TUTORIAL-4

PROBLEM 5.1

5–1. At a location in Europe, it is necessary to supply 300 kW of 60-Hz power. The only power sources available operate at 50 Hz. It is decided to generate the power by means of a motor-generator set consisting of a synchronous motor driving a synchronous generator. How many poles should each of the two machines have in order to convert 50-Hz power to 60-Hz power?

PROBLEM 5.2

5–2. A 2300-V, 1000-kVA, 0.8-PF-lagging, 60-Hz, two-pole, Y-connected synchronous generator has a synchronous reactance of 1.1 Ω and an armature resistance of 0.15 Ω. At 60 Hz, its friction and windage losses are 24 kW, and its core losses are 18 kW. The field circuit has a dc voltage of 200 V, and the maximum I_F is 10 A. The resistance of the field circuit is adjustable over the range from 20 to 200 Ω. The OCC of this generator is shown in Figure P5–1.

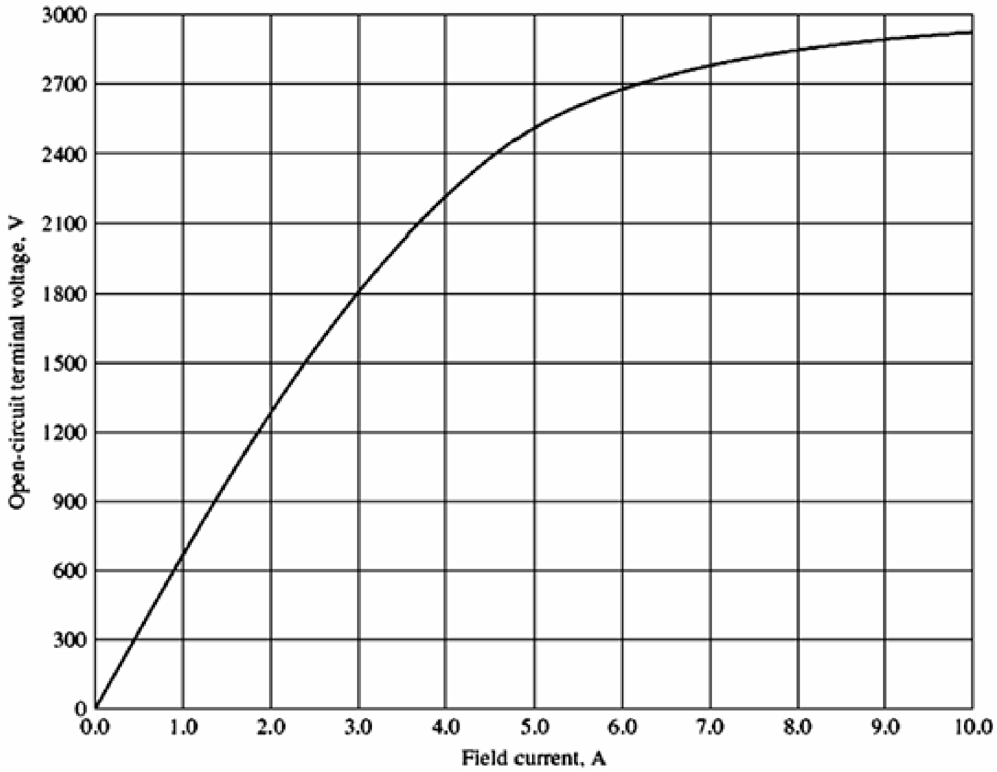

FIGURE P5–1
The open-circuit characteristic for the generator in Problem 5–2.

(*a*) How much field current is required to make V_T equal to 2300 V when the generator is running at no load?
(*b*) What is the internal generated voltage of this machine at rated conditions?

(c) How much field current is required to make V_T equal to 2300 V when the generator is running at rated conditions?
(d) How much power and torque must the generator's prime mover be capable of supplying?
(e) Construct a capability curve for this generator.

PROBLEM 5.3

5–3. Assume that the field current of the generator in Problem 5–2 has been adjusted to a value of 4.5 A.
(a) What will the terminal voltage of this generator be if it is connected to a Δ-connected load with an impedance of $20 \angle 30° \ \Omega$?
(b) Sketch the phasor diagram of this generator.
(c) What is the efficiency of the generator at these conditions?
(d) Now assume that another identical Δ-connected load is to be paralleled with the first one. What happens to the phasor diagram for the generator?
(e) What is the new terminal voltage after the load has been added?
(f) What must be done to restore the terminal voltage to its original value?

