Fuses are inexpensive, fast operating, ... and they do not require protective relays or instrument transformers. Their chief disadvantage is that the fuse or the fuse link must be manually replaced after it melts. They are basically one-shot devices that are, for example, incapable of high-speed reclosing.

PROBLEMS

SECTION 7.1

7.1 In the circuit of Figure 7.1, $V = 220$ volts, $L = 3$ mH, $R = 0.5\ \Omega$, and $\omega = 2\pi 60$ rad/s. Determine (a) the rms symmetrical fault current; (b) the rms asymmetrical fault current at the instant the switch closes, assuming maximum dc offset; (c) the rms asymmetrical fault current 5 cycles after the switch closes, assuming maximum dc offset; (d) the dc offset as a function of time if the switch closes when the instantaneous source voltage is 244 volts.

7.2 Repeat Example 7.1 with $V = 4$ kV, $X = 3\ \Omega$, and $R = 1\ \Omega$.

7.3 In the circuit of Figure 7.1, let $R = 0.125\ \Omega$, $L = 10$ mH, and the source voltage is $e(t) = 151 \sin(377t + \alpha)$ V. Determine the current response after closing the switch for the following cases: (a) no dc offset; (b) maximum dc offset. Sketch the current waveform up to $t = 0.10$ s corresponding to case (a) and (b).

SECTION 7.2

7.4 A 1500-MVA 20-kV, 60-Hz three-phase generator is connected through a 1500-MVA 20-kV Δ/500-kV Y transformer to a 500-kV circuit breaker and a 500-kV transmission line. The generator reactances are $X_d'' = 0.17$, $X_d' = 0.30$, and $X_d = 1.5$ per unit, and its time constants are $T_d'' = 0.05$, $T_d' = 1.0$, and $T_A = 0.10$ s. The transformer series reactance is 0.10 per unit; transformer losses and exciting current are neglected. A three-phase short-circuit occurs on the line side of the circuit breaker when the generator is operated at rated terminal voltage and at no-load. The breaker interrupts the fault 3 cycles after fault inception. Determine (a) the subtransient current through the breaker in per-unit and in kA rms; and (b) the rms asymmetrical fault current the breaker interrupts, assuming maximum dc offset. Neglect the effect of the transformer on the time constants.

7.5 For Problem 7.4, determine (a) the instantaneous symmetrical fault current in kA in phase *a* of the generator as a function of time, assuming maximum dc offset occurs in this generator phase; and (b) the maximum dc offset current in kA as a function of time that can occur in any one generator phase.

7.6 A 300-MVA, 13.8-kV, three-phase, 60-Hz, Y-connected synchronous generator is adjusted to produce rated voltage on open circuit. A balanced three-phase fault is applied to the terminals at $t = 0$. After analyzing the raw data, the symmetrical transient current is obtained as

$$i_{ac}(t) = 10^4(1 + e^{-t/\tau_1} + 6e^{-t/\tau_2}) \quad A$$

where $\tau_1 = 200$ ms and $\tau_2 = 15$ ms. (a) Sketch $i_{ac}(t)$ as a function of time for $0 \leqslant t \leqslant 500$ ms. (b) Determine X_d'' and X_d in per-unit based on the machine ratings.

SECTION 7.3

7.7 Recalculate the subtransient current through the breaker in Problem 7.4 if the generator is initially delivering rated MVA at 0.80 p.f. lagging and at rated terminal voltage.

7.8 Solve Example 7.4, parts (a) and (c) without using the superposition principle. First calculate the internal machine voltages E_g'' and E_m'', using the prefault load current. Then determine the subtransient fault, generator, and motor currents directly from Figure 7.4(a). Compare your answers with those of Example 7.3.

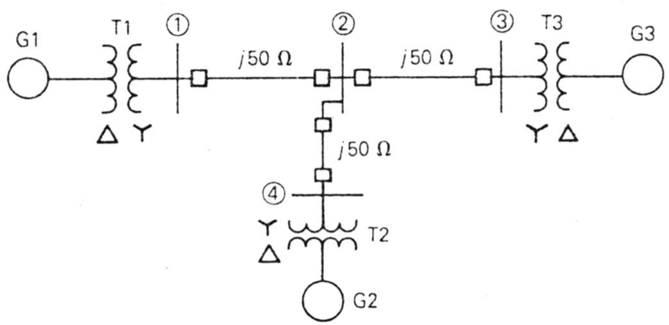
7.9 Equipment ratings for the four-bus power system shown in Figure 7.12 are as follows:

