ECE432 **Test 2** **Nov 6, 2015**

Q. 1 (32 pts)

A 220 kV, 3-phase, 60 Hz transmission line uses a single 795,000 circular mil, 26/7 ACSR conductor for each phase. The three phase conductors are suspended in a flat formation, with adjacent conductors spaced 7 meters apart as shown in Fig. 1. The particular ACSR conductor has an outer envelope radius of 1.407 cm and a geometric mean radius of 1.143 cm.

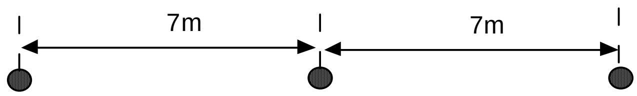


Fig. 1 Conductor formation of 220 kV 3-phase line

Assuming that the line is uniformly transposed and the presence of earth can be neglected, determine

(a) the geometric mean distance between phase conductors,
(b) the phase to neutral inductance per kilometer length of the line,
(c) the phase to neutral capacitance per kilometer length of the line,
(d) the characteristic impedance of the line.

Given $\mu_o = 4\pi x 10^{-7}\ H/m$ and $\varepsilon_o = 8.854 \text{ x } 10^{-12}$ F/m .

$V_{rated} := 220 \times 10^3$ $\quad$ $freq := 60$ $\quad$ $\mu_o := 4 \times \pi \times 10^{-7}$ $\quad$ $\varepsilon_o := 8.854 \times 10^{-12}$

$D_{ab} := 7$ $\quad$ $D_{bc} := 7$ $\quad$ $D_{ac} := 2 \times D_{ab} = 14$ $\quad$ $\omega := 2 \times \pi \times freq = 376.991$

$r_{env} := 1.407 \times 10^{-2}$ $\quad$ $r' := 1.143 \times 10^{-2}$

(a) $GMD := \sqrt[3]{D_{ab} \times D_{bc} \times D_{ac}}$ $\quad$ $GMD = 8.819$ m

(b) phase to neutral inductance per km length

$$L_{ph} := \frac{\mu_o}{2 \times \pi} \times \ln\left(\frac{GMD}{r'}\right) \times 10^3 = 1.33 \times 10^{-3}\ \frac{H}{km}$$

(c) phase to neutral capacitance per km length

$$C_n := \frac{2 \times \pi \times \varepsilon_o}{\ln\left(\frac{GMD}{r_{env}}\right)} \times 10^3 = 8.638 \times 10^{-9}\ \frac{F}{km}$$

(d) Characteristic impedance of the line $\quad$ $Z_o := \sqrt{\frac{L_{ph}}{C_n}} = 392.357$ Ohms

Q. 2 (36 pts)

A 138 kV, 60 Hz , 3-phase transmission line has per phase series impedance of $z = 0.073 + j0.37$ ohms per km and shunt admittance of $y = j4.47\times10^{-6}$ mhos per km .

(12 pts) A 100 km-long section of the above 138 kV line is to be represented by a nominal Π circuit model. Determine the ABCD parameters of the transmission matrix for the entire length of the 100 km long line.

(24 pts) Find the total line losses of all 3 phases of the 100 km line when it is delivering power to a balanced 3-phase load of 80 MVA, 0.9 power factor lagging with the receiving-end line-to-line voltage is held at 138 kV (line-to-line).

(a) $z := 0.073 + j\times 0.37\ \frac{\Omega}{km}$ $\quad y := j\times 4.47\times 10^{-6}\ \frac{mhos}{km}$ $\quad V_{rated} := 138\times 10^{3}$

$Length := 100$ km

Series impedance of series RL circuit $\quad Z := z\times Length = 7.3 + 37j$

Shunt admittance of series RL circuit $\quad Y := y\times Length = 4.47j\times 10^{-4}$

ABCD parameters of nominal pi circuit model of the line

$$A := \frac{Z\times Y}{2} + 1 = 0.992 + 1.632j\times 10^{-3} \qquad B := Z = 7.3 + 37j$$

$$C := Y\times\left(\frac{Z\times Y}{4} + 1\right) = -3.647\times 10^{-7} + 4.452j\times 10^{-4} \qquad D := \frac{Z\times Y}{2} + 1 = 0.992 + 1.632j\times 10^{-3}$$

(b)

$$V_{rated} := 138\times 10^{3} \qquad V_R := \frac{V_{rated}}{\sqrt{3}} = 7.967\times 10^{4}$$

Complex power of 80 MVA load at 0.9 pf lagging $\quad S_{load} := 80\times 10^{6} \quad pf := 0.9$

$$S_R := S_{load}\times e^{j\times acos(pf)} = 7.2\times 10^{7} + 3.487j\times 10^{7}$$

$$I_R := \frac{\overline{S_R}}{3\times V_R} = 301.226 - 145.891j \qquad |I_R| = 334.696 \qquad arg(I_R)\times\frac{180}{\pi} = -25.842$$

