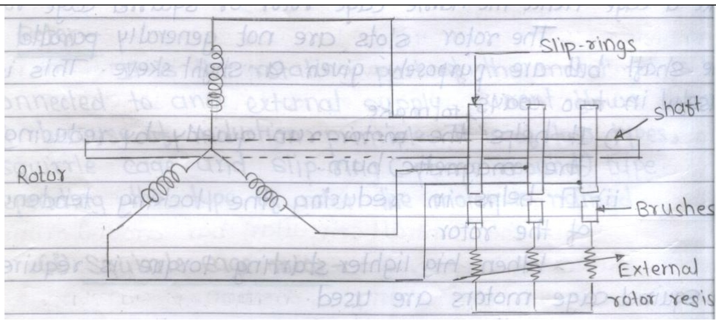
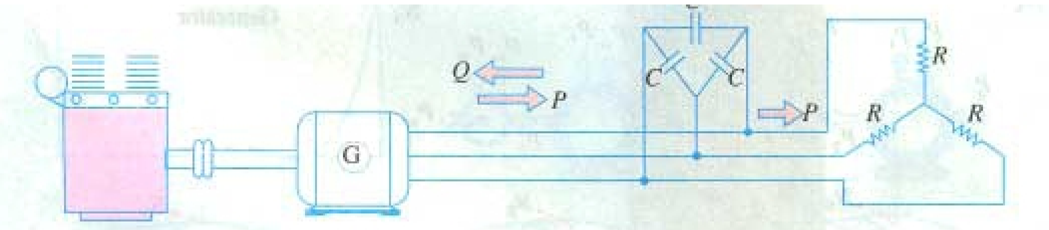
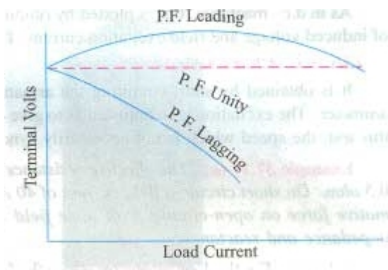
Important suggestions to examiners:

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.
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) Some of the questions are not clearly indicative of the exact answer expected. In such cases, credit may be given by judgment of relevant answer based on candidate's understanding.

Q1. a) i) State and explain working principle of three phase induction Motor	4
When 3-Ph AC supply is given to stator, rotating magnetic flux is produced in air gap. It has constant magnitude & constant speed called as 'synchronous speed'(N_s=120 f/P). when the flux rotates over rotor conductors $d\phi/dt$ is created & emf is induced in rotor conductor according to faradays laws of electromagnetic induction. As rotor is short circuited, current flows through it. Interaction of rotor current and rotating magnetic field produces torque on rotor and it starts rotating.	3
According to 'Lenz Law' the rotor current should oppose the cause which produces it. Here the cause is relative speed between flux & rotor therefore to minimize the relative speed rotor starts rotating in the direction of flux.	1
Q1. a) ii) How Speed of induction motor is controlled by inserting resistance	4
This method is only applicable to slip-ring motors. The motor speed is reduced by introducing an external resistance in the rotor circuit through slip-ring. As rotor resistance increases speed goes on reducing.	2
Limitations:- • Size of rotor rheostat is large therefore system is bulky. • With increases in R2, I^2R losses are increased which reduce efficiency of motor. The loss is directly proportional reduction in speed. • Not suitable for squirrel cage Induction motor. • Large speed variation is not possible.	2



Q1. a) iii) What is induction generator ? list its applications	4
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 reactivep 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.	2
	1
Induction generators are always used in 1) wind power generation 2)Micro hydro power generation.	1
Q1 iv) Define three phase alternator. State the factor affecting the terminal voltage.	4
Three phase alternator is a rotating machine with three phase winding on stator and dc field winding on rotor. When the rotor rotates and the dc field is excited, it produces balanced three phase voltage output.	3
The terminal voltage of alternator depends upon 1) load current 2) pf of the load 1) When load pf is unity or lagging, the terminal voltage drops with increase in load. 2) When the load pf is leading, the terminal voltage increase with increase in load 	1
Q1b i) Explain effect of hunting and phase swinging on the operation of synchronous motor. How it is minimised	4
When a synchronous motor us used for driving a varying load, it produce hunting effect.When there is sudden icrease 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 immdiately 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 postion of	2

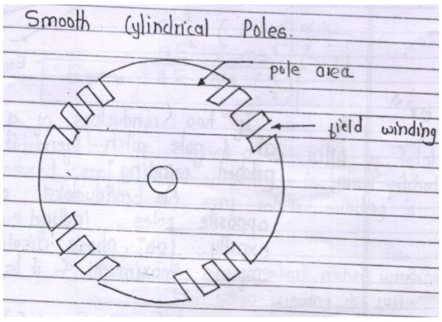
equillibrium. This is called as hunting or phase swinging.

