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EN Department

Solution ST-2

Course: B. Tech.
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Sem: V
Sub: Elements of Power System (NEE-501)

Section: A

A.1. State the effect of electrostatic and electromagnetic effect on communication line. (2)

Ans. When communication line exists in close proximity of power line and may be possible on same support then under certain circumstances power line may produce interference with communication line. Interference is due to electromagnetic and electrostatic induction. Induced currents may be there in communication lines due to electromagnetic induction. Potential of communication lines may rise due to electrostatic induction.

A.2. Why receiving end voltage appears high compared to sending end voltage in case of lightly loaded transmission lines? (2)

Ans. If a long transmission line is open circuited or very light loaded at the receiving end, then receiving end voltage may become higher than the sending end voltage, due to charging current drawn by shunt capacitance..

A.3. What is the need of transposition of transmission line? (2)

Ans. When the conductors of a 3 phase line are not having symmetrical spacing then the flux linkages and inductance of each phase are not the same. A different inductance in each phase results in an unbalanced circuit. Transposition makes possible for each phase conductor to have same average inductance.

A. 4. What are the methods used for equalizing the potential across the string in transmission lines? (2)

Ans. (i) Reduction in the shunt capacitance relative to the capacitance of each unit.

(ii) Capacitance grading :→ In this an increase in capacitance of each unit from tower end towards line end. By correct capacitance grading the voltages across different units can be made equal.

(iii) Static shielding :⇒ By use of metal ring surrounding the bottom unit and connected to the line, the ring is known as grading ring, introduces the capacitances between different joints and line.

A.5. What do you understand by the "characteristic impedance" and "propagation constant" in long transmission lines? (2)

Ans. Characteristic impedance

$$Z_C = \sqrt{\frac{z}{y}} \qquad z = r + jwL \qquad y = g + jwC$$

$z \Rightarrow$ series impedance per unit length

So $$Z_C = \sqrt{\frac{r + jwL}{g + jwC}}$$

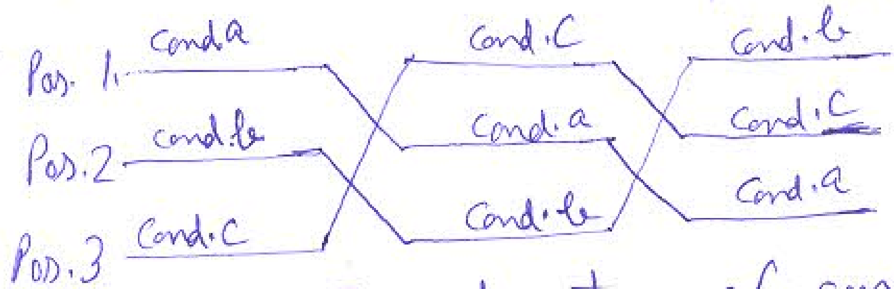
$y \Rightarrow$ shunt admittence per unit length

Propagation constant $\gamma = \sqrt{zy}$

Section - B

B.6. Derive the expression for inductance of a 3 phase unsymmetrical spaced transposed transmission line. (5)

Ans.



Transposition of conductors

The average inductance of a conductor of a transposed line is found by calculating the flux linkages for each position occupied by the conductor and then finding the average flux linkages:–

The flux linkage of conductor a, in position 1, conductor b is in position 2 and conductor c is in position 3 are

$$\psi_{a_1} = 2\times10^{-7}\left[I_a \log_e \frac{1}{r'} + I_b \log_e \frac{1}{D_{12}} + I_c \log_e \frac{1}{D_{31}}\right]$$

with conductor a in position 2, b in position 3 and c in position 1,

$$\psi_{a_2} = 2\times10^{-7}\left[I_a \log_e \frac{1}{r'} + I_b \log_e \frac{1}{D_{23}} + I_c \log_e \frac{1}{D_{12}}\right]$$

with conductor a in position 3, b in position 1 and c in position 2,

$$\psi_{a_3} = 2\times10^{-7}\left[I_a \log_e \frac{1}{r} + I_b \log_e \frac{1}{D_{31}} + I_c \log_e \frac{1}{D_{23}}\right]$$

