Professional Engineers Ontario

Exam

07-Elec-A6 Power Systems and Machines

Spring 2010

Notes:

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

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

3. This is a closed book exam. Candidates may bring ONE aid sheet 8.5" x 11" hand-written on both sides containing notes and formulae. Note, no example or solution problems, or figures, are allowed. The aid sheet must be submitted with the exam paper.

4. 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.

5. You are encouraged to use 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.

1. Power

a. When we get an electricity bill from our local utility, and the rate is 9.145¢/kWh, are we paying for power or for energy? Justify your answer. **(2 marks)**

b. Why can the fourth wire of a balanced 3ϕ, 4-wire, Y-connected load be smaller than the others? **(2 marks)**

c. Two balanced three-phase loads are connected in parallel to a balanced three-phase, 60 Hz source as shown in the circuit of Figure 1 below. The impedance, $\mathbf{Z}_L$, is the impedance of the distribution line between the source and the loads. The voltage *at the loads* is 240 V, line-to-line.

i. Find the line current from the source, and the source voltage. **(4 marks)**

ii. Find the complex power absorbed for each load, as well as the total power for the two loads. **(4 marks)**

iii. If we wish to correct the power factor at the loads to 0.9 lagging, how many VARs of a three-phase capacitor bank are needed (assuming no losses in the capacitor bank)? If the capacitor bank is connected in Y, what is the required phase impedance? **(4 marks)**

iv. What is the line current with the capacitor bank of (iii) connected? **(2 marks)**

v. Draw a phasor diagram showing the line currents without power factor correction and with the power factor corrected to 0.9. **(2 marks)**

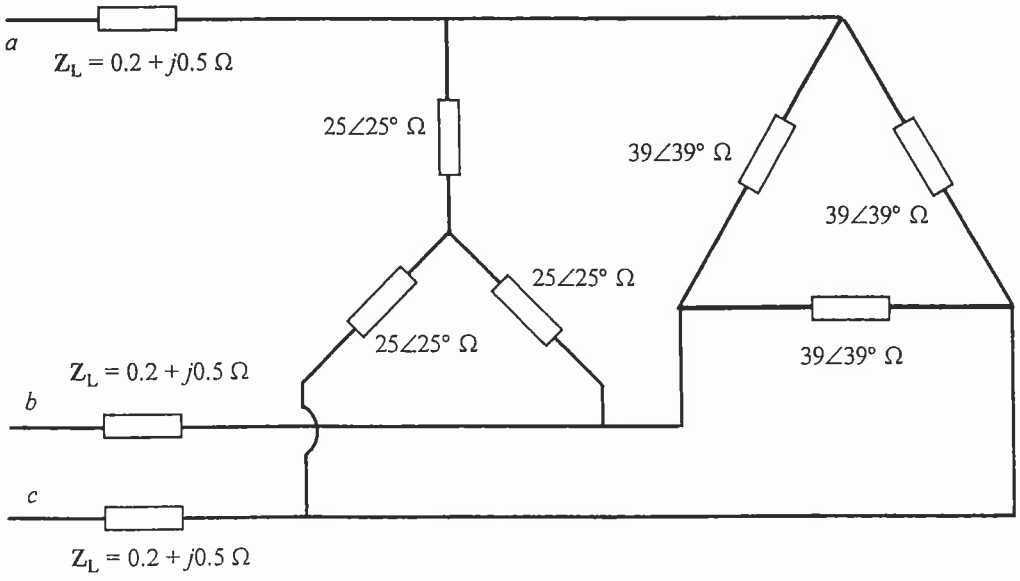
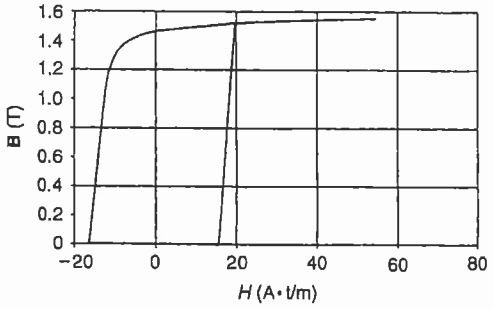


