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POSTAL BOOK PACKAGE 2024

ELECTRICAL ENGINEERING

CONVENTIONAL Practice Sets

CONTENTS

POWER SYSTEMS

1 CHAPTER
Performance of Transmission Lines, Line Parameters and Corona

Q.1 (a) A 220 kV, 20 km long, 3-phase transmission line has the following *ABCD* parameters: $A = D = 0.96\angle 3°$, $B = 55\angle 65°$ Ω/phase, $C = 0.5 \times 10^{-4}\angle 90°$ S/phase. Determine the charging current per phase.

(b) Find the surge impedance loading for 240 kV line
  (i) If line is single circuit overhead line.
  (ii) If line is double circuit overhead line.

Solution:

(a) Given,
$$V_L = 220 \text{ kV}$$
$$V_{ph} = \frac{220}{\sqrt{3}} \text{ kV}$$
$\because$
$$X_C = \frac{1}{Y} = \frac{1}{0.5\times 10^{-4}\angle 90°}\ \Omega$$
Charging current/phase,
$$I_C = \frac{Vph}{X_C}$$
$\Rightarrow$
$$I_C = \frac{220\times 10^3}{\sqrt{3}\left[\dfrac{1}{0.5\times 10^{-4}}\angle -90°\right]}$$
$$= \frac{220\times 10^3\times 0.5\times 10^{-4}}{\sqrt{3}}\angle 90° = 6.35\angle 90° \text{ A}$$

(b) (i)
$$\text{SIL for a line} = \frac{|V|^2}{Z_s}$$
For single circuit overhead line,
$$Z_s = 400\ \Omega$$
Hence,
$$\text{SIL} = \frac{(240)^2\times 10^6}{400} = 144 \text{ MW}$$
(ii) For double circuit overhead line,
$$Z_s = 200\ \Omega$$
Hence,
$$\text{SIL} = \frac{(240)^2\times 10^6}{200} = 288 \text{ MW}$$

Note: In SIL $= \dfrac{|V|^2}{Z_s}$, V is line to line voltage.

Q2 For a 220 kV line, $A = D = 0.94\angle 10°$, $B = 130\angle 73°$ Ω/ph, $C = 0.001\angle 90°$ S/ph. Determine the voltage regulation of the line if the sending end voltage of the line for a given load delivered at nominal voltage 240 kV?

Solution:

Given, Sending end voltage $= V_s = 240$ kV

Full-load receiving end voltage $= (V_R)_{FL} = 220$ kV

$$V_{s(\text{per phase})} = \frac{240}{\sqrt{3}}\text{ kV}$$

As we know, $V_{s(\text{per phase})} = AV_{R(\text{perphase})} + BI_R$

At no-load, $I_R = 0$

No-load receiving end voltage (per phase)

$$= (V_R)_{NL\,(\text{per phase})}$$

$$= \frac{V_{s(\text{per phase})}}{A} = \frac{240}{\sqrt{3}\times 0.94} = \frac{255.32}{\sqrt{3}}\text{ kV}$$

No-load receiving end voltage (line to line) $= (V_R)_{NL} = 255.32$ kV

$$\%\text{ voltage regulation} = \frac{(V_R)_{NL} - (V_R)_{FL}}{(V_R)_{FL}}\times 100 = \frac{255.32 - 220}{220}\times 100 \approx 16\%$$

Q3 Find the length of a 3-phase, 50 Hz, lossless power transmission line if at no load condition, line has sending end and receiving end voltages of 400 kV and 420 kV respectively.
(Assuming the velocity of traveling wave to be the velocity of light).

Solution:

$\because$ $V_s = AV_R + BI_R$

At no load, $I_R = 0$,

Hence, $V_s = AV_R$

$$400 = A\times 420$$

$$A = \frac{400}{420} = 0.9524$$

$$A = 1 + \frac{YZ}{2} = 1 + \frac{(r + j\omega L)(g + j\omega C)}{2}$$

For lossless line $r = 0$, $g = 0$

Then, $A = 1 - \frac{(\omega C)(\omega L)}{2}$

$$\beta l = \sqrt{\omega L\,\omega C}$$

$$A = 0.9524 = 1 - \frac{\beta^2 l^2}{2}$$

$$\beta l = 0.3085$$

$$\beta = \frac{0.3085}{l}$$

$\because$ $\frac{V}{f} = \frac{2\pi}{\beta}$

$$\frac{3\times 10^5}{50} = \frac{2\pi}{\left(\frac{0.3085}{l}\right)}$$

$$l = 294.59\text{ km}$$

Q.4 A transmission line has an electrical line length 9°. What is the length in km if it is a 50 Hz system? If frequency is 60 Hz, what is the length in km?

