LABORATORY SESSION 6
DC GENERATOR LOAD CHARACTERISTICS

Dynamometer is used as a DC Generator in this experiment   Three-phase motor is used as a prime mover

CAUTION: High voltages are present in this Laboratory Experiment! Do not make any connections with the power on! The power must be turned off before the circuit is modified.

PURPOSE

The purpose of this experiment is to obtain the load characteristics of separately-excited and self-excited dc generators, to show how compounding may be used to improve the voltage regulation and to obtain the generator efficiency.

DISCUSSION

One of the advantages of dc machines arise from the wide variety of operating characteristics which can be obtained by selection of the method of excitation of the field windings. The field windings may be separately excited from an external dc source, or they may be self-excited, i.e., the machine may supply its own excitation.

The field current in a generator produces an mmf, which results in the field flux in accordance with the magnetization curve. When the machine is driven by a prime mover an emf is induced in the armature. The internal generated emf of a dc generator is given by

$$E_a = K\omega\phi \qquad (6.1)$$

where ω is the speed in radian per second. When the machine is loaded the armature current creates a flux whose axis is fixed at 90 electrical degrees from the main-field axis by the brush position. This flux interacts with the field flux to produce a unidirectional torque given by

$$T = KI_a\phi \qquad (6.2)$$

The armature mmf distorts the flux density distribution (cross magnetizing effect) and also produces the demagnetizing effect. This is called armature reaction. The armature reaction causes poor commutation leading to sparking, especially when the armature current changes rapidly. To overcome this difficulty, dc machines are sometimes fitted with compensating windings. These take the form of conductors embedded in slots in the field pole faces; they are connected in series with the armature, but carry current in opposite direction so as to cancel the armature reaction flux. In addition, the voltage in the coils undergoing commutation can be

canceled by providing commutating poles or inter-poles. The inter-poles are placed midway between the main poles and their windings are connected in series with the armature. An important generator characteristic is the effect that varying the load current has on the terminal voltage. The relation between the generated emf E_a and the terminal voltage V is given by

$$V = E_a - R_a I_a \qquad\qquad\qquad (6.3)$$

The terminal voltage of a separately excited generator (Figure 6.1) decreases slightly with increase in the load current, principally by the $R_a I_a$ drop. Since the internal generated voltage is independent of I_a, if saturation is neglected, E_a is constant and the terminal voltage characteristic of the separately excited generator is a straight line. However, when measuring the terminal voltage for a real machine, it is noted that the drop is slightly greater than $R_a I_a$. This is due to the fact that an increase in I_a causes an increase in armature reaction, and armature reaction causes flux weakening. From (6.1) it is seen that this flux weakening causes a decrease in E_a.

The terminal characteristic of a dc shunt generator differs from that of a separately excited dc generator, because the amount of field current in the machine depends on its terminal voltage. The terminal voltage will decrease with an increase in load because of the armature $R_a I_a$ drop and the armature reaction. However, when V decreases, the field current in the machine decreases with it. This causes the flux in the machine to decrease, decreasing E_a, thereby causing the terminal voltage to drop still further. If the load is increased excessively and in an extreme case when the terminal voltage is short-circuited ($V = 0$), the field current

($I_f = V / R_f$) is zero and the field will collapse. Under this condition, there will be no generated emf except for a small voltage E_r due to the residual flux, resulting in a small circulating current given by E_r / R_a. Therefore, the dc generator is self-protected against a short circuit at its terminals.

In the series generator the field is connected in series with the armature and since it carries the armature current it is designed to have only a very few turns of wire, and the wire used is much thicker than the wire in the shunt field.

A series generator that is operated at no-load develops a small terminal voltage proportional to the residual flux. As the load increases, the field current rises, so E_a rises rapidly. The $(R_a + R_s)I_a$ drop goes up too, but at first the increase in E_a goes up more rapidly than the $(R_a + R_s)I_a$ drop rises, so V increases. After a while, the machine approaches saturation, and E_a becomes almost constant. At that point, the resistive drop is the predominant effect, and V starts to fall. Series generators are used only in a few specialized applications, where the steep voltage characteristic of the device can be exploited. One such application is arc welding.

