Chapter 10 Problem Solutions

10.1 A 60-Hz alternating voltage having a rms value of 100 V is applied to a series RL circuit by closing a switch. The resistance is 15 Ω and the inductance is 0.12 H.

(*a*) Find the value of the dc component of current upon closing the switch if the instantaneous value of the voltage is 50 V at that time.

(*b*) What is the instantaneous value of the voltage which will produce the maximum dc component of current upon closing the switch?

(*c*) What is the instantaneous value of the voltage which will result in the absence of any dc component of current upon closing the switch?

(*d*) If the switch is closed when the instantaneous voltage is zero, find the instantaneous current 0.5, 1.5 and 5.5 cycles later.

Solution:

(*a*)

$$\begin{aligned}
& v &=& \; V_m \sin(\omega t + \alpha) \\
\text{For } t = 0 \quad & 50 &=& \; \sqrt{2} \times 100 \sin\alpha \\
& \alpha &=& \; 20.70^\circ \text{ or } 159.30^\circ \\
& Z &=& \; 15 + j2\pi \times 60 \times 0.12 \;=\; 47.66\angle 71.66^\circ \\
\text{At } t = 0 \quad & i_{dc} &=& \; -\frac{100 \times \sqrt{2}}{47.66} \sin(20.7^\circ - 71.66^\circ) \;=\; 2.305 \text{ A} \\
\text{or} \quad & i_{dc} &=& \; -\frac{100 \times \sqrt{2}}{47.66} \sin(159.3^\circ - 71.66^\circ) \;=\; -2.965 \text{ A} \quad \text{(max.)}
\end{aligned}$$

(*b*) Maximum dc component occurs when $\sin(\alpha - \theta) = \pm 1$ or when $(\alpha - \theta) = \pm 90^\circ$ when $\alpha = 161.66^\circ$ or -18.34°.

$$v = 100\sqrt{2}\sin 161.66^\circ = 100\sqrt{2}\sin -18.34^\circ = \pm 44.5 \text{ V}$$

(*c*) No dc component will occur when $\alpha - \theta = 0$, or 180°, i.e. when $\alpha = 71.66^\circ$ or 251.66°.

$$v = 100\sqrt{2}\sin 71.66^\circ = 100\sqrt{2}\sin 251.66^\circ = \pm 134.24 \text{ V}$$

(*d*) For $v = 0$ when $t = 0$ and $\alpha = 0$. 0.5 cycles later $\omega t = \pi$ rad.

$$\begin{aligned}
t &= \frac{\pi}{2\pi 60} = 0.008333 \text{ s} \\
i &= \frac{100\sqrt{2}}{47.66}\left[\sin(180^\circ - 71.66^\circ) - \epsilon^{\frac{-15}{0.12}(0.008333)} \times \sin(-71.66^\circ)\right] \\
&= \frac{100\sqrt{2}}{47.66}\left(1 + \epsilon^{-1.0461}\right)\sin(-71.66^\circ) = 3.810 \text{ A}
\end{aligned}$$

Similarly,

$$\text{1.5 cycles later:} \quad \omega t = 3\pi$$
$$t = 0.025 \text{ s}$$
$$i = 2.940 \text{ A}$$

and

$$\text{5.5 cycles later:} \quad \omega t = 11\pi$$
$$t = 0.09167 \text{ s}$$
$$i = 2.817 \text{ A}$$

Note that the dc component has essentially disappeared after 5.5 cycles. (5 time constants = 0.04 s).

10.2 A generator connected through a 5-cycle circuit breaker to a transformer is rated 100 MVA, 18 kV, with reactances of $X_d'' = 19\%$, $X_d' = 26\%$ and $X_d = 130\%$. It is operating at no load and rated voltage when a three-phase short circuit occurs between the breaker and the transformer. Find (*a*) the sustained short-circuit current in the breaker, (*b*) the initial symmetrical rms current in the breaker and (*c*) the maximum possible dc component of the short-circuit current in the breaker.