Solution:

$\because$ v = Velocity of propagation $= 3 \times 10^8$ m/sec

Electrical line length $= \beta$

$$= \frac{9\times\pi}{180} \text{ rad}$$

Velocity, $\nu = \lambda f$ and $\lambda = \dfrac{2\pi}{\beta}$

So, $\nu = \dfrac{2\pi f}{\beta}$; $\beta = \dfrac{2\pi f}{\nu}$

and $\beta l = \dfrac{9\times\pi}{180}$

i.e. $$l = \frac{9\times\pi}{180}\times\frac{1}{\beta} = \frac{9\times\pi}{180}\times\frac{\nu}{2\pi f} \quad \text{...(i)}$$

$$= \frac{9\times\pi}{180}\times\frac{3\times10^8}{2\pi\times50} = 1.5\times10^5 \text{ m}$$

Length, $l = 150$ km

If frequency is 60 Hz from (i), $l = \dfrac{9\times\pi}{180}\times\dfrac{3\times10^8}{2\pi\times60} = 1.25\times10^5 \text{ m} = 125$ km

i.e. if frequency increases at keep electrical line length constant then length of transmission line decreases.

Q.5 For a 400 km long transmission line, the series impedance is (0.0 + j0.5) Ω/km and the shunt admittance is (0.0 + j5.0) μ℧/km. Determine the magnitude of series impedance of the equivalent π-circuit of the line.

Solution:

Given,

$z = (0 + j0.5)\ \Omega$/km,

$l = 400$ km

$Z = zl = (0 + j200)\ \Omega$

$y = (0 + j5)\ \mu℧$/km,

$Y = yl = (0 + j5)\times10^{-6}\times400$

$= (0 + j2\times10^{-3})$ ℧

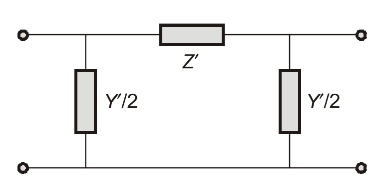
$$\gamma l = \sqrt{ZY} = j\sqrt{(200\times2\times10^{-3})} = j0.6324$$

$$= \alpha l + j\beta l = 0 + j\beta l$$

Hence, $\beta l = 0.6324$ radian

$$Z_c = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{200}{2\times10^{-3}}} = 316.22\ \Omega$$

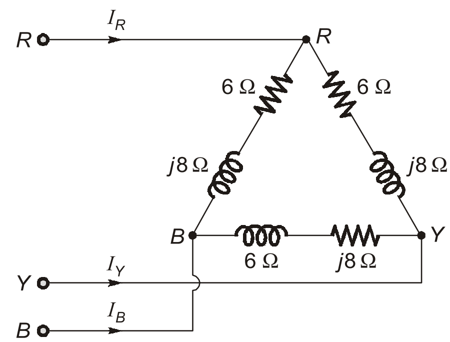
Equivalent π-network:



$$Z' = Z_C \sinh\gamma l$$
$$= Z_C \sinh(\alpha l + j\beta l)$$
$$= Z_C (\sinh\alpha l\cdot\cos\beta l + j\cosh\alpha l\ \sin\beta l)$$
$$= 316.22\left[\sin h(0)\times\cos\left(0.6324\times\frac{180}{\pi}\right) + j\cos h(0)\sin\left(\frac{0.6324\times180}{\pi}\right)\right]$$
$$= j316.22\sin(36.23°)$$

Thus, $|Z'| = 187\ \Omega$

Q.6 In the figure shown below, find the line currents, provided the supply is balanced 100 V, 50 Hz three phase supply.