Generator G1:	500 MVA, 13.8 kV, $X'' = 0.20$ per unit
Generator G2:	750 MVA, 18 kV, $X'' = 0.18$ per unit
Generator G3:	1000 MVA, 20 kV, $X'' = 0.17$ per unit
Transformer T1:	500 MVA, 13.8 Δ/500 Y kV, $X = 0.12$ per unit
Transformer T2:	750 MVA, 18 Δ/500 Y kV, $X = 0.10$ per unit
Transformer T3:	1000 MVA, 20 Δ/500 Y kV, $X = 0.10$ per unit
Each 500-kV line:	$X_1 = 50\ \Omega$

A three-phase short circuit occurs at bus 1, where the prefault voltage is 525 kV. Prefault load current is neglected. Draw the positive-sequence reactance diagram in per-unit on a 1000-MVA, 20-kV base in the zone of generator G3. Determine (a) the Thévenin reactance in per-unit at the fault, (b) the subtransient fault current in per-unit and in kA rms, and (c) contributions to the fault current from generator G1 and from line 1–2.

FIGURE 7.12

Problems 7.9, 7.10, 7.16, 7.20, 7.21, 7.22



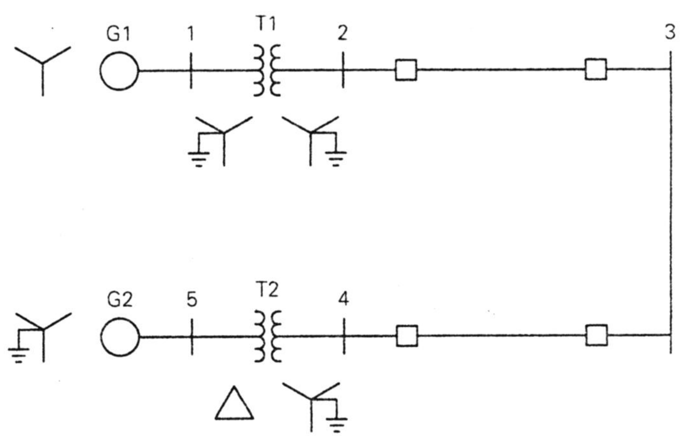
7.10 For the power system given in Problem 7.9, a three-phase short circuit occurs at bus 2, where the prefault voltage is 525 kV. Prefault load current is neglected. Determine the (a) Thévenin equivalent at the fault, (b) subtransient fault current in per-unit and in kA rms, and (c) contributions to the fault from lines 1–2, 2–3, and 2–4.

7.11 Equipment ratings for the five-bus power system shown in Figure 7.13 are as follows:

Generator G1:	50 MVA, 12 kV, $X'' = 0.2$ per unit
Generator G2:	100 MVA, 15 kV, $X'' = 0.2$ per unit
Transformer T1:	50 MVA, 10 kV Y/138 kV Y, $X = 0.10$ per unit
Transformer T2:	100 MVA, 15 kV Δ/138 kV Y, $X = 0.10$ per unit
Each 138-kV line:	$X_1 = 40\ \Omega$

A three-phase short circuit occurs at bus 5, where the prefault voltage is 15 kV. Prefault load current is neglected. (a) Draw the positive-sequence reactance diagram in per-unit on a 100-MVA, 15-kV base in the zone of generator G2. Determine: (b) the Thévenin equivalent at the fault, (c) the subtransient fault current in per-unit and in kA rms, and (d) contributions to the fault from generator G2 and from transformer T2.

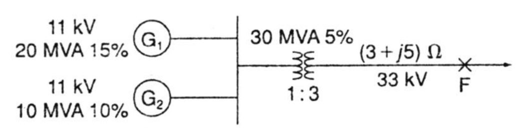
FIGURE 7.13
Problems 7.11, 7.17



7.12 For the power system given in Problem 7.11, a three-phase short circuit occurs at bus 4, where the prefault voltage is 138 kV. Prefault load current is neglected. Determine (a) the Thévenin equivalent at the fault, (b) the subtransient fault current in per-unit and in kA rms, and (c) contributions to the fault from transformer T2 and from line 3–4.

