then synchronized automatically. 1 Mark for methods

Methods of Synchronizing alternators:

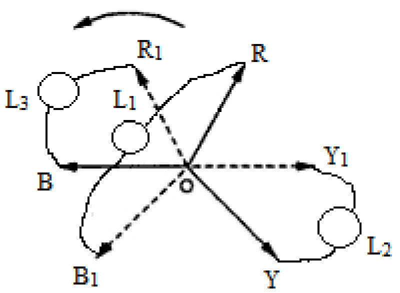
1) Synchroscope method
2) Lamp method

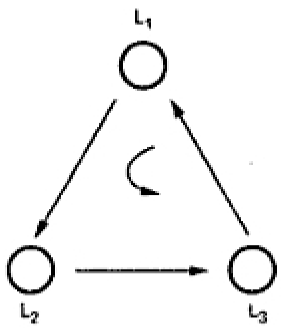
In Lamp method, three lamps are connected across synchronizing triple pole switch between bus-bar and alternator. Depending upon the lamp connections and their indication at the instant of synchronizing, there are three methods:

1) Two Bright, One Dark Lamp Method (refer circuit shown above) 3 Marks for explanation of any one method
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.

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 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:

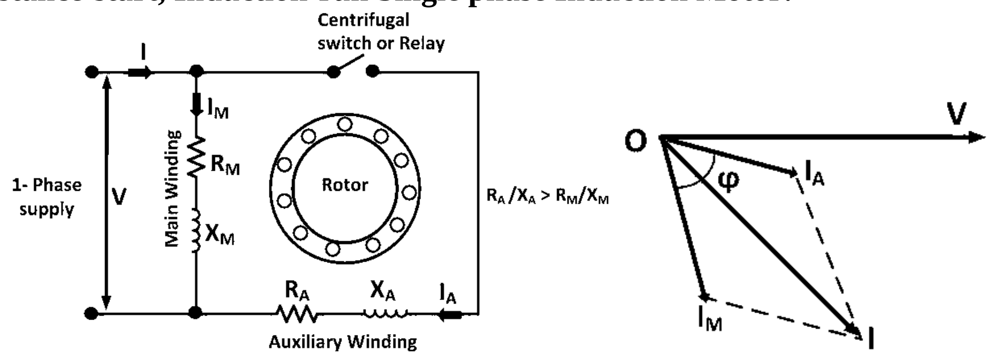
(i) The voltage across L_1 i.e V_{R-B1} is about to become maximum, the lamp L_1 is about to glow maximum bright.
(ii) The voltage across L_2 i.e V_{Y-Y1} is increasing towards maximum, the lamp L_2 glows with brightness increasing towards maximum.
(iii) The voltage across L_3 i.e V_{B-R1} is decreasing and will become zero when R_1 phasor coincides with B phasor. Thus the lamp L_3 glows with brightness decreasing towards dark.

If the lamps are arranged at the vortex of triangle, we can see that the glowing brightness of the lamp follow the sequence $L_1 – L_2 – L_3$ and so on. Thus if the alternator is faster, the lamps glow up and become dark in the sequence $L_1 – L_2 – L_3$. If the alternator is slower, the sequence get reversed i.e $L_1 – L_3 – L_2$. However, if slowly the corresponding phasors coincide i.e R with R_1, Y with Y_1 and B with B_1, that particular instant is the synchronization instant. At this instant, the lamps L_1 and L_3 glow equally bright, whereas the lamp L_2 becomes dark. At this instant the synchronizing switch is closed and the alternator get connected to the busbar.

3 e) Explain the construction and operation of resistance-start, induction-run single phase induction motor with suitable diagram.

Ans:

Resistance-start, Induction-run Single phase Induction Motor:



2 Marks for diagram

It has a single cage rotor and its stator has two windings known as main winding and starting (auxiliary) winding. Both the windings are displaced 90 degrees in space. The main winding has very low resistance and a high inductive reactance whereas the starting winding has high resistance and low inductive reactance.

