Homework # 02
Power Systems Analysis II
EE 457 – Iowa State University

Instructor: Prof. Hugo N. Villegas Pico

Due date: February 14, 2020

The objective of this assignment is to familiarize with modeling and simulation of synchronous machinery and its transient performance during loading and short circuit events. Please, use the *publish* functionality of MATLAB to hand in any code related work. No screen captures of MATLAB code will be accepted. Code is expected to be commented as instructed in the classroom to earn credit. Please, upload your solutions to Canvas.

Warning: This homework is to be individually completed; no collaboration is permitted. Cheating will not be tolerated and reported to the Dean of Students Office.

Problem 1 (20 pts) In class, you were given the following expression for electromagnetic torque for a two-pole round-rotor synchronous machine:

$$T_e = \frac{3}{2} L_A i'_{fd} \left[(i_{as} - 0.5 i_{bs} - 0.5 i_{cs}) \cos\theta_r + \sqrt{3}/2 (i_{bs} - i_{cs}) \sin\theta_r \right] . \tag{1}$$

By assuming that i_{as}, i_{bs}, i_{cs} constitute a balance set of sinusoidal waveforms [e.g, $i_{as}(t) = \sqrt{2} I \cos(\omega_e t)$, $i_{bs}(t) = \sqrt{2} I \cos(\omega_e t - 2\pi/3)$, and $i_{cs}(t) = \sqrt{2} I \cos(\omega_e t + 2\pi/3)$] ; $i'_{fd}(t)$ is constant by definition in steady state, and $\theta_r(t) = \omega_e t + \pi/2 + \delta$ (for constant rotor speed and fixed angle δ), prove that the electromagnetic torque $T_e(t)$ is constant for a fixed δ. Hint: Use trigonometric identities of product to addition of sinusoidal functions.

Problem 2 (50 pts) Simulate and study the dynamic performance of the synchronous machine we derived in class for $t \in [0, 25]$ s. Consider that $L_A = 2.3 \times 10^{-3}$ H, $r_s = 2.43 \times 10^{-3}\,\Omega$, $L_{ls} = 4.079 \times 10^{-4}$ H, $L_{lfd} = 54.5 \times 10^{-3}$ H, $r_{fd} = 0.1345\,\Omega$, $L_{mfd} = 619.7 \times 10^{-3}$ H, $L_{sfd} = 37.8 \times 10^{-3}$ H, and $N_{fd}/N_s = 16.4$. These parameters pertain to a two-pole round-rotor synchronous machine which is rated 835 MVA; its rated line-to-line voltage is 26 kV. For informational purposes, the inertia constant of the machine-turbine assembly is $J = 0.0658 \times 10^6\,\text{Kg}\cdot\text{m}^2$ and the viscous damping constant is $D = 7\,\text{N}\cdot\text{m}\cdot\text{s/rad}$.

Because we are not modeling the dynamics of the prime mover, assume that

$$T_m = -T_e + T_f$$

that is, the prime mover ideally balances the net torque so that angular acceleration is zero. Also assume that the excitation voltage $v_{fd}(t \geq 0) = 230\,\text{V}$, i.e., it remains constant throughout the simulation because we are not modeling the dynamics of the voltage regulator and exciter. The initial conditions of all the states will be zero other than rotor speed which will be $\omega_r(0^-) = 120\pi$ rad/s.

Assume also that the terminals of the machine are connected to a balanced wye-connected restive load with $R_L = 40.48\,\Omega$ for $t \in [0, 15)$ s and that $R_L = 2.7\,\Omega$ for $t \in [15, 25]$ s. Note that this will introduce a transient to the machine around $t = 15$ s, e.g., a load pick up event.

To earn credit, depict the three-phase voltage and current sinusoidal waveforms observed at the terminals of the machine, the field winding current, the rotor speed, and electromagnetic torque as well as electric power measured at the terminals of the machine. Discuss on the observations from the figures.

Problem 3 (30 pts) Repeat problem 2 but consider the following balanced wye-connected resistive load events:

$$R_L = \begin{cases} 40.48\,\Omega & t \in [0, 15)\,\text{s} \\ 2.70\,\Omega & t \in [15, 20)\,\text{s} \\ 0.00\,\Omega & t \in [20, 20 + 5/60)\,\text{s} \\ 2.70\,\Omega & t \geq 20 + 5/60\,\text{s} \end{cases}$$

Note that the terminals of the machine are in short circuit for $t \in [20, 20 + 5/60)$ s. To earn credit, depict the three-phase voltage and current waveforms observed at the terminals of the machine, the field winding current, the rotor speed and electromagnetic torque as well as electric power measured at the terminals of the machine. Discuss on your observations from the figures, specially during the short circuit event.