Model Answers

Winter – 2018 Examination

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

Important Instructions to examiners:

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

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

1 a) (i) State any four applications of 3 phase induction motor.

Ans:

Applications of 3 Phase Induction Motor:

1) Lathes
2) Flour mills
3) Grinders
4) Centrifugal pumps
5) Drilling machines
6) Laundry washing machines
7) Wood working machines
8) Blowers
9) Printing machines
10) Fans
11) In cement mills
12) In textile mills
13) Industrial drives
14) Domestic water pumps
15) Various types of presses
16) Concrete mixers
17) Vibrators
18) Line shafting
19) Large refrigerators
20) Boring machines
21) Lifts
22) Crain
23) Hoists
24) Elevators
25) Compressors
26) Conveyors
27) Crushers
28) Plunger pumps
29) Excavators
30) Turn tables
31) Stokers
32) Winding machines
33) Propulsion of ships
34) Large ventilating fans
35) Rolling machines
36) Cable car
37) In petrochemical industries
38) For generators
39) Driving line shafts
40) For practical purposes in educational institutes.

1 mark for each of any four applications = 4 marks

OR Any Valid Applications

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

Ans: Comparison Between Squirrel Cage Induction Motor and Slip Ring

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Induction Motor:

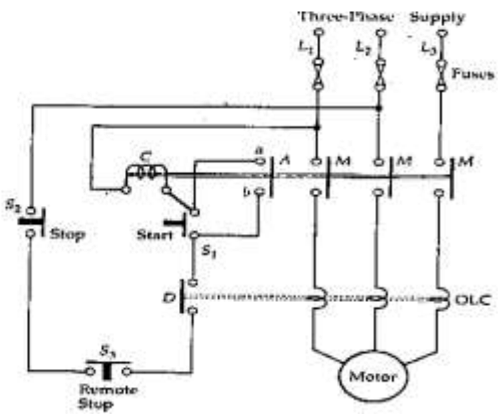
Sr. No.	Squirrel Cage Induction Motor	Slip Ring Induction Motor
1	Rotor is in the form of short circuited bars.	Rotor is in the form of 3-ph winding.
2	No slip-ring and brushes required.	3 slip-rings with brushes are present.
3	External resistance cannot be inserted in rotor circuit.	External resistance 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 0.6 to 0.8 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 side control method only.	Speed control by stator as well as rotor side 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 e.g. Lifts.

Any four points = 4 marks

1 a) (iii) Explain DOL starter used for 3 phase induction motor.

Ans:

DOL Starter Used for 3 Phase Induction Motor:



2 marks for diagram

The direct online starter consist of overload relay (OLC), contactor, start-push button S_1 (normally open), stop-push button S_2 (normally closed), magnetizing coil C, Remote stop button S_3 (normally closed), main contacts M, hold on contact A as shown in above figure.

For staring the motor, the start-push button is pressed. The contactor coil C gets connected across line voltage & ultimately it gets magnetized. It pulls the plunger towards left making contacts of M and A which provides power supply to induction motor and motor starts. — 2 marks for explanation

For stopping the motor after work the stop-push / remote button is pressed which disconnects supply to coil C so it releases the plunger and cuts off the supply of motor and motor stops. The overload coil (OLC) protects the motor against overload and short circuit by opening the contact D.

1 a) (iv) Derive the relationship between Synchronous speed (Ns) and frequency (f) of alternator.

Ans:

Derivation of Relationship Between Synchronous speed (Ns) and Frequency (f) of Alternator:

Let,

Ns = rotor speed in rpm (synchronous speed)

P = number of rotor poles

f = frequency of emf in Hz

Consider a stator conductor that is successively swept by the N and S poles of rotor. If a positive voltage is induced when a N pole sweeps across the conductor, a similar negative voltage is induced when a S pole sweeps it. This means that one complete cycle of emf is generated in the conductor as pair of poles passes it. Hence : — 4 marks for step-wise derivation

Number of cycles / revolution = Number of pair of poles = $\frac{P}{2}$

Number of revolution / second = $\frac{N_S}{60}$

Number of cycles / second = $\frac{\text{Number of cycles}}{\text{revolution}} \times \frac{\text{Number of revolution}}{\text{second}}$

$= \frac{P}{2} \times \frac{N_S}{60}$

Number of cycles / second is the frequency (f) = $\frac{N_S P}{120}$

OR Equivalent derivation

1 b) **Attempt any <u>ONE</u> of the following:** **6**

1 b) (i) Explain speed control method of 3 phase induction motor by the following methods:

(1) Pole changing
(2) Rotor resistance control
(3) Stator voltage

Ans:

Speed Control of 3 Phase Induction Motor:

1) Pole Changing Method:

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

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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)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.

2 marks for each method = 6 marks

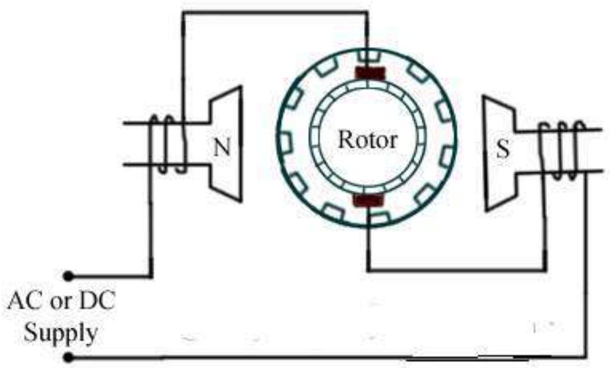
iii)Stator Voltage Control Method:

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.

1b) (ii) Draw and explain working of universal motor. Give two applications of universal motor.

