

SM1. A three-phase, Y-connected, 230-V, 60-Hz, 10-kVA cylindrical-rotor synchronous generator has a synchronous reactance of $1.5 \, \Omega$ per phase and an armature resistance of $0.5 \, \Omega$ per phase.

- (a) Determine the voltage regulation at full load, rated voltage
 - (i) with 0.8 lagging power factor
 - (ii) with 0.8 leading power factor (pf)
- (b) Calculate pf for which the voltage regulation becomes zero on full load, rated voltage.

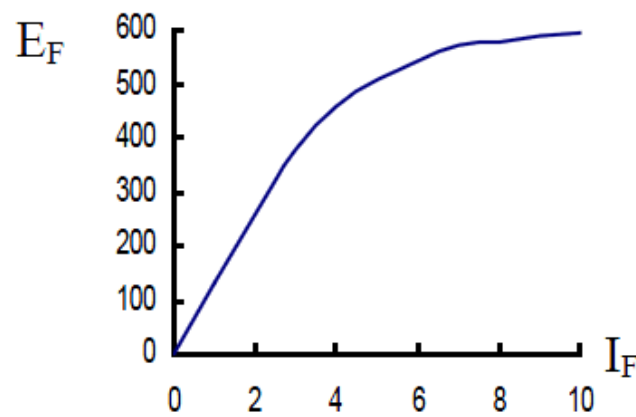
SM2. The following readings are taken from the results of open-circuit and short-circuit tests on a 10-MVA, three-phase, Y-connected, 13.8-kV, two-pole turbine generator driven at synchronous speed:

Field current, A:	170	200
Armature current, short-circuit test, A:	418	460
Line-to-line voltage, open-circuit test, V	13,000	13,800
Line-to-line voltage, air-gap line, V	15,500	17,500

Neglect the armature resistance.

- (a) Determine the unsaturated value of the synchronous reactance in ohms per phase and per unit.
- (b) Compute the saturated value of the synchronous reactance in ohms per phase and per unit.
- (c) Find the short-circuit ratio.
- (d) Calculate the field current required at rated voltage, rated kVA, and 0.8 lagging power factor, while accounting for saturation under load.

- A 480 V, 60 Hz, Y-connected, four pole synchronous generator has the OCC shown below. This generator has a synchronous reactance of 0.1 ohm and negligible armature resistance. At full load, the machine supplies 1200 A and 0.8 pf leading. Under full-load conditions, the friction and windage losses are 40 kW, and the core losses are 30 kW. Ignore field circuit losses.
- How much field current must be supplied to the generator to make the terminal voltage 480 V at no load?
 - If the generator is now connected to a load and the load draws 1200 A at 0.8 pf leading, how much field current will be required to keep the terminal voltage equal to 480 V?
 - Draw the phasor diagram corresponding to condition in II.
 - How much power is the generator now supplying? How much power is supplied to the generator by the prime-mover? What is the machine's overall efficiency?
 - If the generator's load were suddenly disconnected from the line, what would happen to its terminal voltage?



IM2. A 50-kW, 440-V, 50-Hz, two-pole induction motor has a slip of 6 percent when operating at full-load conditions. At full-load conditions, the friction and windage losses are 520 W, and the core losses are 500 W. Find the following values for full-load conditions:

- (a) The shaft speed ω_n
- (b) The output power in watts
- (c) The load torque in newton-meters
- (d) The induced torque in newton-meters
- (e) The rotor frequency in hertz

IM3. A 208-V, four-pole, 60-Hz, Y-connected wound-rotor induction motor is rated at 15 hp. Its equivalent circuit components are

$R_1 = 0.220 \text{ ohm}$	$R_2 = 0.127 \text{ ohm}$	$X_M = 15 \text{ ohm}$
$X_1 = 0.430 \text{ ohm}$	$X_2 = 0.430 \text{ ohm}$	
$P_{\text{mech}} = 300 \text{ W}$	$P_{\text{misc}} = 0$	$P_{\text{core}} = 200 \text{ W}$

