Professional Engineers Ontario

Exam

07-Elec-A6 Power Systems and Machines

Spring 2014

Notes:

1. **FIVE (5)** questions constitute a complete exam paper. Unless you indicate otherwise, the first five questions as they appear in the answer booklet will be the only ones marked. 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.

If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper a clear statement of any assumptions made.

Question 1

Figure 1 below represents a small distribution system having three 3-phase loads, having the following characteristics:

Load A: a three-phase heating unit drawing 20 kW at unity power factor

Load B: a three-phase 25 hp induction motor that operates at a power factor of 0.65 lagging

Load C: a 24 kVA, 18.6 kVAR lagging load

The line-to-line voltage of this system is 600 V and the system frequency is 60 Hz.

a. If two wattmeters, W1 and W2, are used to measure the total power delivered to the loads as shown, determine the wattmeter readings.

b. Because of the low power factor of the system, the decision is made to add power factor correction capacitors in parallel with the loads, to increase the power factor to unity. Determine how many VARs of capacitors are required per phase, and determine the new readings of the two wattmeters with the capacitors installed.

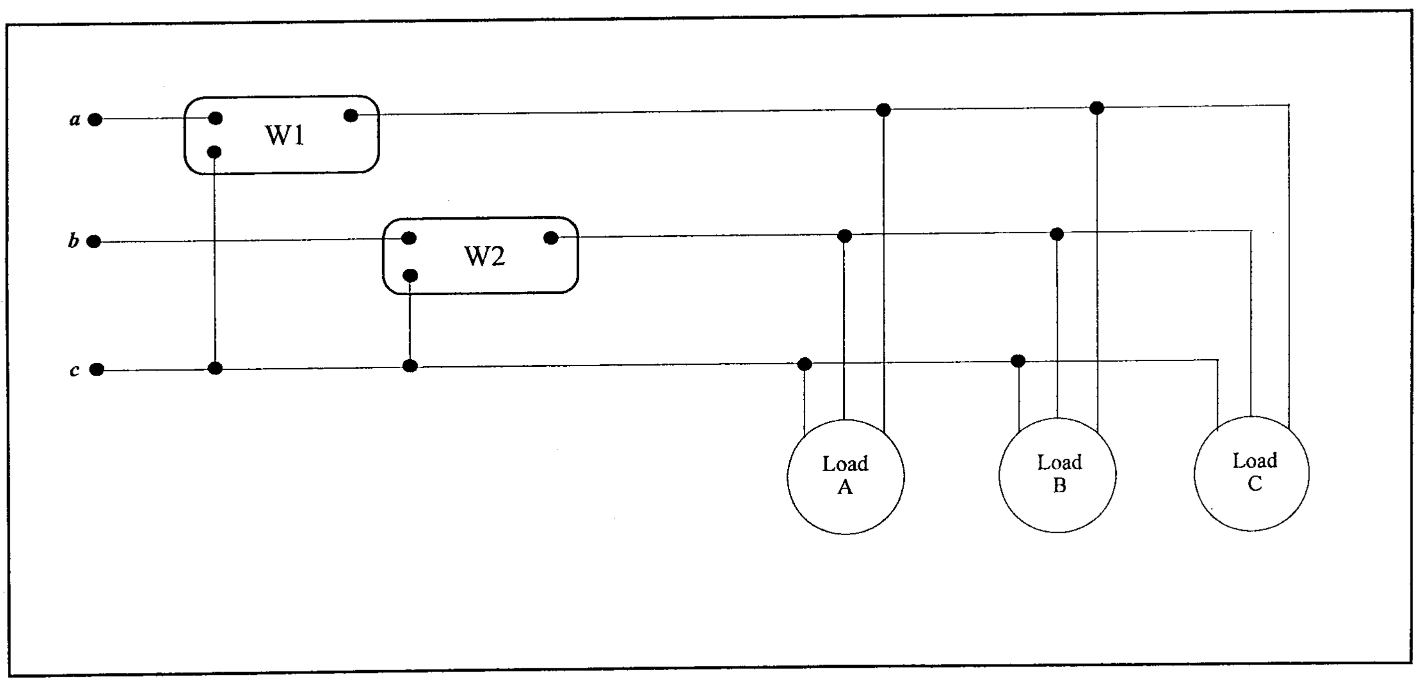

Figure 1

Question 2

For the magnetic circuit shown below in Figure 2, the core material is 1% silicon iron, for which the magnetization curve is shown in Figure 3. The depth of all core members is a uniform 75 mm. The remaining dimensions are as follows: $\delta_1 = 3$ mm; $\delta_2 = 2$ mm; $w = 125$ mm; $h = 150$ mm; and, $l = 50$ mm. Coil 1 has 100 turns. If $\phi_2 = 1$ mWb, find the flux, ϕ_1, and the current, I_1.

