Develop a Simulink model (in per-unit) of a **835-MVA Steam-Turbine Generator** (book p. 176). The generator is to be connected to an ideal source (infinite bus) that supplies a balanced three-phase sinusoidal voltages rated 1pu. Establish the initial conditions that would correspond to an idle steady state operation with $T_m = 0$ and excitation $E_{xkd} = 1.0$ pu. Check the model’s eigenvalues, choose and state the solver, tolerances, and step-size limits that you think are appropriate for your model. **Assume all variables are in pu, unless otherwise specified. Assume positive direction of $T_m$ is toward increasing the rotor speed $\omega_r$ and angle $\delta_r$.**

1) Assume zero initial conditions and $E_{xkd} = 0$. Implement a start-up transient that would emulate starting this synchronous machine from stall like an induction motor. Plot variables $i_{as}$, $T_e$, $\omega_r$. Comment on results: how practical this would be for a machine of this size? How would you recommend bring a large machine (motor or generator) on line?

2) Assume the initial conditions established for idle steady state with $E_{xkd} = 0.1$ pu and $T_m = 0$. Implement the following study: At $t = 1$ sec, the excitation is stepped down to 0.8 pu. Then, at $t = 7.0$ sec. the excitation is stepped up to 1.2 pu. Then, at $t = 15.0$ sec. the torque is stepped to $T_m = 0.85$ pu supplying the power from mechanical system to electrical side and the model is continued to run till $t = 35$ sec. Plot variables $i_{as}$, $i_{qd}$, $i_{kq1}$, $i_{kq2}$, $T_e$, $\delta_r$ (in electrical degrees), $\omega_r$, as well as real power $P_e$, and reactive power $Q_e$. Based on the transient observed, very briefly explain effect of changing excitation. Also explain the effect of applying mechanical torque in general and in your case.

3) Repeat the study of step 2) up to $t = 15.0$ sec. assuming that the $q$-axis dumper windings $kq1$ and $kq2$ are damaged. This can be implemented by setting the resistance for these windings to a very high value, e.g., set $r_{kq1} = r_{kq2} = 1$ pu. Briefly explain the effect and the role of dumper windings based on your study.

4) For the following studies assume that all damper windings are fine and $T_m = 0.85$ and $E_{xkd} = 2.48$ pu.

Review book Ch. 5.10, pages 171-200. Calculate the coefficients $(a,b)pu$ for the steady-state torque-angle characteristic (SSTAC). Establish parameters $E'_q$ and $x'_d$, respectively, and calculate the coefficients $(a',b')pu$ for approximate transient torque-angle characteristic (ATTAC). Plot the SSTAC and ATTAC, and compare them to each other. Which one has higher limits and why? Using the ATTAC, calculate (predict) the clearing angle $\delta_c$ and critical clearing time $\Delta t_c$ after which the generator is supposed to return to the synchronism.

5) Assume the same operating conditions as in step 4), i.e. $T_m = 0.85$ and $E_{xkd} = 2.48$ pu. Run the model until a steady-state is reached and save the final state. You can use this state value as an initial condition to implement the following three-phase fault study:

a) Start the model from a steady-state. At $t = 1.0$ sec., apply a three-phase fault to the generator terminals (set the source voltages to zero). Then, at $t = 1.3$ sec., remove the fault and continue to run the model till $t = 8$ sec. Plot variables $i_{as}$, $T_e$, $\delta_r$ (in electrical degrees), $\omega_r$, $P_e$, and $P_m$.

b) Repeat part a) but this time remove the fault at $t = 1.4$ sec. Very briefly explain the difference between the transient in a) and b).

c) Using your simulation and adjusting the time of fault removal, determine $\Delta t_c$ and $\delta_c$ after which the generator still returns to the synchronism.

6) How close are the values of $\delta_c$ and $\Delta t_c$ found in 4) and 5-c)? Which method is more trustable?

7) What method can you use to estimate the critical clearing time $\Delta t_c$ for the two-phase unsymmetrical fault? Repeat studies in step 5) part c) assuming the two-phase fault. Can you use the ATTAC here?

8) Why do you think it is important to remove the fault in a case of real (practical) generator or motor?