

- 8-15. What is the purpose of a field loss relay?
- 8-16. What types of protective features are included in typical solid-state dc motor drives? How do they work?
- 8-17. How can the direction of rotation of a separately excited dc motor be reversed?
- 8-18. How can the direction of rotation of a shunt dc motor be reversed?
- 8-19. How can the direction of rotation of a series dc motor be reversed?
- 8-20. Name and describe the features of the five types of generators covered in this chapter.
- 8-21. How does the voltage buildup occur in a shunt dc generator during starting?
- 8-22. What could cause voltage buildup on starting to fail to occur? How can this problem be remedied?
- 8-23. How does armature reaction affect the output voltage in a separately excited dc generator?
- 8-24. What causes the extraordinarily fast voltage drop with increasing load in a differentially compounded dc generator?

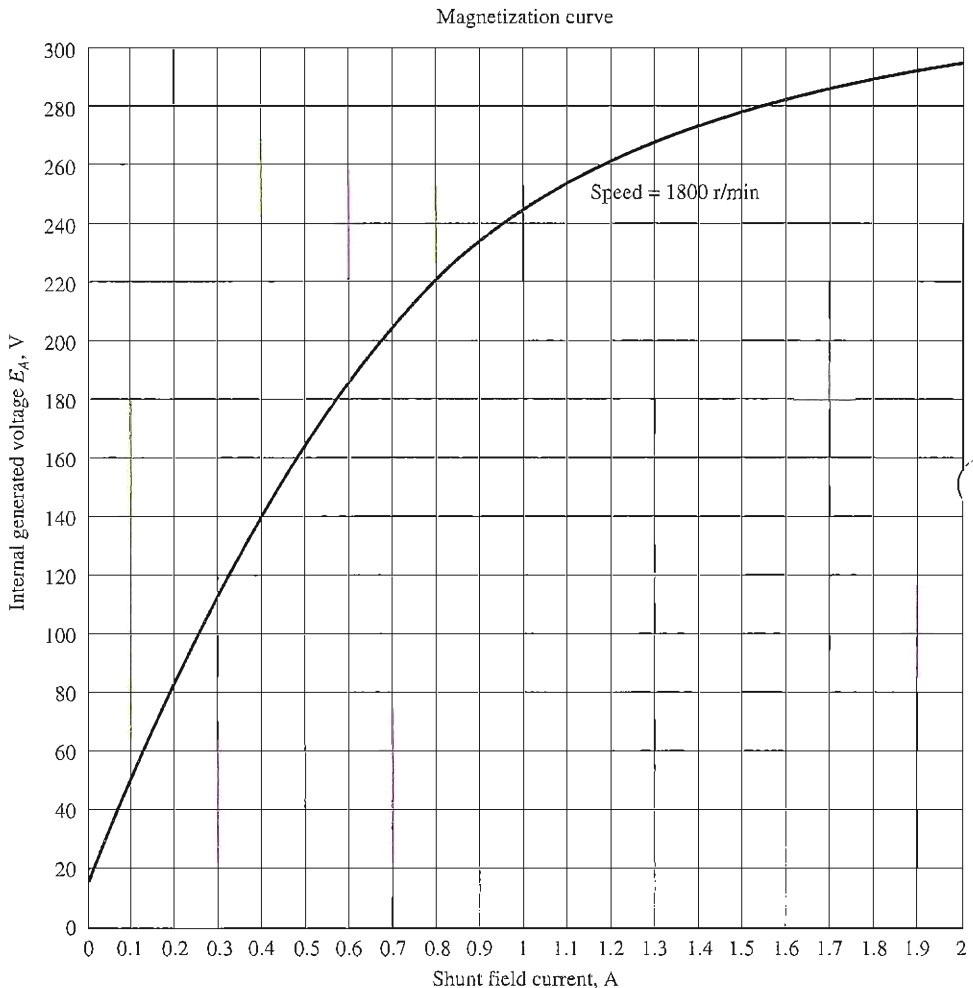
PROBLEMS

Problems 8-1 to 8-12 refer to the following dc motor:

$$\begin{aligned}
 P_{\text{rated}} &= 30 \text{ hp} & I_{L,\text{rated}} &= 110 \text{ A} \\
 V_T &= 240 \text{ V} & N_F &= 2700 \text{ turns per pole} \\
 n_{\text{rated}} &= 1800 \text{ r/min} & N_{SE} &= 14 \text{ turns per pole} \\
 R_A &= 0.19 \, \Omega & R_F &= 75 \, \Omega \\
 R_S &= 0.02 \, \Omega & R_{\text{adj}} &= 100 \text{ to } 400 \, \Omega \\
 \text{Rotational losses} &= 3550 \text{ W at full load.} \\
 \text{Magnetization curve} &\text{ is as shown in Figure P8-1.}
 \end{aligned}$$

In Problems 8-1 through 8-7, assume that the motor can be connected in shunt. The equivalent circuit of the shunt motor is shown in Figure P8-2.

