\[ Z = (\alpha + \beta \ln L) \text{ in length}. \]

For plane pothole excavation, impedeance per unit length.

\[ (\alpha + \beta \ln \frac{d_{eq}}{r} + \frac{\pi}{2} \ln \frac{L}{d_{eq}}) \]

\[ V_A = 2.10 - (\alpha \ln \frac{L}{d_{eq}} + \beta \ln \frac{L}{d_{eq}}) \]
Bundling
Reduce common effort.
Increase power.

Maintenance (T)
\[
\frac{\partial^2}{\partial t^2} \phi_k = \frac{e_n}{2 \pi} \ln \left( \frac{r_{id} \sin \phi + \overline{c}_b \overline{c}_k}{\overline{a}_b} \right) + \frac{2}{3} \overline{c}_b \overline{c}_k \cdot \frac{\partial}{\partial \phi} \int \left( \overline{C}_2 \overline{C}_3 \overline{C}_4 \overline{C}_5 \right) \overline{A}_2 \overline{A}_3 \overline{A}_4 \overline{A}_5 \overline{A}_6 \overline{A}_7 \overline{A}_8 \overline{A}_9 \overline{A}_{10} + \frac{1}{3} \ln \left( \frac{r_{id} \sin \phi + \overline{c}_b \overline{c}_k}{\overline{a}_b} \right) \left( \frac{\partial}{\partial \phi} \int \left( \overline{C}_2 \overline{C}_3 \overline{C}_4 \overline{C}_5 \right) \overline{A}_2 \overline{A}_3 \overline{A}_4 \overline{A}_5 \overline{A}_6 \overline{A}_7 \overline{A}_8 \overline{A}_9 \overline{A}_{10} \right)
\]
GRF = (\( p, p, y \))

GRF = (\( p, p, d \))

\( c = \frac{6 - \text{MPR}}{G - \text{MP}} \)
\[ F = \frac{8 \ln (6 \frac{1}{2} - 2)}{\sqrt{11 \ln 2}} \cdot \frac{C}{2} \times 12 \]

To increase power:

\[ C_{\text{full}} = \left( R_1 \cdot R_2 \right) \frac{1}{12} \]

(1)
EE 421: Line Constants Example

\[ m_0 = 4\pi \cdot 10^{-7} \frac{H}{m} \quad \text{freq} := 60\text{Hz} \]

Problem 4.4 In Analysis of Faulted Power Systems by P.M. Anderson:

Compute the per mile positive and negative sequence impedance for the line configuration of Figure P4.4 where the conductor is 336,400 CM, 26/7 Strand ACSR. Assume ideal transposition.

Define heights relative to the earth

- \( H_{gw} := 36\text{ft} + 11\text{ft} \)
- \( H_a := H_{gw} - 6.5\text{ft} \) \( H_a = 40.5\text{ ft} \)
- \( H_b := 36\text{ft} \)
- \( H_c := H_a - 8\text{ft} \) \( H_c = 32.5\text{ ft} \)

Define horizontal position relative to center of the tower (some are negative).

- \( X_a := -4\text{ft} \)
- \( X_b := 5\text{ft} \)
- \( X_c := -6\text{ft} \)

Now calculate distance between conductors (be careful of negative signs)

\[
D_{ab} := \sqrt{(H_a - H_b)^2 + (X_b - X_a)^2} \quad D_{ab} = 10.062\text{ ft} \quad \checkmark
\]

\[
D_{bc} := \sqrt{(H_b - H_c)^2 + (X_b - X_c)^2} \quad D_{bc} = 11.543\text{ ft} \quad \checkmark
\]

Calculate geometric mean distance between conductors:

\[
D_m := \left( D_{ab} \cdot D_{bc} \cdot D_{ac} \right)^{\frac{1}{3}} \quad D_m = 9.857\text{ ft} \quad \checkmark
\]
GMR and Rac from table A.4 (entry for Linnet in Table A.4 in Glover, Sarma and Overbye)

\[
\begin{align*}
\text{GMR} &= 0.0244 \text{ft} \\
\text{Rac} &= 0.273 \text{ ohm/mi}
\end{align*}
\]

\[
\text{diameter} = 0.721 \text{ in}
\]

at 25°C and 60Hz

For comparison:

\[
\tau' := \left(\frac{\text{diameter}}{2}\right) \cdot \frac{1}{c^4}
\]

\[
\tau' = 0.023 \text{ ft}
\]

As an aside:

- 1 cmil is the area of conductor with diameter of 0.001 in:

\[
cmil = \pi \left(\frac{0.001 \text{ in}}{2}\right)^2
\]

\[
1 \text{ cmil} = 7.854 \times 10^{-7} \text{ in}^2
\]

For this conductor with an area of:

\[
\text{area}_{\text{cmil}} = 336400 \text{ cmil}
\]

\[
\text{Radius}_{\text{eq}} = \sqrt{\frac{\text{area}_{\text{cmil}}}{\pi}}
\]

\[
\text{Radius}_{\text{eq}} = 0.29 \text{ in}
\]

Compare to the diameter of:

\[
\frac{\text{diameter}}{2} = 0.36 \text{ in}
\]

the difference is due to skin effect and the impact of stranding.

\[
\tau' = 0.281 \text{ in}
\]

We can calculate the positive/negative sequence impedance:

\[
L_1 := \frac{\mu_0}{2\pi} \cdot \ln \left(\frac{D_{\text{in}}}{\text{GMR}}\right)
\]

\[
L_1 = 1.932 \text{ mH/mi}
\]

\[
Z_1 := \text{Rac} + j\cdot 2\cdot\pi\cdot\text{freq} \cdot L_1
\]

\[
Z_1 = (0.273 + 0.728i) \frac{\text{ohm}}{\text{mi}}
\]
Now suppose, instead of using a single conductor of 336,400 CM ACSR in each phase, with current carrying capacity of 530 amperes, suppose that each phase consists of a two-conductor bundle of two 3/0 ACSR conductors with capacity of 300 amperes/conductor. Let the two conductors of each bundle be separated by 1.0 ft vertically.

\[ R_{ac3} := 0.560 \text{ ohm/mi} \]
\[ GMR3 := 0.006 \text{ ft} \]
\[ \text{diameter}_3 := 0.502 \text{ in} \]

\[ D_{a1a2} := 1.0 \text{ ft} \]

\[ \text{GMRbundle} := \sqrt{\text{GMR3} \cdot D_{a1a2}} \]
\[ \text{GMRbundle} = 0.077 \text{ ft} \]

Now we'll have

\[ L_{1\text{bun}} = \frac{\mu_0}{2 \cdot \pi} \ln \left( \frac{D_m}{\text{GMRbundle}} \right) \]
\[ L_{1\text{bun}} = 1.56 \text{ mH/mi} \]

\[ Z_{1\text{bun}} = R_{ac3} + j \cdot 2 \cdot \pi \cdot \text{freq} \cdot L_{1\text{bun}} \]
\[ Z_{1\text{bun}} = (0.28 + 0.588j) \text{ ohm/mi} \]

for comparison:

\[ Z_1 = (0.273 + 0.728j) \text{ ohm/mi} \]

Most of change is in the inductive reactance.