$j := \sqrt{-1}$ $\quad MVA := MW$ $\quad pu := 1$ $\quad Tpu := 1$

3.62 A three-phase transformer is rated 1 GW, 13.8kV Δ/345 kV Y with Z_{eq} = j 0.10 per unit. The transformer high-voltage winding has plus or minus 10% taps. The system base quantities are:

$$S_{base\_sys} := 500 \cdot MVA$$

$$V_{base\_XLL} := 13.8 \cdot kV$$

$$V_{base\_HLL} := 345 \cdot kV$$

Determine the per-unit equivalent circuit for the following tap settings:

a. Rated tap and
b. + 10% tap (providing 10% voltage increase for the high-voltage winding.)

$$Z_{base\_sysH} := \frac{V_{base\_HLL}^{2}}{S_{base\_sys}} \qquad Z_{base\_sysH} = 238.05\,\Omega$$

$$Z_{eq} := j \cdot 0.10 \cdot Tpu$$

$$S_{base\_T} := 1000 \cdot MVA$$

$$Z_{base\_T} := \frac{V_{base\_HLL}^{2}}{S_{base\_T}} \qquad Z_{base\_T} = 119.025\,\Omega$$

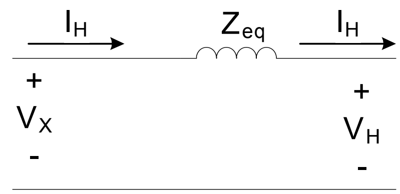
a.

$$a_t := \frac{13.8 \cdot kV}{345 \cdot kV} \qquad a_t = 0.040$$

$$b := \frac{V_{base\_XLL}}{V_{base\_HLL}} \qquad b = 0.040$$

$$c := \frac{a_t}{b} \qquad c = 1$$

$Z_{pu\_sys} := \frac{Z_{eq} \cdot Z_{base\_T}}{Z_{base\_sysH}}$ $\quad Z_{pu\_sys} = 0.05j \cdot pu$



b.

$a_{tp10} := \frac{13.8 \cdot kV}{1.1 \cdot 345 \cdot kV}$ $\quad a_{tp10} = 0.036$

$c := \frac{a_{tp10}}{b}$ $\quad c = 0.909$

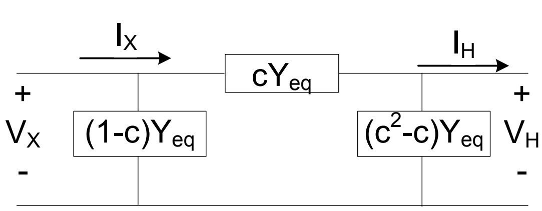
$Y_{eq} := \frac{1}{Z_{pu\_sys}}$

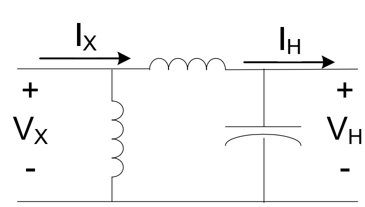
$Y_{eq} = -20j \cdot pu$ $\quad \frac{1}{Y_{eq}} = 0.05j \cdot pu$

$c \cdot Y_{eq} = -18.182j \cdot pu$ $\quad \frac{1}{c \cdot Y_{eq}} = 0.055j \cdot pu$ inductor

$(1 - c)Y_{eq} = -1.818j \cdot pu$ $\quad \frac{1}{(1 - c) \cdot Y_{eq}} = 0.55j \cdot pu$ inductor

$\left(c^2 - c\right)Y_{eq} = 1.653j \cdot pu$ $\quad \frac{1}{\left(c^2 - c\right) \cdot Y_{eq}} = -0.605j \cdot pu$ capacitor





For fun determine the admittance looking in the low side with the high side open circuited.

$$Y_{series} := \frac{c \cdot Y_{eq} \cdot \left(c^2 - c\right) \cdot Y_{eq}}{c \cdot Y_{eq} + \left(c^2 - c\right) \cdot Y_{eq}} \qquad Y_{series} = 1.818j \cdot pu$$

$$(1 - c) \cdot Y_{eq} = -1.818j \cdot pu$$

$$Y_{parallel} := Y_{series} + (1 - c) \cdot Y_{eq} \qquad Y_{parallel} = 0 \cdot pu$$

4.18 A 230-kV, 60 Hz, three-phase completely transposed overhead line has one ACSR 954-kcmil conductor per phase and flat horizontal phase spacing, with 8 m between adjacent conductors.

