SUMMER – 13 EXAMINATION

Important Instruction 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 principle components indicated in a 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 some questions credit may be given by judgment on part of examiner of relevant answer based on candidate understands.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

Q.1 A Attempt any three of the following **12 Marks**

a) Enlist any four parts of 3-Phase induction Motor and state the function of each listed.

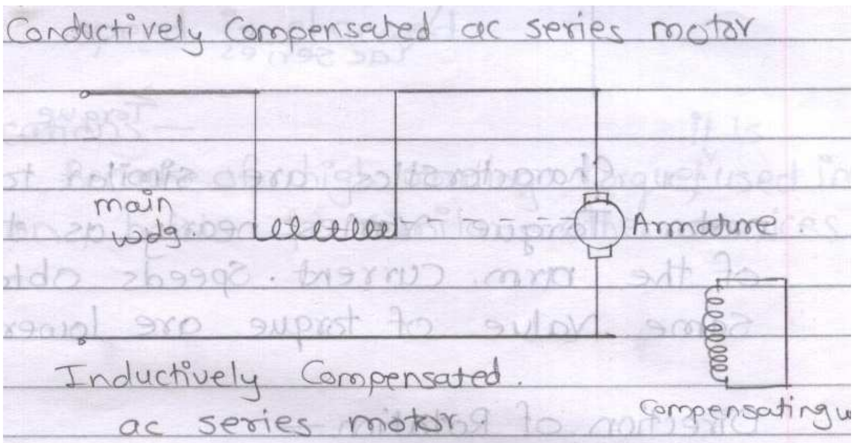
(Any four parts are expected each parts 1 Mark)

S.No	Parts of 3-Ph Induction Motor	Function
1	Stator Frame	Supports the stator core, protects inner parts
2	Stator Core	Stator winding is housed in slots of stator core which provides low reluctance path for rotating magnetic field
3	Stator Winding	Provides rotating magnetic field when supply is given
4	Rotor Core	Rotor conductor is housed in slots of rotor core which provides low reluctance path for rotating magnetic field
5	Rotor Conductor	To produce rotor current
6	Slip-rings in case slip ring I.M	Connect 3-Ph rheostat to the rotor circuit via brushes
7	Brushes in case slip ring I.M	To provide connection between external rheostat to rotor circuit through Slip-ring
8	Shaft	Supports the rotor structure.
9	Cooling Fan	Air circulation and cooling.
10	Air inlet & outlet	Air circulation and cooling
11	Terminal Box	To provide connection to external circuit
12	Foundation	Supports the whole structure of 3-Ph induction motor

b) State any four applications for each of 3 phase squirrel cage induction motor & 3- Ph slip ring Induction Motor. **(1/2 marks to each applications of each motor)**

S.No	Types Of Induction Motor	Applications (Any Four Applications expected)
1	3 phase squirrel cage induction motor	Water Pumps, Tube wells, Lathes Machine, Line shaft, Circular-saws, Grinders, Polishers, Wood Planners, Compressors, Laundry washing machines, fans, and Blowers.
2	3 phase Slip Ring induction motor	Line Shafts, Lifts, Pumps, Generators, winding machine, Auxiliary fans, Smoke exhausters, Printing presses, Elevators and compressors.

c) Practically if D.C series motor has to be supplied with 1- phase A.C. What modification and refinements will on DC series Motor? **(Figure- 2 Marks & Explanation 2 Marks)**



or Equivalent fig

The D.C series motor can be run on A.C supply also, but the following modifications will be done when D.C series motor works on A.C. Supply.

1. The armature & field core are made up of laminated nature to reduce eddy current losses. The Laminations are of silicon steel stampings.
2. The power factor of the motor can be improved by,
   - If possible motor is run at low frequency **or**

- Field is wound with fewer turns than an equivalent DC motor and increase pole area to reduce reluctance.
- And operating the iron at low flux density & at high permeability
- And by keeping small air gap.

3) The sparking of brushes (Armature reaction) will be minimized by compensating winding which is embedded in the pole faces.
If the compensating winding is short circuit on itself as shown in above figure, a motor is said to be inductively compensated.

d) Discuss the advantages of rotating field type alternator.

(Any four Point Expected each point 1 Marks)

Following Advantages of rotating field type alternator:

Various advantages of rotating field can be stated as,

1) The generation level of a.c. voltage may be higher as 11 KV to 33 KV. This gets induced in the armature. For stationary armature large space can be provided to accommodate large number of conductors and the insulations.
2) It is always better to protect high voltage winding from the centrifugal forces caused due to the rotation. So high voltage armature is generally kept stationary. This avoids the interaction of mechanical and electrical stresses.
3) It is easier to collect larger currents at very high voltage from a stationary member than from the slip ring and brush assembly. The voltage required to be supplied to the field is very low (110 V to 220 V d.c.) and hence can be easily supplied with the help of slip ring and brush assembly by keeping it rotating.
4) Due to low voltage level on the field side, the insulation required is less and hence field system has very low inertia. It is always better to rotate low inertia system than high inertia, as efforts required to rotate low inertia system are always less.
5) Rotating field makes the overall construction very simple. With simple, robust mechanical construction and low inertia of rotor, it can be driven at high speeds. So greater output can obtain from an alternator of given size.

6) If field is rotating, to excite it be external d.c. supply two slip rings are enough. Once each for positive and negative terminals. As against this, in three phase rotating armature the minimum number of slip rings required are three and can not be easily insulated due to high voltage levels.
7) The ventilation arrangement for high voltage side can be improved if it is kept stationary.
8) Rotating field is comparatively light and can run with high speed.

Q.1 B Attempt any One of the following **6 Marks**

a) Does the speed of the synchronous motor change when loaded? If not explain how the motor takes load.

