THE OPEN UNIVERSITY OF SRI LANKA
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
DIPLOMA IN TECHNOLOGY

041

ECX 4238 – Electrical Machines
Final Examination – 2008/2009

Date: 08.04.2009 Time: 0930 - 1230

This paper contains eight questions. Answer any **five** questions. All questions carry equal marks. Show your work clearly.

Graph sheets will be given on your request.

Q1)

a. Write a brief description of winding of the transformer.

b. The primary side of a 3-phase transformer is connected in star and secondary side is connected in delta.

   i. What are the standard methods of connecting primary in star and secondary in delta?

   ii. Select one of the winding connections mentioned in part (i) and draw phasor diagram. What is the phase angle between line-line voltage phasors?

c. A three-phase transformer bank consisting of three single-phase transformers is used to step down the voltage of a three-phase, 6600 V transmission line. If line current at primary side is 10 A, calculate:

   i. The secondary line voltage.

   ii. Line current at secondary side.

   iii. Output kVA for the star-delta connection.
   (Neglect losses)

Q2) A series DC motor is mechanically coupled to a fan as shown in figure Q2.

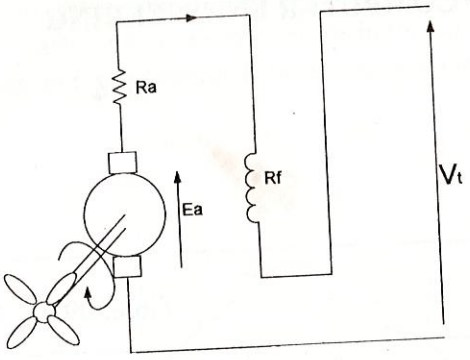

Figure Q2

a. Prove that, the mechanical power delivered to the fan is maximum when back e.m.f (E_a) is equal to half of the applied voltage (V_t).

b. Use above to find the maximum power delivered to the fan.

c. A 240 V, 7.5 kW series motor draws 50 A from the main (240 V) and delivers maximum power to the fan when running at 500 rpm.

   i. Find the value of armature resistance (R_a), if field winding resistance (R_f) is 0.4 Ω.

   ii. Determine the torque developed by the motor in the above operating condition.

   iii. It is given that the torque required by the load is proportional to the square of speed. Calculate the external resistance to be added in series to the armature circuit to reduce the speed up to 250 rpm. What is the power delivered at this speed?

Q3)

a. Explain the term "armature reactance" with respect to DC machine?

b. Draw the equivalent circuit diagram of the DC shunt motor.

c. 750 kW, 250 V, 1200 rpm DC shunt motor has armature and field resistance of 0.03 Ω and 41.67 Ω respectively. The motor is provided with compensating winding to cancel out the armature reaction. Iron and rotational losses can be ignored. The motor is carrying constant torque and running at 1105 rpm, it draws current of 126 A.

   i. Assuming magnetic linearity. What would be the line current and motor speed, if the field current is reduced to 5 A? Calculate the load torque at this condition.

ii. The motor has magnetization data as below. Calculate motor speed and line current as in part (i). Compare and comment upon the results of part (i) and (ii).

Speed: 1200 rpm

If (A)	4	5	6	7
Voc(V)	217	250	267	280

Q4)

a. Discuss the advantages of an induction machine over DC machine.

b. Draw the power flow diagram of an induction motor.

c. Using the equivalent circuit and the power flow diagram of an induction motor, prove the followings.

i. $P_{rcl} = s\,P_{ag}$

ii. $P_m = (1\text{-}s)P_{ag}$

iii. $P_{ag} : P_{rcl} : P_m = 1 : s : (1\text{-}s)$

iv. $\eta = 1\text{-}s$

Where

P_{ag} - air gap power.

P_{rcl} - rotor copper loss

P_m - mechanical power output

s - slip

η - efficiency

d A 8-pole, three phase, 50 Hz induction motor runs at a speed of 710 rpm with an input power of 35 kW. The stator copper loss at this operating condition is 1200 W, while the rotational losses are 600 W.

Find:

i. Rotor copper loss (P_{rcl})

ii. Gross mechanical power.

iii. Net power developed and net torque.

Q5)

a. Draw approximate per phase equivalent circuit model of the three-phase induction motor referred to the stator side.

b. Use this circuit to prove that the maximum torque τ_{max} in a three-phase induction motor is given by

$$\tau_{max} = \frac{3}{\omega_s}\left[\frac{V^2}{2X_r^2}\right],$$

where

V is per phase terminal voltage

ω_s is synchronous speed

X_r is rotor reactance referred to the stator side at supply frequency

(Assume stator impedance to be negligible)

c . A 6-pole, 50 Hz, three-phase induction motor has a rotor resistance of 0.25 Ω per phase and a maximum torque of 10 Nm at 875 rpm. Calculate

i The torque when the slip is 5 %

ii. The resistance to be added to the rotor circuit to obtain 60 % of the maximum torque at starting.

iii. Explain why two values are obtained for this resistance. Which value will be used.

(The stator impedance is assumed to be negligible)

Q6)

a. Draw the phasor diagram of a salient-pole synchronous generator operating at lagging power factor load (Neglect resistance of the synchronous generator)

b. Hence show that the total power developed by a 3-phase synchronous generator is given by

$$P_{total} = \frac{3E_f V}{X_d}\sin\alpha + \frac{3V^2}{2}\left(\frac{1}{X_d} - \frac{1}{X_q}\right)\sin 2\alpha$$

c. A 10 kVA, 380 V, 50 Hz, 3-phase, star-connected salient pole synchronous generator has direct axis and quadrature axis reactance of 12 Ω and 8 Ω respectively. The generator delivers rated load at 0.8 power factor lagging with the terminal voltage being maintained at rated value. If the load angle is 16.15^0 determine

i. The direct axis and quadrature axis components of armature current.

ii. Excitation voltage of the generator.

iii. Total power developed by the generator.

Q7)

a. Define the term "Short-Circuit Ratio (SCR)" in synchronous machine.

b. Draw the open and short circuit characteristics curves of the synchronous generator in the same graph.

c. Hence show that the Short-Circuit Ratio (SCR) of the synchronous generator is

$$\frac{1}{\textit{Perunit adjuested Synchronous Reactance}}$$

d. The open and short circuit tests data on a three phase 150 MW, 13 kV, star connected 0.85 power factor, synchronous generator is given below

Open circuit data

I_f(A)	200	450	600	850	1200
V_{oc}(line)(kV)	4	8.7	10.8	13.3	15.4

Short circuit data

$I_f = 750$ A, $I_{sc} = 8000$ A

i. What is the adjusted synchronous reactance of the machine

ii. Convert the value of reactance in part (i) in its per unit value.

iii. Hence fine the SCR of this machine.

Q8)

a. Discuss the advantages of parallel operation of synchronous generators.

b. Explain the conditions that must be satisfied to operate synchronous generators in Parallel.

c. Two generators having 4 % and 7 % droop in their turbine governors are pre-set to Deliver 50 MW and 100 MW at 50 Hz to an isolated load. Rating of the generators are 150 MW and 200 MW respectively. Each has 2 poles.

i. Calculate the speed of each generator if one is tripped out from the load.

ii. Calculate the maximum overall load the two generators can deliver without overloading any generator, and the corresponding frequency.
(Assume **free governor action**).