Hunting is minimized by placing damper windings on the rotor pole surface. Damper windings are short circuited copper bars placed on rotor pole faces. During rotor equilibrium condition, damper windings are inactive. Whenever the rotor oscillates, because of the relative motion between stator and rotor, currents are induced in damper windings. This produces a torque which restores the rotor back to its equilibrium position and hunting is prevented 2

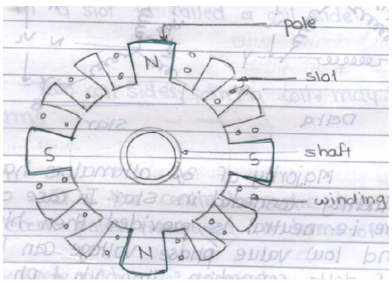
Q1b ii) Explain construction of smooth cylindrical rotor. State its applications 4

Smooth cylindrical rotors are used for turbine driven alernators which run at high speeds. The rotor consists of a smooth cylindrical forged steel sylinder, having number of slots along outer periphery. Field coils are placed in these slots. The central pole faces are surrounded by field coils placed in slots. 1

Such rotors are designed mostly for 2-pole or 4-pole turbo generators running at 3600 or 1800 RPM 1



OR



or Equivalent fig. 2

Q2. a) A 400 Volts, 8 pole, 60Hz, 3 ph slip ring induction motor has standstill impedance/phase 0.05+j0.3 ohm Estimate 8
1) Slip at maximum torque and corresponding torque tonne
2) The external resistance per phase to be inserted in the rotor circuit to obtain maximum torque at start
3) What additional advantage is achieved by adding external resistance

1) Condition for max torque,

$$R_2 = sX_2$$

4

$Z_2 = 0.05 + j0.3$ $R_2 = 0.05\, X_2 = 0.3$ The slip at which max torque occurs is given by $s = 0.05/0.3 = 0.16$ The torque value can't be determined since data is insufficient 2) At starting slip s=1 Let resistance r be added in the rotor circuit so that the effective rotor resistance becomes $R_2 = 0.05 + r$ $\frac{0.05+r}{0.3} = 1 \quad \Rightarrow r = 0.25$ 3) Advantage by adding external resistance is i) Decrease in starting current ii) Maximum starting torque	2 2

Q2. b) Compare Squirrel Cage induction Motor and Slip-ring induction Motor. Also State applications of 3-Ph induction motor. — 8

Any four points

S.No.	Squirrel Cage Induction Motor	Slip Ring Induction Motor
1	Rotor is in the form of bars	Rotor is in the form of 3-ph winding
2	No slip-ring and brushes	Slip-ring and brushes are present
3	External resistance cannot be connected	External resistance can be connected
4	Small or moderate starting torque	High Starting torque
5	Starting torque is of fixed	Starting torque can be adjust
6	Simple construction	Completed construction
7	High efficiency	Low efficiency
8	Less cost,	More cost,
9	Less maintenance	Frequent maintenance due to slip-ring and brushes.
10	Starting power factor is poor	Starting power factor is adjustable & large
11	Size is compact for same HP	Relatively size is larger
12	Speed control by stator control method only	Speed can be control by stator & rotor control method

4

Applications of 3-Ph induction motor

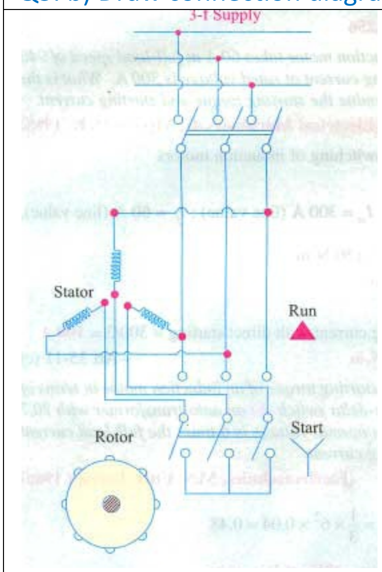
i) Lathes Machine ii) Pumps iii) fans iv) Cranes v) Lifts vi) Elevators