1 Mark for construction

The rotating magnetic field of the resistance-start induction-run motor is produced by the out-of-phase currents in the main and starting windings. Since the main winding appears more inductive and less resistive than the starting winding, the current flow in the main winding will be close to 90 degrees out-of-phase with the applied voltage. The starting winding appears more resistive and less inductive than the main winding, causing the starting winding's current to be less out-of-phase with the applied voltage, as shown in Figure. The phase-angle difference between current in the main winding and current in the starting winding of a resistance-start induction-run motor is generally 35 to 40 degrees. This is enough phase angle difference to produce a weak rotating field, and consequently a weak torque, to start the motor. Once the motor reaches about 75% of its rated speed, the starting winding is disconnected from the circuit and the motor continues to operate on the main winding. In nonhermetically

1 Mark for operation

sealed motors, the starting winding is generally disconnected with a centrifugal switch. The contacts of the centrifugal switch are connected in series with the starting winding. When the motor is at rest or not running, the contacts of the centrifugal switch are closed and provide a circuit to the starting winding. When the motor is started and reaches about 75% of its rated speed, a counterweight on the centrifugal switch moves outward because of centrifugal force, causing the contacts to open and disconnect the starting winding from supply. The motor continues to operate on the main winding.

3 f) What is an universal motor? Comment briefly on its constructional features and speed torque characteristic. State any two applications of this motor.

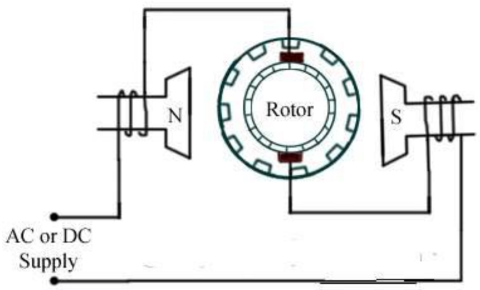
Ans:

Universal Motor:

The motor which operates on both AC and DC supply, is called as Universal Motor. 1 Mark

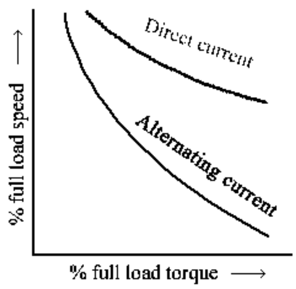
Construction of Universal Motor:

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



1 Mark for construction

Torque-Speed characteristics:



1 Mark for Torque-speed characteristic

Regardless of AC or DC supply, universal motor works on the same principle as that of DC series motor. It exhibits inverse torque-speed characteristics with high starting torque as shown in the figure.

Applications of Universal motor:

1) Mixer and Food processor
2) Heavy duty machine tools
3) Grinder
4) Vacuum cleaners
5) Drills

1 Mark for any two applications

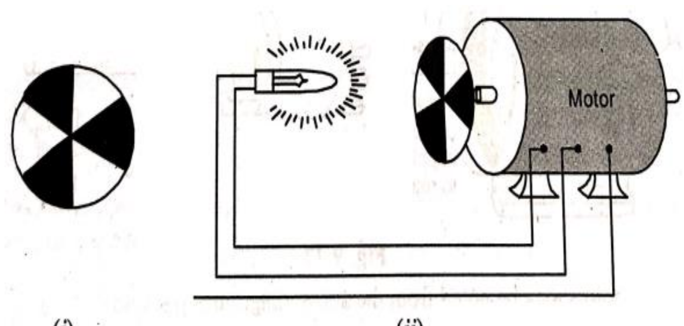
6) Sewing machines
7) Electric Shavers
8) Hair dryers
9) Cloth washing machine

4 Attempt any FOUR of the following: 16

4 a) Explain the stroboscopic method for measurement of slip of 3-ϕ induction motor with neat sketch.

