

Professional Engineers Ontario

Exam

07-Elec-A6 Power Systems and Machines

Spring 2016

Notes:

1. Do only **five** questions from a choice of seven. **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. Neatness is important. 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 real 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. A 1500 KW industrial facility operates at a lagging power factor (PF) of 0.75 with input voltage V_L at the load terminal L1 equal to 2400 V (RMS). The load is fed from a source through a transmission line having an impedance of $0.05 + j0.5 \Omega$ as shown in Figure 1.1.

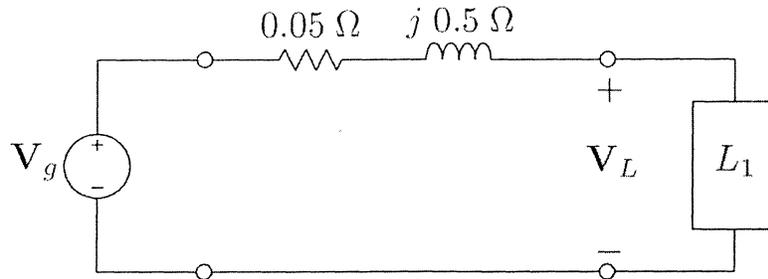


Figure 1.1

- Determine the load current.
- Calculate the average power losses along the transmission line.
- Determine the source voltage, V_g .

In order to improve the PF, an additional load, L_2 , is added in parallel as shown in Figure 1.2. The new load adds 100 KW to the system and improves the overall PF to 0.95 lagging.

- Determine the reactive power and the PF associated with the added load.
- If V_L is kept at 2400 V, obtain the current drawn by the two loads in parallel (L_1 and L_2), the average power losses along the transmission line and the source voltage, V_g , after connecting the additional load.

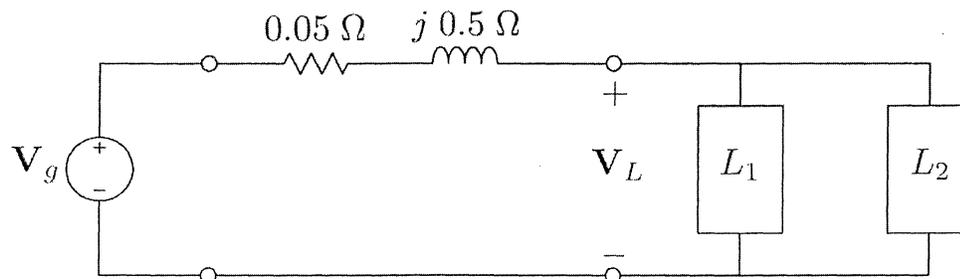


Figure 1.2

Question 2. A balanced Y-connected three-phase load consisting of an impedance of $17\angle 62^\circ \Omega$ in each phase is connected to a balanced three-phase, 60 Hz source as shown in the circuit of Figure 2 below through a distribution line having an impedance, Z_L , of $0.1 + j0.3 \Omega$, between the source and the load. The voltage *at the load* is 600 V, line-to-line.

- Find the line current from the source, and the voltage at the source.
- Find the total average and reactive power of the Y-connected load.
- A three-phase induction motor is connected in parallel with the Y-connected load. The motor output is 23 hp at an efficiency of 83% and a power factor of 0.85 lagging. Determine the new line current with the motor connected, and the voltage at the source. Also, find the average and reactive power drawn by the induction motor. Assume the impedance in the wires connecting the Y-connected load and the induction motor is negligible.
- If we wish to correct the power factor at the loads to unity, 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?
- What is the new line current with the capacitor bank of (d) connected?
- Draw a phasor diagram showing the line currents without power factor correction and with the power factor corrected to unity.

