a. For an cylindrical rotor synchronous machine, if the stator voltage is reduced by half, how does the stator leakage reactance change? __________ how does the synchronous reactance change?____________ if it is a salient-pole machine, how does the d-axis synchronous reactance change? ________________how does the q-axis synchronous reactance change?___________.

a. Is the slip-test measuring saturated value or unsaturated value of Xd and Xq? ____________

1. $V\downarrow, E\downarrow \xrightarrow{f\text{ constant}} \phi\downarrow \rightarrow \lambda\uparrow \rightarrow X_s\uparrow$

X_σ不变 q-轴主要是空气路径，可以认为凸极X_q不变

Ans: remain constant, increases, increases, remain constant

2. unsaturated (因为所加电压低于额定电压

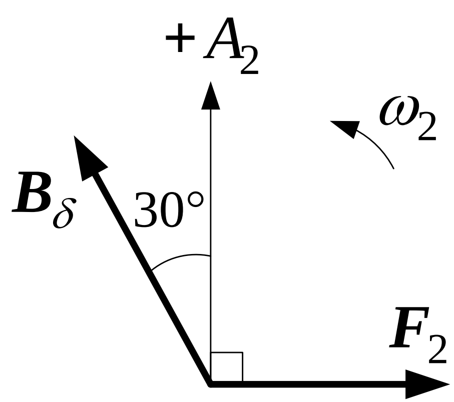
There is a three-phase non-salient pole synchronous generator. The permeability in the iron core can be regard as infinitely large. The armature winding resistance and leakage flux can be neglected. If air gap length is increased by 20%, and the total number of turns in series per phase is reduced by 20%, then the synchronous reactance Xs will be _______________ times of the original one, the steady-state short circuit current (at the same field current) will change to _______________ times of the original one。

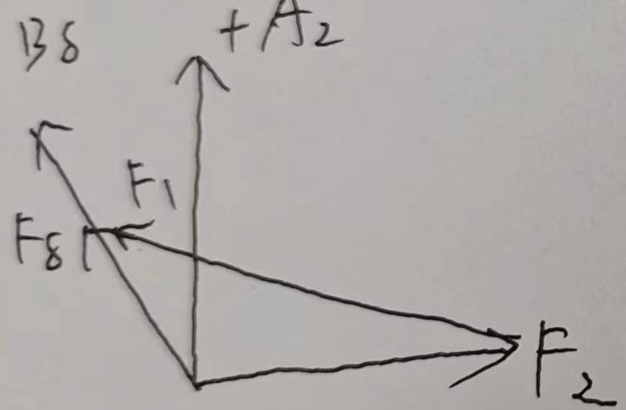
$$\Phi \propto \frac{N}{\Lambda} = \frac{0.8}{1.2} = \frac{2}{3}$$

$$\Psi = N\Phi = 0.8 \cdot \frac{2}{3} = \frac{8}{15} \qquad X = \frac{\Psi}{i}, \quad i \propto E = \frac{d\Phi}{dt}$$

Ans: $\frac{8}{15}$, $\frac{2}{3}$

A three-phase wound-rotor asynchronous machine, the stator winding is connected to a three-phase, 50Hz symmetrical AC power source, and the fundamental air gap magnetic field rotates along counterclockwise direction. At one moment, the rotor space vector diagram is shown in the right picture, and $\omega_2 = 4\pi$ rad/s. At this moment, this machine operates at ___________________state (generator or motor).





$B_8 \rightarrow F_8$

$F_2, F_8 \rightarrow F_1$

根据 F_1, F_2 夹角判断

A separately excited DC motor drives the constant torque load, and the armature terminal voltage U and the excitation current If remain unchanged. If an additional resistor is connected in series with the armature winding. Neglect armature reaction and no-load torque， when the new steady state is reached, how do the following parameters change： the armature current Ia ________________， electromagnetic power Pem ________________。

