**COLORADO SCHOOL OF MINES**
**ELECTRICAL ENGINEERING DEPARTMENT**

**EENG577 Advanced Electric Machine Dynamics for Smart-Grid Systems**

**M4 Project: Synchronous Generator-dq0**

A 659 MVA, 4-Pole, 20 kV, 0.9 P.F., Double-Y Connected (with grounded neutral), 60 Hz turbogenerator, whose armature and field winding parameters (neglecting saturation) are summarized as follows:

| | | | | | |
|---|---|---|---|---|---|
| $r_s$ | = | $7.4\text{x}10^{-4}\ \Omega$ | $r_f$ | = | $0.0860\ \Omega$ |
| $r_{kd1}$ | = | $1.58\text{x}10^{-4}\ \Omega$ | $r_{kd2}$ | = | $0.0130\ \Omega$ |
| $r_{kq1}$ | = | $1.227\text{x}10^{-4}\ \Omega$ | $r_{kq2}$ | = | $0.0174\ \Omega$ |
| $L_{sa}$ | = | $1.95\text{x}10^{-3}$ H | $L_{sv}$ | = | $0.05\text{x}10^{-3}$ H |
| $L_{ma}$ | = | $0.80\text{x}10^{-3}$ H | $L_{mv}$ | = | $0.05\text{x}10^{-3}$ H |
| $L_{afm}$ | = | $26.1\text{x}10^{-3}$ H | $L_{ff}$ | = | $444\text{x}10^{-3}$ H |
| $L_{fkd1}$ | = | $5.05\text{x}10^{-3}$ H | $L_{fkd2}$ | = | $12.38\text{x}10^{-3}$ H |
| $L_{kd1f}$ | = | $6.29\text{x}10^{-3}$ H | $L_{kd2f}$ | = | $12.38\text{x}10^{-3}$ H |
| $L_{akdm1}$ | = | $0.447\text{x}10^{-3}$ H | $L_{akdm2}$ | = | $0.79\text{x}10^{-3}$ H |
| $L_{akqm1}$ | = | $0.670\text{x}10^{-3}$ H | $L_{akqm2}$ | = | $0.378\text{x}10^{-3}$ H |
| $L_{kd1kd1}$ | = | $0.1254\text{x}10^{-3}$ H | $L_{kd1kd2}$ | = | $0.19\text{x}10^{-3}$ H |
| $L_{kd2kd1}$ | = | $0.148\text{x}10^{-3}$ H | $L_{kd2kd2}$ | = | $0.4158\text{x}10^{-3}$ H |
| $L_{kq1kq1}$ | = | $0.3762\text{x}10^{-3}$ H | $L_{kq1kq2}$ | = | $0.159\text{x}10^{-3}$ H |
| $L_{kq2kq1}$ | = | $0.160\text{x}10^{-3}$ H | $L_{kq2kq2}$ | = | $0.1375\text{x}10^{-3}$ H |

## PART I

1. Show a cross-section of the synchronous machine and draw the corresponding winding **schematic diagram** for the data given. Label axes properly (**no values**).

2. Find the Machine parameters $L_{dd}$, $L_{qq}$, $L_{oo}$, and write the state model in the form $\dot{\underline{X}} = \underline{A} \bullet \underline{X} + \underline{B} \bullet \underline{U}$ in the dq0 frame of reference using **compact matrix** notation, given in the course handouts. However, write the **expanded form** using numerical values for matrices A and B.

**PART II**

Assuming that the machine is operating at its rated voltage, current, and power factor (overexcited) as a generator, calculate the necessary excitation field current, the torque angle, $\delta$, and the angle $\sigma_o$, between the magnetic axis of phase a, and the d-axis. Here, consider the terminal voltage (to neutral) of phase a, $V_a$, to be the reference in the phasor diagram.

At time t=0.0 the machine is connected to an infinite busbar where, a, b, and c phase voltages are given by:

$$v_a = \frac{20 \text{ x } 10^3}{\sqrt{3}} \sqrt{2} \cos(\omega \text{ t}) \text{ Volts}$$

$$v_b = \frac{20 \text{ x } 10^3}{\sqrt{3}} \sqrt{2} \cos(\omega \text{ t} - 2\pi/3) \text{ Volts}$$

$$v_c = \frac{20 \text{ x } 10^3}{\sqrt{3}} \sqrt{2} \cos(\omega \text{ t} - 4\pi/3) \text{ Volts}$$

The machine continues to be connected to the infinite bus at rated load for 10 cycles. At the end of the tenth ac cycle a three phase to ground fault develops at the terminals of the generator, and lasts for the next 15 cycles. That is a fault develops at the end of the $10^{th}$ ac cycle and clears at the end of the 25th cycle. The fault is of the three phase to ground (neutral) type.

Assuming that the terminal voltage of the field winding is kept constant by the excitation control system at its prefault steady state value, and that the speed of the turbogenerator is maintained, by its prime mover, constant at its rated synchronous value.

1. Calculate the initial conditions (values at t=0 s) for $i_a$, $i_b$, $i_c$, $i_f$, $i_{kd1}$, $i_{kq1}$, $i_{kd2}$, $i_{kq2}$

2. Perform transient analysis for the following cases:

   i. Neglect the effects of the damping circuits in your model. Calculate by means of numerical integration (MATLAB **or Simulink**) *and plot the profiles versus time over the first 35 cycles* of the transient for the following variables: $i_d$, $i_q$, $i_o$, $i_a$, $i_b$, $i_c$, $i_f$, $e_d$, $e_q$, and $T_{em}$.

   ii. Include the effects of the damping circuits in your model. Calculate by means of numerical integration (MATLAB **or Simulink**) and *plot the profiles versus time over the first 35 cycles* of the transient for the following variables: $i_d$, $i_q$, $i_o$, $i_a$, $i_b$, $i_c$, $i_f$, $i_{kd1}$, $i_{kd2}$, $i_{kq1}$, $i_{kq2}$, $e_d$, $e_q$, and $T_{em}$.

- **Discuss your results especially those of Part II**
- **Include the listing of your program**

*<u>Please Note:</u> This is a group project, please make one group submission. You can discuss the problem with other class groups; however, each group should work independently.*