60 Hz step-down transformer [Non-Ideal]

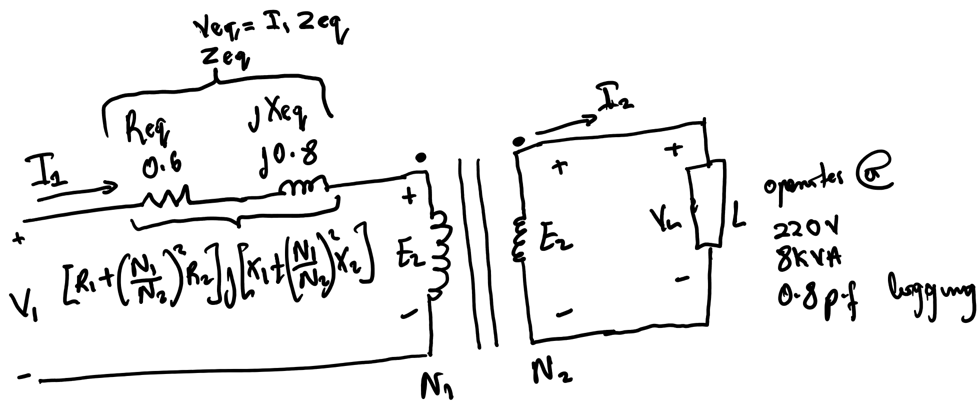
$E_1 / E_2 = 480V / 240V$ @ 10KVA

Load: $V_L = 220V$

$S_L = 8KVA$ @ 0.8 p.f lagging

$Z_{eq_1} = 0.6 + j0.8 \; [\Omega]$

1a



Neglecting exciting Current

1b Load Current $= I_L$

$S_L = V_L \times I_L$

$I_L = \frac{S_L}{V_L}$

$S_L = 8KVA \angle \cos^{-1}(0.8)$

$S_L = 8KVA \angle 36.87°$

$V_L = 220V \angle 0°$

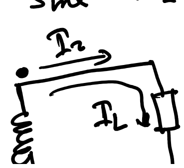
$I_L = \frac{8K\cancel{V}A}{220\cancel{V}} \angle 36.87° - 0°$

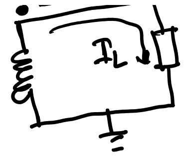
$I_L = 36.36A \angle -36.87°$

Primary Current $I_1 = \frac{N_2}{N_1} \times I_2 = \frac{1}{a_t} I_2$

$a_t = \frac{E_1}{E_2} = \frac{480V}{240V} = 2$

$I_2 = I_L$ since N_2 winding is in Series with Load



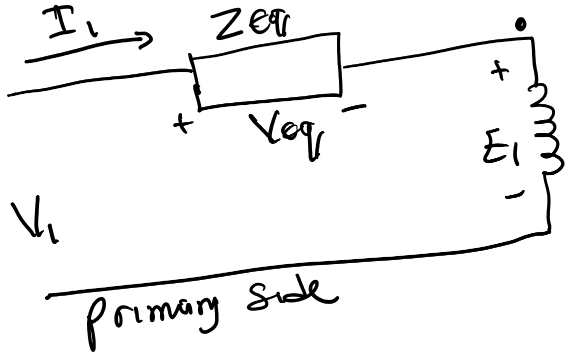


$$I_1 = \frac{1}{a_t} I_L$$

$$I_1 = \frac{1}{2}\left(36.36\angle -36.87^\circ [A]\right)$$

$$I_1 = \boxed{18.18\angle -36.87^\circ \ [A]}$$

1c



$$V_1 = V_{eq} + E_1$$

$$E_1 = 480\,V$$

$$V_{eq} = I_1 \,(Z_{eq}) = \left(18.18\angle 36.87^\circ [A]\right)\left(0.6 + j1.8\right)$$

$$V_{eq} = \left(18.18\angle -36.8^\circ [A]\right)\left(1.897\angle 71.56^\circ [\Omega]\right)$$