PROBLEM 5.4

5–4. Assume that the field current of the generator in Problem 5–2 is adjusted to achieve rated voltage (2300 V) at full-load conditions in each of the questions below.
(a) What is the efficiency of the generator at rated load?
(b) What is the voltage regulation of the generator if it is loaded to rated kilovoltamperes with 0.8-PF-lagging loads?
(c) What is the voltage regulation of the generator if it is loaded to rated kilovoltamperes with 0.8-PF-leading loads?
(d) What is the voltage regulation of the generator if it is loaded to rated kilovoltamperes with unity power factor loads?
(e) Use MATLAB to plot the terminal voltage of the generator as a function of load for all three power factors.

PROBLEM 5.5

5–5. Assume that the field current of the generator in Problem 5–2 has been adjusted so that it supplies rated voltage when loaded with rated current at unity power factor.
(a) What is the torque angle δ of the generator when supplying rated current at unity power factor?
(b) When this generator is running at full load with unity power factor, how close is it to the static stability limit of the machine?

PROBLEM 5.11

5–11. (a) What is the saturated synchronous reactance of this generator at the rated conditions?
(b) What is the unsaturated synchronous reactance of this generator?
(c) Plot the saturated synchronous reactance of this generator as a function of load.

PROBLEM 5.12

5–12. *(a)* What are the rated current and internal generated voltage of this generator?
(b) What field current does this generator require to operate at the rated voltage, current, and power factor?

PROBLEM 6.1

6–1. A 480-V, 60 Hz four-pole synchronous motor draws 50 A from the line at unity power factor and full load. Assuming that the motor is lossless, answer the following questions:

(*a*) What is the output torque of this motor? Express the answer both in newton-meters and in pound-feet.

(*b*) What must be done to change the power factor to 0.8 leading? Explain your answer, using phasor diagrams.

(*c*) What will the magnitude of the line current be if the power factor is adjusted to 0.8 leading?

PROBLEM 6.2

6–2. A 480-V, 60 Hz 400-hp, 0.8-PF-leading, six-pole, Δ-connected synchronous motor has a synchronous reactance of 1.1 Ω and negligible armature resistance. Ignore its friction, windage, and core losses for the purposes of this problem.

(*a*) If this motor is initially supplying 400 hp at 0.8 PF lagging, what are the magnitudes and angles of $\mathbf{E}_A$ and $\mathbf{I}_A$?

(*b*) How much torque is this motor producing? What is the torque angle δ? How near is this value to the maximum possible induced torque of the motor for this field current setting?

(*c*) If $|\mathbf{E}_A|$ is increased by 15 percent, what is the new magnitude of the armature current? What is the motor's new power factor?

(*d*) Calculate and plot the motor's V curve for this load condition.

PROBLEM 6.3

6–3. A 2300-V, 1000-hp, 0.8-PF leading, 60-Hz, two-pole, Y-connected synchronous motor has a synchronous reactance of 2.8 Ω and an armature resistance of 0.4 Ω. At 60 Hz, its friction and windage losses are 24 kW, and its core losses are 18 kW. The field circuit has a dc voltage of 200 V, and the maximum I_F is 10 A. The open-circuit characteristic of this motor is shown in Figure P6–1. Answer the following questions about the motor, assuming that it is being supplied by an infinite bus.

(*a*) How much field current would be required to make this machine operate at unity power factor when supplying full load?

(*b*) What is the motor's efficiency at full load and unity power factor?

(*c*) If the field current were increased by 5 percent, what would the new value of the armature current be? What would the new power factor be? How much reactive power is being consumed or supplied by the motor?

(*d*) What is the maximum torque this machine is theoretically capable of supplying at unity power factor? At 0.8 PF leading?

PROBLEM 6.5

6–5. If a 60-Hz synchronous motor is to be operated at 50 Hz, will its synchronous reactance be the same as at 60 Hz, or will it change? (*Hint:* Think about the derivation of X_S.)

PROBLEM 6.6

6–6. A 480-V, 100-kW, 0.85-PF-leading, 50-Hz, six-pole, Y-connected synchronous motor has a synchronous reactance of 1.5 Ω and a negligible armature resistance. The rotational losses are also to be ignored. This motor is to be operated over a continuous range of speeds from 300 to 1000 r/min, where the speed changes are to be accomplished by controlling the system frequency with a solid-state drive.

(*a*) Over what range must the input frequency be varied to provide this speed control range?

(*b*) How large is E_A at the motor's rated conditions?

(*c*) What is the maximum power that the motor can produce at rated speed with the E_A calculated in part (*b*)?

(*d*) What is the largest E_A could be at 300 r/min?