- 8-1. If the resistor R_{adj} is adjusted to $175 \, \Omega$ what is the rotational speed of the motor at no-load conditions?
- 8-2. Assuming no armature reaction, what is the speed of the motor at full load? What is the speed regulation of the motor?
- 8-3. If the motor is operating at full load and if its variable resistance R_{adj} is increased to $250 \, \Omega$, what is the new speed of the motor? Compare the full-load speed of the motor with $R_{\text{adj}} = 175 \, \Omega$ to the full-load speed with $R_{\text{adj}} = 250 \, \Omega$. (Assume no armature reaction, as in the previous problem.)
- 8-4. Assume that the motor is operating at full load and that the variable resistor R_{adj} is again $175 \, \Omega$. If the armature reaction is $2000 \text{ A} \cdot \text{turns}$ at full load, what is the speed of the motor? How does it compare to the result for Problem 8-2?
- 8-5. If R_{adj} can be adjusted from 100 to 400 Ω , what are the maximum and minimum no-load speeds possible with this motor?
- 8-6. What is the starting current of this machine if it is started by connecting it directly to the power supply V_T ? How does this starting current compare to the full-load current of the motor?

**FIGURE P8-1**

The magnetization curve for the dc motor in Problems 8-1 to 8-12. This curve was made at a constant speed of 1800 r/min.

- 8-7.** Plot the torque-speed characteristic of this motor assuming no armature reaction, and again assuming a full-load armature reaction of $1200 \text{ A} \cdot \text{turns}$. (Assume that the armature reaction increases linearly with increases in armature current.)

For Problems 8-8 and 8-9, the shunt dc motor is reconnected separately excited, as shown in Figure P8-3. It has a fixed field voltage V_F of 240 V and an armature voltage V_A that can be varied from 120 to 240 V.

- 8-8.** What is the no-load speed of this separately excited motor when $R_{\text{adj}} = 175 \Omega$ and (a) $V_A = 120 \text{ V}$, (b) $V_A = 180 \text{ V}$, (c) $V_A = 240 \text{ V}$?

- 8-9.** For the separately excited motor of Problem 8-8:

(a) What is the maximum no-load speed attainable by varying both V_A and R_{adj} ?

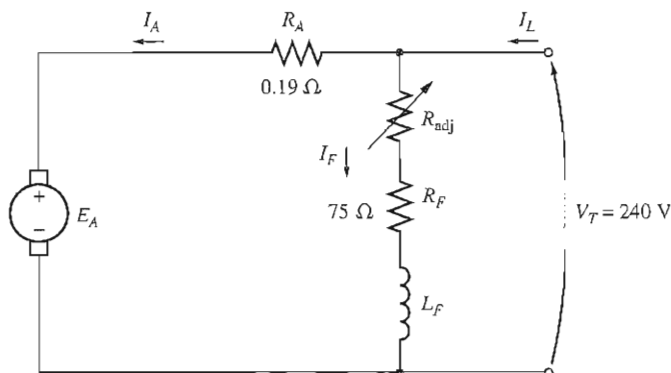


FIGURE P8-2

The equivalent circuit of the shunt motor in Problems 8-1 to 8-7.