$$V_{eq} = 34.49\angle 34.76^\circ \ [V] = 28.33 + j19.66$$

$E_1 = V_p$ rating of transformer

$$E_1 = 480\,V$$

$$V_1 = \left[28.33 + j19.66\right]V + \left[480 + j0\right]V$$

$$V_1 = \boxed{508.33 + j19.66 \ [V]}$$

1d

$$S_1 = I_1 V_1 = \left(18.18\angle -36.8^\circ\ [A]\right) \times \left(508.83 + j\,19.66\ [V]\right)$$

$$S_1 = \left(18.18\angle -36.8^\circ\ [A]\right)\left(508.71\angle 2.21^\circ\ [V]\right)$$

$$S_1 = 9248.35\angle -34.59^\circ\ [VA]$$

$$S_1 = 9.25\angle -34.59^\circ [KVA]$$

$$P_1 = 9.25\cos(-34.59)\ [KW]$$

$$P_1 = 7.62\ [KW]$$

$$Q_1 = j\,9.25\sin(-34.59)[KVAR]$$

$$Q_1 = -j\,5.25\ [KVAR]$$

1e

$$S_1 = I_1^2 Z_{in}$$

$$Z_{in} = \frac{S_1}{I_1^2} = \frac{9.25\angle -34.59^\circ [KVA]}{\left(18.18\angle -36.8^\circ [A]\right)^2}$$

$$Z_{in} = 27.99\angle -34.59^\circ - 2(-36.8^\circ)\quad [\Omega]$$

$$Z_{in} = 27.99\angle 39.01^\circ\ [\Omega]$$

$$Z_{in} = 21.75 + j17.62\ [\Omega]$$

$$Z_{eq} = Z_{in} + Z_L$$

$$Z_L = Z_{eq} - Z_{in}$$

$$- (21.74 + j17.62)\quad [\Omega]$$

$Z_L = Z_{eq} - Z_{in}$

$Z_L = (0.6 + j1.8) - (21.74 + j17.62)$ $[\Omega]$

$Z_L = 21.14 - j15.82$

$R_L = 21.14\ \Omega$ $X_2 = -j15.82\ [\Omega]$

$P_{in} = 6.47\ KW$

1f

$\text{Efficency} = \dfrac{P_{out}}{P_{in}}$

$P_{out} = S_L \times p.f$

$P_{out} = 8KVA \times 0.8$

$P_{out} = 6.4 KW$

$\text{Efficency } \eta = \dfrac{6.4KW}{6.47KW} = 98.9\%$

$S_{rated} = 10\ [KVA]$ $[V_1 : V_2]_{rated} = 480V : 240V$

$S_{Base} = S_{rated} = 10\ [KVA]$ $V_{1Base} = 480V$

$V_{2Base} = 240V$

$I_{1Base} = \dfrac{S_{Base}}{V_{1Base}}$ $I_{2Base} = \dfrac{S_{Base}}{V_{2Base}}$

$I_{1Base} = \dfrac{10\ [KVA]}{480V} = 20.83A$ $I_{2Base} = \dfrac{10\ [KVA]}{240V} = 41.67A$

$Z_{1Base} = \dfrac{V_{1Base}}{I_{1Base}} = \dfrac{480V}{20.83A} = 23.04\Omega$ $Z_{2Base} = \dfrac{V_{2Base}}{I_{2Base}} = \dfrac{240V}{41.67A} = 5.75\Omega$

