13.9 In order to match a source with internal impedance of 500 Ω to a 15-Ω load, what is needed is:

(a) step-up linear transformer
(b) step-down linear transformer
(c) step-up ideal transformer
(d) step-down ideal transformer
(e) autotransformer

13.10 Which of these transformers can be used as an isolation device?

(a) linear transformer (b) ideal transformer
(c) autotransformer (d) all of the above

Answers: 13.1b, 13.2a, 13.3b, 13.4b, 13.5d, 13.6b, 13.7c, 13.8a, 13.9d, 13.10b.

PROBLEMS

Section 13.2 Mutual Inductance

13.1 For the three coupled coils in Fig. 13.72, calculate the total inductance.

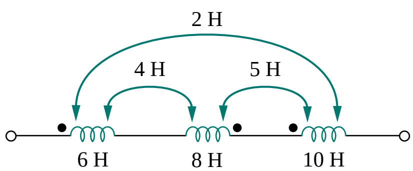

Figure 13.72 For Prob. 13.1.

13.2 Determine the inductance of the three series-connected inductors of Fig. 13.73.

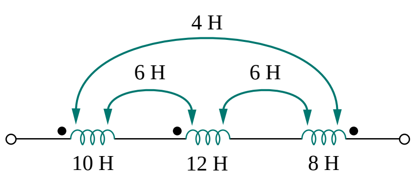

Figure 13.73 For Prob. 13.2.

13.3 Two coils connected in series-aiding fashion have a total inductance of 250 mH. When connected in a series-opposing configuration, the coils have a total inductance of 150 mH. If the inductance of one coil (L_1) is three times the other, find L_1, L_2, and M. What is the coupling coefficient?

13.4 (a) For the coupled coils in Fig. 13.74(a), show that

$$L_{eq} = L_1 + L_2 + 2M$$

(b) For the coupled coils in Fig. 13.74(b), show that

$$L_{eq} = \frac{L_1 L_2 - M^2}{L_1 L_2 - 2M^2}$$

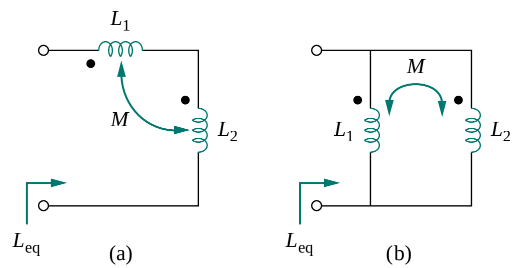

Figure 13.74 For Prob. 13.4.

13.5 Determine $\mathbf{V}_1$ and $\mathbf{V}_2$ in terms of $\mathbf{I}_1$ and $\mathbf{I}_2$ in the circuit in Fig. 13.75.

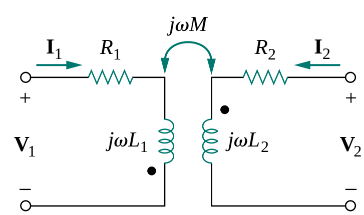

Figure 13.75 For Prob. 13.5.

13.6 Find $\mathbf{V}_o$ in the circuit of Fig. 13.76.

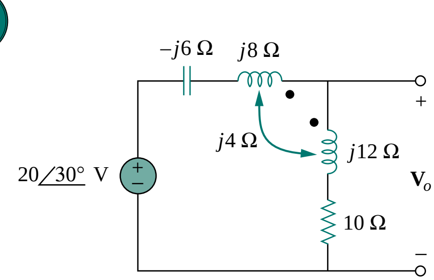

Figure 13.76 For Prob. 13.6.

13.7 Obtain $\mathbf{V}_o$ in the circuit of Fig. 13.77.

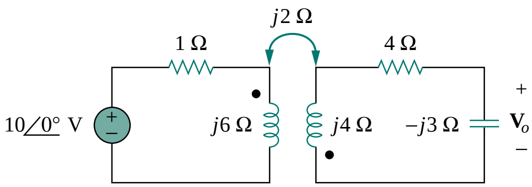

Figure 13.77 For Prob. 13.7.

13.8 Find $\mathbf{V}_x$ in the network shown in Fig. 13.78.

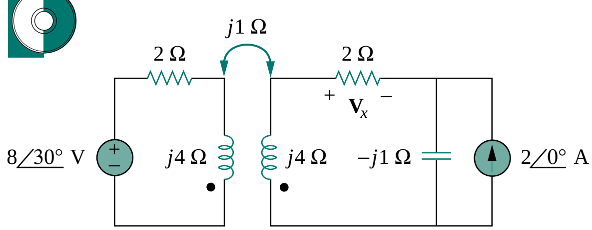

Figure 13.78 For Prob. 13.8.

13.9 Find $\mathbf{I}_o$ in the circuit of Fig. 13.79.

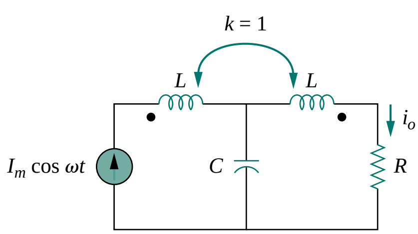

Figure 13.79 For Prob. 13.9.