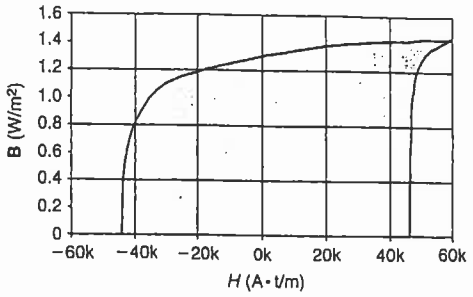
Figure 1

2. Magnetic circuits

a. The B-H curve for two ferromagnetic materials is shown below. Which would be a better choice as transformer magnetic core material in an ac system, (a) or (b)? Justify your answer. **(2 marks)**



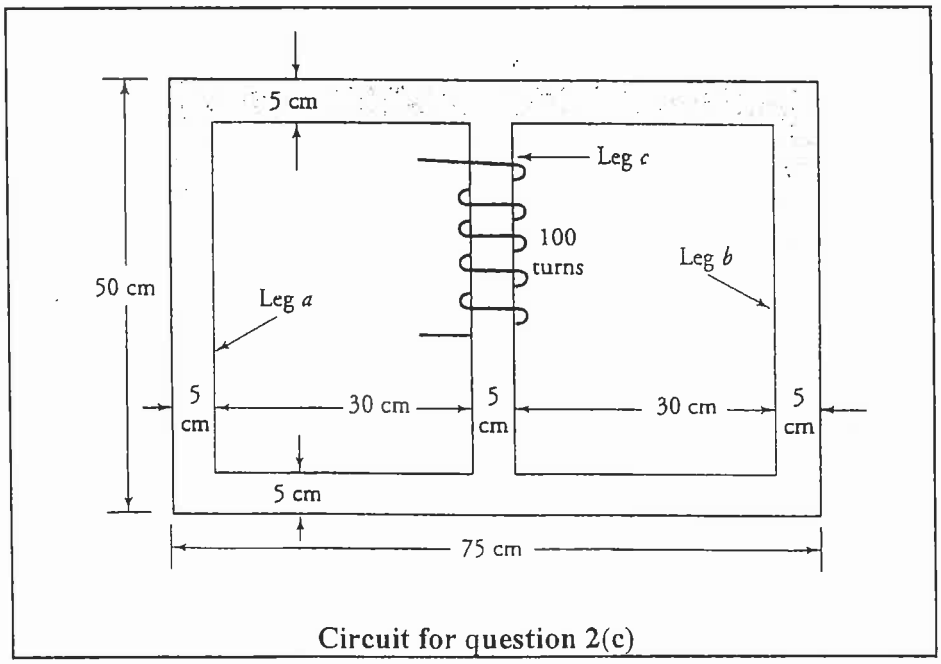
(a)



(b)

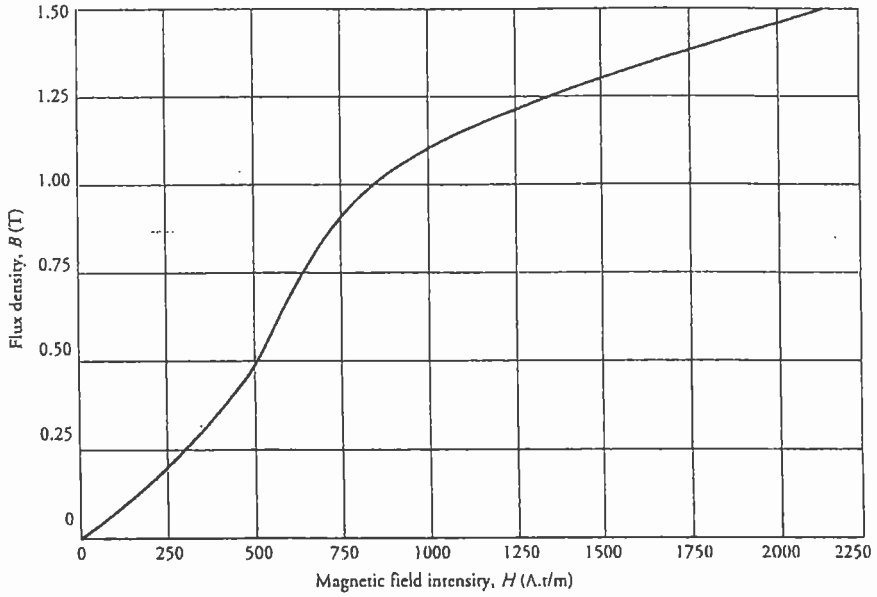
b. In a magnetic circuit, why can we ignore sections that have "infinite permeability" when we analyze the circuit? **(2 marks)**

c. A magnetic core with its dimensions is shown below. The thickness of the magnetic material is 10 cm. What must be the current in a 100-turn coil to establish a flux of 6.5 mWb in leg *c*? The magnetization curve for the material is provided on the next page. Note that $l_a = l_b = 115$ cm, and $l_c = 45$ cm. **(16 marks)**



