UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: February 2020

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

[Three Hours]

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

Q1. a) Armature winding is an essential feature of DC and AC machines. It comprises a set of coils embedded in the slots, uniformly spaced round the armature periphery.

i) Define the following terms associated with armature windings.
Coil pitch
Pole pitch

ii) Define the two terms *phase belt* and *phase speared* associated with AC armature windings.

[2.0 Marks]

b) A three-phase AC generator needs to be designed to generate 50 Hz, 9.0 kV(line-line rms) output voltage. The generator will be connected to a transformer via star (Y) connection. The armature of the machine consists of 24 slots. The rotor is made to produce a field with 4 poles and the strength of the field produced is 1.21 T/pole.

i) Calculate the number of turns per phase required to generate the above voltage, if full pitch armature winding is chosen.

ii) What type of armature winding arrangement can be used for this machine?

iii) Draw the coil side placement table for all three phases and the winding diagram for phase-A for your proposed armature winding arrangement.

[3.0 Marks]

c) A separately excited dc motor's armature is connected to a three-phase full-controlled thyristor converter. The field circuit is also connected to a same type of converter. The ac input to both converters is three-phase, 400 V (line-line rms voltage), 50 Hz. The parameters of the separately excited dc motor are given below.

Rated torque = 80 Nm	The armature resistance = 0.25 Ω
Rated armature voltage = 550 V	Voltage constant = 1.2 V/(A rad/s)
Rated speed = 2000 rpm	Field circuit resistance = 245 Ω.

Assume that except copper losses all other losses in the motor are negligible and the converters are ideal. The armature and the field currents are continuous and ripple free.

i) Draw a circuit diagram to illustrate the converters and the connections of the separately excited dc motor.

ii) If the motor operates in the constant torque region, how do you control the firing angles of the two converters?

iii) In the constant torque region with this connected converter system, calculate the maximum possible speed the motor can achieve with the rated torque?

iv) It is required to run the motor at a speed higher than the speed in iii) with the same armature current. Explain how you can achieve it. Also, explain the consequences you will have to face.

v) Using this converter system, in which quadrants of the speed-torque plane the motor can be operated? Justify your answer.

[5.0 Marks]

Q2. a) i) Explain why it is not possible to get a balanced three phase output from a practical transformer with open-delta (V-V) connection even when a balanced three phase voltage is applied to the primary.

ii) Three-phase delta (Δ)/star (Y) transformers with star (Y) on the LV side is used in distribution grids to supply the load. Explain the reason.

iii) State the four conditions need to be satisfied to operate two three-phase transformers in parallel.

[4.0 Marks]

b) A 500 kVA, single-phase transformer with 0.041+j0.075 pu impedance is connected in parallel with 350 kVA single-phase transformer with 0.032+j0.066 pu impedance. Per unit impedances have been calculated on a base voltage of 230 V. The open circuit voltage of these two transformers are 240 V and 235 V respectively.

i) Draw the equivalent circuit (referred to the secondary sides of the transformers) of the two transformers working in parallel to supply the load.

ii) Calculate the circulating current between two transformers during no-load operation.

iii) Calculate the share of the load supplied by each transformer, when they supply a load with an impedance of 0.092+j0.044 Ω.

[6.0 Marks]

Q3. a) i) Draw the frequency vs active power characteristic and the voltage vs reactive power characteristic of a synchronous generator.

ii) Consider a synchronous generator connected to a utility grid. Using the frequency and voltage characteristics drawn in i), explain how the active and reactive power supplied by the synchronous generator can be increased.

iii) State the four conditions that needs to be satisfied for paralleling two synchronous generators.

[4.0 Marks]

b) Two synchronous generators G_1 and G_2 are connected in parallel and they supply a 10 MVA load at 0.97 power factor lagging. The frequency of this system is 50 Hz. The slopes of the frequency vs active power characteristics of generators G_1 and G_2 are 2.5 MW/Hz and 3.0 MW/Hz respectively. The no-load frequency of generator G_1 is 51.5 Hz.

i) Calculate the active power outputs of each generator.

ii) Calculate the system frequency when only the active power of the load drops by 40%.