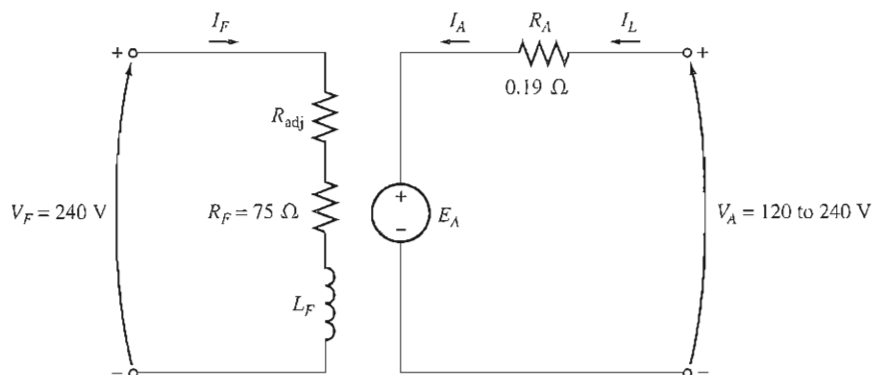


FIGURE P8-3

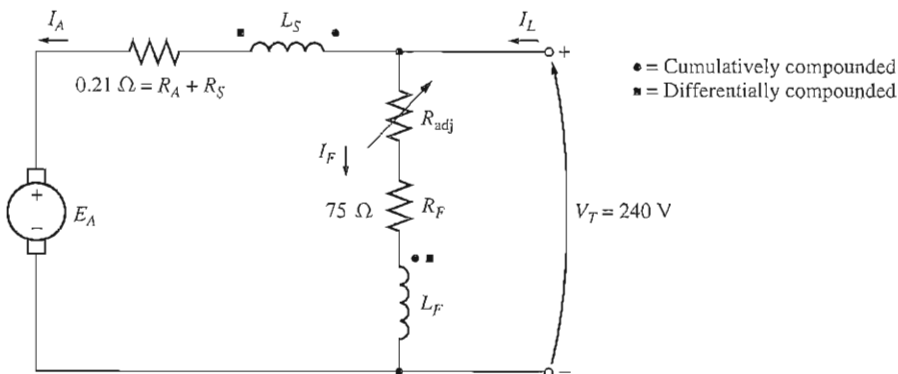
The equivalent circuit of the separately excited motor in Problems 8-8 and 8-9.

- (b) What is the minimum no-load speed attainable by varying both V_A and R_{adj} ?
- (c) What is the motor's efficiency at rated conditions? [Note: Assume that (1) the brush voltage drop is 2 V; (2) the core loss is to be determined at an armature voltage equal to the armature voltage under full load; and (3) stray load losses are 1 percent of full load.]

For Problems 8-10 to 8-11, the motor is connected cumulatively compounded as shown in Figure P8-4

8-10. If the motor is connected cumulatively compounded with $R_{adj} = 175 \Omega$:

- (a) What is its no-load speed of the motor?
- (b) What is its full-load speed of the motor?
- (c) What is its speed regulation?
- (d) Calculate and plot the torque-speed characteristic for this motor. (Neglect armature effects in this problem.)

**FIGURE P8-4**

The equivalent circuit of the compounded motor in Problems 8-10 to 8-12.

- 8-11. The motor is connected cumulatively compounded and is operating at full load. What will the new speed of the motor be if R_{adj} is increased to $250\ \Omega$? How does the new speed compare to the full-load speed calculated in Problem 8-10?

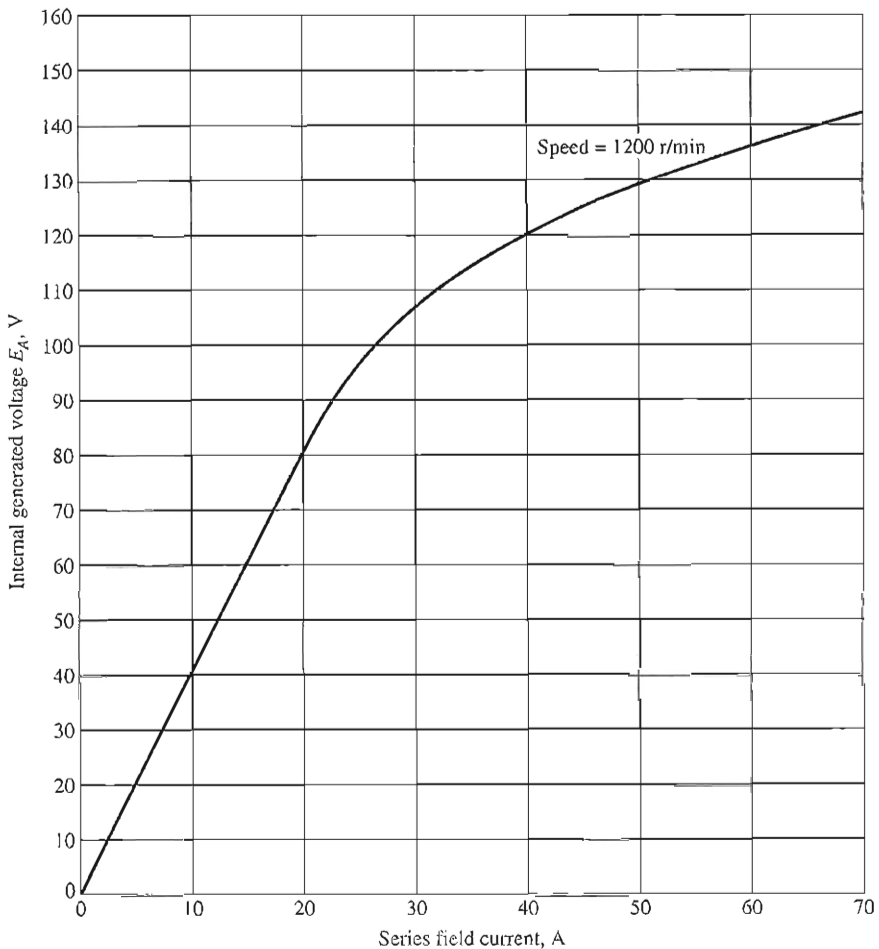
For Problem 8-12, the motor is now connected differentially compounded as shown in Figure P8-4.