$U = E + IR$

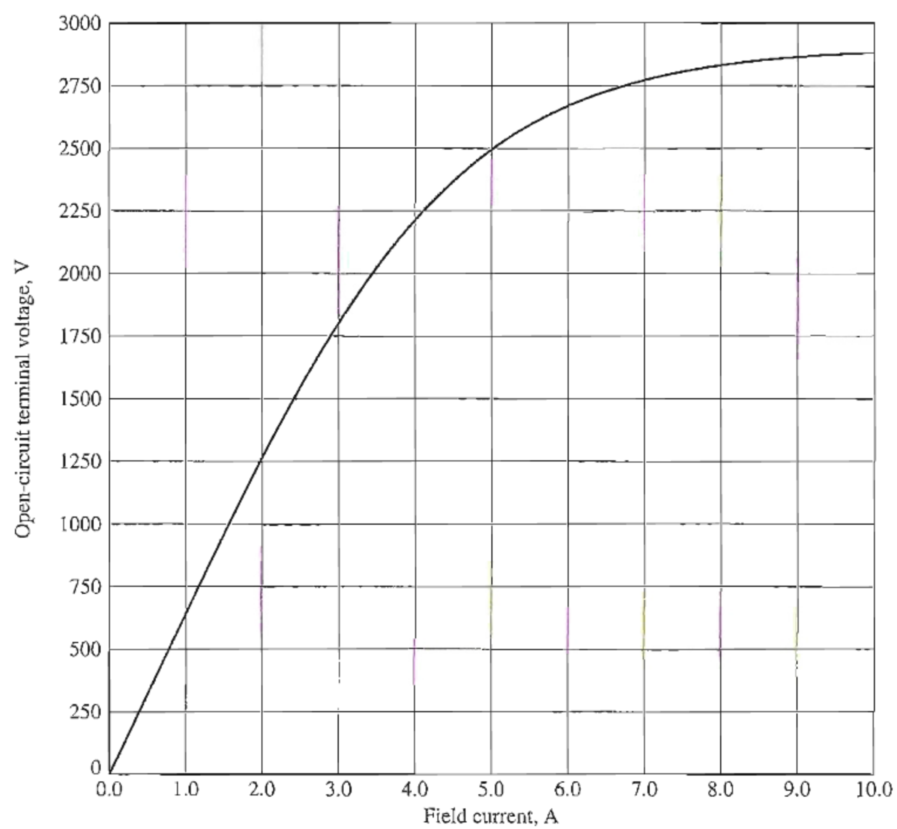
$E = K_e \Phi n$　　$T = K_T \Phi I$

T不变 $\longrightarrow$ Φ不变 $\xrightarrow{T\text{不变}}$ I不变 $\xrightarrow[U\text{不变}]{R\text{增大}}$ E减小 $\longrightarrow$ P_{em} 减小

不变，下降

•A 2300-V, 7kW, 0.8-PF-leading, 60Hz, two pole, Y-connected synchronous **motor** has a synchronous reactance of 2.5 ohm and an armature resistance of 0.5 ohm. At the rated voltage, the measured windage and friction loss is 30kW and the core loss is 20kW. The open-circuit characteristic is shown in the following figure.

1. How much field current is required to make this machine operated at unity power factor when supplying full load?
2. What is the motor's efficiency under the same condition as question a)
3. If the field current is reduced by 5%, what is the new value of the armature current, power factor? What is the reactive power consumed of supplied by the motor?
4. If the field current cannot exceed the rated field current and the maximum stator current is twice the rated current, can the machine supply 7kW at 0.6-PF-lagging when operated as a synchronous generator?



好像数值有问题，以下按照额定功率7MW计算

1. unity power factor 当额定PF计算了

$P_{in} = P_{out} + P_1 + P_{core} = 7000kW + 30kW + 20kW = 7050kW$

$\dot{U} = \dot{E}_0 + \dot{I}(R + jX_s)$

$\dot{I} = \frac{7M}{2300\sqrt{3}} = 1757.15\angle 0$

$\dot{U} = \frac{2300}{\sqrt{3}}\angle\cos^{-1}0.8 = 1327\angle -36.87^\circ$

数值算着有问题，
所以没算

$\dot{E}_0 = 5192.3\angle -87.97$ (好像数值有问题，计算出来很奇怪)

找到 E_0(线电压) 对应各阶段的 I

2. $\eta = \frac{P_{out}}{P_{in}}$

3. $E_0 \to 95\% E_0$

$\dot{U} = \dot{E}_0 + \dot{I}(R + jX_s)$ $\Rightarrow$ 解得 $\dot{U}$，$\dot{I}$

$P = \dot{U} \cdot \dot{I}$ 不变

4 发电机：$\dot{E}_0 = \dot{U} + \dot{I}(R + jX_s)$，$\dot{U}$，$\dot{I}$ 相角满足 0.6PF

$\dot{U} \cdot \dot{I} = 7kW$

求解 E_0 是否满足

A 460V, 50Hz 50kW 4-pole Y-connected induction machine has the following parameters:

R1=0.058 ohm, R2=0.037 ohm, Xm =9.24 ohms, X1=0.32 ohm, X2=0.386 ohm.

