Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science
6.685 Electric Machines

Problem Set 9 — Issued November 3, 2013
Due November 13, 2013

NOTE : This is a two week problem set. It is due the week after Quiz 1.

Quiz 1: In class on November 6. Closed Book. One *handwritten* crib sheet allowed. Calculators OK. Venue: Problem sets 1-8.

Problem 1 : Large Generator

This problem concerns a large two pole synchronous generator that has the following parameters, expressed in per-unit:

Machine Rationg		600	MVA
Rater Terminal Voltage		22	kV
Synchronous, d- axis reactance	x_d	2.0	
Synchronous, q- axis reactance	x_q	1.8	
Transient, d- axis reactance	x_d'	0.40	
Subtransient, d- axis reactance	x_d"	0.20	
Subtransient, q- axis reactance	x_q"	0.20	
Transient, open-circuit time constant	T_do'	5.0	s
Subtransient, open-circuit time constant	T_{do}"	0.2	s
Subtransient, open-circuit time constant	T_{qo}"	0.5	s
Inertial Constant	H	3.0	s
Armature Time Constant	T_a	0.1	s

1. Find equivalent *equal mutuals* circuit models for the d- and q- axes for this machine. Assume for this purpose that the stator leakage inductance is $x_{al} = 0.1$ per-unit.
2. What are the actual parameters (in ohms) of the reactive and resistive parameters for these models, on a machine base of 800 MVA, 24 kV, line-line, RMS?
3. The generator is operated initially unloaded, with terminal voltage equal to 1.0 per-unit. A sudden, symmetrical short circuit is imposed just at the instant when the flux is a maximum in Phase A. Classical methods would tell you that fault current is, in per-unit:

$$i_a = \frac{1}{x_d"} e^{-\frac{t}{T_a}} - \left(\frac{1}{x_d} + \left(\frac{1}{x_d'} - \frac{1}{x_d} \right) e^{-\frac{t}{T_d'}} + \left(\frac{1}{x_d"} - \frac{1}{x_d'} \right) e^{-\frac{t}{T_d"}} \right) \cos \omega t$$

4. Using MATLAB, simulate this transient and compare with the 'classical' result.
5. Now, what happens if the machine is operated at rated current, unity power factor, when the terminals are suddently open circuited. Ignoring the initial voltage spikes and speed change, calculate terminal voltage as a function of time.

6. Calculate and plot the *transient* torque angle curve for this machine, assuming that steady state operation is at rated load, unity power factor. Transient conditions mean that the field winding is assumed to have constant flux. Also calculate a (fictional) torque-angle curve that assumes the d-axis transient reactance on both axes. Remember that this curve should match actual operation at the rating point, which means that the transient torque angle will be displaced somewhat from the actual, steady state torque angle.
7. Find the values of the internal state variables (ψ_d, ψ_q, ψ_{kd}, etc.) corresponding to steady state operation at rated kVA, power factor of 0.85 with the machine delivering reactive power to the system.
8. Show that this is the right initial condition by simulating the machine for a short time (say 1/10 second) and observing that all of the state variables are indeed steady.
9. Simulate what happens if a machine is synchronized with the right terminal voltage and speed (one per unit voltage, rated speed) but 20 degrees out of phase (machine voltage leading). Plot *ordinary* values of terminal current and electromagnetic torque for the first 3 seconds of the transient.

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