- 8-12. The motor is now connected differentially compounded.
- If $R_{adj} = 175\ \Omega$, what is the no-load speed of the motor?
 - What is the motor's speed when the armature current reaches 20 A ? 40 A ? 60 A ?
 - Calculate and plot the torque-speed characteristic curve of this motor.
- 8-13. A 15-hp, 120-V series dc motor has an armature resistance of $0.1\ \Omega$ and a series field resistance of $0.08\ \Omega$. At full load, the current input is 115 A , and the rated speed is 1050 r/min . Its magnetization curve is shown in Figure P8-5. The core losses are 420 W , and the mechanical losses are 460 W at full load. Assume that the mechanical losses vary as the cube of the speed of the motor and that the core losses are constant.
- What is the efficiency of the motor at full load?
 - What are the speed and efficiency of the motor if it is operating at an armature current of 70 A ?
 - Plot the torque-speed characteristic for this motor.
- 8-14. A 20-hp, 240-V, 76-A, 900 r/min series motor has a field winding of 33 turns per pole. Its armature resistance is $0.09\ \Omega$, and its field resistance is $0.06\ \Omega$. The magnetization curve expressed in terms of magnetomotive force versus E_A at 900 r/min is given by the following table:

| $E_A, \text{ V}$ | 95 | 150 | 188 | 212 | 229 | 243 |
|--|-----|------|------|------|------|------|
| $\mathcal{F}, \text{ A} \cdot \text{ turns}$ | 500 | 1000 | 1500 | 2000 | 2500 | 3000 |

Armature reaction is negligible in this machine.

- Compute the motor's torque, speed, and output power at 33, 67, 100, and 133 percent of full-load armature current. (Neglect rotational losses.)
- Plot the terminal characteristic of this machine.

**FIGURE P8-5**

The magnetization curve for the series motor in Problem 8-13. This curve was taken at a constant speed of 1200 r/min.

8-15. A 300-hp, 440-V, 560-A, 863 r/min shunt dc motor has been tested, and the following data were taken:

Blocked-rotor test:

$$V_A = 14.9 \text{ V} \quad \text{exclusive of brushes}$$

$$V_F = 440 \text{ V}$$

$$I_A = 500 \text{ A}$$

$$I_F = 7.52 \text{ A}$$

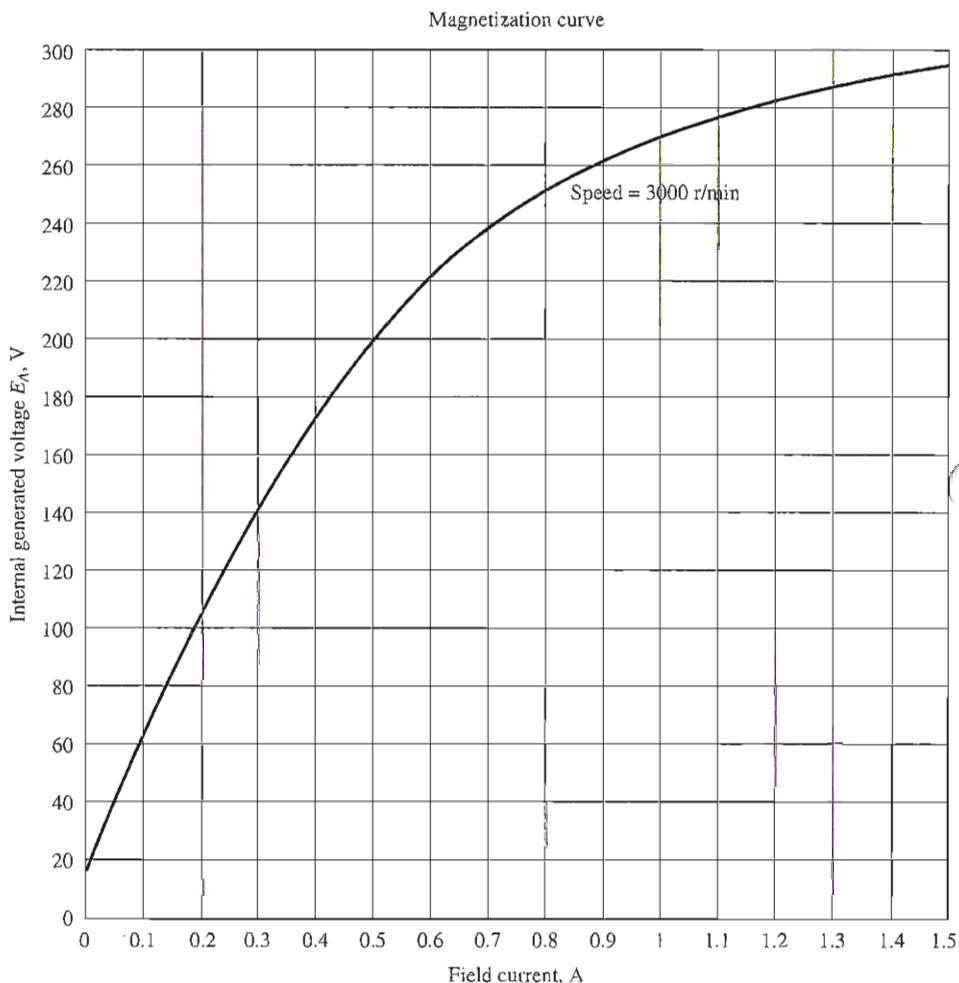
No-load operation:

$$V_A = 440 \text{ V} \quad \text{including brushes}$$

$$I_F = 7.50 \text{ A}$$

$$I_A = 23.1 \text{ A}$$

$$n = 863 \text{ r/min}$$

**FIGURE P8-6**

The magnetization curve for the dc motor in Problems 8-16 to 8-19. This curve was made at a constant speed of 3000 r/min.

What is this motor's efficiency at the rated conditions? [Note: Assume that (1) the brush voltage drop is 2 V; (2) the core loss is to be determined at an armature voltage equal to the armature voltage under full load; and (3) stray load losses are 1 percent of full load.]

Problems 8-16 to 8-19 refer to a 240-V, 100-A dc motor which has both shunt and series windings. Its characteristics are

$$R_A = 0.14 \, \Omega$$

$$R_S = 0.05 \, \Omega$$

$$R_F = 200 \, \Omega$$

$$R_{PB} = 0 \text{ to } 300 \, \Omega, \text{ currently set to } 120 \, \Omega$$

$$N_F = 1500 \text{ turns}$$

$$N_{SE} = 15 \text{ turns}$$

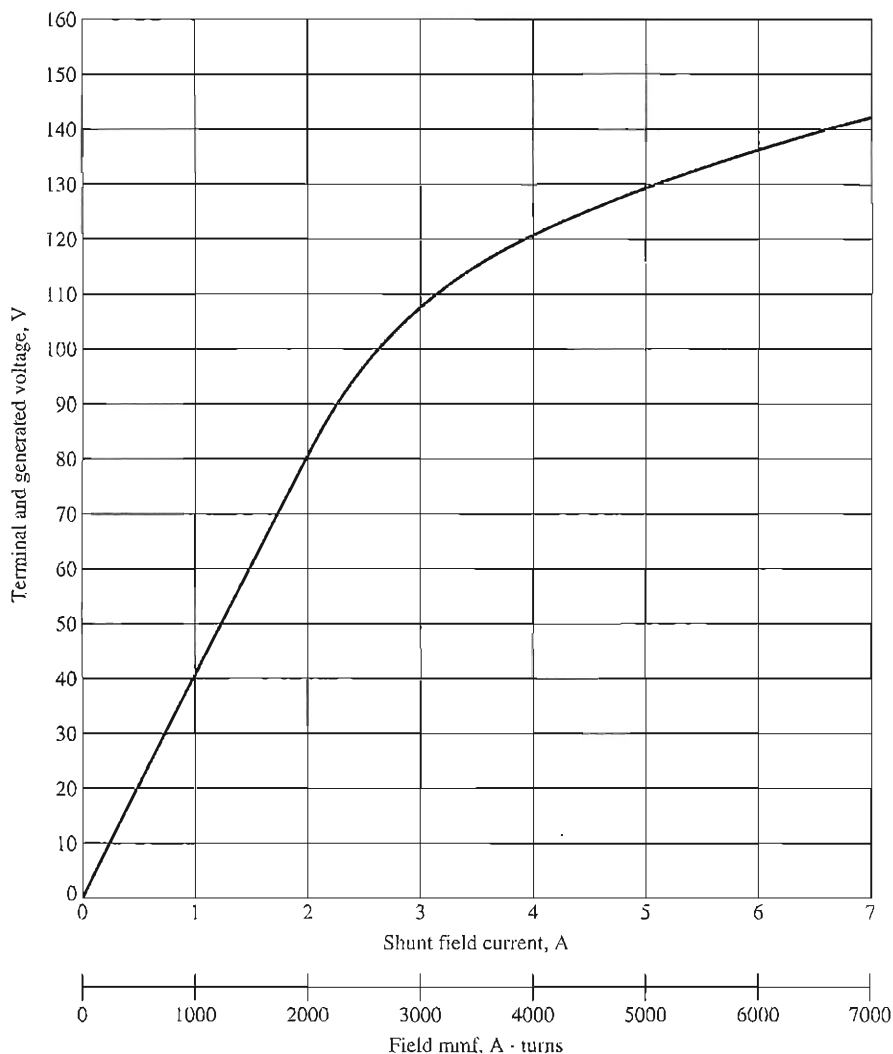
$$n_m = 3000 \text{ r/min}$$

This motor has compensating windings and interpoles. The magnetization curve for this motor at 3000 r/min is shown in Figure P8–6.