A dc machine that has both the shunt and series windings is known as a compound dc machine. If the fluxes of the two coils aid each other, the machine is said to be cumulatively compounded. If the fluxes in the two coils oppose each other, the generator is said to be differentially compounded. Further, if there is enough turns of the series windings, so that the full-load voltage is greater than the no-load voltage, the generator is overcompounded.   If the series turns are such a number that the no-load voltage is the same as the full-load voltage, the generator is

flat compounded. If the turns are such that the full-load voltage is less than the no-load voltage, the generator is undercompounded.   A flat compounded generator would provide a nearly constant voltage at the generator terminals.

DC generators are compared by their voltage ratings, power ratings, efficiencies, and voltage regulations. The voltage regulation of a dc generator is the percent change in terminal voltage from no-load to rated load, with respect to rated voltage.

$$VR = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100 \qquad (6.4)$$

where V_{nl} is the no-load terminal voltage of the generator and V_{fl} is the full-load terminal voltage of the generator.

The efficiency of the generator is given by

$$\eta = \frac{P_o}{P_i} \times 100 \qquad (6.5)$$

In the case of generator output power is electrical and is given by

$$P_o = VI_L \qquad (6.6)$$

where I_L is the load current. For shunt and compound generator $I_L = I_a - I_f$.

The input power is computed from the measurement of the dynamometer as follows:

$$T = \text{Pull (Kg)} \times 9.81 \times \text{Arm radius (0.305m)} \quad \text{N-m N-m} \qquad (6.7)$$

$$P_i = \omega T \quad \text{Watts} \qquad (6.8)$$

where ω is speed in Rad/sec given by $\omega = \frac{2\pi n}{60}$, n is speed in RPM.

PROCEDURE

1. Separately-excited generator

Drive the dc generator at constant speed by means of the synchronous reluctance motor. Connect the synchronous reluctance motor to the 3-phase 208 V supply through a manual ac starter as shown. Place an ac ammeter in one phase. Because of the high starting current a toggle switch shorts the ammeter during starting. This ammeter indicates the current drawn by the ac motor. During the test observe this meter so as <u>not to exceed the rated current of the ac motor</u>.
Separately excite the dc generator by connecting the dc shunt field through a dc ammeter, a rheostat and a pushbutton switch to the 120 V dc source. Connect the 120 V resistor bank in series with a dc ammeter across the armature and use a dc voltmeter to measure the terminal voltage. Zero the dynamometer scale. The ac ammeter is provided with a bypass toggle switch, press the switch to read the ammeter. Turn on the ac power and start the ac motor. Turn on the dc power and adjust the open-circuit voltage to 80 V. With the load bank off record in Table I the field current I_f , armature current ($I_a = I_L$), the terminal voltage V , speed n , and the dynamometer pull. Now, without changing the field rheostat, load the generator using the load

