ET 332b
Ac Machines and Power Systems
Homework Assignments

Assignment #	Lesson#	Problems	Location
1	1	cpmathhw.wp5*	handout
2	2	sglephhw1.docx	handout
3	3	spqhw.wp5	handout
4	3	pfhw.wp5	handout
5	4	hw3phs1.wp5	handout
6	4	hw3phs4.wp5, hw3phs3.wp5	handout
7	4, 5	hw3phs2.wp5, pfcorr.wp5	handout
8	4, 6	wyedhw.wp5, tqspd.wp5	handout
9	7	meterhw.wp5	handout
10	8	2-9	Chapter 2
11	8, 9	2-11	Chapter 2
12	8, 9, 10	2-13	Chapter 2
13	8, 9 , 10	2-15	Chapter 2
14	10	puprobs.docx	handout
15	10	2-23, 2-25	Chapter 2
16	10	2-17	Chapter 2
17	10	2-39	Chapter 2
18	11	3phtxhw.wp5	handout
19	12	3-11	Chapter 3
20	12	3-1, 3-9**	Chapter 3
21	12a	4-4, ind-hw1.wp5	Chapter 4, handout
22	12a, 13	4-6	Chapter 4
23	12a, 13	4-10	Chapter 4
24	12a, 13	4-16	Chapter 4
25	13	indhw1.wp5	handout
26	14	5-22	Chapter 5
27	15	5-31, 5-32	Chapter 5
28	16	5-35	Chapter 5
29	17	8-1, 8-2, 8-3	Chapter 8
30	17, 18	8-5	Chapter 8
31	17, 18	8-7	Chapter 8
32	19	8-17	Chapter 8
33	20-22	9-1, 9-5	Chapter 9

*Homeworks with this type of label come from the homework packet.
**Missprint in problem statement. Use a voltage value of 482 instead of 432.

Hw 1

Name ________________________

ET 332b

COMPLEX NUMBER ARITHMETIC HOME WORK

Convert the following complex numbers from polar to rectangular form. Show work for full credit. All angles are in degrees.

1.) $120\angle 120$ = ____________

2.) $60\angle -50$ = ____________

3.) $15\angle -36.6$ = ____________

4.) $5\angle 90$ = ___________

Convert the following complex numbers from rectangular to polar form.

5.) 30+j40 = ____________

6.) 25+j0 = ___________

7.) -46-j95 = __________

8.) 45-j45 = __________

Add the following complex numbers. Show result in rectangular form.

9.) $170\angle -60$ + (75+j10) = _____________

10.) (67+j38) + (100-j50) = _____________

11.) (-12-j75) + (37+j0) = ______________

12.) $9.434\angle 58$ + $9.849\angle -24$ = ____________

Hw 1

Name ______________________

Subtract the following complex numbers. Show the results in rectangular form.

13.) (15+j2) - (3+j12) = __________

14.) (21-j50) - (11-j23) = __________

15.) 6.4∠51.34 - 10∠180 = __________

16.) (6+j0) - (0+j9) = __________

Multiply the following complex numbers. Show the results in polar form.

17.) (120∠-120)∘(5∠-30) = __________

18.) (120∠0)∘(7.5∠-36.7) = __________

19.) (5∠-90)∘(10∠90) = __________

20.) (45∠180)∘(90∠-60) = __________

Divide the following complex numbers. Show the results in polar form.

21.) (1∠0) / (5∠-24) = ________

22.) (40+j30) /(2∠75) = ________

23.) (4-j4) / (3-j8) = ______

24.) (10∠240) / (2∠120) = ________

25.) (2∠75)/(7-J10) = ________

HW 1

Invert the following complex numbers. Show the results in polar form

26.) 1/(4∠75) = ______

27.) 1/(10∠-22) = ______

28.) 1/(4+j5) = ________

29.) 1/(-3-j8) = ________

30.) 1/(5-j9) = ________

Take the conjugate of the following numbers. Show the results in polar form

31.) (6-j4)* = _______

32.) (3∠45)* = ______

33.) (7-j9)* = _______

Hw 2

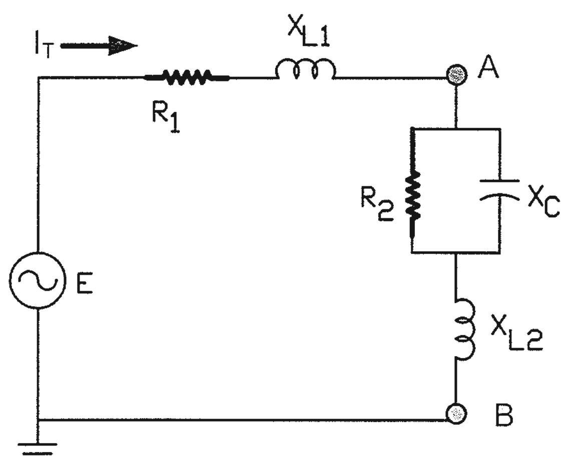
ET 332b
Single Phase Ac Circuit Analysis

The circuit below has the following component values:

$R_1 = 3\ \Omega$ $X_{L1} = 5\ \Omega$
$R_2 = 10\ \Omega$ $X_{L2} = 7\ \Omega$ $X_C = 50\ \Omega$

$E = 240 \angle 0^\circ$

Find the total source current I_T and the voltage between the points A and B on the diagram below. (Voltage across equivalent of all components R_2, X_{L2}, and X_C.)



Hw3

ET 332b
Single Phase AC Power Homework

In the circuit below:

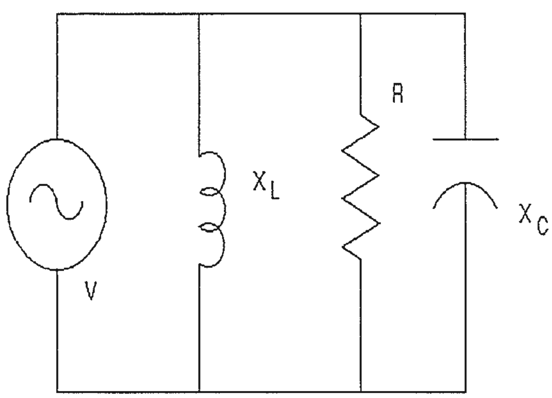
1. find the active and reactive power absorbed by the circuit

2. draw the power triangle for the circuit

3. find the power factor of the circuit

4. find magnitude of the current from the source

$V = 200 \angle 0 \quad X_c = 24\ \Omega \quad X_L = 35\ \Omega$
$R = 17\ \Omega$



HW 4

ET 332b
Power Factor Calculations

A load is connected to a voltage source operating at 60 Hz and 1320 volts. The load dissipates 100 kW with a power factor of 0.867 lagging. Specifiy the capacitance in microfarads to correct the load power factor to:

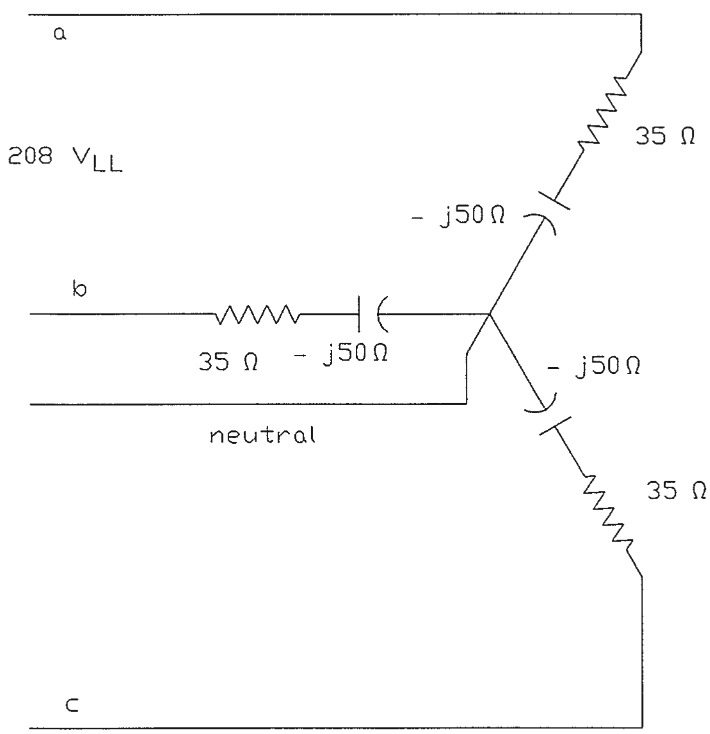
a.) 0.895 lagging
b.) 0.95 leading

HW5

ET 332b
3 Phase System Homework

For the circuit given below, compute:

a.) the magnitude of line-to-neutral voltage
b.) the magnitude of the line current and the phase current
c.) the total apparent power absorbed in the circuit
d.) the power factor for the circuit