- 8–16. The motor described above is connected in *shunt*.
- What is the no-load speed of this motor when $R_{\text{adj}} = 120 \Omega$?
 - What is its full-load speed?
 - What is its speed regulation?
 - Plot the torque–speed characteristic for this motor.
 - Under no-load conditions, what range of possible speeds can be achieved by adjusting R_{adj} ?
- 8–17. This machine is now connected as a cumulatively compounded dc motor with $R_{\text{adj}} = 120 \Omega$.
- What is the no-load speed of this motor?
 - What is its full-load speed?
 - What is its speed regulation?
 - Plot the torque–speed characteristic for this motor.
- 8–18. The motor is reconnected differentially compounded with $R_{\text{adj}} = 120 \Omega$. Derive the shape of its torque–speed characteristic.
- 8–19. A series motor is now constructed from this machine by leaving the shunt field out entirely. Derive the torque–speed characteristic of the resulting motor.
- 8–20. An automatic starter circuit is to be designed for a shunt motor rated at 20 hp, 240 V, and 75 A. The armature resistance of the motor is 0.12Ω , and the shunt field resistance is 40Ω . The motor is to start with no more than 250 percent of its rated armature current, and as soon as the current falls to rated value, a starting resistor stage is to be cut out. How many stages of starting resistance are needed, and how big should each one be?
- 8–21. A 10-hp, 120-V, 1000 r/min shunt dc motor has a full-load armature current of 70 A when operating at rated conditions. The armature resistance of the motor is $R_A = 0.12 \Omega$, and the field resistance R_F is 40Ω . The adjustable resistance in the field circuit R_{adj} may be varied over the range from 0 to 200Ω and is currently set to 100Ω . Armature reaction may be ignored in this machine. The magnetization curve for this motor, taken at a speed of 1000 r/min, is given in the following table:

| | | | | | | |
|-----------------|------|------|------|------|------|------|
| E_A, V | 5 | 78 | 95 | 112 | 118 | 126 |
| I_F, A | 0.00 | 0.80 | 1.00 | 1.28 | 1.44 | 2.88 |

- What is the speed of this motor when it is running at the rated conditions specified above?
- The output power from the motor is 10 hp at rated conditions. What is the output torque of the motor?
- What are the copper losses and rotational losses in the motor at full load (ignore stray losses)?
- What is the efficiency of the motor at full load?
- If the motor is now unloaded with no changes in terminal voltage or R_{adj} , what is the no-load speed of the motor?
- Suppose that the motor is running at the no-load conditions described in part (e). What would happen to the motor if its field circuit were to open? Ignoring armature reaction, what would the final steady-state speed of the motor be under those conditions?
- What range of no-load speeds is possible in this motor, given the range of field resistance adjustments available with R_{adj} ?

**FIGURE P8-7**

The magnetization curve for Problems 8-22 to 8-28. This curve was taken at a speed of 1800 r/min.

- 8-22.** The magnetization curve for a separately excited dc generator is shown in Figure P8-7. The generator is rated at 6 kW, 120 V, 50 A, and 1800 r/min and is shown in Figure P8-8. Its field circuit is rated at 5 A. The following data are known about the machine:

$$R_A = 0.18 \, \Omega$$

$$V_F = 120 \, \text{V}$$

$$R_{\text{adj}} = 0 \text{ to } 40 \, \Omega$$

$$R_F = 20 \, \Omega$$

$$N_F = 1000 \text{ turns per pole}$$

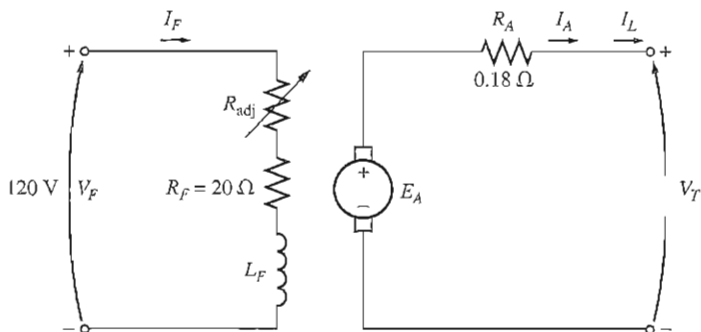


FIGURE P8-8

The separately excited dc generator in Problems 8-22 to 8-24.

