Example 4.1

Compute the phase self and mutual impedances of the 69 kV line shown in Figure 4.6. Assume that the frequency is 60 Hz (ω = 377) and the phase wires are 19-strand 4/0, hard-drawn copper conductors which operate at 25 °C. Ignore the ground wire entirely and assume that the phase wires have the configuration shown for the entire length of the line. Assume that the earth resistivity ρ is 100 ohm-meter and that the line is 40 miles long.

\[ \text{Fig. 4.6. Line configuration of a 69 kV circuit.} \]

Solution

From Table B.4 we find the conductor values

\[ r_a = r_b = r_c = 0.278 \ \Omega/\text{mi} \]
\[ D_{ab} = D_{ab} = D_{ac} = 0.01668 \ \text{ft} \]

From Table 4.2 we find \( D_e = 2790 \ \text{ft} \). At 60 Hz, \( r_d = 0.09528 \ \Omega/\text{mile} \) and the constant \( \omega k \) is, from Table 4.1, \( \omega k = 0.12134 \). Then, from (4.54) the self-impedance terms are

\[ z_{aa} = z_{bb} = z_{cc} = r_a + r_d + j\omega k \ln \frac{D_e}{D_d} \]
\[ = (0.278 + 0.09528) + j(0.12134) \ln \frac{2790}{0.01668} \]
\[ = 0.3733 + j1.4594 \ \Omega/\text{mi} \]

The mutual impedances are computed from (4.55) as follows.

\[ z_{ab} = r_d + j\omega k \ln \frac{D_e}{D_{ab}} \]
\[ = 0.09528 + j(0.12134) \ln \frac{2790}{10} = 0.0953 + j0.6833 \ \Omega/\text{mi} \]
\[ z_{ac} = 0.09528 + j(0.12134) \ln \frac{2790}{20} = 0.0953 + j0.5992 \ \Omega/\text{mi} \]
\[ z_{bc} = z_{ab} = 0.0953 + j0.6833 \ \Omega/\text{mi} \]

For 40 miles of line we multiply the above values by 40 to write, in matrix notation

\[ Z_{abc} = \begin{bmatrix} (14.932 + j58.376) & (3.812 + j27.332) & (3.812 + j23.968) \\ (3.812 + j27.332) & (14.932 + j58.376) & (3.812 + j27.332) \\ (3.812 + j23.968) & (3.812 + j27.332) & (14.932 + j58.376) \end{bmatrix} \ \Omega \]