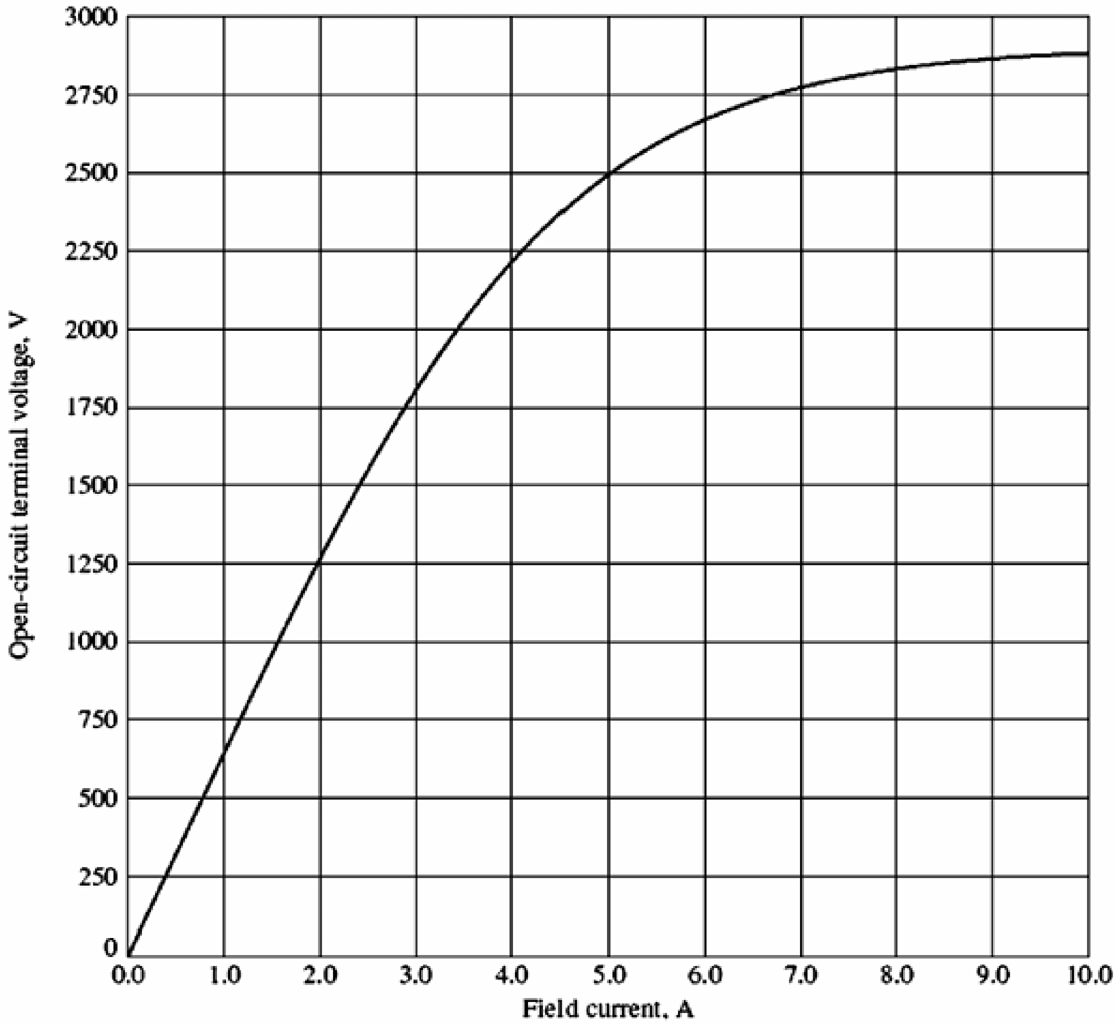

FIGURE P6–1
The open-circuit characteristic for the motor in Problems 6–3 and 6–4.

(*e*) Assuming that the applied voltage V_ϕ is derated by the same amount as E_A, what is the maximum power the motor could supply at 300 r/min?
(*f*) How does the power capability of a synchronous motor relate to its speed?

PROBLEM 6.7

6–7. A 208-V, Y-connected synchronous motor is drawing 40 A at unity power factor from a 208-V power system. The field current flowing under these conditions is 2.7 A. Its synchronous reactance is 0.8 Ω. Assume a linear open-circuit characteristic.
(*a*) Find the torque angle δ.
(*b*) How much field current would be required to make the motor operate at 0.8 PF leading?
(*c*) What is the new torque angle in part *b*?