p.u value using #1 b

$I_L = 36.36A \angle -36.87^\circ$

$I_{Lp.u} = \dfrac{I_L}{I_{2Base}} = \dfrac{36.36}{41.67} \angle -36.87^\circ$

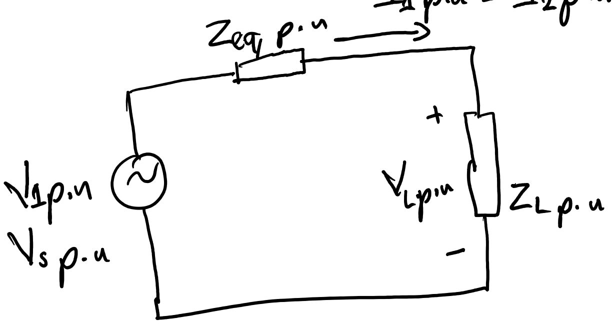
$I_{Lp.u} = 0.87 \angle -36.87^\circ$

$I_1 = 18.18 \angle -36.87^\circ\ [A]$

$I_{1p.u} = \dfrac{18.18}{20.83} \angle -36.87^\circ$

$I_{1p.u} = 0.87 \angle -36.87^\circ$

$I_{Lp.u} = I_{2p.u} \approx I_{1p.u} = 0.87 \angle 36.87^\circ$



p.u value using #1c

$V_1 = 508.33 + j\,19.66\ [V]$

$V_1 = 508.71 \angle 2.21^\circ\ [V]$

$V_{1p.u} = \dfrac{V_1}{V_{1Base}} = \dfrac{508.71}{480} \angle 2.21^\circ$

$V_{1p.u} = 1.06 \angle 2.21^\circ$

$$V_{1\,p.u} = 1.06 \angle 2.21^\circ$$

p.u value using # 1d

$$S_1 = 9.25 \angle -34.59 \,[KVA]$$

$$S_{1\,p.u} = \frac{S_1}{S_{Base}} = \frac{9.25 \angle -34.59^\circ \,[KVA]}{10\,[KVA]}$$

$$S_{1\,p.u} = 0.925 \angle -34.59^\circ$$

$$P_{1\,p.u} = 0.925 \angle -34.59^\circ$$

$$P_{1\,p.u} = 0.761$$

$$Q_{1\,p.u} = 0.925 \sin(-34.59^\circ)$$

$$Q_{1\,p.u} = -0.525$$

p.u value using # 1e

$$Z_{in} = 27.99 \angle -39.01 \,[\Omega]$$

$$Z_{in\,p.u} = \frac{Z_{in}}{Z_{Base}} = \frac{27.99 \angle -39.01^\circ}{23.04}$$

$$Z_{in\,p.u} = 1.21 \angle -39.01^\circ$$

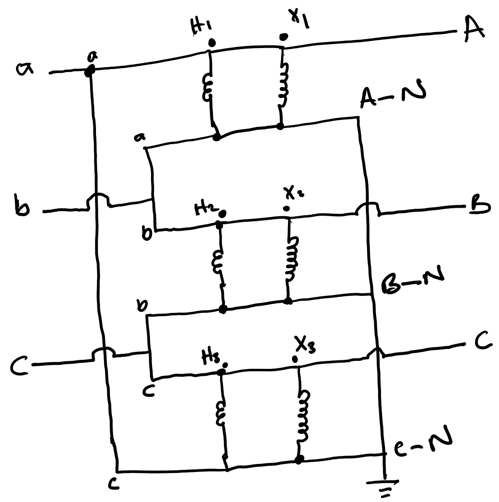
$$Z_L = 21.14 + j15.82$$

$$Z_L = 26.40 \angle 36.81^\circ \,(\Omega)$$

$$Z_{L\,p.u} = \frac{Z_L}{Z_{2\,Base}} = \frac{26.40}{5.75} \angle 36.81^\circ$$

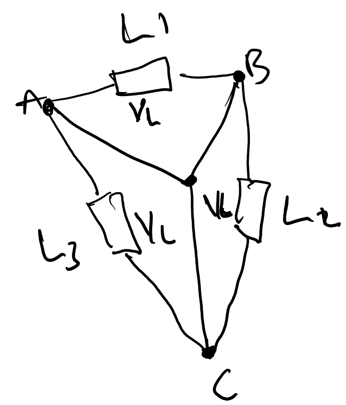
$$Z_{L\,p.u} = 4.59 \angle 36.81^\circ$$

