Professional Engineers Ontario

Electromagnetic Energy Conversion Exam

98-Elec-A6

December 2002

Notes:

1. There are 7 questions. Attempt ***ONLY*** question 1 and FOUR (4) other questions (FIVE (5) questions in all). Unless you indicate otherwise, the first five questions 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. Formulae sheets are attached.
4. Marks will be lost if answers do not include appropriate units
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 may use pencil.
7. Parts of questions may or may not be related - read carefully!

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 - General Knowledge

a. A 40 hp, 460 V, 1180 rpm, 3-phase, 60 Hz, high-efficiency induction motor manufactured by Baldor Electric Company has a full-load efficiency of 93.6%, and a power factor of 0.83. Determine:

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

b. A 6.9 kV transmission line is connected to a transformer having 1500 turns on the primary, and 24 turns on the secondary. If the load across the secondary is 5 Ω, calculate the secondary voltage, and the primary and secondary currents.

c. What is the main difference between an autotransformer and a conventional transformer?

d. If the number of poles on the stator of an induction motor is doubled, will its synchronous speed also double?

e. Why does the rotor of an induction motor turn slower than the revolving stator field?

f. Why is the stator of a synchronous generator always connected in Y?

g. Why does the speed of a synchronous motor remain constant even under variable load?

h. Sketch the equivalent circuit for a synchronous generator. Provide a carefully-labelled phasor diagram for the generator connected to an inductive load.

i. What is the effect of increasing the DC excitation current to a synchronous generator connected to an infinite bus?

Question 2 - Transformers

A 10 kVA, 2200/220 V, 60 Hz, single-phase transformer provides the following test results:

	Voltage	**Current**	**Power input**
Open-circuit test	220 V	2.5 A	100 W
Short-circuit test	150 V	4.55 A	215 W

Question 2 (continued)

a. Indicate on which side the measurements were taken, and the reasons for your choice.

b. Determine the approximate parameters of the transformer referred to the high-voltage winding.

b. The transformer is used as a step-up transformer. If the load is 7 kW at 0.707 pf lagging (attached to the high-voltage winding), and rated voltage appears across the load, what is the voltage at the primary? What is the percent voltage regulation (PVR) for this load?

Question 3 - Three-phase power

In the circuit shown in Figure 1, two three-phase generators supply a 3ϕ load over lines having the impedances per phase given on the diagram. The load requires 30 kW at 0.80 pf lagging. Generator G_1 operates at a terminal voltage of 797 V (line-to-line) and supplies 15 kW at 0.80 pf lagging.

a. Determine
   (1) the load voltage; and,
   (2) the terminal voltage, and the real power and reactive power output of G_2.

b. After adding a 3ϕ heater (pure resistance) in parallel with the existing load, it is found that the combined power factor of the loads is 0.82. How many kW does the heater draw?

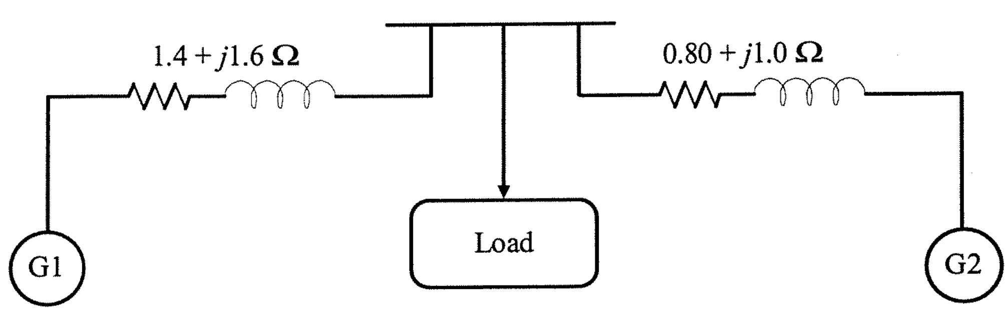


Figure 1

Question 4 - DC Machines

A 230 V DC shunt motor has a full-load efficiency of 89.9%. Rated (full) load is 40 hp. Motor losses, expressed as a percentage of output power are as follows: rotational losses - 3.7%; armature copper loss - 3.9%; and, field copper loss - 2.5%. Stray load losses can be neglected. At full load, the motor speed is 1150 rpm. Neatly sketch an equivalent circuit for the DC shunt motor, and determine:

a. the field current;
b. the armature current at full load;
c. the armature current at half load;
d. the armature current at no load; and,
e. the shaft torque at full load.

