Professional Engineers Ontario

Exam

16-Elec-A6 Power Systems and Machines

May 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. What is power factor correction, and why is it useful?

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

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

d. Why is it impossible for the rotor of an induction motor to rotate at the same speed as that of the magnetic field?

e. Show that, with the aid of a phasor diagram, the power output for a synchronous generator is given by:

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

f. Explain why induction motors have low power factor when they are lightly loaded

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

h. When using the two-wattmeter method to measure total three-phase power, under what conditions might one of the wattmeter readings have a negative value (assuming the meters are connected correctly)?

i. Alternators driven by steam turbines require only few poles to generate the required frequency. Why is that, and why is their construction different than that of the alternators driven by water turbines?

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

Question 2

A 100 kVA, 7200/480 V, 60 Hz, single-phase transformer has the following equivalent circuit parameters:

$R_{1,HV} = 3.06\ \Omega$ $X_{1,HV} = 6.05\ \Omega$

$R_{2,LV} = 0.014\ \Omega$ $X_{2,LV} = 0.027\ \Omega$

$R_{c,\ HV} = 71{,}400\ \Omega$ $X_{m,\ HV} = 17{,}809\ \Omega$

The voltage at the load is 480 V, and the load draws half rated transformer current at 0.75 power factor lagging.

a. Sketch the approximate equivalent circuit for both high voltage (HV) and low voltage (LV) sides.

b. Determine

i. the voltage regulation at 0.75 power factor lagging;
ii. the efficiency of the transformer; and;
iii. the secondary voltage when the load is disconnected;
iv. the amount of the secondary current at which the transformer has its maximum efficiency.

Question 3.

A 3-phase, 480 V, 60 Hz, 100 hp, Y-connected, six-pole wound rotor induction motor has the following parameters in ohm/phase referred to the stator:

$R1 = 0.1\ \Omega$, $X1 = 0.205\ \Omega$, $R'2 = 0.079\ \Omega$, $X'2 = 0.186\ \Omega$, $Xm = 7.5\ \Omega$.

Rotational losses are assumed to be constant and evaluated to be 2950 W. If the motor is operating at a slip of 3.3% at rated voltage and rated frequency, determine:

a) The line current;
b) the stator copper loss;
c) the air-gap power;
d) the rotor copper loss;
e) the mechanical developed power;
f) the mechanical developed torque;
g) the shaft torque;
h) the efficiency;

Question 4.

A 250 V, 1700 rpm **shunt dc motor** operating at **rated conditions** driving a constant torque-load, has a line current of 41.6 A when fed by rated terminal voltage, V_t=250 V. The armature-circuit resistance and field-circuit resistance are 0.4 Ω and 250 Ω respectively.

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; and,
(d) the efficiency.

Without changing the torque-load, the field resistance is decreased to 200 Ω. Under these new conditions, calculate:

(e) the armature current;
(f) the line current;
(g) the new motor speed; and
(h) the new output power.

Assume a linear magnetic circuit

Question 5.

A three-phase source 460 V, 60Hz, supplies power to a plant composed of:

i) A three-phase induction motor with an input Apparent Power 50 kVA and a 0.84 power factor lagging.
ii) A 125 hp, 6 pole, Y- connected synchronous motor with a synchronous reactance of 1.45 Ω/phase, that draws 80 kW.
iii) A heating load of 30 kW.

Determine:

a) the synchronous motor active and reactive power required to operate the plant at unity power factor;
b) the synchronous motor armature current for the conditions in (a);
c) the excitation emf required for the conditions in (a);
d) if the plant is to be operated at 0.80 leading power factor, find:
    i) the new synchronous motor power factor;
    ii) the new synchronous motor armature current; and,
    iii) the new torque angle;
e) If the excitation emf is decreased by 10%, how much reactive power will be consumed or supplied by the motor?

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

$$P_{gap} = P_{input} - 3 I_1^2 R_1 = 3 I'^2_2 \frac{R_2'}{s} = T_{dev} \omega_s$$

$$3 I'^2_2 R_2' = s P_{gap}$$

$$P_{dev} = P_{gap} - 3 I'^2_2 R_2' = (1 - s) P_{gap}$$

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

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

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