13.10 Obtain the mesh equations for the circuit in Fig. 13.80.

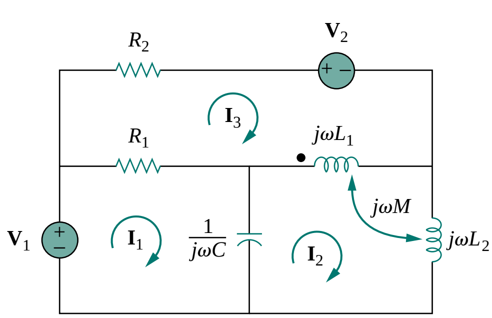

Figure 13.80 For Prob. 13.10.

13.11 Obtain the Thevenin equivalent circuit for the circuit in Fig. 13.81 at terminals *a*-*b*.

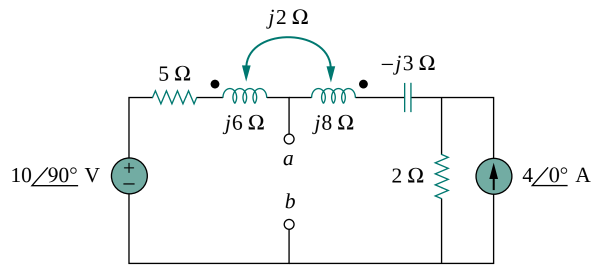

Figure 13.81 For Prob. 13.11.

13.12 Find the Norton equivalent for the circuit in Fig. 13.82 at terminals *a*-*b*.

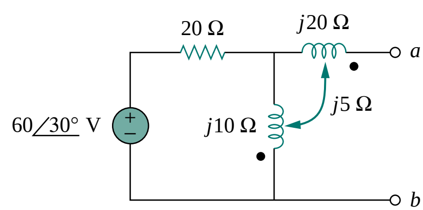

Figure 13.82 For Prob. 13.12.

Section 13.3 Energy in a Coupled Circuit

13.13 Determine currents $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the circuit of Fig. 13.83. Find the energy stored in the coupled coils at $t = 2$ ms. Take $\omega = 1000$ rad/s.

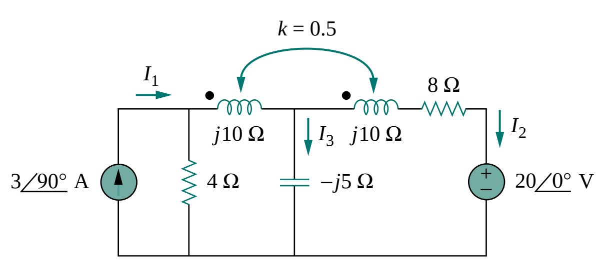

Figure 13.83 For Prob. 13.13.

13.14 Find $\mathbf{I}_1$ and $\mathbf{I}_2$ in the circuit of Fig. 13.84. Calculate the power absorbed by the 4-Ω resistor.

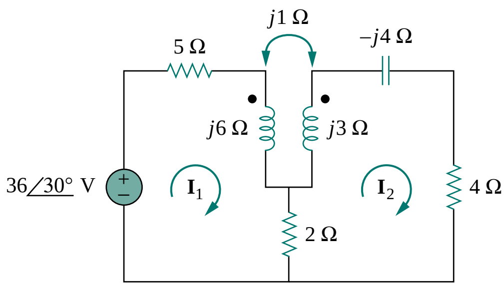

Figure 13.84 For Prob. 13.14.

*__13.15__ Find current $\mathbf{I}_o$ in the circuit of Fig. 13.85.

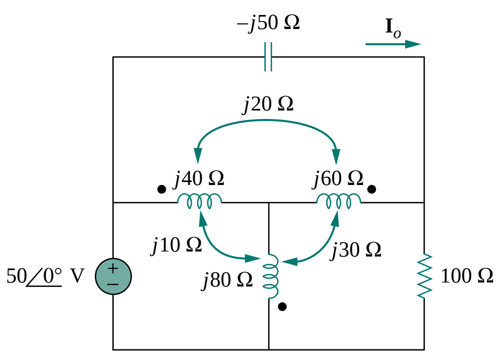

Figure 13.85 For Prob. 13.15.

13.16 If $M = 0.2$ H and $v_s = 12 \cos 10t$ V in the circuit of Fig. 13.86, find i_1 and i_2. Calculate the energy stored in the coupled coils at $t = 15$ ms.

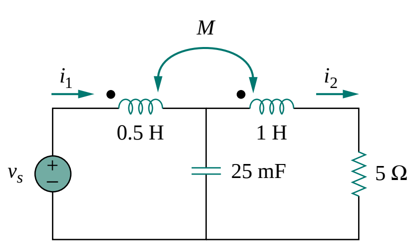

Figure 13.86 For Prob. 13.16.

13.17 In the circuit of Fig. 13.87,

(a) find the coupling coefficient,

(b) calculate v_o,

(c) determine the energy stored in the coupled inductors at $t = 2$ s.

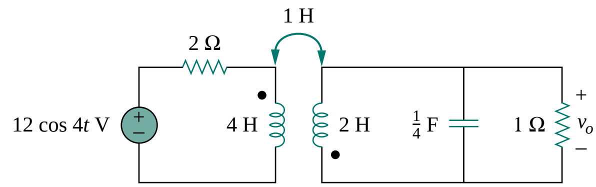

Figure 13.87 For Prob. 13.17.

13.18 For the network in Fig. 13.88, find $\mathbf{Z}_{ab}$ and $\mathbf{I}_o$.

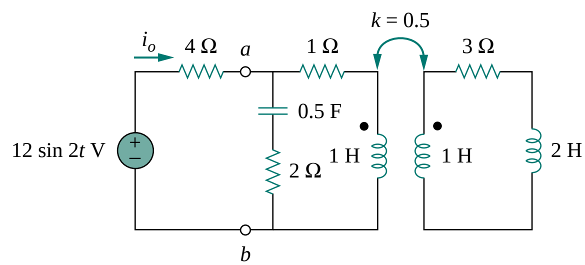

Figure 13.88 For Prob. 13.18.