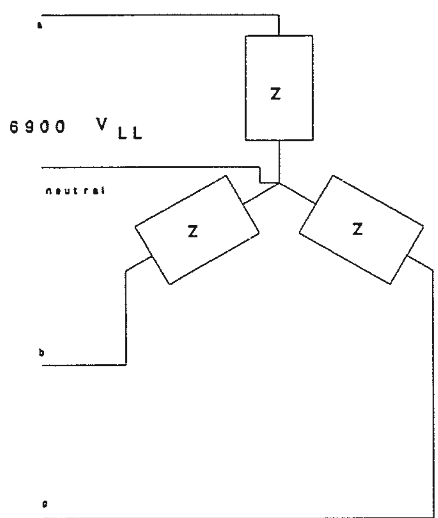


Hw 6

ET 332b
3 Phase System Homework

A three-phase wye connected load absorbs 24 kW with a power factor of 0.8 lagging. The line-to-line voltage is 6900 V. Find:

a.) the line-to-neutral voltage of the load
b.) total apparent power, S, absorbed by the load
c.) line current and phase current magnitudes

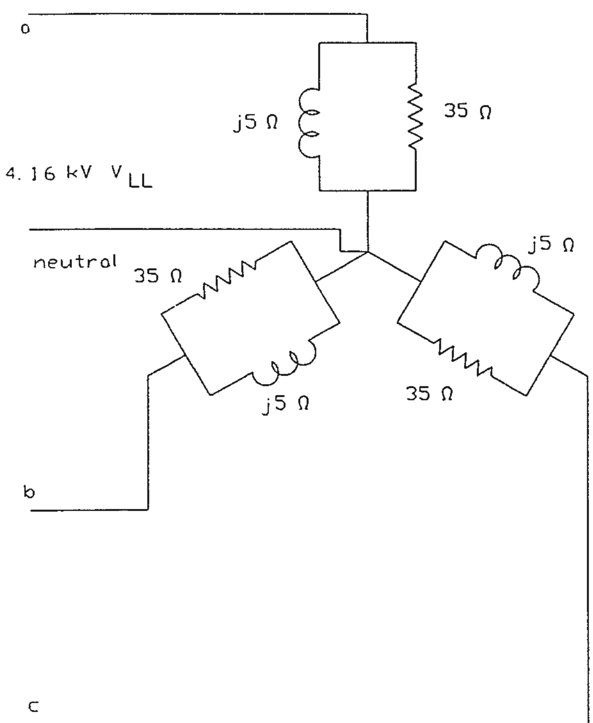


Hw6

ET 332b
3 Phase System Homework

For the circuit given below, compute:

a.) the magnitude of line-to-neutral voltage
b.) the magnitude of the line current
c.) the total apparent power absorbed in the circuit
d.) the apparent power absorbed in one phase
e.) the power factor of the load



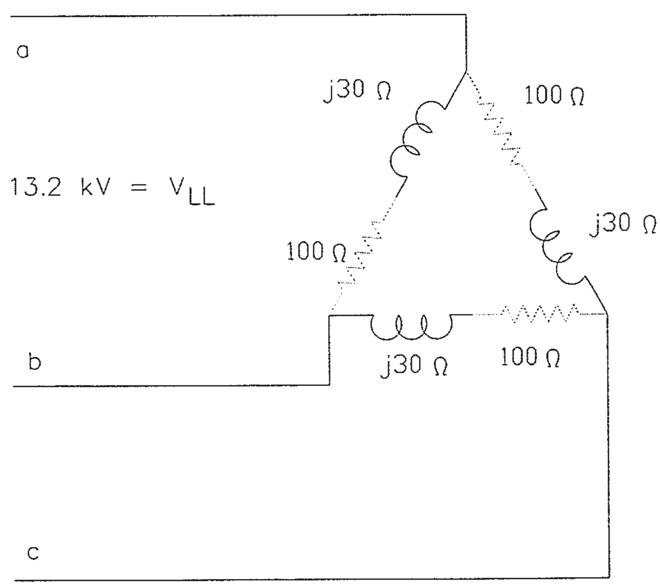
HW 7

ET 332b
3 Phase System Homework

For the circuit given below, compute:

a.) the magnitude of phase voltage
b.) the magnitude and phase angle of the line currents and the phase currents
c.) the total apparent power absorbed in the circuit
d.) the power factor for the circuit

Assume that V_{ab} is the zero reference phasor. V_{bc} phase angle is -120 degrees and V_{ca} phase angle is 120 degrees



Hw 7

ET 332b
Three-Phase Power Calculations

A 480 V line-to-line 60 Hz 3-phase power system supplies three loads:

1.) A 3-phase delta connected induction motor that has a line current of 200 A at a power factor of 70% lagging.
2.) A 3-phase delta connected 100 hp induction motor. This motor is operating at 80% of its rated power output and has an efficiency of 92% and a power factor of 0.80 lagging.
3.) A delta connected resistive heater that draws 50 kW from the 3-phase supply.

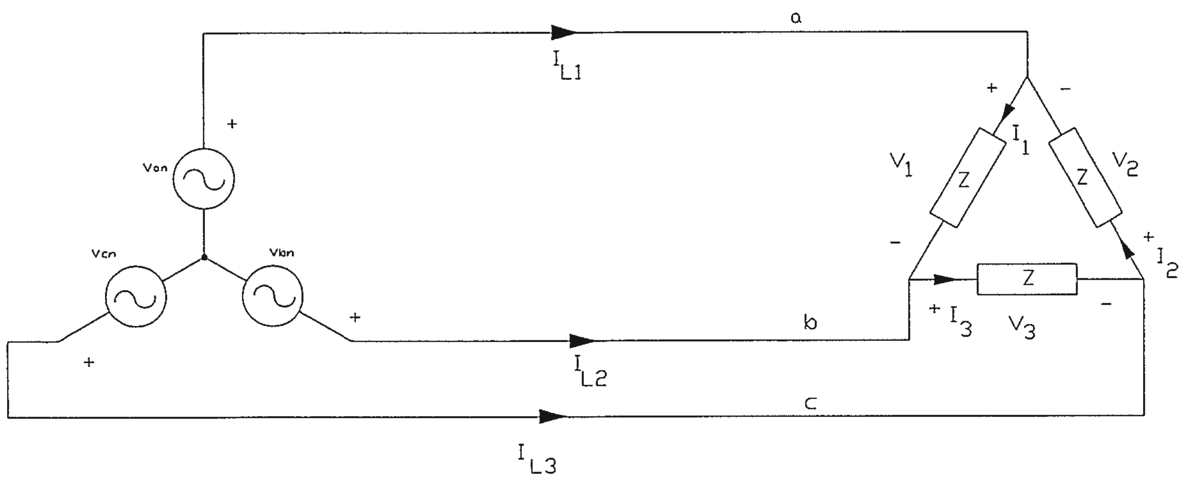
For this system:
a.) Find the total P Q, S and power factor for the combined loads
b.) Find the per phase voltage rating and value of capacitance for a delta connected capacitor bank that is used to correct the power factor of the combined loads to 0.95 lagging.
c.) Find the magnitude of line current for the total connected load when:
    1.) power factor is that computed in part a
    2.) power factor is corrected to 0.95

Hw 8

ET 332b
Three Phase Connections

Consider the system show below. The delta-connected load is balanced and made up of three impedances that have $Z = 27.7 \angle -40°$ ohms per phase. The wye-connected source voltages are $V_{an} = 277.1 \angle 0°$ V, $V_{bn} = 277.1 \angle -120°$ V, and $V_{cn} = 277.1 \angle 120°$ V. Determine:

a.) The phasor load voltages $\mathbf{V_1}$, $\mathbf{V_2}$, and $\mathbf{V_3}$
b.) The phasor load phase currents $\mathbf{I_1}$, $\mathbf{I_2}$, and $\mathbf{I_3}$
c.) The phasor line currents $\mathbf{I_{L1}}$, $\mathbf{I_{L2}}$, and $\mathbf{I_{L3}}$



Hw8

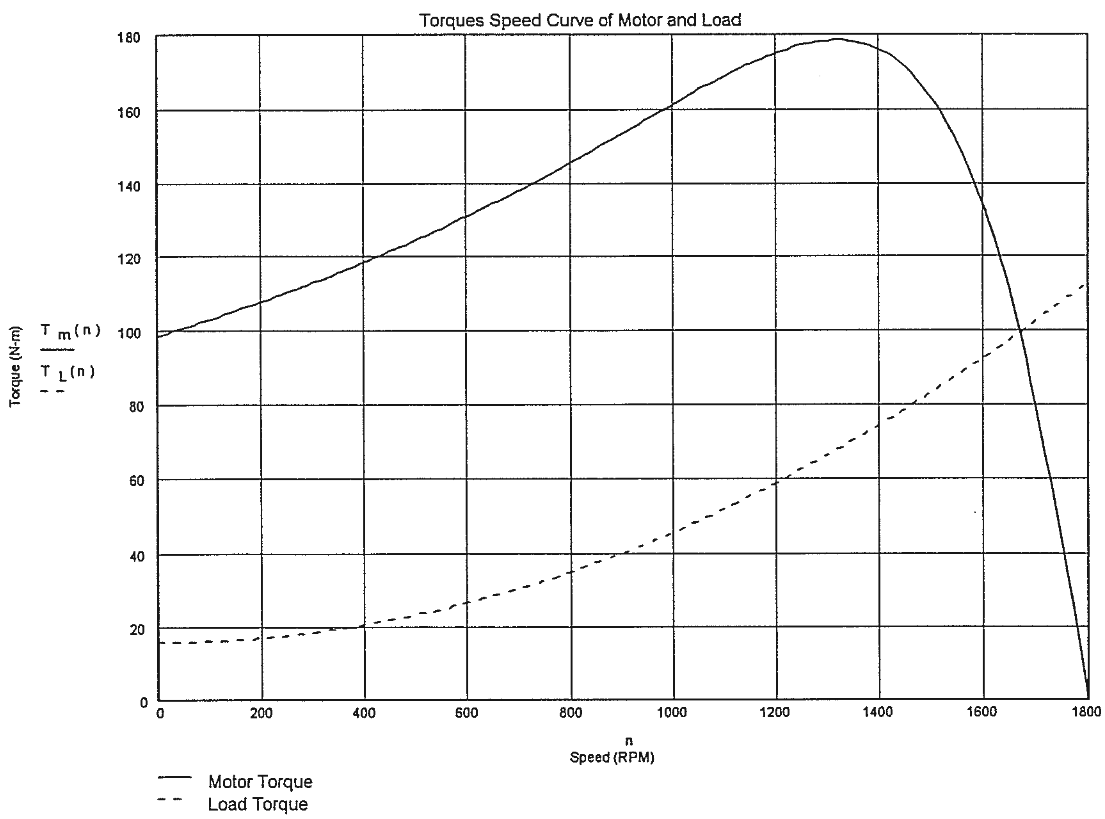
ET 332b
Homework
Motor Load Torque Speed Curves