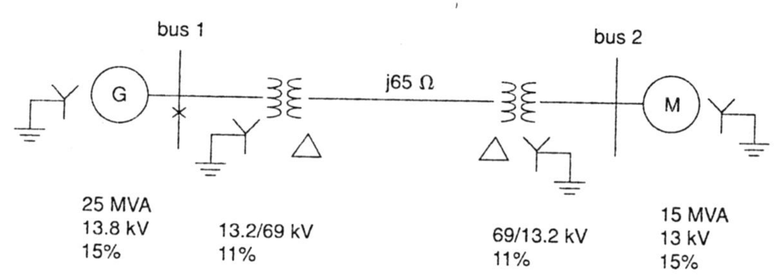
7.13 In the system shown in Figure 7.14, a three-phase short circuit occurs at point F. Assume that prefault currents are zero and that the generators are operating at rated voltage. Determine the fault current.

FIGURE 7.14
Problem 7.13



7.14 A three-phase short circuit occurs at the generator bus (bus 1) for the system shown in Figure 7.15. Neglecting prefault currents and assuming that the generator is operating at its rated voltage, determine the subtransient fault current using superposition.

FIGURE 7.15
Problem 7.14



SECTION 7.4

7.15 The bus impedance matrix for a three-bus power system is

$$Z_{\text{bus}} = j\begin{bmatrix} 0.12 & 0.08 & 0.04 \\ 0.08 & 0.12 & 0.06 \\ 0.04 & 0.06 & 0.08 \end{bmatrix} \quad \text{per unit}$$

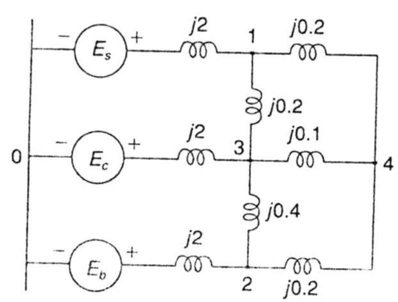
where subtransient reactances were used to compute Z_{bus}. Prefault voltage is 1.0 per unit and prefault current is neglected. (a) Draw the bus impedance matrix equivalent circuit (rake equivalent). Identify the per-unit self- and mutual impedances as well as the prefault voltage in the circuit. (b) A three-phase short circuit occurs at bus 2. Determine the subtransient fault current and the voltages at buses 1, 2, and 3 during the fault.

7.16 Determine Y_{bus} in per-unit for the circuit in Problem 7.9. Then invert Y_{bus} to obtain Z_{bus}.

7.17 Determine Y_{bus} in per-unit for the circuit in Problem 7.11. Then invert Y_{bus} to obtain Z_{bus}.

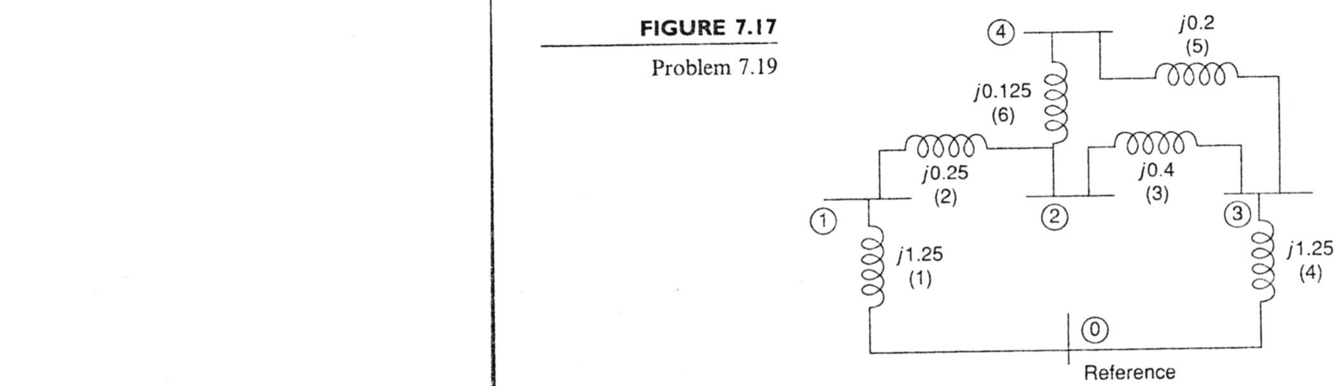
7.18 Figure 7.16 shows a system reactance diagram. (a) Draw the admittance diagram for the system by using source transformations. (b) Find the bus admittance matrix Y_{bus}. (c) Find the bus impedance Z_{bus} matrix by inverting Y_{bus}.

FIGURE 7.16
Problem 7.18



7.19 For the network shown in Figure 7.17, impedances labeled 1 through 6 are in per-unit. (a) Determine Y_{bus}. Preserve all buses. (b) Using MATLAB or a similar computer program, invert Y_{bus} to obtain Z_{bus}.