Ans:

Working of Universal Motor:



2 marks for diagram

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

When fed with AC supply, it still produces unidirectional torque. Because armature winding and field winding are connected in series, they carry same current. Hence, as polarity of AC voltage changes and current reverses its direction, the direction of current in armature conductors and magnetic field in the air-gap reverses at the same time. The direction of magnetic field and the

2 marks for working

direction of armature current reverse in such a way that the direction of force experienced by armature conductors remains same. Thus unidirectional torque is produced and motor continues to run in the same direction.
Thus, regardless of AC or DC supply, universal motor works on the same principle as that of DC series motor.
Since motor works on both the type of supply: AC or DC, it is referred as Universal motor.

Applications of 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 marks for any two applications

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

2 a) State the function of following parts of slip ring induction motor:

(i) Slip ring
(ii) Fan
(iii) Brushes
(iv) Frame

Ans:

Sr. No.	Name of part	Function
1	**Slip ring**	1) The rotor winding terminals are permanently connected to the slip rings. 2) Connects external resistance to rotor circuit through brushes.
2	**Fan**	1) The fan is connected at the one end of the rotor shaft. Its function is to provide cooling to the motor. 2) For air circulation.
3	**Brushes**	The brushes are pressed against slip ring. These are used to make connection between external resistance with rotor circuit.
4	**Frame**	1) It provides mechanical support to the entire internal parts of motor. 2) Protects the inner parts.

1 mark for each function = 4 marks

2 b) A 3∅, 50 Hz, 4 pole IM has a slip of 4%, calculate:

(i) Speed of motor
(ii) Frequency of rotor emf, if the rotor has a resistance of 1Ω and standstill reactance of 4Ω. Calculate the rotor power factor at:
(1) Stand still
(2) A speed of 1440 rpm

Ans:

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Given:
f= 50 Hz, P= 4, Slip = 4%.

$$N_s = \frac{120\ f}{p}$$

$$N_s = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

$$\%\ Slip = (N_s - N / N_s) \times 100$$

$$4 = (1500 - N / 1500) \times 100$$ 1 mark

Speed of motor(N) = 1440 rpm

To find $\cos\phi_2$ at a standstill (s = 1) , $R_2 = 1\ \Omega$, $X_2 = 4\ \Omega$:
$\cos\phi_2$ at standstill

$$\cos\phi_2 = \frac{R_2}{\sqrt{(R_2)^2 + (sX_2)^2}}$$

$$\cos\phi_2 = \frac{1}{\sqrt{(1)^2 + (1 \times 4)^2}}$$

$\cos\phi_2$ = 0.24 lagging 1 mark

Frequency of rotor EMF at standstill

$\mathbf{f_r}$ = s x f ½ mark
= 1 x 50 = **50 Hz**

To find $\cos\phi_2$ at a speed of 1440 rpm, $R_2 = 1\ \Omega$, $X_2 = 4\ \Omega$, s = 0.04

$$\cos\phi_2 = \frac{R_2}{\sqrt{(R_2)^2 + (sX_2)^2}}$$

$$\cos\phi_2 = \frac{1}{\sqrt{(1)^2 + (0.04 \times 4)^2}}$$

$\cos\phi_2$ = 0.98 lagging 1 mark

Frequency of rotor EMF at standstill

$\mathbf{f_r}$ = s x f ½ mark
= 0.04 x 50 = **2 Hz**

2 c) Define pitch factor and distribution factor and state the advantages of short pitches coils for an alternator.

Ans:

Pitch Factor (K_c):

It is the ratio of the voltage generated in the short pitch coil to the voltage generated in the full pitch coil. 1 mark

OR

$$K_c = \frac{\text{Actual voltage generated in the short pitch coil}}{\text{Voltage generated in the full pitch coil}}$$

OR

It is the ratio of vector sum of the individual emfs per coil to the arithmetic sum of individual emfs per coil.

OR

$$K_c = \frac{\text{Vector sum of the individual emfs per coil}}{\text{Arithmetic sum of individual emfs per coil}}$$

Distribution Factor (K_d) :

It is the ratio of emf with distributed winding to emf with concentrated winding.

OR

$$K_d = \frac{\text{Emf with distributed winding}}{\text{Emf with concentrated winding}}$$ 1 mark

OR

It is the ratio of phasor sum of coil emfs per phase to arithmetic sum of coil emfs per phase.

OR

$$K_d = \frac{\text{Phasor sum of coil emfs per phase}}{\text{Arithmatic sum of coil emfs per phase}}$$

Advantages of Short Pitch Coils for an Alternator:

(1) It gives better sinusoidal waveform by reducing the harmonic components.
(2) It saves copper as length required for the connections is less.
(3) High frequency harmonics will get eliminated.
(4) As the high frequency harmonics are illuminated, hysteresis & eddy current losses will be reduced and this increases the efficiency.

2 marks for any two advantages

2 d) The stator of 3 phase, 8 pole, 750 rpm alternator has 72 slots, each of which contains 10 conductors. Calculate the rms value of the emf per phase if the flux per pole is 0.1wb, Sinusoidally distributed. Assume full pitch coils and a winding distribution factor is 0.96.

Ans:

Given: P = 8, N = 750 rpm, ϕ = 0.1 wb / pole, No of Slots = 72,
No of conductors per slot = 10 , Winding distribution factor K_d = 0.96

Frequency:

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

$$f = \frac{8 \times 750}{120} = 50 \text{ Hz}$$ 1 mark

Total No of turns per phase T_{ph}:

Total no of conductors = 10 x 72 =720

Total no of turns = $\frac{720}{2} = 360$

Total No of turns per phase T_{ph} = $\frac{360}{3} = 120$ 1 mark

K_c :

For full pitch coils $\alpha = 0$
Hence, $K_c = \cos\frac{\alpha}{2}$
= 1

The RMS Value of EMF Per Phase

$E_{ph} = 4.44\ f\ \phi\ T_{ph}\ K_d\ K_c$ Volts
= 4.44 x 50 x 0.1 x 120 x 0.96 x 1 1 mark
=2557.44 Volts 1 mark

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

Ans:

Construction and Working of Permanent Magnet Stepper Motor:

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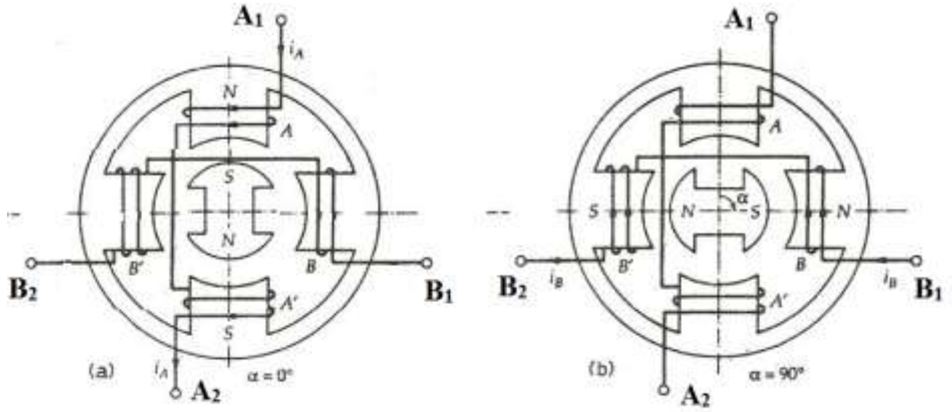


1 mark for diagram

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.

1 mark for constructional details

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 $\alpha = 0^0$.

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 $\alpha = 90^0$.

2 marks for working

Similarly, 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 $\alpha = 180^0$. 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 $\alpha = 270^0$.

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.

2 f) Explain construction and working of D.C. servomotor.

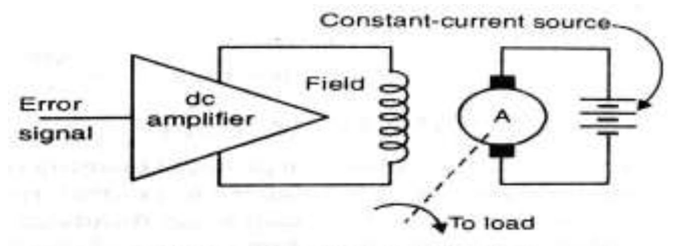
Ans:

Construction and Working of D.C. Servo Motor:

The D.C. motor that is used in servo-mechanism is called a D.C. servo motor.
There are three main types of D.C. servo motor.

- Field controlled D.C. servo motor.
- Armature controlled D.C. servo motor.
- Permanent magnet armature controlled D.C. servo motor.

Field Controlled D.C. Servo Motor:

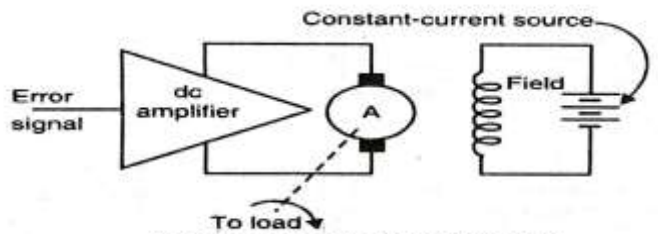


Field-controlled dc servomotor

- In this method the armature is supplied by the constant current source.
- The error voltage represents the difference between the measured signal and the desirable signal.
- The torque produced by the motor is zero when no field excitation is supplied by the d. c. error amplifier.
- Since the armature current is always constant, the torque is directly proportional to the field flux and also it is proportional to the field current up to saturation.
- If the polarity is reversed the motor direction is reversed.

Armature Controlled D.C. Servo Motor:

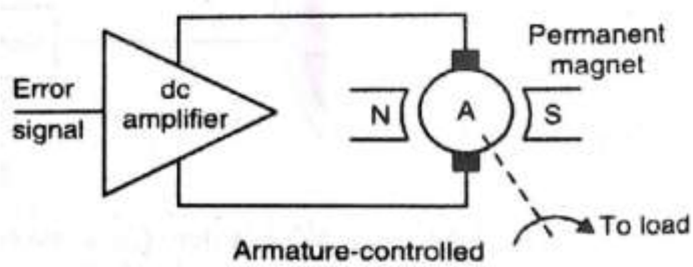
2 marks for diagram and 2 marks for explanation of any one type = 4 marks



Armature-controlled dc servomotor

- In this method the armature is controlled by the electronic amplifier.
- The field winding is supplied by the constant current source.
- The error voltage represents the difference between the measured signal and the desirable signal.
- A sudden large or small change in armature voltage produces an error signal to cause change in torque.
- If the error signal and the polarity of the armature voltage is reversed, the motor reverses its direction.

Permanent Magnet Armature Controlled D.C. Servo Motor:



Armature-controlled permanent magnet dc servomotor

- It uses permanent magnets for constant field excitation instead of the constant current source.
- These types of motors use either alnico or ceramic magnets to produce magnetic field.
- Permanent magnets have several advantages over wound field servo motors including increased efficiency, reduced frame size and high accelerating torque.
- The speed of a PMDC servo motor is varied by changing the voltage applied to the armature.
- Conventional wound field motors are often equipped with interpoles in order to improve commutation and minimize armature reaction.
- The high coercive force of permanent magnet materials used in PM motors eliminates the need for interpoles due to their excellent commutation characteristics.

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

3 a) Derive the condition for maximum running torque of 3 phase induction motor.

Ans:

Condition for Maximum Torque Under Running Conditions:

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

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

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

For maximum torque,

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

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

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

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

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

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

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

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

$$R_2 = sX_2$$ 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.