PROBLEM 6.8

6–8. A synchronous machine has a synchronous reactance of 2.0 Ω per phase and an armature resistance of 0.4 Ω per phase. If $\mathbf{E}_A = 460 \angle -8° \text{ V}$ and $\mathbf{V}_\phi = 480 \angle 0° \text{ V}$, is this machine a motor or a generator? How much power P is this machine consuming from or supplying to the electrical system? How much reactive power Q is this machine consuming from or supplying to the electrical system?

PROBLEM 6.9

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.*

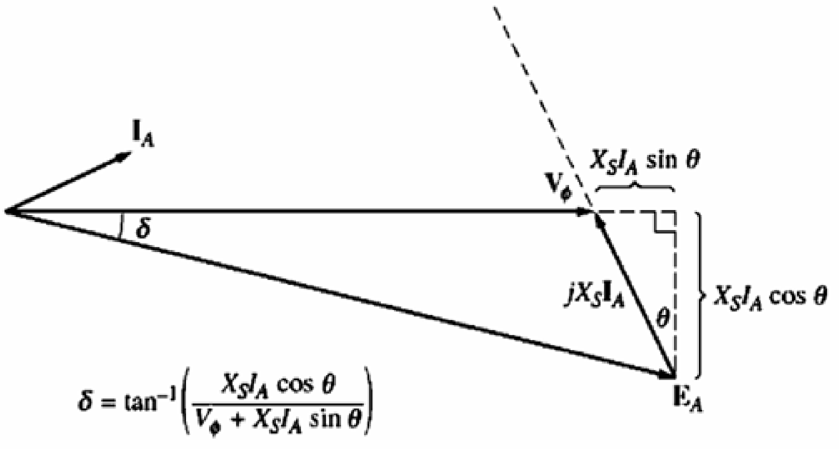

FIGURE P6–2
Phasor diagram of a motor at a leading power factor.

PROBLEM 6.10

6–10. A 480-V, 375-kVA, 0.8-PF-lagging, Y-connected synchronous generator has a synchronous reactance of 0.4 Ω 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 1.1 Ω 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 $\mathbf{E}_A$ 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?

PROBLEM 6.11

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 0.08 Ω, and the synchronous reactance is 1.0 Ω. Find the following quantities for this machine when it is operating at full load:

(*a*) Output torque

(*b*) Input power

(*c*) n_m

(*d*) $\mathbf{E}_A$

(*e*) $|\mathbf{I}_A|$

(*f*) P_{conv}

(*g*) $P_{\text{mech}} + P_{\text{core}} + P_{\text{stray}}$

PROBLEM 6.13

6–13. A 440-V, three-phase, Y-connected synchronous motor has a synchronous reactance of 1.5 Ω per phase. The field current has been adjusted so that the torque angle δ is 28° when the power supplied by the generator is 90 kW.

(*a*) What is the magnitude of the internal generated voltage $\mathbf{E}_A$ in this machine?

(*b*) What are the magnitude and angle of the armature current in the machine? What is the motor's power factor?

(*c*) If the field current remains constant, what is the absolute maximum power this motor could supply?

PROBLEM 6.15

6–15. A 100-hp, 440-V, 0.8-PF-leading, Δ-connected synchronous motor has an armature resistance of 0.22 Ω and a synchronous reactance of 3.0 Ω. Its efficiency at full load is 89 percent.

(*a*) What is the input power to the motor at rated conditions?

(*b*) What is the line current of the motor at rated conditions? What is the phase current of the motor at rated conditions?

(*c*) What is the reactive power consumed by or supplied by the motor at rated conditions?

(*d*) What is the internal generated voltage $\mathbf{E}_A$ of this motor at rated conditions?

(*e*) What are the stator copper losses in the motor at rated conditions?

(*f*) What is P_{conv} at rated conditions?

(*g*) If E_A is decreased by 10 percent, how much reactive power will be consumed by or supplied by the motor?

PROBLEM 6.16

6–16. Answer the following questions about the machine of Problem 6–15.

(*a*) If $\mathbf{E}_A = 430 \angle 13.5°$ V and $\mathbf{V}_\phi = 440 \angle 0°$ V, is this machine consuming real power from or supplying real power to the power system? Is it consuming reactive power from or supplying reactive power to the power system?

(*b*) Calculate the real power P and reactive power Q supplied or consumed by the machine under the conditions in part *a*. Is the machine operating within its ratings under these circumstances?

(*c*) If $\mathbf{E}_A = 470 \angle -12°$ V and $\mathbf{V}_\phi = 440 \angle 0°$ V, is this machine consuming real power from or supplying real power to the power system? Is it consuming reactive power from or supplying reactive power to the power system?

(*d*) Calculate the real power P and reactive power Q supplied or consumed by the machine under the conditions in part *c*. Is the machine operating within its ratings under these circumstances?
