University of Idaho

ECE 523
Symmetrical Components

Session 24

ECE 523: Homework #5

Due Session 27 (November 28)

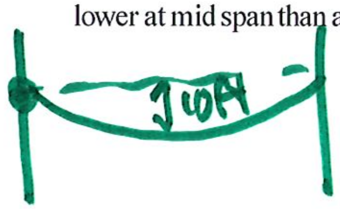
1. Compute the per mile positive and negative sequence impedance for the line configuration of figure below where the conductor is 336,400 CM, 26/7 Strand ACSR.
Ignore the ground wire for problems 1-4.

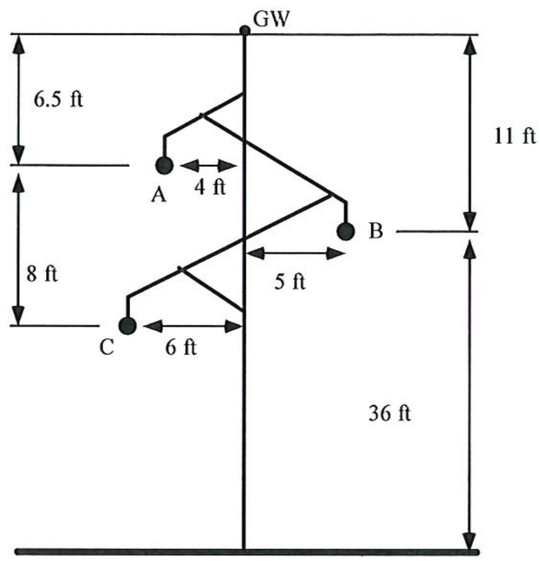
Conductor data from table:

$\mathrm{GMR} := 0.0244\mathrm{ft}$ $\quad$ $\mathrm{diameter} := 0.721\mathrm{in}$

$\mathrm{Rac} := 0.278\,\dfrac{\mathrm{ohm}}{\mathrm{mi}}$ $\quad$ at 25C and 60Hz

Assume each conductor is 10 feet lower at mid span than at tower.





2. Compute the phase impedance matrix Z_{abc} for the line described in problem 1. Assume that the line is 70 miles long and is not transposed. Ignore the ground wire. Calculate the sequence impedance matrix.

3. Compute the total impedance matrix Zabc for the lines of problem 2 with the following transposition arrangements. Calculate the sequence impedance matrix for each.

	Fraction	*Configuration*
(a)	f1 = 0.20	a-b-c
	f2 = 0.80	b-c-a
	f3 = 0.00	c-a-b
(b)	f1 = 0.30	a-b-c
	f2 = 0.60	c-a-b
	f3 = 0.10	c-b-a
(c)	f1 = 1/3	a-b-c
	f2 = 1/3	c-a-b
	f3 = 1/3	b-c-a

1ft

4 Consider the line configuration shown in the figure for problem 1. 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 seperated by 1.0ft vertically. Assume same sag as for problem 1.

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(a) Compute the 6x6 phase impedance matrix Zabc for the bundled conductor configuration and reduce it to the 3x3 equivalent and compare with the previous solution (problem 2).

$$Rac4 := 0.560\frac{ohm}{mi} \qquad \text{from table}$$

$$GMR4 := 0.01404ft \qquad diameter4 := 0.502in$$

(b) Calculate geometric mean radius of the bundle and use the 3x3 matrix method. The is an approximation of the 6x6 matrix approach. Compare the results to part (a).

(c) Compute the sequence impedance matrix for part (a) and compare to problem 2.

5. Consider an untransposed line described in problem 2 with a ground wire added. Let the ground wire be 1/0 ACSR and recalculate the phase impedance matrix Zabc, the sequence impedance matrix Z012, and the unbalance factors. Compare with previous results from problem 2 for the same line without the ground wire. Assume phase conductors have same sag as problem 1, and that the groundwire is 7 feet lower at mid span than at the tower.

- Ground wire data:

$$Rac\_gw := 0.888\frac{ohm}{mi} \qquad \text{at 25C and 60Hz}$$

$$GMR\_gw := 0.01113ft \qquad diameter\_gw := .398in$$

- Phase conductors same as in problem 2.

