Professional Engineers Ontario

Exam

07-Elec-A6 Power Systems and Machines

Spring 2015

Notes:

1. **FIVE (5)** questions constitute a complete exam paper. All questions are of equal value.

2. Start each question on a new page, and clearly indicate the question number. Only work written on the right hand pages of the answer booklets will be marked. Use the pages on the left side for rough work only - ***work presented on the left hand side pages will NOT be marked***.

3. You may use one of the approved Casio or Sharp calculators.

4. This is a closed book exam. Formula sheets are attached.

5. All ac voltages and currents are rms values unless noted otherwise. For three-phase circuits, all voltages are line-to-line voltages unless noted otherwise, and power is total power unless noted otherwise.

6. You are strongly encouraged to use a pencil and eraser for this exam.

The candidate is urged to submit with the answer paper a clear statement of any assumptions made if doubt exists as to the interpretation of any question that requires a written answer.

Question 1 (General Knowledge)

a. Why is the iron core of a transformer laminated?

b. Sketch the torque-speed curve of a typical induction motor

c. How can the direction of a three-phase induction motor be reversed?

d. Describe two methods of varying the speed of three phase induction motors.

e. Explain why a starter is needed when starting a dc shunt motor from the dc mains.

f. Explain why induction motors have low power factor when they are lightly loaded.

g. Describe two methods that can be used to reverse the direction of rotation of a DC shunt motor.

h. Describe two methods for varying the speed of a dc shunt motor.

i. Give two reasons why the synchronous motor is a useful industrial machine.

Question 2

A single-phase transformer has the following ratings: 50 kVA, 2400/240 V and 60 Hz. The following results were obtained from open-circuit and short-circuit tests:

Test	Voltage	Current	Real Power Input
Open-circuit	2400 V	0.9 A	395 W
Short-circuit	195 V	20.83 A	950 W

a. Determine the parameters of this transformer referred to the high side.

b. The secondary of this transformer is connected to a load that draws the rated power at rated voltage and at 0.8 power factor lagging. Determine:

   (i) the efficiency of the transformer; and,

   (ii) the voltage regulation.

c. Determine the amount of load apparent power at which the transformer has the maximum efficiency.

Question 3

A 3-phase, 480V, 60 Hz, 35 hp, Y-connected, two-pole squirrel cage induction motor is operating at a slip of 0.03. Rotational losses are evaluated to be 1850 W and are assumed to be constant.

The motor parameters in ohm/phase referred to the stator are:

$$R_1 = 0.322\ \Omega,\ X_1 = 0.675\ \Omega,\ R_2 = 0.196\ \Omega,\ X_2 = 0.510\ \Omega,\ X_m = 12.5\ \Omega$$

Determine:

a. the line current;
b. the mechanical developed power;
c. the mechanical developed torque;
d. the efficiency; and,
e. the reactive power drawn by the machine.

Question 4

A 250 V, 1600 rpm dc shunt motor operating at rated conditions driving a constant torque-load has a line current of 20 A when fed by rated terminal voltage. The armature-circuit resistance and field-circuit resistance are 0.4 Ω and 250 Ω, respectively.

If the rotational losses of the motor are negligible, calculate the following:

a. the armature current;
b. the output power;
c. the mechanical developed torque; and,
d. the efficiency.

If now the field current is reduced to 0.8 A by inserting an external resistance to the field circuit while keeping the torque load constant. Find:

e. the value and power rating of the inserted resistance;
f. the armature current, I_a;
g. the operating speed; and,
h. the efficiency.

Neglect armature reaction and assume linear magnetic circuit.

Question 5

A 600V, 60Hz, 8-pole, Y-connected, three-phase synchronous motor has a synchronous reactance of 9 Ω per phase and negligible armature resistance. When it runs at no load, the motor draws an armature current of 8 A at a 0.08 pf leading.

For the no-load condition, calculate:

a. the induced voltage;
b. the power angle, δ; and,
c. the rotational losses of the motor.

This motor is used as a synchronous condenser to improve the overall power factor of a small factory, whose other loads include:

- a three-phase induction motor delivering an output power of 15 kW at an efficiency of 90% and a power factor of 0.85 lagging.
- a combined heating and lighting load at a power factor of 0.95 lagging.

Calculate:

d. the synchronous motor active and reactive power required to operate the plant at unity power factor;
e. the synchronous motor armature current for the conditions in (d); and,
f. the excitation emf required for the conditions in (d).

END OF THE EXAM

Potentially useful formulae

$$P = VI\cos\theta = \frac{V_R^2}{R} = I^2R = Re[\mathbf{V}\mathbf{I}^*]$$

$$Q = VI\sin\theta = \frac{V_X^2}{X} = I^2X = Im[\mathbf{V}\mathbf{I}^*]$$

$$\mathbf{S} = \mathbf{V}\mathbf{I}^*$$

$$|\mathbf{S}| = \sqrt{P^2 + Q^2} = VI = I^2Z = \frac{V^2}{Z}$$

$$p.f. = \cos\theta = \frac{R}{Z} = \frac{P}{S}$$

$$P_T = \sqrt{3}V_LI_L\cos\theta = 3P_P \qquad P_P = V_PI_P\cos\theta$$

$$Q_T = \sqrt{3}V_LI_L\sin\theta = 3Q_P \qquad Q_P = V_PI_P\sin\theta$$

$$S_T = \sqrt{3}V_LI_L \qquad S_P = V_PI_P$$

$$B = \frac{\Phi}{A} = \mu H = \mu\frac{\mathscr{F}}{l} = \mu\frac{Ni}{l} \qquad \left[\frac{Wb}{m^2} = T\right]$$

$$H = \frac{NI}{l} = \frac{B}{\mu} = \frac{\Phi/A}{\mu} \qquad \left[\frac{A-t}{m}\right]$$

$$\mathscr{F} = Ni = \Phi\frac{l}{\mu A} = \Re\Phi \qquad [A-t]$$

$$\Re = \frac{l}{\mu A} \qquad \left[\frac{A-t}{Wb}\right]$$

$$\mu_0 = 4\pi \ x \ 10^{-7}\ \frac{Wb}{A-t-m} \qquad \mu = \mu_0\mu_r$$

$$P_e = K_ef^2B^2_{\max}V_{vol} \qquad P_h = K_hfB^x_{\max}V_{vol}$$

$$L = \frac{N^2}{\Re}$$

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

$$P_{dev} = E_a I_a = T_{dev} \omega_m$$

$$P_{out} = P_{dev} - P_{rot} = T_{out} \omega_m$$

$$P_{rot} = \text{No load } P_{dev}$$

$$n_s = 120 \frac{f}{p}$$

$$s = \frac{n_s - n_m}{n_s}$$

$$P_{input} = 3 V_1 I_1 \cos\theta$$

$$P_{gap} = P_{input} - 3 I_1^2 R_1 = 3 I_2'^2 \frac{R_2'}{s} = T_{dev} \omega_s$$

$$3 I_2'^2 R_2' = s P_{gap}$$

$$P_{dev} = P_{gap} - 3 I_2'^2 R_2' = (1 - s) P_{gap}$$

$$P_{out} = P_{dev} - P_{rot} = T_{out} \omega_m$$

$$\mathbf{E_a} = \mathbf{V_t} + \mathbf{I_a}(R_a + jX_s)$$

$$P = \frac{3 V_t E_a}{X_s} \sin\delta$$