Professional Engineers Ontario

Exam

07-Elec-A6 Power Systems and Machines

Spring 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

A DC shunt motor is connected to a 440 V DC source. The armature current is 20 A and the motor runs at 500 RPM. The armature resistance is 0.6 ohms. If the magnetic flux is reduced by 30 %, and the torque developed by the armature increases by 40 % ,what are the new values of the armature current and of the speed?

Question 2

A 4-pole, 208 V, 3ϕ, 60 Hz, Y-connected SCIM has the following characteristics:

$R_1 = 0.210\ \Omega$ $\quad X_1 = 0.442\ \Omega$

$R_2' = 0.137\ \Omega$ $\quad X_1' = 0.442\ \Omega$ $\quad X_m = 13.2\ \Omega$

Rotor losses are 300 W, and core losses are 200 W. If the slip is 0.05, find the following:

a. the motor speed;

b. the line current;

c. the stator copper losses;

d. the power crossing the air gap;

e. the output torque;

f. the motor efficiency; and,

g. the output torque.

Question 3

A 1000 VA, 240/120 V, 60 Hz, single-phase transformer gave the following test results:

Open-Circuit Test (HV side):
Voltage = 240 V
Current = 0.10 A
Power = 5.2 W

Short-circuit Test (HV side):
Voltage = 10.8 V
Current = 4.17 A
Power = 11.75 W

Also assume that the transformer will operate at full load, for which the load has a 0.90 lagging power factor. Determine:

a. the approximate equivalent circuit for the transformer, with all values referred to the HV side;
b. the efficiency of the transformer; and,
c. the percentage voltage regulation.

Question 4

A 480 V, 60 Hz, Y-connected, 6-pole synchronous generator has $X_S = 1.0\ \Omega$ and R_A is negligible. At full load, the machines supplies a rated current of 60 A. Losses (not including copper losses) are 2.5 kW. The field current has been adjusted such that the terminal voltage is 480 V under no load.

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

b. Determine the terminal voltage of the generator if it supplies rated current, and draw a phasor diagram, for each of the following power factors:

(i) 0.8 pf lagging; and,
(ii) 0.8 pf leading.

c Determine the percent voltage regulation for each of the above loads.

d. What is the generator efficiency for load (i) above?

Question 5

A cross-section of a two-pole rotating machine is shown below in Figure 1(a). The rotor of the machine has a radius of 120 mm, and an axial length of 200 mm. Each pole covers an arc of 40°, and has the same axial length a

s the rotor. The coil for each pole has 360 turns, and the two coils are connected in series. Each air gap has length 1.5 mm. The yoke and pole material is made from iron having the magnetization curve shown in Figure 1(b). Draw the equivalent magnetic circuit for this system and determine:

a. the reluctance of each air gap;

b. the flux in each pole if the air-gap flux density is to 0.8 T;

c. the current required in the coils to produce the flux found in part (b) if all iron reluctances are ignored;

d. the flux density in the yoke of the machine, given that its outer radius is 210 mm and its thickness is 25 mm; and,

e. the coil current required for an air-gap flux density of 0.8 T if the yoke mmf is included, but the reluctances of the poles and rotor are ignored.