FIGURE 7.17
Problem 7.19



PW **7.20** PowerWorld Simulator case Problem 7_20 models the system shown in Figure 7.12 with all data on a 1000-MVA base. Using PowerWorld Simulator, determine the current supplied by each generator and the per-unit bus voltage magnitudes at each bus for a fault at bus 2.

PW **7.21** Repeat Problem 7.20, except place the fault at bus 4.

PW **7.22** Repeat Problem 7.20, except place the fault midway between buses 2 and 4. Determining the values for line faults requires that the line be split, with a fictitious bus added at the point of the fault. The original line's impedance is then allocated to the two new lines based on the fault location, 50% each for this problem. Fault calculations are then the same as for a bus fault. This is done automatically in PowerWorld Simulator by first right-clicking on a line, and then selecting "Fault..". The Fault dialog appears as before, except now the fault type is changed to "In-Line Fault." Set the location percentage field to 50% to model a fault midway between buses 2 and 4.

PW **7.23** One technique for limiting fault current is to place reactance in series with the generators. Such reactance can be modeled in Simulator by increasing the value of the generator's positive sequence internal impedance. For the Problem 7_20 case, how much per-unit reactance must be added to G1 to limit its maximum fault current to 1.5 per unit? Where is the location of the most severe bus fault?

PW **7.24** Using PowerWorld Simulator case Example 6_13, determine the per-unit current and actual current in amps supplied by each of the generators for a fault at the LAUF69 bus. During the fault, what percentage of the system buses have voltage magnitudes below 0.75 per unit?

PW **7.25** Repeat Problem 7.24, except place the fault at the AMANS69 bus.

PW **7.26** Redo Example 7.5, except first open the generator at bus 3.

SECTION 7.5

7.27 A three-phase circuit breaker has a 15.5-kV rated maximum voltage, 9.0-kA rated short-circuit current, and a 2.67-rated voltage range factor. (a) Determine the sym-

metrical interrupting capability at 10-kV and 5-kV operating voltages. (b) Can this breaker be safely installed at a three-phase bus where the symmetrical fault current is 10 kA, the operating voltage is 13.8 kV, and the (X/R) ratio is 12?

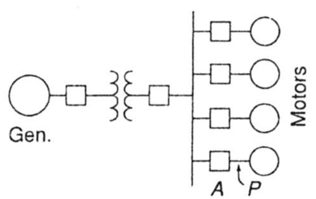
7.28 A 500-kV three-phase transmission line has a 2.2-kA continuous current rating and a 2.5-kA maximum short-time overload rating, with a 525-kV maximum operating voltage. Maximum symmetrical fault current on the line is 30 kA. Select a circuit breaker for this line from Table 7.10.

7.29 A 69-kV circuit breaker has a voltage range factor $K = 1.21$, a continuous current rating of 1200 A, and a rated short-circuit current of 19,000 A at the maximum rated voltage of 72.5 kV. Determine the maximum symmetrical interrupting capability of the breaker. Also, explain its significance at lower operating voltages.

7.30 As shown in Figure 7.18, a 25-MVA, 13.8-kV, 60-Hz synchronous generator with $X_d'' = 0.15$ per unit is connected through a transformer to a bus that supplies four identical motors. The rating of the three-phase transformer is 25 MVA, 13.8/6.9 kV, with a leakage reactance of 0.1 per unit. Each motor has a subtransient reactance $X_d'' = 0.2$ per unit on a base of 5 MVA and 6.9 kV. A three-phase fault occurs at point P, when the bus voltage at the motors is 6.9 kV. Determine: (a) the subtransient fault current, (b) the subtransient current through breaker A, (c) the symmetrical short-circuit interrupting current (as defined for circuit breaker applications) in the fault and in breaker A.

FIGURE 7.18

Problem 7.30



CASE STUDY QUESTIONS

A. Why are arcing (high-impedance) faults more difficult to detect than low-impedance faults?

B. What methods are available to prevent the destructive effects of arcing faults from occurring?

DESIGN PROJECT 4 (*CONTINUED*): POWER FLOW/SHORT CIRCUITS

Additional time given: 3 weeks
Additional time required: 10 hours

This is a continuation of Design Project 4. Assignments 1 and 2 are given in Chapter 6.