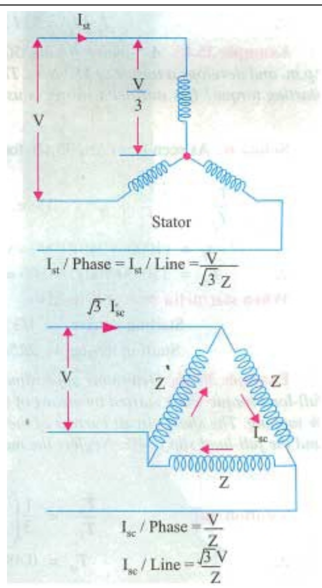
4

vii) Compressor viii) Hoists	
Q2.c An industrial plant has a load of 800KW at a power factor of 0.8 lagging. It is desired to install a synchronous motor to deliver a load of 200 KW and also serve as a synchronous condenser to improve overall power factor of the plant to 0.92. Determine the KVA rating of the synchronous motor and its power factor. Assume that the synchronous motor has efficiency of 90%.	8
1) Load KW = 800, Plant pf = 0.8 before compensation The KVA of load is $KVA = \frac{KW}{pf} \Rightarrow KVA = \frac{800}{0.8} = 1000,\ \phi = 36.86$ The reactive power is $KVAR = KVA \times \sin\phi = 1000 \times \sin(36.86) = 600$ 2) pf needed to improved to 0.92, which means $\phi = 23.07$, total reactive power after compensation becomes $KVA = \frac{800}{0.92} = 869.8 \Rightarrow KVAR = KVA \times \sin(\phi) = 341$ The reactive power to be supplied by synchronous condenser is 600-341 = 259KVAR 3) Power output of synchronous motor is 200KW and $\eta = 0.9 \Rightarrow P_{in} = \frac{200}{0.9} = 222.2KW$ 4) The KVA rating of synch motor is $KVA = \sqrt{P_{in}^2 + Q^2} = \sqrt{222^2 + 259^2} = 341$ 5) Synchronous motor pf = $\frac{KW}{KVA} = \frac{222}{341} = 0.65(lead)$	2 2 2 2
Q3. a) Why single phase induction motor is not self starting? Give reason.	4
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 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	3 1

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.

Q3. b) Draw connection diagram of a star-delta starter. State its applications	4





This method is effective where (2)

starting Torque is less than 1.5times full load torque. It is used for machine tools, pumps, flour mills, drilling machines, motor generator sets. **OR**

2

Applications:-

i) This type of starter is used for in the case of induction motors which are built run normally with a delta connected stator winding such as floor mills, agricultural pumps etc.

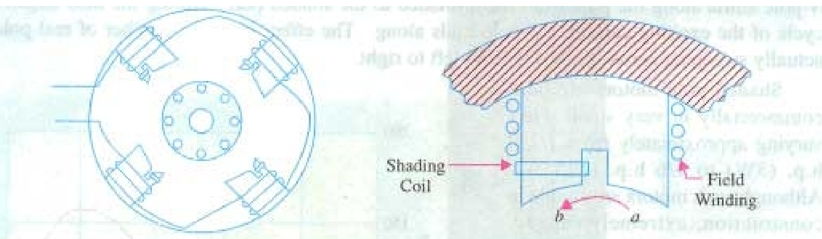
Q3. c) Explain the condition for maximum and starting torque in three phase induction motor.	4

Torque developed by motor at the instant of starting is called as starting torque.