Average flux linkages of conductor a are,

$$\psi_a = \frac{\psi_{a_1} + \psi_{a_2} + \psi_{a_3}}{3}$$

So $\Psi_a = \frac{2\times10^{-7}}{3}\left[3 I_a \log_e \frac{1}{r'} + I_b \log_e \frac{1}{D_{12} D_{23} D_{31}} + I_c \log_e \frac{1}{D_{31} D_{12} D_{23}}\right]$

$I_a = -(I_b + I_c)$

So $\Psi_a = \frac{2\times10^{-7}}{3}\left[3 I_a \log_e \frac{1}{r'} - I_a \log_e \frac{1}{D_{12} D_{23} D_{31}}\right]$

$= 2\times10^{-7} I_a \log_e \frac{\sqrt[3]{D_{12} D_{23} D_{31}}}{r'}$

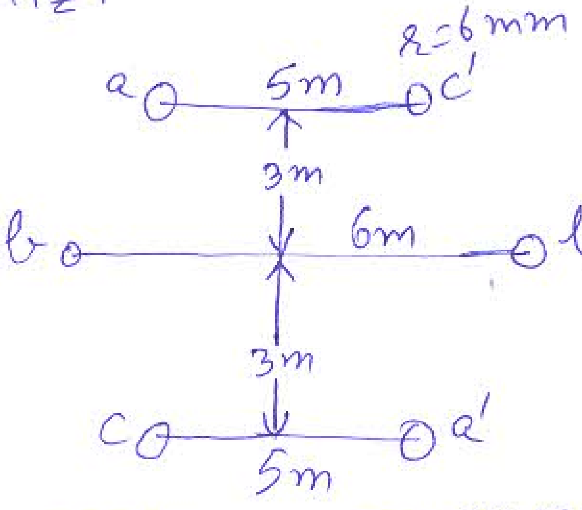
Inductance of phase a is

$L_a = \frac{\Psi_a}{I_a} = 2\times10^{-7} \log_e \frac{\sqrt[3]{D_{12} D_{23} D_{31}}}{r'}$

$= 2\times10^{-7} \log_e \frac{D_{eq}}{r'}$

$D_{eq} = \sqrt[3]{D_{12} D_{23} D_{31}}$

B.7. Find the inductance per phase per km of double circuit 3 phase line shown in figure. The line is completely transposed and operates at a freq. of 50 Hz. (5)



Ans. $r' = 0.7788\, r = 0.7788 \times 6 \times 10^{-3} = 4.6728 \times 10^{-3}$

$= 0.467 \times 10^{-2}$ m

Distance between a and a' = distance between c and c'

$= \sqrt{6^2 + 5^2} = \sqrt{61} = 7.81$ m

GMR of conductors of phase a $= \sqrt{0.467 \times 10^{-2} \times 7.81}$
$= 0.1909$ m

GMR of conductors of phase b $= \sqrt{0.467 \times 10^{-2} \times 6}$
$= 0.1674$ m

GMR of conductors of phase c $= \sqrt{0.467 \times 10^{-2} \times 7.81}$ $= 0.1909$ m

$$D_S = \sqrt[3]{(0.1909)(0.1674)(0.1909)}$$

$$= \sqrt[3]{0.0061} = 0.1827 \text{ m}$$

Distance between conductors a and b $= \sqrt{3^2 + (0.5)^2}$
$= 3.041$ m

Distance between conductors a and b'
$= \sqrt{3^2 + (5.5)^2} = 6.265$ m

Geometric mean distance between phases b and a
$= \sqrt[4]{(3.041 \times 6.265)^2} = 4.365$ m

Geometric mean distance between phases b and c
$= \sqrt[4]{(3.041 \times 6.265)^2} = 4.365$ m