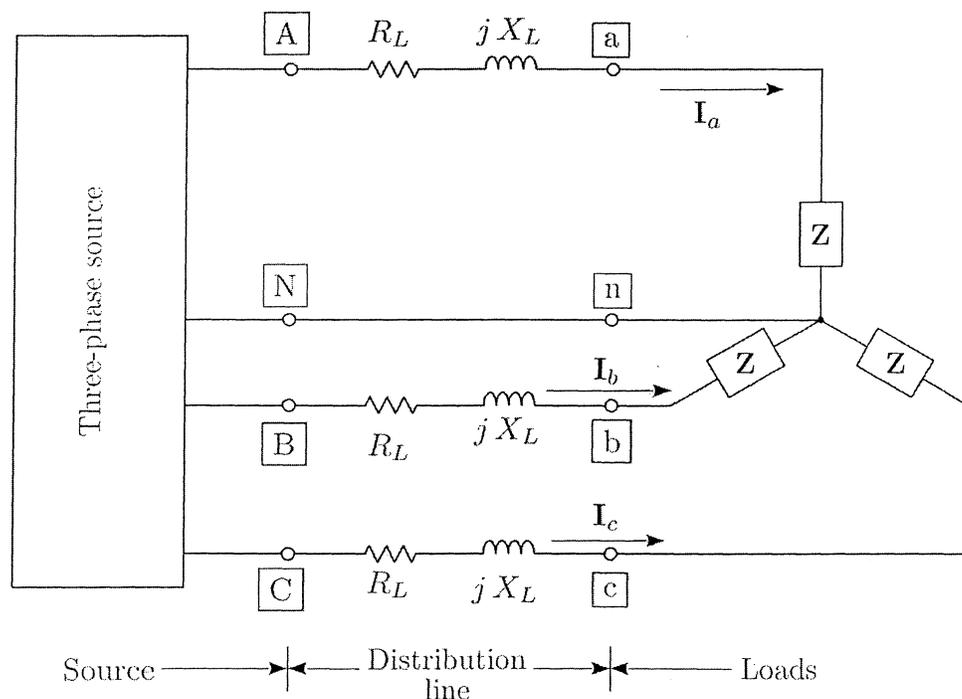


Figure 2

Question 3.

A 220 V DC shunt motor has an armature resistance, $R_a = 0.1 \Omega$, a field resistance, $R_f = 100 \Omega$, and negligible rotational losses. Under certain load conditions, the shunt motor runs at 1600 rpm while drawing a total current, $I_t = 100$ A. Determine:

- the output power of the motor;
- the output torque in N-m; and,
- the efficiency.

Without making any changes to the applied voltage or the field, the motor operates with a new mechanical load that requires a mechanical developed torque of 100 N-m. Determine:

- the total current that the motor consumes;
- the operating speed; and,
- the efficiency.

Question 4.

The following test results were obtained for a 15 kVA, 2300/230 V transformer:

Open-circuit Test	Short-circuit test
$V_{oc} = 2300$ V	$V_{sc} = 47$ V
$I_{oc} = 0.21$ A	$I_{sc} = 6.52$ A
$P_{oc} = 50$ W	$P_{sc} = 160$ W

- On what side of the transformer were each of the tests taken?
- Determine and sketch the approximate equivalent circuit for this transformer, with all voltages referred to the high voltage side.
- Determine the full-load voltage regulation and efficiency with 0.8 leading power factor.

Question 5. A 4-pole, 208 V, three-phase, 60 Hz, 10 hp, Y-connected SCIM has the following characteristics:

$$\begin{array}{ll} R_1 = 0.4 \, \Omega & X_1 = 0.35 \, \Omega \\ R_2' = 0.14 \, \Omega & X_2' = 0.35 \, \Omega \\ X_m = 16 \, \Omega & \end{array}$$

Rotor losses are 360 W. Draw an equivalent circuit showing the given parameters, and, for a motor speed of 1746 rpm, calculate, *on a per-phase basis*, the following:

- a. the stator armature current;
- b. the rotor current;
- c. stator input power;
- d. stator copper loss;
- e. rotor power input;
- f. rotor power developed;
- g. total output power in watts and horsepower;
- h. motor efficiency; and,
- j. output torque.

Question 6. Two 600-kW, 60-Hz, diesel-driven synchronous generators *A* and *B* have governor speed regulations of 2.0 and 5.0 percent, respectively. Both machines are in parallel and supplying equal shares of a 1000-kW bus load at 57 Hz.

- a. Sketch the approximate governor characteristics for both machines on one set of coordinate axes, and indicate the operating frequency. Label both curves.
- b. On the same diagram, approximate a new operating condition that assumes the load on the bus decreases a total of 400kW.
- c. Determine the new frequency and the new load distribution for the conditions in part (b).