Solution:

$$\text{Base current} = \frac{100,000}{\sqrt{3} \times 18} = 3207.5 \text{ A}$$

(*a*) $\dfrac{1}{j1.3} \times 3207.5 = 2,467 \text{ A}$

(*b*) $\dfrac{1}{j0.19} \times 3207.5 = 16,882 \text{ A}$

(*c*) $\sqrt{2} \times 16,882 = 23,874 \text{ A}$

10.3 The three-phase transformer connected to the generator described in Prob. 10.2 is rated 100 MVA, 240Y/18Δ kV, $X = 10\%$. If a three-phase short circuit occurs on the high-voltage side of the transformer at rated voltage and no load, find (*a*) the initial symmetrical rms current in the transformer windings on the high-voltage side and (*b*) the initial symmetrical rms current in the line on the low-voltage side.

Solution:

$$I'' = \frac{1.0}{j\,(0.19 + 0.10)} = -j3.448 \text{ per unit}$$
$$\text{Base } I_{\text{HV}} = \frac{100,000}{\sqrt{3} \times 240} = 240.6 \text{ A}$$
$$\text{Base } I_{\text{LV}} = \frac{100,000}{\sqrt{3} \times 18} = 3207.5 \text{ A}$$

$$
\begin{aligned}
(a) \qquad & 3.448 \times 240.6 = 829.5 \text{ A} \\
(b) \qquad & 3.448 \times 3207.5 = 11{,}060 \text{ A}
\end{aligned}
$$

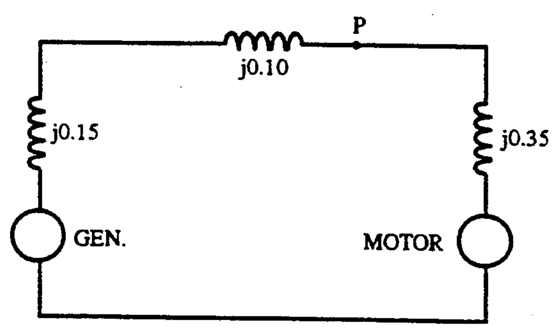
10.4 A 60-Hz generator is rated 500 MVA, 20 kV, with $X''_d = 0.20$ per unit. It supplies a purely resistive load of 400 MW at 20 kV. The load is connected directly across the terminals of the generator. If all three phases of the load are short-circuited simultaneously, find the initial symmetrical rms current in the generator in per unit on a base of 500 MVA, 20 kV.

Solution:

$$
\begin{aligned}
I_{\text{Load}} &= \frac{400}{500} = 0.8 \text{ per unit} \\
E''_g &= 1.0 + 0.8 \times j0.20 = 1.0 + j0.16 \text{ per unit} \\
I''_g &= \frac{1 + j0.16}{j0.20} = 0.8 - j5.0 \text{ per unit or } 5.06 \text{ per unit}
\end{aligned}
$$

10.5 A generator is connected through a transformer to a synchronous motor. Reduced to the same base, the per-unit subtransient reactances of the generator and motor are 0.15 and 0.35, respectively, and the leakage reactance of the transformer is 0.10 per unit. A three-phase fault occurs at the terminals of the motor when the terminal voltage of the generator is 0.9 per unit and the output current of the generator is 1.0 per unit at 0.8 power factor leading. Find the subtransient current in per unit in the fault, in the generator and in the motor. Use the terminal voltage of the generator as the reference phasor and obtain the solution (a) by computing the voltages behind subtransient reactance in the generator and motor and (b) by using Thévenin's theorem.