Geometric mean distance between phases c and a
$= \sqrt[4]{(6 \times 5)^2} = \sqrt{6 \times 5} = 5.477$ m

$$D_{eq} = \sqrt[3]{4.365 \times 4.365 \times 5.477} = 4.708 \text{ m}$$

$$L = 2 \times 10^{-7} \log_e \frac{D_{eq}}{D_S} = 2 \times 10^{-7} \log_e \frac{4.708}{0.1827}$$

$$= 2 \times 10^{-7} \log_e (25.769)$$

$$= 2 \times 10^{-7} \times 3.249 = 6.498 \times 10^{-7} \frac{\text{H}}{\text{phase}}$$

$= 6.498 \times 10^{-4}$ H/phase/Km $= 0.65$ mH/phase/km

B. 8. Explain the phenomenon of corona and factors affecting corona. (5)

Ans. Electric field intensity is maximum at the surface of conductor and then decreases in inverse proportion to the distance from centre of conductor. As the voltage applied to the conductor is increased, a layer adjacent to the conductor gets ionized as soon as $E > 30 \frac{kV}{cm}$ (peak), at the surface of the conductor. This ionization is accompanied by a luminous glow around the conductor. A hissing noise can be heard and ozone smell can be detected. With increase in voltage the glow increases in size and brightness and intensity of hissing noise increases. This phenomenon is termed as corona.

Factors affecting Corona :-

1. Corona depends on frequency of supply.
2. Corona loss increases at a very fast rate with increase in system voltage.
3. Corona loss $\propto \frac{1}{\text{density of air}}$
4. Rain & dust (bad weather) increase the corona loss.
5. Reduced corona loss for large dia conductor.
6. Corona loss depends on surface conditions of conductor i.e. smooth surface or rough surface.

B. 9. Determine the disruptive critical voltage and the visual critical voltages for general corona on a 3 phase overhead transmission line consisting of three stranded copper conductors spaced 2.44 m apart at the corner of an equilateral triangle. Air temperature and pressure are 21°C and

73.5 cm of mercury respectively. Conductor diameter is 1.04 cm. Irregularity factor 0.85 and surface factors for general corona is 0.7, breakdown strength of air is 21.1 KV(rms)/cm. (5)

Ans. conductor radius $= \frac{1.04}{2} = 0.52\,cm = 0.52 \times 10^{-2}$
$= 5.2 \times 10^{-3}\,m$

$$\delta = \frac{3.92\,b}{273+t} = \frac{3.92 \times 73.5 \times 1}{273+21} = \frac{3.92 \times 73.5}{294} = 0.98$$

$m_0 = 0.85, \quad D = 2.44\,m$

$$V_d = \frac{3 \times 10^6}{\sqrt{2}}\, r\,\delta\, m_0 \log_e \frac{D}{r} \text{ Volts}$$

$$= \frac{3 \times 10^6}{\sqrt{2}} \times 5.2 \times 10^{-3} \times 0.98 \times 0.85 \log_e \frac{2.44}{5.2 \times 10^{-3}}$$

$$= \frac{12.995}{\sqrt{2}} \times 10^3 \log_e (0.4692 \times 10^3)$$

$$= \frac{12.995}{\sqrt{2}} \times 10^3 \times 6.151 = 56.529 \times 10^3 \text{ Volts}$$
$$= 56.53\,KV/\text{phase}$$

V_d (line to line) $= 56.53 \times \sqrt{3} = 97.91\,KV$

For general visual corona $m_v = 0.7$

$$V_v = \frac{3 \times 10^6}{\sqrt{2}} \times 5.2 \times 10^{-3} \times 0.98 \times 0.7 \left(1 + \frac{0.03}{\sqrt{0.98 \times 5.2 \times 10^{-3}}}\right) \log_e \frac{2.44}{5.2 \times 10^{-3}}$$

$$= 7.568 \times 10^3 \left(1 + \frac{3 \times 10^{-2}}{0.0714}\right) \times 6.151$$

