UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: January 2022

Module Number: EE6303 **Module Name: Electric Machines II**

[Three Hours]

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

Q1. a) Field and armature windings are the essential features of electric machines. The field windings are simple arrangements with concentrated coils. Armature windings on the other hand comprise a set of coils embedded in the slots, uniformly spaced round the armature periphery.

i) Briefly explain the difference between a full pitch coil and a short pitch coil.

ii) Briefly explain the following terminologies associated with armature windings in ac machines.

Pole pitch
Coil pitch
Phase belt
Slot angle pitch

iii) State the definition for winding factor in ac machines.

[4.0 Marks]

b) The field of a three-phase ac machine constitutes of four poles. The armature of this machine consists of 24 slots. It is needed design an integral slot chorded double-layer winding for this armature by choosing coil pitch of 5 slots.

i) Draw the developed winding diagram of the proposed winding for phase A. Cleary show coil placements for all three phases in a table.

ii) Calculate the flux per pole required to generate 50 Hz ac voltage of 4.8 kV (phase voltage) from the three-phase ac machine mentioned in part b). The number of turns per coil is 5.

[4.0 Marks]

c) Draw the developed armature winding diagram of single layer half-coil bifurcated winding of a three-phase ac machine. The armature of this machine consists of 12 slots and the rotor consists of 4 poles. The phase spread used is 60^o. Show all three phases in the same developed winding diagram.

[2.0 Marks]

Q3. a) A 415 V, 6 kVA, star-connected salient-pole synchronous generator is operated under full-load at 0.85 lagging power factor. Direct-axis and quadrature-axis synchronous per-phase reactances are 5.4 Ω and 3.2 Ω, respectively. Assuming the armature resistance is negligible, draw the phasor diagram for the generator. Calculate the load angle and the voltage regulation for the generator.

[3.0 Marks]

b) A 380 V, 50 Hz, star-connected, synchronous generator is rated at 30 kVA at 0.8 lagging power factor. It has a synchronous reactance of 2.5 Ω per phase. Assume that the generator is connected to a prime mover capable of supplying up to 28 kW of input power. Take the friction and the windage loss of the generator as 500 W, and the core loss as 800 W.

i) Sketch the capability curve of this generator mentioning all the limitations and highlighting the normal operating region.

ii) Can this generator supply a line current of 42 A at 0.6 power factor lagging? Explain your answer.

iii) Calculate the maximum reactive power this generator can absorb while supplying the maximum real power.

[3.5 Marks]

c) A 50 MVA, 12.5 kV, 50 Hz star-connected, three-phase synchronous generator is operating at the rated voltage and no-load when a three-phase short circuit fault occurs at its terminals. Per-unit reactances of the generator to its own base values are

$$X_d = 1.00 \qquad X_d' = 0.20 \qquad X_d'' = 0.10$$

and the time constants are

$$T_{do}' = 1.20\ s \qquad T_{do}'' = 0.03\ s \qquad T_a = 0.2\ s$$

where, all the notations have their usual meanings.

i) Calculate the initial AC RMS component of the fault current.

ii) Calculate the maximum possible initial DC component of the fault current.

iii) Determine the total RMS fault current after 10 cycles if the initial DC component is 1000 A.

[3.5 Marks]

Q4. a) i) State three advantages of brushless DC (BLDC) motors compared to conventional DC motors.

ii) Briefly explain the field-oriented control (FOC) of a permanent magnet synchronous motor (PMSM) using a schematic diagram.

iii) Explain the principle of operation of a shaded-pole induction motor.

iv) At starting, impedances of the main winding and the auxiliary winding of a 230 V, 50 Hz split-phase induction motor are $3.2 + 8.5\,j\,\Omega$ and $8.3 + 3.5\,j\,\Omega$, respectively. Calculate the currents in each winding, line current and power factor of the motor at start.

[5.0 Marks]

b) Discuss the characteristics of following motor types and state two common applications for each type.

i) Universal motor
ii) Synchronous reluctance motor
iii) Hysteresis motor

[3.0 Marks]

c) i) Briefly discuss the four driving modes of stepper motors.

ii) A hybrid stepper motor with a 60-tooth rotor has a resolution of 180. Determine the number of phases in the stator and shaft speed if the stepping frequency is 4500 pulses per second.

[2.0 Marks]

Q5. a) i) Briefly explain the causes of noise generation in a power transformer.

ii) State four differences between ONAN and KDWF transformer cooling systems.