Question 5 - Induction Machines

a. What are the two types of 3ϕ ac induction motor rotors? Give one advantage of each.

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

c. Sketch the speed-torque characteristic of an 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 0.8 pf lagging under these conditions.

Question 6 - Magnetic Circuits

The table below is for the magnetic circuit shown below. The core is made of cast steel and its magnetization curve is provided on the next page. Determine (a) the required coil mmf to provide the specified flux; and, (b) the length of the air gap.

Path	Cross-sectional area (m^2)	Length (m)	Flux (Webers)
cfa	0.05	0.8	
abc	0.03	0.4	4.2×10^{-2}
ad	0.272	0.15	
de	0.272	?	2.8×10^{-2}
ec	0.272	0.15	

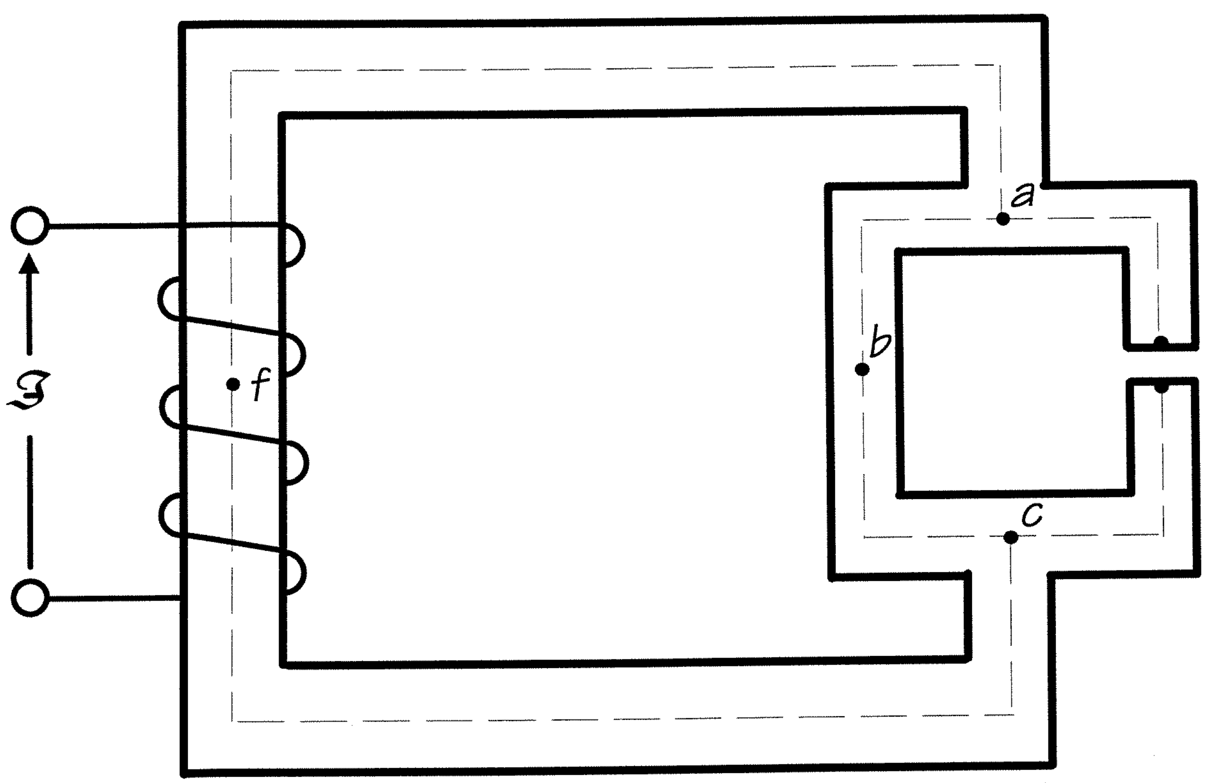
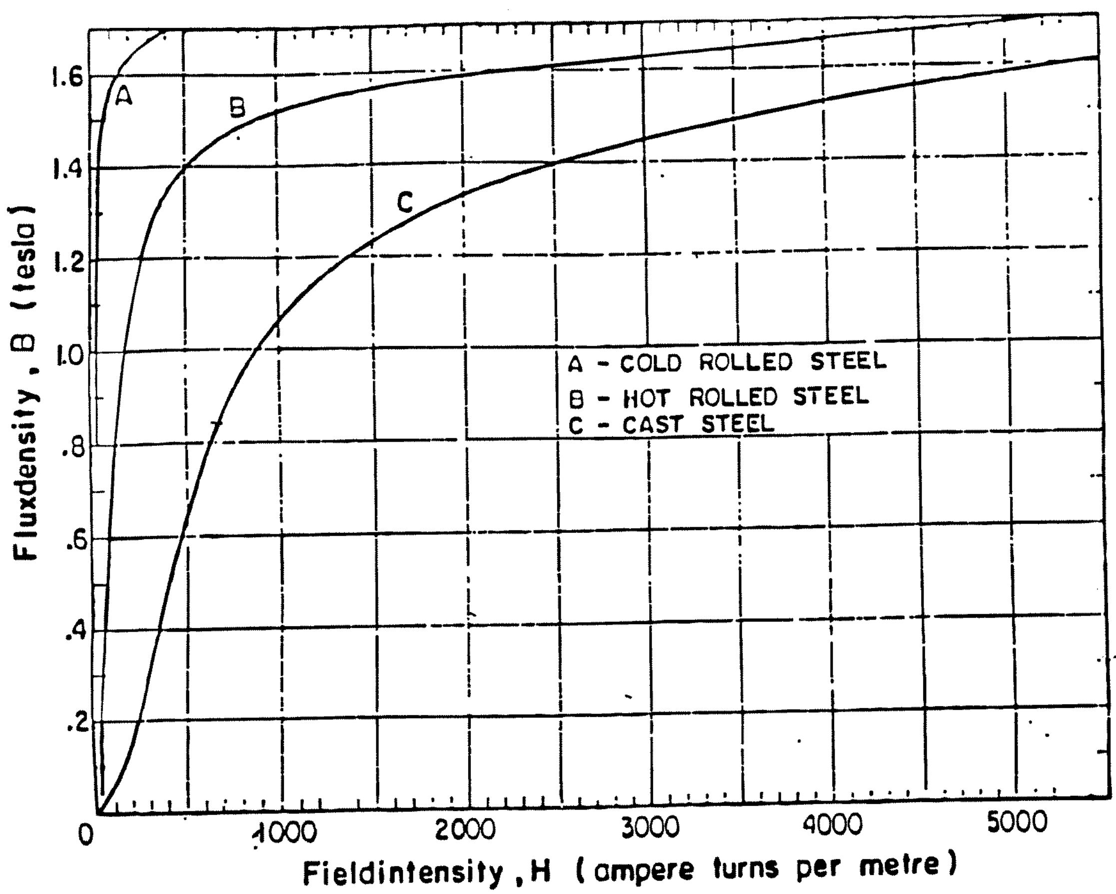