The speed of synchronous motor never changes when it is loaded, due to interlocking between stator & rotor magnetic fields. ------------------------------------ **(3 Marks)**

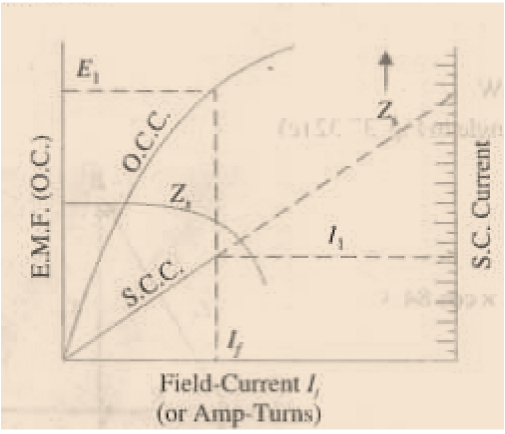
Explanation:-

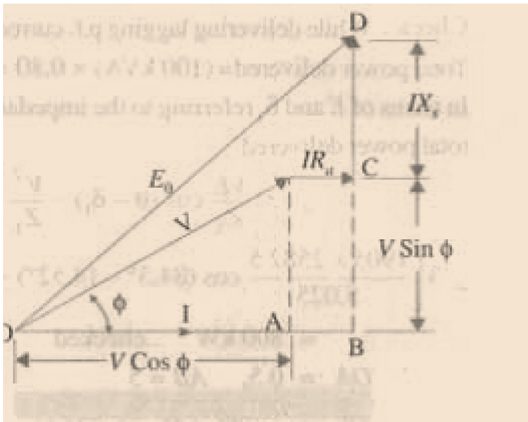
When motor gets loaded, the back emf E_b vector shifts backward due to load angle α.

Thus while operating in normal load condition, α adjusts itself automatically so that power drawn by the motor from A.C supply is just sufficient to fulfill the requirement of the load & losses. -- **(3 Marks)**

b) Discuss fully the synchronous impedance method to calculate voltage regulation of an alternator. Explain why this method is considered as a pessimistic method.

Figure: **or Equivalent fig** **(2 Marks)**





The procedural steps for synchronous impedance method are as follows: -- (2 Marks)

1) The Open Circuit Characteristics OCC is plotted from open circuit test
2) Short Circuit characteristics is plotted from short circuit test:

Short circuit characteristics are straight line through origin. Both characteristics plotted for common field current base. Consider field current If and the corresponding OC voltage E_1.During short circuit, at the same field current, the whole E1 is being used to circulate the short circuit current in armature I_{sc}.

3) The synchronous impedance Zs can be calculated as,

$$E_1 = I_{SC}\, Z_S \rightarrow Z_S = \frac{E_{1OCC}}{I_{SC}}$$

4) By performing resistance test, Effective armature resistance, Ra can be calculated

Synchronous reactance can be calculated as

$$X_S = \sqrt{Z_S^2 - R_a^2}$$

5) The regulation of the alternator at a particular load condition can be calculated as, the generated EMF; E_0 can be calculated as,

$$E_0 = \sqrt{(V\, Cos\phi + I_a R_a)^2 + (V\, Sin\phi + I_a X_S)^2}$$

The % regulation = $\frac{E0 - V}{V} \times 100$

Why this method is considered as a pessimistic method: ------------------------ (2 Marks)

This is indirect method of calculating % regulation, this method assume that the synchronous impedance or reactance is a constant quantity. Actually it is not true, Calculated synchronous impedance or reactance is to large. So regulation obtain by this method is much higher than direct load test method, So it is called the pessimistic method.

Q.2 Attempt any Two of the following **16 Marks**

a) Given Data:

3-Ph, 440V, 50Hz induction Motor, Pole = 4 T_f = 150 N-m
Resistance R_2/Ph = 0.025 Ω Reactance X_2/ Ph =0.15 Ω N= 1440 RPM

$$N_S = \frac{120 f}{4} = \frac{120 \times 50}{4}$$

$N_S = 1500\ RPM$ -- **(1 Mark)**

$$\therefore Slip\ at\ Full\ load\ ie\ Sf = \frac{N_S - N}{N_S} = \frac{1500 - 1440}{1500}$$

$Sf = 0.04$ --- **(1 Mark)**

i) $Speed\ at\ \max.torque\ condition:$

$Condition\ for\ Maximum Torque, R_2 = S\ X_2$

$S = \frac{0.025}{0.15} = Slip\ at\ \max.torque$ ------------------------- **(1 Mark)**

$S = 0.1667$

N = Speed at, S= 0.1667 (Max. torque Slip)

$N = N_S(1 - S) = 1500 \times (1 - 0.1667)$ --------------------------------------- **(1 Mark)**

$N = 1250\ RPM$

ii) We Know, $\frac{T_{full}}{T_{\max}} = \frac{2a\,S_f}{a^2 + S_f{}^2}$, $Where\ a = \frac{R_2}{X_2} = 0.1667$ -------------------------- **(1 Marks)**

$$= \frac{2\,(0.1667)\,(0.04)}{(0.1667)^2 + (0.04)^2}$$

$$= \frac{0.01334}{0.02939}$$

$$= \frac{T_{full}}{T_{\max}} = 0.4539$$

$T_{\max} = \frac{150}{0.4539} = 330.47\ N - m$ -- **(1 Mark)**

iii) $Max.torque\ condition\ for\ Slip\ Ring\ I.M = R_2 + r = S\ X_2$

$Where\ r = External\ rotor\ resistance\ inserted\ per\ ph$

$At\ Start\ S = 1$

$R_2 + r = X_2$

$r = X_2 - R_2 = 0.15 - 0.025$

$r = 0.125\,\Omega / Ph$ ------- **(2 Mark)**

b) Given Data:

3-Ph, 4 Pole, Delta Connected, V= 230 Volt, f= 50 Hz Input P= 10 KW

Speed N= 1440 RPM Stator Losses = 0.6 KW P.f. = 0.8 lag

Windage / Mech. Losses = 0.8 KW

a) The current in each phase

Power I/p = $\sqrt{3}\, V_1\, I_1\, Cos\phi$ -- **(1 Mark)**

$$10\times10^3 = \sqrt{3}\times230\times I_1\times0.8$$

Line Current $I_1 = \dfrac{10\times10^3}{\sqrt{3}\times230\times0.8} = 31.37\ A$ -- **(1 Mark)**

Current in each phase $(I_1/ph) = \dfrac{31.37}{\sqrt{3}} = 18.11\ A$ --- **(1 Mark)**

$$b)\ \therefore Slip\ S_f = \frac{N_S - N}{N_S} = \frac{1500-1440}{1500}$$

$S_f = 0.04\ \ or\ 4\,\%$ --- **(1 Mark)**

c) Rotor I/P = Stator Input – Stator Losses

= 10000-600

= 9400 watts-- **(1Marks)**

Rotor Copper losses = S (Rotor I/P)