13.19 Find $\mathbf{I}_o$ in the circuit of Fig. 13.89. Switch the dot on the winding on the right and calculate $\mathbf{I}_o$ again.

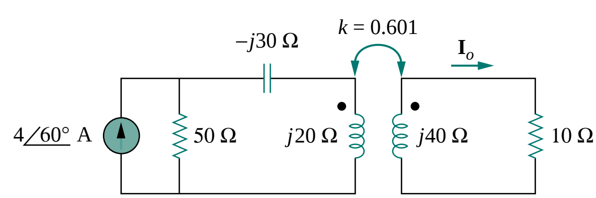

Figure 13.89 For Prob. 13.19.

13.20 Rework Example 13.1 using the concept of reflected impedance.

Section 13.4 Linear Transformers

13.21 In the circuit of Fig. 13.90, find the value of the coupling coefficient k that will make the 10-Ω resistor dissipate 320 W. For this value of k, find the energy stored in the coupled coils at $t = 1.5$ s.

*An asterisk indicates a challenging problem.

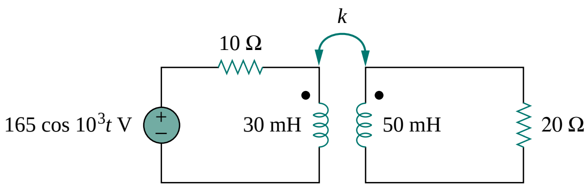

Figure 13.90 For Prob. 13.21.

13.22 (a) Find the input impedance of the circuit in Fig. 13.91 using the concept of reflected impedance.
(b) Obtain the input impedance by replacing the linear transformer by its T equivalent.

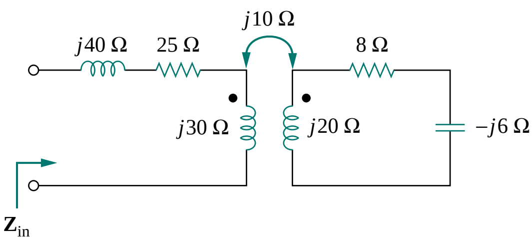

Figure 13.91 For Prob. 13.22.

13.23 For the circuit in Fig. 13.92, find:
(a) the T-equivalent circuit,
(b) the Π-equivalent circuit.

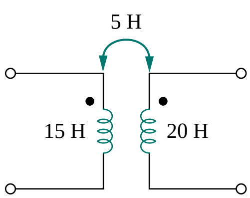

Figure 13.92 For Prob. 13.23.

***13.24** Two linear transformers are cascaded as shown in Fig. 13.93. Show that

$$\mathbf{Z}_{in} = \frac{\omega^2 R(L_a^2 + L_a L_b - M_a^2) + j\omega^3(L_a^2 L_b + L_a L_b^2 - L_a M_b^2 - L_b M_a^2)}{\omega^2(L_a L_b + L_b^2 - M_b^2) - j\omega R(L_a + L_b)}$$

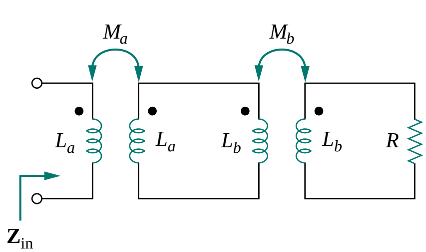

Figure 13.93 For Prob. 13.24.

13.25 Determine the input impedance of the air-core transformer circuit of Fig. 13.94.

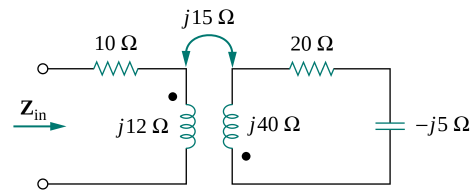

Figure 13.94 For Prob. 13.25.

Section 13.5 Ideal Transformers

13.26 As done in Fig. 13.32, obtain the relationships between terminal voltages and currents for each of the ideal transformers in Fig. 13.95.

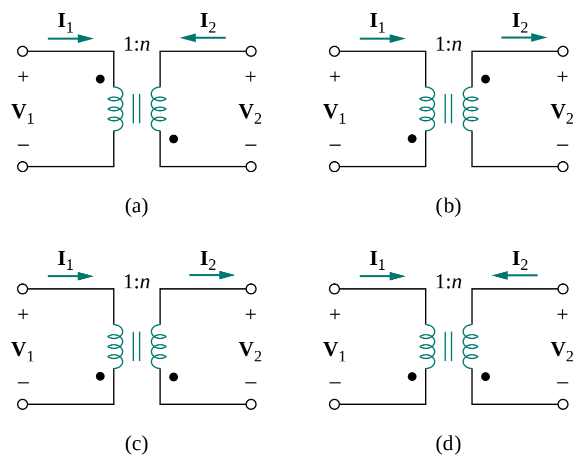

Figure 13.95 For Prob. 13.26.

13.27 A 4-kVA, 2300/230-V rms transformer has an equivalent impedance of $2\angle 10^\circ$ Ω on the primary side. If the transformer is connected to a load with 0.6 power factor leading, calculate the input impedance.