Figure 2



1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
1000
2000
3000
4000
5000
Fluxdensity, B (tesla)
Fieldintensity, H (ampere turns per metre)
A
B
C
A - COLD ROLLED STEEL
B - HOT ROLLED STEEL
C - CAST STEEL

Question 7 - 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 no-load test and a short-circuit test performed in the lab on a three-phase synchronous machine rated 208 V (line-to-line), 6.95 A, 2500 kVA yielded the open-circuit characteristic (OCC) and short-circuit characteristic (SCC) shown in Figure 3 (next page).

i. Why is the SCC a straight line, while the OCC has a "bend?"

ii. Determine the synchronous reactance, X_s. Recall that the synchronous reactance can be determined from the OCC and SCC using the following ratio:

$$X_s = \frac{V_t}{I_{sc}}$$

where V_t is the rated line-to-neutral voltage and I_{sc} is the short-circuit current using the same excitation current that was required to produce rated V_t.

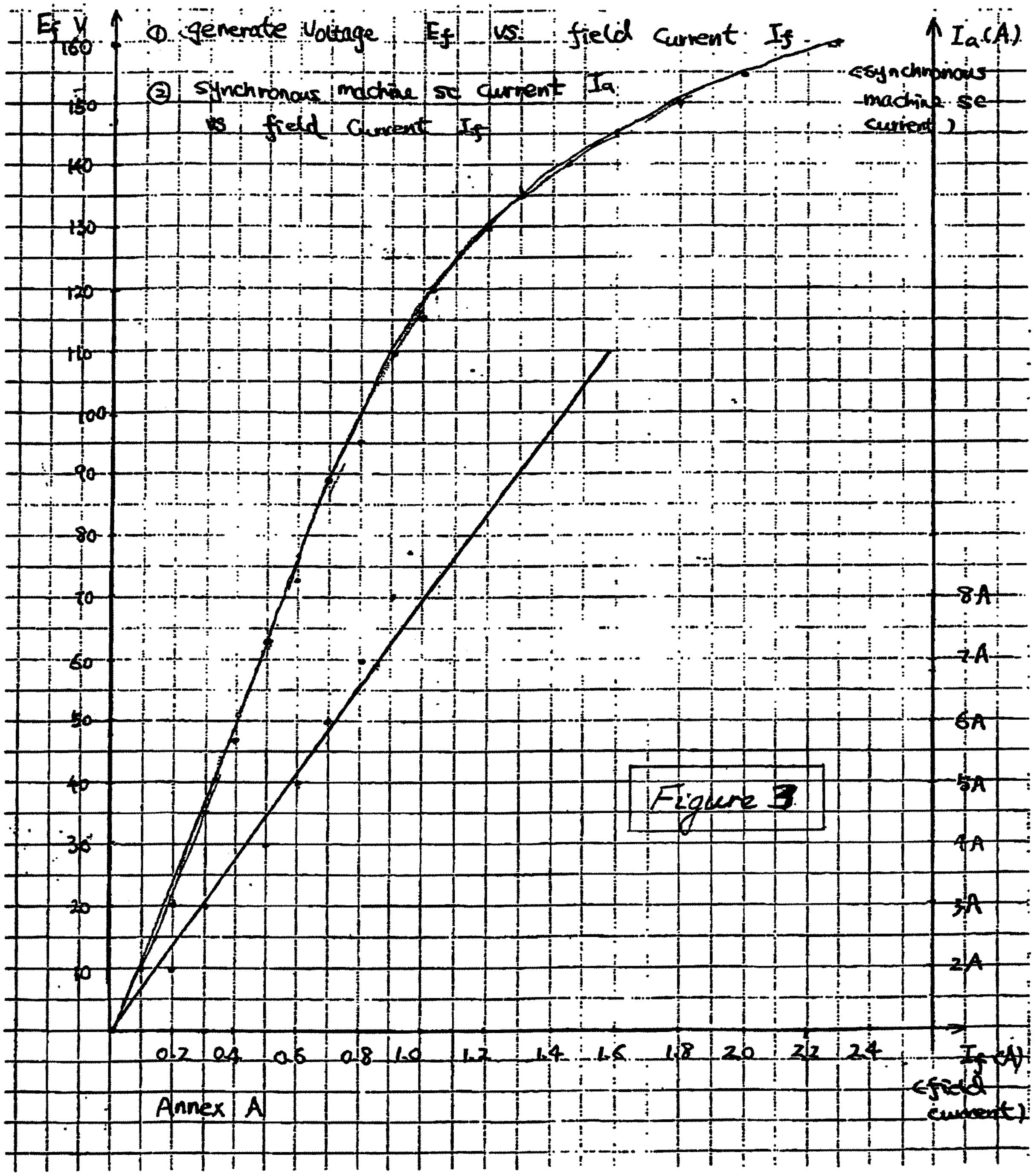
iii. Assume that the machine is being used as a generator connected to the infinite grid, and that the induced voltage is related to the field current by

$$E_f = 25 I_f$$

(a) Determine the field current required to establish rated armature current at 0.8 pf lagging.

(b) Draw a neatly-labeled phasor diagram for the above conditions.

(c) What is the maximum power that the generator can supply without losing synchronization if the excitation is not changed?



Ef V
① generate Voltage Ef vs. field Current If
② synchronous machine sc current Ia vs field Current If
Ia (A)
(synchronous machine sc current)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
8A
7A
6A
5A
4A
3A
2A
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
If (A)
(field current)
Annex A
Figure 3

Figure 3

Potentially useful formulae

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

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

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

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

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

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

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