= 0.04 x 9400

= 376 watts

d) $Gross\ Rotor\ Output = (1-S)\ Rotor\ \ input$

$Gross\ Rotor\ Output = (1-0.04)\,(9400)$

$Gross\ Rotor\ Output = 9024\,Watts$ --- **(1 Mark)**

$\therefore\ Net\ Motor\ o/p\ = Gross\ \ Rotor\ O/P - Mech\ \ losses$

$= 9042 - 800\,W$ ------------------------ **(1 Mark)**

$=\ 8224\ \ W$

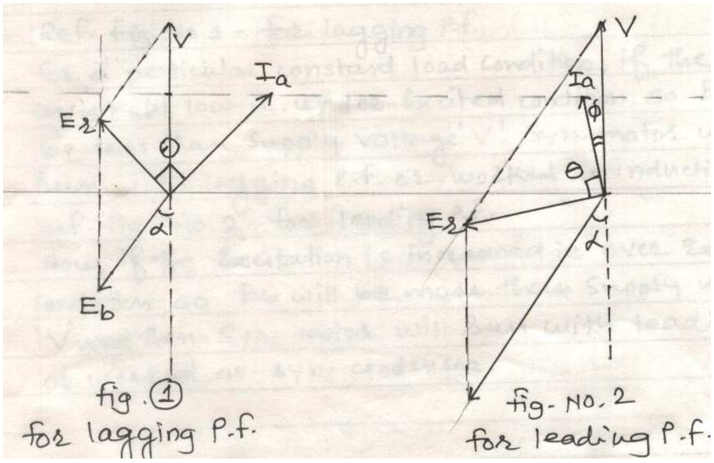
$$\%\eta = \frac{Net\ \ motor\ \ output}{Net\ \ Motor\ \ Input} \times 100$$

$$\%\eta = \frac{8224}{10000} \times 100$$

$\%\eta = 82.24\,\%$ -- **(1 Mark)**

c) Draw and explain the phasor diagram of a synchronous motor operating at a) Lagging Power factor b) Leading Power factor

Phasor Diagram: **(Each Phasor Diagram 2 Mark & Each Explanation 2 Marks)**



or Equivalent fig

a) Ref. Figure No. 1 For Lagging Power Factor:

For a particular constant load condition, if the excitation is kept low i.e. under excited condition, so E_b will be less than supply voltage ‘V’ synchronous motor will run with lagging power factor or worked as inductive load.

b) Ref. Figure No. 2 For Leading Power Factor:

Now, if the excitation is increased i.e. over excited condition, so E_b will be more than supply voltage ‘V’ synchronous motor will run with leading power factor or worked as condenser.

Q.3 Attempt any Four of the following **16 Marks**

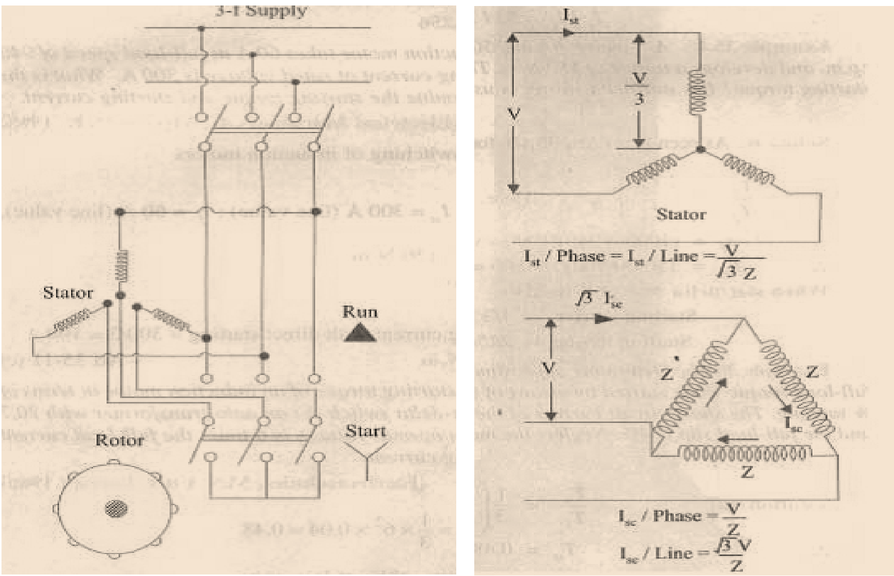
a) Discuss why single phase induction motors is not self starting motor. **(4 Marks)**

- 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 opposite rotating flux of half magnitude.
- These oppositely rotating flux induce current in rotor & there interaction produces two opposite torque hence the net torque is Zero and the rotor remains standstill.
- Hence Single-phase induction motor is not self starting. **OR**

When single phase A.C supply is applied across the single phase stator winding, an alternating field is produced. The axis of this field is stationary in horizontal direction. The alternating field will induce an emf in the rotor conductors by transformer action. Since the rotor has closed circuit, current will flow through the rotor conductors. Due to induced emf and current in the rotor conductors the force experienced by the upper conductors of the rotor will be downward and the force experienced by the lower conductors of the rotor will be upward .The two sets of force will cancel each other and the rotor will experience no torque .Therefore single phase motors are not self starting.

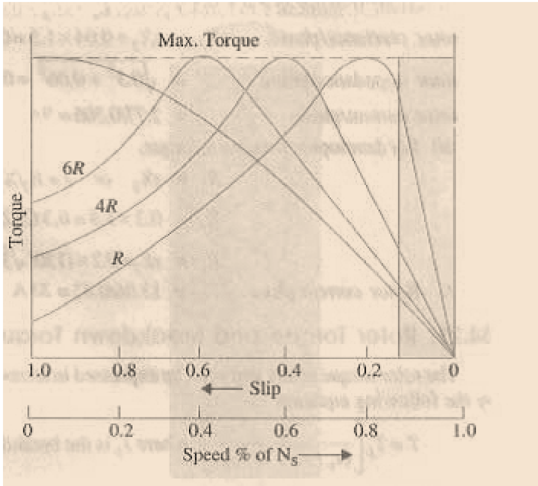
b) Draw the wiring diagram of squirrel cage induction motor with Star-Delta Starter.

