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Tutorial: Transmission Lines

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1. $Z = zl = (0.0165 + j0.3306)300$

$= 4.95 + j99.18\ \Omega$

$Y = yl = j4.674 \times 10^{-6}(300)$

$= j1.4022 \times 10^{-3}\ S$

$A = D = 1 + \frac{YZ}{2} = 1 + \frac{(j1.4022 \times 10^{-3})(4.95 + j99.18)}{2}$

$\approx 0.9305 + j0.0035$

$B = Z = 4.95 + j99.18\ \Omega$

$C = Y\left(1 + \frac{YZ}{4}\right) = (j1.4022 \times 10^{-3})\left[1 + \frac{(j1.4022 \times 10^{-3})(4.95 + j99.18)}{4}\right]$

$\approx (-2.4 \times 10^{-6} + j0.0014)\ S$

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2. $Z = zl = (0.125 + j0.4375)16$

$= 2 + j7 \ \Omega$

Load $\Rightarrow$ 70MVA, 0.8 lag, 64kV

$A = D = 1, \ B = Z, \ C = 0$

$V_R = \frac{64 \times 10^3}{\sqrt{3}} \angle 0° \approx 36.95 \angle 0° \ kV$

$|S_{Load}| = 70 \times 10^6 = 3|V_R||I_R|$

$|I_R| = \frac{70 \times 10^6}{3 \times 36.95 \times 10^3} \approx 631.48 \ A$

$I_S = I_R = 631.48 \angle -36.87° A$

$V_S = V_R + I_R Z = 36.95 \angle 0° + (631.48 \angle -36.87°)(2 + 7j)$

$\approx 40.71 \angle 3.91° \ kV$

$|V_{S\,FL}| = 40.71 \ kV, \quad |V_{R\,FL}| = 36.95$

$\% V_R = \frac{40.71 - 36.95}{36.95} \times 100\% \approx 10.18\%$

$P_{3\phi R} = 70 \times 10^6 \times 0.8 = 56 MW$

$S_S = 3 \cdot V_S \cdot I_S^* = 3(40.71 \angle 3.91°)(631.48 \angle -36.87)^*$

$\approx 58.39 + j50.37 MVA \Rightarrow P_{3\phi S} = 58.39 \ MW$

$\therefore \eta = \frac{P_{3\phi R}}{P_{3\phi S}} \times 100\% = \frac{56}{58.39} \times 100\% \approx 95.91\%$

3. $Z = zl = (0.08 + j0.48)(200)$
$= 16 + j96\ \Omega$

$Y = yl = (j3.33\times10^{-6})(200)$
$= j6.66\times10^{-4}$ S

$A = D = 1 + \frac{YZ}{2} = 1 + \frac{(j6.66\times10^{-4})(16+j96)}{2}$
$\approx 0.9680 + j0.0053$

$C = Y\left[1 + \frac{YZ}{4}\right] = j6.66\times10^{-4}\left[1 + \frac{(j6.66\times10^{-4})(16+j96)}{4}\right]$
$= (-1.774\times10^{-6} + j6.554\times10^{-4})$ S

$B = Z = 16 + j96\ \Omega$

$V_R = \frac{220\times10^3}{\sqrt{3}} \angle 0°$ V

$|I_R| = \frac{P_{load}}{3|V_R|\cos\theta} = \frac{250\times10^6}{3\left(\frac{220\times10^3}{\sqrt{3}}\right)(0.99)} \approx 662.69$ A

$I_R = 662.69 \angle -8.11°$ A

$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}\begin{bmatrix} V_R \\ I_R \end{bmatrix}$

$V_S = AV_R + BI_R = (0.9680 + j0.0053)\left(\frac{220\times10^3}{\sqrt{3}}\angle 0°\right)$
$+ (16 + j96)(662.69\angle -8.11°)$
$\approx 155.4 \angle 23.58°$ kV