6. Repeat problem 5 with the transposition of problem 3, part (c).

7. Repeat problems 1-2 calculating capacitance.

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$$Z_{line} = \begin{pmatrix} 14.932 + 58.374i & 3.812 + 27.33i & 3.812 + 23.965i \\ 3.812 + 27.33i & 14.932 + 58.374i & 3.812 + 27.33i \\ 3.812 + 23.965i & 3.812 + 27.33i & 14.932 + 58.374i \end{pmatrix} \Omega$$

$$a := 1 \cdot e^{j \cdot \frac{2 \cdot \pi}{3}}$$

$$A_{012} := \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix}$$

$$\underline{Z_{012} := A_{012}^{-1} \cdot Z_{line} \cdot A_{012}}$$

Z_0 Z_{01} Z_1

$$Z_{012} = \begin{pmatrix} 22.5555 + 110.7903i & 0.9712 - 0.5607i & -0.9712 - 0.5607i \\ -0.9712 - 0.5607i & 11.12 + 32.1661i & -1.9424 + 1.1214i \\ 0.9712 - 0.5607i & 1.9424 + 1.1214i & 11.12 + 32.1661i \end{pmatrix} \Omega$$

Z_2

angle of Z_0 differs from angle of $Z_1 = Z_2$

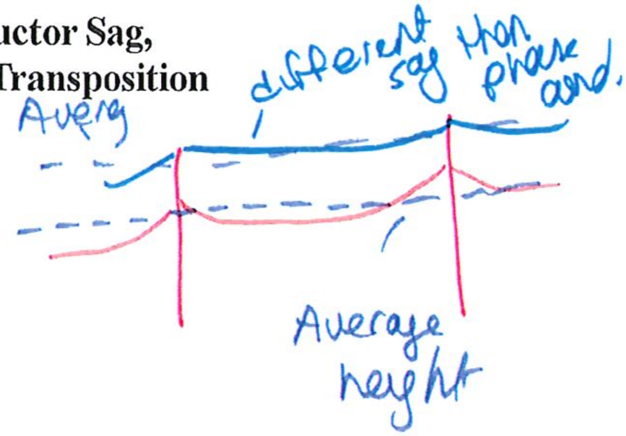
By comparsion:

$$D_m := (D_{ab} \cdot D_{bc} \cdot D_{ac})^{\frac{1}{3}}$$ - geometric mean distance

$$Z_1 := \left(R_{ac} + j \cdot 2 \cdot \pi \cdot freq \cdot \frac{\mu_0}{2 \cdot \pi} \cdot \ln\left(\frac{D_m}{D_s}\right)\right) \cdot 40mi \qquad Z_1 = (11.12 + 32.1661i)\,\Omega$$

$$Z_{012_{1,1}} - Z_1 = 0\,\Omega$$

Representation of Conductor Sag, Rotating and Twisting for Transposition



Conductor Sag

- $Htower := 77ft$
- $Mid := 33ft$ - height at mid span

$sag := Htower - Mid \qquad sag = 44 \cdot ft$

$H_{ave1} := Htower - \frac{2}{3} \cdot sag \qquad H_{ave1} = 47.66667 \cdot ft$

$H_{ave2} := Mid + \frac{1}{3} \cdot sag \qquad H_{ave2} = 47.66667 \cdot ft$

$H_{ave3} := \frac{Htower}{3} + \frac{2}{3} \cdot Mid \qquad H_{ave3} = 47.66667 \cdot ft$

