Professional Engineers Ontario

Exam

07-Elec-A6 Power Systems and Machines

Fall 2013

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.

6. You are 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: 21.5 kW, 0.6 power factor lagging

Load B: 22 kVA, 11 kW (inductive load)

Load C: 17.6 kVAR, 0.8 power factor lagging

The line-to-line voltage of this system is 440 V.

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 the size of the capacitors required per phase (in ohms), and determine the new readings of the two wattmeters with the capacitors installed.

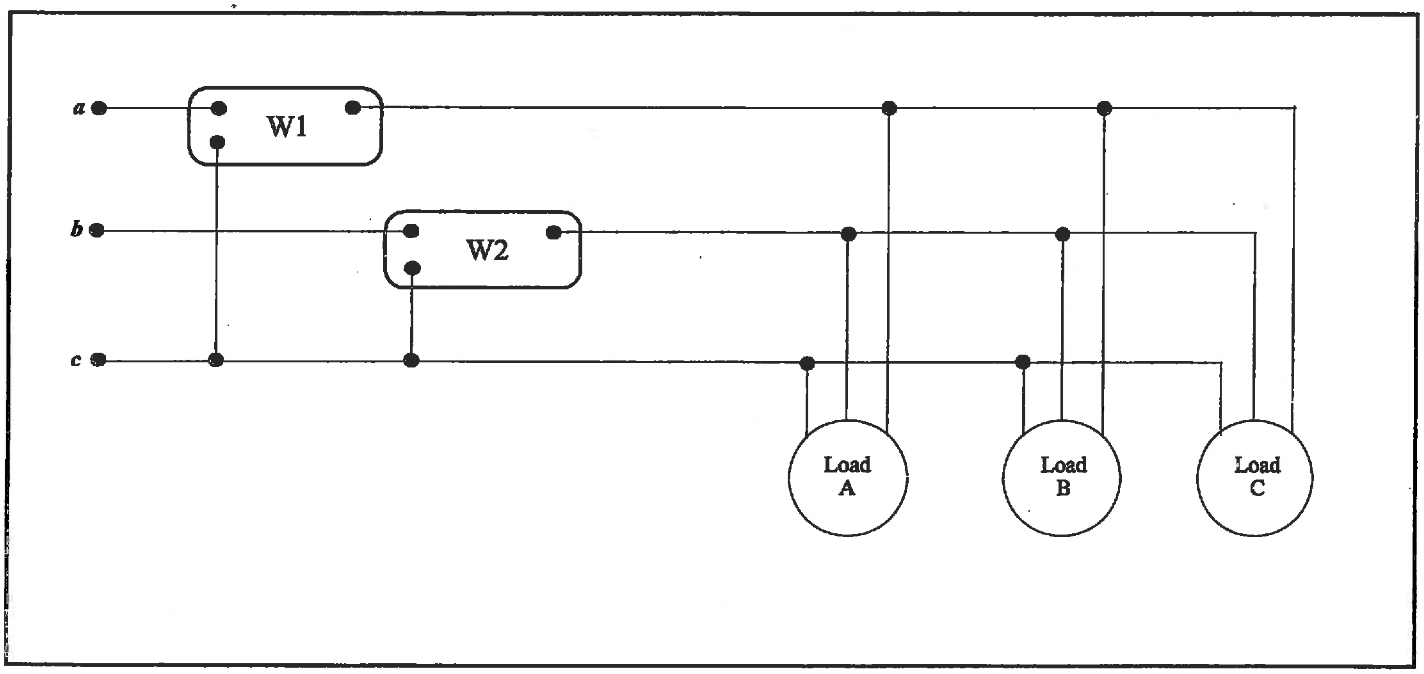


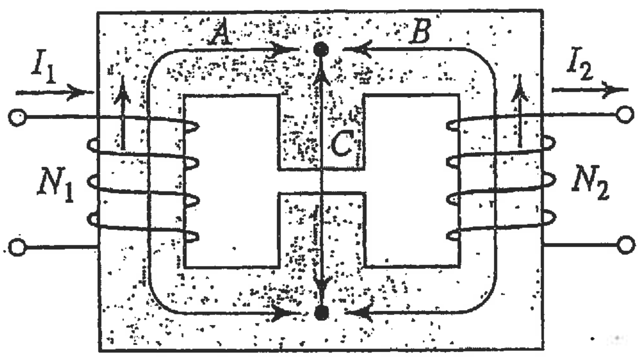
Figure 1

Question 2

The magnetic circuit shown in Figure 2 is made of silicon steel, for which the B-H curve is provided in Figure 3. Each coil has 500 turns. It is required to establish a flux of 3.6 mWb in the air gap, by applying the same current to each coil, i.e., $|I_1| = |I_2|$ (and note their orientation). What is the required current? The dimensions of the magnetic circuit are as follows:

