

ECE 520  
Advanced Electric Machinery  
Spring Semester 2008  
Final Project: Part II Revision 2

FINAL PROJECT RULES

1. You are on your honor to do your own work on this project. That is, you will neither give nor receive aid on this project, except from the *course* instructor. If you violate this confidence, you will receive the grade of zero for this project.
2. Part II is due by 11:59 pm PDT Sunday, May 11, 2008.
3. Please summarize your work at the *beginning* of your project. Thank you!
4. Please read the following statement when you start the project and sign it when you finish the project:

I certify that I have neither given nor have I received any help on this project, except from the *course* instructor.

SIGNED: \_\_\_\_\_

PRINT NAME: \_\_\_\_\_

DATE: \_\_\_\_\_

1	_____ /	50 pts
2	_____ /	50 pts
Total	_____ /	100 pts

Part II of the final project explores which machine parameters and quantities to use with the equal area criteria. A single synchronous machine connected to an infinite bus by a line is used for this purpose. The line is represented only by a reactance,  $X_{sys}$ . That is, the line resistance is ignored. The synchronous machine is delivering 0.77 pu power (torque) to the infinite bus prior to a fault. The electrical power (torque) generated by the machine goes to zero for a period of time,  $t_c$ , the clearing time. The clearing angle,  $\gamma_c$ , is the angle of the rotor with respect to the infinite bus at  $t_c$ . The critical clearing time,  $t_{cr}$ , is the maximum clearing time for stable operation. The critical clearing angle,  $\gamma_{cr}$ , is the angle of the rotor at  $t_{cr}$ .

The following five files should have been attached to the email that you received with this Part II description:

**PartIImIC.m** The line reactance, machine & associated equipment parameters, and initial conditions are specified in this file and “written” to the Matlab workspace. The time of the fault and clearing times are set in this file on lines 71 and 72, respectively. The value of the quadrature inductance,  $L_{qu}$  is set on line 42.

**PartII.mdl** The Simulink representation of the infinite bus, line, governor, turbine, excitor, and generator is contained in this diagram. The parameters and initial conditions are “read” from the Matlab workspace.

**SL2ML.m** This Matlab script post processes data of  $\gamma$  from PartII.mdl. It graphs  $\gamma$  versus time.

This Matlab script determines and displays:

1. the value of  $\gamma$  prior to a fault,  $\gamma_0$ ,
2. the critical clearing angle,  $\gamma_{cr}$ , and
3. the the maximum swing angle,  $\gamma_{maxswing}$ .

Note: The values of the fault and clearing times are determined from the Matlab working space. If Matlab is closed after running PartII.mdl and before running SL2ML.m or the working space was cleared,  $T_{fault}$  and  $t_{clear}$  must be set in the Matlab workspace: e.g.,

$t_{fault} = 10;$

and

$t_{clear} = 0.2000;$  (This value will obviously be different).

**SPEA.m** Salient Pole Equal Area - This Matlab script calculates:

1. the initial angle,  $\gamma_0$ ,
2. the critical clearing angle,  $\gamma_{cr}$ ,
3. the critical clearing time,  $t_{cr}$ , and
4. the the maximum swing angle,  $\gamma_{maxswing}$ .

**SPEA.xmcd** Mathcad version of SPEA.m

## Steady State

In the equal area analytical (non-Simulink) solutions the *steady state* torque before the fault can be written as:

$$T_{ss} = T_{1ss}\sin(\gamma_0) + T_{2ss}\sin(2\gamma_0) \quad \text{pu}$$

$$T_{1ss} = \frac{|E_a||V_{sys}|}{X_{dss}} \quad \text{pu}$$

$$T_{2ss} = \frac{|V_{sys}|^2}{2} \left( \frac{X_{dss} - X_{qss}}{X_{dss}X_{qss}} \right) \quad \text{pu}$$

where  $X_{dss} = X_{du} + X_{sys}$  and  $X_{qss} = X_{qu} + X_{sys}$ .

## Fault

In the equal area analytical (non-Simulink) solutions the torque during the *fault* can be expressed as:

$$T_f = T_{1f}\sin(\gamma) + T_{2f}\sin(2\gamma) \quad \text{pu}$$

$$T_{1f} = \frac{|E_x||V_{sys}|}{X_{df}} \quad \text{pu}$$

$$T_{2f} = \frac{|V_{sys}|^2}{2} \left( \frac{X_{df} - X_{qf}}{X_{df}X_{qf}} \right) \quad \text{pu}$$

where  $X_{df} = X_{dx} + X_{sys}$  and  $X_{qf} = X_{qu} + X_{sys}$ .

