McGill
Department of Electrical and Computer Engineering

ECSE 461 – Electric Machinery

Final Examination – Sample 1

INSTRUCTIONS:
- Attempt 6 out of the 7 questions.
- All 6 questions answered carry equal weight.
- This is an OPEN BOOK examination.
- CRIB SHEETS, NOTES AND ASSIGNMENTS are permitted.
- FACULTY STANDARD CALCULATOR permitted ONLY.
- This examination consists of 7 questions, of a total of 3 pages, including the cover page.
- This examination is PRINTED ON BOTH SIDES of the paper
- This examination paper MUST BE RETURNED

Note: Any reasonable assumption can be made, provided adequate justification is given.

1. An 8 pole, 7000 hp, 13200 V, 60 Hz three-phase squirrel cage induction motor has the following parameters, in Ω/phase:

   $R_s = 0.138$ $X_s = 4.84$ $X_m = 67.27$
   $R_r = 0.140$ $X_r = 3.77$

   Mechanical losses are equal to 156 kW at rated speed.

   (a) For rated voltage and a speed of 895 rpm, compute the input current and power factor.
   (b) Compute the developed power and shaft torque.
   (c) Find the starting torque, current and power factor for line starting. Assume the rotor resistance is increased by a factor of 10 at zero speed.
   (d) Draw the approximate torque/speed curve, indicating the synchronous speed, and the starting and running torque. Show the corresponding motor currents.
   *(e) Calculate the starting torque for a voltage reduced to 60 % of rated value. Compare with line start conditions (current and torque).

2. A 50 MVA, 8 pole, 13.8 kV, 60 Hz, 0.80 pf, synchronous generator has a synchronous reactance of 4.25 Ω per phase. All losses are neglected. The generator operates in stand-alone mode.

   (a) The generator supplies 40 MW to a load of power factor 0.85 (lagging), at a terminal voltage of 13.8 kV. Compute the generator current and the internal voltage. Draw the V-I diagram.
   (b) Draw the power vs load angle (δ) curve. Indicate the operating point and compute the maximum power. Compute the total reactive power supplied by the generator.
   (c) The load power factor is increased to 1.0, the power remains at 40 MW. The generator terminal voltage is adjusted to 13.8 kV. Compute the internal voltage and the change in field current required.
   (d) Calculate the power from the terminal, the generated voltage and load angle for the two operating conditions.
   *(e) Draw, on the same graph, the power vs load angle curves for the two operating conditions, and show the corresponding operating points. Indicate the maximum power operating point.

3. An 8 pole, 5 MW, 13200 V, 60 Hz three-phase squirrel cage induction machine, operating in a pumped storage facility, has the following parameters, in Ω/phase referred to the stator:

   $R_s = 0.138$ $X_s = 4.84$ $X_m = 67.27$

   $R_r = 0.140$ $X_r = 3.77$

   Mechanical losses are equal to 156 kW at synchronous speed.

   (a) The machine is connected to a 13200 V, 60 Hz electric grid and driven by the water turbine at a speed of 905 rpm. Compute the input current, the real power injected into the grid and the reactive power. Indicate if the reactive power is consumed or produced.

   (b) Compute the developed power and shaft power.

   (c) The turbine torque is reduced to 0, the generator remains connected to the grid. Indicate the approximate turbine speed. Find the real and reactive power drawn from the grid, assuming losses are supplied by the grid.

   (d) Draw the approximate torque/speed curve, indicating all operating points. Extend the curve to the motoring region.

4. A 40 MW, 13.8 kV, 60 Hz, 8 pole, 0.80 pf, synchronous machine, is used in a pumped storage facility. The synchronous reactance is 4.25 Ω per phase. All losses are neglected. It is connected to the 13.8 kV electric grid.

   (a) The machine operates as a motor and draws 50 MW at unity pf. Find the generated voltage. Draw the V-I diagram.

   (b) The motor draws 40 MW at a power factor of 0.80, leading current. Indicate the reactive power drawn or supplied. Find the generated voltage. Draw the V-I diagram.

   (c) Draw the torque vs load angle characteristic for the two operating conditions above, and indicate the operating points and the maximum power points.

   (d) The motor is operated under no load conditions. The generated voltage is unchanged from the value in Question (b). Find the reactive power. Draw the V-I diagram. Indicate if reactive power is supplied and the machine excitation mode.

5. A 2 MW, 1500 V, 1800 rpm, 1400 A separately excited dc motor drives a variable speed load. The armature resistance is 0.0204 Ω. Field losses are equal to 20.5 kW and rotational losses 60.5 kW at rated speed.

   (a) For rated armature voltage and current, assuming rated field current, find the internal voltage, the developed power and the shaft torque.

   (b) Compute the full load efficiency. Find the no-load speed and speed regulation.

   (c) The field current is reduced to 70 % of rated value. For rated armature voltage and current, find the speed and developed power. Find the no load speed and speed regulation.

   (d) The motor is operated in regenerative braking mode at rated field. The speed is 1700 rpm and the motor supplies 500 A. Find the armature voltage, developed torque, and regenerated power.

   *(e) Draw the torque vs speed characteristics of the motor for the operating modes and operating conditions of the above questions.

6. Three identical single phase inductive loads, each rated 50 kW, 600 V, 110 A, 60 Hz, are connected to a three-phase electric grid.

   (a) The grid voltage is 550 V. Indicate the load connection. Compute the voltage and current in each load. Give the power factor. Draw the phasor diagram.

   (b) Compute the power in each load and the reactive power. Draw the power diagram.

   (c) Compute the line current and total power and reactive power drawn by the load.

   (d) Compute the total reactive power required to bring the load power factor to 0.93. Draw the power diagram, indicating the uncompensated and compensated values.

   *(e) Compute the reactance of the power correction capacitors, if they are connected in delta. Indicate the voltage and current.

7. A 50 kVA, 13200/350 V, 60 Hz, single phase transformer has the following equivalent circuit parameters in Ω referred to the primary winding: series elements: 39.2 (resistive), 223 (inductive); magnetizing branch: 348500 (resistive), 87100 (inductive).
   - (a) A 35 kW, 0.70 lagging pf load is connected to the secondary. Assuming rated voltage across the load, compute the current and voltage on the primary side.
   - (b) Compute the voltage regulation. Draw the phasor diagram seen from the primary side, indicating primary side voltage and the load voltage, and the load current. Indicate the voltage drop across the transformer.
   - (c) Compute the reactive power consumed by the transformer, and the power factor of the load seen from the primary, including the transformer.
   - (d) Compute the transformer efficiency for the 0.70 power factor load. Repeat for a unity power factor load drawing the same current.
   - *(e) Compute the excitation current drawn from the supply and the no load losses.

** Bonus question*