Δ-Y transformer



8.314KV : 96KV

Secondary side of transformer



3a per unit quantities needed $[I_A \text{ p.u}, V_L \text{ p.u}, S_{Load} \text{ p.u}]$

$$V_{Load\ p.u} = \frac{V_{L/phase}}{V_{2\ rating/phase}}$$

$$V_{Load\ p.u} = \frac{50\text{kV}}{96\text{kV}}$$

$$V_{Load\ p.u} = 0.52$$

$$I_{Load\ p.u} = \frac{I_{Load}}{I_{Base}} \angle -\cos^{-1} p.f$$

$$I_{Load\ p.u} = \frac{4\text{A}}{5.41\text{A}} \angle -\cos^{-1}(0.7071)$$

$$I_{Load\ p.u} = 0.74 \angle -45^\circ$$

$$I_{Base} = \frac{S_{3\phi\ rating}}{V_{2\ rating/phase} \times \sqrt{3}} = \frac{900\text{ KVA}}{96 \times \sqrt{3}\text{ KV}}$$

$$I_{Base} = 5.41\text{ A}$$

$$I_{Load} = \frac{S_{Load\ 1\phi}}{V_{Load\ 1\phi}} = \frac{\overset{4}{\cancel{200}}\,\text{KVA}}{\overset{1}{\cancel{50}}\,\cancel{\text{KV}}}$$

$$I_{Load} = 4\text{ A}$$

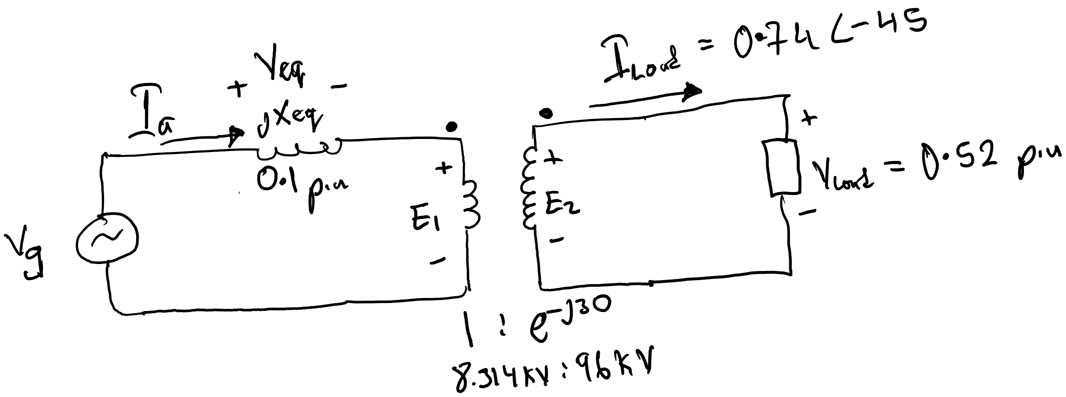
$I_{Load\,p.u} = 0.74 \angle -45$

$I_{Load} = 4\,A$

$$S_{Load\,p.u} = \frac{S_{Load\,1\phi}}{S_{3\phi}/3}$$

$$S_{Load\,p.u} = \frac{200\,KV}{\frac{900\,KV}{3}}$$

$S_{Load\,p.u} = 0.67$



3b $V_g = V_{eq} + E_1$

$V_{eq} = I_a \times jX_{eq}$

$$I_a = \frac{N_2}{N_1} \times I_L \angle(\theta - 30)^\circ$$

$$I_a = \frac{96kV}{8.314kV} \times 0.74 \angle(-45 - 30)^\circ$$

$I_a = 8.54 \angle -75^\circ$ [A]

$V_{eq} = (8.54 \angle -75^\circ A)(j0.1)$

$V_{eq} = 0.825 + j0.221$ p.u

$E_1 = V_L \angle \theta_{VL} - 30^\circ = 0.52 \angle -30^\circ$

$E_1 = 0.45 - j0.26$

$V_g = V_{eq} + E_1$

$V_g = (0.825 + j0.221) + (0.45 - j0.26)$

$V_g = 1.275 - j0.039$ p.u

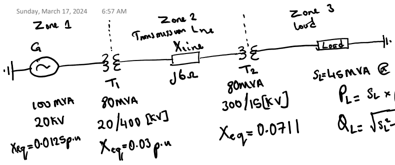
$V_g = 1.28 \angle -1.75^\circ$ p.u

$V_{g\,magnitude} = V_{g\,p.u} \times V_{g\,base}$

$V_{g\,magnitude} = (1.28 \angle -1.75^\circ \text{ p.u})(8.314\text{KV})$

$V_{g\,magnitude} = 10.64 \angle -1.75^\circ$ [KV]