Ans:

Stroboscopic Method for Measurement of Slip of 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

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

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

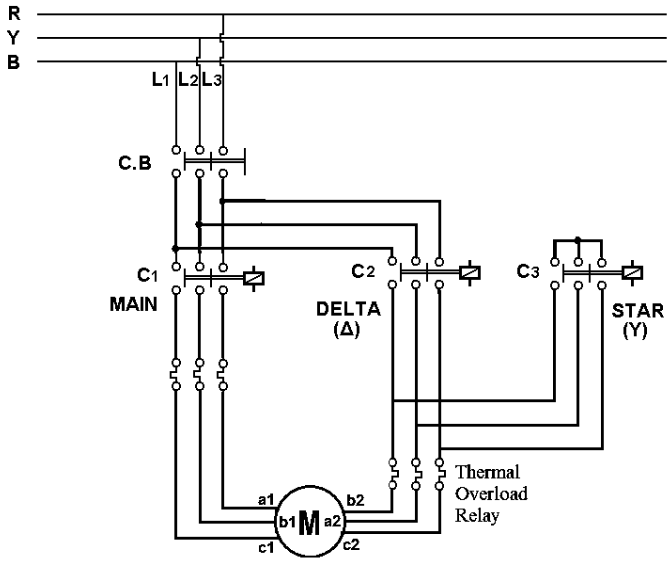
Ns = Synchronous speed.

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

Ans:

Power Circuit of Star Delta Starter:

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



3 Marks for labeled circuit diagram

or Equivalent figure

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

4 c) Explain the factors which affect the terminal voltage of 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)

Factors on which it depends:

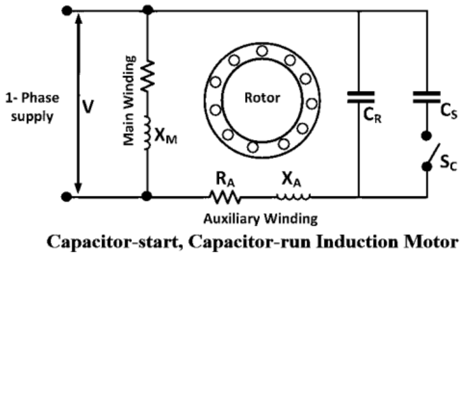
a. Load current (armature current) and its power factor which depends on the load nature.
b. The armature resistance R_a whose higher values lead to higher drops and lower terminal voltage.
c. The synchronous reactance X_s (which covers the effect of leakage reactance and armature reaction) which is kept higher for alternators. The terminal voltage falls as the alternators synchronous reactance is increased.
d. The induced emf Eph 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 Marks for each of four factors = 4 Marks

4 d) Explain working of capacitor start capacitor run single phase induction motor.

Ans:

Capacitor-start, Capacitor- run Induction Motor:



Capacitor-start, Capacitor-run Induction Motor

2 Marks for circuit diagram

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

There are two capacitors in the auxiliary winding circuit. A capacitor C_S is known as the starting capacitor. It is connected in series with the centrifugal switch S_C. So C_S remains in the circuit only at start and it is switched out during normal running. Hence C_S is of electrolytic type, has high value but short duty. Another capacitor C_R is known as running capacitor. It remains in the circuit continuously during starting and running of the motor. It is an oil capacitor having low value and continuous duty. Thus the motor is a two-value capacitor motor. 2 Marks for explanation

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

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

4 e) List any four types of single phase induction motor. Write down any one application for each.

Ans:

Types of single phase induction motors:

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

½ Mark for each of four types = 2 Marks

Applications:

Sr. No.	Name of Motor	Applications
1	Capacitor Start Induction Run Motor	Fans, Blowers, Grinder, Drilling Machine, Washing Machine, Refrigerator, Air conditioner, Domestic Water Pumps, Compressor.
2	Resistance Start Induction Run Motor	Washing Machine, Fans, Blowers, Domestic Refrigerator, Centrifugal Pump, Small electrical Tools, Saw machine
3	Capacitor Start Capacitor Run Motor	Fans, Blowers, Grinder, Drilling Machine, Washing Machine, Refrigerator, Air conditioner, Domestic Water Pumps, compressors.

½ Mark for each motor application = 2 Marks

4	Shaded pole I. M.	Recording Instruments, Record Player, Gramophones, toy Motors, Hair dryers, Photo copy machine, Advertising display , Table Fan

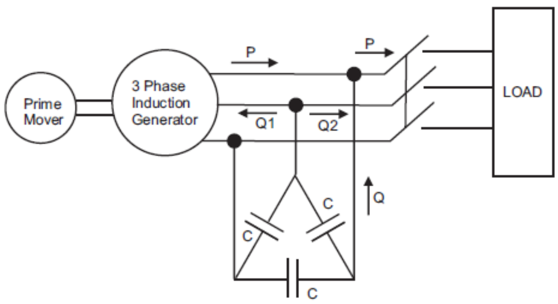
4 f) What is Induction Generator? State it's principle of operation and give any two applications of it.

