COLORADO SCHOOL OF MINES
ELECTRICAL ENGINEERING DEPARTMENT

EENG577 Advanced Electric Machine Dynamics for Smart-Grid Systems

M3 Project: Synchronous Generator-abc

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	=	$7.4\times10^{-4}\ \Omega$	r_f	=	$0.0860\ \Omega$
r_{kd1}	=	$1.58\times10^{-4}\ \Omega$	L_{sv}	=	0.05×10^{-3} H
r_{kq1}	=	$1.227\times10^{-4}\ \Omega$	L_{mv}	=	0.05×10^{-3} H
L_{sa}	=	1.95×10^{-3} H	L_{ff}	=	444×10^{-3} H
L_{ma}	=	0.80×10^{-3} H	L_{akdm1}	=	0.447×10^{-3} H
L_{afm}	=	26.1×10^{-3} H	L_{akqm1}	=	0.670×10^{-3} H
L_{fkd1}	=	5.05×10^{-3} H	L_{kd1kd1}	=	0.1254×10^{-3} H
L_{kd1f}	=	6.29×10^{-3} H	L_{kq1kq1}	=	0.3762×10^{-3} H

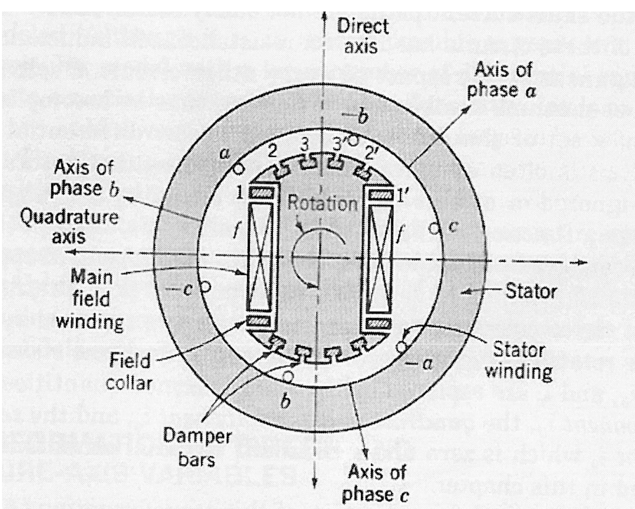

Fig-1: A Typical Machine Cross-section

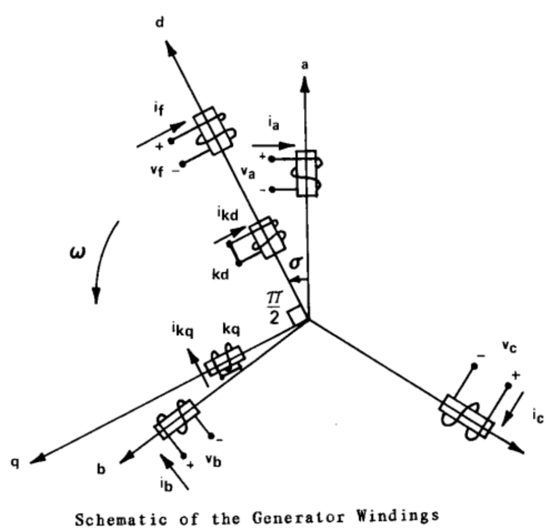

Fig-2 Schematic of Generator Windings

PART I

1. Show a cross-section of the synchronous machine and draw corresponding winding **schematic diagram** and label all axes (a, b, c, f, d, and q) properly.

2. Write down the State Space (SS) model in expanded matrix form, use the symbols in the lecture notes (**no values**) for the following:
   i. Case-1: Neglect the effects of the damping circuits in your SS model. Include only windings a, b, c, and f.
   ii. Case-2: Account for the effects of the damping circuits in your SS model. Include all windings a, b, c, f, kd1, and kq1.

3. Write the state space model in the form $\dot{\underline{X}} = \underline{A} \bullet \underline{X} + \underline{B} \bullet \underline{U}$ using **compact matrix** notation, given in the course handouts. However, write the **expanded form** using expressions and **numerical values for matrices A and B** for:
   i. Case-1: Neglect the effects of the damping circuits in your SS model. Include only windings a, b, c, and f.
   ii. Case-2: Account for the effects of the damping circuits in your SS model. Include all windings a, b, c, f, kd1, and kq1.

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 assuming $V_f = r_f i_f = 338$ V. Also, assume the angle σ, between phase a-axis and the d-axis is equal to zero (meaning in Figs 1 & 2, the a-axis is aligned with the d-axis). In addition, consider the terminal voltage (to neutral) of phase a, V_a, to be the reference in the phasor diagram (meaning having a phase angle equal to zero).

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

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

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

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

Assuming that the terminal voltage of the field winding is kept constant by the excitation control system at $V_f = r_f i_f = 338$ V, 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}

2. Perform 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 30 cycles* for the following variables: i_a, i_b, i_c, i_f, 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 30 cycles* for the following variables: i_a, i_b, i_c, i_f, i_{kd1}, i_{kq1}, and T_{em}

- **Discuss your results especially those of Part II**
- **Include MATLAB code or Simulink block diagram in an appendix**

<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.