(4 Mark)



or Equivalent fig

c) Draw torque Slip Characteristics of 3-Ph Induction Motor. State effect of change of rotor resistance on it. **(Figure-2 Marks & Effect- 2 Marks)**



or Equivalent fig

Effect of variation of Rotor Resistance on the Torque-Slip Characteristics:

1. Starting torque increases with increases in value of rotor resistance**.**
2. Maximum torque remains constant and is independent of the value of rotor resistance**.**
3. The Slip at which maximum torque occurs varies with the variation of rotor resistance.
4. Maximum torque is developed at starting when rotor resistance is equal to the standstill rotor reactance i.e. when R_2 is equal to X_{20}
5. Torque is maximum when the rotor reactance $X_2 = (SX_{20})$ is equal to the rotor resistance R_2.

d) What is hunting? State effect of it on operation of synchronous motor.

(Difination-2 Marks & Effect- 2 Marks)

When a synchronous motor is used for driving a varying load, it produces hunting effect. When there is sudden increase in the load, the load angle is suddenly increased as the rotor is pulled backwards w.r.t. the stator field. If the load is suddenly decreased, then the rotor is immediately pulled up to a new load angle. But in this process the rotor overshoots and again pulled back. In this way, the rotor starts oscillating about its new position of equilibrium. **<u>This is called as hunting or phase swinging.</u>**

Effects of hunting:-

Hunting produces oscillations of the rotor of synchronous motor .If the time period of these oscillations happens to be equal to the natural time period of the machine than mechanical resonance is set up the amplitude of these oscillations is built up to a large value and may throw the machine out of synchronism.

e) List any four types of 1-Ph induction motor. Write down any one application for each.

(Each type of 1-Ph I.M- 1/2 each and any one application of motor 1/2 Mark each)

S.No	Types of 1-Ph Induction Motor (Any Four)	Applications (Any one expected)
1	Split phase Resistance start motors:	Washing Machine, Fans, Blowers, Domestic Refrigerator, Centrifugal Pump, Small electrical Tools
2	Split phase capacitor motor	Fans, Blowers, Grander, Drilling Machine, Washing Machine, Refrigerator, Air conditioner, Domestic Water Pumps, Compressor, conveyors
3	Permanent split single value capacitor motor	Fans, Blowers, Grander, Drilling Machine, Washing Machine, Refrigerator, Air conditioner, Domestic Water Pumps,
4	Two value capacitor motor	Fans, Blowers, Grander, Drilling Machine, Washing Machine, Refrigerator, Air conditioner, Domestic Water Pumps,
5	Single value capacitor starts motor	Fans, Blowers, Grander, Drilling Machine, Washing Machine, Refrigerator, Air conditioner, Domestic Water Pumps,
6	Shaded pole motor	Recording Instruments, Record Player, Gramophones, toy Motors, Hair dryers, Photo copy machine, Advertizing display

Q.4 A) Attempt any Three of the following **12 Marks**

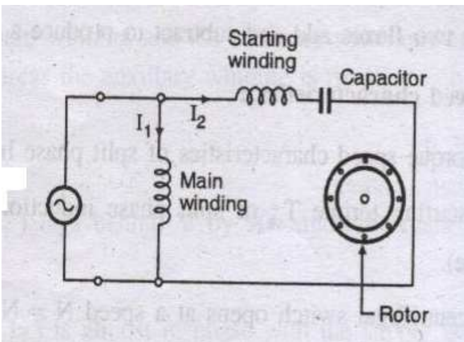
a) State any four points of comparison between squirrel-cage and slip ring induction motor.

(Any four points expected each point- 1 Mark)

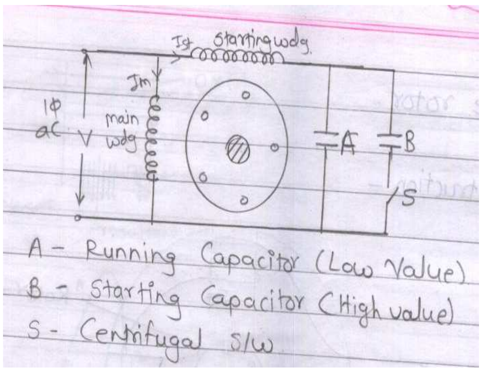
S.No.	Squirrel Cage Induction Motor	Slip Ring Induction Motor
1	**Construction :-**	
	Simple and robust	Complicated and bulkily
2	**Starting Torque :-**	
	Poor	Higher
3	**Operating Efficiency :-**	
	Better	Lower
4	**Applications :-**	
	For driving some how constant load eg. Lathe Machine, Workshop Machine and water pump	For driving heavy load where high starting torque is required eg. Lift, Crane, Elevators, conveyor belts etc
5	**Limitation :-**	
	Low Starting torque external resistance cannot be connected ,speed control is difficult	Frequent maintenance is essential. low efficiency P.f. more costly

b) Explain the principle of working of capacitor start capacitor run induction motor.

(Figure- 2 Mark & Explanation- 2 Mark)



OR



or Equivalent fig

In these motors one capacitor is connected in series with the auxiliary winding. There is no centrifugal switch. Thus this winding along with the capacitor remains energized for both starting and running conditions. Capacitor used serves the purpose of obtaining necessary phase displacement at the time of starting and also improves the power factor of the motor

c) Explain why rotor speed of 3 phases Induction never catches the speed of Stator flux.

(4 Marks)

The working principle of three phase induction motor is based on relative motion between rotating magnetic field and rotor conductors i.e (N_S - N), According to Lenz's law rotor will try to catch the synchronous speed of rotating magnetic field to oppose the 'cause producing it'. But rotor never succeeds due to frictional losses.

If rotor catches the synchronous speed of rotating magnetic field, (N_S - N) i.e is relative motion will be zero and rotor stops to rotate. **OR**

Relative motion between rotor conductors and rotating magnetic field induces rotor currents. Interaction of rotor current of stator flux produces torque on rotor which means that relative motion of rotor is the cause of rotation of rotor. In No-load condition, due to friction of windage rotor has to produce a small torque to overcome frictional force and thus rotor speed never catches synchronous speed

d) Explain the term armature reaction in relation to 3-Phase alternator & discuss the effect of load power factor on armature reaction.

Armature Reaction: - **(1 Mark)**

When the armature conductors carry current they produce their own flux this flux affects the main pole flux. Due to the change in flux the terminal voltage available at the load conditions will be different. The effect of armature flux on pole flux is called as armature reaction.