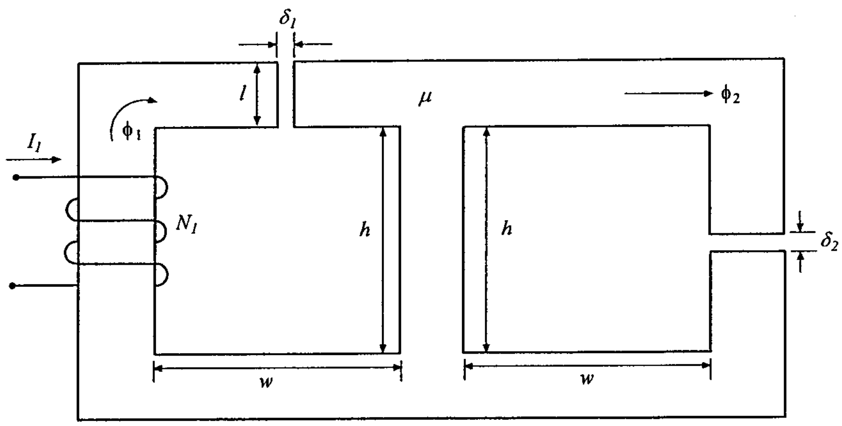

Figure 2

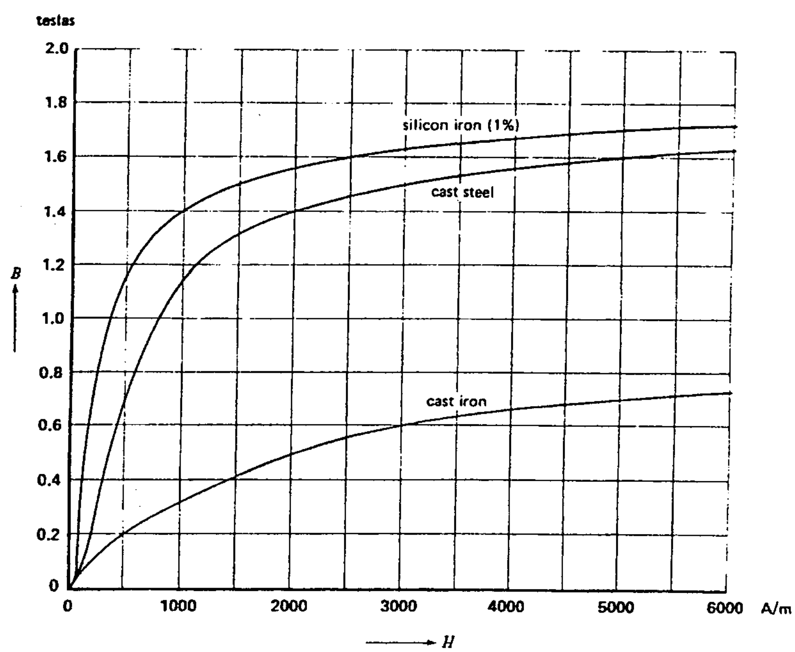

Figure 3

Question 3

A 208V/120 V, 60 Hz, 1800 VA transformer has the following parameters:

$R_C = 416\ \Omega$ (HV side) $R_{eq} = 0.21\ \Omega$ (LV side)

$X_m = 172\ \Omega$ (HV side) $X_{eq} = 0.98\ \Omega$ (LV side)

(Note: HV = high voltage side; LV = low voltage side)

The transformer is to be used as a step-down transformer.

a. If an open-circuit and short-circuit test were performed on this transformer, what would be the wattmeter reading for each test condition? You may place the measuring instruments in either winding.

b. Determine the efficiency and percent voltage regulation if a 1200 W load with a power factor of 0.67 lagging connected to the low voltage side, and the voltage across the load is the rated voltage, i.e., 120 V.

c. Repeat part (b) if the load is changed to a capacitive impedance of 12 Ω.

Question 4

A 240 V, 1600 rpm shunt dc motor operating at rated conditions driving a constant torque-load, has a line current of 41.6 A when fed by rated terminal voltage, V_t, of 240 V. The armature-circuit resistance and field-circuit resistance are 0.4 Ω and 150 Ω, respectively. The rotational losses are determined to be 600 W.

Calculate:

a. the output power;
b. the developed torque
c. the efficiency

Without changing the torque-load, the field resistance is increased to 200 Ω. Under these new conditions, calculate:

d. the armature current, I_a;
e. the line current, I_t;
f. the motor speed (rpm); and,
g. the efficiency.

Assume rotational losses remain constant.

Question 5

a. A 3ϕ synchronous generator is connected to the Hydro One grid. What is the effect on the real and reactive power if the field current is increased?

b. Show, with the aid of a phasor diagram, that the power output for a synchronous generator is given by:

$$P = \frac{3V_t E_f}{X_S}\sin\delta$$

c. A 4-pole, 60 Hz, synchronous generator is connected to an infinite bus that supplies a 60 Hz, 600 V, 2000 kVA load having a power factor of 0.804 lagging. The generator is driven by a steam turbine that delivers 2650 N-m of torque to the generator shaft, resulting in a power angle of 34°. The synchronous reactance is 1.06 Ω per phase. Assuming losses are negligible, determine:

i. the mechanical power input to the generator rotor;

ii. the per-phase excitation voltage;

iii. the armature current;

iv. the total complex power delivered to the bus; and,

v. the generator power factor.

d. Provide a neatly-labelled phasor diagram for part (c).

Question 6

A 50 hp, 440 V, 60 Hz, three-phase, Y-connected induction motor has the following equivalent circuit parameters:

$R_1 = 0.1\ \Omega$ $X_1 = 0.35\ \Omega$

$R_2' = 0.12\ \Omega$ $X_2' = 0.4\ \Omega$

$P_{rot} = 2150\ W$

With no load, the line current is 18 A at 0.089 p.f. lagging. If the motor speed is 1755 rpm, determine

a. the line current;

b. the developed torque;

c. the output power (may be different than rated output); and,

d. the efficiency.

Potentially useful formulae

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

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

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

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

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

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

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