Sending-end phase to neutral voltage

$$V_S := A \times V_R + B \times I_R = 8.661 \times 10^4 + 1.021j \times 10^4$$

$$|V_S| = 8.721 \times 10^4 \qquad \arg(V_S) \times \frac{180}{\pi} = 6.723$$

Sending-end phase current

$$I_S := C \times V_R + D \times I_R = 298.944 - 108.725j$$

$$|I_S| = 318.102 \qquad \arg(I_S) \times \frac{180}{\pi} = -19.986$$

Sending-end 3-phase complex power

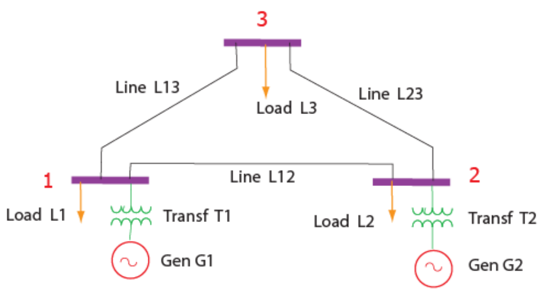
$$S_S := 3 \times V_S \times \overline{I_S} = 7.435 \times 10^7 + 3.741j \times 10^7$$

$$|S_S| = 8.323 \times 10^7 \qquad \cos(\arg(S_S)) = 0.893 \qquad \text{lagging}$$

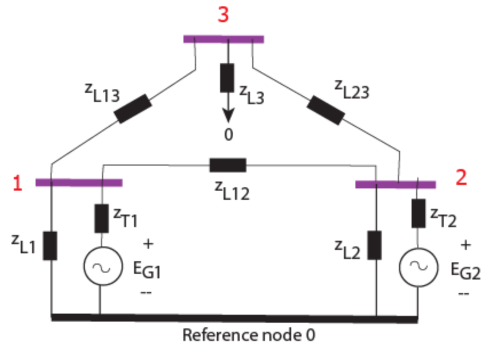
Total line losses in all 3 phases

$$P_{loss} := \mathrm{Re}(S_S) - \mathrm{Re}(S_R) = 2.346 \times 10^6 \text{ Watts}$$

3. (32 pts)



One-line diagram of a small 3-phase power system



Single-phase equivalent representation

Given the following circuit parameter and loading:

Admittances of transformers T1 and T2

$$y_{T1} := \frac{1}{z_{T1}} = -20j \qquad y_{T2} := \frac{1}{z_{T2}} = -25j$$

Admittances of loads at the buses

$$y_{L1} := \frac{1}{z_{L1}} = 0.2 \qquad y_{L2} := \frac{1}{z_{L2}} = 0.16 \qquad y_{L3} := \frac{1}{z_{L3}} = 0.08 - 0.06j$$

Admittances of the lines joining bus

$$y_{L12} := \frac{1}{z_{L12}} = -2.5j \qquad y_{L13} := \frac{1}{z_{L13}} = -8j \qquad y_{L23} := \frac{1}{z_{L23}} = -5j$$

Figure on the above right shows the single-phase equivalent circuit representation of the power system shown on the left where the z's are impedances of the circuit elements and E's, the generator terminal voltages.

The nodal admittance equation for the single-phase equivalent representation can be obtained by first changing the impedances to admittances and voltage sources to current sources before applying KCL to each node.

(a) Using the given circuit parameter and loading values, derive the nodal admittance equation for the 3-bus system in the form of [Ybus][V]=[I], where [V] and [I] are vectors of nodal currents and nodal voltages, respectively, and [Ybus], the nodal admittance matrix.

(b) Update the bus admittance matrix for the full network obtained above for the case when line L12 is open.

(a)

NAE of system is

$$\text{Ybus} \times \begin{pmatrix} V_1 \\ V_2 \\ V_3 \end{pmatrix} := \begin{pmatrix} E_{G1} \times y_{T1} \\ E_{G2} \times y_{T2} \\ 0 \end{pmatrix}$$

where

$$Ybus := \begin{pmatrix} y_{L1} + y_{T1} + y_{L13} + y_{L12} & -y_{L12} & -y_{L13} \\ -y_{L12} & y_{L2} + y_{T2} + y_{L12} + y_{L23} & -y_{L23} \\ -y_{L13} & -y_{L23} & y_{L13} + y_{L3} + y_{L23} \end{pmatrix}$$

$$Ybus = \begin{pmatrix} 0.2 - 30.5j & 2.5j & 8j \\ 2.5j & 0.16 - 32.5j & 5j \\ 8j & 5j & 0.08 - 13.06j \end{pmatrix}$$

(b) Updating Ybus for the condition where line 12 is removed may be accomplished by adding a branch of equal but opposite sign admittance in parallel with that line

$$DY12 := -y_{L12}$$

$$Ybusnew := Ybus + \begin{pmatrix} DY12 & -DY12 & 0 \\ -DY12 & DY12 & 0 \\ 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 0.2 - 28j & 0 & 8j \\ 0 & 0.16 - 30j & 5j \\ 8j & 5j & 0.08 - 13.06j \end{pmatrix}$$