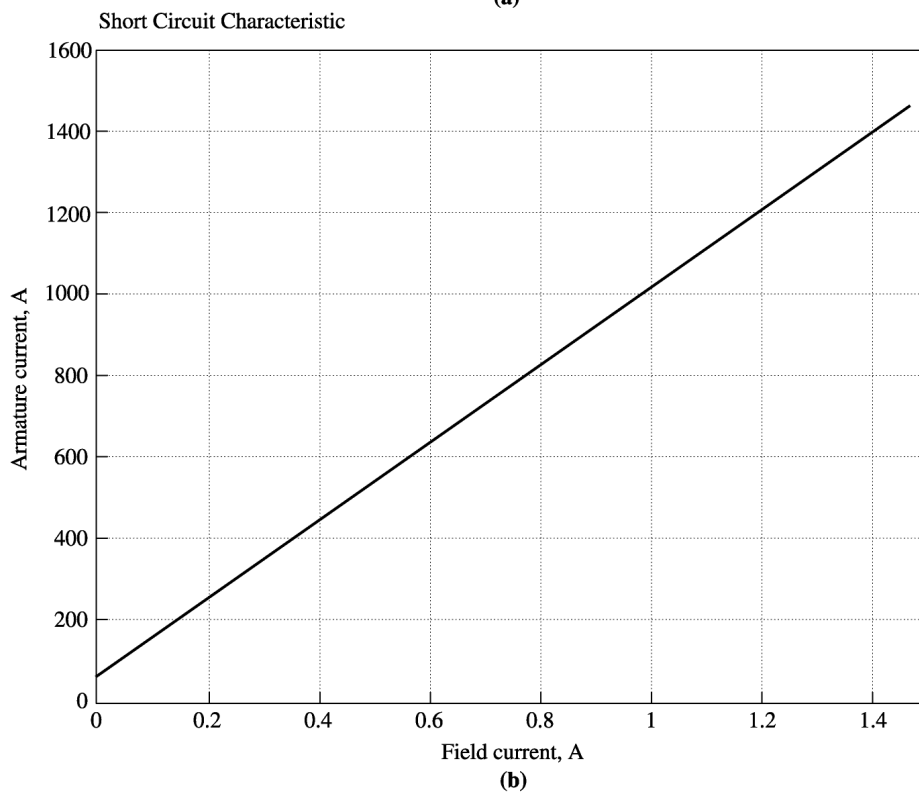
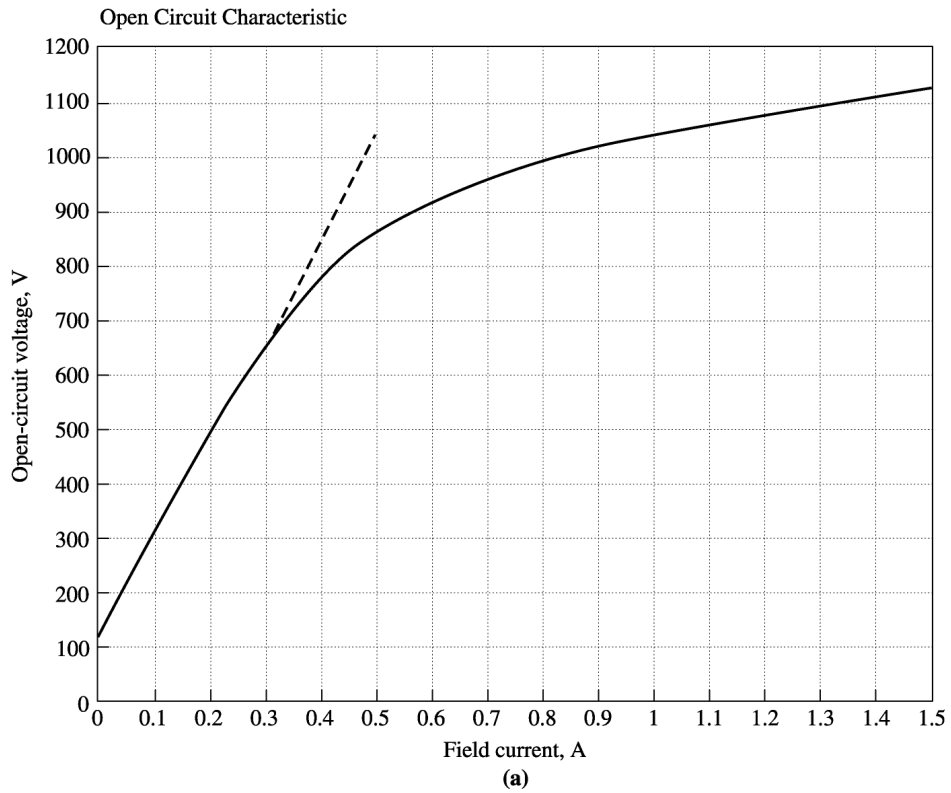


Errata for Electric Machinery Fundamentals 4/e (Current at 10 January 2004)

Please note that some or all of the following errata may be corrected in future reprints of the book, so they may not appear in your copy of the text.