Solution:



P: fault point

(a)

$$
\begin{aligned}
E''_g &= 0.9 + (0.8 + j0.6)(j0.15) = 0.81 + j0.12 \text{ per unit} \\
E''_m &= 0.9 - (0.8 + j0.6)(j0.45) = 1.17 - j0.36 \text{ per unit} \\
I''_g &= \frac{0.81 + j0.12}{j0.25} = 0.48 - j3.24 \text{ per unit}
\end{aligned}
$$

$$I''_m = \frac{1.17 - j0.36}{j0.35} = -1.03 - j3.34 \text{ per unit}$$
$$I''_f = I''_g + I''_m = -0.55 - j6.58 \text{ per unit}$$

(b)

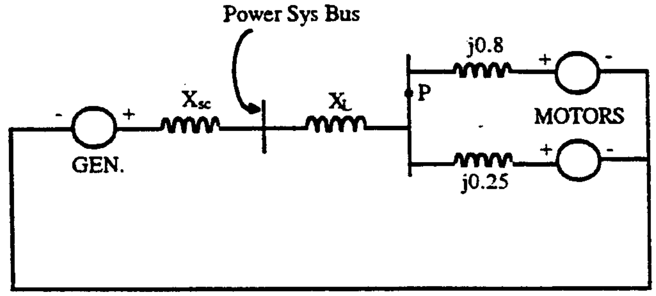
$$V_f = 0.9 - (0.8 + j0.6)(j0.1) = 0.96 - j0.08 \text{ per unit}$$
$$Z_{th} = \frac{j0.25 \times j0.35}{j0.60} = j0.146 \text{ per unit}$$
$$I''_f = \frac{0.96 - j0.08}{j0.146} = -0.55 - j6.58 \text{ per unit}$$

By replacing I''_f by a current source and then applying the principle of superposition,

$$I''_g = 0.8 + j0.6 + \frac{j0.35}{j0.60}(-0.55 - j6.58) = 0.48 - j3.24 \text{ per unit}$$
$$I''_m = -0.8 - j0.6 + \frac{j0.25}{j0.60}(-0.55 - j6.58) = -1.03 - j3.34 \text{ per unit}$$

10.6 Two synchronous motors having subtransient reactances of 0.80 and 0.25 per unit, respectively, on a base of 480 V, 2000 kVA are connected to a bus. This motor is connected by a line having a reactance of 0.023 Ω to a bus of a power system. At the power-system bus the short-circuit megavoltamperes of the power system are 9.6 MVA for a nominal voltage of 480 V. When the voltage at the motor bus is 440 V, neglect load current and find the initial symmetrical rms current in a three-phase fault at the motor bus.

Solution:



P: fault point

$$\text{Base } Z = \frac{0.48^2}{2} = 0.1152\ \Omega$$
$$X_L = \frac{0.023}{0.1152} = 0.20 \text{ per unit}$$
$$X_{SC} = \frac{2}{96} = 0.208 \text{ per unit}$$
$$X_{th} = \frac{1}{\frac{1}{0.8} + \frac{1}{0.25} + \frac{1}{0.408}} = 0.130 \text{ per unit}$$

$$I_f'' = \frac{440/480}{j1.30} = 7.05 \text{ per unit}$$

$$\text{or} \qquad 7.05 \times \frac{2000}{\sqrt{3} \times 0.48} = 17,000 \text{ A}$$

10.7 The bus impedance matrix of a four-bus network with values in per unit is

$$\mathbf{Z}_{\text{bus}} = \begin{bmatrix} j0.15 & j0.08 & j0.04 & j0.07 \\ j0.08 & j0.15 & j0.06 & j0.09 \\ j0.04 & j0.06 & j0.13 & j0.05 \\ j0.07 & j0.09 & j0.05 & j0.12 \end{bmatrix}$$

Generators connected to buses ① and ② have their subtransient reactances included in $\mathbf{Z}_{\text{bus}}$. If prefault current is neglected, find the subtransient current in per unit in the fault for a three-phase fault on bus ④. Assume the voltage at the fault is $1.0\angle 0^\circ$ per unit before the fault occurs. Find also the per-unit current from generator 2 whose subtransient reactance is 0.2 per unit.

> Note to Instructor: This short problem is easily varied by assuming the fault to occur on other buses.

