

# ECEN 460

## Laboratory 4

### Operation of the Synchronous Generator Under Load

#### Objective

To demonstrate the effect of excitation control on the terminal voltage and reactive power generation of a synchronous generator as the load is changed.

#### Equipment

- Synchronous machine (1)
- DC machine (1)
- Multi-meter (3)
- Tachometer (1)
- Inductive Load (1)
- Resistive Load (1)

#### PROCEDURE

##### PART A

- 1) Connect the synchronous generator as shown in Figure 1

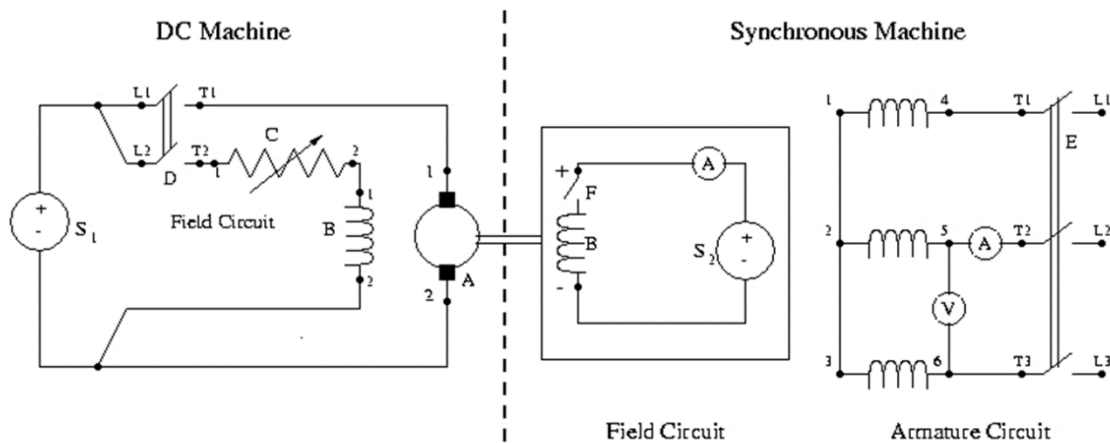


Figure 1

A: Armature	E: 3- $\phi$ circuit switch
B: Shunt Field	F: Field switch (Left pos.: Start, Right pos.: Syn. Run)
C: Field Rheostat	S <sub>1</sub> : 0-125 V, 6A maximum variable DC voltage source (Set S <sub>1</sub> =125 V constant)
D: DC machine start switch	S <sub>2</sub> : 0-150 V, 1 A maximum, variable DC voltage source

- 2) Set the DC variable voltage source (S<sub>2</sub>) to 0 and set the field rheostat 'C' of the DC

motor at its maximum. Move switch F to 'Ind. Start' position (left) so that the synchronous machine can be started as a motor.

- 3) Have the instructor check your machine and meter connections before proceeding.
- 4) Turn on switch 'D' and start the DC motor. Use the field rheostat 'C' to adjust the speed to 1800 rpm. Once the speed is set, move switch F to the 'Syn. Run' position (right).
- 5) Using the variable voltage source S2, adjust the field current of the synchronous generator to obtain the rated terminal voltage. **Keep the field current and speed constant through the end of Step 7.**
- 6) Connect the load resistors (wye-connected) to the synchronous generator as shown in Figure 1.
- 7) Increase the resistive load in the order indicated in Table 1. Use Table 1 to record the magnitude of the terminal voltage ( $|V_t|$ ) and the magnitude of the armature current ( $|I_a|$ ) of the synchronous generator.
- 8) Set the field voltage of synchronous machine to zero and switch off the voltage supply. Stop the DC motor by switching 'D' off and waiting until the machine comes to a full stop.

## **PART B**

- 1) Disconnect the load from the generator.
- 2) Use field rheostat 'C' to adjust the speed to 1800 rpm and adjust the field current to obtain rated terminal voltage. Repeat these adjustments several times until the speed is 1800 rpm and the terminal voltage is at its rated value. **Keep the terminal voltage and the speed of the synchronous generator constant through the end of Step 3.**
- 3) Set the resistive load to 600  $\Omega$ . This value will stay constant throughout this step. Then increase the reactive load by adding inductors in parallel, one at a time, in the order given in Table 2. Use Table 2 to record the armature current ( $|I_a|$ ) and the field current ( $I_f$ ) of the synchronous generator at each step.
- 4) Set the field voltage of synchronous machine to zero and switch off the voltage supply. Stop the DC motor by switching 'D' off and waiting until the machine

comes to a full stop.

## REPORT

### PART A

- 1) Using the synchronous machine model developed in the previous experiment from last week, calculate the expected magnitudes of the terminal voltage ( $|V_t|$ ) and then fill out the corresponding column in Table 1. Plot the calculated and the measured values of  $|V_t|$  vs.  $|I_a|$  on the same graph. Compare and discuss any discrepancies between the two plots.

- 2) Calculate the power angle  $\delta$  for each  $|I_a|$  using  $\delta = \sin^{-1} \left[ \frac{|I_a| \cdot X_s}{|E_f|} \right]$ . Then calculate the three-phase real power  $P$  dissipated by the load for the same  $|I_a|$  values. Fill in the corresponding columns in Table 1. Plot the calculated  $P$  versus  $\delta$  values and comment on the shape of the curve.

### PART B

- 1) Calculate the power factor angle  $\theta$  of the load using the below equation and fill in the  $\theta$  column of Table 2

$$\theta = -\tan^{-1} \left[ \frac{B}{G} \right], \text{ where } G + jB \text{ is the admittance of the per phase load.}$$

- 2) Calculate the field excitation voltage phasor (magnitude and angle) using the below equation assuming that the angle of the terminal voltage is zero. Fill in the  $|E_f|$  and  $\delta$  columns in Table 2.

$$|E_f| \angle \delta = |V_t| \angle 0 + |I_a| \angle -\theta \cdot (R_a + jX_s)$$

- 3) Draw the phasors  $|V_t| \angle 0$ ,  $|E_f| \angle \delta$ ,  $|I_a| \angle -\theta$  for all loading conditions on the same complex plane. Note that for all conditions the terminal voltage will remain the reference phasor along the real axis with a constant magnitude.
- 4) Calculate the three-phase reactive power output,  $Q$ , of the synchronous generator and fill in the  $Q$  column in Table 2. Plot  $Q$  versus  $I_f$ ; comment on the results.

**Table 1:  $I_f = \text{constant}$ ,  $f = 60 \text{ Hz}$** 

<b>R (<math>\Omega</math>)</b>			<b>Recorded Values</b>		<b>Calculated Values</b>		
<b>Resistive Load</b>			$ V_t $ (volts) line-to neutral	$ I_a $ (amps)	$ V_t $ (volts)	$\delta$ ( $^\circ$ )	P (W)
150	300	600					
0	0	0					
0	0	1					
0	1	0					
1	0	1					
1	1	0					
1	1	1					

**Table 2:  $R = 600 \Omega$ ,  $V_t = 120 \text{ V}$  (line-to neutral),  $f = 60 \text{ Hz}$** 

<b>L (H)</b>			<b>Recorded Values</b>		<b>Calculated Values</b>			
<b>Inductive Load</b>			$ I_a $ (amps)	$I_f$ (amps)	$\delta$ ( $^\circ$ )	$ E_f $ (volts)	$Q$ , (var)	$\theta$ ( $^\circ$ )
0.4	0.8	1.6						
0	0	1						
0	1	0						
1	0	0						
1	0	1						
1	1	0						