ECEN 460
Laboratory 3
Synchronous Generator Parameters and Equivalent Circuit

Objective:

To derive the equivalent circuit of a synchronous generator from the results of the open-circuit and short circuit tests. It also aims to show the relations between the field excitation, rotor speed, the open circuit armature voltage and the short circuit current.

EQUIPMENT

Synchronous machine (1)
DC machine (1)
Multi-meter (3)
Tachometer (1)

PROCEDURE

The procedure consists of three steps:

- Open Circuit Test
- Short Circuit Test
- Additional Measurements

Part A: Open Circuit Test

1) Connect the synchronous machine to operate as a 208 V (line-to-line), 3-phase, Y-connected synchronous generator as shown in Figure 1.

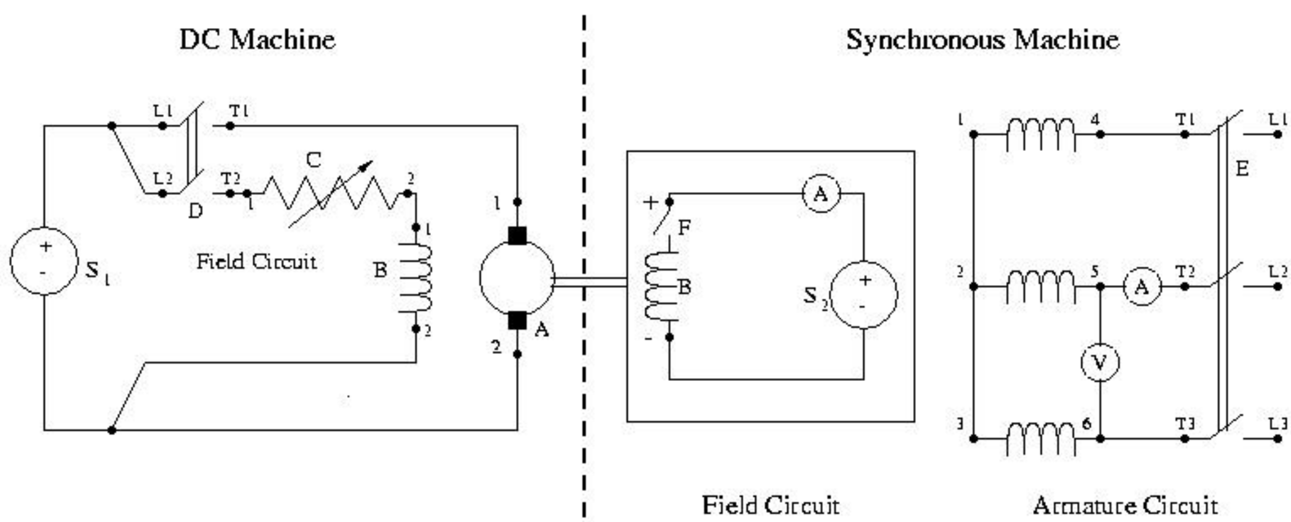

Figure 1

A: Armature	E: 3-ϕ circuit switch
B: Shunt Field	F: Field switch (Left pos.: Start, Right pos.: Syn. Run)
C: Field Rheostat	S_1: 0-125 V, 6A maximum, variable DC voltage source (setting S_1= 125V, constant)
D: DC machine start switch	S_2: 0-150V, 1A maximum, variable DC voltage source

2) Connect the DC machine to operate as a shunt motor as shown in Fig. 1.
3) Adjust the rheostat (C) of the DC motor to be at its maximum value (i.e., turn it **counterclockwise**). Set switch **D** to the **OFF** position. Set switch **E** to the **OFF** position, set **F** to the '**Ind. Start**' position (left).
4) Have the instructor check your machine and meter connections before proceeding.
5) Start the DC motor by switching '**D**' to the **on** position. Gradually increase the S_1 voltage, eventually reaching 125V (DC). Then adjust the speed to 1800 rpm by varying the rheostat 'C'. Keep the speed constant until step 8.
6) Apply field voltage (S_2) to the synchronous machine by switching **F** to the '**Syn. Run**' position (Right). Adjust S_2 in order to get 120% of the rated armature voltage (rated armature voltage is 208 V line-to-line, hence V_{LL} = 208 $\times$1.2 = 249.6 V, V_{LN} = 144 V). Record the voltage at the generator's terminals V_{LL} and its field current I_f. Then tabulate them in Table 1.1. Check the speed and be sure that it is constant (i.e., 1800 rpm).
7) Obtain six more data points for the open circuit armature voltage and field current by decreasing I_f to 0.60 A, then 0.54 A, 0.50 A, 0.45 A, 0.40 A and 0 A. Record V_{LL}, I_f and tabulate them in Table 1.1. ***In order to avoid hysteresis effects, never increase the field current to make minor corrections as you reduce the field current.***
8) Adjust the speed to 1600 rpm by varying the rheostat 'C' and repeat steps 6 – 7. Then tabulate the results in Table 1.2.
9) Set the field voltage (S_2) of synchronous machine to zero and switch the voltage supply off. Stop the DC motor by first gradually reducing S_1 to zero and then switch 'D' off and wait until the machine stops completely.

Part B: Short Circuit Test

1) Create a 3-phase short circuit across the armature terminals of the synchronous generator as shown in Figure 2.