In the sequence domain,

$$S_s = V_0 I_0^* + V_1 I_1^* + V_2 I_2^*$$
$$= 0 + (277.1\angle{-1.77^\circ})(25.82\angle{45.55^\circ})$$
$$+ (9.218\angle{216.59^\circ})(0.8591\angle{-172.81^\circ})$$
$$= 7155\angle{43.78^\circ} + 7.919\angle{43.78^\circ}$$
$$= 5172 + j4958 = 7163\angle{43.78^\circ} \quad \text{VA}$$

Also,

$$3S_s = 3(7163\angle{43.78^\circ}) = 21{,}490\angle{43.78^\circ} = S_p$$

PROBLEMS

SECTION 8.1

8.1 Using the operator $a = 1\angle{120^\circ}$, evaluate the following in polar form: (a) $(a+1)/(1+a-a^2)$, (b) $(a^2+a+j)/(ja-a^2)$, (c) $(1-a)(1+a^2)$, (d) $(a+a^2)(a^2+1)$.

8.2 Using $a = 1\angle{120^\circ}$, evaluate the following in rectangular form:

a. a^{10}

b. $(ja)^{10}$

c. $(1-a)^3$

d. e^a

Hint for (d): $e^{(x+jy)} = e^x e^{jy} = e^x\angle{y}$, where y is in radians.

8.3 Determine the symmetrical components of the following line currents: (a) $I_a = 10\angle{90^\circ}$, $I_b = 10\angle{340^\circ}$, $I_c = 10\angle{200^\circ}$ A; (b) $I_a = 100$, $I_b = j100$, $I_c = 0$ A.

8.4 Find the phase voltages V_{an}, V_{bn}, and V_{cn} whose sequence components are: $V_0 = 20\angle{80^\circ}$, $V_1 = 100\angle{0^\circ}$, $V_2 = 30\angle{180^\circ}$ V.

8.5 One line of a three-phase generator is open circuited, while the other two are short-circuited to ground. The line currents are $I_a = 0$, $I_b = 1500\angle{90^\circ}$, and $I_c = 1500\angle{-30^\circ}$ A. Find the symmetrical components of these currents. Also find the current into the ground.

8.6 Given the line-to-ground voltages $V_{ag} = 280\angle{0^\circ}$, $V_{bg} = 290\angle{-130^\circ}$, and $V_{cg} = 260\angle{110^\circ}$ volts, calculate (a) the sequence components of the line-to-ground voltages, denoted V_{Lg0}, V_{Lg1}, and V_{Lg2}; (b) line-to-line voltages V_{ab}, V_{bc}, and V_{ca}; and (c) sequence components of the line-to-line voltages V_{LL0}, V_{LL1}, and V_{LL2}. Also, verify the following general relation: $V_{LL0} = 0$, $V_{LL1} = \sqrt{3}V_{Lg1}\angle{+30^\circ}$, and $V_{LL2} = \sqrt{3}V_{Lg2}\angle{-30^\circ}$ volts.

8.7 A balanced Δ-connected load is fed by a three-phase supply for which phase C is open and phase A is carrying a current of $10\angle{0^\circ}$ A. Find the symmetrical components of the line currents. (Note that zero-sequence currents are not present for any three-wire system.)

8.8 A Y-connected load bank with a three-phase rating of 500 kVA and 2300 V consists of three identical resistors of 10.58 Ω. The load bank has the following applied

voltages: $V_{ab} = 1860\angle 82.8^\circ$, $V_{bc} = 2760\angle -41.4^\circ$, and $V_{ca} = 2300\angle 180^\circ$ V. Determine the symmetrical components of (a) the line-to-line voltages V_{ab0}, V_{ab1}, and V_{ab2}; (b) the line-to-neutral voltages V_{an0}, V_{an1}, and V_{an2}; (c) and the line currents I_{a0}, I_{a1}, and I_{a2}. (Note that the absence of a neutral connection means that zero-sequence currents are not present.)

SECTION 8.2

8.9 The currents in a Δ load are $I_{ab} = 10\angle 0^\circ$, $I_{bc} = 20\angle -90^\circ$, and $I_{ca} = 15\angle 90^\circ$ A. Calculate (a) the sequence components of the Δ-load currents, denoted $I_{\Delta 0}$, $I_{\Delta 1}$, $I_{\Delta 2}$; (b) the line currents I_a, I_b, and I_c, which feed the Δ load; and (c) sequence components of the line currents I_{L0}, I_{L1}, and I_{L2}. Also, verify the following general relation: $I_{L0} = 0$, $I_{L1} = \sqrt{3}I_{\Delta 1}\angle -30^\circ$, and $I_{L2} = \sqrt{3}I_{\Delta 2}\angle +30^\circ$ A.