Selecting motors in practice requires knowledge of the torque-speed or power-speed characteristic of the load. Simple load examples were given in the lecture. Most motors are used to drive industrial devices such as axial flow and centrifugal flow pumps and blowers. These devices have a torque-speed characteristic given by

$$T_L = c_p \cdot n^2$$

This equation shows that the toque of these devices is proportional to the square of the speed. The graph below shows the characteristics of a three-phase induction motor and a typical axial flow device plotted together. Where the two curves intersect is the operating point for the motor load combination. The motor will drive the load with is torque and speed.

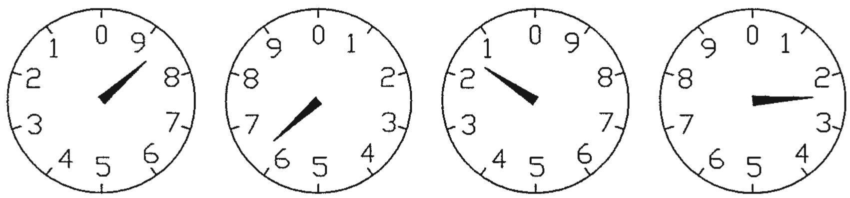
From these plots determine: a.) the maximum torque that the motor can develop, b.) the torque that the motor develops when its shaft speed is zero, c.) the horsepower that the motor must have to drive the pump.



Hw9

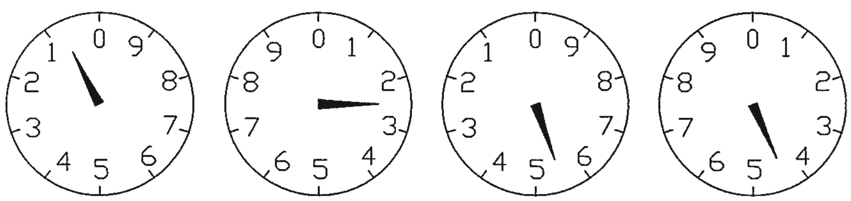
ET 332b
Energy and Demand Measurement Homework

The following meter reading was seen on October 1, 1997 on a customers meter.



10-1-97 Meter Reading

On October 30, 1997 the meter was read again and the dials on the meter were as shown below.



10-30-97 Meter Reading

Find the following:

The meter reading on 10-1-97 __________

The meter reading on 10-30-97 __________

The total energy usage for the period from 10-1 to 10-30 __________
(Assume that the meter is scaled like the class example)

If the above meter is coupled to the load through instrument transformers with the following ratings:

potential circuit: 13.8 kV / 115 Vac
current circuit: 1200/5 A connected on the 800/5 tap

Find the following: PTR= ________ CTR = ________

Power Ratio ________

The total energy consumed with the meter readings from 10-1 and 10-30.

The an estimate of the instantaneous demand is made with the above meter. The meter has a k_h of 7.2 Wh/rev. The meter disk makes 20 revolutions in 12.5 seconds. What is the value of D_i for this case? (Show work for credit.)

What is the demand if the meter is connected to the load through the instrument transformers above? (Show work for credit.)

HW
10, 11, 12

Sketch the appropriate equivalent circuit and phasor diagram and, assuming step-down operation, determine (a) the magnetizing current and the core-loss component of exciting current; (b) the exciting current; (c) the no-load power factor; (d) the eddy-current losses.

2–7/5 The hysteresis and eddy-current losses for a 75-kVA, 480—120 V, 60-Hz transformer are 215 W and 115 W, respectively. The magnetizing current is 2.5 percent rated current, and the transformer is operating in the step-up mode. Sketch the appropriate equivalent circuit and phasor diagram and determine (a) the exciting current; (b) the no-load power factor; (c) the reactive power input at no load.

2–8/8 A 480—120-V, 60-Hz transformer has its high-voltage winding connected to a 460-V system, and its low-voltage winding connected to a $24\angle 32.8°$-Ω load. Assume the transformer is ideal. Determine (a) the secondary voltage; (b) secondary current; (c) primary current; (d) input impedance at the primary terminals; (e) active, reactive, and apparent power drawn by the load.

2–9/8 A 7200—240-V, 60-Hz transformer is connected for step-up operation, and a $144\angle 46°$-Ω load is connected to the secondary. Assume the transformer is ideal and the input voltage is 220 V at 60 Hz. Determine (a) secondary voltage; (b) secondary current; (c) primary current; (d) input impedance at primary terminals of transformer; (e) active, reactive, and apparent power input to the transformer.

2–10/8 A 200-kVA, 2300—230-V, 60-Hz transformer operating at rated voltage in the step-down mode is supplying 150 kVA at 0.654 power-factor lagging. Assume the transformer is ideal. Determine (a) secondary current; (b) impedance of the load; (c) primary current.

2–11/8 A 50-Hz ideal transformer with a 5-to-1 turns ratio has a low-side current of $15.6\angle -32°$ A when operating in the step-down mode and feeding a load impedance of $8\angle 32°$ Ω. Sketch the circuit and determine (a) low-side voltage; (b) high-side voltage; (c) high-side current; (d) active, reactive, and apparent power input to the transformer.

2–12/10 A 100-kVA, 60-Hz, 7200—480-V, single-phase transformer has the following parameters.

$$R_{HS} = 2.98\ \Omega \qquad X_{HS} = 6.52\ \Omega$$
$$R_{LS} = 0.021\ \Omega \qquad X_{LS} = 0.031\ \Omega$$

Determine the equivalent impedance of the transformer (a) referred to the high side; (b) referred to the low side.

2–13/10 A 30-kVA, 60-Hz, 2400—600-V transformer has the following parameters in ohms:

$$R_{HS} = 1.86 \qquad X_{HS} = 3.41 \qquad X_{M,HS} = 4962$$
$$R_{LS} = 0.15 \qquad X_{LS} = 0.28 \qquad R_{fe,HS} = 19{,}501$$

HW 12 cont.
HW 13
HW 16

Determine the equivalent impedance of the transformer (a) referred to the high side; (b) referred to the low side.

2–14/10 A single-phase, 25-kVA, 2200—600-V, 60-Hz transformer used for step-down operation has the following parameters expressed in ohms:

$$R_{HS} = 1.40 \qquad X_{HS} = 3.20 \qquad X_{M,HS} = 5011$$
$$R_{LS} = 0.11 \qquad X_{LS} = 0.25 \qquad R_{fe,HS} = 18{,}694$$

Sketch the appropriate equivalent circuit and determine (a) the input voltage required to obtain an output of 25 kVA at 600 V and 0.8 power-factor lagging; (b) the load component of primary current; (c) the exciting current.

13 **2–15/10** A 100-kVA, 60-Hz, 7200—480-V, single-phase transformer has the following parameters expressed in ohms:

$$R_{HS} = 3.06 \qquad X_{HS} = 6.05 \qquad X_{M,HS} = 17{,}809$$
$$R_{LS} = 0.014 \qquad X_{LS} = 0.027 \qquad R_{fe,HS} = 71{,}400$$

The transformer is supplying a load that draws rated current at 480 V and 75 percent power-factor lagging. Sketch the appropriate equivalent circuit and determine (a) the equivalent resistance and equivalent reactance referred to the high side; (b) the input impedance of the combined transformer and load; (c) the load component of high-side current; (d) the input voltage to the transformer; (e) the exciting current and its components; (f) the input impedance at no load.

2–16/10 A 75-kVA, 60-Hz, 4160—240-V, single-phase transformer operating in the step-down mode is feeding a $1.45\angle{-38.74°}$-Ω load at 270 V. The transformer parameters expressed in ohms are:

$$R_{LS} = 0.0072 \qquad X_{LS} = 0.0128$$
$$R_{HS} = 2.16 \qquad X_{HS} = 3.84$$

Sketch the appropriate equivalent circuit and determine (a) the equivalent impedance of the transformer referred to the high side; (b) the input impedance; (c) the voltage impressed at the high-side terminals that results in a load voltage of 270 V. (d) Sketch the phasor diagram for the low-side voltage and current, and determine the power factor at the high side of the transformer.