For a slip of 0.05, find

- (a) The line current I_l
- (b) The stator copper losses P_{SCL}
- (c) The air-gap power P_{AG}
- (a) The power converted from electrical to mechanical form P_{conv}
- (e) The induced torque T_{ind}
- (f) The load torque T_{load}
- (g) The overall machine efficiency
- (h) The motor speed in revolutions per minute and radians per second

A 230-V, 4-pole, 60-Hz, Y-connected, three-phase induction motor has the following parameters on a per phase basis:

$$R_1 = 10.12 \, \Omega \quad X_1 = 38.61 \, \Omega \quad R_2 = 28.97 \, \Omega \quad X_2 = 11.56 \, \Omega \quad X_m = 432.48 \, \Omega$$

- i. Calculate the slip at which the motor develops maximum torque.
- ii. What is the maximum torque developed by the motor?
- iii. What is the power developed by the motor at this slip?

A 240 V shunt motor takes a current of 3.5 A on no load. The armature circuit resistance is $0.4\ \Omega$ and the shunt-field-winding resistance is $160\ \Omega$. When the motor operates at the full load at 2,400 rpm, it takes 24 A. Determine,

- a) Its efficiency at the full load
- b) The torque developed and the useful torque
- c) The no load speed
- d) Percent speed regulation
- e) Sketch the power flow diagram for each operation condition.

A 100-kW, 250-V DC shunt generator has an armature resistance of $0.05\ \Omega$ and field circuit resistance of $60\ \Omega$. With the generator operating at rated voltage, determine the induced voltage at full load.

A 10-hp, 250-V shunt motor has an armature-circuit resistance of 0.5 ohm and a field resistance of 200 ohm. At no load, rated voltage, and 1,200 r/min, the armature current is 3 A. At full load and rated voltage, the line current is 40 A, and the flux is 5% less than its no-load value because of armature reaction. Compute the full-load speed.

Synchronous Machines

SM1. A three-phase, Y-connected, 230-V, 60-Hz, 10-kVA cylindrical-rotor synchronous generator has a synchronous reactance of 1.5Ω per phase and an armature resistance of 0.5Ω per phase.

- (a) Determine the voltage regulation at full load, rated voltage
 - (i) with 0.8 lagging power factor [0.256]
 - (ii) with 0.8 leading power factor (pf) [-0.053]
- (b) Calculate pf for which the voltage regulation becomes zero on full load, rated voltage. [0.894 leading]

SM2. The following readings are taken from the results of open-circuit and short-circuit tests on a 10-MVA, three-phase, Y-connected, 13.8-kV, two-pole turbine generator driven at synchronous speed:

Field current, A:	170	200
Armature current, short-circuit test, A:	418	460
Line-to-line voltage, open-circuit test, V	13,000	13,800
Line-to-line voltage, air-gap line, V	15,500	17,500

Neglect the armature resistance.

- (a) Determine the unsaturated value of the synchronous reactance in ohms per phase and per unit.
[21.41 Ω /ph, 1.12 pu]
- (b) Compute the saturated value of the synchronous reactance in ohms per phase and per unit.
[17.32 Ω /ph, 0.91 pu]
- (c) Find the short-circuit ratio. [1.1]
- (d) Calculate the field current required at rated voltage, rated kVA, and 0.8 lagging power factor, while accounting for saturation under load. [342 A]

SM3. The following data are taken from the open-circuit and short-circuit characteristics of a 45-kVA, three-phase, wye-connected, 220-V, six-pole, 60-Hz synchronous machine.

From the open-circuit characteristic: Line-to-line voltage = 220 V; Field current = 2.84 A

From the short-circuit characteristic: Armature current, A: 118 152
Field current, A: 2.20 2.84

From the air-gap line: Field current = 2.20 A; Line-to-line voltage = 202 V

Compute the unsaturated value of the synchronous reactance, its saturated value at rated voltage, and the short-circuit ratio. Express the synchronous reactance in ohms per phase and in per unit on the machine rating as a base. [0.987 Ω /ph, 0.92 pu, 0.836 Ω /ph, 0.775 pu, 1.29]

SM4. A 480-V, 60-Hz, delta-connected, four-pole synchronous generator has the OCC shown in Figure 1. This generator has a synchronous reactance of 0.1Ω and an armature resistance of 0.015Ω . At full load, the machine supplies 1200 A at 0.8 PF lagging. Under full-load conditions, the friction and windage losses are 40 kW, and the core losses are 30 kW. Ignore any field circuit losses.