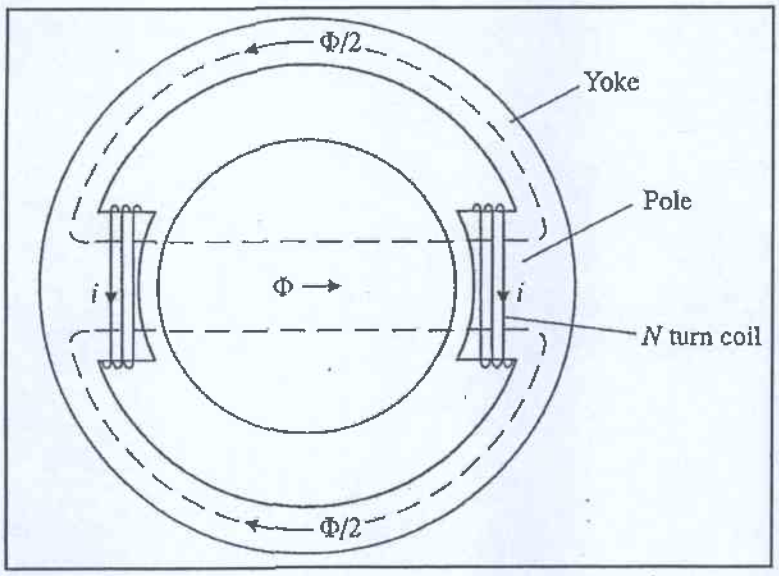

Figure 1(a)

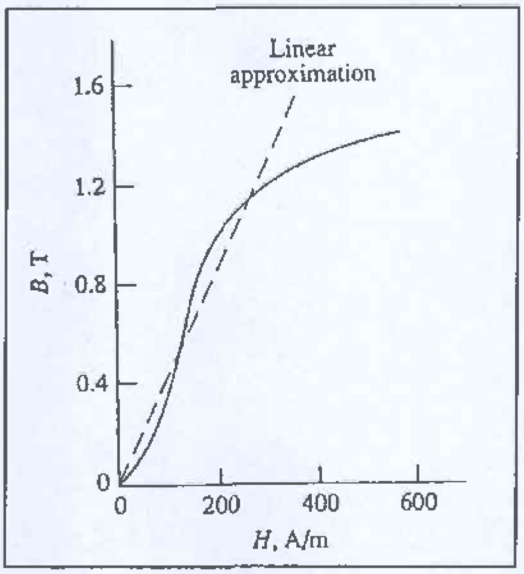

Figure 1(b)

Question 6

Two three-phase generators supply the same load bus, as shown in Figure 2, below. Also connected to the load bus is a balanced three-phase load. For the generator on the left side, $V_a = 120\angle 0°$, and for the generator on the right, $V_a' = 115\angle 0°$. Determine the following:

a. the three phasor currents, $\mathbf{I}_a$, $\mathbf{I}_a'$ and $\mathbf{I}_a''$;

b. the total complex power supplied to the load;

c. the line-to-line voltage at the load; and,

d. the complex power supplied by each generator.

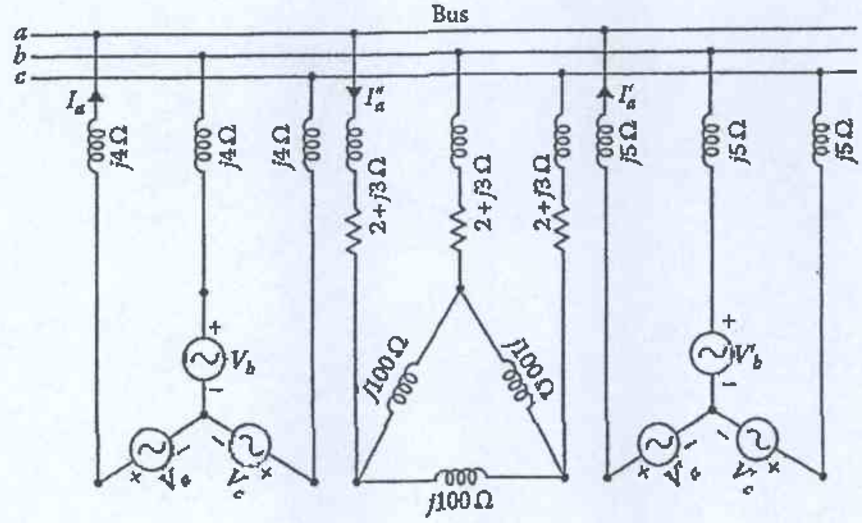

Figure 2

Potentially useful formulae

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

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

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

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

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

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

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