The effect of armature reaction depends upon power factor the load:

1) **For Resistive load or unity P.f.:-** In this case the armature flux crosses the main flux. This Effect is called **'Cross magnetizing effect**. Due to this, the main flux will be distributed and terminal voltage drops ie $V_T \langle E$.----------------------------------**(1 Mark)**
2) **For lagging P.f. or inductive load: -** In this case the armature flux opposes the main flux. This effect is called as **de-magnetizing Effect**. Due to this, the main flux will be weakened and terminal voltage drops ie $V_T \langle E$.--------------------------------**(1 Mark)**

3) **For leading P.f. or capacitive load: -** In this case the armature flux assists the main flux. This Effect is called as Strong **magnetizing** and due to this ,the main flux will be stronger & terminal voltage increases ie $V_T \rangle E$.-----------------------------------**(1 Mark)**

Q.4 B) Attempt any One of the following **6 Marks**

a) Is it possible to change the direction of rotation of shaded-pole type single phase Induction? **(6-Marks)**

The Shaded pole motor generally has a definite direction of rotation which cannot be reversed. However, if such reversal is essential, it can by achieved by providing two shading coils, one on each end of every pole. Then by open circuiting one set of shading coils and short circuiting the other set, desired direction of rotation can be achieved.

b) Derive e.m.f equation of 3-Ph alternator considering chording factor and distribution factor.

Let, P = no. of rotor poles. ϕ = Flux per pole Z= Number of stator conductors

N = Speed in rpm

$$\therefore turns\ per\ phase\ (Tph) = \frac{Z_{Ph}}{2}$$

$\therefore$ Frequency of induced emf is

f = Cycles per rotation x rotation per sec

$$\therefore = \frac{P}{2} \times \frac{N}{60}$$

$$\therefore f = \frac{PN}{120}$$ --- **(1 Marks)**

Consider one rotation of rotor then change in flux linkage is,

$d\phi = P.\ \phi$ Time required for one rotation is,

$$\therefore dt = \frac{1}{n} = \frac{1}{(N/60)} = \frac{60}{N} ----------Sec.$$ ----------------------------- **(1 Marks)**

By faradays law of Electromagnetic induction

$$\therefore Average\ emf\ per\ conductor = \frac{d\phi}{dt}$$

$$\therefore E_{ave} / \text{Conductor} = \frac{P.\phi}{(N/60)}$$

$$\therefore E_{ave} / \text{Conductor} = \frac{P\times\phi\times N}{60} --------Volt$$ --------------------- **(1 Marks)**

$$\therefore E_{ave} / \text{turn} = 2\ E_{ave} / \text{Conductor}\ \frac{P\times\phi\times N}{60} --------Volt$$

$$\therefore E_{ave} / \text{turn} = 2\ \frac{P\times\phi\times N}{60} --------Volt$$

$$\therefore \qquad = \frac{4P\phi\ N}{120} --------Volt$$

$$\therefore \qquad = 4(\frac{P\ N}{120})\ \phi$$

$$\therefore E_{ave} / \text{turn} = 4\ f\ \phi \quad \therefore (f = \frac{P\ N}{120})$$

$$\therefore E_{ave} / \text{Phs} = E_{ave} / \text{ x Number of turns per phase}$$

$$= 4\ f\ \phi\times T_{Ph}$$ -- **(1 Marks)**

RMS Value per phase is given by,

$$E_{ph} = E_{ph}\text{ (ave) x Form Factor}$$

$$= 4\ f\ \phi\times T_{Ph}\times 1.11$$ -- **(1 Marks)**

$$\boxed{E_{ph} = 4.44\ f.\phi.T_{Ph}}$$

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

$$\boxed{E_{Ph} = 4.44\ f\ \phi.T_{Ph}.kd.kc}$$

---------------------------------- **(1 Marks)**

Kc = coil span factor or chording factor

Kd = Distribution factor

Q.5 A) Attempt any Two of the following **16 Marks**

a) Given Data:

3Ph, 6 Pole, 50 Hz I.M   Full load Slip = 3.5 %   Stator Losses 1700 watts

Torque at shaft i.e Gross Torque = 153 N-m = T_g Mechanical Losses = 575 watt

Where $N_S = \dfrac{120\,f}{P} = \dfrac{120\times 50}{6} = 1000\,RPM$ -------------------------------- **(1 Marks)**

Full Load Speed = Ns (1-S),

Full Load Speed = 1000 (1-0.035)

Full Load Speed = 965 RPM ------ ------------------------- **(1 Marks)**

1) Gross Rotor Output = $2\,\pi\,N\,T_g$ (Where, N in RPS)