bank and repeat the measurements as each load is switched on. You may load the dynamometer up to 9 A for a short time if readings are taken quickly.
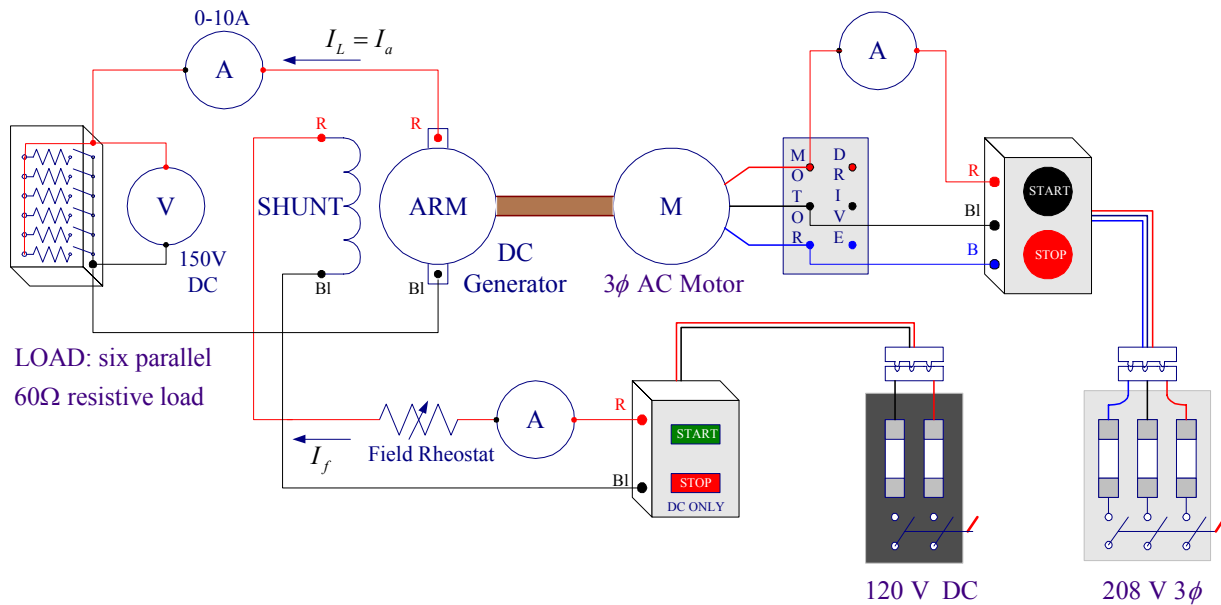

Figure 6.1 ac motor and dc generator connections

Table I Separately excited generator

Measured Data					Calculated Data				
V	I_a	I_f	n	Pull	$I_L = I_a$	$P_0 = VI_L$	Torque	$P_i = \omega T$	η
Volts	Amps	Amps	RPM	Kg	Amps	Watts	N-m	Watts	Percent

Evaluate the calculated data and enter in Table I.

CAUTION: TURN OFF POWER BEFORE MAKING ANY CHANGES

2. Self-excited shunt generator

Disconnect the dc generator shunt field from the power supply and connect it to the armature terminals as shown in Figure 6.2.
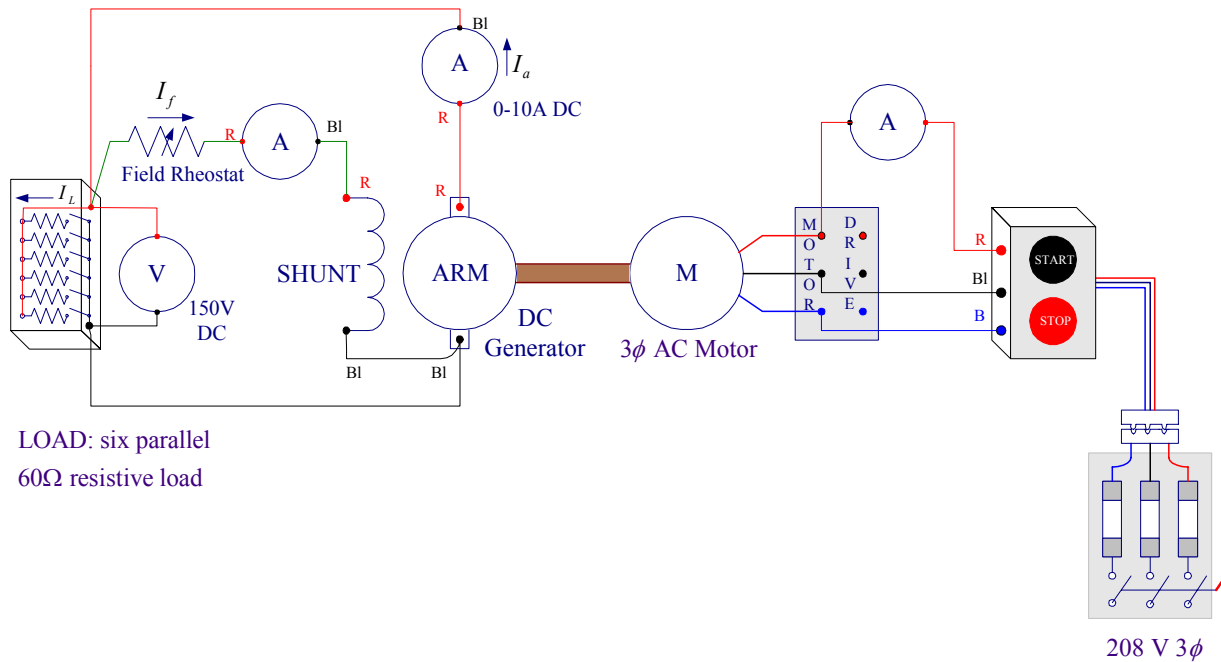
Figure 6.2   Circuit for self-excited shunt generator