Rotation

$$Z_{123} := \begin{pmatrix} 100 & 12 & 13 \\ 21 & 200 & 23 \\ 31 & 32 & 300 \end{pmatrix} \quad V_{123} := \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}$$

$$R_p := \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

$$\left.\begin{array}{ll} V_{312} := R_p \cdot V_{123} & V_{312} = \begin{pmatrix} 3 \\ 1 \\ 2 \end{pmatrix} \\ V_{231} := R_p^{-1} \cdot V_{123} & V_{231} = \begin{pmatrix} 2 \\ 3 \\ 1 \end{pmatrix} \end{array}\right\}$$

use this on impedance matrix too

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$$R_p \cdot Z_{123} = \begin{pmatrix} 31 & 32 & 300 \\ 100 & 12 & 13 \\ 21 & 200 & 23 \end{pmatrix}$$

premultiply
swaps rows

$$Z_{123} \cdot R_p^{-1} = \begin{pmatrix} 13 & 100 & 12 \\ 23 & 21 & 200 \\ 300 & 31 & 32 \end{pmatrix}$$

pos multiply
swap colums

$$Z_{312} := \underbrace{R_p \cdot Z_{123} \cdot R_p^{-1}}_{\text{swap rows \& colm}} \qquad Z_{312} = \begin{array}{c} \begin{array}{ccc} 3 & 1 & 2 \end{array} \\ \begin{pmatrix} 300 & 31 & 32 \\ 13 & 100 & 12 \\ 23 & 21 & 200 \end{pmatrix} \end{array} \begin{array}{c} 3 \\ 1 \\ 2 \end{array}$$

$$R_p^{-1} \cdot Z_{123} = \begin{pmatrix} 21 & 200 & 23 \\ 31 & 32 & 300 \\ 100 & 12 & 13 \end{pmatrix}$$

$$Z_{123} \cdot R_p = \begin{pmatrix} 12 & 13 & 100 \\ 200 & 23 & 21 \\ 32 & 300 & 31 \end{pmatrix}$$

$$Z_{231} := R_p^{-1} \cdot Z_{123} \cdot R_p \qquad Z_{231} = \begin{array}{c} \begin{array}{ccc} 2 & 3 & 1 \end{array} \\ \begin{pmatrix} 200 & 23 & 21 \\ 32 & 300 & 31 \\ 12 & 13 & 100 \end{pmatrix} \end{array} \begin{array}{c} 2 \\ 3 \\ 1 \end{array}$$

$$f_1 := \frac{1}{3} \qquad f_2 := \frac{1}{3} \qquad f_3 := \frac{1}{3}$$

$f_1 + f_2 + f_3 = 1$

$$Z_{eq} := f_1 \cdot Z_{123} + f_2 \cdot Z_{231} + f_3 \cdot Z_{312} \qquad Z_{eq} = \begin{pmatrix} 200 & 22 & 22 \\ 22 & 200 & 22 \\ 22 & 22 & 200 \end{pmatrix}$$

- Note that it is balanced, the numbers themselves don't have meaning

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- ***Transposition***

$$Rp := \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

Example 1:

$f1 := 0.2 \quad f2 := 0.3 \quad f3 := 0.5$

$$Z_{net} := f1 \cdot Z_{line} + f2 \cdot Rp^{-1} \cdot Z_{line} \cdot Rp + f3 \cdot Rp \cdot Z_{line} \cdot Rp^{-1}$$

$$Z_{net} = \begin{pmatrix} 14.9318 + 58.3742i & 3.8118 + 25.6473i & 3.8118 + 26.6566i \\ 3.8118 + 25.6473i & 14.9318 + 58.3742i & 3.8118 + 26.3202i \\ 3.8118 + 26.6566i & 3.8118 + 26.3202i & 14.9318 + 58.3742i \end{pmatrix} \Omega$$

- off diagonal smaller
- diagonal unchanged (Z_0, Z_1, Z_2)

$$Z_{0121} := A_{012}^{-1} \cdot Z_{net} \cdot A_{012}$$

$$Z_{0121} = \begin{pmatrix} 22.5555 + 110.7903i & -0.2914 - 0.0561i & 0.2914 - 0.0561i \\ 0.2914 - 0.0561i & 11.12 + 32.1661i & 0.5827 + 0.1121i \\ -0.2914 - 0.0561i & -0.5827 + 0.1121i & 11.12 + 32.1661i \end{pmatrix} \Omega$$

Example 2:

$f13 := 0.4 \qquad f23 := 0.6 \qquad f33 := 0.0$

$$Z_{net3} := f13 \cdot Z_{line} + f23 \cdot Rp^{-1} \cdot Z_{line} \cdot Rp + f33 \cdot Rp \cdot Z_{line} \cdot Rp^{-1}$$

$$Z_{net3} = \begin{pmatrix} 14.9318 + 58.3742i & 3.8118 + 27.3295i & 3.8118 + 25.9838i \\ 3.8118 + 27.3295i & 14.9318 + 58.3742i & 3.8118 + 25.3109i \\ 3.8118 + 25.9838i & 3.8118 + 25.3109i & 14.9318 + 58.3742i \end{pmatrix} \Omega$$

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Measure of imbalance

define unit: $mS := \frac{S}{1000}$

Original System

$Y_{012} := Z_{012}^{-1}$

$$Y_{012} = \begin{pmatrix} 1.7687 - 8.6713i & 0.3107 + 0.0104i & -0.1464 - 0.2743i \\ -0.1464 - 0.2743i & 9.7166 - 27.8455i & -1.9327 - 0.2845i \\ 0.3107 + 0.0104i & 0.72 + 1.816i & 9.7166 - 27.8455i \end{pmatrix} \cdot mS$$

First transposed case:

$Y_{0121} := Z_{0121}^{-1}$

$$Y_{0121} = \begin{pmatrix} 1.7647 - 8.6671i & -0.0572 - 0.0523i & 0.0739 + 0.0256i \\ 0.0739 + 0.0256i & 9.6082 - 27.7751i & 0.3356 + 0.3876i \\ -0.0572 - 0.0523i & -0.4562 - 0.2345i & 9.6082 - 27.7751i \end{pmatrix} \cdot mS$$

Second transposed case:

$Y_{0123} := Z_{0123}^{-1}$

$$Y_{0123} = \begin{pmatrix} 1.7655 - 8.668i & 0.0235 + 0.1483i & -0.1436 + 0.0535i \\ -0.1436 + 0.0535i & 9.6322 - 27.7908i & -0.0464 - 1.0228i \\ 0.0235 + 0.1483i & 1.0058 - 0.1965i & 9.6322 - 27.7908i \end{pmatrix} \cdot mS$$

Calculate series Y_{012}
(not same as shunt Y_{012} from capacitance)

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Fully Transposed Case

$$Y_{0126} := Z_{0126}^{-1}$$

$$Y_{0126} = \begin{pmatrix} 1.7645 - 8.6668i & 0 & 0 \\ 0 & 9.6002 - 27.7698i & 0 \\ 0 & 0 & 9.6002 - 27.7698i \end{pmatrix} \cdot \text{mS}$$

Imbalance factors: - pos to zero

$$M_{0\_original} := \frac{Y_{012_{0,1}}}{Y_{012_{1,1}}} \qquad \left|M_{0\_original}\right| = 0.0105$$

- pos

- neg to pos

$$M_{2\_original} := \frac{Y_{012_{2,1}}}{Y_{012_{1,1}}} \qquad \left|M_{2\_original}\right| = 0.0662$$

$$M_{0\_trans1} := \frac{Y_{0121_{0,1}}}{Y_{0121_{1,1}}} \qquad \left|M_{0\_trans1}\right| = 2.6354 \times 10^{-3}$$

$$M_{2\_trans1} := \frac{Y_{0121_{2,1}}}{Y_{0121_{1,1}}} \qquad \left|M_{2\_trans1}\right| = 0.0175$$

$$M_{0\_trans2} := \frac{Y_{0123_{0,1}}}{Y_{0123_{1,1}}} \qquad \left|M_{0\_trans2}\right| = 5.1064 \times 10^{-3}$$

$$M_{2\_trans2} := \frac{Y_{0123_{2,1}}}{Y_{0123_{1,1}}} \qquad \left|M_{2\_trans2}\right| = 0.0348$$