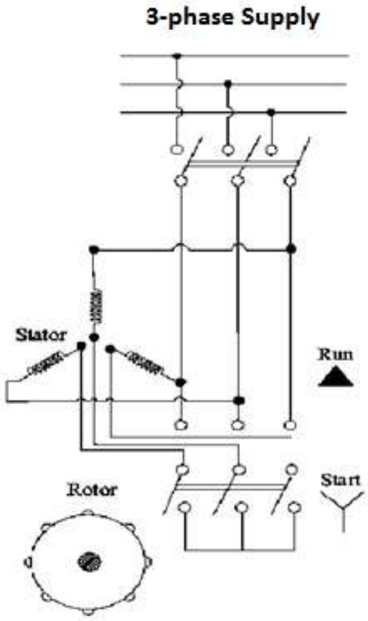
This is the condition for maximum torque produced by motor under running condition. 1 mark

OR Equivalent Derivation

3 b) Draw and explain star delta starter for 3 phase induction motor.

Ans:

Star Delta Starter for 3 Phase Induction Motor:
Diagram



2 marks for diagram

Explanation:
The stator winding of the motor which is designed for delta operation is connected in star during starting period. The arrangement is shown in the above figure; here six leads of the stator windings are connected to change over switch. At the instant of starting the switch is on the "Start" position which connects the stator winding in star connection so that each stator phase gets the $V_L/\sqrt{3}$ volts, where V_L is the line voltage. The application of reduction in voltage reduces the starting current and protects the motor. When motor pick up 75% of rated speed, the changeover switch is put to "Run" position which connects stator windings in delta connection. Now each stator phase gets full line voltage V_L.

2 marks for explanation

3 c) A 12 pole, 50Hz, 3ϕ alternator is coupled to an engine running at 500 rpm. It supplies an induction motor which has full load speed of 1440 rpm. Find the slip and no. of poles of the induction motor.

Ans:
The frequency of generated emf of 3-phase alternator :

$$f = \frac{N_S P}{120} = \frac{500 \times 12}{120} = 50\text{Hz}$$ 1 mark

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

Assume, Ns = Synchronous speed of Induction motor close to actual speed of 1440rpm.

Ns = 1500rpm. 1 mark

∴ No. of poles $= \frac{120\,f}{P} = \frac{120 \times 50}{1500} = 4$

∴ P = 4 pole 1 mark

$\% \, s = \frac{Ns-N}{Ns} \times 100 = \frac{1500-1440}{1500} \times 100$ 1 mark

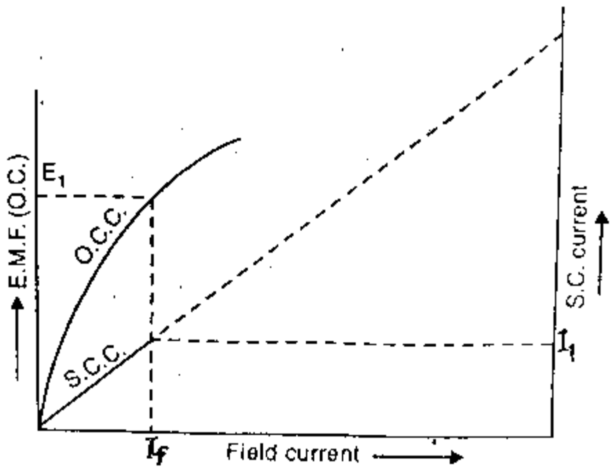
% s = 4 % or 0.04.

3 d) Explain the procedure to calculate voltage regulation of a 3 phase alternator by synchronous impedance method with necessary graphs and phasor diagrams.

Ans:

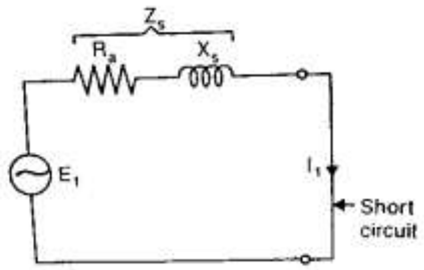
Procedure to calculate Voltage Regulation of a 3-phase Alternator by Synchronous Impedance Method:

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



1 mark

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 Zs this is illustrated in following figure:



1 mark

Now $E_1 = I_1 Z_S$

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

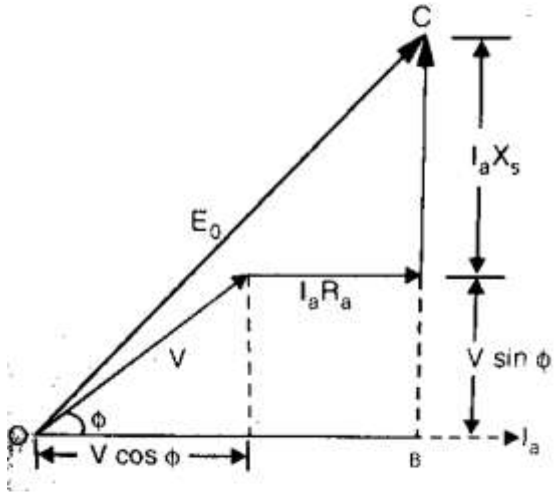
3) By performing resistance test the effective armature resistance Ra can be calculated.

4) The synchronous reactance can be calculated as

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

5) Once we know Ra and Xs the phasor diagram can be drawn for any load and

any p.f. Following figure shows the phasor diagram for usual case of inductive load. Here current Ia has been taken as reference phasor.



1 mark

The E_0 can be found out as: $E_0 = \sqrt{(OB^2 + BC^2)}$

But, OB = $Vcos\emptyset + I_a\,R_a$ and BC = $Vsin\emptyset + I_a\,X_s$

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

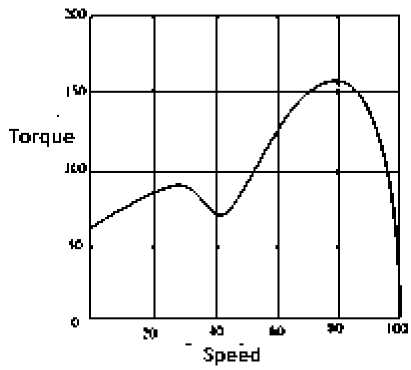
$$\%\ \text{Voltage Regulation} = \frac{E_0 - V}{V} \times 100$$

1 mark

3 e) Draw torque characteristics of shaded pole IM. State its any two applications.