$$T = k\, sE_2 I_2 \cos(\phi_2)$$

$T = kE_2 \dfrac{E_2}{Z_2}\dfrac{R_2}{Z_2}$ $T = k\dfrac{sE_2^{\,2}R_2}{R_2^{\,2}+(sX_2)^2}$, the constant $k = \dfrac{3}{2\pi N_s}$, $N_s = synchronous\,speed$ At starting, s=1 $T_{st} = k\dfrac{E_2^{\,2}R_2}{R_2^{\,2}+(X_2)^2}$ starting torque is 1.5times full load torque. In running condition, maximum torque condition is reached which can be expressed by equating $\dfrac{dT}{ds} = 0$. The maximum torque occurs when slip "s" is $s = \dfrac{R_2}{X_2}$ The maximum torque can be expressed as $T = k\dfrac{sE_2^{\,2}R_2}{R_2^{\,2}+(R_2)^2} = k\dfrac{sE_2^{\,2}R_2}{2R_2^{\,2}} = k\dfrac{sE_2^{\,2}}{2R_2}$ Or $T = k\dfrac{sE_2^{\,2}R_2}{R_2^{\,2}+(R_2)^2} = k\dfrac{sE_2^{\,2}sX_2}{s^2X_2^{\,2}} = k\dfrac{E_2^{\,2}}{2X_2}$ To achieve maximum torque at starting, $s = \dfrac{R_2}{X_2} = 1 \Rightarrow R_2 = X_2$	2 2
Q3. d) What are the methods of starting 3-phase synchronous motor? Explain any one in detail.	4
Methods of starting:- i) Using a small DC Machine (Exciter) ii) Using a small induction Motor (pony motor) iii) Using a damper winding. iv) Variable frequency starting Explanation:- i) Using a small DC Machine (Exciter) :- Many a time's large size synchronous motors are provided with DC generator which acts as exciter. It's DC output is used to supply a field winding of synchronous motor. At the beginning the exciter is fed with DC supply to run it as a motor. This motor	2 2

brings speed of rotor to synchronous speed. The field of synchronous motor is then excited and motor gets synchronized. ii) Using a small induction Motor (pony motor) :- A small induction motor is used to bring the rotor to synchronous speed then DC field is switched ON, motor gets synchronized and induction motor is decoupled. iii) Using a Damper winding:- It is an additional winding induced on the rotor side. Damper winding is in the form of copper bars placed in pole shoes of rotor. These copper bars are connected to each other using copper rings.(similar to squirrel cage rotor of I.M) When the rotor is rotating at synchronous speed, the relative velocity between RMF and rotor is zero. Hence induced emf and current in the damper winding is zero. The damper winding is ineffective when motor is running. At the time of Starting, relative velocity between rmf and rotor is equal to Synchronous speed. This will induce emf into the damper winding and current will flow. Similar to I.M principle, Copper rotor is accelerated in the direction same as that of rmf. As soon as rotor reaches near the synchronous speed, magnetic locking takes place between stator and rotor. The rotor then start rotating synchronously and damper winding is now ineffective. Thus damper winding is used for starting.	

Q3e. Explain operation of shaded pole motor with neat diagrams	4
Shaded pole single phase motor have salient pole stator and squirrel cage rotor. The laminated pole has one slot cut across the laminations approximately one-third distance from one edge. Around the small part of the pole, there is a short circuited copper coil known as shading coil. This part is called as shaded part. When alternating current is passed through the stator winding, the axis of the pole shifts from unshaded part to shaded part. The shifting of magnetic axis is equivalent to rotating magnetic field. This causes torque on the rotor and it starts rotating. Shaded pole motors are manufactured in very small capacities. They are simple in construction, rugged and cheap. Their disadvantages are low starting torque, little over load capacity, low efficiency.  	2 2
Q4. a) i) Explain the effect of change in supply voltage on torque slip characteristics	4

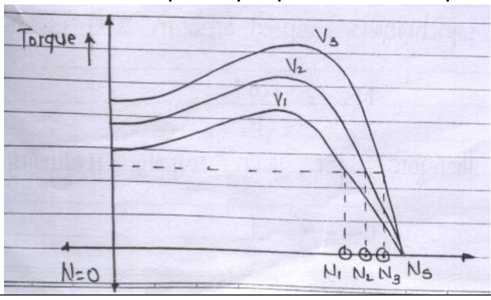
Three phase induction motor torque is given by

$$T = \frac{ksE_2^{\,2} R_2}{R_2^{\,2} + s^2 x_2^{\,2}}$$ 2

In the above expression $E_2 \propto E_1 \propto V_1$ where V_1 is the supply voltage 2

$$T \propto V_1^{\,2}$$

The above expression indicates that the torque is proportional to square of supply voltage



Q4 a) ii) With neat sketch explain double field revolving theory in connection with starting of single phase induction motor. 4

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. 2

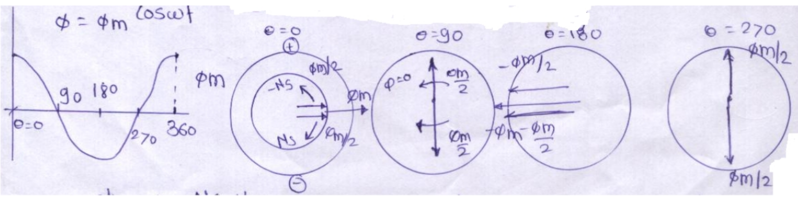
These oppositely rotating flux induce current in rotor & there interaction produces two opposite torque hence the net torque is Zero and the rotor remains standstill.