13.28 A 1200/240-V rms transformer has impedance $60\angle -30^\circ$ Ω on the high-voltage side. If the transformer is connected to a $0.8\angle 10^\circ$-Ω load on the low-voltage side, determine the primary and secondary currents.

13.29 Determine $\mathbf{I}_1$ and $\mathbf{I}_2$ in the circuit of Fig. 13.96.

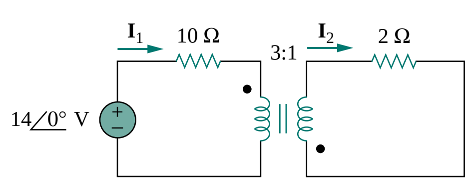

Figure 13.96 For Prob. 13.29.

13.30 Obtain $\mathbf{V}_1$ and $\mathbf{V}_2$ in the ideal transformer circuit of Fig. 13.97.

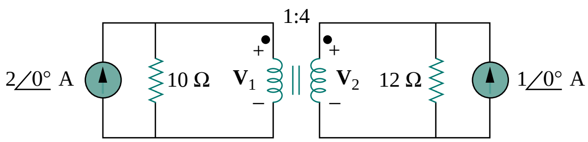

Figure 13.97 For Prob. 13.30.

13.31 In the ideal transformer circuit of Fig. 13.98, find $i_1(t)$ and $i_2(t)$.

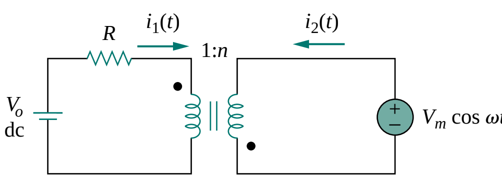

Figure 13.98 For Prob. 13.31.

13.32 (a) Find $\mathbf{I}_1$ and $\mathbf{I}_2$ in the circuit of Fig. 13.99 below.
(b) Switch the dot on one of the windings. Find $\mathbf{I}_1$ and $\mathbf{I}_2$ again.

13.33 For the circuit in Fig. 13.100, find $\mathbf{V}_o$. Switch the dot on the secondary side and find $\mathbf{V}_o$ again.

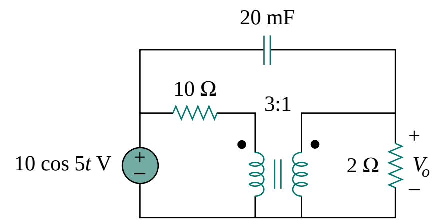

Figure 13.100 For Prob. 13.33.

13.34 Calculate the input impedance for the network in Fig. 13.101 below.

13.35 Use the concept of reflected impedance to find the input impedance and current $\mathbf{I}_1$ in Fig. 13.102 below.

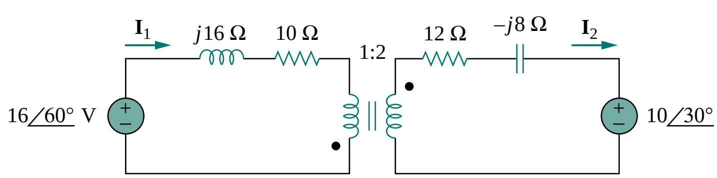

Figure 13.99 For Prob. 13.32.

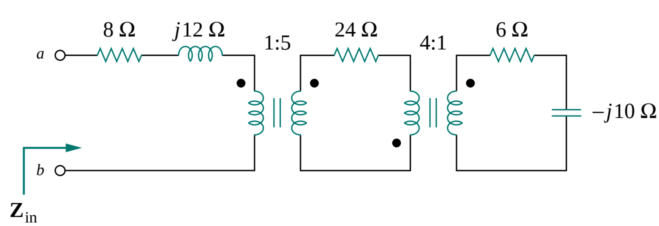

Figure 13.101 For Prob. 13.34.

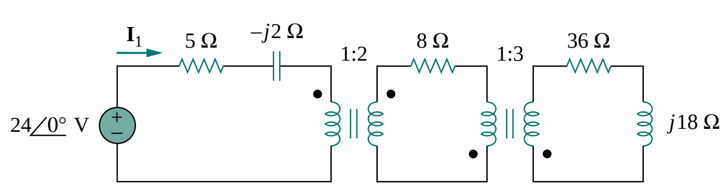

Figure 13.102 For Prob. 13.35.

13.36 For the circuit in Fig. 13.103, determine the turns ratio n that will cause maximum average power transfer to the load. Calculate that maximum average power.

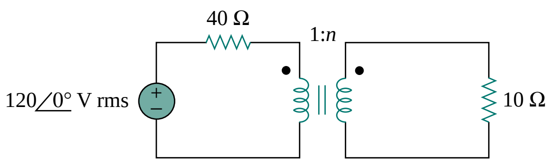

Figure 13.103 For Prob. 13.36.

13.37 Refer to the network in Fig. 13.104.

(a) Find n for maximum power supplied to the 200-Ω load.

(b) Determine the power in the 200-Ω load if $n = 10$.

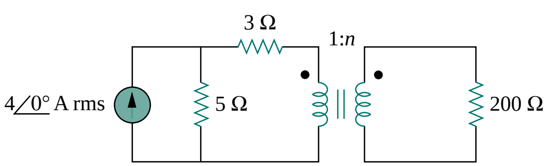

Figure 13.104 For Prob. 13.37.

13.38 A transformer is used to match an amplifier with an 8-Ω load as shown in Fig. 13.105. The Thevenin equivalent of the amplifier is: $V_{Th} = 10$ V, $Z_{Th} = 128\ \Omega$.

