Professional Engineers Ontario

Exam

16-Elec-A6 Power Systems and Machines

December 2017

Notes:

1. **FIVE (5)** questions constitute a complete exam paper. 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 250 V, 3-hp dc shunt motor has an armature-circuit resistance and a field-circuit resistance of 0.4 Ω and 250 Ω respectively. When fed by rated terminal voltage the motor runs at 1600 rpm and draws a line current of 21 A.
If the rotational losses of the motor are negligible, calculate the following:

(a) the armature current;
(b) the output power;
(c) the mechanical developed torque;
(d) the efficiency.

If now the new field current is reduced to 0.8 A by inserting an external resistance to the field circuit while keeping the torque load constant. Find:

(e) the new armature current;
(f) the new operating speed;
(g) the new efficiency.
(h) the value and power rating of the inserted resistance.

Neglect armature reaction and assume linear magnetic circuit.

Question 2

A 3-phase, 575V, 60 Hz, 25 hp, Y-connected, six-pole squirrel cage induction motor is operating under certain load conditions with a shaft speed of 1164 rpm. The core and rotational losses are evaluated to 764.2 W and 345.8 W respectively. The total rotational losses are assumed constant. The motor parameters in ohm/phase referred to the stator are:

$R_l = 0.3723\ \Omega$, $X_l = 1.434\ \Omega$, $R'_2 = 0.390\ \Omega$, $X'_2 = 2.151\ \Omega$, $X_m = 26.59\ \Omega$ and $R_c = 354.6\ \Omega$

Determine:

a) The line current;
b) The active, reactive and apparent power of the motor;
c) the air-gap power;
d) the rotor copper loss;
e) the mechanical power developed;
f) the mechanical developed torque;
g) the shaft (output) torque;
h) The speed at which the maximum torque is developed.

Question 3

The following test results were obtained for a 100 kVA, 7200/240 V, 60 Hz single-phase transformer:

Open-circuit Test	Short-circuit test
$V_{OC} = 7200$ V	$V_{SC} = 250$ V
$I_{OC} = 0.45$ A	$I_{SC} = 13.88$ A
$P_{OC} = 355$ W	$P_{SC} = 1275$ W

a. On what side of the transformer were each of the tests taken?

b. Determine and sketch the approximate equivalent circuit for this transformer, with all voltages referred to the high voltage side.

c. Determine the full-load voltage regulation and efficiency with 0.8 leading power factor.

Question 4

a. A 480V, 6-pole, 60 Hz, Δ-connected cylindrical-rotor synchronous generator has a synchronous reactancc of 0.95 Ω per phase and a negligible armature resistance. Its full-load armature current is 55 A at a 0.8 power factor (pf) lagging. The generator has a combined friction and windage losses of 1.5 kW, and core losses of 1.25 kW at full load. The field current has been adjusted so that the no-load terminal voltage is 480 V. Determine the following:

i. The speed of rotation of the generator.
ii. Its terminal voltage when it is delivering the rated current at 0.8 pf leading.
iii. Its voltage regulation when it is operating under full load conditions at 0.85 pf lagging.
iv. The efficiency of this generator when it is operating with rated current and the pf is 0.8 lagging.
v. Its input torque that must be applied by a prime mover at full load?

Question 5

a. What are three advantages of a three-phase power distribution system over a single-phase system? Alternators driven by steam turbines require only few poles to generate the required frequency.

b. A synchronous generator connected to an infinite bus has its frequency and terminal voltage fixed. What is the effect of increasing the excitation current in this case?

c. Why is a synchronous motor not self-starting?

d. Give five important specifications to be considered in selecting induction motors.

e. Large utility customers with low power factor often pay a penalty for it. Why is that?

f. A distribution transformer is rated at 18 kVA, 20 kV/480 V, and 60 Hz. Can this transformer safely supply 15 kVA to a 415 V load at 50 Hz? Why or why not?

g. Why is the efficiency of an induction motor so poor at high slip?

h. Name and describe three means of controlling the speed of induction motors.

i. Why is the iron core of a transformer laminated?

j. Give two reasons why the synchronous motor is a useful industrial machine?

Potentially useful formulae

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

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

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

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

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