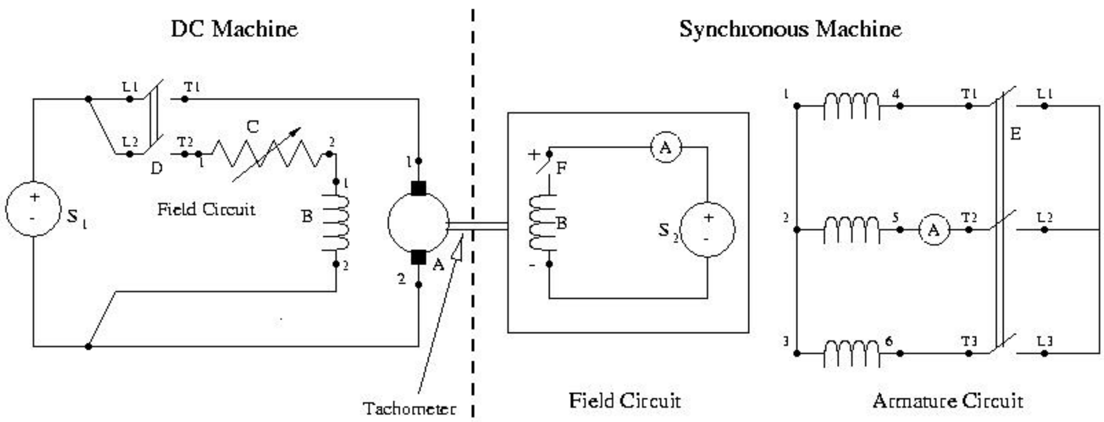

Figure 2

2) Repeat steps 3, 4 and 5 of Part A.
3) Apply field voltage (S_2) to the synchronous machine by switching **F** to '**Syn. Run**' position (Right). Adjust S_2 to obtain approximately 120% of the rated armature current through the short circuit (rated armature current is 1.7 A, hence $I_{armature}$ = 1.7 $\times$1.2 = 2.04 A). Record the armature current $I_{armature}$ and the field current I_f, and tabulate the data points in Table 2.1.
4) Obtain six more data points for the short circuit armature current and field current by decreasing the field current I_f to 1 A, 0.9 A, 0.8 A, 0.72 A, 0.6 A, 0.54 A. Record $I_{armature}$, I_f and tabulate the data points in Table 2.1. Remember that changing the field current will change the speed. **Make sure that the speed is equal to 1800 rpm** before recording any values.
5) Adjust the speed to 1600 rpm and repeat 3 – 4 of Part B. Tabulate the values in Table 2.2.
6) Set the field voltage (S_2) of synchronous machine to zero and switch the voltage supply off. Stop the DC motor by first gradually reducing S_1 to zero and then switch 'D' to off and wait until the machine stops completely.

Part C: Additional measurements

Measure the armature winding resistance of the synchronous generator.

REPORT

1. Plot on the same graph the open circuit armature voltage versus the field current when the speed is 1800 rpm and 1600 rpm. These are referred to as the open circuit characteristics (OCC).
2. Plot on the same graph the short circuit armature current versus the field current when the speed is 1800 rpm and 1600 rpm. These are referred to as the short circuit characteristics (SCC).
3. Using the plots from parts 1 and 2, plot the synchronous reactance versus field current when the speed is 1800 rpm. Note that the synchronous reactance is defined as the ratio of the open circuit terminal voltage (line-to-neutral) to the short circuit armature current corresponding to the same field current excitation.
4. Draw a tangent to the OCC (for 1800 rpm) at the origin. This straight line is referred to as the air gap line (AGL). Is the armature voltage zero at the origin (I_f=0)? Why or why not? Explain.
5. Calculate the saturated synchronous reactance by using the following definition:

   $$X_s = \frac{V_r}{I_0}$$

   where:

   V_r = Rated armature voltage (line to neutral) .

   I_0 = Armature current from the SCC corresponding to the value of I_f which will yield rated armature voltage on the OCC.
6. Calculate the unsaturated synchronous reactance by using the following definition:

   $$X_u = \frac{V_{agl}}{I_0}$$

   where:

   V_{agl} = Line to neutral AGL voltage corresponding to the rated value of I_f (which gives the rated armature voltage at OCC).

   I_0 = Armature current from the SCC corresponding to the rated value of I_f .
7. Draw and label the equivalent circuit.
8. Show that the per unit value of the saturated synchronous reactance can be calculated by using the following expression

$$X_s(p.u.) = \frac{I_{fi}}{I_{fv}}$$

where:

I_{fi} = Value of I_f corresponding to the rated armature current on the SCC.

I_{fv} = Value of I_f corresponding to rated armature voltage on the OCC

9. What is the relation between the rotor speed and open circuit armature voltage? Verify your answer by using experimental data. Does the relation remain the same for different values of field current? Explain why or why not.
10. What is the relation between the rotor speed and short circuit armature current? Does it remain the same for different field currents? Explain your answer.

Table 1.1 (Open Circuit Test, Speed = 1800 rpm)

V_{LL} (Volts)							
I_f (A)							

Table 1.2 (Open Circuit Test, Speed = 1600 rpm)

V_{LL} (Volts)							
I_f (A)							

Table 2.1 (Short Circuit Test, Speed = 1800 rpm)

$I_{armature}$ (A)						
I_f (A)						

Table 2.2 (Short Circuit Test, Speed = 1600 rpm)

$I_{armature}$ (A)						
I_f (A)						