9-2

$A = 500\ MCM = 500{,}000$ cir mils

$$R_{DC,20} = \frac{\rho l}{A} = \frac{(10.66)(5280)}{500{,}000} = 0.1126\ \Omega/mi$$

$$R_{DC,60} = \frac{M+T_{60}}{M+T_{20}} R_{DC,20} = \left(\frac{241.5+60}{241.5+20}\right)(0.1126) = 0.1298\ \Omega/mi$$

$$X = 0.0636\sqrt{\frac{\mu f}{R_{DC}}} = 0.0636\sqrt{\frac{(1)(50)}{0.1298}} = 1.24 \approx 1.2$$

From Table 5, $\alpha = 1.0107$

$$R_{AC} = \alpha R_{DC} = (1.0107)(0.1298) = 0.1312\ \Omega/mi$$

9-4

$r = \frac{1.5}{2} = 0.75\ cm = 0.0075\ m$

$r' = r e^{-1/4} = 0.0075\, e^{-1/4} = 5.84 \times 10^{-3}\ m$

$L_{conductor} = 2 \times 10^{-7} \ln \frac{D}{r'} = 2 \times 10^{-7} \ln\left(\frac{3}{5.84 \times 10^{-3}}\right) = 1.248 \times 10^{-6}\ H/m = 1.248\ mH/km$

$= 2\ mH/mi$

$L_T = 2 L_{conductor} = (2)(2) = 4\ mH/mi$

9-8

$r' = re^{-1/4} = 0.015e^{-1/4} = 0.01168\ m$

ⓐ $L_a = 2\times10^{-7} \ln \frac{D}{r'} = 2\times10^{-7} \ln\left(\frac{4}{0.01168}\right) = 1.167\times10^{-6}\ H/m$

$= 1.167\ mH/km = 1.878\ mH/mi$

ⓑ $X_L = 2\pi f L = (2\pi)(60)(1.167) = 0.44\ \Omega/km = 0.708\ \Omega/mi$

9-19

$$r = \frac{d}{2} = \frac{0{,}25}{(2)(12)} = 0{,}0104 \text{ ft}$$

$$C_{an} = \frac{2\pi\epsilon}{\ln\left(\frac{D}{r}\right)} = \frac{(2\pi)(8{,}854 \times 10^{-12})}{\ln\left(\frac{10}{0{,}0104}\right)} = 8{,}1 \times 10^{-12} \text{ F/m}$$

9-24

$$GMD = \sqrt[3]{(7)(7)(10)} = 7{,}884 \text{ m}$$

$$r = \frac{d}{2} = \frac{5}{2} = 2{,}5 \text{ cm} = 0{,}025 \text{ m}$$

ⓐ $$C_{an} = \frac{2\pi\epsilon}{\ln\left(\frac{D}{r}\right)} = \frac{(2\pi)(8{,}854\times10^{-12})}{\ln\left(\frac{7{,}884}{0{,}025}\right)} = 9{,}67\times10^{-12} \text{ F/m} = 9{,}67\times10^{-9} \text{ F/km}$$

$$C_T = C_{an}\,\ell = (9{,}67\times10^{-9})(100) = 0{,}967\times10^{-6} \text{ F} = 0{,}967 \ \mu\text{F}$$

ⓑ $$X_c = \frac{1}{2\pi f C_T} = \frac{1}{(2\pi)(60)(0{,}967\times10^{-6})} = 2{,}743 \text{ k}\Omega$$

ⓒ $$Y = j\frac{1}{X_c} = j\frac{1}{2{,}743\times10^{3}} = j\,0{,}364\times10^{-3} \text{ S}$$

$$I_{chg} = Y V_{ph} = (0{,}364\times10^{-3})\left(\frac{138{,}000}{\sqrt{3}}\right) = 29 \text{ A}$$

9-29

$\ell = 40$ km (use short line model)

$Z = z\ell = (0.20 + j0.50)(40) = 8 + j20\ \Omega$

(a) $A = 1.0$

$B = Z = 8 + j20 = 21.54 \angle 68.2^\circ\ \Omega$

$C = 0$

$D = 1.0$

(b) $V_R = \dfrac{33{,}000}{\sqrt{3}} \angle 0^\circ = 19{,}052 \angle 0^\circ$

$I_R = \dfrac{10{,}000}{\sqrt{3}(33)} \angle -\cos^{-1} 0.9 = 175 \angle -25.8^\circ$ A

$V_S = AV_R + BI_R = (1.0)(19{,}052 \angle 0^\circ) + (8+j20)(175 \angle -25.8^\circ)$

$= 21{,}983 \angle 6.5^\circ$ V (line-to-neutral) $= 38.1$ kV (line-to-line)

(c) $I_R = \dfrac{10{,}000}{\sqrt{3}(33)} \angle \cos^{-1} 0.9 = 175 \angle 25.8^\circ$ A

$V_S = (1.0)(19{,}052 \angle 0^\circ) + (8+j20)(175 \angle 25.8^\circ)$

$= 19{,}162 \angle 11.3^\circ$ V (line-to-neutral) $= 33.2$ kV (line-to-line)

9-31

$\ell = 200$ km (use medium length line model)

$Z = z\ell = (0.10 + j0.35)(200) = 20 + j70 = 72.8 \angle 74° \ \Omega$

$Y = y\ell = (j5 \times 10^{-6})(200) = j10^{-3}$ S

(a) $A = D = \frac{ZY}{2} + 1 = \frac{(20+j70)(j10^{-3})}{2} + 1 = 0.965 \angle 0.6°$