(a) Find the required turns ratio for maximum energy power transfer.

(b) Determine the primary and secondary currents.

(c) Calculate the primary and secondary voltages.

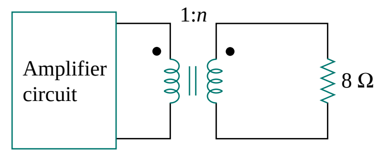

Figure 13.105 For Prob. 13.38.

13.39 In Fig. 13.106 below, determine the average power delivered to $\mathbf{Z}_s$.

13.40 Find the power absorbed by the 10-Ω resistor in the ideal transformer circuit of Fig. 13.107.

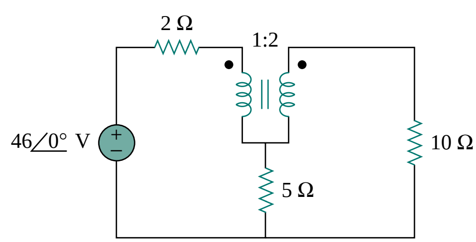

Figure 13.107 For Prob. 13.40.

13.41 For the ideal transformer circuit of Fig. 13.108 below, find:

(a) $\mathbf{I}_1$ and $\mathbf{I}_2$,

(b) $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{V}_o$,

(c) the complex power supplied by the source.

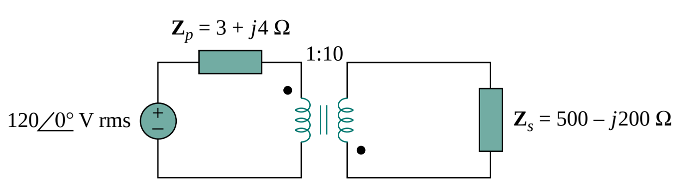

Figure 13.106 For Prob. 13.39.

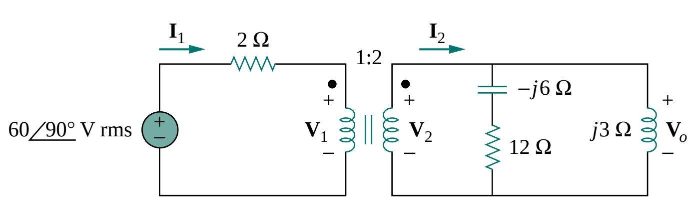

Figure 13.108 For Prob. 13.41.

13.42 Determine the average power absorbed by each resistor in the circuit of Fig. 13.109.

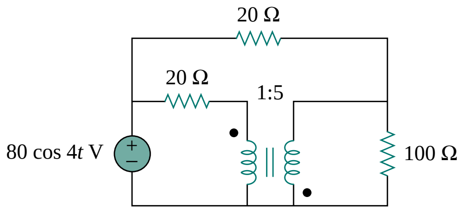

Figure 13.109 For Prob. 13.42.

13.43 Find the average power delivered to each resistor in the circuit of Fig. 13.110.

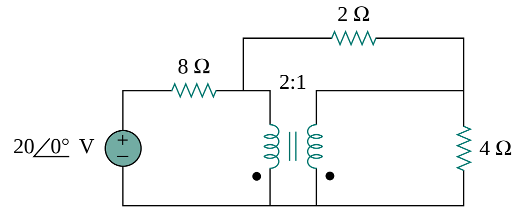

Figure 13.110 For Prob. 13.43.

13.44 Refer to the circuit in Fig. 13.111 below.
(a) Find currents $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$.
(b) Find the power dissipated in the 40-Ω resistor.

***13.45** For the circuit in Fig. 13.112 below, find $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{V}_o$.

13.46 For the network in Fig. 13.113 below, find
(a) the complex power supplied by the source,
(b) the average power delivered to the 18-Ω resistor.

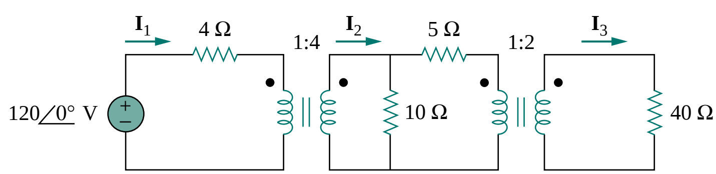

Figure 13.111 For Prob. 13.44.

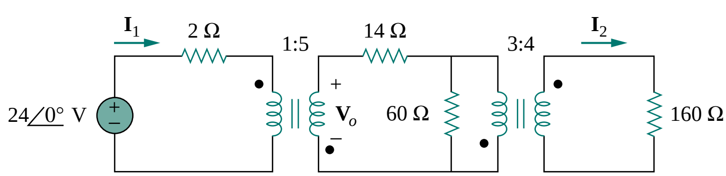

Figure 13.112 For Prob. 13.45.

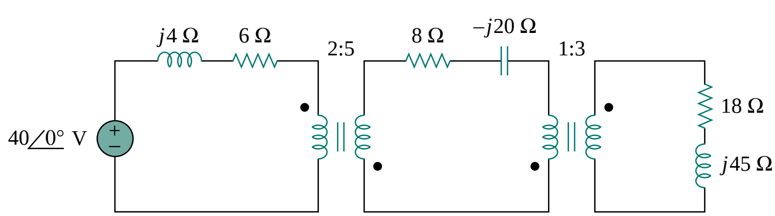

Figure 13.113 For Prob. 13.46.

13.47 Find the mesh currents in the circuit of Fig. 13.114 below.

Section 13.6 Ideal Autotransformers

13.48 An ideal autotransformer with a 1:4 step-up turns ratio has its secondary connected to a 120-Ω load and the primary to a 420-V source. Determine the primary current.

