UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 4 Examination in Engineering: November 2022

Module Number: EE4304 **Module Name: Electric Machines I**

[Three Hours]

[Answer **all questions**, each question carries 12.5 marks]

Q1 a) i) State two characteristics of an ideal transformer.

ii) What are the types of losses take place in an imperfect core of a transformer during the operation?

iii) Briefly explain how the open circuit and short circuit tests are performed for a given transformer.

[3.5 Marks]

b) A 12 kVA, 230/460 V single phase transformer has been tested to determine its equivalent circuit. The high voltage winding is kept open to perform the open circuit test and the low voltage winding is short circuited to do the short circuit test. The results of these tests are shown below.

Open Circuit Test		*Short Circuit Test*	
I_{OC}	= 1.6 A	V_{SC}	= 24 V
P_{OC}	= 134 W	P_{SC}	= 248 W

i) Obtain the approximate equivalent circuit of this transformer referred to the law-voltage side.

ii) Draw the phasor diagram of transformer at rated conditions and 0.8 power factor lagging.

iii) Calculate the voltage regulation and the efficiency of the transformer at rated conditions and 0.8 power factor lagging.

[5.0 Marks]

c) A voltage source of 600 V feeds a load through a 2 kVA 480/240 V, 50 Hz single phase transformer and a feeder as illustrated in Figure Q1. The impedance of load and feeder are $40\angle 30^0$ Ω and 40.0 + j150 Ω, respectively. The transformer's equivalent series impedance referred to its low-voltage side is 0.12 + j0.5 Ω.

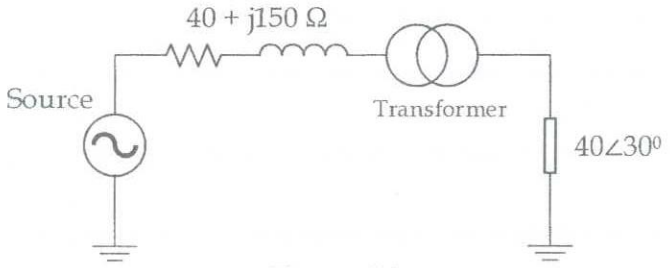

Figure Q1

i) Calculate the load current, load voltage and power factor.

ii) Calculate the input power factor and the overall efficiency of the system.

[4.0 Marks]

Q2 a) i) State three advantages of induction machines over synchronous machines.

ii) "A three-phase induction motor runs at a speed slightly lower than the synchronous speed but not at the synchronous speed."
Is this statement correct? Briefly explain your answer giving reasons.

iii) Sketch the torque-speed characteristic of a three-phase induction motor indicating critical torques and speeds with usual notations.

iv) Show that the induction motors normally connected in delta can be connected in star at the start to reduce the starting current.

[4.5 Marks]

b) A 400 V, 50 Hz, Y-connected three phase induction motor is rated at the speed of 1425 rpm. The motor has the following impedances per phase referred to the stator circuit. Note that all the notations have their usual meanings.

$R_S = 0.32\ \Omega$ $R_R = 0.12\ \Omega$ $X_m = 25\ \Omega$

$X_S = 0.42\ \Omega$ $X_R = 0.42\ \Omega$

i) Determine the number of stator poles.

ii) Calculate the starting line current of the motor. Hence deduce the starting line current of the motor if it is connected in delta (Δ) at the start.

iii) Find the starting torque, pullout torque and rated torque of the motor.

iv) Calculate the pullout speed of the motor in **rpm**.

v) Sketch the torque (**Nm**)-speed (**rpm**) characteristic of the motor.

Hint: The output characteristic equation of a three-phase induction motor is given by,

$$\tau_{ind} = \frac{3R_R}{s\omega_s}\left[\frac{V_{TH}^2}{\left(R_{TH} + {}^{R_R}/_{S}\right)^2 + (X_{TH} + X_R)^2}\right]$$

Note that all the notations have their usual meanings.

[8.0 Marks]

Q3 a) i) Write three applications of synchronous machines in a power system.

ii) What is meant by "Excitation" in synchronous machines.

iii) State two advantages of a brushless excitation system.

[2.5 Marks]

b) The internal generated voltage and the output terminal voltage per phase of a non-salient pole synchronous generator is given by E_a and V_φ, respectively.

i) Draw the per phase equivalent circuit of synchronous generator.

ii) What is the relationship between E_a and V_φ at no-load condition?

iii) What are the factors that cause the difference between E_a and V_φ in normal operation?

iv) Show that the armature reaction can be modeled as an inductor in series with the internal generated voltage in the equivalent circuit.

[3.5 Marks]

c) A 20-MVA, 12.2-kV, two pole, 0.8-PF-lagging, Y-connected synchronous generator has a negligible armature resistance and a synchronous reactance of 1.1 per-unit. The generator is connected with a 60-Hz, 12.2-kV infinite bus that is capable of supplying or consuming any amount of real or reactive power with no change in frequency or terminal voltage. The field current of the synchronous generator is kept constant during the operation.

i) What is the speed of rotation of the prime mover of this generator?
ii) What is the internal generated voltage (E_a) and torque angle (δ) of this generator under rated conditions?
iii) What is the maximum possible power output of this generator?
iv) Calculate the armature current of machine when it supplies a half rated load.
v) Sketch the phasor diagram to illustrate the behavior of this machine when the load is changed from rated load to half rated load.

[6.5 Marks]

Q4 a) i) Classify DC machines based on their excitation.
ii) What is meant by the armature reaction in a DC machine?
iii) Briefly explain two methods used to mitigate the effect of armature reaction in DC machines.

[3.5 Marks]

b) From first principles, show that the internal generated voltage (E_A) of a DC generator is given by,

$$E_A = \left(\frac{pz}{60a}\right)\varphi n_m$$

where all the notations have their usual meanings.

[1.5 Marks]

c) In a laboratory trainer kit, A 200 V, 50 Hz, six pole delta connected synchronous motor having a synchronous reactance of 8 Ω and negligible armature resistance per phase is coupled with a short shunt compound DC generator (SSC-DCG) as the prime mover. The SSC-DCG has the armature resistance of 0.22 Ω and the series and shunt field resistances of 0.1 Ω and 125 Ω, respectively. The field current of the synchronous motor is kept constant during the operation. Assume that the rotational losses and core losses of machines are negligible.

i) Let E_a, I_a, v_φ and $\cos\theta$ be the per phase internal generated voltage, armature current, input phase voltage and input power factor of the synchronous motor, respectively. Draw the phasor diagram of the synchronous motor having a leading line current.
ii) At a certain operating point, the load on the SSC-DCG is 50 Ω supplied by a terminal voltage of 250 V. Calculate the torque supplied by the motor.
iii) If the measured input power factor of the motor is 0.8 leading, calculate the E_a of the motor.
iv) Calculate the current drawn by the motor if the terminal voltage of the SSC-DCG needs to be increased by 20%.

[7.5 Marks]