Professional Engineers Ontario

07-Elec-A6 Power Systems and Machines

Spring 2011

Notes:

1. Please pay attention to the directions on the answer booklet regarding solutions and rough work (i.e., rough work on the left, answers on the right). Also, please start each question on a new page.

2. ***FIVE (5) questions constitute a complete exam paper - you must do Question 1, plus four (4) other questions. Unless you indicate otherwise, the first five questions as they appear in the answer book will be the only ones marked. All questions are of equal value.***

3. You may use one of the approved Casio or Sharp calculators.

4. This is a closed book exam. Candidates may bring in ONE aid sheet, 8.5" x 11" and hand-written on both sides, containing notes and formulae (no figures). Example problems and solutions are not permitted!

5. Marks will be lost if answers do not include appropriate units.

6. All a.c. voltages and currents are rms values unless noted otherwise. For three-phase circuits, all voltages are line-to-line voltages unless noted otherwise.

7. You are encouraged to use a pencil and eraser.

8. 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.

General knowledge

1) You must do this question. Please keep your answers short and concise.

   a) What is the purpose of a commutator in a dc generator?
   b) In a DC machine, what are compensating windings?
   c) What are the two types of core losses that occur in the metal of most machines?
   d) What happens if a shunt dc motor operates without a load and if a series dc motor operates with a load?
   e) Draw the per-phase equivalent circuit of the armature of a synchronous machine and explain what each element in the circuit is supposed to model.
   f) What is the speed regulation of a synchronous motor?
   g) Give two reasons why a three-phase power system is preferable to three single-phase systems for delivering the same amount of power.
   h) Describe two methods of varying the speed of three-phase induction motors.
   i) IEEE Standard 519 (*Recommended Practice and Requirements for Harmonic Control in Electric Power Systems*) is a standard that specifies the levels of harmonics that are acceptable in ac power systems (harmonics are voltage and current components whose frequencies are integral multiples of the fundamental frequency; e.g. in a 60 Hz system, the third harmonic is 180 Hz). The standard does not allow *any* DC component. Why is that?

Induction motors

2) The parameters of the per-phase equivalent circuit for a three-phase, wye-connected, 220-V, 10-hp, 60-Hz, six-pole induction motor are as follows (all values are referred to the stator):

   $R_1 = 0.3\ \Omega$, $R_2 = 0.15\ \Omega$, $R_c = \infty\ \Omega$, $X_1 = 0.5\ \Omega$, $X_2 = 0.2\ \Omega$, $X_M = 15\ \Omega$

   The total friction, windage, and core losses are 400 W. For a slip of 0.02, and the motor operated at rated voltage and frequency, calculate:

   a. the stator current;
   b. the power factor at the stator terminals;
   c. the rotor speed;
   d. the rotor copper losses; and,
   e. the output torque

Transformers

3) The terminal voltage of the secondary (high voltage) winding of a transformer is given by $v_s(t) = 282.8 \sin 377t$ V. The turns ratio of the transformer is 50:200 (primary:secondary). The impedances for the transformer approximate equivalent circuit (referred to the primary side) are:

$$R_{eq} = 0.05\ \Omega,\ X_{eq} = 0.225\ \Omega,\ R_C = 75\ \Omega,\ X_M = 20\ \Omega$$

If the secondary current is $i_s(t) = 7.07 \sin (377t - 36.87°)$ A, determine:

a. the primary voltage and current;
b. the transformer voltage regulation; and,
c. the transformer efficiency.

Three-phase power

4) A plant is supplied by a three-phase source of 460 V (line-to-line), 60 Hz. It has several loads:

(i) a three-phase induction motor drawing 50 kVA at a power factor of 0.86;
(ii) a synchronous motor that operates at 0.62 power factor leading and having $X_s = 6.052\ \Omega$; and,
(iii) a delta-connected load, with each branch having an impedance $\mathbf{Z} = 2 + 2j\ \Omega$.

Determine:

a. the active and reactive power drawn by the induction motor;
b. the induction motor line current;
c. the active and reactive power drawn by the delta-connected load;
d. the active and reactive power drawn by the synchronous motor if the plant is operating at unity power factor;
e. the synchronous motor line current; and,
f. the excitation voltage of the synchronous motor.

Synchronous motors

5) A 670 kW, 720 rpm synchronous motor connected to a 3980 V (line-to-line), 3-phase line produces an internally generated voltage of 1790 V (line-to-neutral) when the field current is 25 A. The synchronous reactance is 22 Ω, the stator has a resistance of 0.64 Ω per-phase, and the torque angle between the internally generated voltage and the terminal voltage is 30°. The rotor I^2R losses are 3.2 kW, the stator core loss is 3.3 kW, and the windage and friction loss is 1.5 kW. Calculate:

   a. the voltage drop across X_S;
   b. the ac line current – both magnitude and phase;
   c. the power factor of the motor;
   d. the mechanical power delivered by the motor;
   e. the torque delivered to the shaft (neglect the stator winding resistance); and,
   f. the efficiency of the motor.

DC Motors

6) A 250 V, 1700 rpm, DC shunt motor operating at rated conditions driving a constant torque load has a line current of 41.6 A. The armature circuit resistance and field circuit resistance is 0.4 Ω and 250 Ω, respectively. Assuming rotational losses 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 (in rpm); and,
   h. the new output power.

End of the exam