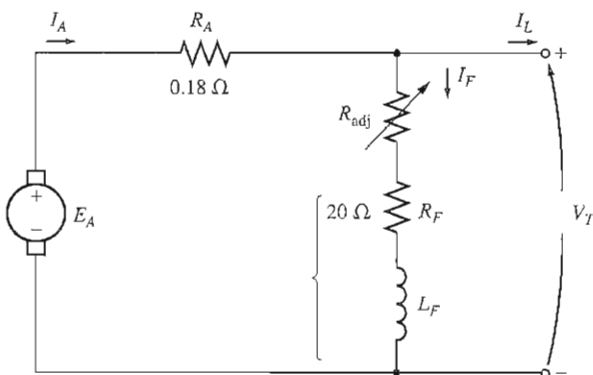
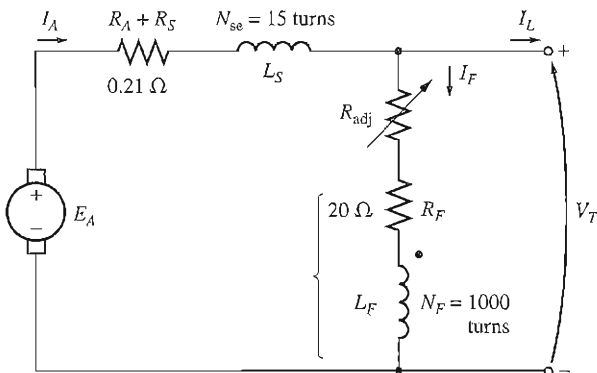


FIGURE P8-9

The shunt dc generator in Problems 8-25 and 8-26.

Answer the following questions about this generator, assuming no armature reaction.

- (a) If this generator is operating at no load, what is the range of voltage adjustments that can be achieved by changing R_{adj} ?
 - (b) If the field rheostat is allowed to vary from 0 to 30 Ω and the generator's speed is allowed to vary from 1500 to 2000 r/min, what are the maximum and minimum no-load voltages in the generator?
- 8-23. If the armature current of the generator in Problem 8-22 is 50 A, the speed of the generator is 1700 r/min, and the terminal voltage is 106 V, how much field current must be flowing in the generator?
- 8-24. Assuming that the generator in Problem 8-22 has an armature reaction at full load equivalent to 400 A \cdot turns of magnetomotive force, what will the terminal voltage of the generator be when $I_F = 5$ A, $n_m = 1700$ r/min, and $I_A = 50$ A?
- 8-25. The machine in Problem 8-22 is reconnected as a shunt generator and is shown in Figure P8-9. The shunt field resistor R_{adj} is adjusted to 10 Ω , and the generator's speed is 1800 r/min.

**FIGURE P8-10**

The compounded dc generator in Problems 8-27 and 8-28.

- (a) What is the no-load terminal voltage of the generator?
 - (b) Assuming no armature reaction, what is the terminal voltage of the generator with an armature current of 20 A? 40 A?
 - (c) Assuming an armature reaction equal to 300 A • turns at full load, what is the terminal voltage of the generator with an armature current of 20 A? 40 A?
 - (d) Calculate and plot the terminal characteristics of this generator with and without armature reaction.
- 8-26.** If the machine in Problem 8-25 is running at 1800 r/min with a field resistance $R_{adj} = 10 \Omega$ and an armature current of 25 A, what will the resulting terminal voltage be? If the field resistor decreases to 5Ω while the armature current remains 25 A, what will the new terminal voltage be? (Assume no armature reaction.)
- 8-27.** A 120-V, 50-A, cumulatively compounded dc generator has the following characteristics:

$$R_A + R_S = 0.21 \Omega$$

$$R_F = 20 \Omega$$

$$R_{adj} = 0 \text{ to } 30 \Omega, \text{ set to } 10 \Omega$$

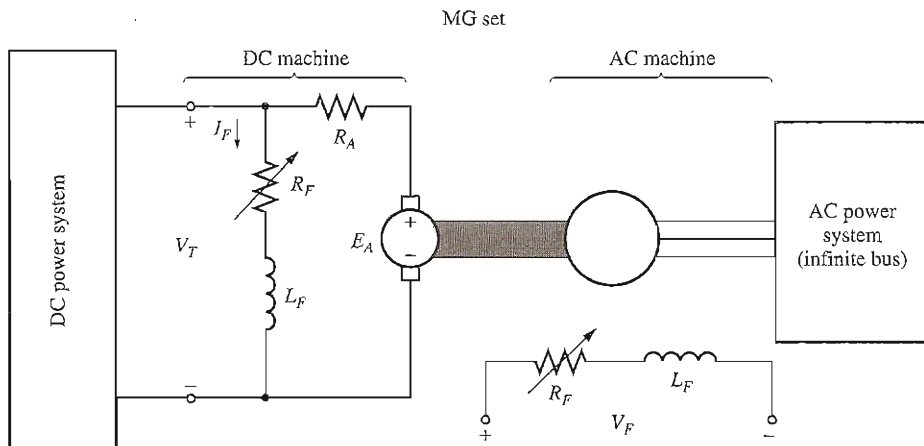
$$N_F = 1000 \text{ turns}$$

$$N_{se} = 25 \text{ turns}$$

$$n_m = 1800 \text{ r/min}$$

The machine has the magnetization curve shown in Figure P8-7. Its equivalent circuit is shown in Figure P8-10. Answer the following questions about this machine, assuming no armature reaction.

