

Electric Energy (3rd Edition)

Chapter 14, Problem 9E

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Step-by-step solution

Step 1 of 14

Refer to Figure 14.5 in the text book.

Consider the matrix equations consisting of the line impedances and admittances to find the currents in each line.

$$\begin{bmatrix} 1 + (\overline{Y}_6 + \overline{Y}_1)\overline{Z}_{11} & -\overline{Y}_6\overline{Z}_{12} & 0 \\ -\overline{Y}_6\overline{Z}_{21} & 1 + (\overline{Y}_6 + \overline{Y}_2)\overline{Z}_{22} & 0 \\ -\overline{Y}_6\overline{Z}_{31} & -\overline{Y}_6\overline{Z}_{32} & 1 \end{bmatrix} \begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} = \begin{bmatrix} \overline{V}_1 \\ \overline{V}_2 \\ -(\overline{V}_3 + \overline{V}_0) \end{bmatrix} (\overline{P}_1)$$

Substitute $\frac{1}{j4}$ S for $\overline{Y}_1$, $\frac{1}{j5}$ S for $\overline{Y}_2$, 0 for $\overline{Y}_6$, $50 + j5 \Omega$ for $\overline{Z}_{11}$, $10 + j2 \Omega$ for $\overline{Z}_{22}$ and $\frac{500 \text{ kV}}{\sqrt{3}}$ for $\overline{V}_3$.

$$\begin{bmatrix} 1 + \left(0 + \frac{1}{j4}\right)(50 + j5) & -\left(0\right)(10 + j2) & 0 \\ -\left(0\right)(50 + j5) & 1 + \left(0 + \frac{1}{j5}\right)(10 + j2) & 0 \\ -\left(\frac{1}{j4}\right)(50 + j5) & -\left(\frac{1}{j5}\right)(10 + j2) & 1 \end{bmatrix} \begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} = \begin{bmatrix} \frac{1}{j4} \\ \frac{1}{j5} \\ -\left(\frac{500 \text{ k}}{\sqrt{3}}\right) \end{bmatrix}$$
$$\begin{bmatrix} 1 + (-j0.25)(50 + j5) & 0 & 0 \\ -\left(0\right)(50 + j5) & 1 + (-j0.2)(10 + j2) & 0 \\ -(-j0.25)(50 + j5) & -(-j0.2)(10 + j2) & 1 \end{bmatrix} \begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} = \begin{bmatrix} -j0.25 \\ -j0.2 \\ -\left(-j0.25 - j0.2\right) \end{bmatrix} \begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} \begin{bmatrix} (288.6751 \text{ k}) \\ (288.6751 \text{ k}) \\ (288.6751 \text{ k}) \end{bmatrix}$$
$$\begin{bmatrix} 1 + 1.25 - j12.5 & 0 & 0 \\ 0 & 1 + 0.4 - j2 & 0 \\ -1.25 + j12.5 & -0.4 + j2 & 1 \end{bmatrix} \begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} = \begin{bmatrix} -j0.25 \\ -j0.2 \\ j0.45 \end{bmatrix} \begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} \begin{bmatrix} (288.6751 \text{ k}) \\ (288.6751 \text{ k}) \\ (288.6751 \text{ k}) \end{bmatrix}$$
$$\begin{bmatrix} 12.7009\angle -78.8^\circ & 0 & 0 \\ 0 & 2.4413\angle -55.01^\circ & 0 \\ 12.5624\angle 95.71^\circ & 2.0396\angle 101.31^\circ & 1 \end{bmatrix} \begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} = \begin{bmatrix} 72.0663\angle -90^\circ \text{ k} \\ 57.735\angle -90^\circ \text{ k} \\ 129.9038\angle 90^\circ \text{ k} \end{bmatrix} \dots (1)$$

Comment

Step 2 of 14

Consider matrix A

$$A = \begin{bmatrix} 12.7009\angle -78.8^\circ & 0 & 0 \\ 0 & 2.4413\angle -55.01^\circ & 0 \\ 12.5624\angle 95.71^\circ & 2.0396\angle 101.31^\circ & 1 \end{bmatrix}$$

Calculate determinant for matrix A

$$|A| = \begin{vmatrix} 12.7009\angle -78.8^\circ & 0 & 0 \\ 0 & 2.4413\angle -55.01^\circ & 0 \\ 12.5624\angle 95.71^\circ & 2.0396\angle 101.31^\circ & 1 \end{vmatrix}$$
$$= (12.7009\angle -78.8^\circ)(2.4413\angle -55.01^\circ)$$
$$= 31.0067\angle -133.81^\circ$$

Therefore, the determinant of matrix A is $31.0067\angle -133.81^\circ$.

