

Exercise 1

Inertia in the Power System

M. K. Ranjram

1 Introduction

In this exercise, we investigate the multimachine system described by the one-line diagram in Fig. 1¹. The per-unit generator reactances are: $x'_{d1} = 0.08$, $x'_{d2} = 0.18$, $x'_{d3} = 0.12$. All data are provided on the base of the generators.

The system begins in steady-state with the following per-unit bus voltages:

$$\begin{bmatrix} V_4 \\ V_5 \\ V_6 \\ V_7 \\ V_8 \end{bmatrix} = \begin{bmatrix} 1.04 \angle 0^\circ \\ 1.02 \angle -3.55^\circ \\ 1.05 \angle -2.90^\circ \\ 0.9911 \angle -7.48^\circ \\ 1.0135 \angle -7.05^\circ \end{bmatrix}$$

The generators deliver the following real and reactive power:

$$\begin{bmatrix} P_{G1} \\ P_{G2} \\ P_{G3} \end{bmatrix} = \begin{bmatrix} 1.9991 \\ 0.6661 \\ 1.6000 \end{bmatrix}, \quad \begin{bmatrix} Q_{G1} \\ Q_{G2} \\ Q_{G3} \end{bmatrix} = \begin{bmatrix} 0.8134 \\ 0.2049 \\ 1.051 \end{bmatrix}$$

We can study faults in this system using the tools we have developed in Module 1. For your convenience, these tools have been integrated into a MATLAB Live Script (*Exercise - Module 1.mlx*) which accompanies this exercise.

The script is set up to allow you to introduce a three-phase to ground fault at one of busses 4, 5, 6, 7, or 8. This fault is applied for an amount of time that you may also specify. After this amount of time elapses, you may specify which of the 6 transmission lines connecting the busses is removed in response to this fault. The series elements of these lines are inductors with $j0.1$ p.u. impedances while the shunt elements are capacitors with admittance $j0.01$ p.u.

It is assumed that the internal generator voltages are constant throughout the fault (i.e. we are considering timescales too short for any higher-level control to respond). The script shows the evolution during the fault of the bus voltage magnitudes and phases, the relative generator rotor angles, and the generator frequencies. It also shows the relative generator rotor angles and frequencies once the fault has been cleared. A damping of 0.05 in each generator is applied so that you may have a better sense of the steady-state values after the fault.

Finally, you are able to specify the per-unit inertia constants of each generator. This allows us to explore the impact of these values on the system.

2 Study the MATLAB Code

For your reference, it is worthwhile to examine the associated MATLAB code and understand how this system is analyzed. In particular, answer the following questions:

1. How is the admittance matrix Y modified to introduce a fault?
2. How is the multimachine swing equation solved in code?
3. How is the admittance matrix Y modified post-fault?

¹This exercise is adapted from Example 14.6 in *A. R. Bergen and V. Vittal, Power Systems Analysis, 2nd ed. Upper Saddle River, NJ, NJ: Prentice Hall, 2000.*

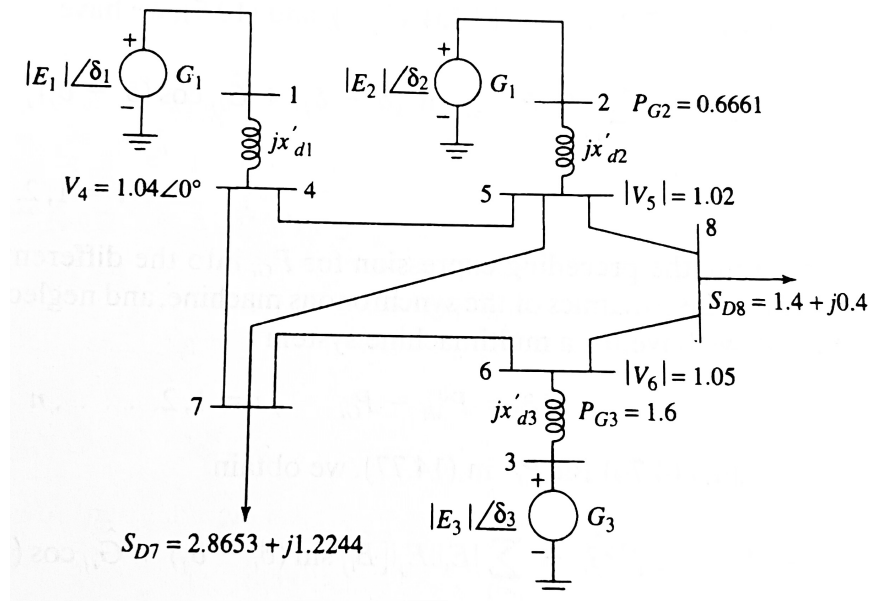


Figure 1: One-line diagram of a three generator, eight bus system.

3 Consider a Fault on Bus 7

Configure the system for a fault on bus 7 with the line between busses 6 and 7 being removed to clear the fault after 0.1 seconds. Set the generator inertias to 10, 3, and 6.4 for generator 1, 2, and 3, respectively.

1. Which generator has the highest frequency during the fault? Which has the highest excursion after the fault is cleared? Could we determine this just by knowing the relative inertias of the generators? **Generator 3 to both. No, we need to study to full system to understand how it evolves**
2. If the maximum tolerable system frequency is 61Hz, what is the longest fault duration that can be tolerated (within 0.05 seconds)? Which generator hits this limit first? **0.2**
3. Increase the inertia constant for the generator in part (3). How high must you make it for the system to tolerate a 0.2 second fault? **Generator 3, 8.2**
4. If the fault is instead cleared by removing line 5-7 or line 4-7, does the generator with the largest frequency excursion after a 0.1 second fault change? **Yes, if you remove 4-7, generator 1 has the largest excursion. The point is it isn't a single generator's fault!**

4 Continue to Explore the Model

Try setting different faulted busses and cleared lines, and get a feel for the importance of inertia in limiting the system's response to faults. In particular, you'll notice that if any of the three inertia constants is very low (e.g. less than 1), the fault responses become extremely volatile. This is a small example system, but it still provides insight into what could happen in a system where a significant portion of the generation having low inertia (e.g. if much of the generation was sourced from inverter-based resources without grid-support functionality).