CHUKA UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EENG 465 Power Systems II

CAT 1

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Question 1

A 275 kV overhead transmission line has the following characteristics: $Z = 12.5 + j66\,\Omega$, $Y = j4.4 \times 10^{-4}\,S$ The line delivers 250 MW at a lagging power factor of 0.9. Determine:

(i) ABCD constants

(ii) Surge impedance of the line

(iii) Sending-end voltage

(iv) Sending-end current

(v) Line charging current

(vi) Transmission efficiency

(vii) Voltage regulation

Solution

Given:

$$Z = 12.5 + j66, \quad Y = 4.4 \times 10^{-4} \angle 90^\circ$$

$$P = 250\text{MW}, \quad V_R = 275\text{kV}, \quad \cos\phi_R = 0.9$$

$$\phi_R = \cos^{-1} 0.9 = 25.842^\circ$$

The receiving end active power is given by ,

$$P = \sqrt{3} V_R I_R \cos\phi_R \tag{1}$$

$$I_R = \frac{250 \times 10^6}{\sqrt{3} \times 275 \times 10^3 \times 0.9} = 583.18A \tag{2}$$

$$I_R = 583.18\angle - 25.842^\circ A$$

(i) **Calculating ABCD constant for long transmission line,**

$$A = D = \cosh\gamma = \frac{1}{2}\left[e^{\alpha + j\beta} + e^{-(\alpha + j\beta)}\right] \tag{3}$$

$$A = D = \frac{1}{2}\left[e^{\alpha}\angle\beta + e^{-\alpha}\angle - \beta\right]$$

$$\gamma = \sqrt{ZY} \tag{4}$$

$$\gamma = \sqrt{(12.5 + j66) \times (4.4 \times 10^{-4}\angle 90^\circ)}$$

$$\gamma = \sqrt{0.0295\angle 169.27^\circ}$$

$$\gamma = 0.172\angle 84.635^\circ = 0.0160 + j0.171 \tag{5}$$

comparing with $\alpha + j\beta$, we get the following

$$\alpha = 0.0160 \text{ rad}, \quad \beta = \frac{0.171 \times 180}{\pi} = 9.797^\circ$$

$$A = D = \frac{1}{2}\left[e^{0.016}\angle 9.797^\circ + e^{-0.016}\angle - 9.797^\circ\right] \tag{6}$$

$$A = D = 0.9855\angle 0.1582^\circ \tag{7}$$

$$\sinh\gamma = \frac{1}{2}\left[e^{\alpha}\angle\beta - e^{-\alpha}\angle - \beta\right] \tag{8}$$

$$= \frac{1}{2}\left[e^{0.016}\angle 9.797^\circ - e^{-0.016}\angle - 9.797^\circ\right]$$

$$\sinh\gamma = 0.171\angle 84.71^\circ \tag{9}$$

(ii) The surge impedance of the line (Z_0) is given as,

$$Z_0 = \sqrt{\frac{Z}{Y}} \tag{10}$$

Substituting the given values:

$$Z_0 = \sqrt{\frac{12.5 + j66}{j4.4 \times 10^{-4}}}$$

$$Z_0 = \sqrt{152666.55\angle - 10.724^\circ}$$

$$Z_0 = 390.725\angle - 5.362^\circ\ \Omega \tag{11}$$

so that

$$B = Z_0 \sinh\gamma \tag{12}$$

$$B = 390.725\angle - 5.362^\circ \times 0.171\angle 84.71^\circ$$

$$B = 66.814\angle 79.348^\circ \tag{13}$$

$$C = \frac{\sinh\gamma}{Z_0} = \frac{0.171\angle 84.71^\circ}{390.725\angle - 5.36^\circ} \tag{14}$$

$$C = 4.376 \times 10^{-4}\angle 90.072^\circ \tag{15}$$

(iii) Sending end voltage is given as,

$$V_s = AV_R + BI_R \tag{16}$$

$$V_s = (0.9855\angle 0.1582^\circ) \times \left(\frac{275 \times 10^3}{\sqrt{3}}\right)$$

$$+(66.814\angle 79.348^\circ) \times (583.18\angle -25.842^\circ)$$

$$V_s = 182427.57\angle 0.025^\circ V \tag{17}$$

(iv) Sending end current is given as,

$$I_s = CV_R + DI_R \tag{18}$$

$$I_s = \left(4.376 \times 10^{-4}\angle 90.072^\circ\right)\left(\frac{275 \times 10^3}{\sqrt{3}}\angle 0^\circ\right)$$

$$+ (0.9855\angle 0.1582^\circ)\ (583.18\angle -25.842^\circ)$$

$$I_s = 69.478\angle 90.072^\circ + 574.72\angle -25.68^\circ$$
$$I_s = 548.12\angle -19.12^\circ \text{ A} \tag{19}$$

(v) The line charging current is given by:

$$I_c = j\omega CV_R \tag{20}$$

From the ABCD calculations:

$$C = 4.376 \times 10^{-4}\angle 90.072^\circ$$

$$I_c = \left(4.376 \times 10^{-4}\angle 90.072^\circ\right) \times \left(\frac{275 \times 10^3}{\sqrt{3}}\right)$$

$$I_c = 69.478\angle 90.072^\circ A \tag{21}$$

Sending end power factor,

$$\phi_s = 0.025^\circ - (-19.12^\circ) = 19.145^\circ \tag{22}$$

$$\cos\phi_s = \cos 19.145^\circ = 0.9448 \tag{23}$$

(vi) Calculating the transmission efficiency of the line,

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{3V_R I_R \cos\phi_R}{3V_S I_S \cos\phi_S} \tag{24}$$

$$\eta = \frac{250 \times 10^6}{3 \times 182427.57 \times 548.12 \times 0.8733}$$

$$\eta = 95.43\% \tag{25}$$

(vii) Finally the Voltage regulation of transmission line,

$$\text{Regulation} = \frac{\left|\frac{V_S}{A}\right| - |V_R|}{|V_R|} \tag{26}$$

$$= \frac{\frac{182427.57}{0.9855} - \frac{275\times10^3}{\sqrt{3}}}{\frac{275\times10^3}{\sqrt{3}}}$$

$$= 0.1659 = 16.59\% \tag{27}$$

2. (15 pts.) Consider the following system:

[Diagram not shown]

Here, the system F is defined by the input-output relationship

$$F\{z[n]\} = z[n] - z[n-1],$$

and Δ is the unit delay

$$\Delta\{w[n]\} = w[n-1].$$

Write down the linear difference equation describing this system.

Solution. Let $z[n]$ be the output of the summer, as shown above. Then

$$y[n] = F\{z[n]\} = z[n] - z[n-1].$$

Now,

$$z[n] = 2x[n] - \Delta\{y[n]\} = 2x[n] - y[n-1].$$

Therefore, substituting the expression for $z[n]$ into the first equation, we can write

$$\begin{aligned} y[n] &= z[n] - z[n-1] \\ &= \underbrace{2x[n] - y[n-1]}_{=z[n]} - \underbrace{2x[n-1] - y[n-2]}_{=z[n-1]} \\ &= 2x[n] - y[n-1] - 2x[n-1] + y[n-2]. \end{aligned}$$

$$\boxed{\text{y[n] + y[n-1] - y[n-2] = 2x[n] - 2x[n-1]}}$$