Solution:

At bus ④,

$$I_f'' = \frac{1}{j0.12} = -j8.33 \text{ per unit}$$

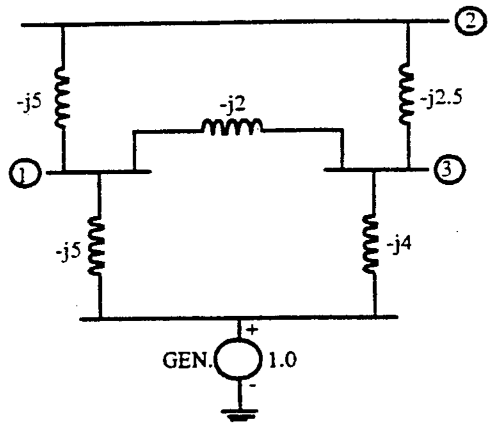
$$V_2 = 1.0 - \frac{0.09}{0.12} = 0.25 \text{ per unit}$$

From generator 2,

$$I_2'' = \frac{1 - 0.25}{j0.2} = -3.75 \text{ per unit}$$

10.8 For the network shown in Fig. 10.17, find the subtransient current in per unit from generator 1 and in line ①-② and the voltages at buses ① and ③ for a three-phase fault on bus ②. Assume that no current is flowing prior to the fault and that the prefault voltage at bus ② is $1.0\underline{/0^\circ}$ per unit. Use the bus impedance matrix in the calculations.

Solution:



Thevenin Network
(Admittances marked in per unit)

$$\mathbf{Y}_{\text{bus}} = \begin{bmatrix} -j12 & j5 & j2 \\ j5 & -j7.5 & j2.5 \\ j2 & j2.5 & -j8.5 \end{bmatrix}$$

$$\begin{aligned} \Delta &= \frac{1}{-j}\{12(7.5\times 8.5 - 2.5\times 2.5) + 5(-5\times 8.5 - 2\times 2.5) - 2[-5(-25) - (-2\times 7.5)]\} \\ &= j397.5 \end{aligned}$$

For the fault at bus ② the impedances needed are

$$\begin{aligned} Z_{12} &= \frac{\Delta_{21}}{\Delta} = -\frac{j5(-j8.5) - j2.5(j2)}{j397.5} = \frac{-42.5 - j5}{j397.5} = j0.1195 \\ Z_{22} &= \frac{\Delta_{21}}{\Delta} = \frac{-j12(-j8.5) - j2(j2)}{j397.5} = \frac{-102+4}{j397.5} = j0.2465 \\ Z_{32} &= \frac{\Delta_{23}}{\Delta} = -\frac{-j12(j2.5) - (j5)(j2)}{j397.5} = \frac{-30-10}{j397.5} = j0.1006 \\ I_f'' &= \frac{1.0}{-j0.2465} = -j4.056 \text{ per unit} \\ V_1 &= 1 - \frac{j0.1195}{j0.2465} = 0.515 \text{ per unit} \\ V_3 &= 1 - \frac{j0.1006}{j0.2465} = 0.592 \text{ per unit} \\ I_{12}'' &= \frac{0.515}{j0.2} = -j2.58 \text{ per unit} \end{aligned}$$

From generator 1,

$$I_g'' = \frac{1 - 0.515}{j0.2} = -j2.43 \text{ per unit}$$

10.9 For the network shown in Fig. 10.17 determine $\mathbf{Y}_{\text{bus}}$ and its triangular factors. Use the triangular factors to generate the elements of $\mathbf{Z}_{\text{bus}}$ needed to solve Prob. 10.8.

Solution:

$$\mathbf{Y}_{\text{bus}} = \begin{bmatrix} -j12 & j5 & j2 \\ j5 & -j7.5 & j2.5 \\ j2 & j2.5 & -j8.5 \end{bmatrix} \text{ per unit}$$

$$= \underbrace{\begin{bmatrix} -j12 & \cdot & \cdot \\ j5 & -j5.4167 & \cdot \\ j2 & j3.3333 & -j6.1154 \end{bmatrix}}_{\mathbf{L}} \underbrace{\begin{bmatrix} 1 & -0.4167 & -0.1667 \\ \cdot & 1 & -0.6154 \\ \cdot & \cdot & 1 \end{bmatrix}}_{\mathbf{U}}$$

$$\mathbf{Y}_{\text{bus}}{}^{-1} = \mathbf{U}^{-1}\mathbf{L}^{-1} \quad \text{where}$$

$$\mathbf{U}^{-1} = \begin{bmatrix} 1 & 0.4167 & 0.4231 \\ \cdot & 1 & 0.6154 \\ \cdot & \cdot & 1 \end{bmatrix} \qquad \mathbf{L}^{-1} = \begin{bmatrix} j0.0833 & & \\ j0.0769 & j0.1846 & \\ j0.0692 & j0.1006 & j0.1635 \end{bmatrix}$$