16 **2–17/11** The parameters for a 250-kVA, 2400—480-V, single-phase transformer operating at rated voltage, rated kVA, and 0.82 power-factor lagging, are $X_{eq,HS} = 1.08\ \Omega$ and $R_{eq,HS} = 0.123\ \Omega$. The transformer is operating in the step-down mode. Sketch the appropriate equivalent circuit and determine (a) the equivalent low-side parameters; (b) the no-load voltage; (c) the voltage regulation at 0.82 power-factor lagging.

2–18/11 Re-solve Problem 2–17/11(b) and (c) assuming operation in the step-up mode and 0.70 power-factor leading.

HW 14

ET 332B
Per Unit Homework Problems

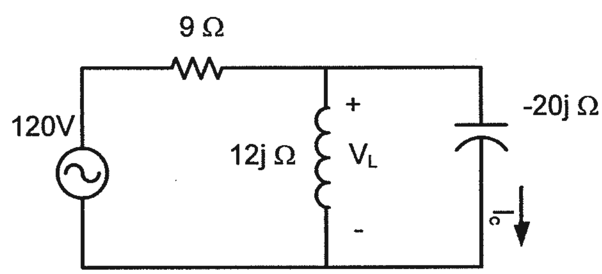
1.) A single phase 60 Hz control voltage transformer is rated at 500 VA, 480-120 volts. It has a total winding impedance in terms of the secondary side of 0.125 +0.355j ohms. Compute the per unit winding impedance of the transformer based on the transformer power rating and the rated secondary voltage.

2.) Refer the impedance give in problem 1 to the primary side. Repeat problem 1 using the rated primary voltage as the voltage base. Compare and comment on the results of the two calculations.

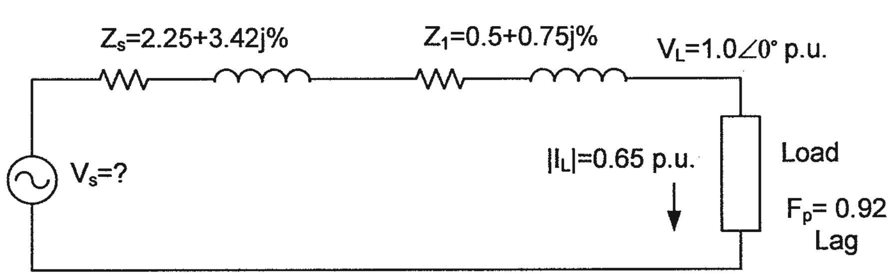
3.) A 10 kVA, 2400-120 volt transformer has a percent winding impedance of 1.25+2.5J% based on transformer power and voltage ratings.

a.) Find the winding impedance in ohms based on the rated transformer primary voltage.
b.) Find the winding impedance in ohms based on the rated transformer secondary voltage.

4.) The circuit shown below has a base voltage of 120 Vac and a base power of 1000 VA.
a.) Find the per unit current phasor, I_c, flowing through the capacitor.
b.) Find the per unit voltage drop phasor, V_L, across the inductor.
c.) Convert the per unit values from parts a and b into capacitor current in amps and the inductor voltage in volts.



5.) The system below has a base voltage of 240V and a base power of 25 kVA find the source voltage (in actual volts) required to maintain 1 p.u. voltage on the load with the indicated current flowing.



HW 15

2–19/11 A 333-kVA, 60-Hz, 4160—2400-V transformer operating in the step-down mode has an equivalent resistance and equivalent reactance referred to the high side of 0.5196 Ω and 2.65 Ω, respectively. Assume operation is at rated voltage, rated load, and 0.95 power-factor leading. Sketch the appropriate equivalent circuit and determine (a) the no-load voltage, (b) the voltage regulation; (c) the combined input impedance of the transformer and load.

2–20/11 A 100-kVA, 4800—480-V, 60-Hz, single-phase distribution transformer has 6 V/turn and an equivalent impedance referred to the high side of $8.48\underline{/71^\circ}$ Ω. The transformer is operating in the step-down mode supplying a 50-kVA, unity power-factor load at 480 V. Determine (a) the output voltage when the load is removed; (b) the inherent voltage regulation of the transformer when operating at 78 percent power-factor lagging. *Note:* By definition, inherent voltage regulation infers rated kVA.

2–21/11 A 37.5-kVA, 6900—230-V, 60-Hz, single-phase transformer is operating in the step-down mode at rated load, rated voltage, and 0.68 power-factor lagging. The equivalent resistance and reactance referred to the low side are 0.0224 Ω and 0.0876 Ω, respectively. The magnetizing reactance and equivalent core-loss resistance (high side) are 43.617 Ω and 174.864 Ω, respectively. Determine (a) the output voltage when the load is removed; (b) the voltage regulation: (c) the combined input impedance of transformer and load; (d) the exciting current and input impedance at no load.

2–22/11 A 500-kVA, 7200—600-V, 60-Hz transformer is operating in the step-down mode at rated kVA and 0.83 power-factor lagging. The output voltage when the load is removed is 625 V. Determine the equivalent impedance of the transformer referred to the high side (assume the equivalent resistance is negligible). *Hint:* Draw a phasor diagram showing **I**, **E**, **V**, and the impedance drop. Use trigonometry to solve for IX_{eq} and then determine X_{eq}.

2–23/12 A 25-kVA, 480—120-V, 60-Hz transformer has a 2.1 percent impedance. Determine (a) the equivalent impedance referred to the high side; (b) the equivalent impedance referred to the low side.

2–24/12 The percent impedance and the percent resistance of a 25-kVA, 7200—600-V, 60-Hz transformer are 2.3 and 1.6 percent, respectively. Determine (a) the percent reactance; (b) the equivalent resistance, equivalent reactance, and equivalent impedance referred to the high side; (c) repeat (b) for the equivalent low-side values.

2–25/12 A 500-kVA, 7200—240-V, 60-Hz transformer with a 2.2 percent impedance was severely damaged as a result of a dead short across the secondary terminals. Determine (a) the short-circuit current; (b) the required percent impedance of a replacement transformer that will limit the low-side short-circuit current to 60,000 A.

2–26/12 A 167-kVA, 60-Hz, 600—240-V, 60-Hz, 4.1 percent impedance distribution transformer with 46 turns on the high side is operating at rated load and 0.82 power-factor lagging. Determine (a) the voltage regulation; (b) the

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50-Hz system, with the restriction that it maintain the same maximum core flux and the same total losses. Determine (a) the new voltage rating; (b) the new kVA rating.

2–35/13 A 75-kVA, 450—120-V, 60-Hz, single-phase transformer has percent resistance and percent reactance of 1.75 and 3.92, respectively. Its efficiency when operating at rated voltage, rated frequency, and rated load at 0.74 power-factor lagging is 97.1 percent. Determine (a) the core loss; (b) the core loss and efficiency if the transformer is powered at the same voltage, load, and power factor, but at 50 Hz. Assume the core-loss ratio $P_h : P_e$ is 2.5.

2–36/13 A 200-kVA, 7200—600-V, 60-Hz transformer is operating at rated load and 90 percent power-factor lagging. The core loss, resistance, and reactance of the transformer, expressed in per-unit values, are 0.0056, 0.0133, and 0.0557, respectively. Determine (a) the efficiency; (b) the inherent voltage regulation; (c) the efficiency and regulation at 30 percent load and 80 percent power-factor lagging.

2–37/13* A 50-kVA, 2300—230-V, 60-Hz transformer supplies a 0.8 lagging power-factor load whose kVA is adjustable from no load to 120 percent rated kVA. The percent resistance, percent reactance, and percent core loss are 1.56, 3.16, and 0.42, respectively. For 2-kVA increments of load, tabulate and plot the efficiency of the transformer from no load to 120 percent rated load.

2–38/14 A short-circuit test performed on a 150-kVA, 4600—230-V, 60-Hz transformer provided the following data:

$$V_{SC} = 182 \text{ V} \qquad I_{SC} = 32.8 \text{ A} \qquad P_{SC} = 1902 \text{ W}$$

Determine (a) per-unit resistance and per-unit reactance; (b) regulation when operated at 0.6 power-factor lagging.

2–39/14 The following test data were obtained from short-circuit and open-circuit tests of a 50-kVA, 2400—600-V, 60-Hz transformer.

$$V_{OC} = 600 \text{ V} \qquad V_{SC} = 76.4 \text{ V}$$
$$I_{OC} = 3.34 \text{ A} \qquad I_{SC} = 20.8 \text{ A}$$
$$P_{OC} = 484 \text{ W} \qquad P_{SC} = 754 \text{ W}$$

Determine (a) the equivalent high-side parameters; (b) regulation; (c) efficiency at rated load and 0.92 power-factor lagging.

