Lab 8: DC generators: shunt, series, and compounded.

Objective: *to study the properties of DC generators under no-load and full-load conditions; to learn how to connect these generators; to obtain their armature voltage vs. armature current load curves.*

Equipment: Power Supply, DAI, Synchronous motor (8241), Direct current machine (DC generator) (8211), 2 Variable Resistance modules (8311), Timing belt.

Theory:

A DC machine can run either as a motor or as a generator. A motor converts *electrical power* into *mechanical power* while a generator converts *mechanical power* into *electrical power*. A generator must, therefore, be mechanically driven in order that it may produce electricity.

Since the field winding is an electromagnet, current must flow through it to produce a magnetic field. This current is called the *excitation current*, and can be supplied to the field winding in one of two ways: it can come from a separate, external dc source, in which case the generator is called *a separately excited generator;* or it can come from the generator's own output, in which case the generator is called *a self-excited generator*.

Assume that the shunt field is excited by a dc current, thereby setting up a magnetic flux in the generator. If the rotor (or more correctly, the armature) is rotated by applying mechanical effort to the shaft, the armature coils will cut the magnetic flux, and a voltage will be induced in them. This voltage is ac and in order to get dc out of the generator, a rectifier must be employed. This role is carried out by the commutator and the brushes.

The voltage induced in the coils (and, therefore, the dc voltage at the brushes) depends only upon two things - the speed of rotation and the strength of the magnetic field. If the speed is doubled, the voltage doubles. If the field strength is increased by 20%, the voltage also increases by 20%.

Although **separate excitation** requires a separate dc power source, it is useful in cases where a generator must respond quickly and precisely to an external control source, or when the output voltage must be varied over a wide range.

With no electrical load connected to the generator, no current flows and only a voltage appears at the output. But if a resistance load is connected across the output, current will flow and the generator will begin to deliver electric power to the load.

The machine driving the generator must then furnish additional mechanical power to the generator. This is often accompanied by increased noise and vibration of the motor and the generator, together with a drop in speed.

The **separately excited generator** has many applications. However, it does have the disadvantage that a separate direct current power source is needed to excite the shunt field. This is costly and sometimes inconvenient; and the **self-excited DC generator** is often more suitable.

In a self-excited generator, the field winding is connected to the generator output. It may be connected *across* the output, in *series* with the output, or a *combination* of the two. The way in which the field is connected *(shunt, series or compound)* determines many of the generator's characteristics.

All of the above generators can have identical construction. Self-excitation is possible because of the residual magnetism in the stator pole pieces. As the armature rotates a small voltage is induced across its windings. When the field winding is connected in parallel *(shunt)* with the armature a small field current will flow. If this small field current is flowing in the proper direction, the residual magnetism will be reinforced which further increases the armature voltage and thus, a rapid voltage buildup occurs.

If the field current flows in the wrong direction, the residual magnetism will be reduced and voltage build-up cannot occur. In this case, interchanging the shunt field leads will correct the situation.

Self-excited shunt generators have the disadvantage in that changes in their load current from no-load to full-load cause their output voltage to change also. Their poor voltage regulation is due to three factors:

a) The magnetic field strength drops as the armature voltage drops, which further reduces the magnetic field strength, which in turn reduces the armature voltage etc.

b) The armature voltage drop *(I^2R losses)* from no-load to full-load.

c) The running speed of the driving motor may change with load. (This is particularly true of internal combustion engines and induction motors).

The two field windings (shunt and series) on the **compound generator** are connected so that their magnetic fields *aid* each other. Thus, when the load current increases, the current through the shunt field winding decreases reducing the strength of the magnetic field. However, if the same increase in load current is made to flow through the series field winding, it will increase the strength of the magnetic field.

With the proper number of turns in the series winding, the increase in magnetic strength will compensate for the decrease caused by the shunt winding. The combined magnetic field strength remains almost unchanged and little change in output voltage will take place as the load goes from no-load to full-load.

If the series field is connected so that the armature current flows in such a direction as to oppose the shunt field, we obtain *a differential compound generator*. This type of generator has poor regulation, but is useful in applications such as welding and arc lights where maintaining a constant output current is more important than a constant output voltage.

When the field winding is connected in *series* with the armature winding, the generator is called **a series generator**. The exciting current through the field winding of a series generator is the same current the generator delivers to the load. If the load has high resistance, only a minimum output voltage can be generated because of the minimum field current. On an open circuit, the generator will only have a minimum output voltage due to its residual magnetism. If the load draws current, the excitation current increases, the magnetic field becomes stronger and the generator delivers an output voltage. Therefore, in a series generator, changes in load current greatly affect the generator output voltage. A series generator has very poor voltage regulation and is not recommended for use as a power source.