Start the ac motor. Adjust the field rheostat for the same no-load generated emf as before (80 V), and record the measurements in Table II. Without any further adjustment of the field rheostat load the generator steadily and record all measurements for each load in Table II.
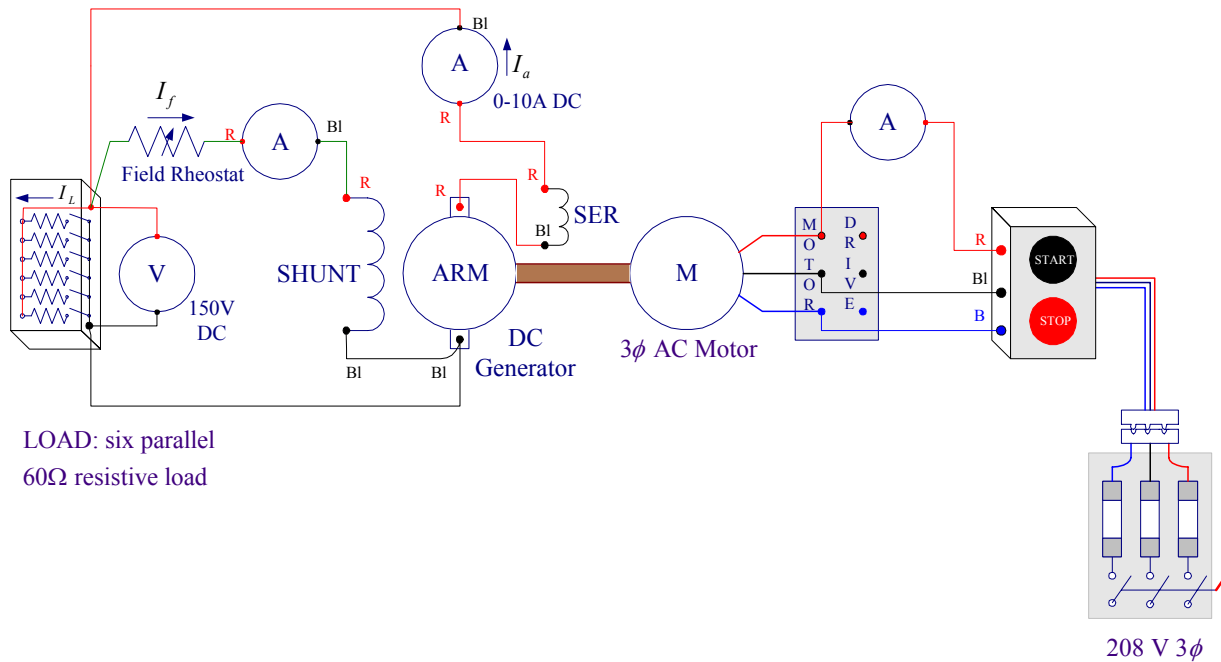
Table II Self-excited Shunt-excited generator

Measured Data					Calculated Data				
V	I_a	I_f	n	Pull	$I_L = I_a - I_f$	$P_0 = VI_L$	Torque	$P_i = \omega T$	η
Volts	Amps	Amps	RPM	Kg	Amps	Watts	N-m	Watts	Percent

Turn the power off. Evaluate the calculated data and enter in Table II.