Ans:

Torque Characteristics of Shaded Pole IM:



2 marks for diagram

Applications of Shaded Pole Induction Motor:

1) Small Fans
2) Recording Instruments
3) Record Players
4) Gramophones
5) Toy motors
6) Photocopying machines
7) Small clocks
8) Hair dryers

2 marks for any two applications

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

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4 a) i) A 12 pole, 50Hz, 3 phase induction motor has rotor resistance of 0.15 Ω and stand still reactance of 0.25 Ω per phase. On full load, it is running at a speed of 480 rpm. The rotor induced emf per phase at standstill is observed to be 32 V. Calculate:

(1) Starting torque
(2) Full load torque
(3) Maximum torque
(4) Speed at maximum torque

Ans:

P = 12, f = 50Hz, R_2 / phase = 0.15Ω, X_2 / phase=0.25Ω, N_{FL}= 480 rpm, E_2 / phase=32V

$$Ns = \frac{120f}{P} = \frac{120 \times 50}{12} = 500rpm = 8.333\ rps$$

$$\%\ s = \frac{Ns-N}{Ns} \times 100 = \frac{500-480}{500} \times 100 = 4\%\ or\ 0.04$$

(1)Starting Torque (T_{st}):

$$T_{st} = \frac{3}{2\pi Ns} \times \frac{E_2^2\ R_2}{(R_2)^2+(X_2)^2}\ (Ns\ in\ rps)$$

$$T_{st} = \frac{3}{2\pi \times 8.333} \times \frac{(32)^2 \times 0.15}{(0.15)^2+(0.25)^2} = 103.542\ Nm$$ 1 mark

(2)Full Load Torque (T_{FL}):

$$T_{F.L} = \frac{3}{2\pi Ns} \times \frac{sE_2^2\ R_2}{(R_2)^2+(sX_2)^2}$$

$$T_{F.L} = \frac{3}{2\pi \times 8.333} \times \frac{0.04 \times (32)^2 \times 0.15}{(0.15)^2+(0.04 \times 0.25)^2} = 15.577\ Nm$$ 1 mark

(3)Maximum Torque (T_{max}):

$$T_{F.L} = \frac{3}{2\pi Ns} \times \frac{E_2^2}{2X_2}$$

$$T_{F.L} = \frac{3}{2\pi \times 8.333} \times \frac{(32)^2}{2 \times 0.25} = 117.348\ Nm$$ 1 mark

(4) Speed at Maximum Torque :

The maximum torque occurs at slip:

$$s_m = \frac{R_2}{X_2} = \frac{0.15}{0.25} = 0.6$$

∴ Speed at maximum torque:

N = Ns (1 - S_m) = 500 (1 - 0.6) 1 mark

N = 200 rpm

4 a) ii) A 500 V, 3ph, 50 Hz induction motor develops an output of 15 kW at 950 rpm. If the power factor is 0.86 lagging. Mechanical losses are 730 W and the stator losses 1500 W.

Find

(1) The slip
(2) The rotor Cu loss
(3) The motor input
(4) The line current

Ans:

Given: V_L = 500V, P_{out} = 15 kW, Speed N = 950 rpm
P.F. = cosØ = 0.86 lag
Mechanical loss = 730W, Stator losses = 1500 W.

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

attempted to solve the problem)

Step 1: Find N_s and s :

Assuming the synchronous speed as 1000 rpm, which is close to 950 rpm OR assuming number of poles as 6,

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

$$s = \frac{Ns-N}{Ns} = \frac{1000-950}{1000} = 0.05\ or\ 5\%$$ 1 mark

Step 2 : Find Rotor Output:

Rotor output = P_{out} + Mechanical losses

= 15 kW + 730W = 15.73 kW

Step3 : Find Rotor Copper Loss:

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

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

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

Step 4: Find motor input:

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

= 15000 +1500 +730 +827.89

= 18057.89 W 1 mark

Step 5: Find line current:

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

$$\therefore I_L = \frac{P_{in}}{\sqrt{3}V_L\cos\emptyset} = \frac{18057.89}{\sqrt{3}\times 500\times 0.86} = 24.25\ \text{amp}$$ 1 mark

4 a) iii) A 3300V, 50 Hz star connected alternator has a full load current of 90A. When the output terminals of alternator are shorted a field current of 6A produces a full load current. The open circuit emf for the same field current was 1000V. If the armature resistance per phase is 0.5Ω, find voltage regulation at 0.8 p.f. lagging.

Ans:

Given:

Rated line voltage V_L = 3300V

Phase Voltage $V_{Ph} = \frac{V_L}{\sqrt{3}} = \frac{3300}{\sqrt{3}}$ = 1905.255 V

Frequency f = 50Hz

Star connected alternator

Armature resistance per phase R = 0.5Ω

A)Determination of Synchronous Impedance (Z_S):

For a field current of I_f = 6A, the OC and SC test results are:

Short-circuit current I_{SC} = Full load current = 90A

(phase current = line current = 90A)

Open-circuit line voltage V_{OCline} = 1000 V

$\therefore$Open-circuit phase voltage $V_{OCphase}$ = 1000/√3 = 577.35V

Synchronous impedance is given by,

$$Z_S = \frac{V_{OCphase}}{I_{SC}phase} = \frac{577.35}{90} = 6.415\Omega$$ 1 mark

B)Determination of Synchronous Reactance (X_S):

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

$\therefore$ Synchronous reactance $X_S = \sqrt{(Z_S^2 - R^2)} = \sqrt{(6.415^2) - (0.5)^2}$

$X_S = 6.395\Omega$ 1 mark

C)Voltage regulation at 0.8 lagging:

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

The emf is given by,

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

$= \sqrt{[(1905.255 \times 0.8 + 90 \times 0.5)^2 + (1905.255 \times 0.6 + 90 \times 6.395)^2]}$

$= \sqrt{[2462401.194 + 2953940.002]} = \sqrt{5416341.196}$

$E_0 = 2327.303$ volt

$\% \text{ Voltage Regulation} = \frac{E_0 - V}{V} \times 100$ 1 mark

$= \frac{2327.303 - 1905.255}{1905.255} \times 100$

= 22.15 % 1 mark

4 a) iv) Two alternators are operating is parallel and supply a load of 10 MW at 0.8 ~~log~~ lag. The output of one of the alternator is adjusted to 6 MW at 0.92 ~~log~~ lag. Find ~~pt~~. pf. of the other alternator.