The **generator regulation** can be evaluated as follows:

$$regulation = \frac{E_{NL} - E_{FL}}{E_{FL}} \cdot 100\,\% \tag{08-1}$$

where E_{NL} and E_{FL} are the no-load and full-load output voltages of the generator.

Experiment:

1) Due to its constant speed, synchronous motor (Fig. 08-1) will be used to mechanically drive the DC generators. Therefore, couple the synchronous motor and the generator and connect the synchronous motor according to Figure 08-2.

Figure 08-1

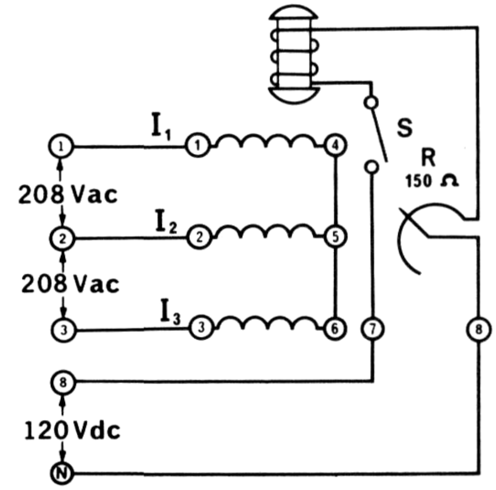

Figure 08-2

Notice that the terminals *1, 2,* and *3* of the PS provide fixed 3-phase power for the three stator windings. Terminals *8* and *N* of the PS provide fixed DC power for the rotor winding. Set the rheostat control knob to its 8 o'clock position (synchronous motor will be explained in later experiments).

2) Construct the circuit implementing the DC separately excited shunt generator as shown in Figure 08-3. Have your instructor to check your circuit.

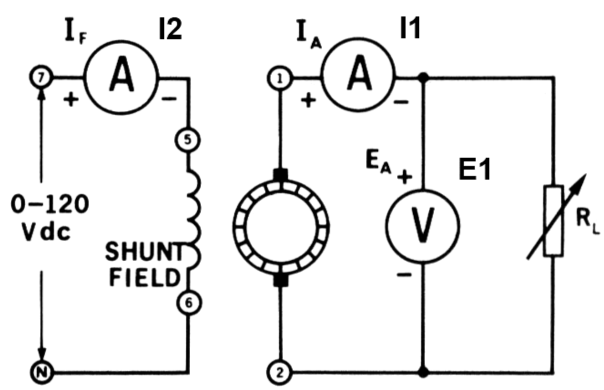

Figure 08-3

3) Set up the load resistance to ∞ (all switches are open). Make sure that the switch in the synchronous motor is open (lower position). Caution: the switch in the synchronous motor should be closed (upper position) ONLY when the motor is running! Turn ON the PS. The synchronous motor should start running. Close the motor's switch. Vary the shunt field current by changing the DC voltage on the PS.

4) Measure and record in a Data table the values of armature voltage E_A, armature current I_A, and field current I_F for the values of field current from 0 mA to 400 mA with steps of 50 mA. Turn OFF the PS.

5) Reverse the polarity of the shunt field by interchanging the leads to terminals *5* and *6* on the generator. Turn ON the PS and adjust for a field current of 300 mA. Record the values of currents and voltage in your data table. Return the voltage to zero and turn OFF the PS.

6) Reverse the rotation of the driving motor by interchanging any two of the stator lead connections (terminals 1, 2, or 3) to the synchronous motor. Turn ON the PS and adjust for a field current of 300 mA. Record the values of currents and voltage in your data table. Return the voltage to zero and turn OFF the PS.

7) By the proper selection of resistance switches, set the load resistance to 120 **Ω** (refer to Table 08-1 for help).

Table 08-1

R_L, Ω	1200	600	300	1200	600	300	1200	600	300
∞									
200		ON	ON						
150			ON			ON			
120	ON		ON	ON		ON			
100			ON			ON			ON
80	ON		ON	ON		ON	ON		ON
75		ON	ON		ON	ON			ON

Turn ON the PS and adjust the shunt field current I_F until the output voltage of the generator is 120 V. The output current must be approximately 1 A. Record the values of voltage and currents in the Data table. The value of the field current is nominal at the rated power output (120 V, 1A, 120 W) of the DC generator. Start the oscilloscope to observe the generator voltage as a function of time. Set the oscilloscope to read the E_1 channel in (important!) the **AC** mode, **2**V/div, **50** ms/div. Save the oscilloscope data in a text file.

8) Adjust the load resistance to obtain each of the values listed in Table 08-1 while maintaining the nominal field current found in Part 7. Record armature voltage and current and the field current in your data table for each load resistance. *Note: although the nominal output current rating of the generator is 1 A, it may be overloaded by 50 % without any harm.*

9) With the load resistance of 75 **Ω**, turn the field current OFF by setting the voltage by the PS to zero. Do you notice that the driving motor seems to work harder when the generator is delivering power to the load?