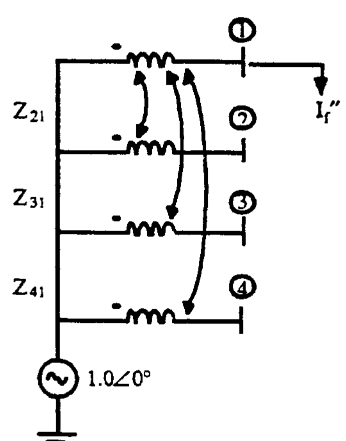
Hence,

$$\mathbf{Z}_{\text{bus}} = \mathbf{Y}_{\text{bus}}{}^{-1} = \mathbf{U}^{-1}\mathbf{L}^{-1} = \begin{bmatrix} j0.1447 & j0.1195 & j0.0692 \\ j0.1195 & j0.2465 & j0.1006 \\ j0.0692 & j0.1006 & j0.1635 \end{bmatrix} \text{ per unit}$$

10.10 If a three-phase fault occurs at bus ① of the network of Fig. 10.5 when there is no load (all bus voltages equal $1.0\angle 0^\circ$ per unit), find the subtransient current in the fault, the voltages at buses ②, ③ and ④, and the current from the generator connected to bus ④. Use equivalent circuits based on $\mathbf{Z}_{\text{bus}}$ of Example 10.3 and similar to those of Fig. 10.7 to illustrate your calculations.

Solution:

$$I_f'' = \frac{1.0\angle 0^\circ}{Z_{11}} = \frac{1.0\angle 0^\circ}{j0.2436} = -j4.105 \text{ per unit}$$



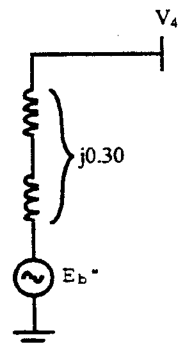
During the fault,

$$\begin{bmatrix} V_2 \\ V_3 \\ V_4 \end{bmatrix} = 1.0\angle 0^\circ \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - I''_f \begin{bmatrix} Z_{21} \\ Z_{31} \\ Z_{41} \end{bmatrix}$$

$$= 1.0\angle 0^\circ \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - (-j4.105) \begin{bmatrix} j0.1938 \\ j0.1544 \\ j0.1456 \end{bmatrix} = \begin{bmatrix} 0.2444\angle 0^\circ \\ 0.3662\angle 0^\circ \\ 0.4023\angle 0^\circ \end{bmatrix} \text{ per unit}$$

Current from generator at bus ④ is calculated to be

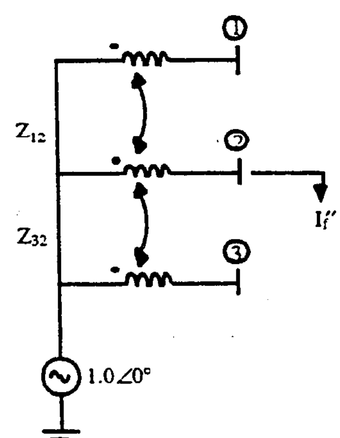
$$\frac{(E''_b - V_4)}{j0.30} = \frac{(1.0 - 0.4023)}{j0.30} = -j1.992 \text{ per unit}$$



10.11 The network of Fig. 10.8 has the bus impedance matrix given in Example 10.4. If a short-circuit fault occurs at bus ② of the network when there is no load (all bus voltages equal $1.0\angle 0^\circ$ per unit), find the subtransient current in the fault, the voltages at buses ① and ③, and the current from the generator connected to bus ①. Use equivalent circuits based on $\mathbf{Z_{bus}}$ and similar to those of Fig. 10.7 to illustrate your calculations.