Ans:

kVAR = $kW \times tan\emptyset$

Load pf, $cos\emptyset = 0.8\ lag$; $\therefore \emptyset_L$= 36.869°

$\therefore tan\emptyset_L$= 0.7499

Power Factor of first alternator Unit A = $cos\emptyset_A$= 0.92 $\therefore \emptyset_A$= 23.073°

$\therefore tan\emptyset_A$= 0.426

Total Load kW = $10 \times 10^3 = 10000$ kW

Total Load kVAR = $10000 \times tan\emptyset_L = 10000 \times 0.7499$

= 7499 kVAR

kW Load of Unit A = 6000 kW 1 mark

kVAR of Unit A = 6000 x $tan\emptyset_A$

= 6000 x 0.426

= 2556 kVAR 1 mark

kW Load of Unit B = 10000 – 6000 = 4000 kW

kVAR of Unit B = 7499 - 2556

= 4943 kVAR 1 mark

$tan\emptyset_B = \frac{\text{kVAR of Unit B}}{\text{kW of Unit B}} = \frac{4943}{4000}$ = 1.235

$\emptyset_B = tan^{-1}(1.235) = 51°$

Power Factor of Unit B = $cos\emptyset_B = cos51°$ = 0.6293 lag 1 mark

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

4 b) i) OC and SC test were performed on a 3 phase 0.5 MVA, 3.6 kV, star connected alternator. The results are given below :

O.C. : I_f = 10A, ~~V_{sc}~~=V_{OC} = 3000 V

S.C. : I_f = 10A, I_{sc} = 150 A

Ra / ph = 1Ω, Calculate the percentage regulation for full load condition at 0.8 p.f. lagging.

Ans:

Given:

Alternator power rating = P = 0.5 MVA = 0.5×10^6 VA
Rated line voltage V_L = 3.6 kV = 3600V
Star connected alternator
Armature resistance per phase R = 1 Ω

A)Determination of Synchronous Impedance (Z_S):
For a field current of I_f = 10 A, the OC and SC test results are:
Short-circuit current I_{SC} = 150A (phase current = line current= 150A)
Open-circuit line voltage V_{OCline} = 3000V
∴Open-circuit phase voltage $V_{OCphase}$ = 3000 / √3 = 1732.050V
Synchronous impedance is given by,

$$Z_S = \frac{V_{OCphase}}{I_{SC}} = \frac{1732.050}{150} = 11.547\Omega$$ 1mark

B)Determination of Synchronous Reactance (X_S):
Since $Z_S = R + jX_S$ and $(Z_S)^2 = R^2 + X_S^2$

∴Synchronous reactance $X_S = \sqrt{(Z_S^2 - R^2)} = \sqrt{(11.547^2 - 1^2)}$

$$X_S = 11.503\Omega$$ 1 mark

C)Determination of Full-Load Current (I):
Alternator power rating $P = \sqrt{3}V_L I_L = 0.5 \times 10^6 VA$

∴ Full-load current $I = \frac{MVA \times 10^6}{\sqrt{3}V_L} = \frac{0.5 \times 10^6}{\sqrt{3}(3600)} = 80.187 amp$ 1 mark

Phase voltage V = V_L/√3 = 3600/√3 = 2078.460 V

D)Voltage Regulation at 0.8 Lagging:
$cos\emptyset = 0.8 \qquad \therefore sin\emptyset = 0.6$
The emf is given by,

$$E_0 = \sqrt{[(Vcos\emptyset + I_a R_a)^2 + (Vsin\emptyset + I_a X_S)^2]}$$ 1 mark

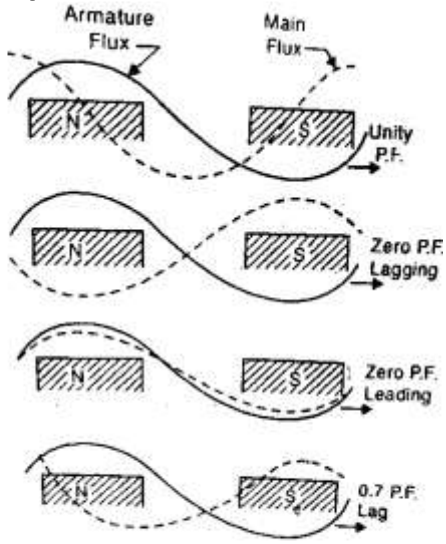
$= \sqrt{[(2078.46 \times 0.8 + 80.187 \times 1)^2 + (2078.46 \times 0.6 + 80.187 \times 11.503)^2]}$
$= \sqrt{[3037892.132 + 4706587.064]} = \sqrt{7744479.196}$
$\boldsymbol{E_0 = 2782.890\ volt}$ 1 mark

$$\%\ \text{Voltage Regulation} = \frac{E_0 - V}{V} \times 100$$
$$= \frac{2782.89 - 2078.46}{2078.46} \times 100$$
= 33.891 % 1 mark

4 b) ii) Define Armature reaction and explain armature reaction at various power factor with sketch.

