# Professional Engineers Ontario

# Exam

# 07-Elec-A6 Power Systems and Machines

# Fall 2015

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**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 (Three-phase power)

a. A 40 hp, 460 V, 1180 rpm, 3-phase, 60 Hz, premium efficiency induction motor has a full-load efficiency of 93.6%, and a power factor of 0.83 lagging. Determine:

   i. the active power drawn by the motor in kW;
   ii. the apparent power drawn by the motor; and,
   iii. the full-load line current.

b. Two loads are connected in parallel to a balanced 3-phase, 3-wire 208 V, 60 Hz supply. The first load is Y-connected, and consists of three equal impedances of $10\angle 45°\ \Omega$. The second load is Δ-connected, and each phase consists of an 8 Ω resistor in series with a 16 mH inductor. Determine the capacitance needed that must be connected in parallel to obtain unity power factor.

c. What would be the reading of two wattmeters connected between the supply and the first load for the loads of part (b), before and after the installation of the capacitors?

## Question 2 (Transformers)

a. Can a transformer be used in DC circuits? Why or why not?

b. A short-circuit occurs in the secondary of a transformer. What will be the result in the primary?

c. Will transformer heating be approximately the same for resistive or inductive loads of the same *VA* rating? Explain.

d. A single-phase, 300 kVA, 11 kV/2.2 kV, 60 Hz transformer has the following equivalent circuit parameters, all referred to the high-voltage side:

$$R_{c(\mathrm{HV})} = 57.6\ \mathrm{k}\Omega \qquad X_{m(\mathrm{HV})} = 16.34\ \mathrm{k}\Omega$$
$$R_{\mathrm{eq(HV)}} = 2.784\ \Omega \qquad X_{\mathrm{eq(HV)}} = 8.45\ \Omega$$

Determine:

   i. no-load current as a percentage of full-load current;
   ii. no-load power loss (core loss);
   iii. no-load power factor;
   iv. the full-load copper loss; and,
   v. if the load impedance on the low-voltage side is $\mathbf{Z}_{\mathrm{load}} = 16\angle 60°\ \Omega$, determine the voltage regulation using the approximate equivalent circuit.

## Question 3 (DC motors)

a. Explain three methods of speed control for a DC shunt motor, outlining the advantages and disadvantages of each.

b. A DC shunt motor, rated 20 hp, 230 V, 1250 rpm has an armature resistance of 0.18 ohms. At rated speed and load, the armature current is 78 amperes, and the field current is 1.8 amperes. Determine:

   i. Ea, the induced armature voltage;
   ii. the output torque;
   iii. the mechanical losses;
   iv. the efficiency;
   v. the starting current; and,
   vi. the no-load speed.

## Question 4 (Induction motors)

a. What are the two types of three-phase a.c. induction motor rotors? Give one advantage of each.

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

c. Sketch and label the speed-torque characteristic of a three-phase induction motor.

d. The full-load slip of a 4-pole, 60 Hz, 440 V (line-to-line) three-phase induction motor is 0.05.

   i. What is the speed of the rotating stator field? What is the frequency (in Hz) of the rotor current?

   ii. When the output power of the motor is 90 hp at a speed of 1732 rpm, rotational losses (which include frictional and core losses) are 10,100 W, while copper losses for both the rotor and stator total 3700 W. Determine the motor efficiency and line current, assuming the motor has a power factor of 0.8 lagging under these conditions.

## Question 5 (Synchronous machines)

a. A synchronous generator connected to an infinite grid has its frequency and terminal voltage fixed. What is the effect of increasing the excitation current in this case?

b. A six-pole, Y-connected three-phase synchronous machine rated 208 V (line-to-line), 5500 VA has a synchronous reactance of 8 Ω per phase at rated terminal voltage. It is operating as a generator connected to an infinite grid.

  i. Determine the excitation voltage and the power angle if the machine delivers rated kVA at a factor of 0.8 lagging. Draw the phasor diagram for this condition.

  ii. If the field excitation current is increased by 20% without changing the prime mover input power, find the new armature current, power factor and reactive power supplied by the machine.

  iii. Assume that the field excitation current is reduced to its original value (part (i) above and then the prime mover input power is slowly increased. What is the steady-state stability limit? What are the corresponding values of the armature current, power factor and reactive power at this maximum power transfer condition?

**END OF THE EXAM**

## Potentially useful formulae



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

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

$$\mathbf{S} = \mathbf{VI}^*$$

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

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

$$P_T = \sqrt{3}\,V_L I_L \cos\theta = 3P_P \qquad P_P = V_P I_P \cos\theta$$

$$Q_T = \sqrt{3}\,V_L I_L \sin\theta = 3Q_P \qquad Q_P = V_P I_P \sin\theta$$

$$S_T = \sqrt{3}\,V_L I_L \qquad S_P = V_P I_P$$

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

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

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

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

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

$$P_e = K_e f^2 B^2_{\max} V_{vol} \qquad P_h = K_h f B^x_{\max} V_{vol}$$

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

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

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

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

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

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

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