- (a) If the generator is operating at no load, what is its terminal voltage?
 - (b) If the generator has an armature current of 20 A, what is its terminal voltage?
 - (c) If the generator has an armature current of 40 A, what is its terminal voltage?
 - (d) Calculate and plot the terminal characteristic of this machine.
- 8-28.** If the machine described in Problem 8-27 is reconnected as a differentially compounded dc generator, what will its terminal characteristic look like? Derive it in the same fashion as in Problem 8-27.
- 8-29.** A cumulatively compounded dc generator is operating properly as a flat-compounded dc generator. The machine is then shut down, and its shunt field connections are reversed.

**FIGURE P8-11**

The motor-generator set in Problem 8-30.

- If this generator is turned in the same direction as before, will an output voltage be built up at its terminals? Why or why not?
- Will the voltage build up for rotation in the opposite direction? Why or why not?
- For the direction of rotation in which a voltage builds up, will the generator be cumulatively or differentially compounded?

8-30. A three-phase synchronous machine is mechanically connected to a shunt dc machine, forming a motor-generator set, as shown in Figure P8-11. The dc machine is connected to a dc power system supplying a constant 240 V, and the ac machine is connected to a 480-V, 60-Hz infinite bus.

The dc machine has four poles and is rated at 50 kW and 240 V. It has a per-unit armature resistance of 0.03. The ac machine has four poles and is Y-connected. It is rated at 50 kVA, 480 V, and 0.8 PF, and its saturated synchronous reactance is 3.0 Ω per phase.

All losses except the dc machine's armature resistance may be neglected in this problem. Assume that the magnetization curves of both machines are linear.

- Initially, the ac machine is supplying 50 kVA at 0.8 PF lagging to the ac power system.
 - How much power is being supplied to the dc motor from the dc power system?
 - How large is the internal generated voltage E_A of the dc machine?
 - How large is the internal generated voltage E_A of the ac machine?
- The field current in the ac machine is now decreased by 5 percent. What effect does this change have on the real power supplied by the motor-generator set? On the reactive power supplied by the motor-generator set? Calculate the real and reactive power supplied or consumed by the ac machine under these conditions. Sketch the ac machine's phasor diagram before and after the change in field current.

- (c) Starting from the conditions in part (b), the field current in the dc machine is now decreased by 1 percent. What effect does this change have on the real power supplied by the motor-generator set? On the reactive power supplied by the motor-generator set? Calculate the real and reactive power supplied or consumed by the ac machine under these conditions. Sketch the ac machine's phasor diagram before and after the change in the dc machine's field current.
- (d) From the preceding results, answer the following questions:
1. How can the real power flow through an ac-dc motor-generator set be controlled?
 2. How can the reactive power supplied or consumed by the ac machine be controlled without affecting the real power flow?

REFERENCES

1. Chaston, A. N.: *Electric Machinery*, Reston Publications, Reston, Va., 1986.
2. Fitzgerald, A. E., and C. Kingsley, Jr.: *Electric Machinery*, McGraw-Hill, New York, 1952.
3. Fitzgerald, A. E., C. Kingsley, Jr., and S. D. Umans: *Electric Machinery*, 6th ed., McGraw-Hill, New York, 2003.
4. Heck, C.: *Magnetic Materials and Their Applications*, Butterworth & Co., London, 1974.
5. IEEE Standard 113-1985, *Guide on Test Procedures for DC Machines*, IEEE, Piscataway, N.J., 1985. (Note that this standard has been officially withdrawn but is still available.)
6. Kloeffer, S. M., R. M. Kerchner, and J. L. Brenneman: *Direct Current Machinery*, rev. ed. Macmillan, New York, 1948.
7. Kosow, Irving L.: *Electric Machinery and Transformers*, Prentice Hall, Englewood Cliffs, N.J., 1972.
8. McPherson, George: *An Introduction to Electrical Machines and Transformers*, Wiley, New York, 1981.
9. Siskind, Charles S.: *Direct-Current Machinery*, McGraw-Hill, New York, 1952.
10. Slemon, G. R., and A. Straughen. *Electric Machines*, Addison-Wesley, Reading, Mass., 1980.
11. Werninck, E. H. (ed.): *Electric Motor Handbook*, McGraw-Hill, London, 1978.