If the rotor rotates in the direction of forward revolving filed then, torque in that direction will increases and torque will opposite direction will decreases this will make rotor to rotate in forward direction.

OR

When single phase 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 .



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Q4 iii)Draw and explain torque slip characteristics of 3ph Induction motor	4

The torque equation of three phase induction motor is given by,

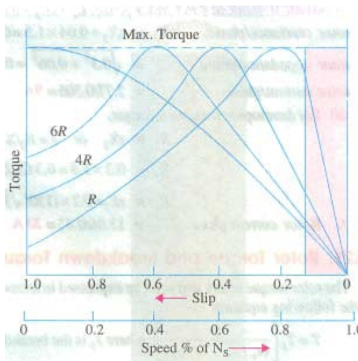
$$T = \frac{k\phi s E_2 R_2}{R_2^{\,2} + (sX_2)^2}$$ 1

At normal speeds the term is very small and the equation becomes $T \propto \frac{s}{R_2}$ i.e. for low values of slip the T-s curve (sX_2) is linear. As the slip increases the torque is increased till maximum torque or (pull-out or breakdown torque), at s=R2/X2 2

Further increase in load causes increase in slip but decrease in motor torque as the $(sX_2)^2 >> R_2$

$$T \propto \frac{s}{(sX_2)^2} \propto \frac{1}{s}$$

And, the curve beyond Tmax is hyperbolic in nature. 1



Q4. a) iv) Explain with neat diagram synchronous impedance method of determining regulation of an alternator	4

The procedural steps for synchronous impedance method are as follows 2

1) The Open Circuit Characteristics OCC is plotted from open circuit test

2) Short Circuit Chract. Is plotted from short circuit test

SCC charact. Is a straight line through origin. Both characteristics are plotted for common field current base.

Consider field current If and the corresponding OC voltage E1

During short circuit, at the same field current, the whole E1 is being used to circulate the short circuit current in armature Isc

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

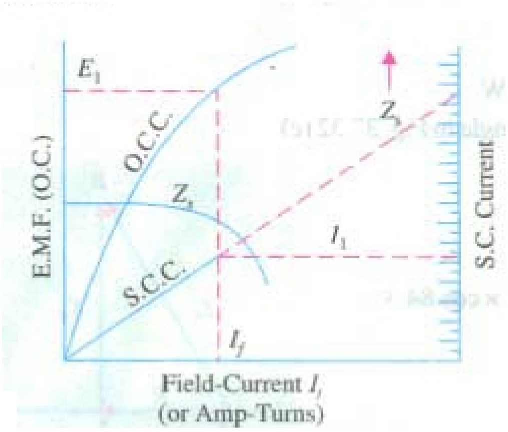
$X_s = \sqrt{Z_s^{\,2} - R_a^{\,2}}$ 2

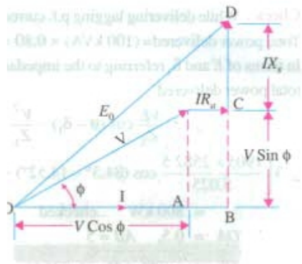
5) The regulation of the alternator at a particular load condition can be calculated as

The generated EMF, Eo 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 $= \dfrac{E_0 - V}{V} \times 100$





Q4b) i) A 50Hz split phase induction motor has a resistance 5ohms and inductive reactance of 20ohms in both main and auxiliary winding. Determine the value of resistance and capacitance to be added in series with the auxiliary winding to send same current in each winding with a phase difference of 90^0. 6

1) Here $Z_m = 5 + j20 \quad and \ Z_a = 5 + j20$

The main winding phase angle w.r.t supply voltage is

$$\angle Z_m = tan^{-1}(\frac{X_m}{R_m}) = tan^{-1}(\frac{5}{20}) = 89.32^0$$ 1

Since Im must at 900 w.r.t. Ia, the angle $\angle Z_a = 90\text{-}89.32 \cong 0$

Which implies that the auxiliary winding current should be in phase with voltage. 1