At the rated voltage, the tested windage and friction loss is 700 W, core loss is 600W (hysteresis loss=eddy current loss).

a. What is the output power at slip =0.01?
b. What is the max torque the motor can deliver? What is the motor speed at the max torque?
c. Assume we are allowed to change R2. For a slip of 1 to 0.05, the load torque of the motor is equal to half of the max torque you calculated in question b. for slip below 0.05, the load torque is reduced to 0. what is the range of R2 that the motor can start and run at a slip lower than 0.05 at steady state?
d. If we decided to run the motor with a variable speed motor drive, what is the maximum voltage applied to the motor at 25Hz? what is the maximum efficiency of the motor at this voltage? Assume windage and friction loss is proportional to rotating speed.

参考思路，
无计算

a. $V_{TH} \approx V_\phi \frac{X_M}{X_1+X_M}$

$R_{TH} \approx R_1 \left(\frac{X_M}{X_1+X_M}\right)^2$

$X_{TH} \approx X_1$

$$I_2 = \frac{V_{TH}}{R_{TH}+R_2/s+jX_{TH}+jX_2}$$

$P_m = 3 I_2^2 \frac{1-s}{s} R_2$

$P_{out} = P_m - P_{wf} - P_{core}$

b. $$\tau_{max} = \frac{3V_{TH}^2}{2\omega_{sync}\left[R_{TH}+\sqrt{R_{TH}^2+(X_{TH}+X_2)^2}\right]}$$

$$s_{max} = \frac{R_2}{\sqrt{R_{TH}^2+(X_{TH}+X_2)^2}}$$

$n_{max} = (1-s_{max})\, n_{syn}$

c. 忽略损耗

$$\tau_{ind} = \frac{3V_{TH}^2 R_2/s}{\omega_{sync}\left[(R_{TH}+R_2/s)^2+(X_{TH}+X_2)\right]^2}$$

$s=1$ 和 $s=0.05$ 时，$\tau_{ind}=\frac{1}{2}\tau_{max}$ 计算 R_2 即可

d. 至不变 E_1/f_1 不变，原来 $E_1 = U_1 - I_1(jX_1+R_1)$，现在 $E_1 = U_1 - I_1(jX_1+R_1)$
（X_1 随 f 变化）

令 $s=0$，$I_2=0$，计算 I_1 得 U_1 最大值

$$\eta = \frac{P_{out}}{P_{in}} = \frac{3U_1I_1 - (I_2^2R_2 + \underbrace{P_h}_{\propto f_1} + \underbrace{P_{ed}}_{\propto f_1^2} + P_{wf}\cdot\frac{1-s}{2} + I_1^2R_1)}{3U_1I_1}$$

求 η 最大值

A shunt excited DC motor, the no-load characteristic is a straight line. The armature loop total resistance Ra＝0.25 Ω, the excitation winding resistance Rf ＝110 Ω， the rated value is： UN＝220 V， IN＝62 A， n_N＝1000 r/min， no-load torque is neglected.

（1）If the load torque is reduced to 1/4 of the rated value， the source voltage is reduced to $U_N/2$， find the armature EMF Ea and rotor speed n when the motor is in steady state?

（2）If the DC motor is driven by a prime mover as a generator, the armature terminal voltage is still U_N. How much is the rotor speed n when the output power is 11kW?

(1). rated condition:

$$I_{Na} = I_N - U_N/R_f = 60A$$

$$E_N = U_N - I_N R_a = \cancel{204.5V}\ 205V$$

now:

$$U_N \rightarrow U_N/2,\ I_f \rightarrow \frac{I_f}{2},\ \phi \rightarrow \frac{\phi}{2}$$

$$T = K_T \phi I_a,\ T \rightarrow \frac{T}{4} \longrightarrow I_a \rightarrow \frac{I_N}{2}$$

$$E_a = U - I_a R_a = \frac{220}{2} - \frac{60}{2} \cdot 0.25 = 102.5V$$

$$E = K_e \phi n \qquad n = \frac{E}{K_e \phi}$$

$$n = \frac{n_N}{\frac{E_N}{\phi_N}} \cdot \frac{E_a}{\phi} = \frac{1000}{\cancel{204.5}\ 205} \cdot \frac{102.5}{\frac{1}{2}} = 1000\ r/min$$

(2) U_N不变, I_f不变 $\longrightarrow \phi$不变

$$E = K_e \phi n = \frac{n}{n_N} \cdot E_N$$

$$I = \frac{P}{U_N} = \frac{11kW}{220V} = 50A \quad I_a = I + \frac{U_N}{R_f} = 52A$$

$$E = U_N + I_a R_a = 220 + 52 \cdot 0.25 = \cancel{232.5}\ 233V$$

$$n = \frac{E}{E_N} \cdot n_N = \frac{\cancel{232.5}\ 233}{\cancel{204.5}\ 205} \cdot 1000 = 1136.6\ r/min$$