3. Self-excited cumulatively-compound generator

Connect the dc generator for long-shunt cumulatively compound operation as shown in Figure 6.3.

Figure 6.3 Circuit for self-excited long-shunt compound generator

Start the motor. Adjust the field rheostat for the same no-load generated emf as before (80 V), and record the measurements in Table III. Without any further adjustment of the field rheostat load the generator steadily and record all measurements for each load in Table III.

Table III Long shunt Cumulatively compound dc generator

Measured Data					Calculated Data				
V	I_a	I_f	n	Pull	$I_L = I_a - I_f$	$P_0 = VI_L$	Torque	$P_i = \omega T$	η
Volts	Amps	Amps	RPM	Kg	Amps	Watts	N-m	Watts	Percent

Turn the power off. Evaluate the calculated data and enter in Table III.

4. Self-excited differentially compound generator

Connect the dc generator for long-shunt differentially compound operation by reversing the series field connections. Start the motor. Adjust the field rheostat for the same no-load generated emf as before (80 V), and record the measurements in Table IV. Without any further adjustment of the field rheostat load the generator steadily and record all measurements for each load in Table IV. <u>Do not exceed the ac motor rated current</u>.

Table IV Long shunt Differentially compound dc generator

Measured Data					Calculated Data				
V	I_a	I_f	n	Pull	$I_L = I_a - I_f$	$P_0 = VI_L$	Torque	$P_i = \omega T$	η
Volts	Amps	Amps	RPM	Kg	Amps	Watts	N-m	Watts	Percent

Turn the power off. Evaluate the calculated data and enter in Table IV.

5. Series generator

Connect the series field in series with the armature as shown in Figure 6.4. Add a 5Ω, 1000W resistor in parallel with the resistor load bank for additional load. If you are using the starting resistor for this purpose, make sure the switch is in the in position and do not switch to the position that replaces the resistor with a short circuit. For light loading you must physically remove the 5Ω resistor out of the circuit. Start the motor and load the generator steadily and record all measurements for each load in Table V. <u>Do not exceed the ac motor rated current</u>.

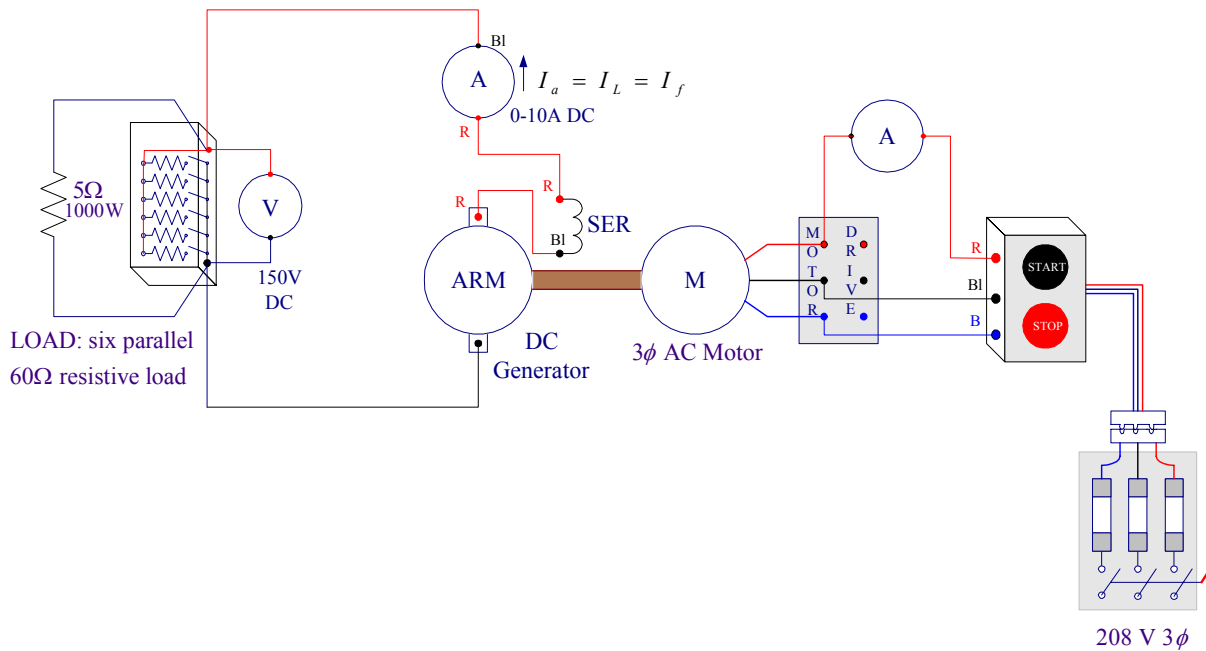Turn the power off. Evaluate the calculated data and enter in Table V.