8.10 The voltages given in Problem 8.6 are applied to a balanced-Y load consisting of $(6 + j8)$ ohms per phase. The load neutral is solidly grounded. Draw the sequence networks and calculate I_0, I_1, and I_2, the sequence components of the line currents. Then calculate the line currents I_a, I_b, and I_c.

8.11 Repeat Problem 8.10 with the load neutral open.

8.12 Repeat Problem 8.10 for a balanced-Δ load consisting of $(12 + j16)$ ohms per phase.

8.13 Repeat Problem 8.10 for the load shown in Example 8.4 (Figure 8.6).

8.14 Perform the indicated matrix multiplications in (8.2.21) and verify the sequence impedances given by (8.2.22)–(8.2.27).

8.15 The following unbalanced line-to-ground voltages are applied to the balanced-Y load shown in Figure 3.3: $V_{ag} = 100\angle 0^\circ$, $V_{bg} = 75\angle 180^\circ$, and $V_{cg} = 50\angle 90^\circ$ volts. The Y load has $Z_Y = 3 + j4\ \Omega$ per phase with neutral impedance $Z_n = j1\ \Omega$. (a) Calculate the line currents I_a, I_b, and I_c without using symmetrical components. (b) Calculate the line currents I_a, I_b, and I_c using symmetrical components. Which method is easier?

8.16 The three-phase impedance load shown in Figure 8.7 has the following phase impedance matrix:

$$Z_P = \begin{bmatrix} (6+j10) & 0 & 0 \\ 0 & (6+j10) & 0 \\ 0 & 0 & (6+j10) \end{bmatrix} \Omega$$

Determine the sequence impedance matrix Z_s for this load. Is the load symmetrical?

8.17 The three-phase impedance load shown in Figure 8.7 has the following sequence impedance matrix:

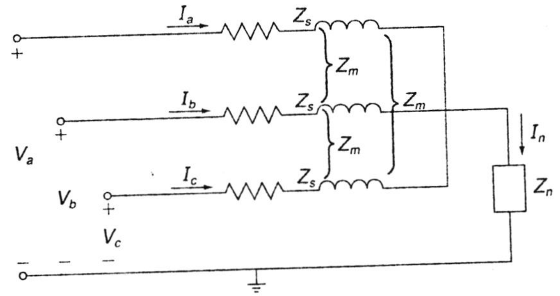
$$Z_S = \begin{bmatrix} (8+j12) & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 4 \end{bmatrix} \Omega$$

Determine the phase impedance matrix Z_p for this load. Is the load symmetrical?

8.18 Consider a three-phase balanced Y-connected load with self and mutual impedances as shown in Figure 8.23. Let the load neutral be grounded through an impedance Z_n. Using Kirchhoff's laws, develop the equations for line-to-neutral voltages, and then determine the elements of the phase impedance matrix. Also find the elements of the corresponding sequence impedance matrix.

FIGURE 8.23

Problem 8.18



8.19 A three-phase balanced voltage source is applied to a balanced Y-connected load with ungrounded neutral. The Y-connected load consists of three mutually coupled reactances, where the reactance of each phase is $j12\ \Omega$ and the mutual coupling between any two phases is $j4\ \Omega$. The line-to-line source voltage is $100\sqrt{3}$ V. Determine the line currents (a) by mesh analysis without using symmetrical components, and (b) using symmetrical components.

8.20 A three-phase balanced Y-connected load with series impedances of $(8 + j24)\ \Omega$ per phase and mutual impedance between any two phases of $j4\ \Omega$ is supplied by a three-phase unbalanced source with line-to-neutral voltages of $V_{an} = 200\underline{/25°}$, $V_{bn} = 100\underline{/-155°}$, $V_{cn} = 80\underline{/100°}$ V. The load and source neutrals are both solidly grounded. Determine: (a) the load sequence impedance matrix, (b) the symmetrical components of the line-to-neutral voltages, (c) the symmetrical components of the load currents, and (d) the load currents.

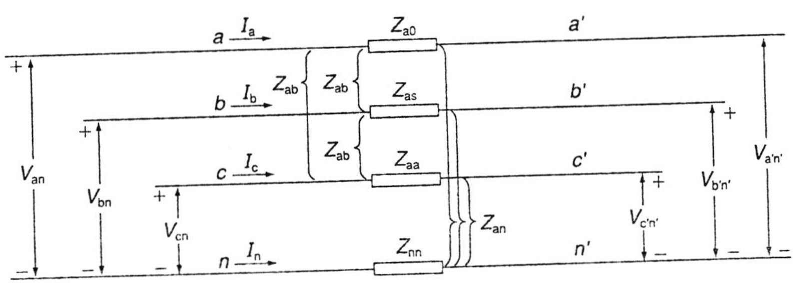
SECTION 8.3

8.21 Repeat Problem 8.10 but include balanced three-phase line impedances of $(3 + j4)$ ohms per phase between the source and load.