10) Construct the circuit implementing the DC self-excited shunt generator as shown in Figure 08-4. Place the resistance switches to the no-load positions. Turn the DC generator field rheostat control knob to its utmost clockwise position for minimum resistance.

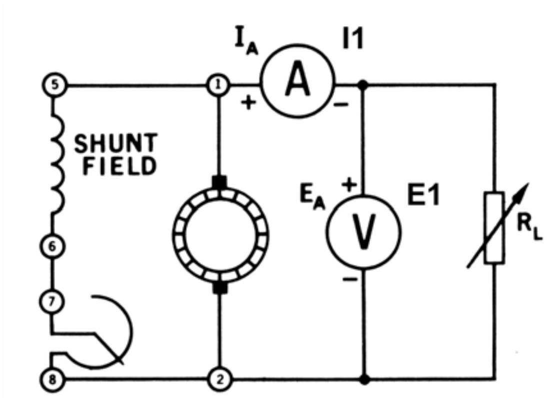

Figure 08-4

11) Turn ON the PS. The synchronous motor should start running. Notice if the armature voltage E_A builds up. If not, turn OFF the PS and interchange the shunt field leads at terminals *5* and *6*. Vary the field rheostat and notice if the armature voltage changes.

12) Set up the load resistance to 120 Ω and adjust the field rheostat until the generator delivers the output voltage of 120 V. Consult with your instructor if 120 V cannot be reached (the generator brushes may need adjustment). The armature current must be approximately 1 A. Once the rated voltage and current are delivered to the load, the correct setting for the field rheostat is achieved. Do not readjust the field rheostat for the remainder of the experiment with self-excited generator!

13) Adjust the load resistance switches to obtain each of the values listed in Table 08-1. Record the values of armature voltage, armature current, and power delivered to the load in a new Data table. Turn OFF the PS.

14) Reverse the rotation of the driving motor by interchanging any two of the stator lead connections (terminals 1, 2, or 3) to the synchronous motor. Remove the generator's load. Turn ON the PS. Does the generator voltage build up?

15) Construct the circuit implementing the DC compound generator as shown in Figure 08-5. Place the resistance switches to the no-load (all switches open) positions. Turn the DC generator field rheostat control knob to its utmost clockwise position for minimum resistance.

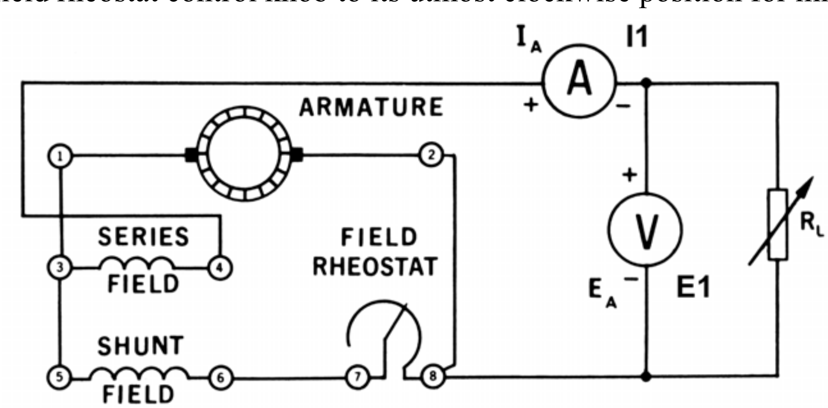

Figure 08-5

16) Turn ON the PS. The synchronous motor should start running. Notice if the armature voltage builds up. If not, turn OFF the PS and reverse the direction of rotation of the motor by interchanging any two of the stator connection leads. Turn ON the PS, vary the field rheostat and notice whether the armature voltage changes.

17) Adjust the field rheostat for the no-load armature voltage of 120 V. Do not readjust the field rheostat while doing Part 18!

18) Adjust the load resistance switches to obtain each of the values listed in Table 08-1. Record the values of armature voltage, armature current, and power delivered to the load in your Data table. Turn OFF the PS.

19) Interchange the connections to the series field only (terminals 3 and 4) such that the armature current flows through it in the opposite direction. Have your instructor to check your circuit.

20) Turn ON the PS. Adjust the field rheostat for the no-load armature voltage of 120 V. Do not readjust the field rheostat while doing Part 21!

21) Adjust the load resistance switches to obtain each of the values listed in Table 08-1. Record the values of armature voltage, armature current, and power delivered to the load in your Data table. Turn OFF the PS.

22) Using two Variable resistance modules, construct the circuit implementing the DC series generator as shown in Figure 08-6. Place the resistance switches to the no-load (all switches open) positions.