2–40/14 Data from short-circuit and open-circuit tests of a 25-kVA, 6900—230-V, 60-Hz transformer are:

$$V_{OC} = 230 \text{ V} \qquad V_{SC} = 513 \text{ V}$$
$$I_{OC} = 5.4 \text{ A} \qquad I_{SC} = 3.6 \text{ A}$$
$$P_{OC} = 260 \text{ W} \qquad P_{SC} = 465 \text{ W}$$

Determine (a) the magnetizing reactance referred to the high side; (b) the per-unit parameters; (c) efficiency; (d) voltage regulation at 0.65 per-unit

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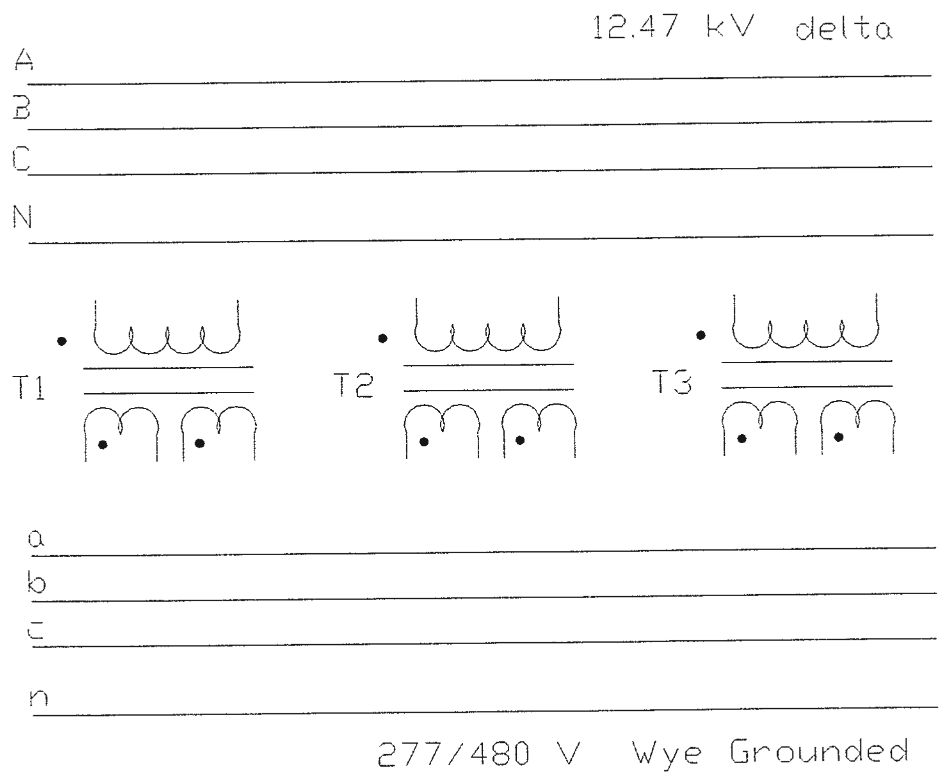
ET 332b
Three Phase Transformer Connection Homework

Three single phase transformer are to be connected to form a three phase bank. The bank will supply a combined single and three phase load of 225 kVA. (Assume that the single phase load is equally divide between all phases) The primary side connects to a 12.47 kV system and the secondary side is grounded wye connected. The secondary voltage levels are to be 277/480 V. Each winding in the secondary is rated at 277 V.

1.) Draw the necessary connections in the figure to achieve a 12.47 kV delta / 277/480 V grounded wye secondary connection with 30° phase shift across the bank. Use T1 for phase A, T2 for phase B, and T3 for Phase C.

2.) What is the turns ratio of each of the single phase transformers in the bank?

3.) What should the power rating of each of the three transformers be to handle the anticipated bank load?



HW: 19
HW 20

3–8/6 Two 50-kVA, 60-Hz transformers have the following voltage ratios and equivalent low-side impedances:

Transformer	Voltage Ratios	$R_{eq,Ls}$ (Ω)	$X_{eq,Ls}$ (Ω)
A	4800—482	0.0688	0.1449
B	4800—470	0.0629	0.1634

The transformers are connected in parallel and operated from a 4800-V, 60-Hz system. Calculate the circulating current.

3–9/6 A 75-kVA, 60-Hz, 4800—432-V transformer *A* is connected in parallel with a similar transformer *B*, whose exact ratio is unknown. The transformers are operating in the step-down mode and have a circulating current of $37.32\angle{-63.37°}$ A. The respective impedances as determined from a short-circuit test, and referred to the low side, are

$$\mathbf{Z}_{eq,A} = 0.0799\angle{62°}\,\Omega \qquad \mathbf{Z}_{eq,B} = 0.0676\angle{65°}\,\Omega$$

Determine the voltage ratio of transformer *B*.

3–10/7 Two 2400—240-V, 60-Hz, 100-kVA transformers *A* and *B* are operating in parallel and supplying 150-kW at 0.8 lagging power factor to a distribution system. The turns ratios are the same, and the equivalent impedances referred to the high side are $(0.869 + j2.38)\Omega$, and $(0.853 + j3.21)\Omega$, respectively. Determine the high-side current drawn by each transformer if the incoming voltage is 2470-V.

3–11/7 Two 4800—480-V, 167-kVA transformers are operated in parallel and supply a 480-V, 200-kVA, 0.72 lagging power-factor load. The percent impedance of each transformer is

$$\mathbf{Z}_A = (1.11 + j3.76)\% \qquad \mathbf{Z}_B = (1.46 + j4.81)\%$$

Sketch the equivalent circuit and determine (a) the total load current; (b) the current supplied by each transformer secondary.

3–12/7 Two 7200—240-V, 75-kVA transformers are to be operated in parallel. The per-unit impedances of the two transformers are

$$\mathbf{Z}_{A,PU} = 0.0121 + j0.0551 \qquad \mathbf{Z}_{B,PU} = 0.0201 + j0.0382$$

Determine the current supplied by each transformer secondary as a percentage of the total load current.

3–13/7 Three single-phase, 2400—120-V, 60-Hz, 200-kVA transformers are to be operated in parallel and supply a 500-kVA unity power-factor load. The percent resistance and percent reactance of the respective transformers are

Transformer	%*R*	%*X*
A	1.30	3.62
B	1.20	4.02
C	1.23	5.31

Hw 20

Test Code for Liquid Immersed Distribution, Power, and Regulating Transformers, and Guide for Short-Circuit Testing of Distribution and Power Transformers. ANSI C57.12.90-1980, American National Standards Institute, New York, 1980.

Westinghouse Staff. *Electrical Transmission and Distribution Reference Book.* Westinghouse Electric Corp., 1964.

REVIEW QUESTIONS

1. Differentiate between subtractive polarity and additive polarity as it pertains to transformers. Why is subtractive polarity preferred?
2. What is meant by the basic impulse level (BIL) of a transformer?
3. How does an autotransformer differ physically and electrically from a two-winding transformer?
4. Sketch the circuit for a step-down autotransformer connected to a load and show the relative magnitude of currents and voltages in the windings.
5. What are the advantages and disadvantages of an autotransformer with respect to a two-winding transformer?
6. If a 50-kVA transformer has a turns ratio of 20 : 1, what would be its power rating if it is reconnected as an autotransformer?
7. What is meant by utilization voltage?
8. What is a buck-boost transformer, and what are its applications?
9. Using a circuit diagram, explain the effect of different turns ratios on the performance of paralleled transformers.
10. Under what conditions must the nameplate-power-rating of a transformer be rerated to a lower value? Explain.
11. What is transformer in-rush current? What does it depend on? What is its approximate range of values? Approximately how long does it last? Why is this information important?
12. What are transformer harmonics, and how are they generated?
13. Explain what would happen if three-phase transformer banks that have a 30° phase difference between corresponding secondary line voltages are paralleled.
14. State and explain the adverse effect on a three-phase distribution system if the third-harmonic component of exciting current is suppressed.
15. What are the advantages and disadvantages of a three-phase transformer over an equivalent three-phase bank composed of three single-phase transformers?
16. Sketch a circuit showing a transformer feeding a load. Include current and potential transformers along with associated instruments in both primary and secondary circuits.

PROBLEMS

3–1/4 A 2300—450-V, 60-Hz autotransformer is used for step-down operation and supplies a load whose impedance is $2\angle 10^\circ\ \Omega$. Neglecting the internal impedance of the transformer, determine (a) the load current; (b) high-side

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9. Explain how slip affects rotor frequency and rotor voltage.
10. (a) Draw the circle diagram for the rotor of an induction motor. (b) Using the circle diagram as an aid to your analysis, explain the changes that take place in air-gap power as the rotor accelerates from standstill to near synchronous speed.
11. Differentiate between air-gap power, mechanical power developed, and shaft power out.
12. (a) Sketch the equivalent circuit for an induction-motor rotor and the related impedance diagram. (b) Determine from the impedance diagram the magnitude and phase angle of the rotor impedance in terms of its components.
13. (a) Draw the circle diagram for the rotor of an induction motor. (b) Using the circle diagram as an aid to your analysis, explain the changes that take place in air-gap power as the rotor accelerates from standstill to near synchronous speed.
14. (a) Sketch a representative torque-slip characteristic of a squirrel-cage induction motor and circle the points corresponding to locked rotor, breakdown torque, and rated torque. (b) Sketch the circle diagram for the rotor and draw the current phasors corresponding to the points circled in (a). (c) Using the sketches as an aid to your analysis, explain in detail the behavior of an induction motor as the machine is loaded from no load, to full load, to breakdown; assume that the machine had accelerated to rated speed before loading. Include in your analysis the reasons for changes in motor torque with increased shaft load.
15. What causes parasitic torques and what adverse effect can they have on induction-motor operation?
16. Differentiate between locked-rotor torque, pull-up torque, and breakdown torque.
17. Differentiate between efficiency and power factor.
18. List the types of losses in an induction motor and state the factors affecting these losses.
19. Sketch the power-flow diagram for an induction motor and show the relationship between power in, air-gap power, shaft power out.