13.49 In the ideal autotransformer of Fig. 13.115, calculate $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_o$. Find the average power delivered to the load.

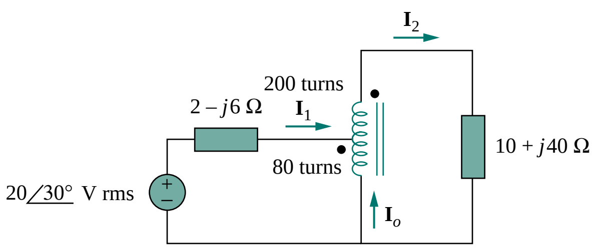

Figure 13.115 For Prob. 13.49.

*__13.50__ In the circuit of Fig. 13.116, $\mathbf{Z}_L$ is adjusted until maximum average power is delivered to $\mathbf{Z}_L$. Find $\mathbf{Z}_L$ and the maximum average power transferred to it. Take $N_1 = 600$ turns and $N_2 = 200$ turns.

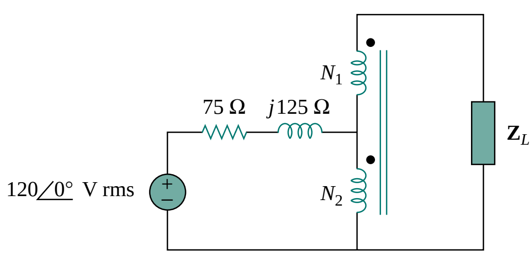

Figure 13.116 For Prob. 13.50.

13.51 In the ideal transformer circuit shown in Fig. 13.117, determine the average power delivered to the load.

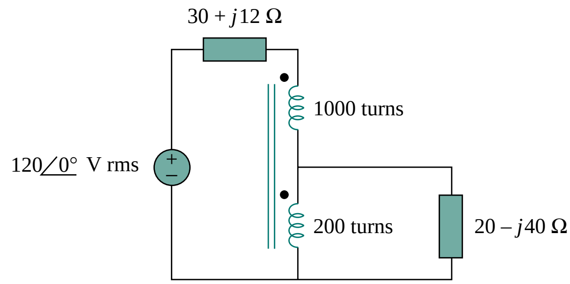

Figure 13.117 For Prob. 13.51.

13.52 In the autotransformer circuit in Fig. 13.118, show that

$$\mathbf{Z}_{\text{in}} = \left(1 + \frac{N_1}{N_2}\right)^2 \mathbf{Z}_L$$

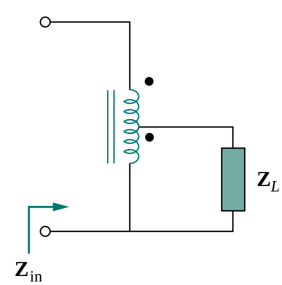

Figure 13.118 For Prob. 13.52.

Section 13.7 Three-Phase Transformers

13.53 In order to meet an emergency, three single-phase transformers with 12,470/7200 V rms are connected in Δ-Y to form a three-phase transformer which is fed by a 12,470-V transmission line. If the transformer supplies 60 MVA to a load, find:

(a) the turns ratio for each transformer,

(b) the currents in the primary and secondary windings of the transformer,

(c) the incoming and outgoing transmission line currents.

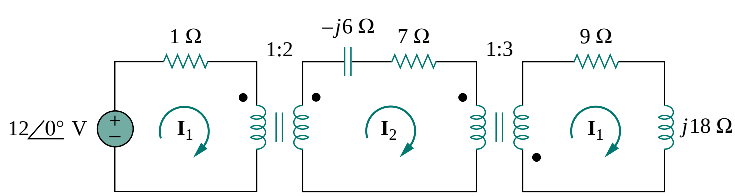

Figure 13.114 For Prob. 13.47.

13.54 Figure 13.119 below shows a three-phase transformer that supplies a Y-connected load.

(a) Identify the transformer connection.

(b) Calculate currents $\mathbf{I}_2$ and $\mathbf{I}_c$.

(c) Find the average power absorbed by the load.

13.55 Consider the three-phase transformer shown in Fig. 13.120. The primary is fed by a three-phase source with line voltage of 2.4 kV rms, while the secondary supplies a three-phase 120-kW balanced load at pf of 0.8. Determine:

(a) the type of transformer connections,

(b) the values of I_{LS} and I_{PS},

(c) the values of I_{LP} and I_{PP},

(d) the kVA rating of each phase of the transformer.

13.56 A balanced three-phase transformer bank with the Δ-Y connection depicted in Fig. 13.121 below is used to step down line voltages from 4500 V rms to 900 V rms. If the transformer feeds a 120-kVA load, find:

(a) the turns ratio for the transformer,

(b) the line currents at the primary and secondary sides.

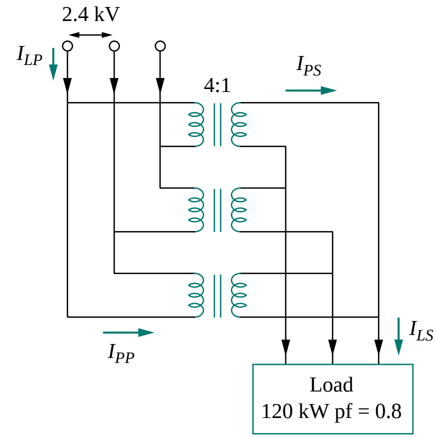

Figure 13.120 For Prob. 13.55.