The capacitive reactance to be added can be calculated from

$$jX_a - jX_{ca} = 0 \Rightarrow X_{ca} = 20\Omega$$

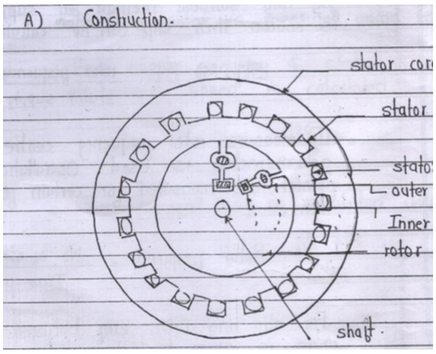
$$C = \frac{1}{2\pi f X_{ca}} = 160\mu F$$ 2

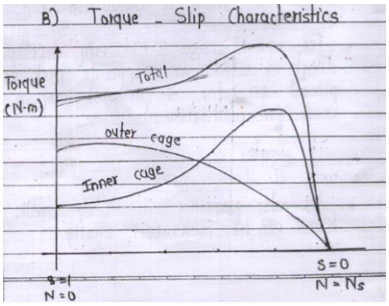
(resonant circuit)

For maintaining same current in both main and auxiliary winding, the resistance value of auxiliary winding should be equal to $\lvert Z_m \rvert = \sqrt{{R_m}^2 + {X_m}^2} = \sqrt{5^2+20^2} = 20.61$ Additional resistance in the auxiliary winding is (20.61-5)= 15.61ohms	2
Q4b) ii) A three phase, 16 pole, 60Hz, star connected alternator has 144 slots with 8 conductors/slot. The coil span is 2/3 pole pitch. Determine the phase and line emfs if the flux per pole is 0.62 wb.	6
The alternator output voltage RMS value given by 1) $E_{rms} = 4.44 f\phi k_c k_d T$ Here f=60, ϕ=0.62, 2) Total no. of conductors = 144 X 8 No of coil sides /ph = $\frac{144\times 8}{3\times 2} = \Rightarrow T = 192$ 3) $m = no\,of\ slots/ph/pole = 144/(3\times 16) = 3$ $\beta = \frac{180}{no\,of\ slots/pole}$ =20^0 $k_d = \frac{\sin(m\beta/2)}{m\sin(\beta/2)}$ =0.959 4) Coil span is 2/3 pole pitch. It is short by 1/3 pole pitch $\alpha = 60$ $k_c = \cos(\alpha/2) = 0.866$ 5) $E_{rms} - phase =$ 2633V/phase and $E_{rms} - line =$ 4561V ($\sqrt{3}E_{rms}$)	1 1 2 2
Q5a) Explain the construction and working of double cage induction motor, draw torque slip curves of individual cage combined cage characteristics.	8
Construction:- • Stator of double cage I.M is same as normal motor. It has three identical stator winding placed at 1200 from each other & connected in star or delta. • Rotor has two independent sets of windings called as 'outer' & 'inner cage'. • Outer cage is made from copper alloy & conductors have small cross section, therefore it has high resistance. It is placed just near to periphery & air gap (silt) is kept on both sides. Therefore inductance is very low. • Inner cage is made from copper conductors of large cross-section. Therefore it has very low resistance. It is placed in deep slots hence it has high inductance. Working:- • At starting N= 0 & S =1. Therefore rotor frequency is equal to stator supply frequency which is high. Hence inductive reactance of inner cage is very high therefore starting current mainly flows through outer cage. As resistance of outer cage is very high it gives high starting torque & less starting current. • During normal running slip is below 5%. Hence rotor frequency is negligible which	2 2

causes negligible reactance of inner cage. Thus running current flows mainly through inner cage.

As inner cage has very low resistance, it gives high running torque & high overall efficiency.





