Institut en génie de l'énergie électrique

IGEE 402 Power System Analysis – Fall 2024

Experiment 4 – Transient Stability

1 Objectives

1. Understand the principles of transient stability analysis.
2. Perform numerical simulations of the swing equation on a simple system.

2 Theory

The theory related to transient stability can be found in Chapter 11 of the course textbook [1]. The basic equation in transient stability studies is the swing equation:

$$\frac{2H}{\omega_0}\omega_{pu}(t)\frac{d\omega(t)}{dt} = P_{pu}^m - P_{pu}^e - D\frac{(\omega(t)-\omega_0)}{\omega_0} = P_{pu}^a$$
$$\frac{d\delta(t)}{dt} = \omega(t) - \omega_0$$

This is a nonlinear differential equation. An analytic solution to the swing equation is possible if it is assumed that $\omega_{pu} \approx 1$. However, the modelling tools to be used in this lab will permit the simulation of the a single machine transient stability taking into account the nonlinearities of the equation. Note that here we have also included the possibility to model the machine's damping which is proportional to the speed deviation and the constant D.

In this experiment you will be assessing the transient stability of a single generator oscillating against an infinite bus under two specific contingency conditions by solving the swing equation through Powerworld's transient stability calculation module. The assumptions for these simulations are that the input mechanical power and pre-fault generator internal voltage stay constant during the simulation time. This is a reasonable assumption since the elements (actuators) that control the mechanical power and internal voltage of a synchronous generator take some time to respond, typically times much greater than those of the fault duration.

3 Preliminary Calculations

A transient stability study is to be performed in the system shown in Figure 1. All impedances are given in per-unit of a common 100 MVA system base. The infinite bus receives 1.0 p.u. of active power at a power factor of 0.95 lagging. The inertial constant of the generator is $H = 3.0$ per unit-seconds on the system base and the generator transient reactance $X'_d = 0.3$ p.u.

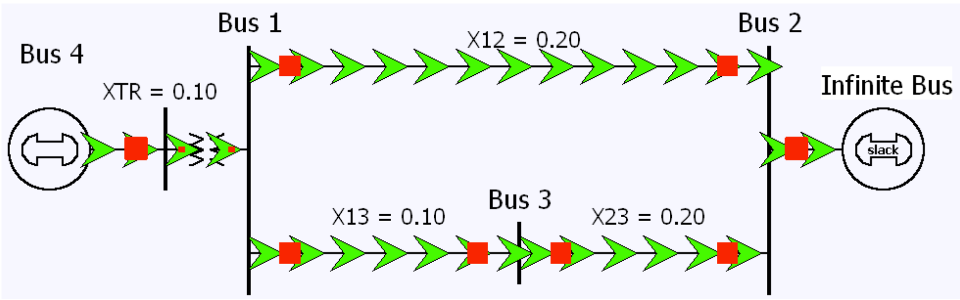

Figure 1: Power system under study

Before a fault is initiated, the power system was operating in steady state. Determine:

1. The terminal voltage (magnitude and phase) of generator G1 at $t = 0^-$.
2. The excitation voltage and the power angle of the generator at $t = 0^-$.
3. The mechanical power input into the turbine of the generator at $t = 0^-$ and $t = 0^+$.
4. The active power transfer expression (from the generator to the infinite bus) for the pre-fault state (both lines connected) as a function of the generator's power angle.
5. The active power transfer expression (from the generator to the infinite bus) for the fault state as a function of generator's power angle. Do so for the following two fault conditions:
   (a) A bolted three-phase fault at Bus 1.
   (b) A bolted three-phase fault at Bus 3.
6. Apply the equal-area criterion to assess the transient stability for the above two contingencies; assume a fault clearing time of 6 cycles:
   (a) A bolted three-phase fault at Bus 1. Assume that once the fault is cleared the system is back to its initial topology.
   (b) A bolted three-phase fault at Bus 3. Assume that once the fault is cleared, lines between Bus 1 and Bus 3 as well as Bus 2 and Bus 3 remain open.

4 Experimental Procedures

1. Investigate the stability of the power system for a three-phase fault at Bus 1. To do so, use Powerworld's Transient Stability tool. Describe what you are seeing when simulating for a clearing time of 0.10 s (6 cycles). Simulate for at least 10 seconds.

Provide sufficient simulation evidence in your report. At the minimum, provide a plot closing in onto the initial instants of the disturbance (0 – 0.2 s) and one showing the steady-state stability of the system.

Note that on top of the plot automatically generated by Poweworld, you can visualize the generator rotor dynamics by selecting *Options* → *General* → *Transfer Results to Power Flow After Interval Check.*

2. Determine experimentally the critical clearing time for the three-phase bolted fault at Bus 1; give an answer to the nearest millisecond. Provide simulation evidence in your report to support your claim: a plot closing in on the initial instants of the disturbance (0–0.2 s) and one showing the long-term instability of the system. Indicate on your plot when the rotor angle overpasses the critical angle value found in the Preliminary Calculations.

   How is the stability limit prediction in the Preliminary Calculations comparing to the simulation? Identify sources of discrepancies.

3. Now add damping to the generator model. Assign a value of $D = 1.0$ p.u. by accessing the *Stability* → *Machine Models* tabs in the *Generator Information Dialog.* Describe what happens when simulating the conditions from 1. with damping. Find the critical fault clearing time to the nearest millisecond with damping.

   In your report provide a plot closing in on the initial instants of the disturbance (0 – 0.2 s) and one showing the long-term instability of the system. Does damping contribute in significantly increasing the critical clearing time?

4. Restore the generator damping to 0.0 p.u. Investigate the stability of the power system for a three-phase fault at Bus 3. Describe what you are seeing when simulating with the default setting (clearing time of 0.10 s (6 cycles) via simultaneous opening of lines Bus 1-Bus 3 and Bus 2-Bus 3). Simulate for at least 10 seconds. In your report provide a plot closing in on the initial instants of the disturbance (0 – 0.2 s) and one showing the steady-state stability of the system.

   What is the critical clearing time to the nearest millisecond for this fault? Provide sufficient simulation evidence to justify your finding. Indicate on your plot when the rotor angle overpasses the critical angle value found in the Preliminary calculations. How is the stability limit prediction in the preliminary calculations comparing to the findings in the simulations?

References

[1] Glover, J.D., Sarma, M.S., & Overbye, T.J. (2012). *Power System Analysis & Design.* 5th SI ed. Stamford, CT: Cengage Learning.