1. Page 56, Problem 1-6, there are 400 turns of wire on the coil, as shown on Figure P1-3. The body of the problem incorrectly states that there are 300 turns.
2. Page 56, Problem 1-7, there are 400 turns of wire on the left-hand coil, and 300 turns on the right-hand coil, as shown on Figure P1-4. The body of the problem is incorrect.
3. Page 62, Problem 1-19, should state: "Figure P1-14 shows a simple single-phase ac power system with three loads. The voltage source is $V = 120 \angle 0^\circ \text{ V}$, and the three loads are ..."
4. Page 64, Problem 1-22, should state: "If the bar runs off into a region where the flux density falls to 0.30 T...". Also, the load should be 10 N, not 20.
5. Page 147, Problem 2-10, should state that the transformer bank is **Y- Δ** , not Δ -Y.
6. Page 226, Problem 3-10, the holding current I_H should be 8 mA.
7. Page 342, Figure p5-2, the generator for Problems 5-11 through 5-21, the OCC and SCC curves are in error. The correct curves are given below. Note that the voltage scale and current scales were both off by a factor of 2.



8. Page 344, Problem 5-28, the voltage of the infinite bus is 12.2 kV.
9. Page 377, Problem 6-11, the armature resistance is 0.08Ω , and the synchronous reactance is 1.0Ω .
10. Page 470, Problem 7-20 (a), the holding the infinite bus is 460-V.

11. Page 623, Figure P9-2 and Figure P9-3, $R_A = 0.40$ and $R_F = 100$. Values are stated correctly in the text but shown incorrectly on the figure.
12. Page 624, Figure P9-4, $R_A = R_S = 0.44$ and $R_F = 100$. Values are stated correctly in the text but shown incorrectly on the figure.
13. Page 627, Problem 9-21, R_{adj} is currently set to 90Ω . Also, the magnetization curve is taken at 1800 r/min.
14. Page 627, Problem 9-22, R_A is 0.18Ω .
15. Page 630, Figure P9-10, $R_A = R_S = 0.21$ N_{SE} is 20 turns. Values are stated correctly in the text but shown incorrectly on the figure.
16. Page 680, Problem 10-6, refers to Problem 10-5 instead of Problem 10-4.

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- 1-4. A motor is supplying $60 \text{ N} \cdot \text{m}$ of torque to its load. If the motor's shaft is turning at 1800 r/min, what is the mechanical power supplied to the load in watts? In horsepower?
- 1-5. A ferromagnetic core is shown in Figure P1-2. The depth of the core is 5 cm. The other dimensions of the core are as shown in the figure. Find the value of the current that will produce a flux of 0.005 Wb. With this current, what is the flux density at the top of the core? What is the flux density at the right side of the core? Assume that the relative permeability of the core is 1000.

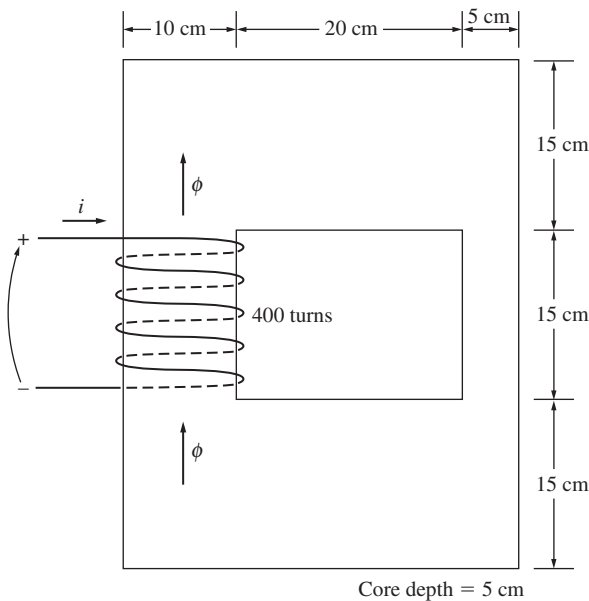


FIGURE P1-2

The core of Problems 1-5 and 1-16.

- 1-6. A ferromagnetic core with a relative permeability of 1500 is shown in Figure P1-3. The dimensions are as shown in the diagram, and the depth of the core is 7 cm. The air gaps on the left and right sides of the core are 0.070 and 0.050 cm, respectively. Because of fringing effects, the effective area of the air gaps is 5 percent larger than their physical size. If there are 400 turns in the coil wrapped around the center leg of the core and if the current in the coil is 1.0 A, what is the flux in each of the left, center, and right legs of the core? What is the flux density in each air gap?
- 1-7. A two-legged core is shown in Figure P1-4. The winding on the left leg of the core (N_1) has 400 turns, and the winding on the right (N_2) has 300 turns. The coils are wound in the directions shown in the figure. If the dimensions are as shown, then what flux would be produced by currents $i_1 = 0.5 \text{ A}$ and $i_2 = 0.75 \text{ A}$? Assume $\mu_r = 1000$ and constant.
- 1-8. A core with three legs is shown in Figure P1-5. Its depth is 5 cm, and there are 200 turns on the leftmost leg. The relative permeability of the core can be assumed to be 1500 and constant. What flux exists in each of the three legs of the core? What is the flux density in each of the legs? Assume a 4 percent increase in the effective area of the air gap due to fringing effects.

