UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: December 2018

Module Number: EE6303 **Module Name: Electrical Machines and Drives**

[Three Hours]

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

Q1. a) What are the advantages of using three single-phase transformers to make a three phase transformer, instead of making a 3-phase transformer as a single unit?

[1.5 Marks]

b) An ideal 3-phase step down transformer connected in delta/star delivers power to a balanced 3-phase inductive load of 50 kVA at 0.84 power factor. The input line voltage is 11 kV and the turns ratio of the transformer is 48. Determine the phase voltages, phase currents, line voltages and line currents on the primary and the secondary sides of the transformer.

[2.5 Marks]

c) State the conditions that need to be satisfied in order to connect two or more transformers in parallel.

[1.5 Marks]

d) Discuss the advantages and the disadvantages of an autotransformer compared to a conventional transformer.

[1.5 Marks]

e) A 20 kVA, 4400/400 V transformer with an equivalent impedance of 0.01 Ω is to operate with a 15 kVA, 4400/400 V transformer with an equivalent impedance of 0.012 Ω. The two transformers are connected in parallel and supply a load of 25 kVA. Assume the angles of both the impedances are the same.

i) Calculate the individual load currents.

ii) Determine the percentage of used capacity in each transformer.

[3.0 Marks]

Q2 a) State the conditions that need to be satisfied in order to operate two generators in parallel.

[1.0 Mark]

b) Two generators (G1 and G2) connected in parallel with the grid supply a load of 8 MW, 0.92 power factor lagging. The two generators supply 80% of the active power demand of the load and 100% of the reactive power demand of the load. The no-load set points of G1 are 52 Hz, and 12.2 kV. The frequency droops of G1 and G2 are 1.4 MW/Hz and 1.3 MW/Hz, respectively. The voltage droops of G1 and G2 are 1.1 MVAr/V and 1.2 MVAr/V, respectively. The frequency and the voltage of the grid are 50 Hz and 11 kV respectively.

i) Calculate the active and reactive power outputs of the two generators.

ii) Determine the no-load frequency and the no-load voltage set points of G2.

iii) During a grid failure, the two generators and the load will be disconnected from the grid so that the load is supplied by the two generators alone. Determine the frequency and the voltage of the system when the system is operating in isolated mode.

iv) How can the frequency of the isolated system be restored to 50 Hz when the system is not connected to the grid?

[3.0 Marks]

c) Per-phase equivalent circuit of a synchronous generator is shown in Figure Q2. The armature resistance of the generator is neglected.

i) Draw the phasor diagram for this circuit and then derive the power diagram using the phasor diagram you have drawn.

ii) Draw the capability curve by drawing the loci of rotor heating limit, stator heating limit and prime mover power limit on the power diagram you have drawn in part (i).

iii) A 1.2 kV, 50 Hz, star connected synchronous generator is rated at 150 kVA, 0.8 power factor lagging. It has synchronous reactance of 2.72 Ω per phase. Assume that the generator is connected to a turbine capable of supplying power up to 145 kW. The maximum no-load voltage of the generator is 1.25 kV. Using the capability curve drawn above, find out whether the generator is capable of supplying a line current of 70 A at 0.85 power factor lagging.

[4.0 Marks]

d) A 22 kV, 80 MW, star-connected salient pole generator is supplying 50 MW power output at a lagging power factor of 0.85 in synchronized with 22 kV bus. The generator reactances are Xd = 2.14 Ω and Xq = 1.87 Ω. Calculate the power angle and the excitation voltage.

[2.0 Marks]

Q3. a) Briefly explain the two types of starting techniques used in single phase induction motors.

[2.0 Marks]

b) i) Explain the operating principle of a two pole, three phase stepper motor.

ii) It is required to control the position of a shaft in steps of 15^0 and the speed of rotation of the shaft needs to be controlled in the range of 0-100 rpm. Calculate the number of poles of the stepper motor required for this application and the maximum required pulse rate to the control unit.

[3.0 Marks]

c) Consider the motor nameplate shown in Figure Q3.

i) Determine the maximum starting current you can expect for this motor using Table Q3.

ii) State the information you can get from service factor, duty, insulation class and NEMA design letter of the motor mentioned on the nameplate.

iii) State three constructional differences between a standard efficiency motor and a premium efficiency motor.

iv) Calculate the revised motor ratings if the motor needs to be operated on a 60 Hz three phase supply. Clearly state the assumptions you make.

[5.0 Marks]

Q4 a) i) Briefly explain the reason behind transformer humming.

ii) Calculate the maximum overload that can be carried by a 40 hp motor, if the temperature rise is not to exceed 70 ^{0}C after two hours on overload. Starting from cold conditions, the temperature rise on full load after 1 hour is 25 ^{0}C and after 2 hours is 35 ^{0}C. Assume losses are proportional to the square of the load.

[3.0 Marks]

b) i) Briefly explain two methods which can be used for induction motor speed controlling by changing the number of stator poles.

ii) Illustrate how the torque speed characteristic curve of a 3-phase induction motor changes when rotor resistance, supply frequency, supply voltage and number of stator poles are varied.