[2.0 Marks]

b) A nameplate of a three-phase squirrel-cage type induction motor is shown in Figure Q5.

i) State the standard used for this nameplate and give four reasons for your answer.

ii) Explain why rated voltage for this motor is shown as 208-230/460 V.

iii) Discuss whether this motor is suitable to use for an outdoor water pump.

iv) Calculate the maximum starting current for this motor using Table Q5.

v) Determine the maximum power output this motor can deliver under temporary overload conditions and the maximum hotspot temperature allowed inside the motor.

vi) Briefly explain the two efficiencies given in the nameplate.

[3.5 Marks]

c) i) From first principles, show that the temperature rise θ of an electric machine after a time of t can be expressed as

$$\theta = \theta_f - \left(\theta_f - \theta_0\right) e^{-\frac{t}{T}}$$

where, θ_0 is the initial temperature rise, θ_f is the final steady state temperature rise and T is the overall heating time constant of the electric machine. Assume that the heat generation in the machine remain constant, heat dissipation rate is proportional to temperature difference and the temperature in the cooling medium remains constant.

ii) A 10 hp motor has a heating time constant of 80 minutes and when run continuously on full-load attains a steady-state temperature of 70 ^{0}C when ambient temperature is constant at 30 ^{0}C. Calculate the 15 min and 30 min ratings of the motor for this temperature rise, assuming that it cools down completely between each load period and the losses are proportional to square of the load.

[4.5 Marks]

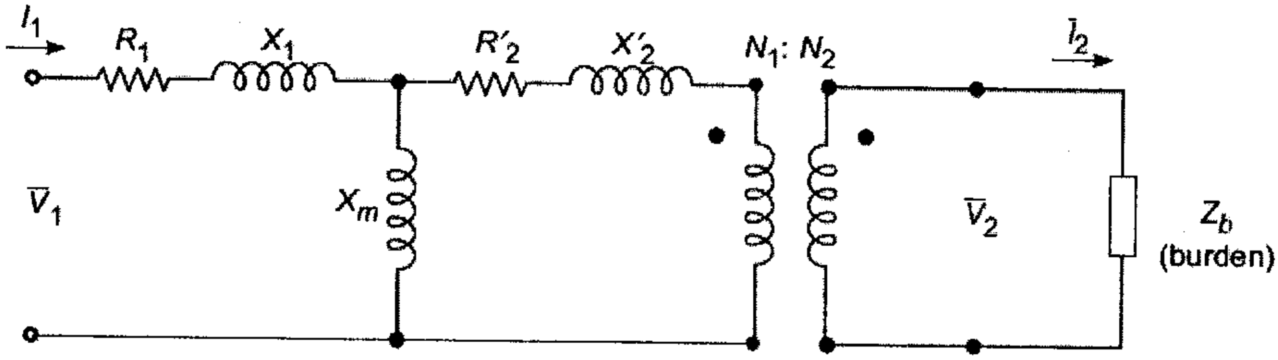

Figure Q2

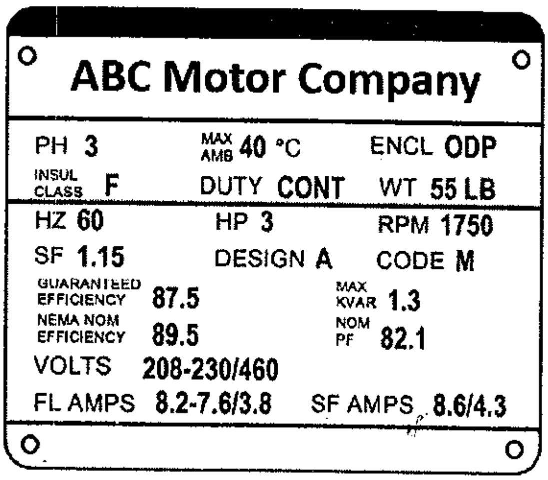

Figure Q5

Table Q5

Letter associate with starting current	Range of kVA/HP with locked rotor	Approximate Mid-Range Value (kVA/HP)
A	0 - 3.14	1.6
B	3.15 - 3.55	3.3
C	3.55 - 3.99	3.8
D	4.0 - 4.49	4.3
E	4.5 - 4.99	4.7
F	5.0 - 5.59	5.3
G	5.6 - 6.29	5.9
H	6.3 - 7.09	6.7
J	7.1 - 7.99	7.5
K	8.0 - 8.99	8.5
L	9.0 - 9.99	9.5
M	10.0 - 11.19	10.6
N	11.2 - 12.49	11.8
P	12.5 - 13.99	13.2
R	14.0 - 15.99	15.0
S	16.0 - 17.99	-
T	18.0 - 19.99	-
U	20.0 - 22.39	-
V	22.4 and up	-