UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 3 Examination in Engineering: July 2017

Module Number: EE3303 **Module Name: Electric Machines**

[Three Hours]

[Answer **all questions**, each question carries **10 marks**]

Q1. a) i) Name three ferromagnetic materials used in magnetic cores.

ii) State the four basic principles behind the operation of a transformer, generator and motor.

iii) Explain how the hysteresis loss and the eddy current loss occur in magnetic cores.

[3.5 Marks]

b) The transformer core shown in Figure Q1 is made of a ferromagnetic material having relative permeability of 1500. Its primary side winding has 600 turns and secondary side winding has 200 turns. The center leg of the core has an air gap distance of x. Magnetic field intensities at point A and point B are 2000 A-t/m and 1800 A-t/m respectively. Take permeability of air as $4\pi \times 10^{-7}$ Wb/A-t m and assume core doesn't saturate.

i) Calculate the flux densities at point A and point B.

ii) Determine the air gap distance x, if the primary side current i_1 is 10 A. State the assumptions you made.

iii) Calculate the flux densities at point A and point B for the same primary current in part (ii) if the center leg didn't have an air gap.

iv) Draw the flux variation at point A, $\Phi_A(t)$, flux variation at point B, $\Phi_B(t)$ and voltage variation at secondary side $e_2(t)$, if the primary current i_1 is linearly increased from 0 to 10 A within 100 ms.

[6.5 Marks]

Q2 a) i) State three main applications of transformers in a typical power system.

ii) Briefly explain why high voltage winding is wrapped and wound top of the low voltage winding in transformer construction.

iii) Discuss main function of each of the following component in a conservator tank type oil immersed transformer.

A. Dehydrating breather
B. Buchholz relay
C. Bushings

[3.5 Marks]

b) A 7.5 kVA, 100/200 V, single phase, step-up transformer is tested to determine its equivalent circuit parameters. The results of the tests are given in Table Q2.

i) Find the approximated equivalent circuit of the transformer referred to the primary side.

ii) Calculate the load impedance, voltage regulation and efficiency when the transformer output is kept at rated voltage and delivers 3 kW with a 0.85 lagging power factor.

iii) Determine the output power factor, voltage regulation and efficiency when the transformer output is kept at rated output voltage and connected to a load impedance of 5-2j Ω.

iv) Draw the phasor diagrams for part (ii) and part (iii).

[6.5 Marks]

Q3. a) i) State the parameters which can be used to control the speed of a DC motor.

ii) Construct the typical torque-speed characteristic curve of a shunt DC motor using torque equation and emf equation.

iii) Briefly explain why a shunt DC motor should not be started on heavy loads.

iv) From the first principles, show that internally generated voltage E_A of a separately excited DC generator can be expressed by

$$E_A = \left(\frac{pz}{2\pi a}\right)\phi_f \, \omega_m$$

where all the notations have their usual meanings.

[4.0 Marks]

b) A 25 hp, 110 V shunt motor with metal graphite brushes takes an armature current of 65 A. The armature and the field resistances are 0.15 Ω and 40 Ω respectively. The core and mechanical losses are 270 W. Assume that machine operates at a constant speed of 1200 rpm and armature reaction is negligible.

i) Determine the induced back emf in the armature.

ii) Calculate the efficiency of the motor assuming that the stray losses are 1% of the rated output power.

[2.5 Marks]

c) A 220 V series DC motor has armature and field resistances of 0.15 Ω and 0.10 Ω respectively. It takes a current of 30 A from the supply while running at 1000 rpm. If a diverter resistance of 0.2 Ω is connected across the field coil of the motor, calculate the new steady state armature current and the speed. Assume the load torque remains constant and rotational loss is negligible.

[3.5 Marks]

Q4 a) i) Draw the typical torque speed characteristic curve of an induction motor indicating important points.

ii) Describe the two rotor constructions used for three phase induction machines.

iii) Briefly explain three starting methods used in induction motors.

[3.5 Marks]

b) Test results taken on a 415 V, 50 Hz, 35 hp delta-connected, design class 'C' three phase induction motor for three tests are given in Table Q4. Determine

i) equivalent circuit parameters at rated frequency, and

ii) total rotational loss.

[3.0 Marks]

c) A 400 V, 50 Hz, 2850 rpm, two pole wye-connected wound-rotor induction motor has following equivalent circuit parameters referred to the stator. Terms have their usual meanings.