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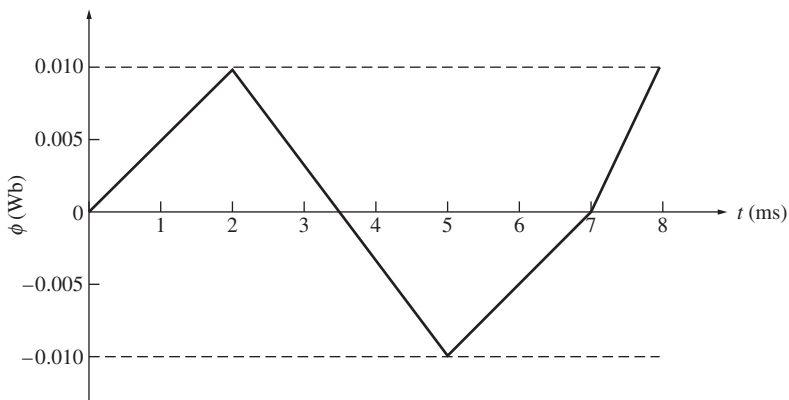


FIGURE P1-12
Plot of flux ϕ as a function of time for Problem 1-16.

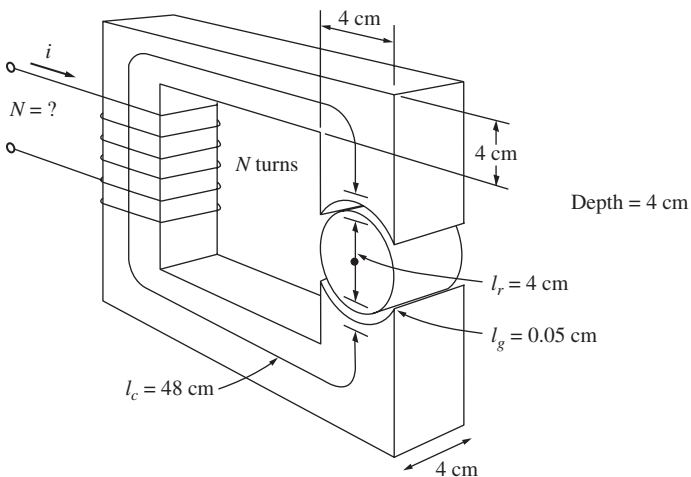


FIGURE P1-13
The core of Problem 1-17.

(d) Calculate the reactive power consumed or supplied by this load. Does the load consume reactive power from the source or supply it to the source?

1-19. Figure P1-14 shows a simple single-phase ac power system with three loads. The voltage source is $\mathbf{V} = 120\angle 0^\circ$ V, and the impedances of the three loads are

$$Z_1 = 5\angle 30^\circ \Omega \quad Z_2 = 5\angle 45^\circ \Omega \quad Z_3 = 5\angle -90^\circ \Omega$$

Answer the following questions about this power system.

(a) Assume that the switch shown in the figure is open, and calculate the current \mathbf{I} , the power factor, and the real, reactive, and apparent power being supplied by the load.

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- (a) If this bar has a load of 10 N attached to it opposite to the direction of motion, what is the steady-state speed of the bar?
- (b) If the bar runs off into a region where the flux density falls to 0.30 T , what happens to the bar? What is its final steady-state speed?
- (c) Suppose V_B is now decreased to 80 V with everything else remaining as in part *b*. What is the new steady-state speed of the bar?
- (d) From the results for parts *b* and *c*, what are two methods of controlling the speed of a linear machine (or a real dc motor)?

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1. Alexander, Charles K., and Matthew N. O. Sadiku: *Fundamentals of Electric Circuits*, McGraw-Hill, 2000.
2. Beer, F., and E. Johnston, Jr.: *Vector Mechanics for Engineers: Dynamics*, 6th ed., McGraw-Hill, New York, 1997.
3. Hayt, William H.: *Engineering Electromagnetics*, 5th ed., McGraw-Hill, New York, 1989.
4. Mulligan, J. F.: *Introductory College Physics*, 2nd ed., McGraw-Hill, New York, 1991.
5. Sears, Francis W., Mark W. Zemansky, and Hugh D. Young: *University Physics*, Addison-Wesley, Reading, Mass., 1982.

- 2-8.** A 200-MVA, 15/200-kV single-phase power transformer has a per-unit resistance of 1.2 percent and a per-unit reactance of 5 percent (data taken from the transformer's nameplate). The magnetizing impedance is $j80$ per unit.
- Find the equivalent circuit referred to the low-voltage side of this transformer.
 - Calculate the voltage regulation of this transformer for a full-load current at power factor of 0.8 lagging.
 - Assume that the primary voltage of this transformer is a constant 15 kV, and plot the secondary voltage as a function of load current for currents from no load to full load. Repeat this process for power factors of 0.8 lagging, 1.0, and 0.8 leading.
- 2-9.** A three-phase transformer bank is to handle 600 kVA and have a 34.5/13.8-kV voltage ratio. Find the rating of each individual transformer in the bank (high voltage, low voltage, turns ratio, and apparent power) if the transformer bank is connected to
- Y-Y, (b) Y- Δ , (c) Δ -Y, (d) Δ - Δ , (e) open Δ , (f) open Y-open Δ .
- 2-10.** A 13,800/480-V three-phase Y- Δ -connected transformer bank consists of three identical 100-kVA 7967/480-V transformers. It is supplied with power directly from a large constant-voltage bus. In the short-circuit test, the recorded values on the high-voltage side for one of these transformers are

$$V_{SC} = 560 \text{ V} \quad I_{SC} = 12.6 \text{ A} \quad P_{SC} = 3300 \text{ W}$$