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Q5b) Derive emf equation of an alternator for what purpose they are used. 8

Let, P= no. of rotor poles. ϕ = Flux per pole Z= Number of stator conductors 1

N = Speed in rpm

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

$\therefore$ Frequency of induced emf is 1

f = Cycles per rotation x rotation per sec

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

$$\therefore f = \frac{PN}{120}$$

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

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

$$\therefore\ dt = \frac{1}{n} = \frac{1}{(N/60)} = \frac{60}{N}..........\text{sec}.$$ 1

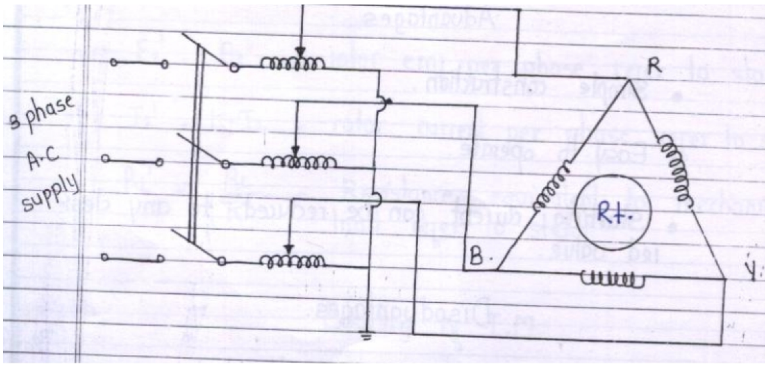
By' faradays law of Electromagnetic induction

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

$$\therefore Eave\ /\ conductor = \frac{P.\phi}{(60/N)}$$

2

$\therefore Eave / conductor = \dfrac{P \times \phi \times N}{60} ....volt$ $\therefore Eave / turn = 2 \;\; Eave / conductor$ $\therefore Eave / turn = 2 \dfrac{P \times \phi \times N}{60} ....volt$ $\therefore \quad = \dfrac{4P \, \phi N}{120} ....volt$ $\therefore \quad = 4 (\dfrac{P \, N}{120}) \, \phi$ $E_{ave} / turn = \quad 4 f \, \phi \qquad \therefore \;\; (f = \dfrac{PN}{120})$ Eave / phs = Eave / turn x Number of turns per phase $= \quad 4 f \, \phi \times Tph$ RMS value per phase is given by, Eph = Eph (ave) x Form Factor $= \quad 4.f.\phi \times Tph \times 1.11$ $\boxed{E\,ph = 4.44.f.\phi.\; Tph}$ It is for full pitched concentrated winding. If winding is distributed & short pitched then. $\boxed{E_{Ph} = \quad 4.44.f.\phi.\; Tph .kd .kc}$ Purpose Alternator:- Alternator converts mechanical energy into electrical energy, It is used is generating power plant to generate electricity. Note: The emf equation can also be derived in following form $e(t) = 2\pi f \phi k_c k_d T \sin(\omega t)$	2 1 1
Q5c) Draw a neat sketch of auto transformer starter for three phase induction motor. Explain its working.	8
Working:- • Three phase auto transformer is connected is star & supplied from 3-ph AC supply. • Variable terminal of each phase is connected to motor phase. • Variable terminal of auto-transformer is adjusted to any desired level so that voltage given to motor is X times supply voltage. • As motor current is directly proportional to applied voltage, motor current at starting reduces by X times. Then supply current at primary of auto-transformer reduces by X2	4

times.  	4
Q6. a) Define i) slip ii) frequency iii) Reactance iv) impedance	4
Note: The question is vague and answer to be examined by judgment	
i) Slip: - It is the ratio of difference between synchronous speed of rotating magnetic field and actual speed of rotor to the synchronous speed of rotating magnetic field. OR $Slip\ \% = \frac{N_S - N}{N_S} \times 100$	1
ii) Frequency:- Number of cycles per second is known as frequency OR It is the reciprocal of time for one cycle. OR Rotor frequency is equal to slip into supply frequency. $F_r = S \times f$	1
iii) Reactance: - It is property of material which opposes change in current. OR $Reactance\ X_L = 2\pi fL$ OR $Rotor\ reactance\ X_2 = 2\pi fL_2 \quad when\ rotor\ is\ standstill$ $X_{2R} = S\,(2\pi fL_2) \quad When\ rotor\ is\ running\ condition$	1
iv) Impedance: - The combined effect of resistance and reactance is called impedance, which opposes the flow of current. OR $Z = \sqrt{R^2 + (X_L - X_C)^2} \quad ohm$ $Rotor\ reactance\ Z_2 = \sqrt{R_2^2 + X_2^2} \quad when\ rotor\ is\ standstill$ $Z_{2R} = \sqrt{R_2^2 + (S \times X_2)^2} \quad When\ rotor\ is\ running\ condition$	1
Q6. b) Compare rotor frequency and stator frequency methods to measure slip 3-phase induction motor.	4
This method is based on the formula	1