$R_S = 0.25\ \Omega$ $R'_R = 0.15\ \Omega$ $X_S = 0.42\ \Omega$ $X'_R = 0.42\ \Omega$ $X_M = 18.6\ \Omega$

Take the rotational losses of the motor as 1 kW. Core losses and stray losses are negligible.

i) Calculate the input line current and developed torque at start.

ii) Calculate the input line current, developed torque and the efficiency at rated speed of the motor.

iii) Determine the load torque and rotor side power factor in part (ii).

[3.5 Marks]

Q5 a) i) State the parameters which need to be synchronized for parallel operation of synchronous generators.

ii) Explain why excitation is important for synchronous machine operation and state two advantages of a brushless excitation system.

iii) Which synchronous machine type is typically used in hydro power plants? Justify your answer.

iv) Briefly explain how the output voltage and frequency of a synchronous generator is kept at desired levels.

[3.5 Marks]

b) A 100 hp, 440 V, 0.8 p.f. leading power factor, delta-connected three phase synchronous motor has an armature resistance of 0.22 Ω and a synchronous reactance of 3.0 Ω. Its efficiency at full load is 89%.

i) Calculate the line current at rated condition.

ii) Calculate the internal generated voltage E_A, reactive power supplied by the motor Q_{out} and converted power P_{conv} at rated conditions.

iii) If E_A is decreased by 10%, how much reactive power will be supplied by the motor? Neglect the armature resistance and take $E_A \sin(\delta)$ quantity remains the same where δ is the load angle.

[3.5 Marks]

c) A 10 kV, 50 Hz, four pole, wye-connected three phase synchronous machine has the following test results for a field current of 40 A.

Open circuit test : V_{OC} = 10 kV at 1000 rpm
Short circuit test : I_{SC} = 1200 A at 500 rpm

Stator resistance and core losses are negligible. Assume open circuit characteristic curve is linear.

i) Determine the per phase synchronous reactance X_S.
ii) Calculate the field current required for the machine to operate as a generator on an infinite bus of 10 kV line to line, delivering 6 MVA at 0.85 power factor lagging.
iii) Sketch the phasor diagram for the operation described in part (ii).
iv) Find the voltage regulation and the load angle for the operation described in part (ii).

[3.0 Marks]

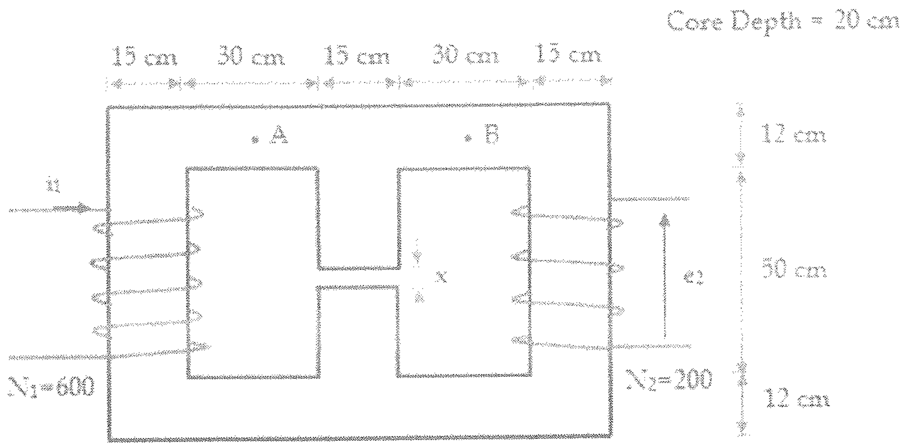

Figure Q1

Table Q2

Open-circuit Test	Short-Circuit Test
V_{OC} = 100 V I_{OC} = 0.9 A P_{OC} = 80 W	V_{SC} = 35 V I_{SC} = 37.5 A P_{SC} = 720 W

Table Q4

DC Test	Blocked Rotor Test	No-load Test
V_{DC} = 25 V I_{DC} = 40.5 A	V_{BR} = 28 V P_{BR} = 1.2 kW I_{BR} = 38.9 A f_{test} = 12.5 Hz	V_{NL} = 415 V P_{NL} = 750 W I_{NL} = 15.8 A f_{NL} = 50 Hz