Solution:

$$I''_f = \frac{1.0\angle 0^\circ}{Z_{22}} = \frac{1.0\angle 0^\circ}{j0.1338} = -j7.474 \text{ per unit}$$



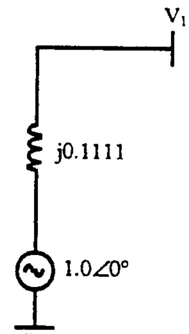
During the fault,

$$\begin{bmatrix} V_1 \\ V_3 \end{bmatrix} = 1.0\angle 0^\circ \begin{bmatrix} 1 \\ 1 \end{bmatrix} - I''_f \begin{bmatrix} Z_{12} \\ Z_{32} \end{bmatrix}$$

$$= 1.0\angle 0^\circ \begin{bmatrix} 1 \\ 1 \end{bmatrix} - (-j7.474) \begin{bmatrix} j0.0793 \\ j0.0664 \end{bmatrix} = \begin{bmatrix} 0.5830\angle 0^\circ \\ 0.5037\angle 0^\circ \end{bmatrix} \text{ per unit}$$

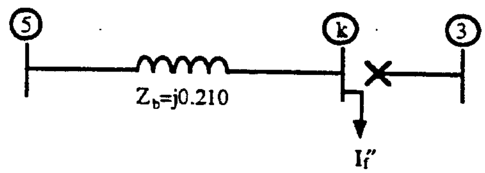
Current from generator at bus ① is calculated to be

$$\frac{(1.0\angle 0^\circ - V_1)}{j0.1111} = \frac{(1.0 - 0.5830)}{j0.1111} = -j3.753 \text{ per unit}$$



10.12 $\mathbf{Z}_{\text{bus}}$ for the network of Fig. 10.8 is given in Example 10.4. If a tail-end short-circuit fault occurs on line ③–⑤ of the network on the line side of the breaker at bus ③, calculate the subtransient current in the fault when only the near-end breaker at bus ③ has opened. Use the equivalent circuit approach of Fig. 10.11.

Solution:



$$I''_f = \frac{1.0\angle 0^\circ}{Z_{kk,\text{new}}} \quad \text{where}$$

$$Z_{kk,\text{new}} = Z_{55} + Z_b - \frac{(Z_{55} - Z_{35})^2}{Z_{\text{th},53} - Z_b}$$

$$Z_{\text{th},53} = Z_{55} + Z_{33} - 2Z_{53}$$

Hence,

$$Z_{\text{th},53} = j\,[0.1301 + 0.0875 - 2 \times 0.0603] = j0.097 \text{ per unit}$$

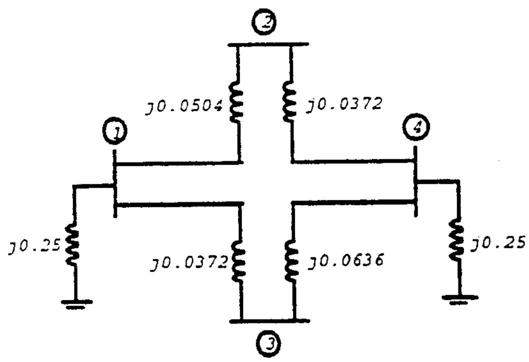
$$Z_{kk,\text{new}} = j\left[0.1301 + 0.210 - \frac{(0.1301 - 0.0603)^2}{0.097 - 0.210}\right] = j0.2970 \text{ per unit}$$