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

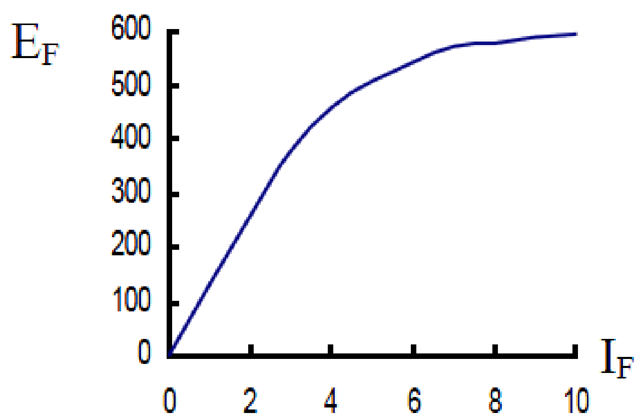
I. How much field current must be supplied to the generator to make the terminal voltage 480 V at no load?

II. 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?

III. Draw the phasor diagram corresponding to condition in II.

IV. 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?

V. 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_m
(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

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

For a slip of 0.05, find

(a) The line current I_1
(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:

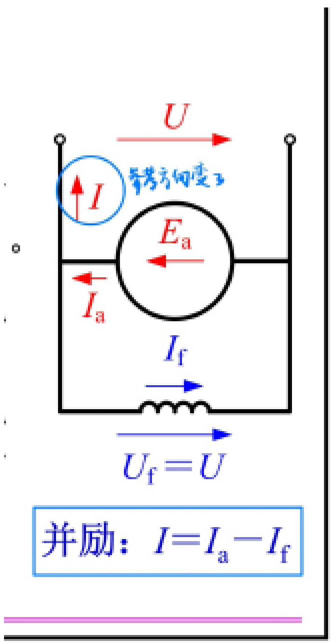
$R_1 = 10.12\ \Omega$ $X_1 = 38.61\ \Omega$ $R_2 = 28.97\ \Omega$ $X_2 = 11.56\ \Omega$ $X_m = 432.48\ \Omega$

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 Ω and the shunt-field-winding resistance is 160 Ω. 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 Ω and field circuit resistance of 60 Ω. With the generator operating at rated voltage, determine the induced voltage at full load.



$I = I_a = I_f$.

发电机： $E_a = U + I_aR_a$

$U = 250V = U_f$

$I = \frac{P}{U} = 400A$

$I_f = \frac{U_f}{R_f} = \frac{25}{6}A$

$\therefore I_a = I + I_f = 404.17A$

$\therefore E_a = U + I_aR_a = 270.2V$.

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 1.5 Ω per phase and an armature resistance of 0.5 Ω 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 characterictics 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 0.1 Ω and an armature resistance of 0.015 Ω. 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_{in}=889.6 kW, Effi=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]

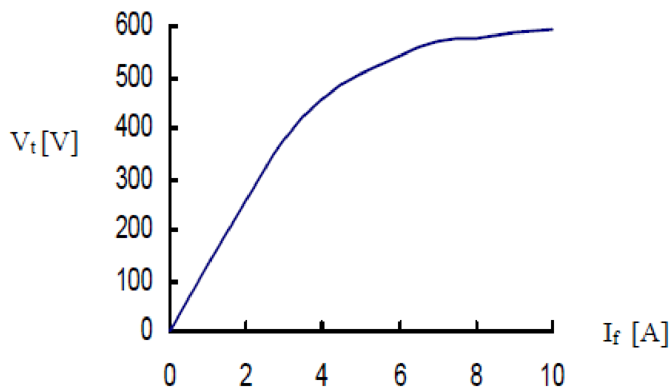


Fig. 1. OCC for problem SM4.

SM5. A 480-V, 50-Hz, Y-connected, six-pole synchronous generator has a per phase synchronous reactance of 1.0 H. 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(l-l)]
2. It is loaded with the rated current at 1.0 PF. [468.4 V(l-l)]
3. It is loaded with the rated current at 0.8 PF leading. [535 V(l-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

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

For a slip of 0.05, find

(a) The line current I_l [42.3<-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 ohm R_2 = 0.071 ohm X_M= 5.244 ohm X_1 = 0.211 ohm X_2 = 0.317 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 ohm
X_m= 16 ohm
X_1= 0.42 ohm
X_2= 0.42 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

a. Determine the critical field resistance for self-excitation at 1,200 r/min. [66.67 ohm]
b. 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]