Determine the inductance in H/m and the inductive reactance in Ω/km.

Looking at Table A.4: Cardinal has 954-kcmil.

$$r' := 0.0403 \cdot ft \qquad r' = 1.228 \cdot cm$$

$$D_{12} := 8 \cdot m \qquad D_{13} := 16 \cdot m \qquad D_{23} := 8 \cdot m$$

$$D_s := \sqrt[3]{D_{12} \cdot D_{13} \cdot D_{23}} \qquad D_s = 10.079 \cdot m$$

$$L_a := 2 \cdot 10^{-7} \cdot \frac{H}{m} \cdot \ln\left(\frac{D_s}{r'}\right) \qquad L_a = 1.342 \times 10^{-6} \cdot \frac{H}{m}$$

$$X_a := 2 \cdot \pi \cdot 60 \cdot Hz \cdot L_a \qquad X_a = 0.506 \cdot \frac{\Omega}{km}$$

4.19 Rework Problem 4.18 if the phase spacing between adjacent conductors is:

a. increased by 10% to 8.8 m,
b. decreased by 10% to 7.2 m.

Compare the results with those of Problem 4.18

a.

$D_{12i} := 8.8 \cdot m$ $\quad D_{13i} := 17.6 \cdot m$ $\quad D_{23i} := 8.8 \cdot m$

$D_{si} := \sqrt[3]{D_{12i} \cdot D_{13i} \cdot D_{23i}}$ $\quad D_{si} = 11.087 \cdot m$

$L_{ai} := 2 \cdot 10^{-7} \cdot \frac{H}{m} \cdot \ln\left(\frac{D_{si}}{r'}\right)$ $\quad L_{ai} = 1.361 \times 10^{-6} \cdot \frac{H}{m}$ $\quad \frac{L_{ai} - L_a}{L_a} = 1.42 \cdot \%$

$X_{ai} := 2 \cdot \pi \cdot 60 \cdot Hz \cdot L_{ai}$ $\quad X_{ai} = 0.513 \cdot \frac{\Omega}{km}$ $\quad \frac{X_{ai} - X_a}{X_a} = 1.42 \cdot \%$

b.

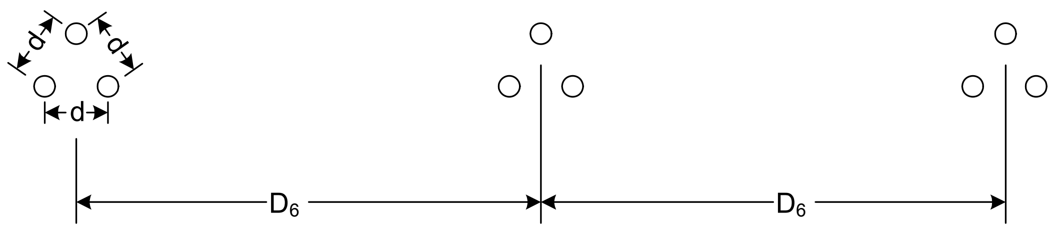
$D_{12d} := 7.2 \cdot m$ $\quad D_{13d} := 14.4 \cdot m$ $\quad D_{23d} := 7.2 \cdot m$

$D_{sd} := \sqrt[3]{D_{12d} \cdot D_{13d} \cdot D_{23d}}$ $\quad D_{sd} = 9.071 \cdot m$