- (a) What is the speed of rotation of this generator? [1,800 r/min]

- (b) How much field current must be supplied to the generator to make the terminal voltage 480 V at no load? [4.5 A]
- (c) If the generator is now connected to a load and the load draws 1200 A at 0.8 PF lagging, how much field current will be required to keep the terminal voltage equal to 480V? [5.7 A]
- (d) How much power is the generator now supplying? How much power is supplied to the generator by the prime mover? What is this machine's overall efficiency? [$P_{out}=798$ kW, $P_m=889.6$ kW, $Eff=89.75\%$]
- (e) If the generator's load were suddenly disconnected from the line, what would happen to its terminal voltage? [532 V]
- (f) Finally, suppose that the generator is connected to a load drawing 1200 A at 0.8 PF leading. How much field current would be required to keep V_t at 480 V? [4.1 A]

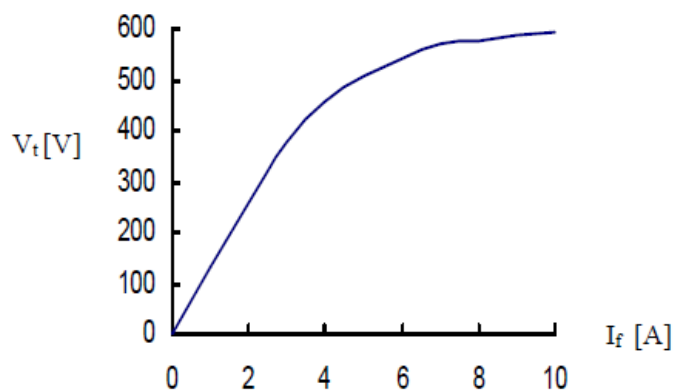


Fig. 1. OCC for problem SM4.

SM5. A 480-V, 50-Hz, Y-connected, six-pole synchronous generator has a per phase synchronous reactance of 1.0 Ω . Its full-load armature current is 60 A at 0.8 PF lagging. This generator has friction and windage losses of 1.5 kW and core losses of 1.0 kW at 60 Hz at full load. Since the armature resistance is being ignored, assume that the I^2R losses are negligible. The field current has been adjusted so that the terminal voltage is 480 V at no load.

- (a) What is the speed of rotation of this generator? [1,000 r/min]
- (b) What is the terminal voltage of this generator if the following are true?
1. It is loaded with the rated current at 0.8 PF lagging. [410 V(1-l)]
 2. It is loaded with the rated current at 1.0 PF. [468.4 V(1-l)]
 3. It is loaded with the rated current at 0.8 PF leading. [535 V(1-l)]
- (c) What is the efficiency of this generator (ignoring the unknown electrical losses) when it is operating at the rated current and 0.8 PF lagging? [93.2%]
- (d) How much shaft torque must be applied by the prime mover at full load? How large is the induced counter torque? [271.3 N.m]
- (e) What is the voltage regulation of this generator at 0.8 PF lagging? At 1.0 PF? At 0.8 PF leading. [17.1%, 2.6%, -10.3%]

Induction Machines

IM1. A three-phase, 60-Hz induction motor runs at 715 r/min at no load and at 670 r/min at full load.

- (a) How many poles does this motor have? [10]
- (b) What is the slip at rated load? [6.94%]
- (c) What is the speed at one-quarter of the rated load? [707 r/min]
- (d) What is the rotor's electrical frequency at one-quarter of the rated load? [1.04 Hz]

IM2. A 50-kW, 440-V, 50-Hz, two-pole induction motor has a slip of 6 percent when operating at full-load conditions. At full-load conditions, the friction and windage losses are 520 W, and the core losses are 500 W. Find the following values for full-load conditions:

- (a) The shaft speed ω_n [2,820 r/min]
- (b) The output power in watts [50,000]
- (c) The load torque in newton-meters [169.3]
- (d) The induced torque in newton-meters [173.4]
- (e) The rotor frequency in hertz [3.0]