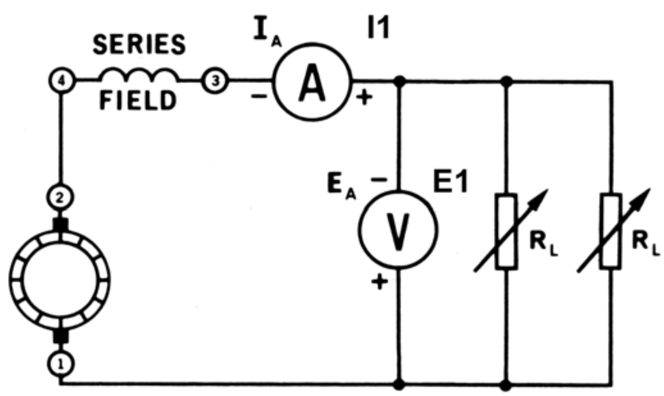

Figure 08-6

23) Turn ON the PS. The synchronous motor should be running. Do you observe any output voltage across the open load circuit?

24) Place a 28.5 Ω load in the circuit by closing **all** of the resistance switches on **both** resistance modules and note whether the armature voltage increases. If not, turn OFF the PS and interchange the series field leads at terminals *3* and *4*.

25) Adjust the load resistance switches to obtain each of the values listed in Table 08-2. Record the values of armature voltage, armature current, and power delivered to the load in your Data table. Turn OFF the PS. Disconnect your circuit.

Table 08-2

R_L,Ω	1200	600	300	1200	600	300	1200	600	300	1200	600	300	1200	600	300	1200	600	300
∞																		
40.0	ON		ON	ON		ON	ON		ON	ON		ON	ON		ON	ON		ON
37.5		ON	ON		ON	ON		ON	ON		ON	ON			ON			ON
35.3		ON	ON		ON	ON		ON	ON		ON	ON		ON	ON			ON
33.3		ON	ON		ON	ON		ON	ON		ON	ON		ON	ON		ON	ON
31.6	ON	ON	ON	ON	ON	ON		ON	ON		ON	ON		ON	ON		ON	ON
30.0	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON		ON	ON		ON	ON
28.5	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON

In your report:

1) Using Matlab and the data collected in Part 4, plot the armature voltage E_A vs. the field current I_F characteristic curve for the shunt generator. Is this graph linear? Are there any reasons for non-linearity?

2) For the data collected in Part 5, did you observe a change of polarity of the armature voltage as a result of polarity change of the shunt field? Was the armature voltage approximately the same as in Part 4? Discuss possible sources of discrepancy.

3) For the data collected in Part 6, did you observe a change of polarity of the armature voltage as a result of change of the direction of rotation? Was the armature voltage approximately the same as in Part 4? Discuss possible sources of discrepancy.

4) Report the nominal value of the field current you found in Part 7 for the separately excited shunt generator. Load the oscilloscope data you collected in Part 7 to Matlab and plot (include it in your report) the armature voltage E_A as a function of time. What do you conclude about the generated voltage?

5) Using Matlab and the data collected in Part 8, plot the armature voltage E_A vs. the armature current I_A regulation curve for the DC separately excited shunt generator. Calculate and plot on separate axes the power delivered to the load vs. the load resistance.

6) Calculate and report the regulation from no-load to full-load (1 A) using the data collected in Part 8 for the separately excited shunt generator.

7) Using Matlab and the data collected in Part 13, plot the armature voltage E_A vs. the armature current I_A regulation curve for the DC self-excited shunt generator.

8) Calculate and report the regulation from no-load to full-load (1 A) using the data collected in Part 13 for the self-excited shunt generator. Compare it to the regulation of the separately excited shunt generator. What do you conclude?

9) Did you observe any considerable generator voltage build up when the direction of rotation was reversed in Part 14? Explain.

10) Using Matlab and the data collected in Part 18, plot the armature voltage E_A vs. the armature current I_A regulation curve for the DC compound generator.

11) Calculate and report the regulation from no-load to full-load (1 A) using the data collected in Part 18 for the DC compound generator.

12) Using Matlab and the data collected in Part 21, plot the armature voltage E_A vs. the armature current I_A regulation curve for the DC compound generator. Which of the compound generators (Part 18 or Part 21) was a **differential** compound generator? Why?

13) Using Matlab and the data collected in Part 25, plot the armature voltage E_A vs. the armature current I_A regulation curve for the DC series generator. To what do you attribute the open circuit voltage observed in Parts 23 and 25?

14) Calculate and report the regulation from no-load to full-load (1 A) using the data collected in Part 25 for the DC series generator.

15) Compare the characteristics of the DC generators studied in this laboratory exercise:
    a) Separately excited shunt generator;
    b) Self-excited shunt generator;
    c) Compound generator;
    d) Differential compound generator;
    e) Series generator.