$L_{ad} := 2 \cdot 10^{-7} \cdot \frac{H}{m} \cdot \ln\left(\frac{D_{sd}}{r'}\right)$ $\quad L_{ad} = 1.321 \times 10^{-6} \cdot \frac{H}{m}$ $\quad \frac{L_{ad} - L_a}{L_a} = -1.57 \cdot \%$

$X_{ad} := 2 \cdot \pi \cdot 60 \cdot Hz \cdot L_{ad}$ $\quad X_{ad} = 0.498 \cdot \frac{\Omega}{km}$ $\quad \frac{X_{ad} - X_a}{X_a} = -1.57 \cdot \%$

4.20 Calculate the inductive reactance in Ω/km of a bundled, 60 Hz, three-phase completely transposed overhead line having three ACSR 1113-kcmil conductors per bundle, with 0.5m between conductors in the bundle. The horizontal spacing between bundle centers are 10, 10, and 20 m



$d := 0.5 \cdot m$ $\qquad D_6 := 10 \cdot m$

Looking at Table A.4: Finch has 1113-kcmil.

Calculate the GMR

$r'_6 := 0.0435 \cdot ft$ $\qquad r'_6 = 1.326 \cdot cm$

$D_{SL} := \sqrt[3]{r'_6 \cdot d^2}$ $\qquad D_{SL} = 0.149\, m$

Calculate the GMD

$D_{126} := D_6$ $\qquad D_{136} := 2 \cdot D_6$ $\qquad D_{236} := D_6$

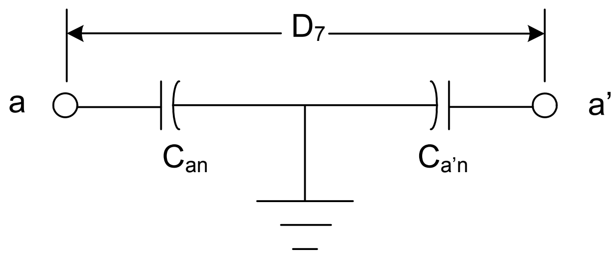
$D_{s6} := \sqrt[3]{D_{126} \cdot D_{236} \cdot D_{136}}$ $\qquad D_{s6} = 12.599\, m$

Calculate the inductive reactance

$X_{L6} := 2 \cdot \pi \cdot 60 \cdot Hz \cdot 2 \cdot 10^{-7} \cdot \frac{H}{m} \cdot \ln\left(\frac{D_{s6}}{D_{SL}}\right)$ $\qquad X_{L6} = 0.335 \cdot \frac{\Omega}{km}$

4.32 Calculate the capacitance-to-neutral in F/m and admittance-to-neutral in S/km for the single-phase line in Problem 4.8. Neglect the effect of the earth plane.

(4.8 A 60 Hz single-phase, two-wire overhead line has solid cylindrical copper conductors with 1.5 cm diameter. The conductors are arranged in a horizontal configuration with 0.5 m spacing.)



$D_7 := 0.5 \cdot m$

$r_7 := \frac{1.5}{2} \cdot cm$

$r_7 = 0.75 \cdot cm$

$\varepsilon_0 = 8.854 \times 10^{-12} \cdot \frac{F}{m}$

$$C_{an} := \frac{2 \cdot \pi \cdot \varepsilon_0}{\ln\left(\frac{D_7}{r_7}\right)} \qquad C_{an} = 13.247 \times 10^{-12} \cdot \frac{F}{m}$$

$$Y_{an} := j \cdot 2 \cdot \pi \cdot 60 \cdot Hz \cdot C_{an} \qquad Y_{an} = 4.994j \times 10^{-6} \cdot \frac{S}{km}$$

OR

$$Z_{an} := \frac{1}{j \cdot 2 \cdot \pi \cdot 60 \cdot Hz \cdot C_{an}} \qquad Z_{an} = -2.002j \times 10^{8} \cdot \Omega \cdot m$$

$$Y_{an} := \frac{1}{Z_{an}} \qquad Y_{an} = 4.994j \times 10^{-6} \cdot \frac{S}{km}$$