$B = Z = 20 + j70 = 72.8 \angle 74° \ \Omega$

$C = Y\left(\frac{ZY}{4} + 1\right) = (j10^{-3})\left[\frac{(20+j70)(j10^{-3})}{4} + 1\right] = 9.825 \times 10^{-4} \angle 90.3°$ S

(b) $V_R = \frac{220{,}000}{\sqrt{3}} \angle 0° = 127{,}017 \angle 0°$ V

$I_R = \frac{250{,}000}{\sqrt{3}(220)(0.95)} \angle -\cos^{-1} 0.95 = 690.6 \angle -18.2°$

$V_S = AV_R + BI_R = (0.965 \angle 0.6°)(127{,}017 \angle 0°) + (20+j70)(690.6 \angle -18.2°)$

$= 156{,}767 \angle 15.9°$ V (line-to-neutral) $= 271.5$ kV (line-to-line)

$I_S = CV_R + DI_R = (9.825 \times 10^{-4} \angle 90.3°)(127{,}017 \angle 0°) + (0.965 \angle 0.6°)(690.6 \angle -18.2°)$

$= 639.2 \angle -6.9°$ A

(c) $V.R. = \frac{V_S/A - V_R}{V_R} = \frac{(156{,}767/0.965) - 127{,}017}{127{,}017} 100\% = 27.9\%$

9-34 $\quad \ell = 300$ mi (use long line model)

$Z = 40 + j175\ \Omega$

$Y = j10^{-3}\ S$

$$Z_0 = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{40+j175}{j10^{-3}}} = 423.7\angle{-6.4^\circ}$$

$$\gamma\ell = \sqrt{ZY} = \sqrt{(40+j175)(j10^{-3})} = 0.4237\angle 83.6^\circ = 0.0475 + j0.421$$

$$e^{\gamma\ell} = e^{0.0475+j0.421} = 1.0486\angle 24.1^\circ$$

$$e^{-\gamma\ell} = e^{-0.0475-j0.421} = 0.9536\angle{-24.1^\circ}$$

$$A = D = \cosh\gamma\ell = \tfrac{1}{2}(e^{\gamma\ell} + e^{-\gamma\ell}) = \tfrac{1}{2}(1.0486\angle 24.1^\circ + 0.9536\angle{-24.1^\circ})$$
$$= 0.914\angle 1.2^\circ$$

$$\sinh\gamma\ell = \tfrac{1}{2}(e^{\gamma\ell} - e^{-\gamma\ell}) = \tfrac{1}{2}(1.0486\angle 24.1^\circ - 0.9536\angle{-24.1^\circ})$$
$$= 0.411\angle 83.9^\circ$$

$$B = Z_0 \sinh\gamma\ell = (423.7\angle{-6.4^\circ})(0.411\angle 83.9^\circ) = 174\angle 77.5^\circ$$

$$C = \frac{1}{Z_0}\sinh\gamma\ell = \frac{0.411\angle 83.9^\circ}{423.7\angle{-6.4^\circ}} = 9.7\times10^{-4}\angle 90.3^\circ$$

(a) $$V_R = \frac{220}{\sqrt{3}}\angle 0^\circ = 127\angle 0^\circ \text{ kV}$$

$$I_R = \frac{300}{\sqrt{3}(220)(0.9)}\angle{-\cos^{-1}0.9} = 0.875\angle{-25.8^\circ} \text{ kA}$$

$$V_S = AV_R + BI_R = (0.914\angle 1.2^\circ)(127\angle 0^\circ) + (174\angle 77.5^\circ)(0.875\angle{-25.8^\circ})$$
$$= 242\angle 29.6^\circ \text{ kV (line-to-neutral)} = 419 \text{ kV (line-to-line)}$$

$$I_S = CV_R + DI_R = (9.7\times10^{-4}\angle 90.3^\circ)(127\angle 0^\circ) + (0.914\angle 1.2^\circ)(0.875\angle{-25.8^\circ})$$
$$= 0.756\angle{-16.1^\circ} \text{ kA}$$

$$B = Z_o \sinh \gamma l = (1.077 \angle -7^\circ)(0.371 \angle 83.3^\circ) = 0.3996 \angle 76.3^\circ$$

$$C = \frac{1}{Z_o} \sinh \gamma l = \left(\frac{1}{1.077 \angle -7^\circ}\right)(0.371 \angle 83.3^\circ) = 0.3445 \angle 90.3^\circ$$

$$V_s = AV_R + BI_R = (0.931 \angle 1.05^\circ)(1.0 \angle 0^\circ) + (0.3996 \angle 76.3^\circ)(1.0 \angle 0^\circ)$$

$$= 1.1027 \angle 21.56^\circ \ pu = 253.6 \ kV$$

$$I_s = CV_R + DI_R = (0.3445 \angle 90.3^\circ)(1.0 \angle 0^\circ) + (0.931 \angle 1.05^\circ)(1.0 \angle 0^\circ)$$

$$= 0.9969 \angle 21.26^\circ \ pu = (.9969)(376.5) = 375.3 \ A$$

$$PF_s = \cos(21.56^\circ - 21.26^\circ) = \cos 0.3^\circ \approx 1.0$$

$$P_s = V_s I_s \cos \theta_s = (1.1027)(0.9969) \cos 0.3^\circ = 1.0993 \ pu$$

$$= (1.0993)(150) = 165 \ MW$$