[3.0 Marks]

c) The 3-phase induction motor with the nameplate shown in Figure Q3 is used to drive a load having a linear rising torque speed characteristic. V/f controlling method is used for motor controlling. Under rated voltage and rated frequency motor runs at 1482 rpm with a torque of 154 Nm. Calculate the required supply frequency and supply voltage to the motor for each of the following operating condition. State any assumption you make.

i) To drive the load at a speed of 850 rpm.

ii) To drive the load at 50% of the rated motor torque.

[4.0 Marks]

Q5. a) i) Classify electric motor drives into two categories based on the expected performance and explain the differences using suitable examples.

ii) Briefly discuss how AC motors became more popular than DC motors for variable speed applications over the time.

iii) Compare armature control and field control of a DC motor.

[3.5 Marks]

b) Following details are given for a DC motor drive system. Notations have their usual meanings.

Permanent magnet DC Motor

$R_a = 0.95\ \Omega$, $L_a = 5.3$ mH, $K_{E\phi} = 0.2$ Vs, $J_m = 3.5 \times 10^{-4}$ kgm^2

DC-DC converter

$V_d = 100$ V, $f_S = 25$ kHz, $V_{tri}(peak) = 5$ V

A closed loop control system needs to be designed having current, speed and position control loops. Crossover frequency of the current controller should be 10% of the switching frequency and the phase margin for the speed controller should be 40^0. Determine the controller parameters. State any assumption you make.

[3.0 Marks]

c) A 100 V, 15 hp separately excited DC motor is powered through a 3-phase fully controlled converter working on a 400 V, 50 Hz supply. Under rated conditions motor draws an armature current of 175.68 A and runs at 2000 rpm. The armature resistance is 0.207 Ω. The load torque is proportional to the quadratic value of the motor speed. The field circuit of the motor is powered through a single switch DC-DC converter connected to a DC battery. Under rated conditions, duty of the converter is 1 and the field flux is 0.015 Wb per pole.

i) Calculate the motor speed range for a firing angle range from 80^0 to 86^0 if the field flux is kept at its rated value.

ii) Determine the required duty of the DC-DC converter if the motor speed needs to be increased to 3000 rpm at its rated power and rated voltage. Assume field flux is linearly proportional to the duty of the converter.

[3.5 Marks]

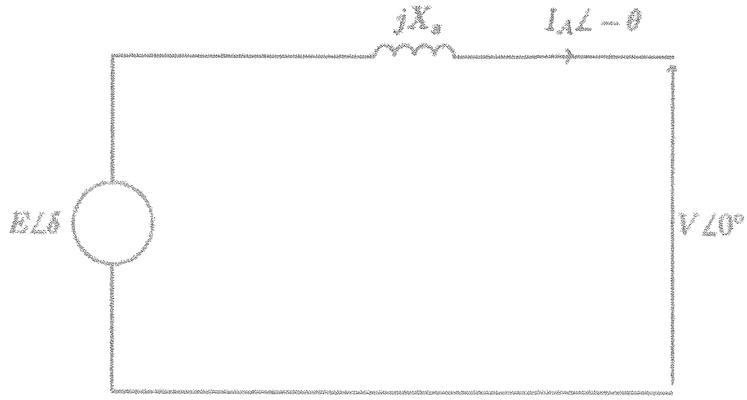

Figure Q2

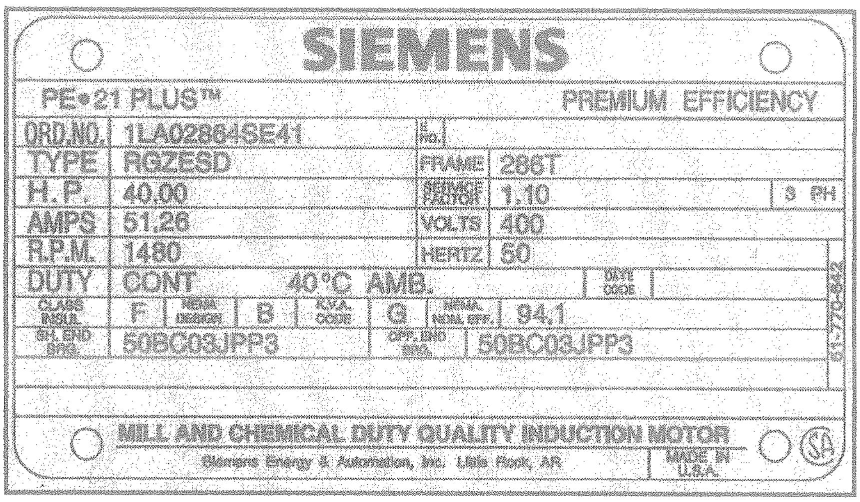

Figure Q3

NEMA Code	KVA/HP range with locked rotor
A	0 - 3.14
B	3.15 - 3.55
C	3.55 - 3.99
D	4.0 - 4.49
E	4.5 - 4.99
F	5.0 - 5.59
G	5.6 - 6.29
H	6.3 - 7.09
J	7.1 - 7.99

Table Q3