- If this bank delivers a rated load at 0.85 PF lagging and rated voltage, what is the line-to-line voltage on the high-voltage side of the transformer bank?
 - What is the voltage regulation under these conditions?
 - Assume that the primary voltage of this transformer is a constant 13.8 kV, and plot the secondary voltage as a function of load current for currents from no-load to full-load. Repeat this process for power factors of 0.85 lagging, 1.0, and 0.85 leading.
 - Plot the voltage regulation of this transformer as a function of load current for currents from no-load to full-load. Repeat this process for power factors of 0.85 lagging, 1.0, and 0.85 leading.
- 2-11.** A 100,000-kVA, 230/115-kV Δ - Δ three-phase power transformer has a resistance of 0.02 pu and a reactance of 0.055 pu. The excitation branch elements are $R_C = 110$ pu and $X_M = 20$ pu.
- If this transformer supplies a load of 80 MVA at 0.85 PF lagging, draw the phasor diagram of one phase of the transformer.
 - What is the voltage regulation of the transformer bank under these conditions?
 - Sketch the equivalent circuit referred to the low-voltage side of one phase of this transformer. Calculate all the transformer impedances referred to the low-voltage side.
- 2-12.** An autotransformer is used to connect a 13.2-kV distribution line to a 13.8-kV distribution line. It must be capable of handling 2000 kVA. There are three phases, connected Y-Y with their neutrals solidly grounded.
- What must the N_C/N_{SE} turns ratio be to accomplish this connection?
 - How much apparent power must the windings of each autotransformer handle?
 - If one of the autotransformers were reconnected as an ordinary transformer, what would its ratings be?
- 2-13.** Two phases of a 13.8-kV three-phase distribution line serve a remote rural road (the neutral is also available). A farmer along the road has a 480-V feeder supplying

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3-10. A series-capacitor forced commutation chopper circuit supplying a purely resistive load is shown in Figure P3-5.

$$\begin{aligned} V_{DC} &= 120 \text{ V} & R_1 &= 20 \text{ k}\Omega \\ I_H &= 8 \text{ mA} & R_{load} &= 250 \Omega \\ V_{BO} &= 200 \text{ V} & C &= 150 \mu\text{F} \end{aligned}$$

- (a) When SCR₁ is turned on, how long will it remain on? What causes it to turn off?
- (b) When SCR₁ turns off, how long will it be until the SCR can be turned on again? (Assume that 3 time constants must pass before the capacitor is discharged.)
- (c) What problem or problems do these calculations reveal about this simple series-capacitor forced-commutation chopper circuit?
- (d) How can the problem(s) described in part c be eliminated?

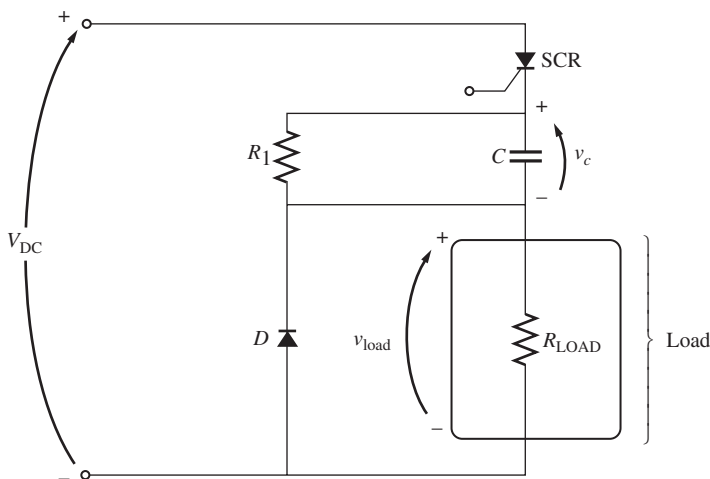


FIGURE P3-5 The simple series-capacitor forced-commutation circuit of Problem 3-10.

3-11. A parallel-capacitor forced-commutation chopper circuit supplying a purely resistive load is shown in Figure P3-6.

$$\begin{aligned} V_{DC} &= 120 \text{ V} & R_1 &= 20 \text{ k}\Omega \\ I_H &= 5 \text{ mA} & R_{load} &= 250 \Omega \\ V_{BO} &= 250 \text{ V} & C &= 15 \mu\text{F} \end{aligned}$$

- (a) When SCR₁ is turned on, how long will it remain on? What causes it to turn off?
 - (b) What is the earliest time that SCR₁ can be turned off after it is turned on? (Assume that 3 time constants must pass before the capacitor is charged.)
 - (c) When SCR₁ turns off, how long will it be until the SCR can be turned on again?
 - (d) What problem or problems do these calculations reveal about this simple parallel-capacitor forced-commutation chopper circuit?
 - (e) How can the problem(s) described in part d be eliminated?
- 3-12. Figure P3-7 shows a single-phase rectifier-inverter circuit. Explain how this circuit functions. What are the purposes of C₁ and C₂? What controls the output frequency of the inverter?