IM3. A 208-V, four-pole, 60-Hz, Y-connected wound-rotor induction motor is rated at 15 hp. Its equivalent circuit components are

$R_1 = 0.220 \text{ ohm}$	$R_2 = 0.127 \text{ ohm}$	$X_M = 15 \text{ ohm}$
$X_1 = 0.430 \text{ ohm}$	$X_2 = 0.430 \text{ ohm}$	
$P_{\text{mech}} = 300 \text{ W}$	$P_{\text{MSC}} = 0$	$P_{\text{core}} = 200 \text{ W}$

For a slip of 0.05, find

- (a) The line current I_l [42.3 \angle -25.7° A]
- (b) The stator copper losses P_{SCL} [1,180 W]
- (c) The air-gap power P_{AG} [12.54 kW]
- (a) The power converted from electrical to mechanical form P_{conv} [11.92 kW]
- (e) The induced torque T_{ind} [66.5 N.m]
- (f) The load torque T_{load} [63.8 N.m]
- (g) The overall machine efficiency [83.2%]
- (h) The motor speed in revolutions per minute and radians per second [1,710 r/min and 179 rad/sec]

IM4. 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: 13.5V, 64 A

Find the equivalent circuit of this motor.

$$[R_1 = 0.105 \text{ ohm} \quad R_2 = 0.071 \text{ ohm} \quad X_M = 5.244 \text{ ohm} \quad X_1 = 0.211 \text{ ohm} \quad X_2 = 0.317 \text{ ohm}]$$

IM5. A 208-V, four-pole, 10-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 208 V. The per-phase circuit model impedances of the motor are

$R_1 = 0.33 \text{ ohm}$
 $X_m = 16 \text{ ohm}$
 $X_1 = 0.42 \text{ ohm}$
 $X_2 = 0.42 \text{ ohm}$

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

- (a) Find the value of the rotor resistance R_2 . [0.17 ohm]
- (b) Find T_{\max} , s_{\max} , and the rotor speed at maximum torque for this motor. [0.19, 1,457 r/min and 90.2 N.m]
- (c) Find the starting torque of this motor. [38.3 N.m]

DC Machines

DC1. A 100-kW, 250-V shunt generator has an armature-circuit resistance of 0.05 ohm, and field-circuit resistance of 60 ohm. With the generator operating at rated voltage, determine the induced voltage at (a) full load, and (b) half-full load. Neglect brush-contact drop. [270.2 V and 260.2 V]

DC2. A 10-hp, 250-V shunt motor has an armature-circuit resistance of 0.5 ohm and a field resistance of 200 ohm. At no load, rated voltage, and 1,200 r/min, the armature current is 3 A. At full load and rated voltage, the line current is 40 A, and the flux is 5% less than its no-load value because of armature reaction. Compute the full-load speed. [1,170.6 r/min]

DC3. A 20-hp, 250-V shunt motor has a total armature-circuit resistance of 0.25 ohm and a field-circuit resistance of 200 ohm. At no load and rated voltage, the speed is 1,200 r/min and the line current is 4.5 A. At full load and rated voltage, the line current is 65 A. Assume the field flux to be reduced by 6% from its value at no load due to the demagnetizing effect of armature reaction. Compute the full-load speed. [1,199 r/min]

DC4. The open-circuit characteristic data of a shunt generator at 1,200 r/min are given below:

Field current, A:	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0
Terminal voltage, V:	67	100	134	160	180	200	210	220	230	242

- Determine the critical field resistance for self-excitation at 1,200 r/min. [66.67 ohm]
- Find the total field-circuit resistance if the induced voltage is 230 V. [46 ohm]

DC5. A dc series motor operates at 750 r/min with a line current of 100 A from the 250-V mains. Its armature-circuit resistance is 0.15 ohm and its series-field resistance is 0.1 ohm. Assuming that the flux corresponding to a current of 25 A is 40% of that corresponding to a current of 100 A, determine the motor speed at a line current of 25 A at 250 V. [2,031 r/min]