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. — 1 Mark for explanation

Applications of Induction Generator:

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

1 Mark for two applications

5 Attempt any TWO of the following: 16

5 a) A 4 pole, 3-phase, 50 Hz, 400 V induction motor develops an output of 55 kW at 1400 rpm. The mechanical torque lost is 2.5 N-m, stator losses total to 314 watt. Calculate

efficiency and current drawn at this output. Draw power flow diagram inserting values of this loading, power factor = 0.866.

Ans:

Data Given: Poles P = 4, Frequency f = 50 Hz, V_L = 400V,
Output Power P_{out} = 55 kW = 55000 W, Speed N = 1400 rpm
P.F. = cosØ = 0.866 lag
Mechanical torque lost to compensate the mechanical loss T_L= 2.5 N-m
Mechanical loss = $\frac{2\pi N T_L}{60} = \frac{2\pi(1400)(2.5)}{60}$ = 366.52 W — 1 Mark
Stator losses = 314 W.

Step 1: Find Synchronous Speed N_s and Slip s :

$$N_S = \frac{120f}{P} = \frac{120\times50}{4} = 1500\ rpm$$

$$s = \frac{Ns-N}{Ns} = \frac{1500-1400}{1500} = 0.0667\ or\ 6.67\%$$

1 Mark

Step 2 : Find Rotor output:

Rotor output = P_{out} + Mechanical losses — ½ Mark
= 55000 + 366.52 = 55366.52 W

Step3 : Find Rotor copper loss:

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

$$\therefore \text{Rotor copper loss} = \left(\frac{s}{1-s}\right)\text{Rotor output}$$ ½ Mark

$$= \left(\frac{0.0667}{1-0.0667}\right)55366.52 = 3956.87\ \text{W}$$

Step 4: Find motor input:

Motor input = P_{in} = Motor o/p + stator losses + Rotor losses+ Mech. losses
= 55000 +314 +3956.87 +366.52 — 1 Mark
= 59637.39 W

Step 5: Efficiency:

$$\text{Efficiency} = \frac{Output\ Power}{Input\ Power}\times 100$$

$$= \frac{55000}{59637.39}\times 100 = 92.22\%$$

1 Mark

Step 6: Find line current:

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

$$\therefore I_L = \frac{P_{in}}{\sqrt{3}V_L\cos\emptyset} = \frac{59637.39}{\sqrt{3}\times400\times0.866} = 99.4\ \text{amp}$$

1 Mark

Power Flow Diagram:

Motor Input in stator **P_1** 59637.39W	Stator copper loss + Iron loss (constant) **314 W**	Stator Output = Rotor input **P_2** **59323.39W**	Rotor Copper Loss **3956.87 W**	Mech. Power Developed in the rotor **P_M =** **Rotor Output** **55366.52 W**	Friction & Windage Losses = Mechanical Loss **366.52 W**	Net Motor Output **P_{OUT}** **55000W**

2 Marks

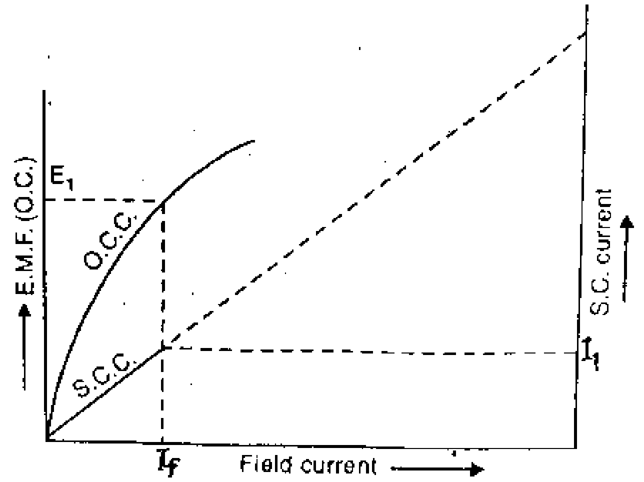
5 b) Explain the "Synchronous Impedance" method of determining voltage regulation of an alternator.