$$= 2\times 3.142\times \frac{965}{60}\times 153$$

$= 15463.35\,Watts$ -- **(1 Marks)**

Net Motor output = Gross Rotor output – mech. Losses

= 15463.35 - 575

Net Motor output = 14888.35 Watts--- **(1 Marks)**

2) Rotor Input = $\dfrac{Gross\ \ Rotor\ \ output}{(1-S)}$ --- **(1 Marks)**

Rotor Input = $\dfrac{15463.35}{(1-0.035)} = 16024.2\,Watts$

Rotor Copper Losses = $S\times Rotor\ \ Input$

Rotor Copper Losses = 0.035×16024.2

Rotor Copper Losses = $560.847\ \ Watts$ -- **(1 Marks)**

3) Net Motor Input = $Rotor\ Input + Stator\ Losses$

Net Motor Input = $16024.2 + 1700\ \ Watts$

Net Motor Input = $17724.2\ \ Watts$ --- **(1 Marks)**

$$\% \eta = \frac{Net\ \ Motor\ output}{Net\ Motor\ Input} \times 100$$

$$\% \eta = \frac{14888.35}{17724.2} \times 100$$

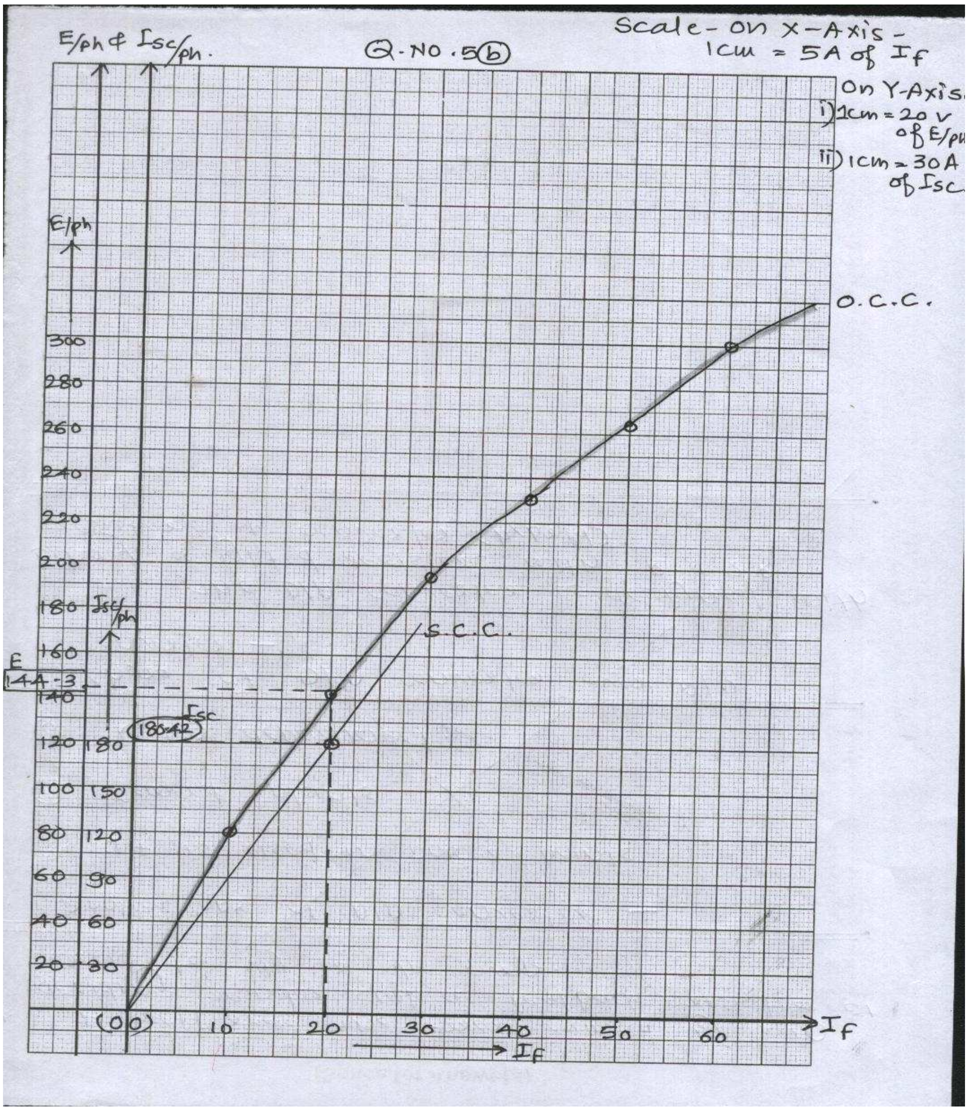
$\% \eta = 84\,\%$ -- **(1 Marks)**

b) Given Data:

3-Ph, 400V, P = 125 KVA Ra = 0.15 ohm

Field current (A)	0	10	20	30	40	50	60
Open circuit emf (V)	0	140	250	340	400	460	520
Open circuit V per Phase		**80.8**	**144.3**	**196.3**	**230.9**	**256.6**	**300**

Note : In Graph Scale may be different : --- (2Mark)



Phase Resistance, R_a = 0.15 ohm

Phase Voltage V= $\frac{400}{\sqrt{3}} = 230.90\, volts$ ---------------------------------- **(1/2Mark)**

Full load Line current I = I_a = $\frac{125\times10^3}{\sqrt{3}\times440}$ =$180.42 A$ -------------------- **(1/2Mark)**

From OCC and SCC:-

$$\therefore Synchronous\ impedance\ per\ phase = Zs = \frac{O.C\ Voltage/ph}{S.C\ Current/ph} = \frac{144.3}{180.42}$$

$$\therefore Synchronous\ impedance\ per\ phase = Zs = 0.8\Omega$$ --------------------------- **(1/2Mark)**

Synchronous reactance, $X_S = \sqrt{Z_S^2 - R_a^2} = \sqrt{0.8^2 - 0.15^2} =$ 0.7858 Ω --------- **(1/2Mark)**

i) 0.8 Lagging Power Factor;

$$No.\, load\ emf\ E_0 = \sqrt{(V\, Cos\phi + I_a R_a)^2 + (V\sin\phi + I_a X_S)^2}$$ ------------------------ **(1Mark)**

$$No.\, load\ emf\ E_0 = \sqrt{(230.9\times0.8 + 180.42\times0.15)^2 + (230.9\times0.6 + 180.42\times180.42\times0.7858)^2}$$

$$No.\, load\ emf\ E_0 = \sqrt{(2211.783)^2 + (280.31)^2}$$

$$No.\, load\ emf\ E_0 = 351.32\, Volt$$

$$\text{Re}\,gulation = \frac{E_0 - V_T}{V_T}\times100 = 230.9\times100$$

% Regulation = 52.15 %--- **(1Mark)**

ii) 0.707 leading Power Factor;

$$No.\, load\ emf\ E_0 = \sqrt{(V\, Cos\phi + I_a R_a)^2 + (V\sin\phi + I_a X_S)^2}$$

$$No.\, load\ emf\ E_0 = \sqrt{(230.9\times0.707 + 180.42\times0.15)^2 + (230.9\times0.707 + 180.42\times0.7858)^2}$$

$$No.\,load\ emf\ \ E_0 = \sqrt{(190.31)^2 + (21.47)^2}$$

$$No.\,load\ emf\ \ E_0 = 191.52\ \ Volt$$

$$\text{Re}\,gulation = \frac{E_0 - V_T}{V_T} \times 100 = \frac{191.52 - 230.9}{230.9} \times 100$$

% Regulation = -17.05 % -- **(1Mark)**

iii) Unity Power Factor;

$$No.\,load\ emf\ \ E_0 = \sqrt{(V\ Cos\phi + I_a R_a)^2 + (V\ \sin\phi + I_a X_S)^2}$$

$$No.\,load\ emf\ \ E_0 = \sqrt{(230.9 \times 1 + 180.42 \times 0.15)^2 + (180.42 \times 0.7858)^2}$$

$$No.\,load\ emf\ \ E_0 = \sqrt{(257.96)^2 + (141.77)^2}$$

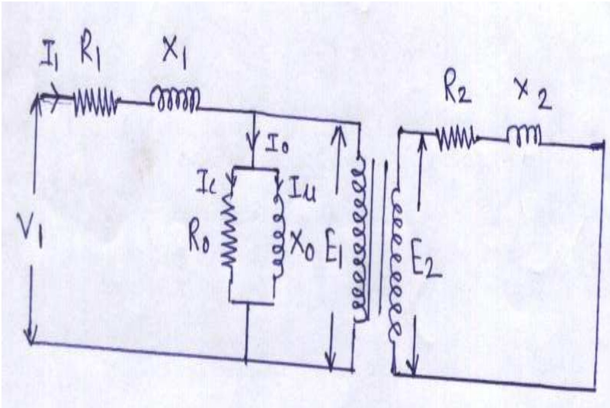
$$No.\,load\ emf\ \ E_0 = 294.35\ \ Volt$$

$$\text{Re}\,gulation = \frac{E_0 - V_T}{V_T} \times 100 = \frac{294.35 - 230.9}{230.9} \times 100$$