$f_2r = S.f \qquad S = f_2r \,/\, f$

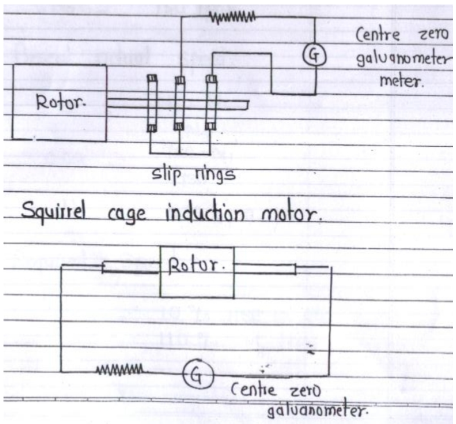
Where, f2r = frequency of rotor induced emf

f = supply frequency

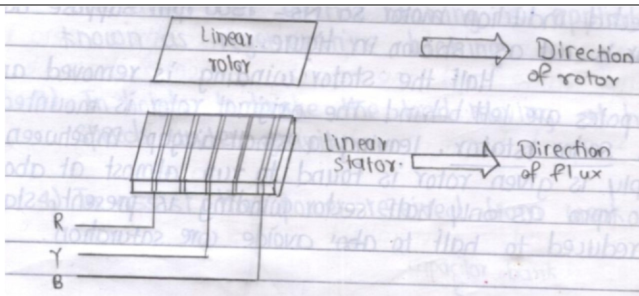
In case of slip-ring motor the leads of milli-voltmeter lightly pressed against the adjacent revolving Slip-ring. The oscillations of pointer of the milli-voltmeter are measured which indicate frequency of rotor induced emf (f2r). 1

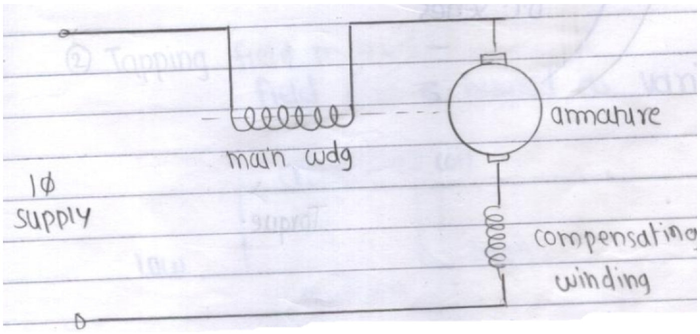
In case of squirrel cage motor the leads of milli-voltmeter connected across the shaft and oscillations indicate frequency of rotor induced emf (f2r)

2



Q6. C) what is starting and running torque of squirrel cage and slip ring induction motor	4
Torque equation of three phase induction motor $$T = \frac{3}{2\pi N_s} \frac{sE_2{}^2 R_2}{R_2{}^2 + s^2 X_2{}^2}$$	1
Running torque of sq. cage I.M is same as above Starting torque of sw. cage I.M. is by substituting s=1 in above expression $$T = \frac{3}{2\pi N_s} \frac{E_2{}^2 R_2}{R_2{}^2 + X_2{}^2}$$	1
Starting torque of slip ring I.M. with external rotor resistance $T = \frac{3}{2\pi N_s} \frac{E_2{}^2 R_2}{(R_2 + r)^2 + X_2{}^2}$ where *r* is the external resistance in rotor circuit Running torque of slip ring I.M I s same as that of squirrel cage I.M as the external resistance is cut while running **OR** **(Student may be write in the form of statement instead of above equation please accepts the answer in form of statement also.)**	2
Q6. d) Explain operation of linear induction motor	4
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, aluminium or copper or iron plate is used as rotor.	2
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 Vs = 2 wf Where, Vs = 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.	2



Q6. e) Explain the construction and operation of single phase series motor	4
Construction of ac series motor is slightly different than that of dc series motor. Special metals laminations and extra windings are used for reducing eddy current and hysteresis loss. In conductively compensated AC series motor, the compensating winding is connected in series with the armature, where as in inductively compensated AC series motor the compensating winding is short circuited and has no interconnection with motor circuit. The compensating winding acts as a short circuited secondary of a transformer, for which armature winding acts as primary. The current in compensating winding is proportional to armature current but 1800 out of phase with it. Characteristics of ac series motor are same as that of dc series motor. They have high starting torque and are used for fans, drills, small appliances.  	2 2