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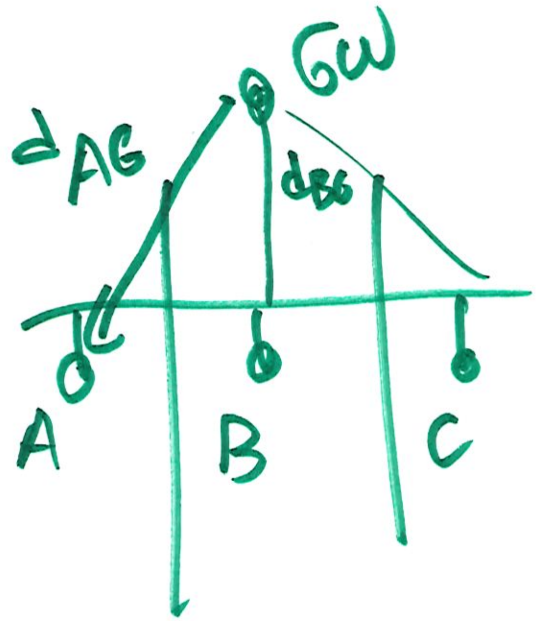
$$M_{0\_trans3} := \frac{Y_{0126_{0,1}}}{Y_{0126_{1,1}}} \qquad \left|M_{0\_trans3}\right| = 0$$

$$M_{2\_trans3} := \frac{Y_{0126_{2,1}}}{Y_{0126_{1,1}}} \qquad \left|M_{2\_trans3}\right| = 0$$



B. Ground Wire Added

-steel

AC Resistance from table (not available in our textbook):

$$R_{gw} := 4.0\,\frac{ohm}{mi} \qquad R_{selfgw} := R_{gw} + R_d$$

ABC

$$R' := \begin{pmatrix} R_{self} & R_d & R_d & R_d \\ R_d & R_{self} & R_d & R_d \\ R_d & R_d & R_{self} & R_d \\ R_d & R_d & R_d & R_{selfgw} \end{pmatrix}$$

GW

$$R' = \begin{pmatrix} 0.3733 & 0.0953 & 0.0953 & 0.0953 \\ 0.0953 & 0.3733 & 0.0953 & 0.0953 \\ 0.0953 & 0.0953 & 0.3733 & 0.0953 \\ 0.0953 & 0.0953 & 0.0953 & 4.0953 \end{pmatrix} \cdot \frac{ohm}{mi}$$

Calculate GMR from conductor diameter

$$\text{dia} := 0.528\text{in} \qquad \text{GMR} := e^{\frac{-1}{4}} \cdot \frac{\text{dia}}{2} \qquad \text{GMR} = 0.01713 \cdot \text{ft}$$

$D_{sgw} := 0.01\text{ft}$ From table (not available in the appendices in Anderson)

$$D_{agw} := \sqrt{(10\text{ft})^2 + (15\text{ft})^2} \qquad D_{cgw} := D_{agw} \qquad D_{bgw} := 15\text{ft}$$

$$L' := \frac{\mu_0}{2\cdot\pi} \cdot \begin{array}{cc} & \begin{array}{cccc} A & B & C & GW \end{array} \\ & \left(\begin{array}{cccc} \ln\left(\frac{D_e}{D_s}\right) & \ln\left(\frac{D_e}{D_{ab}}\right) & \ln\left(\frac{D_e}{D_{ac}}\right) & \ln\left(\frac{D_e}{D_{agw}}\right) \\ \ln\left(\frac{D_e}{D_{ab}}\right) & \ln\left(\frac{D_e}{D_s}\right) & \ln\left(\frac{D_e}{D_{bc}}\right) & \ln\left(\frac{D_e}{D_{bgw}}\right) \\ \ln\left(\frac{D_e}{D_{ac}}\right) & \ln\left(\frac{D_e}{D_{bc}}\right) & \ln\left(\frac{D_e}{D_s}\right) & \ln\left(\frac{D_e}{D_{cgw}}\right) \\ \ln\left(\frac{D_e}{D_{agw}}\right) & \ln\left(\frac{D_e}{D_{bgw}}\right) & \ln\left(\frac{D_e}{D_{cgw}}\right) & \ln\left(\frac{D_e}{D_{sgw}}\right) \end{array}\right) \end{array} \begin{array}{c} A \\ B \\ C \\ GW \end{array}$$