Ans:

Winter – 2019 Examinations
Model Answers
Subject & Code: A. C. Machines (17511)

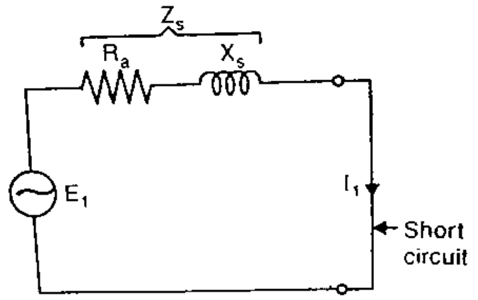
Voltage Regulation of 3-phase Alternator by Synchronous Impedance Method:

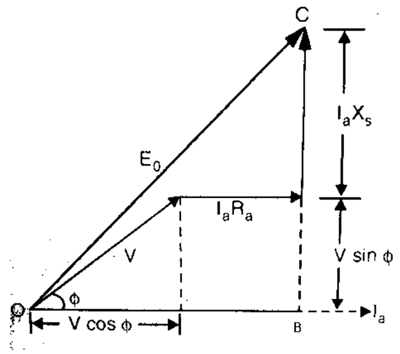
1) Plot the OCC and SCC on the same field current base as shown in following figure:



1 Mark for characteristic

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 for eq. circuit

1 Mark for phasor diagram

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

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

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.

5 Marks for stepwise explanation

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 = $Vsin\emptyset + I_a\,X_s$

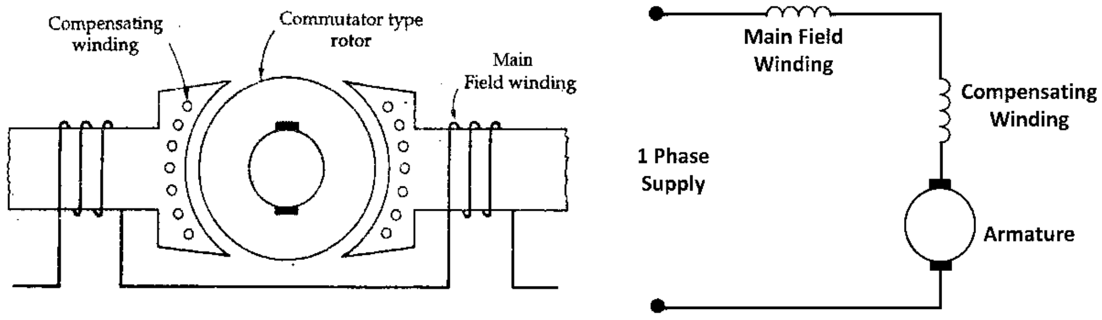
$$E_0 = \sqrt{[(Vcos\emptyset + I_aR_a)^2 + (Vsin\emptyset + I_aX_s)^2]}$$

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

5 c) (i) Draw a schematic diagram of an AC series motor.

Ans:

Schematic Diagram of AC Series Motor:



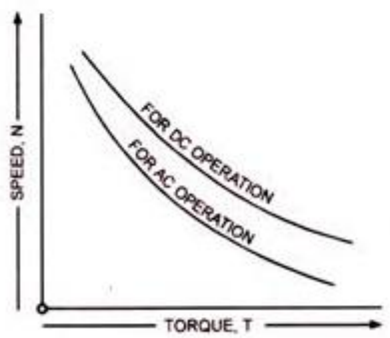
Schematic and Connection Diagram of AC Series Motor

4 Marks for labeled diagram

5 c) (ii) Draw speed torque characteristics of AC Series motor.