Comment

Step 3 of 14

Recall matrix A.

$$A = \begin{bmatrix} 12.7009\angle -78.8^\circ & 0 & 0 \\ 0 & 2.4413\angle -55.01^\circ & 0 \\ 12.5624\angle 95.71^\circ & 2.0396\angle 101.31^\circ & 1 \end{bmatrix}$$

Calculate the adjoint matrix A.

$$\text{adj}(A) = \begin{bmatrix} 2.4413\angle -55.01^\circ & 0 & 30.6686\angle -139.3^\circ \\ 0 & 12.7009\angle -78.8^\circ & 25.9048\angle -157.49^\circ \\ 2.4413\angle -55.01^\circ & 0 & 31.0067\angle -133.81^\circ \end{bmatrix}$$
$$= \begin{bmatrix} 2.4413\angle -55.01^\circ & 0 & 0 \\ 0 & 12.7009\angle -78.8^\circ & 0 \\ 30.6686\angle -139.3^\circ & 25.9048\angle -157.49^\circ & 31.0067\angle -133.81^\circ \end{bmatrix}$$

Comment

Step 4 of 14

The solutions for equation (1) is,

$$\begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} = \frac{\text{adj}(A)}{\det(A)} \begin{bmatrix} 72.0663\angle -90^\circ \text{ k} \\ 57.735\angle -90^\circ \text{ k} \\ 129.9038\angle 90^\circ \text{ k} \end{bmatrix}$$

Substitute $\begin{bmatrix} 2.4413\angle -55.01^\circ & 0 & 0 \\ 0 & 12.7009\angle -78.8^\circ & 0 \\ 30.6686\angle -139.3^\circ & 25.9048\angle -157.49^\circ & 31.0067\angle -133.81^\circ \end{bmatrix}$ for $\text{adj}(A)$ and $31.0067\angle -133.81^\circ$ for $\det(A)$.

$$\begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} = \begin{bmatrix} \frac{1}{31.0067\angle -133.81^\circ} \times \begin{bmatrix} 72.0663\angle -90^\circ \text{ k} \\ 57.735\angle -90^\circ \text{ k} \\ 129.9038\angle 90^\circ \text{ k} \end{bmatrix} \\ \frac{1}{31.0067\angle -133.81^\circ} \times \begin{bmatrix} 175.9355\angle -145.01^\circ \text{ k} \\ 733.2865\angle -168.8^\circ \text{ k} \\ 932.4527\angle 16.76^\circ \text{ k} \end{bmatrix} \\ \frac{1}{31.0067\angle -133.81^\circ} \times \begin{bmatrix} 5.6741\angle -11.2^\circ \text{ k} \\ 23.6493\angle -34.99^\circ \text{ k} \\ 30.0726\angle 150.57^\circ \text{ k} \end{bmatrix} \end{bmatrix}$$
$$\begin{bmatrix} \overline{I}_1 \\ \overline{I}_2 \\ -\overline{I}_3 \end{bmatrix} = \begin{bmatrix} 5.6741\angle -11.2^\circ \text{ k} \\ 23.6493\angle -34.99^\circ \text{ k} \\ 30.0726\angle 150.57^\circ \text{ k} \end{bmatrix} \text{ A}$$

Therefore, the values of the currents $\overline{I}_1$, $\overline{I}_2$ and $\overline{I}_3$ are $5.6741\angle -11.2^\circ$ kA, $23.6493\angle -34.99^\circ$ kA and $30.0726\angle -29.43^\circ$ kA respectively.

Comment

Step 5 of 14

Calculate the power consumed by load 1.

$$P_1 = 3\overline{I}_1^2 R_{L1}$$

Substitute 5.6741 kA for I_1 and 50Ω for R_{L1} .

$$P_1 = 3(5.6741 \text{ k})^2 (50)$$
$$= (32.1954 \text{ M})(50)$$
$$= 4.8293 \text{ GW}$$

Therefore, the value of the power consumed by load 1 is 4.8293 GW .

Comment

Step 6 of 14

Calculate the power consumed by load 2.

$$P_2 = 3\overline{I}_2^2 R_{L2}$$

Substitute 23.6493 kA for I_2 and 40Ω for R_{L2} .

$$P_2 = 3(23.6493 \text{ k})^2 (40)$$
$$= (559.2894 \text{ M})(120)$$
$$= 67.1147 \text{ GW}$$

Therefore, the value of the power consumed by load 2 is 67.1147 GW .

Comment

Step 7 of 14

Calculate the power produced by the generator.

$$P_3 = P_1 + P_2$$

Substitute 67.1147 GW for P_2 and 4.8293 GW for P_1 .

$$P_3 = 4.8293 \text{ G} + 67.1147 \text{ G}$$
$$= 71.944 \text{ GW}$$

Therefore, the value of the power generated by the generator is 71.944 GW .