$$L' = \begin{pmatrix} 3.8711 & 1.8123 & 1.5892 & 1.6227 \\ 1.8123 & 3.8711 & 1.8123 & 1.6818 \\ 1.5892 & 1.8123 & 3.8711 & 1.6227 \\ 1.6227 & 1.6818 & 1.6227 & 4.0357 \end{pmatrix} \cdot \frac{\text{mH}}{\text{mi}}$$

$$Z'_{gw} := R' + j \cdot 2 \cdot \pi \cdot \text{freq} \cdot L'$$

$$Z'_{gw} = \begin{pmatrix} 0.373 + 1.459i & 0.095 + 0.683i & 0.095 + 0.599i & 0.095 + 0.612i \\ 0.095 + 0.683i & 0.373 + 1.459i & 0.095 + 0.683i & 0.095 + 0.634i \\ 0.095 + 0.599i & 0.095 + 0.683i & 0.373 + 1.459i & 0.095 + 0.612i \\ 0.095 + 0.612i & 0.095 + 0.634i & 0.095 + 0.612i & 4.095 + 1.521i \end{pmatrix} \cdot \frac{\text{ohm}}{\text{mi}}$$

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$$\underbrace{\begin{bmatrix} V_{AG} \\ V_{BG} \\ V_{CG} \end{bmatrix}}_{V_{ABC}} \quad \begin{bmatrix} \cancel{V_{gwg}}\ 0 \end{bmatrix} = \begin{bmatrix} Z_A^{3\times3} & Z_B^{3\times1} \\ \hline Z_C^{1\times3} & Z_D^{1\times1} \end{bmatrix} \begin{bmatrix} \underbrace{\begin{matrix} I_A \\ I_B \\ I_C \end{matrix}}_{I_{ABC}} \\ \hline I_{GW} \end{bmatrix}$$

$$\underline{V_{ABC}} = [Z_A] \cdot \underline{I_{ABC}} + [Z_B] I_{GW}$$

$$0 = V_{gwg} = [Z_C](\underline{I_{ABC}}) + Z_D I_{GW}$$

$$-[Z_D] I_{GW} = (Z_C) \underline{I_{ABC}}$$

$$I_{GW} = -[Z_D]^{-1}[Z_C] I_{ABC} \rightarrow \text{substitute for } I_{GW}$$

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$$\underline{V}_{ABC} = [Z_A]\,\underline{I}_{ABC} + [Z_B]\left[-[Z_D]^{-1}[Z_C]\right]\underline{I}_{ABC}$$

$$= \underbrace{\left[[Z_A] - [Z_B][Z_D]^{-1}[Z_C]\right]}_{[Z_{ABC_{eq}}]}\underline{I}_{ABC}$$

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If length = 40 miles: $Z_{linegw} := Z'_{gw} \cdot 40mi$

ABC

$$Z_{linegw} = \left(\begin{array}{ccc|c} 14.932 + 58.374i & 3.812 + 27.33i & 3.812 + 23.965i & 3.812 + 24.469i \\ 3.812 + 27.33i & 14.932 + 58.374i & 3.812 + 27.33i & 3.812 + 25.362i \\ 3.812 + 23.965i & 3.812 + 27.33i & 14.932 + 58.374i & 3.812 + 24.469i \\ \hline 3.812 + 24.469i & 3.812 + 25.362i & 3.812 + 24.469i & 163.812 + 60.857i \end{array}\right) \Omega$$

ZA ZB Zc ZD

Kron Reduct.

Reduce to equivalent 3x3 matrix by removing 4th row and column

Row, col

$Z_a := \text{submatrix}(Z_{linegw}, 0, 2, 0, 2)$ $Z_b := \text{submatrix}(Z_{linegw}, 0, 2, 3, 3)$

$Z_c := \text{submatrix}(Z_{linegw}, 3, 3, 0, 2)$ $Z_d := \text{submatrix}(Z_{linegw}, 3, 3, 3, 3)$