PROBLEMS

4–1/7 A four-pole, 60-Hz, 10-hp, 460-V, three-phase induction motor operates at 1750 r/min when fully loaded and at its rated frequency and rated voltage. Determine (a) synchronous speed; (b) slip speed; (c) per-unit slip.

4–2/7 A 100-hp, 16-pole, 460-V, three-phase, 60-Hz induction motor has a slip of 2.4 percent when running at rated conditions. Determine (a) synchronous speed; (b) rotor speed; (c) rotor frequency.

4–3/7 A 60-Hz, four-pole, 450-V, three-phase induction motor operating at rated conditions has a speed of 1775 r/min. Determine (a) synchronous speed; (b) slip; (c) slip speed; (d) rotor frequency.

4–4/7 A 200-hp, 2300-V, three-phase, 60-Hz, wound-rotor induction motor has a blocked-rotor voltage of 104-V. The shaft speed and slip speed, when operating at rated load, are 1775 r/min and 25 r/min, respectively. Determine (a)

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ET 332b
Homework

A four pole 3 phase induction motor operates on a 60 Hz power system. The motor has a rated slip of 0.055. Find:

a.) The synchronous speed of the rotating magnetic field in the stator.

b.) The rated speed of the motor in RPM.

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HW 23

number of poles; (b) slip; (c) rotor frequency; and (d) rotor voltage at slip speed.

4–5/7 A six-pole three-phase induction motor is operating at 480 r/min from a 25-Hz, 230-V supply. The voltage induced in the rotor when blocked is 90 V. Determine (a) slip speed; (b) rotor frequency and rotor voltage at 480 r/min.

22 **4–6/7** A 100-hp, three-phase induction motor, operating at rated load, runs at 423 r/min when connected across a 450-V, 60-Hz supply. The slip at this load is 0.06. Determine (a) synchronous speed; (b) number of stator poles; (c) rotor frequency.

4–7/7 A four-pole/eight-pole, multispeed, 60-Hz, 10-hp, 240-V, three-phase induction motor operating with four poles runs at 1750 r/min when fully loaded and at its rated voltage and frequency. Determine (a) slip speed; (b) percent slip; (c) the synchronous speed if operating in the eight-pole mode and at 20 percent rated frequency.

4–8/11 A 20-hp, 230-V, 60-Hz, four-pole, three-phase induction motor operating at rated load has a rotor copper loss of 331 W, and a combined friction, windage, and stray power loss of 249 W. Determine (a) mechanical power developed; (b) air-gap power; (c) shaft speed; (d) shaft torque.

4–9/11 A 12-pole, 50-Hz, 20-hp, 220-V, squirrel-cage motor operating at rated conditions runs at 480 r/min, is 85 percent efficient, and has a power factor of 0.73 lagging. Determine (a) synchronous speed; (b) slip; (c) line current; (d) rated torque; (e) rotor frequency.

23. **4–10/11** A three-phase, 230-V, 30-hp, 50-Hz, six-pole induction motor is operating with a shaft load that requires 21.3kW of input to the rotor. The rotor copper losses are 1.05 kW, and the combined friction, windage, and stray power losses for this load are 300 W. Determine (a) shaft speed; (b) mechanical power developed; (c) developed torque; (d) shaft torque; (e) percent of rated horsepower load that the machine is required to deliver.

4–11/15 A 30-hp, three-phase, 12-pole, 460-V, 60-Hz induction motor operating at reduced load draws a line current of 35 A, and has an efficiency and power factor of 90 and 79 percent, respectively. The stator conductor loss, rotor conductor loss, and core loss are 837 W, 485 W, and 375 W, respectively. Sketch the power-flow diagram, enter known values, and determine (a) input power; (b) shaft horsepower; (c) total losses; (d) rotor speed; (e) shaft torque; (f) combined windage, friction, and stray load loss.

4–12/15 A three-phase 5000-hp, 4000-V, 60-Hz, four-pole induction motor is operating at 4130 V, 60 Hz, and 67 percent rated load. The breakdown of losses for this load are as follows: stator conductors, 12.4 kW; rotor conductors, 9.92 kW; core, 12.44 kW; stray power, 10.2 kW; friction and windage, 18.2 kW. Sketch the power-flow diagram, enter known values, and determine (a) shaft speed; (b) shaft torque; (c) developed torque; (d) input power to the stator; (e) overall efficiency.

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4–13/15 A 10-pole, 125-hp, 575-V, 60-Hz, three-phase induction motor operating at rated conditions draws a line current of 125 A and has an overall efficiency of 93 percent. The core loss, stator conductor loss, and rotor conductor loss are 1053 W, 2527 W, and 1755 W, respectively. Sketch the power-flow diagram, substitute values, and determine (a) shaft speed; (b) developed torque; (c) shaft torque; (d) power factor; (e) combined windage, friction, and stray power loss.

4–14/15 A 40-hp, 50-Hz, 2300-V, eight-pole induction motor is operating at 80 percent rated load and 6 percent reduced voltage. The efficiency and power factor for these conditions are 85 and 90 percent, respectively. The combined windage, friction, and stray power losses are 1011 W, the rotor conductor losses are 969 W, and the stator conductor losses are 1559 W. Sketch the power-flow diagram, enter values, and determine (a) mechanical power developed; (b) shaft speed; (c) shaft torque; (d) slip speed; (e) line current; (f) core loss.

4–15/15 A three-phase, 5-hp, 60-Hz, 115-V, four-pole induction motor operating at rated voltage, rated frequency, and 125 percent rated load has an efficiency of 85.4 percent. The stator conductor loss, rotor conductor loss, and core loss are 223.2 W, 153 W, and 114.8 W, respectively. Sketch the power-flow diagram, enter the given data, and determine (a) shaft speed; (b) shaft torque; (c) loss in torque due to the combined friction, windage, and stray power.

4–16/15 A three-phase, 50-hp, 230-V, 60-Hz, four-pole induction motor is operating at rated load, rated voltage, and rated frequency. Assume a system overload results in a 5 percent drop in frequency, and a 7 percent drop in voltage. To help reduce the system load, the shaft load is reduced to 70 percent rated horsepower, resulting in a line current of 100 A. Assume the losses for the new operating conditions are as follows: stator conductor loss, 1015 W; rotor conductor loss, 696 W; core loss, 522 W; and the combined windage, friction, and stray power loss is 667 W. Sketch the power-flow diagram, enter given data, and determine (a) percent efficiency; (b) speed; (c) shaft torque; (d) power factor.

4–17/15 A three-phase, 25-hp, 230-V, 60-Hz, two-pole induction motor drives a load that demands a constant torque regardless of speed (constant load torque). The machine is operating at rated voltage, rated frequency, and its rated speed of 3575 r/min. Determine the shaft horsepower, speed, and efficiency if the frequency drops to 54 Hz. The power factor and line current for the new conditions are 89 percent and 55 A, respectively, and the respective stator conductor loss, rotor conductor loss, and core loss, are 992.7 W, 496 W, and 546 W, respectively.

hw 25

ET 332b
Induction Motor Homework

The following constants apply to a 2200 V 50 hp, three-phase 60 Hz wye-connected, 6 pole squirrel-cage induction motor.

$R_1 = 3.5\ \Omega$/phase
$R_2 = 2.4\ \Omega$/phase
$X_1 = X_2 = 7.2\ \Omega$/phase
$R_{fe} = 4170\ \Omega$/phase
$X_M = 328\ \Omega$/phase

Assume that the value of R_{fe} includes the friction, windage and stray losses. Also assume that the motor core losses are negligible. Calculate for a slip of 0.019: a.) the rotor developed torque; b.) the motor efficiency c.) the motor power factor.

Hw 26

5–19/8 A three-phase, 125-hp, 60-Hz, eight-pole, 575-V, design B induction motor is to be operated from a 50-Hz system. Determine (a) allowable voltage at 50 Hz; (b) allowable shaft load in horsepower; (c) new synchronous speed; (d) shaft speed assuming a slip of 2.1 percent; (e) shaft torque at 2.1 percent slip.

5–20/9 A three-phase, wye-connected, 25-hp, 60-Hz, 575-V, six-pole, wound-rotor motor, operating at nameplate conditions, runs at 1164 r/min with the rheostat shorted. The stator/rotor turns ratio is 2.15, and the motor parameters in ohms/phase are

$$R_1 = 0.3723 \qquad R_2 = 0.390 \qquad R_{fe} = 26.59$$
$$X_1 = 1.434 \qquad X_2 = 2.151 \qquad X_m = 354.6$$

Determine (a) slip at which $T_{D,\max}$ occurs; (b) $T_{D,\max}$; (c) the rheostat resistance/phase required to operate the machine at rated torque load and 1074 r/min.

5–21/9 A 40-hp, 60-Hz, 460-V, four-pole, wye-connected wound-rotor motor, with slip rings shorted, has its breakdown torque occur at 25 percent slip. The rotor impedance in ohms/phase referred to the stator is $0.158 + j0.623$, and the turns ratio is 1.28. Determine the rheostat resistance required to cause the breakdown torque to occur at 60 percent slip.