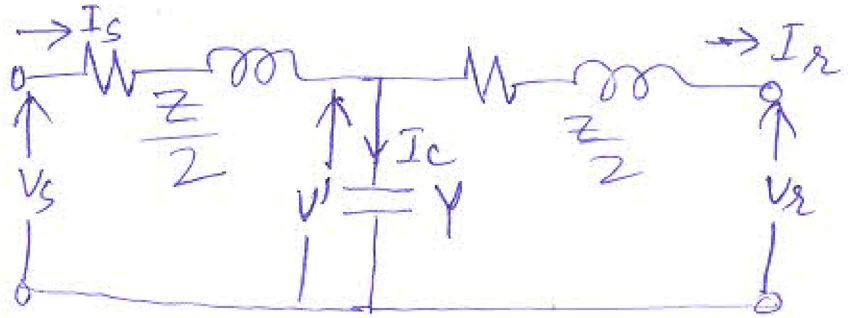
$$= 7.568 \times 10^3 \times 1.4201 \times 6.151$$

$$= 66.107 \times 10^3 = 66.107\,KV/\text{phase}$$

V_v (line to line) $= 66.107 \times 1.732 = 114.5\,KV$

B. 10. Derive A, B, C, D constants of a medium length transmission line and hence prove that $AD - BC = 1$.

Ans.



Nominal T circuit of a medium length transmission line

$$V' = V_R + I_R \frac{Z}{2}$$

$$I_C = V'Y = \left(V_R + I_R \frac{Z}{2}\right) Y$$

$$I_S = I_R + I_C = I_R + V_R Y + I_R \frac{YZ}{2} = V_R Y + I_R\left(1 + \frac{ZY}{2}\right)$$

$$V_S = V' + I_S \frac{Z}{2} = V_R + I_R \frac{Z}{2} + \left(V_R Y + I_R \frac{ZY}{2} + I_R\right)\frac{Z}{2}$$

$$= \left(1 + \frac{ZY}{2}\right) V_R + \left(1 + \frac{ZY}{4}\right) I_R Z$$

equation for V_S and I_S can be written in matrix form as

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} \left(1 + \frac{ZY}{2}\right) & Z\left(1 + \frac{ZY}{4}\right) \\ Y & \left(1 + \frac{ZY}{2}\right) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

So on comparing with the equations $\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$

$A = 1 + \frac{ZY}{2}$, $B = Z\left(1 + \frac{ZY}{4}\right)$

$C = Y$, $D = 1 + \frac{ZY}{2}$

$$AD - BC = \left(1 + \frac{ZY}{2}\right)^2 - ZY\left(1 + \frac{ZY}{4}\right)$$

$$= 1 + \frac{Z^2Y^2}{4} + ZY - ZY - \frac{Z^2Y^2}{4} = 1$$

hence proved.

Section - C

C. 11. A 3-phase, 50 HZ overhead transmission line 100 km long has the following constants:

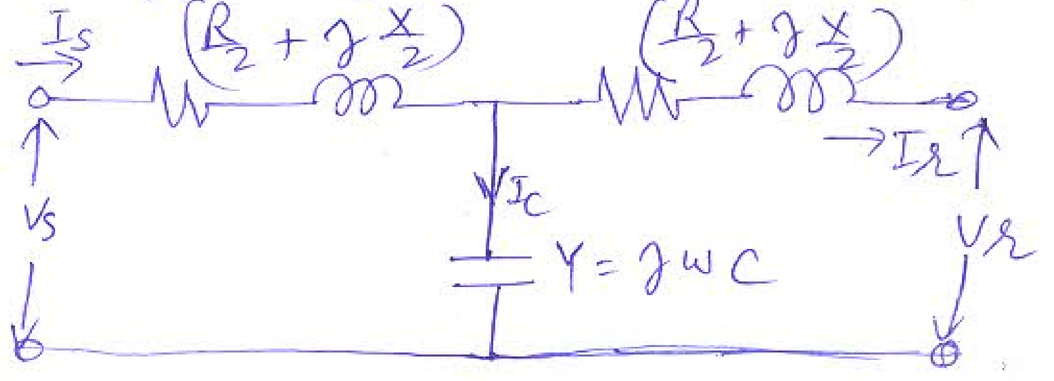
Resistance/km/phase = 0.1 Ω

Inductive reactance/km/phase = 0.2 Ω

Capacitive susceptance/km/phase = 0.04×10^{-4} ℧

Determine (i) sending end current (ii) sending end voltage (iii) sending end power factor and (iv) transmission efficiency when supplying a balanced load of 10,000 kW at 66 kV, p.f. 0.8 lagging, using nominal T method. (7.5)

Ans.