8.22 Consider the flow of unbalanced currents in the symmetrical three-phase line section with neutral conductor as shown in Figure 8.24. (a) Express the voltage drops across the line conductors given by $V_{aa'}$, $V_{bb'}$, and $V_{cc'}$ in terms of line currents, self-impedances defined by $Z_s = Z_{aa} + Z_{nn} - 2Z_{an}$, and mutual impedances defined by $Z_m = Z_{ab} + Z_{nn} - 2Z_{an}$. (b) Show that the sequence components of the voltage drops between the ends of the line section can be written as $V_{aa'0} = Z_0 I_{a0}$, $V_{aa'1} = Z_1 I_{a1}$, and $V_{aa'2} = Z_2 I_{a2}$, where $Z_0 = Z_s + 2Z_m = Z_{aa} + 2Z_{ab} + 3Z_{nn} - 6Z_{an}$ and $Z_1 = Z_2 = Z_s - Z_m = Z_{aa} - Z_{ab}$.

FIGURE 8.24

Problem 8.22



8.23 Let the terminal voltages at the two ends of the line section shown in Figure 8.24 be given by:

$$V_{an} = (182 + j70)\ \text{kV} \qquad V_{an'} = (154 + j28)\ \text{kV}$$
$$V_{bn} = (72.24 - j32.62)\ \text{kV} \qquad V_{bn'} = (44.24 + j74.62)\ \text{kV}$$
$$V_{cn} = (-170.24 + j88.62)\ \text{kV} \qquad V_{cn'} = (-198.24 + j46.62)\ \text{kV}$$

The line impedances are given by:

$$Z_{aa} = j60\ \Omega \qquad Z_{ab} = j20\ \Omega \qquad Z_{nn} = j80\ \Omega \qquad Z_{an} = 0$$

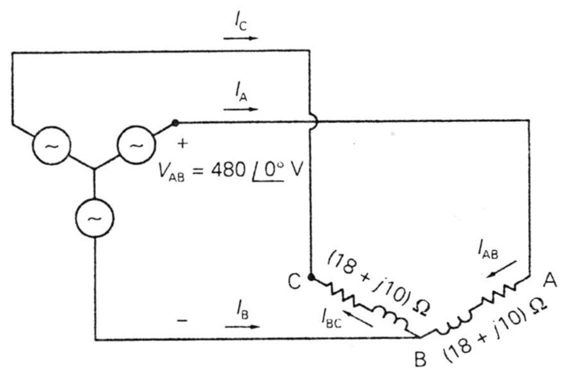
(a) Compute the line currents using symmetrical components. (*Hint:* See Problem 8.22.) (b) Compute the line currents without using symmetrical components.

SECTION 8.5

8.24 As shown in Figure 8.25, a balanced three-phase, positive-sequence source with $V_{AB} = 480\angle 0^\circ$ volts is applied to an unbalanced Δ load. Note that one leg of the Δ is open. Determine: (a) the load currents I_{AB} and I_{BC}; (b) the line currents I_A, I_B, and I_C, which feed the Δ load; and (c) the zero-, positive-, and negative-sequence components of the line currents.

FIGURE 8.25

Problem 8.24



8.25 A balanced Y-connected generator with terminal voltage $V_{bc} = 480\angle 90^\circ$ volts is connected to a balanced-Δ load whose impedance is $20\angle 40^\circ$ ohms per phase. The line impedance between the source and load is $0.5\angle 80^\circ$ ohm for each phase. The generator neutral is grounded through an impedance of $j5$ ohms. The generator sequence impedances are given by $Z_{g0} = j7$, $Z_{g1} = j15$, and $Z_{g2} = j10$ ohms. Draw the sequence networks for this system and determine the sequence components of the line currents.

8.26 In a three-phase system, a synchronous generator supplies power to a 208-volt synchronous motor through a line having an impedance of $0.5\angle 80^\circ$ ohm per phase. The motor draws 10 kW at 0.8 p.f. leading and at rated voltage. The neutrals of both the generator and motor are grounded through impedances of $j5$ ohms. The sequence impedances of both machines are $Z_0 = j5$, $Z_1 = j15$, and $Z_2 = j10$ ohms. Draw the sequence networks for this system and find the line-to-line voltage at the generator terminals. Assume balanced three-phase operation.