% Regulation = 27.48 % -- **(1Mark)**

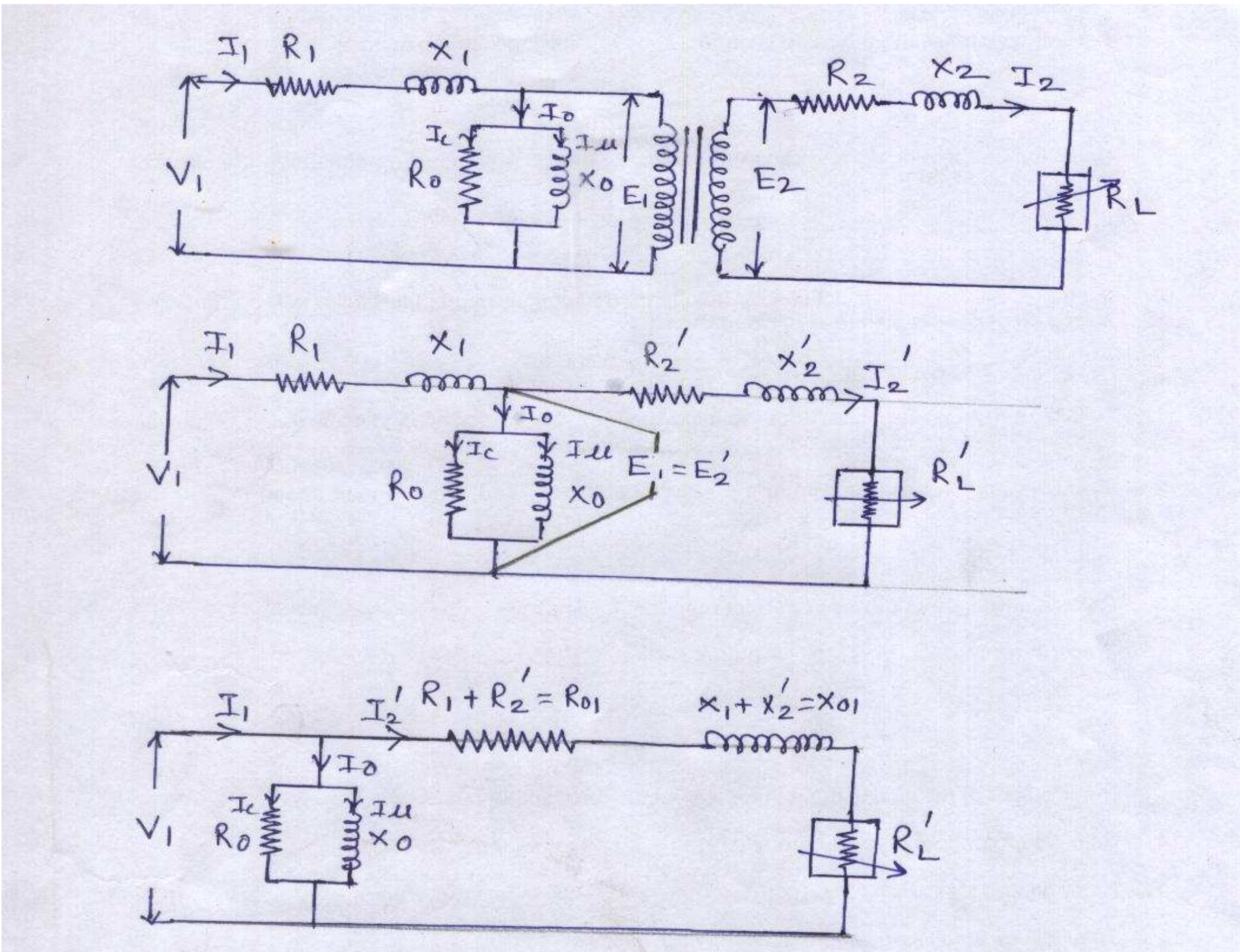
c) Derive equivalent circuit diagram of 3-ph Induction motor. State the terms used in it.

- Terms used in equivalent circuit diagram of 3-Ph induction motor all the quantities are per phase quantities.
- **Stator Side:** i) V_1 = Input Voltage to Stator ii) I_1 = Total Stator current
  iii) I_0 = No load stator current iv) I_C = Working component of I_0
  v) I_μ = Magnetizing component of I_0 vi) I_2' = Rotor current referred to stator side
  vii) E_1 = Self induced emf at standstill in stator viii) R_1= Stator Resistance
  ix) X_1 = Stator Reactance Standstill
- **Rotor Side :** i) I_2 = Rotor Current ii) R_2 = Rotor Resistance
  iii) X_2 = Rotor Reactance at standstill iv) E_2= Mutual induced emf in Rotor at standstill
  v) R_L = Mech. Load Representative vi) S = % Slip



----------- **(5 Marks)**

Each remaining steps 1 Mark Each



where $R_2' = \frac{R_2}{K^2}$; $X_2' = \frac{X_2}{K^2}$; $R_L' = R_2'\left(\frac{1}{S} - 1\right)$

$I_2' = I_2 K$; $E_2' = \frac{E_2}{K}$

Q.6 Attempt any Four of the following **16 Marks**

a) Derive the condition for maximum torque under running condition.