Ans:
Armature Reaction:
The effect of armature flux on main flux is called as armature reaction. 1 mark for definition

Armature Reaction at Various Power Factors:
When armature is loaded, the armature flux modifies the air gap flux & its angle (electrical) with respect to main flux depends on the load power factor. This is illustrated in waveform diagram as below :



2 marks for diagrams

a) When the load p.f. is unity, the effect of armature reaction is wholly distorting. In other words, flux in air gap is distorted but not weakened. As shown in figure at unity p.f. armature flux is 90° electrically behind the main flux. The result is that the total flux is strengthened at trailing pole tips and weakened at leading pole tips. However the average flux in the air gap practically remains unaltered.

b) When the load p.f. is zero lagging, the effect of armature reaction is wholly demagnetizing. In other words the flux in air gap is weakened. As shown in figure, at zero p.f. lagging, the armature flux and main flux are in direct opposition with each other resulting in considerably reduction in air gap flux and hence generated emf.

3 marks for explanation

c) When the load p.f. is zero leading, the effect of armature reaction is wholly magnetizing. In other words the flux in air gap is increased. As shown in figure at zero p.f. leading the armature flux and main flux are in phase with each other resulting in considerably increased in air gap flux.

d) For intermediate values of load p.f. the effect of armature reaction is partly distorting and partly weakening for inductive loads which is shown in figure for 0.7 lagging p.f. For capacitive loads the effect of flux is partly distorting and partly strengthening

OR Equivalent Diagrams & Explanation

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

5 a) State the methods of slip measurement and explain any one method.

Ans:

Methods of Slip Measurement:

(i) Actual measurement of motor speed (Tachometer method)

(ii) Compairing rotor and stator supply frequency

(iii) Stroboscopic method.

2 marks for methods

(i)Actual Measurement of Motor Speed (Tachometer Method)

This method requires measurement of actual motor speed N and calculation of synchronous speed ‘Ns’.The actual motor speed ‘N’ is measured with the help of a tachometer (Speedometer) and Ns is calculated from the knowledge of supply frequency and the number of poles of the motor.Then slip is calculated by using formula

$$\% S = \frac{Ns-N}{Ns} x\ 100.$$

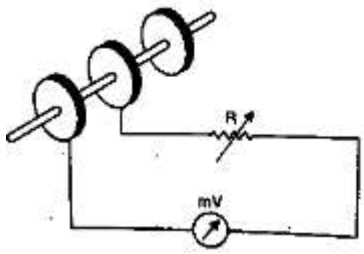
This method is easy & simple for calculation of slip.

(ii)Compairing Rotor and Stator Supply Frequency:

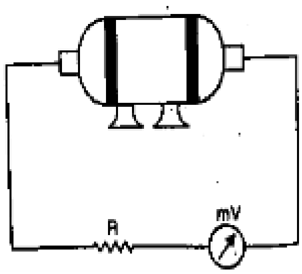
(a) The folowing figure shows the arrangement for measuring the rotor frequency of a slip-ring motor. The leads of the millivoltmeter are lightly pressed across the adjacent slip rings as they revolve.The current in the millivoltmeter follows the variations of the rotor current and hence the pointer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

2 marks for explanation of any one method

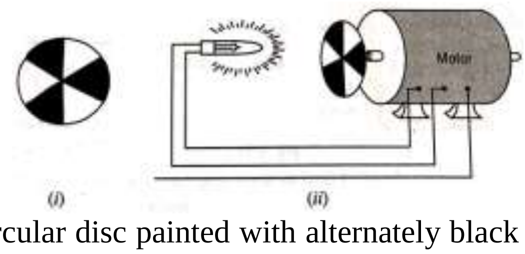
$$\therefore \text{ Slip, s } = \frac{Rotor\ current\ frequency}{Stator\ current\ frequency} = \frac{f_r}{f}$$



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



(iii)Stroboscopic Method:



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 cycle. If the disc were to 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 number 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

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

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

5b) Explain the effect of Armature resistance and leakage reactance on the terminal voltage of alternator.

Ans:

Effect of Armature Resistance on the Terminal Voltage of Alternator:

As the armature or stator winding has some resistance (Ra) there will be an IRa drop when current I flows through armature winding while supplying the load by alternator ultimately the terminal voltage decreases by IRa drop. As load current I increase the terminal voltage further decreases. 2 marks

Effect of Leakage Reactance on the Terminal Voltage of Alternator:

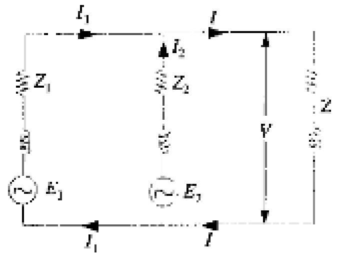
When current flows through the armature winding, flux is set up and a part of it does not cross the air gap and links the coil sides. The leakage flux alternates with current and gives the winding self-inductance. This is called as armature leakage reactance. Therefore there will be IX_L drop which is also effective in reducing the terminal voltage. 2 marks

5c) Explain the concept of load sharing.

Ans:

Concept of Load Sharing:

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



1 mark for diagram

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,

$$\mathbf{V = E_1 - I_1 Z_1 = E_2 - I_2 Z_2}$$

The load sharing can be then given by,

$$\therefore\ I_1 = \frac{E_1 - V}{Z_1} \quad \text{and} \quad I_2 = \frac{E_2 - V}{Z_2}$$ 1 mark

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

For every alternator, two inputs are available:

i) Shaft power input from prime mover

ii) Excitation input from DC supply

A) Effect of change in shaft power input:

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

B) Effect of change in excitation:

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

5 d) State any four advantages of operating alternators ~~is~~ in parallel.