Here $\frac{Z}{2} = \left(\frac{0.1 + j0.2}{2}\right) \times 100 = (5 + j10)\ \Omega$

$= \sqrt{125} \angle \tan^{-1} 2$

$= 11.18 \angle 63.43^\circ\ \Omega$

$Y = j\,0.04 \times 10^{-4} \times 100\ ℧ = j\,4 \times 10^{-4}\ ℧ = 4 \times 10^{-4} \angle 90^\circ\ ℧$

$V_r/\text{phase} = \frac{66}{\sqrt{3}} \times 10^3 = 22\sqrt{3} \times 10^3\ V$

$= 38104 \angle 0^\circ\ V$

$I_r = \frac{10000 \times 10^3}{\sqrt{3} \times 66 \times 0.8 \times 10^3} \angle(-\cos^{-1} 0.8) = 109.35 \angle -36.87^\circ\ A$

$$V_s = \left(1+\frac{ZY}{2}\right) V_R + Z\left(1+\frac{ZY}{4}\right) I_R$$

$$= 38104\left(1+11.18\angle 63.43^\circ \times 4\times10^{-4}\angle 90^\circ\right)$$

$$+ 22.36\angle 63.43 \cdot 109.35\angle -36.87^\circ \left(1+\frac{11.18\angle 63.43 \times 4\times10^{-4}\angle 90^\circ}{2}\right)$$

$$= 38104\left(1+44.72\times10^{-4}\angle 153.43^\circ\right) + 2445.06\angle 26.56^\circ\left(1+22.36\times10^{-4}\angle 153.43^\circ\right)$$

$$= 38104 + 170.4\angle 153.43^\circ + 2445.06\angle 26.56^\circ + 5.467\angle 179.99$$

$$= 38104 + 170.4(-0.8944 + j0.4473) + 2445.06(0.8944 + j0.4473) + 5.467(-1+j0)$$

$$= 38104 + 0.8944(2445.06 - 170.4) + j0.4473(2445.06 + 170.4) - 5.467$$

$$= 38104 + 0.8944\times 2274.66 + j0.4473\times 2615.46 - 5.467$$

$$= 38104 + 2034.45 - 5.467 + j1169.89$$

$$= 40132.98 + j1169.89 = \sqrt{1610656324.48 + 1368642.61}\ \angle \tan^{-1}\frac{1169.89}{40132.98}$$

$$= 40150.03\angle \tan^{-1} 0.0291$$

$$= 40150.03\angle 1.667^\circ$$

sending end line voltage $= \sqrt{3}\times 40150.03\ \text{V} = 69.54\ \text{kV}$

Power angle $= 1.667^\circ$

Now sending end current $I_s = V_R Y + I_R\left(1+\frac{ZY}{2}\right)$

So $I_s = 38104\times 4\times10^{-4}\angle 90^\circ + 109.35\angle -36.87^\circ\left(1+\frac{11.18\angle 63.43^\circ \times 4\times10^{-4}\angle 90^\circ}{2}\right)$

$$I_S = 15.24\angle 90^\circ + 109.35\angle -36.87^\circ\left(1 + 44.72\times10^{-4}\angle 153.43\right)$$

$$= j15.24 + 109.35\angle -36.87^\circ + 0.489\angle 116.56^\circ$$

$$= j15.24 + 109.35(0.8 - j0.6) + 0.489(-0.447 + j0.8944)$$

$$= 87.48 - 0.2186 + j15.24 - j65.61 + j0.437$$

$$\doteq 87.26 - j49.93 = \sqrt{(87.26)^2 + (49.93)^2}\angle -\tan^{-1}\frac{49.93}{87.26}$$