Note: The student can follow for different method of derivation also

Let us consider the equation of torque,

$$T = \frac{K\,\phi\,S\,E_2\,R_2}{R_2{}^2 + S^2\,X^2}$$ -- **(1 Mark)**

Condition of maximum torque can be found out by taking derivative of torque equation w.r.t. Slip and equating it to zero. For the simplicity of derivation, let us put $\frac{1}{T} = M$

$$M = \frac{R_2{}^2 + S^2\,X_2{}^2}{K\,\phi\,S\,E_2\,R_2}$$ --- **(1 Mark)**

$$M = \frac{R_2^2}{K\,\phi\,S\,E_2\,R_2} + \frac{S^2\,X_2{}^2}{K\,\phi\,S\,E_2\,R_2}$$

$$M = \frac{R_2}{K\,\phi\,S\,E_2} + \frac{S\,X^2}{K\,\phi\,E_2\,R_2}$$

$$\frac{d(M)}{dS} = \frac{d}{dS}\left[\frac{R_2}{K\,\phi\,S\,E_2} + \frac{S\,X_2{}^2}{K\,\phi\,E_2\,R_2}\right] = 0$$ ----------------------- **(1 Mark)**

$$-\frac{R_2}{K\,\phi\,S^2\,E_2} + \frac{X_2{}^2}{K\,\phi\,E_2\,R_2} = 0$$

$$\frac{X_2{}^2}{K\,\phi\,E_2\,R_2} = \frac{R_2}{K\,\phi\,S^2\,E_2}$$

$$\frac{S^2 X_2{}^2}{K\,\phi\,E_2\,R_2} = \frac{R_2^2}{K\,\phi\,S^2\,E_2}$$

$$S^2 X_2{}^2 = R_2^2$$

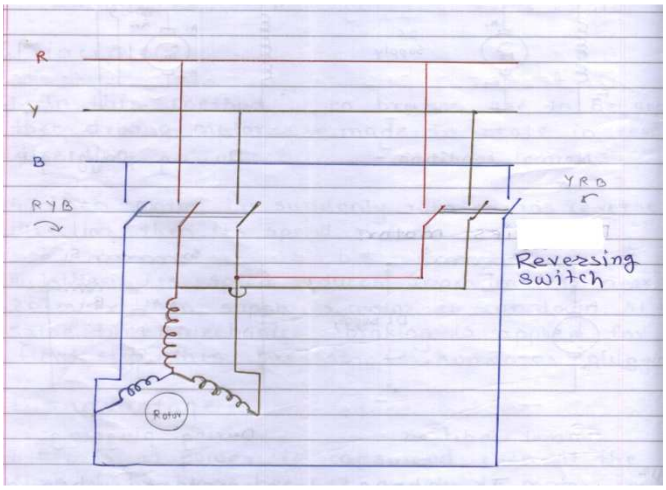
$$\boxed{\therefore R_2 = S\,X_2}$$

------------------------ **(1Mark)**

This is the condition for maximum torque of 3-Ph induction motor under running

b) Explain in brief how the direction of induction motor change with circuit can diagram.

(Figure – 2 Marks & Explanation-2 Marks)



Direction of 3-Ph induction motor can be changed by changing any 2 phases of stator supply as shown in figure for this reversing switch is used. **OR**

The direction of rotation of three phase induction motor can be changed by changing its phase sequence

c) Given Data:

N = 700 RPM Slip = 4% P =? (if f = 60Hz & 50 Hz) Actual Speed N_r =?

As speed is 700 rpm is synchronous speed must be greater than 700 RPM

$$Ns = \frac{120\ f}{P}$$

Where f = Supply frequency P = No. of pole

Number of poles must be even integrate

When Frequency f = 60 Hz Number of pole:

$$N_S = \frac{120\ f}{p}$$ -- **(1/2 Mark)**

If P = 10

$$\therefore Ns = \frac{120\ f}{P} = \frac{120 \times 60}{10}$$

N_S = 720 RPM

$P = 10\ Nos\ pole\ \ for\ f = 60Hz$ -- **(1/2 Mark)**

When Frequency f = 50 Hz Number of pole:

$$N_S = \frac{120\ f}{p}$$ -- **(1/2 Mark)**

If P = 8

$$N_S = \frac{120 \times 50}{8} \quad N_S = 750 RPM$$

$P = 8\ Nos\ pole\ \ for\ f = 50Hz$ -- **(1/2 Mark)**

Actual Speed:

When, F = 60 Hz, $N_S = 720$

$$N = N_S\ (1 - S)$$

$$N = 720\ (1 - 0.04)$$

$N = 691.2\ RPM$ -- **(1 Mark)**

When, F = 50 Hz, $N_S = 750$

$$N = N_S\ (1 - S)$$

$$N = 750\ (1 - 0.04)$$

$N = 720\ RPM$ -- **(1 Mark)**

d) What is induction generator? Under what condition induction motor will acts as Induction generator? What will be the value of slip in case of induction generator?

Induction generator: **(2 Mark)**

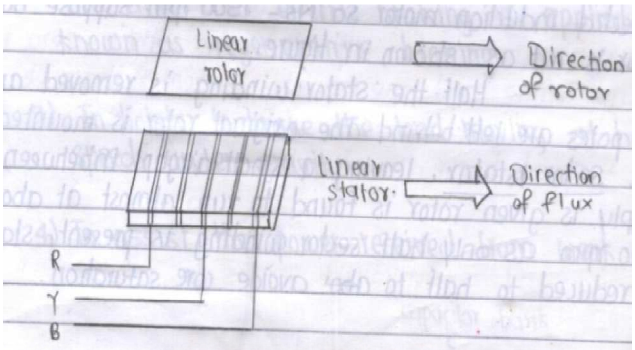
When rotor of induction motor runs faster than synchronous speed, induction motor runs as generator and called as induction generator. It converts mechanical energy it receives from the shaft into electrical energy which is released by stator. However, for creating its own magnetic field, it absorbs reactive power Q from the lime to which it is connected. The reactive power is supplied by a capacitor bank connected at the induction generator output terminals.

Under condition induction motor will acts as Induction generator: When rotor speed is greater than synchronous speed than induction motor will acts as Induction generator **(1 Mark)**

What will be the value of slip in case of induction generator: Slip will be negative **(1Mark)**

e) Explain the principle of operation of linear induction motor.

(Figure- 2 Marks & Principle – 2 Marks)



In a sector IM, if sector is made flat and squirrel cage winding is brought to it we get linear I.M. In practice instead of a flat squirrel cage winding, aluminum or copper or iron plate is used as rotor.

The flat stator produces a flux that moves in a straight line from its one end to other at a linear synchronous speed given by $V_s = 2\ wf$

Where, V_s = linear synchronous speed in m/sec

w = width of one pitch in m.

f = supply frequency (Hz)

The speed does not depends on number of poles but only on the poles pitch and supply frequency. As the flux move linearly it drags the rotor plate along with it in same direction. However in much practical application the rotor is stationary while stator moves.

--END--