5–22/12 A 75-hp, 460-V, six-pole NEMA design A machine with Code letter H is operating at rated load, is 89 percent efficient, has a power factor of 84 percent, and has a slip of 2.36 percent. Determine (a) rated current; (b) the expected range of locked-rotor current with rated voltage and rated frequency applied.

5–23/12 A 30-hp, 60-Hz, 230-V, two-pole, design E motor, with Code letter C, operating at rated conditions has an efficiency of 91.8 percent and a power factor of 86.2 percent. Determine (a) rated current; (b) the expected range of locked-rotor current.

5–24/12 A 150-hp, 60-Hz, 460-V, four-pole, design B motor, with Code letter R, operating at rated conditions has an efficiency of 94.5 percent and a power factor of 86.2 percent. Determine (a) rated current; (b) the expected range of locked-rotor current.

5–25/15 A 60-hp, design C, 230-V, 60-Hz, six-pole motor with a 1.15 service factor and Class B insulation is operating at rated horsepower from an unbalanced three-phase system. The three line-to-line voltages are 232 V, 238 V, and 224 V. The machine is new and has an expected life of 20 years. Determine (a) the percent voltage unbalance; (b) the expected approximate temperature rise if operating at rated load in a 40°C ambient situation, with the percent unbalance in (a); (c) the expected insulation life; (d) the required rerating, if any, to prevent shortening the life of the insulation.

5–26/15 A three-phase, 30-hp, 460-V, 60-Hz, 1770 r/min, design B induction motor with Class F insulation and service factor 1.0 is operating at rated shaft load in a 40°C ambient situation, and has an expected 20-year life. A preventive maintenance check shows line-to-line voltages to be 449.2 V, 431.3 V, and

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462.4 V. Determine (a) percent voltage unbalance; (b) expected temperature rise; (c) expected insulation life; (d) rerating of motor, if any to prevent shortening insulation life.

5–27/16 A three-phase, wye-connected 10-hp, 60-Hz, 230-V, four-pole induction motor has the following per-unit parameters:

$R_1 = 0.0358$	$R_2 = 0.0264$	R_{fe} = not known
$X_1 = 0.0964$	$X_2 = 0.1450$	$X_M = 3.02$

Determine the machine parameters in ohms/phase.

5–28/16 A three-phase, 460-V, wye-connected, 200-hp, 60-Hz, eight-pole, design *B*, squirrel-cage induction motor, has the following per-unit parameters:

$R_1 = 0.011$	$R_2 = 0.011$	R_{fe} = not known
$X_1 = 0.123$	$X_2 = 0.210$	$X_M = 2.994$

Determine the corresponding ohmic values.

5–29/16 A three-phase, wye-connected, 100-hp, 60-Hz, 440-V, 10-pole induction motor has the following parameters in ohms:

$R_1 = 0.0864$	$R_2 = 0.078$	$R_{fe} = 110$
$X_1 = 0.146$	$X_2 = 0.218$	$X_M = 3.185$

Determine the corresponding per-unit values.

5–30/17 A three-phase, design *B*, wye-connected, 25-hp, 575-V, 60-Hz induction motor, operating at rated conditions, draws a line current of 27 A. Data from a 15-Hz blocked-rotor test, a 60-Hz no-load test, and a DC test are:

Blocked Rotor	No-Load	DC
$V_{line} = 54.7$ V	$V_{line} = 575$ V	$V_{DC} = 20$ V
$I_{line} = 27.0$ A	$I_{line} = 11.8$ A	$I_{DC} = 27$ A
$P_{3\text{-phase}} = 1653$ W	$P_{3\text{-phase}} = 1264.5$ W	

Determine R_1, R_2, X_1, X_2, X_M, and the combined core, friction, and windage loss.

5–31/17 The following data were obtained from a no-load test, a 15-Hz blocked-rotor test, and a DC test on a three-phase, wye-connected, four-pole, 30-hp, 460-V, 60-Hz, 40-A, design *C* induction motor:

Blocked Rotor	No-Load	DC
$V_{line} = 42.39$ V	$V_{line} = 458.6$ V	$V_{DC} = 15.4$ V
$I_{line} = 40$ A	$I_{line} = 17.0$ A	$I_{DC} = 40.2$ A
$P_{3\text{-phase}} = 1828.8$ W	$P_{3\text{-phase}} = 1381.4$ W	

Determine R_1, R_2, X_1, X_2, X_M, and the combined core, friction, and windage loss.

5–32/17 A three-phase, design *A*, wye-connected, 15-hp, 460-V, 60-Hz induction motor draws a line current of 14 A when operating at rated conditions. A

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60-Hz no-load test, a 15-Hz blocked-rotor test, and a DC test provide the following data:

Blocked Rotor	No-Load	DC
$V_{line} = 18.5$ V	$V_{line} = 459.8$ V	$V_{DC} = 5.6$ V
$I_{line} = 13.9$ A	$I_{line} = 6.2$ A	$I_{DC} = 14.0$ A
$P_{3\text{-phase}} = 264.6$ W	$P_{3\text{-phase}} = 799.5$ W	

Determine R_1, R_2, X_1, X_2, X_M, and the combined core, friction, and windage loss.

5–33/18 A 75-hp, 2300-V, 60-Hz, two-pole, wye-connected motor, driven at 3650 r/min by a steam turbine, is connected to a 2300-V, 60-Hz distribution system. The motor parameters in ohms are:

$$R_1 = 1.08 \qquad R_2 = 2.14 \qquad R_{fe} = 1892$$
$$X_1 = 8.14 \qquad X_2 = 3.24 \qquad X_M = 187.5$$

Determine the active power that the machine delivers to the system.

5–34/18 A 60-Hz, 15-hp, 460-V, six-pole, wye-connected, three-phase induction motor is connected to a 460-V distribution system and driven at 1210 r/min by a diesel engine. The motor parameters in ohms are:

$$R_1 = 0.200 \qquad R_2 = 0.250 \qquad X_M = 42.0$$
$$X_1 = 1.20 \qquad X_2 = 1.29 \qquad R_{fe} = 317$$

Determine the active power that the machine delivers to the system.

27 **5–35/18** A three-phase, wye-connected, 400-hp, four-pole, 380-V, 50-Hz induction motor is driven by a wind turbine at 1515 r/min. The motor parameters in ohms are:

$$R_1 = 0.00536 \qquad R_2 = 0.00613 \qquad R_{fe} = 7.66$$
$$X_1 = 0.0383 \qquad X_2 = 0.0383 \qquad X_M = 0.5743$$

Determine the active power that the machine delivers to the system.

5–36/20 A 200-hp, 1150 r/min, 440-V, 60-Hz pump motor uses a wye-connected autotransformer for reduced voltage starting. The transformer has a 65 percent tap. The starting torque at rated voltage is 150 percent rated torque. Sketch a one-line diagram and determine the blocked-rotor torque when (a) starting at rated voltage; (b) starting at reduced voltage.

5–37/20 A three-phase 12-pole, 220-V, 60-Hz, 50-hp squirrel-cage motor, operating at rated load, has a speed of 595 r/min, an efficiency of 89 percent, and a power factor of 81 percent lagging. The locked-rotor current and locked-rotor torque at rated voltage and rated frequency are 725 A and 120 percent rated torque, respectively. Determine (a) rated line current; (b) rated torque; (c) minimum voltage required to obtain a blocked-rotor torque equal to 70

Hw 29 30 31

13. Differentiate between pull-in torque, pull-out torque, and locked-rotor torque.
14. What effect does load inertia have on pull-in torque, pull-out torque, and locked-rotor torque?
15. Explain the dynamic braking process for synchronous motors.

PROBLEMS

29 **8–1/3** Determine the speed of a 40-pole synchronous motor operating from a three-phase, 50-Hz, 4600-V system.

8–2/3 Determine the frequency required to operate a 16-pole, 480-V synchronous motor at 225 r/min.

8–3/3 A three-phase 50-hp, 2300-V, 60-Hz synchronous motor is operating at 90 r/min. Determine the number of poles in the rotor.

8–4/7 A two-pole, three-phase, 1000-hp, 2300-V, wye-connected synchronous motor operating at rated power, rated voltage, and rated frequency has a power factor of 0.80 leading, an efficiency of 96.5 percent, and a power angle of $-23°$. The synchronous reactance is 4.65 Ω/phase. Determine (a) line current; (b) cemf/phase.

30 **8–5/7** A 4000-hp, 13,200 V, 60-Hz, two-pole, three-phase, wye-connected cylindrical-rotor synchronous motor, operating at rated load and 0.84 power-factor leading, has an efficiency (excluding field losses and armature resistance losses) of 96.5 percent. The synchronous reactance per phase is 49.33 Ω. Sketch the phasor diagram and determine (a) rated torque; (b) armature current; (c) excitation voltage; (d) power angle; (e) pull-out torque.

8–6/7 A 2500-hp, 6600-V, 60-Hz, 3600 r/min, three-phase, wye-connected synchronous motor is operating at a power angle of $-28.5°$ and a cemf of 4500 V/phase. The synchronous reactance is 15.8 Ω/phase. Determine (a) the developed torque; (b) the shaft-power out, assuming a mechanical efficiency of 94.3 percent; (c) power factor; (d) pull-out torque.