8.27 Calculate the source currents in Example 8.6 without using symmetrical components. Compare your solution method with that of Example 8.6. Which method is easier?

8.28 A Y-connected synchronous generator rated 20 MVA at 13.8 kV has a positive-sequence reactance of $j2.38\ \Omega$, negative-sequence reactance of $j3.33\ \Omega$, and zero-sequence reactance of $j0.95\ \Omega$. The generator neutral is solidly grounded. With the generator operating unloaded at rated voltage, a so-called single line-to-ground fault occurs at the machine terminals. During this fault, the line-to-ground voltages at the generator terminals are $V_{ag} = 0$, $V_{bg} = 8.071\underline{/-102.25^\circ}$, and $V_{cg} = 8.071\underline{/102.25^\circ}$ kV. Determine the sequence components of the generator fault currents and the generator fault currents. Draw a phasor diagram of the pre-fault and post-fault generator terminal voltages. (*Note:* For this fault, the sequence components of the generator fault currents are all equal to each other.)

SECTION 8.6

8.29 Three single-phase, two-winding transformers, each rated 450 MVA, 20 kV/288.7 kV, with leakage reactance $X_{eq} = 0.12$ per unit, are connected to form a three-phase bank. The high-voltage windings are connected in Y with a solidly grounded neutral. Draw the per-unit zero-, positive-, and negative-sequence networks if the low-voltage windings are connected: (a) in Δ with American standard phase shift, (b) in Y with an open neutral. Use the transformer ratings as base quantities. Winding resistances and exciting current are neglected.

8.30 The leakage reactance of a three-phase, 500-MVA, 345 Y/23 Δ-kV transformer is 0.09 per unit based on its own ratings. The Y winding has a solidly grounded neutral. Draw the sequence networks. Neglect the exciting admittance and assume American standard phase shift.

8.31 Choosing system bases to be 360/24 kV and 100 MVA, redraw the sequence networks for Problem 8.30.

8.32 Draw the zero-sequence reactance diagram for the power system shown in Figure 3.33. The zero-sequence reactance of each generator and of the synchronous motor is 0.05 per unit based on equipment ratings. Generator 2 is grounded through a neutral reactor of 0.06 per unit on a 100-MVA, 18-kV base. The zero-sequence reactance of each transmission line is assumed to be three times its positive-sequence reactance. Use the same base as in Problem 3.29.

SECTION 8.7

8.33 Draw the positive-, negative-, and zero-sequence circuits for the transformers shown in Figure 3.31. Include ideal phase-shifting transformers showing phase shifts determined in Problem 3.20. Assume that all windings have the same kVA rating and that the equivalent leakage reactance of any two windings with the third winding open is 0.10 per unit. Neglect the exciting admittance.

8.34 A single-phase three-winding transformer has the following parameters: $Z_1 = Z_2 = Z_3 = 0 + j0.05$, $G_c = 0$, and $B_m = 0.2$ per unit. Three identical transformers, as described, are connected with their primaries in Y (solidly grounded neutral) and with their secondaries and tertiaries in Δ. Draw the per-unit sequence networks of this transformer bank.

SECTION 8.8

8.35 For Problem 8.10, calculate the real and reactive power delivered to the three-phase load.

8.36 A three-phase impedance load consists of a balanced-Δ load in parallel with a balanced-Y load. The impedance of each leg of the Δ load is $Z_\Delta = 6 + j6\ \Omega$, and the impedance of each leg of the Y load is $Z_Y = 2 + j2\ \Omega$. The Y load is grounded through a neutral impedance $Z_n = j1\ \Omega$. Unbalanced line-to-ground source voltages V_{ag}, V_{bg}, and V_{cg} with sequence components $V_0 = 10\underline{/60^\circ}$, $V_1 = 100\underline{/0^\circ}$, and $V_2 = 15\underline{/200^\circ}$ volts are applied to the load. (a) Draw the zero-, positive-, and negative-sequence networks. (b) Determine the complex power delivered to each sequence network. (c) Determine the total complex power delivered to the three-phase load.

8.37 For Problem 8.8, compute the power absorbed by the load using symmetrical components. Then verify the answer by computing directly without using symmetrical components.

8.38 For Problem 8.20, determine the complex power delivered to the load in terms of symmetrical components. Verify the answer by adding up the complex power of each of the three phases.

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