Ans:

Speed Torque characteristics of AC Series motor:



Speed-Torque Characteristics of Series Motors

4 Marks

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

6 a) A 6 pole, 50 Hz, 3 phase induction motor running on full load with 3% slip develops a torque of 150 Nm at its pulley rim. The total mechanical losses are 550 W and stator losses are 1800 W. Calculate:

(i) Output power
(ii) Rotor copper loss
(iii) Efficiency on full load

Ans:

Data Given: 3-phase induction motor running on full load, f = 50 Hz, P = 6
Slip s = 3% = 0.03
Developed torque T = 150 Nm
Stator losses = Ps_{loss} = 1800W
Mechanical losses = $P_{Mech\text{-}loss}$ = 550W

Synchronous speed $N_S = \frac{120f}{P} = \frac{120\times50}{6} = 1000$ rpm — 1 Mark for N_s

Slip s = $\frac{N_s-N}{N_s}$

Speed N = (1 – s) N_s = (1- 0.03)(1000) = 970 rpm — 1 Mark for N

1) Output Power:

Mechanical power developed $P_{mech} = \frac{2\pi NT}{60} = \frac{2\pi(970)(150)}{60}$ = 15236.72 W — 1 Mark for P_{mech}

Gross Rotor output power = Mechanical power developed P_{mech} = 15236.72 W

Shaft Output power = Gross Rotor output power – Mechanical losses

= 15236.72 – 550

∴ Output power P_{out} = 14686.72 W — 1 Mark for P_{out}

2) Rotor Copper Loss:

Gross Rotor output power = (1- s) Rotor input power

Rotor input power = Gross Rotor output power /(1- s)

= 15236.72 / (1 – 0.03)

= 15707.96 W — 1 Mark

Rotor Cu-loss = s × Rotor input power = 0.03 × 15707.96 — 1 Mark

∴ Rotor Cu-loss = 471.24 W

3) Efficiency on full load:

Rotor input power = Stator input power - Stator losses

Stator input power = Rotor input power + Stator losses

= (15707.96 + 1800)

∴ Stator input power = 17507.96 W — 1 Mark

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

$$= \frac{14686.72}{17507.96}\times 100$$ — 1 Mark

∴Efficiency on full load = 83.89%

6 b) A 3ϕ, star connected, 100 kVA, 11000V alternator has rated current of 52.5A. The a.c. resistance of the winding per phase is 0.45 Ω. The test results are given below:
O.C. test: Field current = 12.5A, Voltage between lines = 422 V.
S.C. test: Field current = 12.5A, Line current is equal to 52.5 A.
Determine the full load voltage regulation of the alternator at pf 0.8 lagging and 0.8 pf leading.

Ans:

Data Given: 3ϕ, star connected, 100 kVA, 11000V alternator

V_L = Rated line voltage = 11000V, — 1 Mark for V

∴ Rated Phase voltage V = $V_L / \sqrt{3} = 11000/\sqrt{3}$ = 6350.85 V

Full load current I = 52.5A — 1 Mark for Zs

Armature resistance per phase R = 0.45 Ω,

Synchronous impedance per phase $Z_S = \frac{Voc_{ph}}{Isc} = (422/\sqrt{3})/52.5$ = 4.64 Ω, — 1 Mark for Xs

Synchronous reactance per phase $X_S = \sqrt{(Z_S^2 - R^2)} = \sqrt{4.64^2 - 0.45^2}$ = 4.618 Ω. — ½ Mark for equation of E

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

$$E = \sqrt{[(V\cos Ø + IR)^2 + (V\sin Ø \pm IX_S)^2]}$$ — ½ Mark for eq.of %R

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

i) At 0.8 pf lagging:

cosØ = 0.8 and sinØ = 0.6 and +ve sign to be taken in expression. 1 Mark

$E = \sqrt{[(6350.85 \times 0.8 + 52.5 \times 0.45)^2 + (6350.85 \times 0.6 + 52.5 \times 4.618)^2]}$

= 6517.7 V 1 Mark

% Regulation = [(6517.7 – 6350.85)/6350.85] x 100 = **0.0263 OR 2.63%**

ii) At 0.8 pf leading:

cosØ = 0.8 and sinØ = 0.6 and –ve sign to be taken in expression. 1 Mark

$E = \sqrt{[(6350.85 \times 0.8 + 52.5 \times 0.45)^2 + (6350.85 \times 0.6 - 52.5 \times 4.618)^2]}$

= 6227.76 V 1 Mark

% Regulation = [(6227.76– 6350.85)/6350.85] x 100 = **– 0.0194 OR – 1.94%**

6 c) Describe armature reaction with flux distribution waveforms in a three phase alternator when the nature of load on the alternator is resistive, purely inductive and purely capacitive.