31 **8–7/7** A 200-hp, 460-V, four-pole, 60-Hz, three-phase, wye-connected synchronous motor, operating at rated load, has an efficiency of 94 percent and a power factor of 80 percent leading. Assuming the synchronous reactance is 1.16 Ω/phase, determine (a) the excitation voltage and power angle; (b) the pull-out torque; (c) the pull-out torque if the excitation voltage is cut in half.

8–8/8 The phasor diagram for a synchronous motor operating at 0.5 rated load is shown in Figure 8.17. Using the same applied voltage phasor, construct a new phasor diagram that shows the new conditions, assuming the shaft load is increased to its rated value. Show all construction lines.

8–9/9 Given the phasor diagram for the synchronous motor shown in Figure 8.18, neglecting magnetic saturation, and showing all construction lines, construct a new phasor diagram for each of the following specified conditions: (a) field current unchanged, shaft load doubled; (b) shaft load unchanged, field current doubled; (c) shaft load doubled, field current doubled.

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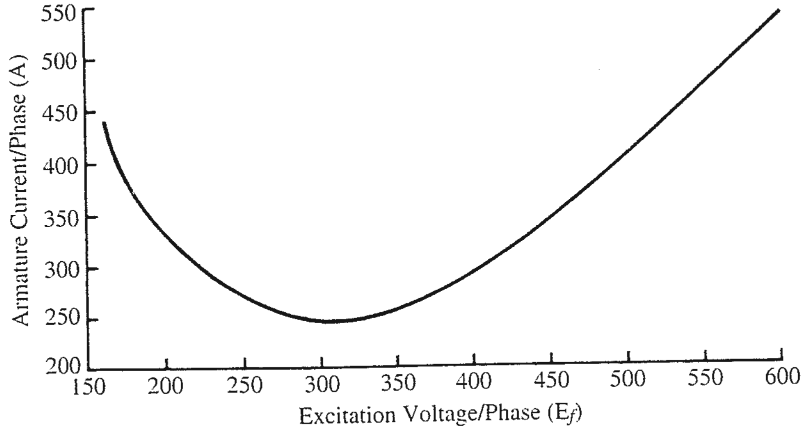

FIGURE 8.20.
V curve for Problem 8–13/10.

a wye-connected synchronous motor that is operating at 0.62 power factor leading, and has a synchronous impedance of 6.05 Ω/phase. If the system is operating at unity power factor, determine (a) active and reactive components of synchronous motor power; (b) synchronous motor current; (c) excitation line voltage.

32 **8–17/12** A three-phase, 60-Hz, 575-V system, operating at 1.5 MW and 0.92 power factor lagging, includes a 500-hp, 575-V, 1200 r/min synchronous motor operating at rated load, 0.84 power-factor leading, and an efficiency (discounting field losses) of 96.2 percent. The synchronous reactance is 0.567 Ω/phase. Determine (a) system power factor if the synchronous motor is disconnected; (b) system power factor if the synchronous motor is unloaded but remains connected to the bus and its excitation remains unchanged. Assume the no-load losses are negligible.

8–18/13 A 3500-hp, 60-Hz, 4000-V, 450 r/min, wye-connected synchronous motor has a direct-axis synchronous reactance of 5.76 Ω/phase, and a quadrature-axis synchronous reactance of 4.80 Ω/phase. The motor is operating at rated conditions with a power angle and efficiency of −34.6° and 97.1 percent, respectively. Determine (a) excitation voltage; (b) magnet component of torque; (c) reluctance component of torque; (d) percent of total power contributed by the reluctance component.

8–19/14 A 20-pole, 700-hp, 2300-V, 60-Hz, 0.8 power-factor wye-connected synchronous motor has a direct-axis reactance of 8.91 Ω/phase and a quadrature-axis reactance of 6.48 Ω/phase. Using Table 8.1, determine (a) minimum expected locked-rotor torque; (b) minimum expected pull-in torque, assuming normal Wk^2; (c) minimum expected pull-out torque, assuming rated field current is applied.

19. Using phasor diagrams, explain why the transfer of active power between alternators in parallel causes a change in the division of reactive power between them.
20. How can the transfer of reactive power be accomplished between alternators in parallel? What instruments are used to observe this transfer?
21. Explain why adjustment of the field excitation of alternators in parallel affects the power factor of the machines.
22. Explain with the aid of a phasor diagram how it is possible for one alternator to operate at a leading power factor and another in parallel with it to operate at a lagging power factor when the bus power factor is unity.
23. Explain with the aid of a phasor diagram how it is possible for the individual power factors of two paralleled alternators and the power factor of the bus to be all lagging and all different.
24. (a) State in outline form the correct procedure for paralleling a 2000-V, 50-Hz, 1000-kVA alternator with another on the bus. Assume both machines have identical characteristics. Include the approximate values of the voltage and frequency of the incoming machine just prior to synchronizing. (b) Assuming the bus load is 800 kW at 0.8 power-factor lagging, what adjustments must be made to each machine in order that both machines will divide equally the active power of the bus? (c) What adjustments must be made to each machine in order that both machines will divide equally the reactive power of the bus?
25. What are the losses in an AC generator? How is the heat dissipated?

PROBLEMS

9–1/2 Determine the speed required to obtain a frequency of 50 Hz from a four-pole alternator.

9–2/2 A certain three-phase alternator operating at no load has an induced emf of 2460 V at 60 Hz. Determine the voltage and frequency if the pole flux and rotor speed are each increased by 10 percent.

9–3/2 An alternator operating at no load has a generated emf of 346.4 V/phase and a frequency of 60 Hz. If the pole flux is decreased by 15 percent and the speed is increased by 6.8 percent, determine (a) induced voltage; (b) frequency.

9–4/3 A 2400-V, 60-Hz, three-phase, six-pole, wye-connected synchronous generator is connected to an infinite bus and is supplying 350 kW at a power angle of 28.2°. The stator has a synchronous reactance of 12.2 Ω/phase. Neglecting losses, determine (a) input torque to the alternator; (b) excitation voltage per phase; (c) armature current; (d) active and reactive components of power; (e) power factor.

9–5/3 A four-pole, 600-V synchronous generator is connected to an infinite bus that supplies a 60-Hz, 600-V, 2000-kVA, 80.4 percent power-factor load. The generator is driven by a steam turbine that delivers 1955 lb-ft of torque

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to the generator shaft, causing a power angle of 36.4°. The synchronous reactance is 1.06 Ω/phase. Neglecting losses, determine (a) mechanical power input to the generator rotor; (b) excitation voltage per phase; (c) armature current; (d) active and reactive components of apparent power delivered to the bus; (e) generator power factor.

9–6/3 A six-pole, 75-kVA, 340-V, 60-Hz, wye-connected diesel generator is supplying a bus load of 54.5 kVA at 78.9 percent power-factor lagging, 220 V, and 60 Hz. The armature has a synchronous impedance of $0.18 + j0.92$ Ω/phase. Determine (a) armature current; (b) excitation voltage per phase; (c) power angle; (d) shaft torque supplied by the diesel engine (neglect losses).

9–7/11 The ratings of two turbine generators *A* and *B* are 300-kW, 3.5 percent speed regulation and 600-kW, 2.5 percent speed regulation, respectively. The machines are operating in parallel at 60 Hz, 480 V. Machine *A* is supplying 260 kW, and machine *B* is supplying 590 kW. (a) Sketch a one-line diagram for the system. (b) On the same coordinate axes sketch the approximate governor-droop characteristics of both machines and label the curves. (c) Opening of a distribution breaker results in a remaining bus load of 150 kW. Determine the new frequency and the active power load carried by each machine.

9–8/11 Two 600-kW, 60-Hz, diesel-driven synchronous generators *A* and *B* have governor speed regulations of 2.0 and 5.0 percent, respectively. Both machines are in parallel and supplying equal shares of a 1000-kW bus load at 57 Hz. (a) Sketch the approximate governor characteristics for both machines on one set of coordinate axes, and indicate the operating frequency. Label both curves. (b) On the same diagram, approximate a new operating condition that assumes the load on the bus decreases to a total of 400 kW. (c) Determine the new frequency and the new load distribution for the conditions in (b).

9–9/11 A 700-kW, 60-Hz generator *A*, with 2.0 percent speed regulation, is operating in parallel with generator *B* of equal kilowatt rating, but whose speed regulation is 6.0 percent. The total bus load of 1000 kVA at 60 Hz, 2400 V, and 80.6 percent power-factor lagging is divided equally between the two machines. If a 200-kVA, 60.0 percent power-factor load is disconnected from the bus, determine (a) the new operating frequency; (b) the active power load on each machine.

9–10/11 Three 600-kW, 60-Hz, 480-V synchronous machines are in parallel, each supplying the following loads: generator *A*, 200 kW; generator *B*, 100 kW; and generator *C*, 300 kW. The speed regulations for machines *A*, *B*, and *C* are 2.0, 2.0, and 3.0 percent, respectively. The system frequency is 60 Hz. If the system load increases to 2000 kVA at 70.0 percent power-factor lagging, determine the new operating frequency and active power load carried by each machine.

9–11/11 Three 25-Hz turbine generators *A*, *B*, and *C* are connected in parallel and operating at 25 Hz, 2400 V. Generator *A* is rated at 600 kW and has a speed regulation of 2.0 percent. Generator *B* is rated at 500 kW and has a speed