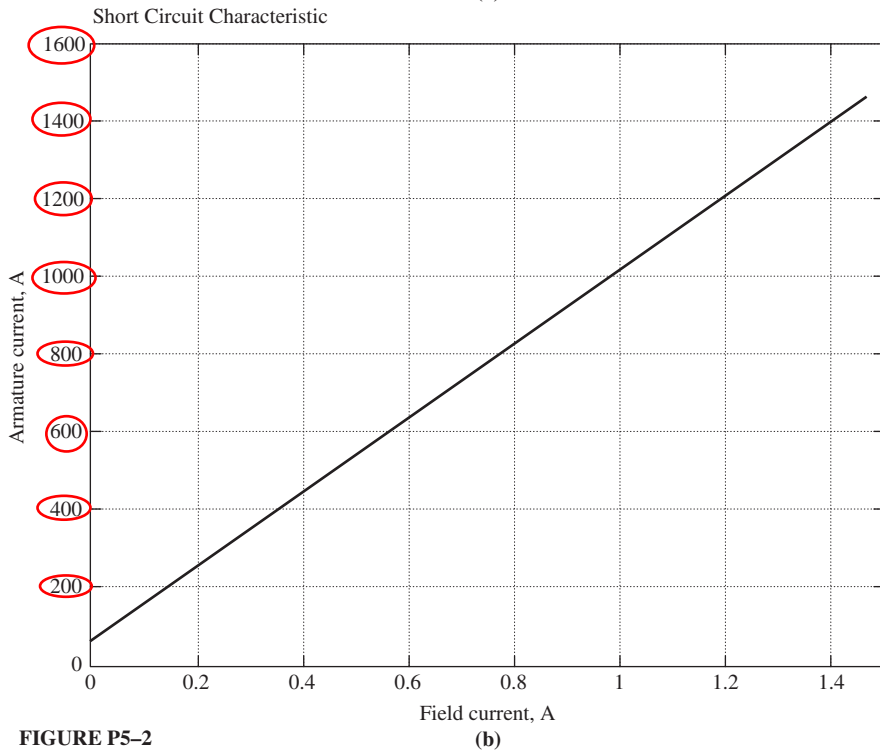
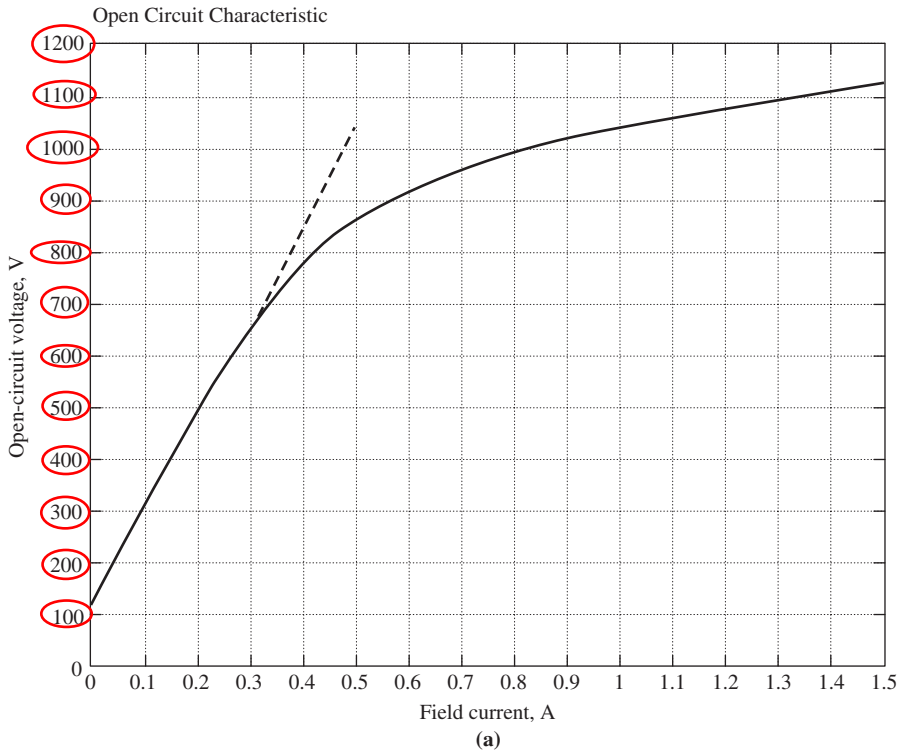


FIGURE P5-2

(a) Open-circuit characteristic curve for the generator in Problems 5–11 to 5–21. (b) Short-circuit characteristic curve for the generator in Problems 5–11 to 5–21.

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- 5–27. A 25-MVA, three-phase, 13.8-kV, two-pole, 60-Hz Y-connected synchronous generator was tested by the open-circuit test, and its air-gap voltage was extrapolated with the following results:

Open-circuit test					
Field current, A	320	365	380	475	570
Line voltage, kV	13.0	13.8	14.1	15.2	16.0
Extrapolated air-gap voltage, kV	15.4	17.5	18.3	22.8	27.4

The short-circuit test was then performed with the following results:

Short-circuit test					
Field current, A	320	365	380	475	570
Armature current, A	1040	1190	1240	1550	1885

The armature resistance is 0.24Ω per phase.