Circuit for question 2(c)

Magnetic circuits (continued from previous page)



Magnetization curve for question 2(c)

3. Transformers

a. What is the PVR of a transformer delivering rated current to a purely resistive load if the transformer has R_{eq} = 0.03 pu Ω and X_{eq} = 0.044 pu Ω (the magnetizing branch impedance can be neglected)? Assume that the source voltage is 1 pu. **(2 marks)**

b. At the start of the 20th century, most power systems were DC systems. However, with the introduction of the transformer, most systems became ac systems. Why weren't transformers used in the DC systems? **(2 marks)**

c. A 50 kVA, 2400/600 V, 60 Hz, single-phase transformer provides the following test results:

	Voltage	Current	Power input
Open-circuit test	600 V	3.34 A	484 W
Short-circuit test	76.4 V	20.8 A	754 W

i. Indicate on which side the measurements were taken, and the reasons for your choice. **(4 marks)**

ii. Determine the approximate parameters of the transformer, with all values referred to the high-voltage winding, and make a sketch of the approximate equivalent circuit. **(6 marks)**

iii. Using the equivalent circuit determined in part (ii), determine the efficiency and voltage regulation at rated load and 0.92 power factor lagging. **(6 marks)**

4. Autotransformers

a. How does an autotransformer differ physically and electrically from a two-winding transformer? **(4 marks)**

b. If a 50 kVA transformer has a turns ratio of 20:1, what would be its power rating if it is reconnected as an autotransformer? **(2 marks)**

c. A 100 kVA, 60 Hz, 440/240 V autotransformer supplies a load consisting of a 240 V, 8 kW heater and a 240 V, 60 Hz 10 hp motor. The motor operates at 90% load at a power factor of 0.86 lagging, and is 88% efficient at the load. The heater is purely resistive.

i. Sketch the circuit for the transformer, showing the two loads. **(2 marks)**

ii. For these conditions, determine:

(a). the total complex power supplied by the transformer; **(4 marks)**

(b). the total complex power conducted; and, **(5 marks)**

(c). the total complex power transformed. **(3 marks)**

5. DC motors

a. In a DC shunt motor, the field current is decreased by 10%. What, if any, is the effect on motor speed? Why? **(2 marks)**

b. What does E_a represent in the equivalent circuit of a DC motor? **(2 marks)**

c. A 30 hp, 240 V, 1150 rpm DC shunt motor, operating at rated conditions, has an efficiency of 88.5 percent. The armature resistance is 0.064 Ω and the field resistance is 93.6 Ω. Draw an equivalent circuit for the motor, and determine:

i. what percentage of the total losses are due to rotation losses; **(5 marks)**

ii. the external resistance needed in series with the armature circuit to limit the starting current to 175 percent of rated armature current on start-up; and, **(5 marks)**

iii. the new speed if the flux is reduced by 10 percent and the shaft load is adjusted to maintain rated armature current. **(6 marks)**

6. Synchronous machines

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? **(2 marks)**

b. Show, with the aid of a phasor diagram, that the power output for a synchronous generator is given by: **(2 marks)**

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

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; **(3 marks)**

ii. the per-phase excitation voltage; **(3 marks)**

iii. the armature current; **(3 marks)**

iv. the total complex power delivered to the bus; and, **(3 marks)**

v. the generator power factor. **(2 marks)**

d. Provide a neatly-labelled phasor diagram for part (c). **(2 marks)**

7. Induction machines

a. For an induction machine, differentiate between synchronous speed, rotor speed, slip speed and slip. **(4 marks)**

b, What are the constraints for using a 60-Hz induction motor in a system supplied at 50 Hz? **(2 marks)**

c.A 3-phase, 230 V, 30 hp, 50 Hz, 6-pole induction motor is operating with a shaft load that requires 21.3 kW input to the rotor. Rotor copper losses are 1.05 kW, and the combined friction, windage and stray load losses for this load are 300 W. Determine:

i. the shaft speed; **(3 marks)**

ii. the mechanical power developed; **(2 marks)**

iii. developed torque; **(3 marks)**

iv. shaft torque; and, **(3 marks)**

v. the percentage of rated horsepower that the machine is delivering to the load. **(3 marks)**

END OF THE EXAM