Solution:

Given, $$Z_{ph} = (\sigma + 8j)\ \Omega = 10\angle 53.13\ \Omega$$

$$I_{ph}\text{ (phase current)} = \frac{V_{ph}}{Z_{ph}}$$

In Δ connection, $$V_{ph} = V_{L-L}$$

and $$I_L = \sqrt{3}\, I_{ph}$$

Here, $$I_{ph(RY)} = \frac{100\angle 0°}{10\angle 53.13°} = 10\angle{-53.13°}\text{ A}$$

Similarly, $$I_{ph(YB)} = \frac{100\angle -120°}{10\angle 53.13°} = 10\angle{-173.13°}\text{ A}$$

and $$I_{ph(BR)} = \frac{100\angle +120°}{10\angle 53.13°} = 10\angle 66.87°\text{ A}$$

The line currents in each line would be same and are given by

$$|I_L| = \sqrt{3}\,|I_{ph}| = 17.32\text{ A} \qquad [\therefore\ I_R = I_Y = I_B]$$

Q.7 A 220 kV, 3-phase line with 3.4 cm diameter conductor is built so that corona takes place if the line voltage exceeds 350 kV (rms). If the value of the potential gradient at which ionisation occurs can be taken as 30 kV/cm. Find the spacing between the conductors.

Solution:

Given that:

Radius of conductor, $$r = \frac{3.4}{2} = 1.7\text{ cm}$$

Dielectric strength of air, $$g_0 = \frac{30}{\sqrt{2}} = 21.21\text{ kV/cm}$$

Descriptive critical voltage to neutral,

$$V_{d0} = \frac{350}{\sqrt{3}} = 202.0726\text{ kV}$$

Assume smooth conductor i.e irregularity factor $m_0 = 1$. Standard pressure and temperature for which air density factor, $\delta = 1$

and let spacing between conductors be dc cm

$$V_{d0} = g_0\, \delta\, m_0\, r \ln \frac{d}{r}$$

$$202.0726 = 21.21 \times 1 \times 1 \times 1.7\ ln\ \frac{d}{1.7}$$

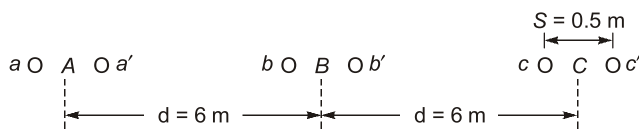
$$ln\ \frac{d}{1.7} = 5.60425$$

$$d = 1.7 \times 271.58 = 461.686 \text{ c.m}$$

$$= 4.61686 \text{ m} \simeq 4.617 \text{ m}$$

Spacing between conductors, $d = 4.617$ m

Q.8 A 3-phase bundle conductor line with 2 conductors per phase with spacing of 50 cm phase to phase separation is 6 m in horizontal configuration. Find the inductive reactance of the line. Assume all conductors are ACSR with diameter of 4 cm.



Solution:

Given that,

$$\text{Radius of each sub conductor} = \frac{4}{2} = 2 \text{ cm}$$

Geometric mean radius of each sub conductor,

$$r' = 0.7788\, r$$

$$r' = 0.7788 \times 2 \times 10^{-2} = 1.5576 \times 10^{-2} \text{ m}$$

Phase to phase separation, $d = 6$ m

Spacing between sub conductors of one phase,

$$S = 50 \text{ cm} = 0.5 \text{ m}$$

Geometric mean radius of bundle conductor,

GMR, $$D_s = \sqrt{r' \cdot S} = \sqrt{1.5576 \times 10^{-2} \times 0.5}$$

$$D_s = 0.8825 \times 10^{-1} = 0.08825 \text{ m}$$

$$D_{ab} = D_{bc} = \sqrt[4]{d_{ab} \cdot d_{ab'} \cdot d_{a'b} \cdot d_{a'b'}} = \sqrt[4]{6 \times 6.5 \times 5.5 \times 6} = 5.989 \text{ m}$$

$$D_{ca} = \sqrt[4]{d_{ca} d_{ca'} d_{c'a} d_{c'a'}} = \sqrt[4]{12 \times 11.5 \times 12.5 \times 12}$$

$$= 11.9947 \text{ m}$$

$$D_m = \sqrt[3]{D_{ab} D_{bc} D_{ca}} = \sqrt[3]{5.989 \times 5.989 \times 11.9947} = 7.549 \text{ m}$$