Cross-sectional area of all legs: 30 cm^2
Length of path A: 90 cm
Length of path B: 90 cm
Length of path C: 45 cm
Air gap length: 0.4 mm

Figure 2



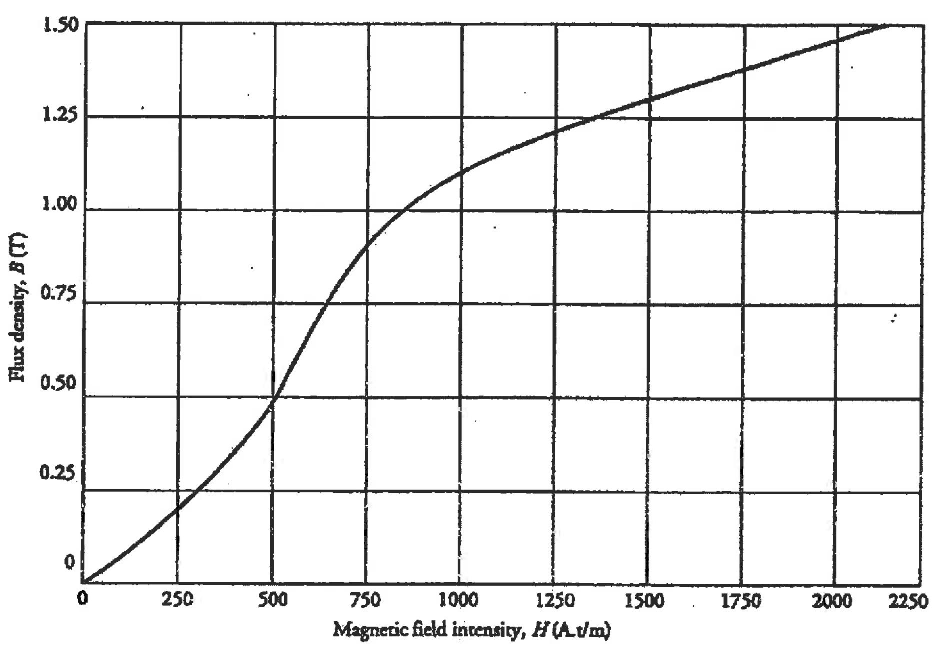


Figure 3

Question 3

A 60 VA, 208/120 V, 60 Hz, single-phase transformer gave the following test results:

Open-Circuit Test (LV side):
Voltage = 120 V
Current = 25.07 mA
Power = 2 W

Short-circuit Test (HV side):
Voltage = 16.85 V
Current = 300 mA
Power = 4.7 W

Determine:

a. the approximate equivalent circuit for the transformer, with all values referred to the HV side;
b. the full-load efficiency of the transformer for a power factor of 0.8 leading (load connected to the low voltage winding, and source voltage adjusted to provide rated voltage at the load); and,
c. the percentage voltage regulation.

Question 4

A three-phase, 14 kV, 10 MVA, 60 Hz, Y-connected, 2-pole synchronous generator has $X_S = 20.0\ \Omega$ and $R_A = 2.0\ \Omega$ per phase. The generator is connected to an infinite bus at a power factor of 0.85 lagging.

a. What is the speed of rotation of the generator?

b. Determine the excitation voltage of the generator if it supplies rated power. Draw the phasor diagram for this condition.

c. Determine the power angle for the condition in part (b).

d. If the field current is kept constant, what is the maximum power the generator can supply? The armature resistance can be neglected for this calculation.

e. For the condition in part (d), determine the generator current and the power factor. Draw the phasor diagram for this condition.

Question 5

A 240 V, 20 hp, 2000 rpm DC shunt motor has an efficiency of 76% at full load. The armature resistance is 0.2 Ω, and the motor draws a field current of 1.8 A. Determine:

a. the full-load line current;
b. the full-load shaft torque;
c. the value of resistance needed to limit the starting current to 1.5 times the full-load current;
d. the no-load speed where the no-load current is 23 A; and,
e. the speed regulation.

Question 6

A 4-pole, 230 V, 3ϕ, 60 Hz, Y-connected SCIM has the following equivalent circuit parameters on a per-phase basis:

$R_1 = 10.12\ \Omega$ $X_1 = 38.61\ \Omega$

$R_2' = 21.97\ \Omega$ $X_2' = 11.56\ \Omega$ $X_m = 432.48\ \Omega$

Mechanical losses are 5.9 W, and core losses are 10.72 W. If the motor operates at its rated speed of 1550 W, find the following:

a. the stator current;

b. the magnetization current;

c. the rotor current;

d. the power input;

e. the stator copper losses;

f. the rotor copper losses;

g. the power output;

h. the shaft torque; and,

i. the motor efficiency.

Potentially useful formulae

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

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

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

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

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

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

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