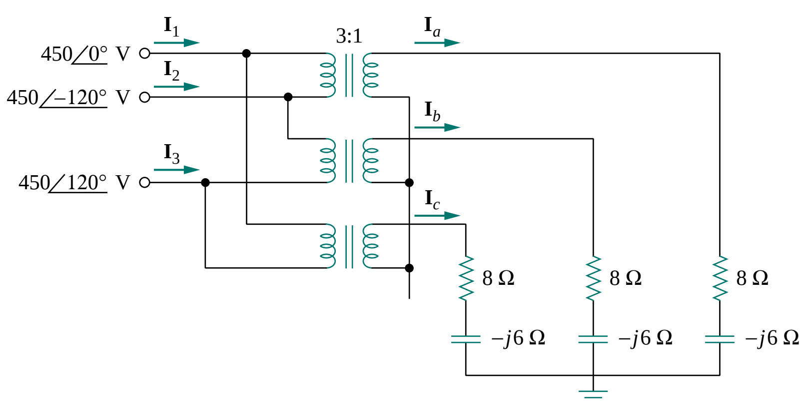

Figure 13.119 For Prob. 13.54.

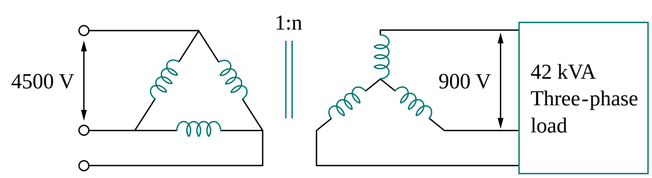

Figure 13.121 For Prob. 13.56.

13.57 A Y-Δ three-phase transformer is connected to a 60-kVA load with 0.85 power factor (leading) through a feeder whose impedance is $0.05 + j0.1\ \Omega$ per phase, as shown in Fig. 13.122 below. Find the magnitude of:

(a) the line current at the load,

(b) the line voltage at the secondary side of the transformer,

(c) the line current at the primary side of the transformer.

13.58 The three-phase system of a town distributes power with a line voltage of 13.2 kV. A pole transformer connected to single wire and ground steps down the high-voltage wire to 120 V rms and serves a house as shown in Fig. 13.123.

(a) Calculate the turns ratio of the pole transformer to get 120 V.

(b) Determine how much current a 100-W lamp connected to the 120-V hot line draws from the high-voltage line.

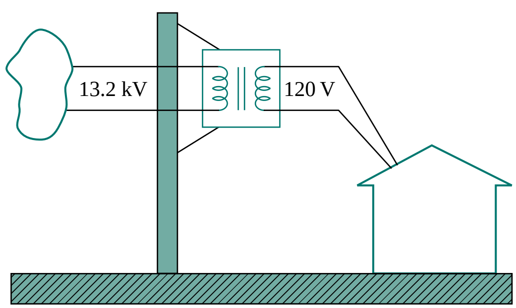

Figure 13.123 For Prob. 13.58.

Section 13.8 *PSpice* Analysis of Magnetically Coupled Circuits

13.59 Rework Prob. 13.14 using *PSpice*.

13.60 Use *PSpice* to find $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the circuit of Fig. 13.124.

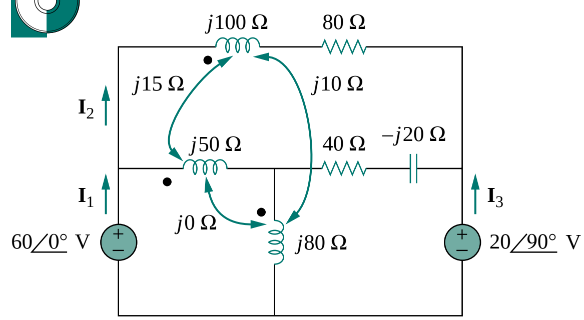

Figure 13.124 For Prob. 13.60.

13.61 Rework Prob. 13.15 using *PSpice*.

13.62 Use *PSpice* to find $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the circuit of Fig. 13.125.

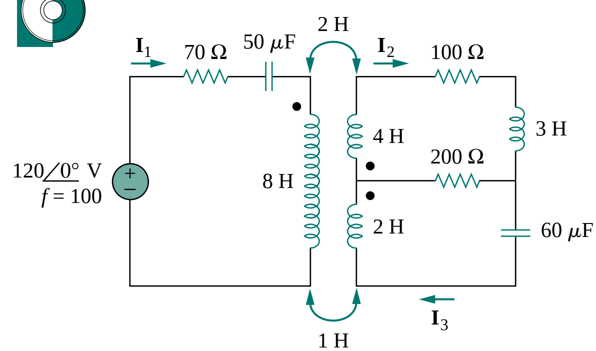

Figure 13.125 For Prob. 13.62.

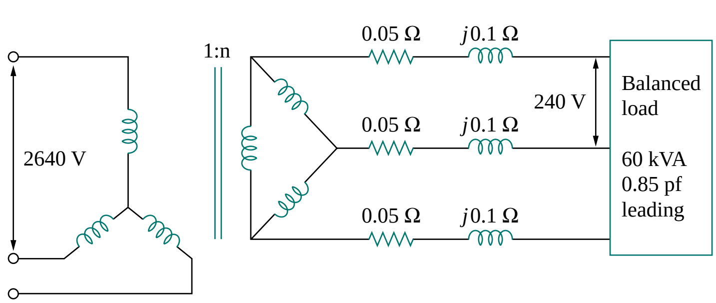

Figure 13.122 For Prob. 13.57.