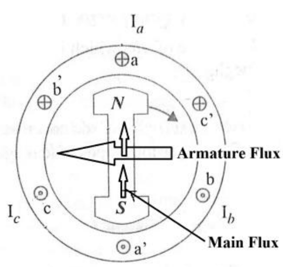
Ans:

Armature reaction:

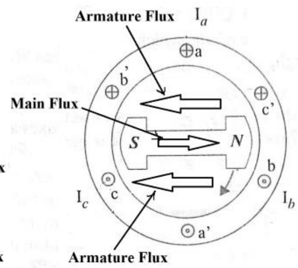
The effect of armature flux on main flux is called as armature reaction. When the armature conductors of alternator carry current, they produce their own flux, called armature flux. This flux affects the main pole flux and resultant flux in the air-gap is modified. This affects the terminal voltage of alternator. The power factor of the load has a considerable effect on the armature reaction. 2 Marks for armature reaction

Armature Reaction when the load is Purely Resistive:

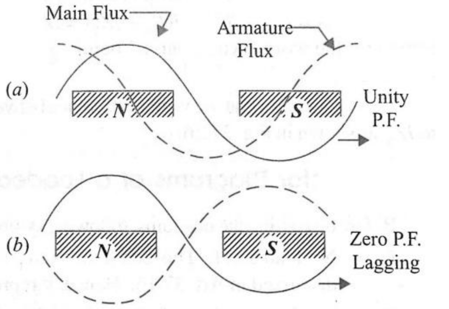
Consider a 2 pole, 3-phase simple alternator supplying purely resistive load. Referring to fig. (a), for shown pole positions, the phase-a conductors lie exactly under the poles. So phase-a emf is maximum. Since load is purely resistive, the current is in phase with voltage, resulting the currents is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



(a) Purely Resistive Load (UPF)



(b) Purely Inductive Load (Zero pf lagging)



Armature Reaction when the load is Purely Inductive:

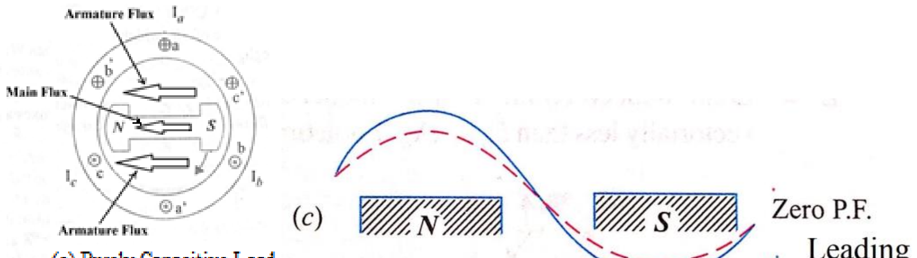
Referring to fig. (b), for shown pole positions, the phase-a conductors lie exactly on magnetic neutral axis, so phase-a emf is zero. Since load is purely inductive, the current lags behind the voltage by 90°, resulting the current in phase-a as positive maximum with zero voltage induced in it. Thus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

2 Marks for armature reaction of purely inductive load

Armature Reaction when the load is Purely Capacitive:

Referring to fig. (c), for shown pole positions, the phase-a conductors lie exactly on magnetic neutral axis, so phase-a emf is zero. Since load is purely capacitive, the current leads the voltage by 90°, resulting the current in phase-a as positive maximum with zero voltage induced in it. Thus the current pattern in all phases remains same as shown in the figure. It is seen that the armature flux appears to be aiding the main flux. Therefore, the armature reaction is wholly magnetizing, resulting greater induced emf. With reference to the rotation, we can say that the armature flux is in-phase with the main flux. Therefore, the net effect of magnetization is to increase the main flux, resulting rise in the terminal voltage. The flux distribution waveform is also shown in the figure.

2 Marks for armature reaction of purely capacitive load



(c) Purely Capacitive Load
(Zero pf leading)