Sunday, March 17, 2024 6:57 AM



$S_L = 45$ MVA @ 0.7 p.f lagging

$P_L = S_L \times p.f = 31.5$ MW

$Q_L = \sqrt{S_L^2 - P_L^2} = 32.14$ MVAR

4b

Using System base of 100 MVA & Voltage @ T_1 primary = 10KV

" " T_2 secondary = 10KV

Determine Base Values of each Zone

Zone 1

$$V_{g\,p.u} = \frac{10KV}{V_{g\,Base}} = \frac{10KV}{20KV} = 0.5\angle 0^\circ \text{ p.u}$$

$S_{Base} = 100$ MVA

$V_{1Base} = 20$ KV

$$Z_{1Base} = \frac{(V_{1Base})^2}{S_{Base}}$$

$$Z_{1Base} = \frac{(20KV)^2}{100MVA} = 4\Omega$$

$$I_{1Base} = \frac{V_{1Base}}{Z_{1Base}} = \frac{20KV}{4\Omega}$$

$I_{1Base} = 5KA$

Zone 2

$$V_{2Base} = \left(\frac{400}{20}\right)(20) = 400KV$$

$$Z_{2Base} = \frac{(400KV)^2}{100MVA} = 1.6k\Omega$$

$$I_{2Base} = \frac{400KV}{1.6k\Omega} = 250A$$

Zone 3

$$V_{3Base} = \left(\frac{15}{300}\right)(400) = 20KV$$

$$Z_{3Base} = \frac{(20KV)^2}{100MVA} = 4\Omega$$

$$I_{3Base} = \frac{V_{3Base}}{Z_{3Base}} = \frac{20KV}{4\Omega} = 5KA$$

Determine per unit Values

$$Z_{p.u.new} = Z_{p.u.old}\left(\frac{V_{base\,old}}{V_{base\,new}}\right)^2\left(\frac{S_{base\,new}}{S_{base\,old}}\right)$$

At Zone 1

$$Z_{1\,p.u.new} = 0.03\left(\frac{\cancel{20KV}}{\cancel{20KV}}\right)^2\left(\frac{10\cancel{0MVA}}{8\cancel{0MVA}}\right)$$

$$Z_{1\,p.u\,new} = 0.0375 \text{ p.u}$$

$$V_{1\,p.u} = \frac{10KV}{20KV} = 0.5 \text{ p.u}$$

$$Z_{G\,p.u} = \frac{\frac{(V_{T_1})^2}{S_{Base}}}{Z_{1Base}}$$

$$Z_{G\,p.u} = \frac{\frac{(10KV)^2}{100MVA}}{4\Omega}$$

$$Z_{G\,p.u} = 0.25 \text{ p.u}$$

At Zone 2

$$Z_{2\,p.u\,new} = 0.0711\left(\frac{300KV}{400KV}\right)^2\left(\frac{100MVA}{80MVA}\right)$$

$$Z_{2\,p.u.new} = 0.05 \text{ p.u}$$

At the Transmission line

$$X_{Line\,p.u} = \frac{X_{Line}}{Z_{2Base}} = \frac{6\Omega}{1.6\Omega} = 0.00375\Omega$$