$$= \sqrt{7614.30 + 2493.005}\angle -\tan^{-1}0.5722$$

$$= 100.53\angle -29.78^\circ \text{ A}$$

Sending end line current = 100.53 A

Sending end power factor = $\cos(1.667^\circ + 29.78^\circ)$

$$= \cos(31.44^\circ) = 0.85$$

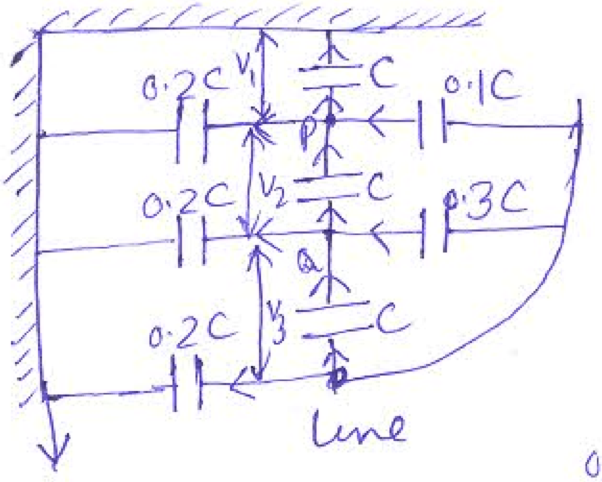
% Transmission efficiency

$$= \frac{\text{O/P Power}}{\text{I/P Power}} \times 100 = \frac{10000\times10^3}{\left(\sqrt{3}\times 69.54\times10^3 \times 100.53\times0.85\right)}\times100$$

$$= \frac{10000\times10^3}{10291.94\times10^3}\times100 = 97.16\%$$

C.12. Each line of a 3 phase system is suspended by a string of 3 identical insulators of self capacitance C Farad. The shunt capacitance of connecting metal work of each insulator is 0.2 C to earth and 0.1 C to line. Calculate the string efficiency of the system if a guard ring increases the capacitance to line of metal work of the lowest insulator to 0.3C.

Ans.



By applying KCL at junction P,

$$\omega C V_1 + 0.2\omega C V_1 - 0.1\omega C(V_2+V_3) = \omega C V_2$$

or $V_2 = 1.2V_1 - 0.1V_2 - 0.1V_3$

or $1.1V_2 = 1.2V_1 - 0.1V_3$ — (1)

at junction Q $\omega C V_3 = \omega C V_2 + 0.2\omega C(V_1+V_2) - 0.3\omega C V_3$

or $1.3V_3 = 1.2V_2 + 0.2V_1$ — (2)

From (1) $V_2 = \frac{12}{11}V_1 - \frac{1}{11}V_3$

So (2) $1.3V_3 = 1.2 \times \frac{12}{11}V_1 - \frac{1.2}{11}V_3 + 0.2V_1$

or $\left(1.3 + \frac{1.2}{11}\right)V_3 = 0.2V_1\left(1 + \frac{72}{11}\right) = \frac{16.6}{11}V_1$

or $\frac{15.5}{11}V_3 = \frac{16.6}{11}V_1$ or $V_3 = \frac{166}{155}V_1 = 1.071V_1$

So from (1) $1.1V_2 = 1.2V_1 - 0.1(1.071)V_1$

$= (1.2 - 0.1071)V_1 = 1.093V_1$

or $V_2 = \frac{1.093}{1.1}V_1 = 0.9935V_1$

% string efficiency $(\%\eta) = \frac{V_1+V_2+V_3}{3V_3} \times 100$

$= \frac{V_1 + 0.9935V_1 + 1.071V_1}{3 \times 1.071V_1} \times 100$

$= \frac{1.9935 + 1.071}{3.213} \times 100 = \frac{3.0645 \times 100}{3.213} = 95.38\%$