- Find the unsaturated synchronous reactance of this generator in ohms per phase and per unit.
 - Find the approximate saturated synchronous reactance X_S at a field current of 380 A. Express the answer both in ohms per phase and per unit.
 - Find the approximate saturated synchronous reactance at a field current of 475 A. Express the answer both in ohms per phase and in per-unit.
 - Find the short-circuit ratio for this generator.
- 5–28. A 20-MVA, 12.2-kV, 0.8-PF-lagging, Y-connected synchronous generator has a negligible armature resistance and a synchronous reactance of 1.1 per unit. The generator is connected in parallel with a 60-Hz, 12.2-kV infinite bus that is capable of supplying or consuming any amount of real or reactive power with no change in frequency or terminal voltage.
- What is the synchronous reactance of the generator in ohms?
 - What is the internal generated voltage \mathbf{E}_A of this generator under rated conditions?
 - What is the armature current \mathbf{I}_A in this machine at rated conditions?
 - Suppose that the generator is initially operating at rated conditions. If the internal generated voltage \mathbf{E}_A is decreased by 5 percent, what will the new armature current \mathbf{I}_A be?
 - Repeat part *d* for 10, 15, 20, and 25 percent reductions in \mathbf{E}_A .
 - Plot the magnitude of the armature current I_A as a function of E_A . (You may wish to use MATLAB to create this plot.)

6-9. Figure P6-2 shows a synchronous motor phasor diagram for a motor operating at a leading power factor with no R_A . For this motor, the torque angle is given by

$$\tan \delta = \frac{X_S I_A \cos \theta}{V_\phi + X_S I_A \sin \theta}$$

$$\delta = \tan^{-1} \left(\frac{X_S I_A \cos \theta}{V_\phi + X_S I_A \sin \theta} \right)$$

Derive an equation for the torque angle of the synchronous motor if the armature resistance is included.

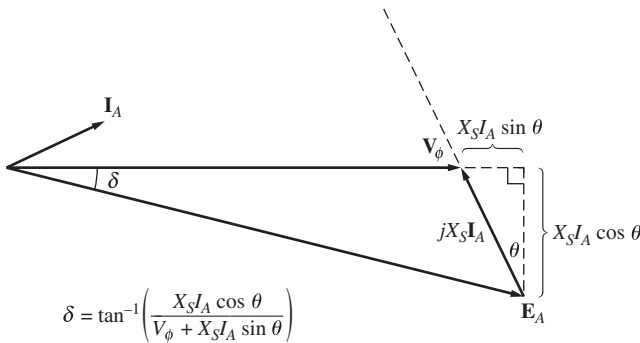


FIGURE P6-2 Phasor diagram of a motor at a leading power factor.

6-10. A 480-V, 375-kVA, 0.8-PF-lagging, Y-connected synchronous generator has a synchronous reactance of 0.4Ω and a negligible armature resistance. This generator is supplying power to a 480-V, 80-kW, 0.8-PF-leading, Y-connected synchronous motor with a synchronous reactance of 1.1Ω and a negligible armature resistance. The synchronous generator is adjusted to have a terminal voltage of 480 V when the motor is drawing the rated power at unity power factor.

- (a) Calculate the magnitudes and angles of E_A for both machines.
- (b) If the flux of the motor is increased by 10 percent, what happens to the terminal voltage of the power system? What is its new value?
- (c) What is the power factor of the motor after the increase in motor flux?

6-11. A 480-V, 100-kW, 50-Hz, four-pole, Y-connected synchronous motor has a rated power factor of 0.85 leading. At full load, the efficiency is 91 percent. The armature resistance is 0.08Ω , and the synchronous reactance is 1.0Ω . Find the following quantities for this machine when it is operating at full load:

- (a) Output torque
- (b) Input power
- (c) n_m
- (d) E_A
- (e) $|I_A|$
- (f) P_{conv}
- (g) $P_{mech} + P_{core} + P_{stray}$

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- (a) The line current I_L
 (b) The stator power factor
 (c) The rotor power factor
 (d) The stator copper losses P_{SCL}
 (e) The air-gap power P_{AG}
 (f) The power converted from electrical to mechanical form P_{conv}
 (g) The induced torque τ_{ind}
 (h) The load torque τ_{load}
 (i) The overall machine efficiency η
 (j) The motor speed in revolutions per minute and radians per second
- 7-15. For the motor in Problem 7-14, what is the pullout torque? What is the slip at the pullout torque? What is the rotor speed at the pullout torque?
- 7-16. If the motor in Problem 7-14 is to be driven from a 440-V, 60-Hz power supply, what will the pullout torque be? What will the slip be at pullout?
- 7-17. Plot the following quantities for the motor in Problem 7-14 as slip varies from 0 to 10 percent: (a) τ_{ind} ; (b) P_{conv} ; (c) P_{out} ; (d) efficiency η . At what slip does P_{out} equal the rated power of the machine?
- 7-18. A 208-V, 60 Hz six-pole, Y-connected, 25-hp design class B induction motor is tested in the laboratory, with the following results:

No load:	208 V, 22.0 A, 1200 W, 60 Hz
Locked rotor:	24.6 V, 64.5 A, 2200 W, 15 Hz
DC test:	13.5 V, 64 A

Find the equivalent circuit of this motor, and plot its torque–speed characteristic curve.

- 7-19. A 460-V, four-pole, 50-hp, 60-Hz, Y-connected, three-phase induction motor develops its full-load induced torque at 3.8 percent slip when operating at 60 Hz and 460 V. The per-phase circuit model impedances of the motor are

$$\begin{aligned} R_1 &= 0.33 \, \Omega & X_M &= 30 \, \Omega \\ X_1 &= 0.42 \, \Omega & X_2 &= 0.42 \, \Omega \end{aligned}$$

Mechanical, core, and stray losses may be neglected in this problem.