Figure 6.4 Circuit for series generator

Table V Series dc generator

Measured Data					Calculated Data				
V	I_a	$I_f = I_a$	n	Pull	$I_L = I_a$	$P_0 = VI_L$	Torque	$P_i = \omega T$	η
Volts	Amps	Amps	RPM	Kg	Amps	Watts	N-m	Watts	Percent

Turn the power off. Evaluate the calculated data and enter in Table V.

6. Resistance Measurements

Disconnect all circuits. Using an ohmmeter, measure the armature resistance, shunt field resistance, and the series field resistance of the dc generator.

7. Use **ee340lab6** function as explained in the Appendix to check your computed data.

REPORT

1. Using (6.4) determine the percentage voltage regulation at full-load for each type of connection except the differential compound. For the purpose of this experiment, assume that the full-load current of the dc generator is about 6 A. For the separately excited generator, using (6.3) and the measured terminal voltage at full-load compute the no-load generated voltage E_a and compare with the measured no-load generated voltage. How many volts difference are there and what is the reason for this difference?
2. Plot terminal voltage versus armature current on one graph paper for each type of connection. Explain the theoretical basis for the shape of all the curves. List all effects, if any that tend to cause the terminal voltage to decrease with load. Why does the terminal voltage fall so rapidly with simple shunt excitation? Why does the terminal voltage of the series generator rise with increase in load?
3. Using (6.5)-(6.8) compute and tabulate the power output, torque, the power input and efficiency of the generator for each type of connection. Include a sample calculation. Plot efficiency versus the power output for each connection. You may use the MATLAB commands to verify your calculations and obtain the required plots.

Appendix

In MATLAB, from **F**ile/**N**ew/**M**-File, open the MATLAB Editor. Enter the data for the separately excited dc generator in the $n \times 5$ matrix named Sep. Each column represents a variable that must be entered in the order shown below. Enter the data for the remaining cases. Use the function named **ee340lab6** as indicated below to obtain the calculated data and the required plots. The function **ee340lab6** has been added to the MATLAB available on the MSOE network. If you have your own MATLAB student version you may download this function to your Laptop.

```
%           V        Ia       If      n        Pull
Sep =     [
                                              ];

%          V        Ia       If      n        Pull
Shunt =    [
                                              ];

%          V        Ia       If      n        Pull
CumComp = [
                                              ];

%          V        Ia       If      n        Pull
DiffComp =[
                                              ];

%          V        Ia       If      n        Pull
Series =  [
                                              ];
ee340lab6(Sep, Shunt, CumComp, DiffComp, Series)
```

Once you have finished entering all the data save with a file name having extension m and run at the MATLAB prompt.