Ans:

Advantages of operating alternators in parallel:

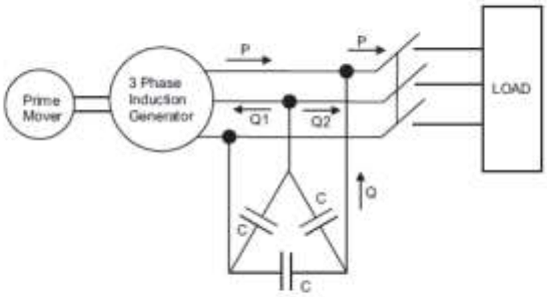
1) Share the electric load on the power system.
2) Reduce the size of the standby unit (reserve unit).
3) Operate the generator units near or at their maximum efficiencies.
4) Increase the reliability of the electric power system as in case of any problem with one of the units, the remaining units can take up the load.
5) Maintain the cost of generation per unit of energy to the minimum.
6) Maintenance and repair becomes easy without disturbing supply continuity
7) Easy future expansion.
8) Saving in fuel.

1 mark for each of any 4 advantages = 4 marks

5 e) Explain working principle of induction generator.

Ans:

Working Principle of Induction Generator:



1 mark for circuit 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

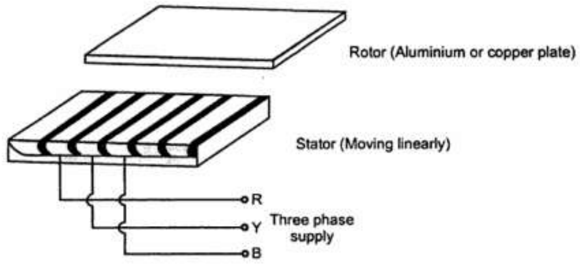
3 marks for explanation

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.

5 f) Explain with diagram working of Linear induction motor.

Ans:

Working of Linear Induction Motor:



2 marks for diagram

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

$v_s = 2\ W f$ *(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.

2 marks for explanation

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

6 a) Explain the method of finding regulation of an alternator by ampere turn method.

Ans:

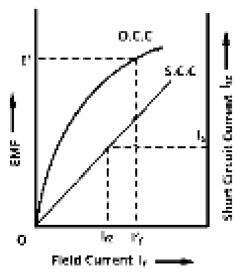
Ampere Turn Method (also called as MMF method):

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

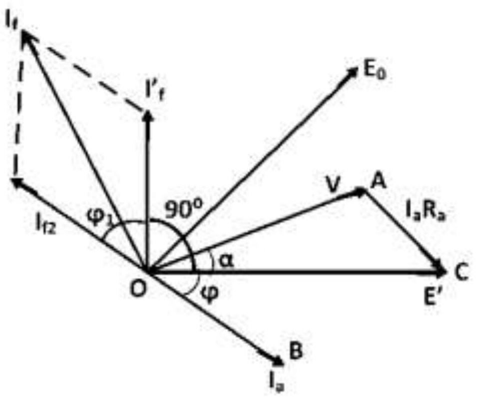
For the phasor diagram:

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.

Model Answers
Winter – 2018 Examination
Subject & Code: A. C. MACHINES (17511)

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'.



Considering the Open Current Characteristics shown above the field current I'_f corresponding to the voltage E' is read. 1 mark

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,

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

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,

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 and voltage regulation can be found out as:

$$\%\ \text{Voltage Regulation} = \frac{E_0 - V}{V} \times 100$$ 1 mark

6b) Why single phase induction motor is not self-starting? Explain.

Ans:

Single Phase Induction Motors are Not Self-Starting:

- When single phase AC supply is given to main winding it produces alternating flux.
- According to double field revolving theory, alternating flux can be represented by two oppositely rotating fluxes of half magnitude.
- These oppositely rotating fluxes induce current in rotor & there interaction produces two opposite torques, hence the net torque is Zero and the rotor remains standstill. 4 marks

Hence Single-phase induction motor does not have starting torque and is not self-starting.

OR

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

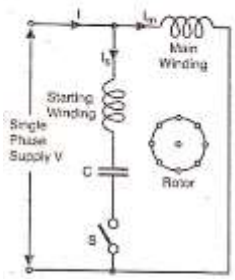
That is why a single phase motor does not have starting torque and is not self-starting.

OR Any Equivalent Answer

6c) Describe with phasor diagrams phase splitting technique in capacitor start induction run ~~run induction~~ motor.

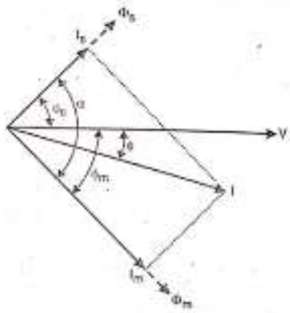
Ans:

Phase Splitting Technique in Capacitor Start Induction Run Motor:



2 marks for diagrams

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°. So splitting of current is achieved here hence 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.



2 marks for description

6d) Write two applications of the following 1 phase 1 M.
(i) Resistances start induction run.
(ii)Capacitors start induction run.

Ans:

(i)Applications of Resistances start induction run:

1) Washing Machine
2) Fans
3) Blowers
4) Domestic Refrigerator
5) Centrifugal Pump
6) Small electrical Tools
7) Saw machine
8) Separators
9) Duplicating Machines
10)Oil Burners

1 mark for each of any two applications = 2 marks

(ii)Applications of Capacitors start induction run:

1) Washing Machine
2) Large Fans
3) Blowers
4) Refrigerator
5) Water Pumps

1 mark for each of any

6) Grinders
7) Drilling Machine
8) Air conditioner
9) Compressors
10)Small portable hoists

two applications = 2 marks

6 e) Write two application of the following motor
(i) AC servo motor
(ii) Stepper motor

Ans:

(i)Applications of AC Servo Motor:
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.Aircraft control system
12.Programming devices

(ii)Applications of Stepper Motor:
1. Computer controlled systems
2. 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
15.Wall Clocks
16.Scanners
17.Respirators
18.Digital Dental Photograph
19.Laser cutters
20.Extruders
21.Engravers
22.Analytical and Medical instruments
23.Embroidery Machines
24.Packeging Machines

2 mark for any two applications of each motor = 4 marks