13.63 Use *PSpice* to find $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{I}_o$ in the circuit of Fig. 13.126.

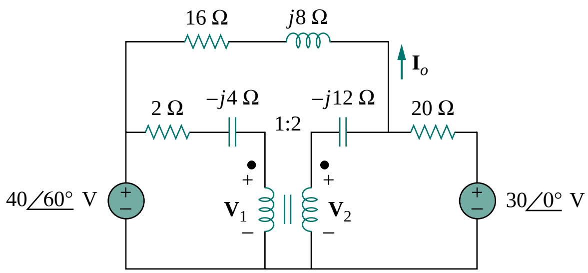

Figure 13.126 For Prob. 13.63.

13.64 Find $\mathbf{I}_x$ and $\mathbf{V}_x$ in the circuit of Fig. 13.127 below using *PSpice*.

13.65 Determine $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the ideal transformer circuit of Fig. 13.128 using *PSpice*.

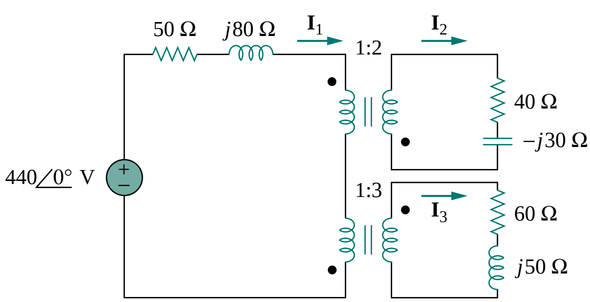

Figure 13.128 For Prob. 13.65.

Section 13.9 Applications

13.66 A stereo amplifier circuit with an output impedance of 7.2 kΩ is to be matched to a speaker with an input impedance of 8 Ω by a transformer whose primary side has 3000 turns. Calculate the number of turns required on the secondary side.

13.67 A transformer having 2400 turns on the primary and 48 turns on the secondary is used as an impedance-matching device. What is the reflected value of a 3-Ω load connected to the secondary?

13.68 A radio receiver has an input resistance of 300 Ω. When it is connected directly to an antenna system with a characteristic impedance of 75 Ω, an impedance mismatch occurs. By inserting an impedance-matching transformer ahead of the receiver, maximum power can be realized. Calculate the required turns ratio.

13.69 A step-down power transformer with a turns ratio of $n = 0.1$ supplies 12.6 V rms to a resistive load. If the primary current is 2.5 A rms, how much power is delivered to the load?

13.70 A 240/120-V rms power transformer is rated at 10 kVA. Determine the turns ratio, the primary current, and the secondary current.

13.71 A 4-kVA, 2400/240-V rms transformer has 250 turns on the primary side. Calculate:

(a) the turns ratio,

(b) the number of turns on the secondary side,

(c) the primary and secondary currents.

13.72 A 25,000/240-V rms distribution transformer has a primary current rating of 75 A.

(a) Find the transformer kVA rating.

(b) Calculate the secondary current.

13.73 A 4800-V rms transmission line feeds a distribution transformer with 1200 turns on the primary and 28 turns on the secondary. When a 10-Ω load is connected across the secondary, find:

(a) the secondary voltage,

(b) the primary and secondary currents,

(c) the power supplied to the load.

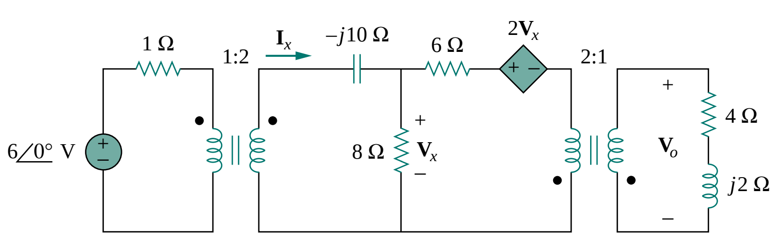

Figure 13.127 For Prob. 13.64.

COMPREHENSIVE PROBLEMS

13.74 A four-winding transformer (Fig. 13.129) is often used in equipment (e.g., PCs, VCRs) that may be operated from either 110 V or 220 V. This makes the equipment suitable for both domestic and foreign use. Show which connections are necessary to provide:

(a) an output of 12 V with an input of 110 V,

(b) an output of 50 V with an input of 220 V.

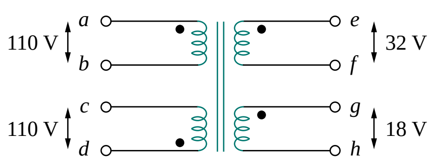

Figure 13.129 For Prob. 13.74.

*__13.75__ A 440/110-V ideal transformer can be connected to become a 550/440-V ideal autotransformer. There are four possible connections, two of which are wrong. Find the output voltage of:

(a) a wrong connection,

(b) the right connection.

13.76 Ten bulbs in parallel are supplied by a 7200/120-V transformer as shown in Fig. 13.130, where the bulbs are modeled by the 144-Ω resistors. Find:

(a) the turns ratio n,

(b) the current through the primary winding.

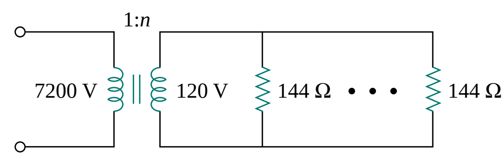

Figure 13.130 For Prob. 13.76.