- (a) Find the value of the rotor resistance R_2 .
 (b) Find τ_{max} , s_{max} , and the rotor speed at maximum torque for this motor.
 (c) Find the starting torque of this motor.
 (d) What code letter factor should be assigned to this motor?
- 7-20. Answer the following questions about the motor in Problem 7-19.
- (a) If this motor is started from a 460-V infinite bus, how much current will flow in the motor at starting?
 (b) If transmission line with an impedance of $0.35 + j0.25 \, \Omega$ per phase is used to connect the induction motor to the infinite bus, what will the starting current of the motor be? What will the motor's terminal voltage be on starting?
 (c) If an ideal 1.4:1 step-down autotransformer is connected between the transmission line and the motor, what will the current be in the transmission line during starting? What will the voltage be at the motor end of the transmission line during starting?

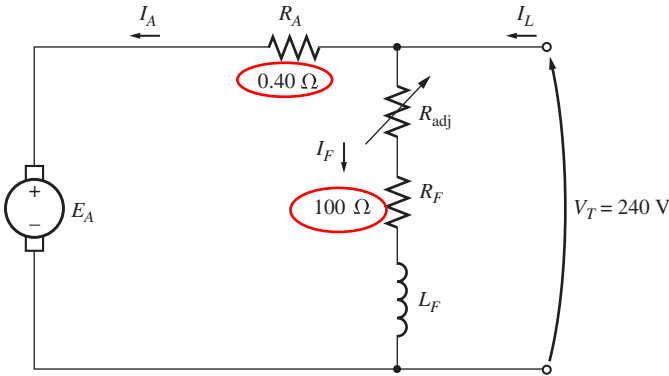


FIGURE P9-2
The equivalent circuit of the shunt motor in Problems 9-1 to 9-7.

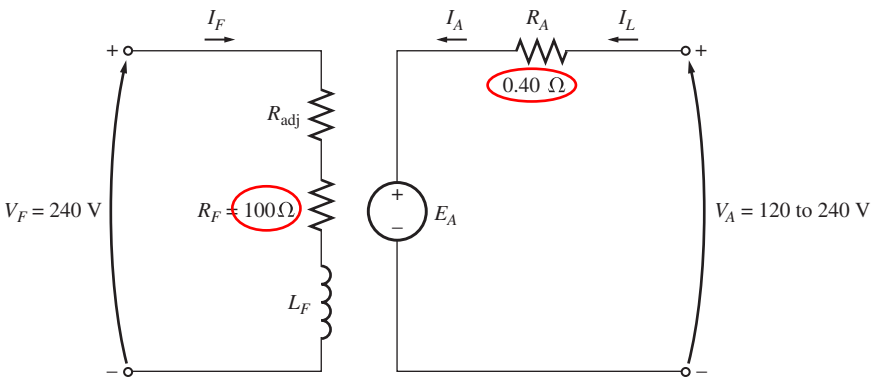


FIGURE P9-3
The equivalent circuit of the separately excited motor in Problems 9-8 and 9-9.

- 9-10.** If the motor is connected cumulatively compounded as shown in Figure P9-4 and if $R_{adj} = 175 \Omega$, what is its no-load speed? What is its full-load speed? What is its speed regulation? Calculate and plot the torque-speed characteristic for this motor. (Neglect armature effects in this problem.)
- 9-11.** 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 250Ω ? How does the new speed compare to the full-load speed calculated in Problem 9-10?
- 9-12.** 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.
- 9-13.** A 7.5-hp, 120-V series dc motor has an armature resistance of 0.2Ω and a series field resistance of 0.16Ω . At full load, the current input is 58 A, and the rated speed is

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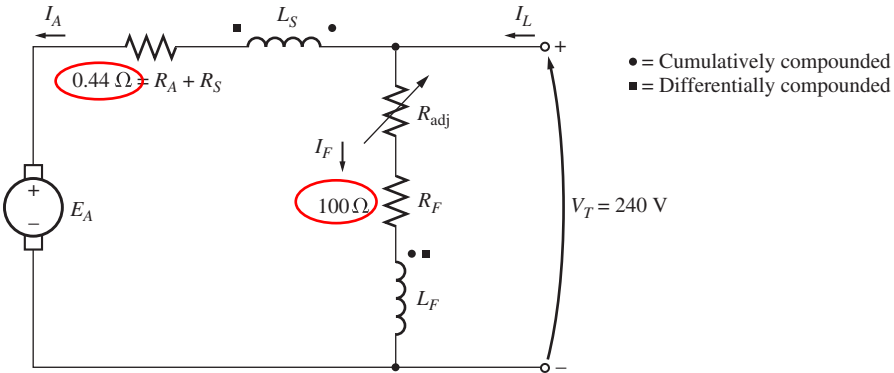


FIGURE P9-4
The equivalent circuit of the compounded motor in Problems 9-10 to 9-12.

1050 r/min. Its magnetization curve is shown in Figure P9-5. The core losses are 200 W, and the mechanical losses are 240 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.

- (a) What is the efficiency of the motor at full load?
 - (b) What are the speed and efficiency of the motor if it is operating at an armature current of 35 A?
 - (c) Plot the torque–speed characteristic for this motor.
- 9-14.** 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 Ω, and its field resistance is 0.06 Ω. The magnetization curve expressed in terms of magnetomotive force versus E_A at 900 r/min is given by the following table:

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

Armature reaction is negligible in this machine.