Comment

Step 8 of 14

Calculate the value of the voltage $\overline{V}_1$.

$$\overline{V}_1 = \overline{Z}_{11}\overline{I}_1$$

Substitute $50 + j5 \Omega$ for $\overline{Z}_{11}$ and $5.6741\angle -11.2^\circ$ kA for I_1 .

$$\overline{V}_1 = (50 + j5)(5.6741\angle -11.2^\circ \text{ k})$$
$$= (50.2494\angle 5.71^\circ)(5.6741\angle -11.2^\circ \text{ k})$$
$$= 285.1201\angle -5.49^\circ \text{ kV}$$

Therefore, the value of the voltage $\overline{V}_1$ is $285.1201\angle -5.49^\circ \text{ kV}$.

Comment

Step 9 of 14

Calculate the value of the voltage $\overline{V}_2$.

$$\overline{V}_2 = \overline{Z}_{22}\overline{I}_2$$

Substitute $10 + j2 \Omega$ for $\overline{Z}_{22}$ and $23.6493\angle -34.99^\circ$ kA for I_2 .

$$\overline{V}_2 = (10 + j2)(23.6493\angle -34.99^\circ \text{ k})$$
$$= (10.198\angle 11.31^\circ)(23.6493\angle -34.99^\circ \text{ k})$$
$$= 241.1756\angle -23.68^\circ \text{ kV}$$

Therefore, the value of the voltage $\overline{V}_2$ is $241.1756\angle -23.68^\circ \text{ kV}$.

Comment

Step 10 of 14

The acceptable voltage ranges of the load is $(274.2414 \text{ kV} - 303.1089 \text{ kV})$.

The value of voltage is $\overline{V}_1$ is with in 5% limit of rated voltage 288.6751 kV . Whereas the value of the voltage $\overline{V}_2$ is much lower. Hence, system is not secure from current point of view.

Comment

Step 11 of 14

Calculate the value of the line current $\overline{I}_{L1}$.

$$\overline{I}_{L1} = (\overline{V}_2 - \overline{V}_1)\overline{Y}_{12}$$

Substitute $241.1756\angle -23.68^\circ \text{ kV}$ for $\overline{V}_2$ and $285.1201\angle -5.49^\circ \text{ kV}$ for $\overline{V}_1$ and 0 for $\overline{Y}_{12}$.

$$\overline{I}_{L1} = (241.1756\angle -23.68^\circ \text{ k} - 285.1201\angle -5.49^\circ \text{ k})(0)$$
$$= 0 \text{ A}$$

Therefore, the value of the line current $\overline{I}_{L1}$ is 0 A .

Comment

Step 12 of 14

Calculate the value of the line current $\overline{I}_{L2}$.

$$\overline{I}_{L2} = (\overline{V}_3 - \overline{V}_1)\overline{Y}_{13}$$

Substitute 288.6751 kV for $\overline{V}_3$ and $285.1201\angle -5.49^\circ \text{ kV}$ for $\overline{V}_1$ and $\frac{1}{j4}$ S for $\overline{Y}_{13}$.

$$\overline{I}_{L2} = (288.6751 \text{ k} - 285.1201\angle -5.49^\circ \text{ k})\left(\frac{1}{j4}\right)$$
$$= (27.7081\angle 79.89^\circ \text{ k})(0.25\angle -90^\circ)$$
$$= 6.9270\angle -10.11^\circ \text{ kA}$$

Therefore, the value of the line current $\overline{I}_{L2}$ is $6.9270\angle -10.11^\circ \text{ kA}$.

Comment

Step 13 of 14

Calculate the value of the line current $\overline{I}_{L3}$.

$$\overline{I}_{L3} = (\overline{V}_3 - \overline{V}_2)\overline{Y}_{23}$$

Substitute 288.6751 kV for $\overline{V}_3$ and $241.1756\angle -23.68^\circ \text{ kV}$ for $\overline{V}_2$ and $\frac{1}{j5}$ S for $\overline{Y}_{23}$.

$$\overline{I}_{L3} = (288.6751 \text{ k} - 241.1756\angle -23.68^\circ \text{ k})\left(\frac{1}{j5}\right)$$
$$= (118.2373\angle 55.01^\circ \text{ k})(0.2\angle -90^\circ)$$
$$= 23.6575\angle -34.99^\circ \text{ kA}$$

Therefore, the value of the line current $\overline{I}_{L3}$ is $23.6575\angle -34.99^\circ \text{ kA}$.

Comment

Step 14 of 14

The line currents $\overline{I}_{L1}$ and $\overline{I}_{L2}$ are within the rated capacity range but the line current $\overline{I}_{L3}$ exceeds the rated capacity 15 kA . Hence, system is not secure from current point of view. Therefore, the given system is not secure when the line L_3 is tripped.

Comment

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