$$I''_f = \frac{1.0\angle 0^\circ}{j0.2970} = -j3.367 \text{ per unit}$$

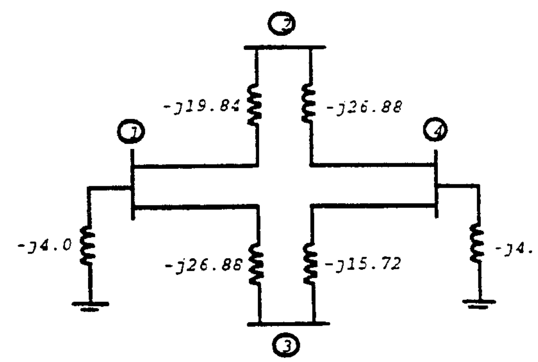
10.13 Figure 9.2 shows the one-line diagram of a single power network which has the line data given in Table 9.2. Each generator connected to buses ① and ④ has a subtransient reactance of 0.25 per unit. Making the usual fault-study assumptions, summarized in Sec. 10.6, determine for the network (a) $\mathbf{Y}_{\text{bus}}$, (b) $\mathbf{Z}_{\text{bus}}$, (c) the subtransient current in per unit in a three-phase fault on bus ③ and (d) the contributions to the fault current from line ①–③ and from line ④–③.

Solution:

Reactance diagram:



Admittance diagram:



(a)

$$\mathbf{Y}_{\text{bus}} = \begin{array}{c} \\ ① \\ ② \\ ③ \\ ④ \end{array} \begin{array}{c} \begin{array}{cccc} ① & ② & ③ & ④ \end{array} \\ \begin{bmatrix} -j50.72 & j19.84 & j26.88 & j0 \\ j19.84 & -j46.72 & j0 & j26.88 \\ j26.88 & j0 & -j42.60 & j15.72 \\ j0 & j26.88 & j15.72 & -j46.60 \end{bmatrix} \end{array}$$

(b)

$$\mathbf{Z}_{\text{bus}} = \mathbf{Y}_{\text{bus}}^{-1} = \begin{array}{c} \\ ① \\ ② \\ ③ \\ ④ \end{array} \begin{array}{c} \begin{array}{cccc} ① & ② & ③ & ④ \end{array} \\ \begin{bmatrix} j0.1357 & j0.1234 & j0.1278 & j0.1143 \\ j0.1234 & j0.1466 & j0.1246 & j0.1266 \\ j0.1278 & j0.1246 & j0.1492 & j0.1222 \\ j0.1143 & j0.1266 & j0.1222 & j0.1357 \end{bmatrix} \end{array}$$

(c) From a fault at bus ③,

$$I_f'' = \frac{1.0\angle 0^\circ}{Z_{33}} = \frac{1.0\angle 0^\circ}{j0.1492} = -j6.702 \text{ per unit}$$

(d) During the fault,

$$\begin{bmatrix} V_1 \\ V_4 \end{bmatrix} = 1.0\angle 0^\circ \begin{bmatrix} 1 \\ 1 \end{bmatrix} - I_f'' \begin{bmatrix} Z_{13} \\ Z_{43} \end{bmatrix}$$

$$= 1.0\angle 0^\circ \begin{bmatrix} 1 \\ 1 \end{bmatrix} - (-j6.702) \begin{bmatrix} j0.1278 \\ j0.1222 \end{bmatrix} = \begin{bmatrix} 0.1435\angle 0^\circ \\ 0.1810\angle 0^\circ \end{bmatrix} \text{ per unit}$$

Current flow in line ①–③ is calculated to be

$$\frac{(V_1 - V_3)}{jX_{13}} = \frac{(0.1435 - 0)}{j0.0372} = -j3.857 \text{ per unit}$$

Current flow in line ④–③ is calculated to be

$$\frac{(V_4 - V_3)}{jX_{43}} = \frac{(0.1810 - 0)}{j0.0638} = -j2.846 \text{ per unit}$$

where the sum of these currents is $-j6.703 (\cong I_f'')$.

10.14 A 625-kV generator with $X_d'' = 0.20$ per unit is connected to a bus through a circuit breaker as shown in Fig. 10.18. Connected through circuit breakers to the same bus are three synchronous motors rated 250 hp, 2.4 kV, 1.0 power factor, 90% efficiency, with $X_d'' = 0.20$ per unit. The motors are operating at full load, unity power factor and rated voltage, with the load equally divided between the machines.