Inductance of bundle conductor line,

$$L = 0.2 ln \frac{D_m}{D_s} \text{ mH/ km} = 0.2 ln \frac{7.549}{0.08825} \text{ mH/ km}$$

$$= 0.8898 \text{ mH/km}$$

Inductive reactance of the bundle conductor line per phase,

$$X_L = 2\pi f L = 2\pi \times 50 \times 0.8898 \times 10^{-3}$$

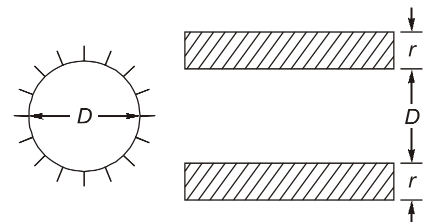
$$X_L = 0.2795\ \Omega/\text{km}$$

Q.9 A transmission line conductor having a diameter of 20 mm weights 0.67 kg/m. The span is 260 m. The wind pressure is 45 kg/m^2 of projected area with ice coating of 18 mm. The ultimate strength of the conductor is 4700 kg. Calculate maximum sag if safety factor is 2 and ice weighs 890 kg/m^3.

Solution:

Working Tension, $T = \dfrac{\text{Ultimate strength}}{\text{Factor of safety}}$

$$T = \frac{4700}{2} = 2350 \text{ kg}$$



ice coating

Weight of ice coating per meter length,

$$\omega_i = \text{Density of ice} \times \pi\, r\,(D + r)$$
$$\omega_i = 890 \times \pi \times 18 \times 10^{-3} \times (20 + 18) \times 10^{-3}$$
$$= 1.9124 \text{ kg}$$

Wind force per meter length of conductor

$$\omega_\omega = \text{wind pressure} \times (D + 2r)$$
$$= 45 \times (20 + 2 \times 18) \times 10^{-3} = 2.52 \text{ kg}$$

Resultant force per meter length of conductor,

$$\omega_r = \sqrt{(\omega_c + \omega_i)^2 + \omega_\omega^2} = \sqrt{(0.67 + 1.9124)^2 + (2.52)^2}$$
$$\omega_r = 3.608 \text{ kg}$$

Maximum sag, $S = \dfrac{\omega_r L^2}{8T} = \dfrac{3.608 \times (260)^2}{8 \times 2350} = 12.974 \text{ m}$

Maximum sag, $S \approx 13 \text{ m}$

Q.10 There are 6 conductors in a double circuit transmission line. Each conductor has a radius of 12 mm. The 6 conductors are arranged horizontally. The centre to centre distance between all the conductors is 2 m. The sequence of conductors is from left to right as follows: *a*, *b*, *c*, *a*′, *b*′, *c*′. Calculate the inductance per km per phase of this system.

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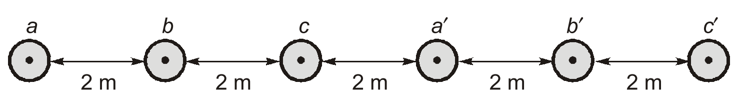
Solution:



$$GMD_1 = (2.4.8.10)^{1/4} = (640)^{1/4} = 5.03 \text{ m}$$

Similarly, $GMD_2 = (2.2.4.8)^{1/4} = (128)^{1/4} = 3.36 \text{ m}$

and $GMD_3 = (4.2.2.4)^{1/4} = (64)^{1/4} = 2.83 \text{ m}$

Equivalent, $GMD = \sqrt[3]{GMD_1 \times GMD_2 \times GMD_3}$

The equivalent, $GMD = \{(5.03)\cdot(3.36)\cdot(2.83)\}^{1/3} = 3.63 \text{ m}$

$$GMR_1 = \text{Self } GMD_1 = \sqrt{r' \times D_{aa'}} = \sqrt{0.7788 \times r \times D_{aa'}}$$
$$= \sqrt{0.7788 \times 6 \times 12 \times 10^{-3}} = 0.237 \text{ m}$$

Similarly, $GMR_2 = \sqrt{0.7788 \times 6 \times 12 \times 10^{-3}} = 0.237 \text{ m}$

and $GMR_3 = \sqrt{.7788 \times 6 \times 12 \times 10^{-3}} = 0.237 \text{ m}$

The equivalent,

$$GMR = (0.237 \times 0.237 \times 0.237)^{1/3} = 0.237 \text{ m}$$

Inductance per phase $= 2 \times 10^{-7} \ln \dfrac{GMD}{GMR} = 2 \times 10^{-7} \ln \dfrac{3.63}{0.237}$

$$= 5.458 \times 10^{-7} \text{ Henry/m}$$
$$= 5.458 \times 10^{-4} \text{ Henry/km} = 0.5458 \text{ mH/km}$$