[2.0 Marks]

c) A 3.0 kV(line-line rms), star (Y) connected cylindrical rotor synchronous machine is rated at 100 kVA, 0.7 power factor lagging. The synchronous reactance of this generator is 7.86 Ω/phase. The generator is connected to a turbine capable of supplying 100 kW of active power. The armature induced voltage of this machine is limited to 1820 V.

i) Draw the capability curve of this generator.

ii) Find the maximum amount of reactive power that can be supplied at 80 kW of active power output.

[2.5 Marks]

d) A three-phase, 400 V(line-line rms), star (Y) connected, salient pole synchronous generator supplies a 12 A current with a phase angle of 30° lagging. The direct and quadrature axis synchronous reactances of this machine are $X_d = 9.2\ \Omega$, $X_q = 4.8\ \Omega$, armature resistance is negligible.

i) Draw the phasor diagram for the above salient pole generator and calculate the direct axis and quadrature axis currents.

ii) Calculate the no-load voltage of this salient pole generator.

[1.5 Marks]

Q4. a) i) State three constructional differences between a universal motor and a series DC motor.

ii) Briefly explain the operation of a brushless DC motor.

iii) A hybrid stepper motor has a stator with 5-phases and a rotor with 60 teeth. Calculate the step angle and the pulse rate required to obtain a rotor speed of 2000 rpm.

iv) A 230 V, 50 Hz capacitor-start single-phase induction motor has a main winding with an impedance of 4+j8 Ω and a starting winding with an impedance of 10+j2.5 Ω at the start. Determine the value of capacitance to be connected in series with the starting winding to obtain maximum starting torque.

[4.0 Marks]

b) i) Write four characteristics of an ODWF cooling system used in a power transformer.

ii) Briefly explain the information you can obtain from service factor, letter code, design letter, insulation class and time rating given in a NEMA standard motor nameplate.

[3.0 Marks]

c) In a transformer, the temperature rise is 20 ^{0}C after 1 hour and 35 ^{0}C after 2 hours, starting from cold conditions. The transformer is disconnected when it reaches to its final steady state temperature. Then its temperature falls from the final steady value to 45 ^{0}C within 1.0 hour. If the ambient temperature remains constant at 28 ^{0}C, Calculate the followings;

i) The heating time constant

ii) The final steady temperature the transformer reached due to heating

iii) The cooling time constant

iv) The time it will take to cool down to 50 ^{0}C after disconnection

[3.0 Marks]

Q5. a) i) Using torque equation for a three-phase induction motor explain why it is necessary to maintain the rated air-gap flux in a three-phase induction motor during its operation.

ii) Explain how the rated air-gap flux in a three-phase induction motor is maintained using stator supplied voltage and frequency. State any assumptions you make.

iii) What is meant by voltage boost? Explain why it is necessary.

[2.5 Marks]

b) i) Using the general torque equation, air-gap flux equation and the rotor current equation for a three-phase induction motor, show that when maintaining a constant air-gap flux in a three-phase induction motor, the torque T_{em} can be expressed as

$$T_{em} = K(\omega_s - \omega_r)$$

where, K - motor dependent constant, ω_s - synchronous speed and ω_r - rotor speed. Clearly state the assumptions you make.

ii) A three-phase, star(Y) connected, four-pole, 5 kW, 50 Hz, 400 V (line-line, rms) squirrel-cage induction motor is driving a fan, which has quadratic load characteristics. The motor is supplied by a voltage source inverter with v/f control strategy. At 50 Hz, the fan runs at 1470 rpm delivering rated power. If the fan is to be rotated at 735 rpm,

I. find the stator frequency required,

II. find the stator line-line voltage required and,

draw the torque-speed characteristics showing the operating point. Also, in the same plot indicate the operating point at 50 Hz operation.

[7.5 Marks]