$I_S = CV_R + DI_R = (-1.774\times10^{-6} + j6.554\times10^{-4})\left(\frac{220\times10^3}{\sqrt{3}}\angle 0°\right)$
$+ (0.9680 + j0.0053)(662.69\angle -8.11°)$
$\approx 635.38 \angle -0.34°$ A

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4. $Z = (r + j\omega L) \times 130$

$= [0.036 + j(2\pi \cdot 50 \cdot 0.8 \times 10^{-3})] 130$

$\approx 4.68 + j32.67\,\Omega$

$Y = (j\omega C) 130 = j(100\pi)(0.112 \times 10^{-6}) 130$

$\approx j4.57 \times 10^{-4}\,S$

$A = D = 1 + \frac{YZ}{2} = 0.9925 + j0.0011$

$B = Z = 4.68 + j32.67\,\Omega$

$C = \left(1 + \frac{YZ}{4}\right) Y = (-0.2448 \times 10^{-8} + j0.4557 \times 10^{-5})\,S$

(a) Load $\Rightarrow$ 270 MVA @ 0.8 lag @ 325 kV

$V_R = \frac{325 \times 10^3}{\sqrt{3}} \angle 0^\circ\,V = 187.64\,kV \angle 0^\circ\,V$

$|I_R| = \frac{270 \times 10^6}{3\left(\frac{325 \times 10^3}{\sqrt{3}}\right)} \approx 479.65\,A$

$I_R = 479.65 \angle -36.87^\circ\,A$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ 479.65 \angle -36.87^\circ \end{bmatrix}$$

$V_S = 197.764 \angle 3.30^\circ\,kV$

$I_S = 430.27 \angle -27.66^\circ\,A$

$\% V_R = \frac{|V_{R_{N-L}}| - |V_{R_{F-L}}|}{|V_{R_{F-L}}|}$

$V_{R_{N-L}} = \frac{V_{S\,F-L}}{A} = \frac{197.764 \angle 3.30^\circ\,kV}{0.9925 + j0.0011} = \frac{197.764 \times 10^3 \angle 3.30}{0.9925 \angle 0.0635^\circ}$

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$$|V_{R_{N-L}}| = \frac{197.764\times10^3}{0.9925} \approx 199.25\,kV$$

$$\%V_R = \frac{199.25-187.64}{187.64}\times100\% = 6.19\%$$

$$S_{3\phi S} = 3V_sI_s^* = 218.9 + j131.3\,MVA$$
$$P_{S3\phi} = 218.9\,MW$$
$$P_{R3\phi} = 270\,MVA \times 0.8 = 216\,MW$$
$$\eta = \frac{216}{218.9}\times100\% = 98.7\%$$

(b) $V_R = \frac{325\times10^3}{\sqrt{3}}\angle0^\circ\,V$

$$|I_R| = \frac{270\times10^6}{3\left(\frac{325\times10^3}{\sqrt{3}}\right)} = \frac{1S1}{3V_R} = 479.65\,A$$

$$I_R = 479.65\angle -\cos^{-1}(0.95) = 479.65\angle-18.19^\circ\,A$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}\begin{bmatrix} V_R \\ 479.65\angle-18.19^\circ \end{bmatrix}$$

$V_s = 193.796\times10^3\angle4.26^\circ\,V$

$I_s = 456.70\angle-7.88^\circ A$

$$|V_{R_{N-L}}| = \left|\frac{V_s}{A}\right| = \frac{193.796\times10^3\angle4.26^\circ}{0.9925} \approx 195.26\,kV$$

$V_{RF-L} = 187.64\,kV$

$$\%V_R = \frac{195.26-187.64}{187.64} \approx 4.06\%$$

$$S_{3\phi S} = 3V_sI_s^* = 259.58 + j55.84\,MVA$$
$$P_{3\phi S} = 259.58\,MW$$

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$P_{3\phi} = 270 \times 0.95 = 256.5\,MW$

$\eta = \frac{256.5}{259.58} \times 100\% = 98.8\%$