At zone 3

$$Z_{Load} = \frac{S_{Load}}{V_{Load}}$$

$S_{Load} = 45\,MVA$ @ 0.7 p.f lagging

$V_{Load} = 10KV$

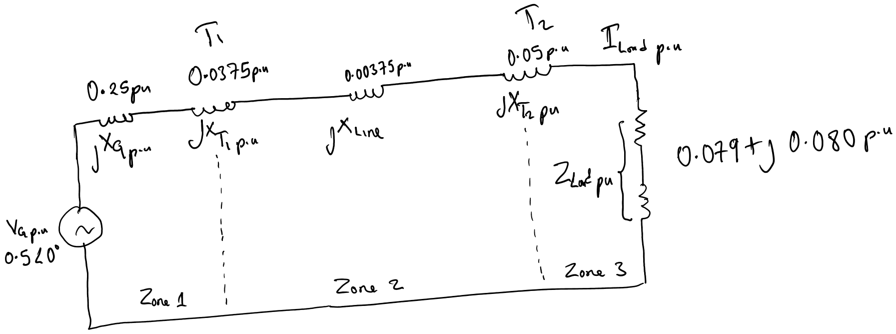
$$Z_{Load} = \frac{45\,MVA}{(10KV)^2} \angle -\cos^{-1} 0.7$$

$$Z_{Load} = 0.45 \angle -45.57^\circ\ \Omega$$

$$Z_{Load} = 0.315 + j\,0.321\ [\Omega]$$

$$Z_{Load\ p.u} = \frac{0.315 + j\,0.321\ [\Omega]}{4\,\Omega}$$

$$Z_{Load\ p.u} = 0.079 + j\,0.080\ p.u$$



4c

$$I_{Load\ p.u} = \frac{V_{G\,p.u}}{Z_{Total}}$$

$$Z_{Total} = j(0.25 + 0.0375 + 0.00375 + 0.05) + (787.5 + j802.5)$$

$Z_{Total} = 0.079 + j\,0.4213$ from matlab

$$I_{Load\ p.u} = \frac{0.5\angle 0^\circ}{0.079 + j\,0.4213}$$

$I_{Load\ p.u} = 0.215 - j\,1.147$ from matlab

$I_{3\,Base} =$ 5KA from above

$$I_{actual} = I_{3\,Base} \times I_{Load\ p.u}$$

$$I_{actual} = 5KA\,(0.215 - j1.147)$$

$$I_{actual} = 1.0752 - j5.733\ [KA]$$

$$= 5.83 \angle -79.38^\circ\ [KA]$$

$V_{g\,p.u} = \frac{10KV}{V_{g\,Base}} = \frac{10KV}{20KV} = 0.5\angle 0°\ p.u$ from above

$V_{G\,p.u} = V_{s\,p.u} = 0.5\angle 0°\ p.u$

$$S_{Line\ p.u} = (I_{p.u})^2 (jX_{Line\ p.u})$$

$$S_{Line\ p.u} = (0.215 - j1.147)^2 (j0.00375)$$

$$S_{Line\ p.u} = 0.0018 - j0.0048\ p.u$$

$$S_{Line} = I_{actual}^2 \times jX_{Line}$$

$$S_{Line} = (1.0752 - j5.733\ [kA])^2 \times j6\ \Omega$$

$$S_{Line} = 73.97 + j190.27\ [MVA]$$

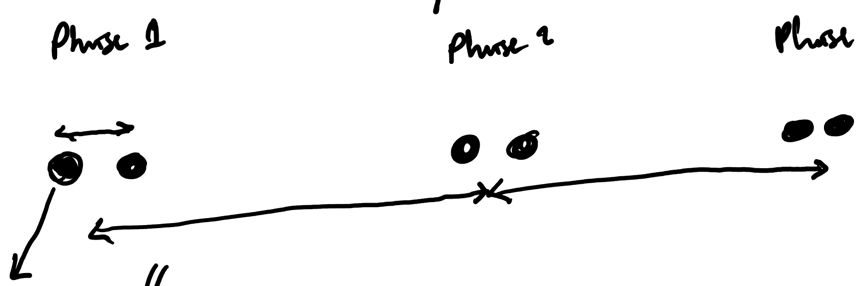
$$S_{Line} = 204.14\angle 68.76°\ [MVA]$$