(*a*) Draw the impedance diagram with the impedances marked in per unit on a base of 625 kVA, 2.4 kV.

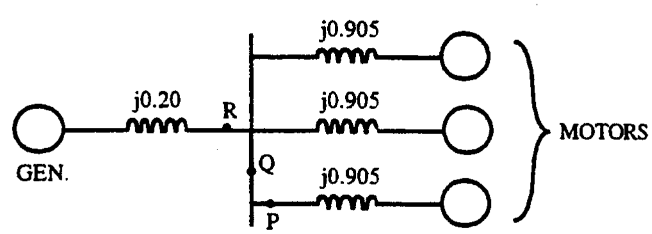
(*b*) Find the symmetrical short-circuit current in amperes which must be interrupted by breakers *A* and *B* for a three-phase fault at point *P*. Simplify the calculations by neglecting the prefault current.

(*c*) Repeat part (*b*) for a three-phase fault at point *Q*.

(*d*) Repeat part (*b*) for a three-phase fault at point *R*.

Solution:

(*a*)



$$\text{Motor input} = \frac{250 \times 0.746}{0.9} = 207.2 \text{ kVA}$$

$$X_m'' = 0.2 \times \frac{625}{207.2} = 0.603 \text{ per unit}$$

For interrupting current use

$$1.5X_m = 1.5 \times 0.603 = 0.905 \text{ per unit}$$

$$\text{Base I} = \frac{625}{\sqrt{3} \times 2.4} = 150.4 \text{ per unit}$$

$$Z_{th} = \frac{(j0.905/3)j0.2}{j0.905/3 + j0.2} = j0.1203 \text{ per unit}$$

$$I_f'' = \frac{1}{j0.1203} = -j8.315 \text{ per unit}$$

From the generator:

$$I = -j8.315\left(\frac{j0.905/3}{j0.905/3 + j0.2}\right) = -j5.000 \text{ per unit, or } 752 \text{ A}$$

From each motor:

$$I = \frac{[-j8.315 - (-j5.0)]}{3} = -j1.105 \text{ per unit, or } 166.2 \text{ A}$$

(*b*) Fault at P

$$\begin{aligned}\text{Thru A:} \quad I &= 752 \text{ A (gen. only)}\\ \text{Thru B:} \quad I &= -j5.0 + 2(-j1.105) = -j7.210 \text{ per unit or } 1084 \text{ A}\end{aligned}$$

(*c*) Fault at Q

$$\begin{aligned}\text{Thru A:} \quad I &= 752 \text{ A (gen. only)}\\ \text{Thru B:} \quad I &= 166.2 \text{ A (one motor)}\end{aligned}$$

(*d*) Fault at R

$$\begin{aligned}\text{Thru A:} \quad I &= 3(166.2) = 493.6 \text{ A}\\ \text{Thru B:} \quad I &= 166.2 \text{ A}\end{aligned}$$

Maximum currents to be interrupted by A and B are 752 A and 1084 A, respectively.

10.15 A circuit breaker having a nominal rating of 34.5 kV and a continuous current rating of 1500 A has a voltage range factor K of 1.65. Rated maximum voltage is 38 kV and the rated short-circuit current at that voltage is 22 kA. Find (*a*) the voltage below which rated short-circuit current does not increase as operating voltage decreases and the value of that current and (*b*) rated short-circuit current at 34.5 kV.

Note to Instructor: The attention of the student should be directed to the paragraph just preceding Example 10.7. Students wishing to learn about circuit breaker applications should review Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, ANSI C37.010-1979, American National Standards Institute, New York. This publication is also IEEE Std 320-1979.

Solution:

(*a*) The voltage below which rated short-circuit current does not increase as operating voltage decreases and the value of that current are

$$\begin{aligned}V &= \frac{38}{1.65} = 23.0 \text{ kV}\\ I &= 1.65 \times 22,000 = 36,300 \text{ A}\end{aligned}$$

(*b*) The rated short-circuit current at 34.5 kV is

$$I = \frac{22,000 \times 38}{34.5} = 24,232 \text{ A}$$