$Z_{abceq} := Z_a - Z_b \cdot Z_d^{-1} \cdot Z_c$

$$Z_{abceq} = \begin{pmatrix} 17.6939 + 56.2093i & 6.6842 + 25.1028i & 6.5739 + 21.8003i \\ 6.6842 + 25.1028i & 17.9189 + 56.0842i & 6.6842 + 25.1028i \\ 6.5739 + 21.8003i & 6.6842 + 25.1028i & 17.6939 + 56.2093i \end{pmatrix} \Omega$$

$Z012_{GW} := A_{012}^{-1} Z_{abceq} \cdot A_{012}$

$$Z012_{GW} = \begin{pmatrix} 31.0638 + 104.1716i & 0.8614 - 0.6264i & -0.9731 - 0.4328i \\ -0.9731 - 0.4328i & 11.1214 + 32.1656i & -1.9436 + 1.1205i \\ 0.8614 - 0.6264i & 1.9421 + 1.1229i & 11.1214 + 32.1656i \end{pmatrix} \Omega$$

Small change in Z_ϕ & Z_c

Reduce to 3x3 we only have A, B, C connections at terminals

- GW is grounded every few towers
- continuous GW

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For comparison, without the groundwire: – same as original 3x3 w/o GW

$$Z_{012old} := A_{012}^{-1} \cdot Z_a \cdot A_{012}$$

$$Z_{012old} = \begin{pmatrix} 22.5555 + 110.7903i & 0.9712 - 0.5607i & -0.9712 - 0.5607i \\ -0.9712 - 0.5607i & 11.12 + 32.1661i & -1.9424 + 1.1214i \\ 0.9712 - 0.5607i & 1.9424 + 1.1214i & 11.12 + 32.1661i \end{pmatrix} \Omega$$

As a check:

$$\overrightarrow{\left| Z012_{GW} - Z_{012old} \right|} = \begin{pmatrix} 10.7796 & 0.128 & 0.128 \\ 0.128 & 1.5191 \times 10^{-3} & 1.5191 \times 10^{-3} \\ 0.128 & 1.5191 \times 10^{-3} & 1.5191 \times 10^{-3} \end{pmatrix} \Omega$$

Unbalance Factors:

$$Y012_{GW} := Z012_{GW}^{-1}$$

$$M0_{gw} := \frac{Y012_{GW_{0,1}}}{Y012_{GW_{1,1}}} \qquad \left| M0_{gw} \right| = 0.0104$$

Compare to case without GW:

$$\left| M_{0\_original} \right| = 0.0105 \qquad \text{Small change}$$

$$\left| \frac{\left| M_{0\_original} \right| - \left| M0_{gw} \right|}{\left| M_{0\_original} \right|} \right| = 1.2224 \cdot \%$$

Zero sequence ~~volta~~ imbalance factors changes

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$$M2_{gw} := \frac{Y012_{GW_{2,1}}}{Y012_{GW_{1,1}}} \qquad \left|M2_{gw}\right| = 0.0662$$

neg seq imbalance factor stays same w/ GW

Compare to case without GW:

$$\left|M_{2\_original}\right| = 0.0662 \qquad \text{No change}$$

$$\left|\frac{\left|M_{2\_original}\right| - \left|M2_{gw}\right|}{\left|M_{2\_original}\right|}\right| = 1.4306 \times 10^{-3} \cdot \%$$

C. Example with Two Conductor Bundles (no ground wire). Conductors are 795 kCMIL ACSR, 18 inches apart

AC Resistance from table $\quad Rac_{bund} := 0.117 \frac{ohm}{mi}$ at 25 C and $\quad freq := 60Hz$

$$Rself_{bund} := Rac_{bund} + R_d \qquad Rself_{bund} = 0.2123 \cdot \frac{ohm}{mi}$$

$$R' := \begin{pmatrix} Rself_{bund} & R_d & R_d & R_d & R_d & R_d \\ R_d & Rself_{bund} & R_d & R_d & R_d & R_d \\ R_d & R_d & Rself_{bund} & R_d & R_d & R_d \\ R_d & R_d & R_d & Rself_{bund} & R_d & R_d \\ R_d & R_d & R_d & R_d & Rself_{bund} & R_d \\ R_d & R_d & R_d & R_d & R_d & Rself_{bund} \end{pmatrix}$$