Question 7. Find the current required to establish a flux of 2 mWb in the air gap of the magnetic structure shown in Figure 3 below (the magnetization curve is also provided). The coil has 500 turns, and the structure the following dimensions:

$$A_1 = 40 \text{ cm}^2 \quad A_2 = 12 \text{ cm}^2 \quad A_3 = A_4 = 25 \text{ cm}^2 \quad A_g = 26 \text{ cm}^2$$

$$l_1 = 40 \text{ cm} \quad l_2 = 24 \text{ cm} \quad l_3 = l_4 = 26 \text{ cm} \quad l_g = 25 \times 10^{-3} \text{ cm}$$

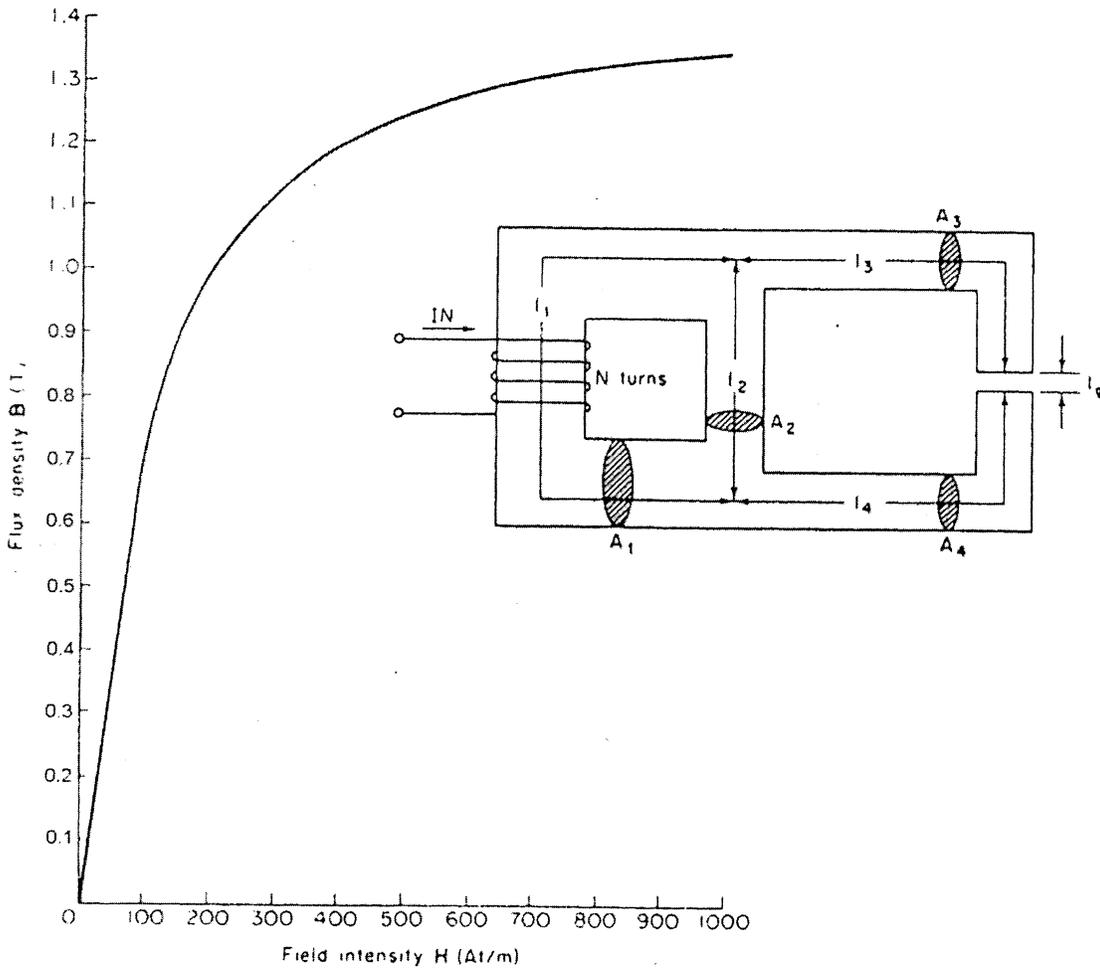


Figure 3

END OF THE EXAM

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

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

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

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

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

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

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

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

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

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

$$\mathcal{F} = Ni = \Phi \frac{l}{\mu A} = \mathfrak{R} \Phi \quad [A-t]$$

$$\mathfrak{R} = \frac{l}{\mu A} \quad \left[\frac{A-t}{Wb} \right]$$

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

$$P_e = K_f f^2 B_{\max}^2 V_{\text{vol}} \quad P_h = K_h f B_{\max}^x V_{\text{vol}}$$

$$L = \frac{N^2}{\mathfrak{R}}$$

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

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

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

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

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

$$\mathbf{E}_a = \mathbf{V}_t + \mathbf{I}_a (R_a + jX_s)$$

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