Yes S_{Line} rating exceed all the [MVA] ratings

3ϕ transmission line with 2 lines / bundle

$f = 60\,Hz$ $V = 345\,kV$ # Strand = 30

$T = 50°C$ $\rho = 2.7 \times 10^{-8}\ \Omega\text{-}m$ @ $20°C$ for Aluminium



$D = 0.1628''$ from table A.4

Resistance

$$R_{DC} = \frac{\rho_{50°C}\, L}{A \times \#\text{Lines/Bundle}}$$

$$\rho_{50°C} = 2.7\times10^{-8}\ \Omega\text{-}m \left(1 + 0.0039\,(50°C - 20°C)\right)$$

$$\rho_{50°C} = 3.0159 \times 10^{-8}\ \Omega\text{-}m$$

$$L = 1\,m$$

$$A = \pi\left(\frac{D}{2}\right)^2 \quad \text{for Mallard } D = 0.1628 \text{ inches}$$

$$A = 30\pi\left(\left(\frac{0.1628}{2}\right)\left(0.0254\,\tfrac{m}{inch}\right)\right)^2$$

$$A = 4.029 \times 10^{-4}\, m^2$$

$$R_{DC} = \frac{(3.0159 \times 10^{-8}\, \Omega\text{-}m)(1\, m)}{2 \times 4.029 \times 10^{-4}\, m^2}$$

$$R_{DC} = \boxed{3.742 \times 10^{-5}\, \frac{\Omega}{m}}$$

$$R_{DC/km} = (1.07)\left(3.742 \times 10^{-5}\, \frac{\Omega}{m}\right)\left(\frac{1000\, m}{km}\right)$$

$$R_{DC/km} = \boxed{40.04\, m\, [\Omega/km]}$$

from Table A.4

$$ra = 0.1288\, \Omega/\text{mile} \quad @\ 50^\circ C\ \&\ 60 Hz$$

$$ra_{/2\,bundle} = \frac{0.1288\, \Omega/\text{mile}}{2}\left(\frac{1}{1.609}\, \frac{\text{mile}}{km}\right)$$

$$\boxed{= 40.02\, m\, [\Omega/km]}$$

Line Spacing $d = 2.5m$

$f = 50 Hz$

$1\phi \quad L = 20 miles$

Conductor Type Finch $\Rightarrow D = 0.1436''$

$$L_a = (4\times10^{-7}) \ln\left(\frac{d}{0.7788\sqrt{\left(\frac{D}{2}\right)^2}}\right) H/m$$

$$L_a = (4\times10^{-7}) \ln\left(\frac{2.5m}{0.7788\left(\frac{0.1436\times0.0254}{2}\right)}\right)$$

$$L_a = 2.99\,\mu H/m$$

$$L_{a/20mile} = 2.99\,\mu H/m\,(20\times1609\,m/mile)$$

$$L_{a/20mile} = 0.09619\,H/mile$$

$$L_{a/20mile} = 96.19\,m[H/mile]$$

$$X_{L_{a\,20mile}} = \omega L_{a/20mile} \qquad \omega = 2\pi f$$

$$X_{L_{a\,20mile}} = 2\pi(50Hz)(96.19m\,H/mile)$$

$$X_{L_{a\,20mile}} = 30.22\,[\Omega/mile]$$

Monday, March 18, 2024 2:02 AM

line spacing $d = 0.4 m$ $f = 60 Hz$ ACRS Type Mallard

phase spacing $D = 6 m$ $T = 50°C$

$Z_{Line} = R_{Line} + j X_{Line}$

r_a from Table A.4 = 0.1288 Ω/mile @ 50°C 60 Hz

$$R_{Line/km} = \left(0.1288\ \Omega/\cancel{mile}\right)\left(\frac{1}{1.609}\frac{\cancel{mile}}{km}\right)$$

$$R_{Line/km} = \boxed{0.0800\ [\Omega/km]}$$

$$R_{Line/km} = 80.0\ m\ [\Omega/km]$$

X_a from table A.4 = 0.393 Ω/feet

$$X_{Line/km} = \left(0.393\ \Omega/feet\right)\left(3.048\times10^{-4}\ feet/km\right)$$

$$X_{Line/km} = \boxed{2.4399\times10^{-5}\ \Omega/km}$$

$$X_{Line/km} = 243.99\ m\ [\Omega/km]$$

$$Z_{Line} = \boxed{80 + j\,243.99\ [m\Omega/km]}$$