

Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science
6.691 Seminar in Advanced Electric Power Systems

Problem Set 5

Issued April 10, 2006
Due April 26, 2006

This problem involves the same large synchronous generator that you considered in Problem Set 4. Now you will do simulations on that machine. You have the starting point: fluxes for steady state operation of the machine. In class and in the notes we have built up a simulation model for the machine. You should use your initial conditions and the simulation model to estimate what happens in the following situations:

Terminal Fault From the rated point, suddenly set terminal voltage to zero and plot phase currents and shaft torque. Plot for a period of time that seems interesting to you.

Transient Stability Assume the machine is suddenly open circuited for a short period of time and then re-connected. Plot torque angle vs. time. By varying the time the machine is open you can find out how long that can be and still recover stable synchronous operation. How long is that?

Bad Mistake Suppose that, in a new power plant, someone has mis-wired the synchronizing apparatus so that when this generator is first synchronized it is 120 degrees out of phase. Simulate this situation assuming the local system is really stiff. (That is, the terminals of the machine are connected to a voltage source). Assume also that the machine is, before being synchronized, generating one per-unit voltage. Plot terminal current and torque vs. time.

Small Signal Variations What we will do here is to linearize the machine model and use that result to derive a simplified machine model. Assume that this generator is connected to an infinite bus through an impedance:

$$z = j0.1$$

The machine is driven by a steam turbine which you should regard as a pure torque source.

1. First, write down the 'simulation' model for the machine. You should have seven state equations. Note that these equations involve finding currents which are linear functions of fluxes. It is necessary to invert the flux/current relationships. This inversion will take the form:

$$\begin{bmatrix} y_{dd} & y_{dk} & y_{df} \\ y_{kd} & y_{kk} & y_{kf} \\ y_{fd} & y_{fk} & y_{ff} \end{bmatrix} = \begin{bmatrix} x_d & x_{ad} & x_{ad} \\ x_{ad} & x_{kd} & x_{ad} \\ x_{ad} & x_{ad} & x_f \end{bmatrix}^{-1}$$

You should leave your model in terms of the parameters y as shown here.

2. Next, note that your equations are nonlinear with sinusoidal dependency on torque angle and with torque that is dependent on the product of state variables. Linearize these equations by assuming a steady state value (as in your solution to Problem Set 4)

and *small* perturbations for each state variable. You should be able to develop a linear equation of the form

$$\dot{S} = \underline{A}S$$

where S is the vector of small signal perturbations of state variables.

3. Now, using MATLAB to do the heavy lifting, find the eigenvalues of the system. (Hint: eig() will be useful).
4. You should be able to identify the eigenvalues with important phenomena in the machine: to wit,
 - A complex pair of eigenvalues relate to the stator and have relatively large imaginary parts,
 - Another complex pair of eigenvalues are associated with machine 'swings' and have relatively smaller imaginary parts,
 - One eigenvalue is on the negative real axis with a small value and is associated with the field,
 - Two other real eigenvalues are associated with the dampers
5. We have been using an equivalent mechanical equation for the machine which is:

$$\frac{2H}{\omega_0} \frac{d^2\delta}{dt^2} + B \frac{d\delta}{dt} = t^e + t^m$$

A linearized version of this would be something like:

$$\frac{2H}{\omega_0} \frac{d^2\delta_1}{dt^2} + B \frac{d\delta_1}{dt} + A\delta_1 = 0$$

Find values of A and B which cause the swing frequency and damping to correspond with the linearized system you found in the earlier parts of this problem.