- (a) Compute the motor’s torque, speed, and output power at 33, 67, 100, and 133 percent of full-load armature current. (Neglect rotational losses.)
 - (b) Plot the torque–speed characteristic of this machine.
- 9-15.** 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:

$$\begin{aligned} V_A &= 16.3 \text{ V} && \text{exclusive of brushes} && V_F &= 440 \text{ V} \\ I_A &= 500 \text{ A} && && I_F &= 8.86 \text{ A} \end{aligned}$$

No-load operation:

$$\begin{aligned} V_A &= 16.3 \text{ V} && \text{including brushes} && I_F &= 8.76 \text{ A} \\ I_A &= 23.1 \text{ A} && && n &= 863 \text{ r/min} \end{aligned}$$

- 9–19.** 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.
- 9–20.** An automatic starter circuit is to be designed for a shunt motor rated at 15 hp, 240 V, and 60 A. The armature resistance of the motor is 0.15Ω , 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?
- 9–21.** A 15-hp, 230-V, 1800 r/min shunt dc motor has a full-load armature current of 60 A when operating at rated conditions. The armature resistance of the motor is $R_A = 0.15 \Omega$, and the field resistance R_F is 80Ω . The adjustable resistance in the field circuit R_{adj} may be varied over the range from 0 to 200Ω and is currently set to 90Ω . Armature reaction may be ignored in this machine. The magnetization curve for this motor, taken at a speed of 1800 r/min , is given in tabular form below:

$E_A, \text{ V}$	8.5	150	180	215	226	242
$I_F, \text{ A}$	0.00	0.80	1.00	1.28	1.44	2.88

- (a) What is the speed of this motor when it is running at the rated conditions specified above?
- (b) The output power from the motor is 7.5 hp at rated conditions. What is the output torque of the motor?
- (c) What are the copper losses and rotational losses in the motor at full load (ignore stray losses)?
- (d) What is the efficiency of the motor at full load?
- (e) If the motor is now unloaded with no changes in terminal voltage or R_{adj} , what is the no-load speed of the motor?
- (f) 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?
- (g) What range of no-load speeds is possible in this motor, given the range of field resistance adjustments available with R_{adj} ?
- 9–22.** The magnetization curve for a separately excited dc generator is shown in Figure P9–7. The generator is rated at 6 kW, 120 V, 50 A, and 1800 r/min and is shown in Figure P9–8. Its field circuit is rated at 5 A. The following data are known about the machine:

$$\begin{aligned}
 R_A &= 0.18 \Omega & V_F &= 120 \text{ V} \\
 R_{\text{adj}} &= 0 \text{ to } 30 \Omega & R_F &= 24 \Omega \\
 N_F &= 1000 \text{ turns per pole}
 \end{aligned}$$

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 30Ω 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?

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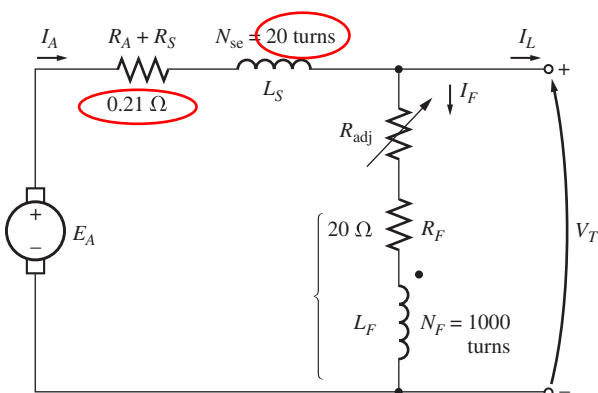


FIGURE P9-10
The compounded dc generator in Problems 9-27 and 9-28.

The machine has the magnetization curve shown in Figure P9-7. Its equivalent circuit is shown in Figure P9-10. 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.
- 9-28.** If the machine described in Problem 9-27 is reconnected as a differentially compounded dc generator, what will its terminal characteristic look like? Derive it in the same fashion as in Problem 9-27.
- 9-29.** 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.
- (a) 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?
 - (b) Will the voltage build up for rotation in the opposite direction? Why or why not?
 - (c) For the direction of rotation in which a voltage builds up, will the generator be cumulatively or differentially compounded?
- 9-30.** A three-phase synchronous machine is mechanically connected to a shunt dc machine, forming a motor-generator set, as shown in Figure P9-11. 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 0.04. 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 2.0 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.

- (a) Initially, the ac machine is supplying 50 kVA at 0.8 PF lagging to the ac power system.

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- (f) P_{out}
 - (g) τ_{ind}
 - (h) τ_{load}
 - (i) Efficiency
- 10-6.** Find the induced torque in the motor in Problem 10-5 if it is operating at 5 percent slip and its terminal voltage is (a) 190 V, (b) 208 V, (c) 230 V.
- 10-7.** What type of motor would you select to perform each of the following jobs? Why?
- (a) Vacuum cleaner
 - (b) Refrigerator
 - (c) Air conditioner compressor
 - (d) Air conditioner fan
 - (e) Variable-speed sewing machine
 - (f) Clock
 - (g) Electric drill
- 10-8.** For a particular application, a three-phase stepper motor must be capable of stepping in 10° increments. How many poles must it have?
- 10-9.** How many pulses per second must be supplied to the control unit of the motor in Problem 10-8 to achieve a rotational speed of 600 r/min?
- 10-10.** Construct a table showing step size versus number of poles for three-phase and four-phase stepper motors.

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