The parameters used for  $E_x$  and  $X_{dx}$  are specified for each question.

1. (50 points) Question one looks at a salient pole machine.

- (a) Use PartIIImIC.m and PartII.mdl to determine the critical clearing time,  $t_{cr}$  by simulation. That is, vary  $t_{clear}$ , ( $t_{clear} = t_c$ ) in the script PartIIImIC.m, run it, run PartII.mdl, check to see if it is stable, and repeat. Determine  $t_{cr}$  to four significant digits.

For the critical clearing time determined above, run SL2ML.m to determine:

- i. the initial angle,  $\gamma_0$ ,
  - ii. the critical clearing angle,  $\gamma_{cr}$ , and
  - iii. the the maximum swing angle,  $\gamma_{maxswing}$ .
- (b) Set  $E_x = E_{qp}$  and  $X_{dx} = X_{dp}$  in the Matlab script SPEA.m or the Mathcad sheet SPd.xmcd and use SPEA.m or SPd.xmcd to determine:

- i. the initial angle,  $\gamma_0$ ,
- ii. the critical clearing angle,  $\gamma_{cr}$ ,
- iii. the critical clearing time,  $t_{cr}$ , and
- iv. the the maximum swing angle,  $\gamma_{maxswing}$ .

Note: The values of  $E_{qp}$  and  $X_{dp}$  are calculated and output by PartIIImIC.m.

- (c) Set  $E_x = E_a$  and  $X_{dx} = X_{du}$  in the Matlab script SPEA.m or Mathcad sheet SPEA.xmcd and use SPEA.m or SPEA.xmcd to determine:

- i. the initial angle,  $\gamma_0$ ,
- ii. the critical clearing angle,  $\gamma_{cr}$ ,
- iii. the critical clearing time,  $t_{cr}$ , and
- iv. the the maximum swing angle,  $\gamma_{maxswing}$ .

Note: The values of  $E_a$  and  $X_{du}$  are calculated and output by PartIIImIC.m.

- (d) Set  $E_x = E_{qp}$  and  $X_{dx} = X_{dp}$  and set  $T_{2ss} = T_{2f} = 0$  (round rotor approximation) in the Matlab script SPEA.m or the Mathcad sheet SPd.xmcd and use SPEA.m or SPd.xmcd to determine:

- i. the initial angle,  $\gamma_0$ ,
- ii. the critical clearing angle,  $\gamma_{cr}$ ,
- iii. the critical clearing time,  $t_{cr}$ , and
- iv. the the maximum swing angle,  $\gamma_{maxswing}$ .

- (e) Set  $E_x = E_a$  and  $X_{dx} = X_{du}$  and set  $T_{2ss} = T_{2f} = 0$  (round rotor approximation) in the Matlab script SPEA.m or the Mathcad sheet SPd.xmcd and use SPEA.m or SPd.xmcd to determine:

- i. the initial angle,  $\gamma_0$ ,
- ii. the critical clearing angle,  $\gamma_{cr}$ ,
- iii. the critical clearing time,  $t_{cr}$ , and
- iv. the the maximum swing angle,  $\gamma_{maxswing}$ .

2. Create a table that summarizes your numerical results. Include the values of  $E_x$ ,  $X_{dx}$ ,  $\gamma_0$ ,  $\gamma_{cr}$ ,  $t_{cr}$ , and  $\gamma_{maxswing}$  as columns for the five different methods specified above. For the first case you will not have entries for  $E_x$  and  $X_{dx}$ .
3. Which parameters are the best to use in the equal area approximation for the analytical solution.
4. Explain with words (no equations) why the parameters selected in the previous answer work the best.
5. (50 points) Repeat the first four questions with  $X_q$  changed to 1.07 pu; i.e., a "round rotor" machine. Change  $X_q$  ( $L_q$ ) in Part IImIC.m and SPEA.m (or SPEA.xmcd).

Hand in:

1. the table required in Question 2 for the salient pole machine (angles in degrees),
2. the table required in Question "2" for the round rotor machine (angles in degrees),
3. the answer to Question 3 for the salient pole machine,
4. the answer to Question "3" for the round rotor machine,
5. the answer to Question 4 for the salient pole machine, and
6. the answer to Question "4" for the round rotor machine.

I don't need anything else. You are only using the files that I have provided. You will not need to write any "code."