Procedure for Computing Positive/Negative/Zero Sequence Line Constants for Transmission Lines in Air

Prof. Mack Grady, October 27, 2004

POSITIVE/NEGATIVE SEQUENCE CALCULATIONS

Assumptions

Balanced, far from ground, ground wires ignored. Valid for identical single conductors per phase, or for identical symmetric phase bundles with N conductors per phase and bundle radius A.

Computation of positive/negative sequence capacitance

$$C_{+/-} = \frac{2\pi\varepsilon_o}{\ln\dfrac{GMD_{+/-}}{GMR_{C+/-}}} \text{ farads per meter,}$$

where

$$GMD_{+/-} = \sqrt[3]{D_{ab} \bullet D_{ac} \bullet D_{bc}} \text{ meters,}$$

where D_{ab}, D_{ac}, D_{bc} are

- distances between phase conductors if the line has one conductor per phase, or
- distances between phase bundle centers if the line has symmetric phase bundles,

and where

- $GMR_{C+/-}$ is the actual conductor radius r (in meters) if the line has one conductor per phase, or
- $GMR_{C+/-} = \sqrt[N]{N \bullet r \bullet A^{N-1}}$ if the line has symmetric phase bundles.

Computation of positive/negative sequence inductance

$$L_{+/-} = \frac{\mu_o}{2\pi}\ln\frac{GMD_{+/-}}{GMR_{L+/-}} \text{ henrys per meter,}$$

where $GMD_{+/-}$ is the same as for capacitance, and

- for the single conductor case, $GMR_{L+/-}$ is the conductor r_{gmr} (in meters), which takes into account both stranding and the $e^{-1/4}$ adjustment for internal inductance. If r_{gmr} is not given, then assume $r_{gmr} = re^{-1/4}$, and
- for bundled conductors, $GMR_{L+/-} = \sqrt[N]{N \bullet r_{gmr} \bullet A^{N-1}}$ if the line has symmetric phase bundles.

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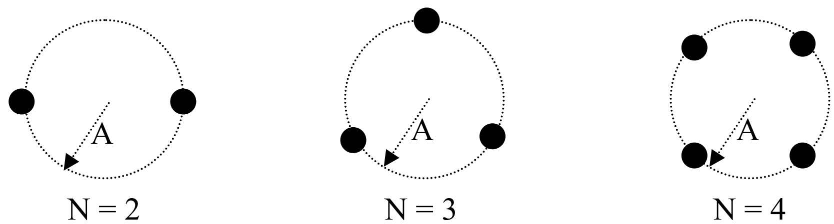
Computation of positive/negative sequence resistance

R is the 60Hz resistance of one conductor if the line has one conductor per phase. If the line has symmetric phase bundles, then divide the one-conductor resistance by N.

Some commonly-used symmetric phase bundle configurations

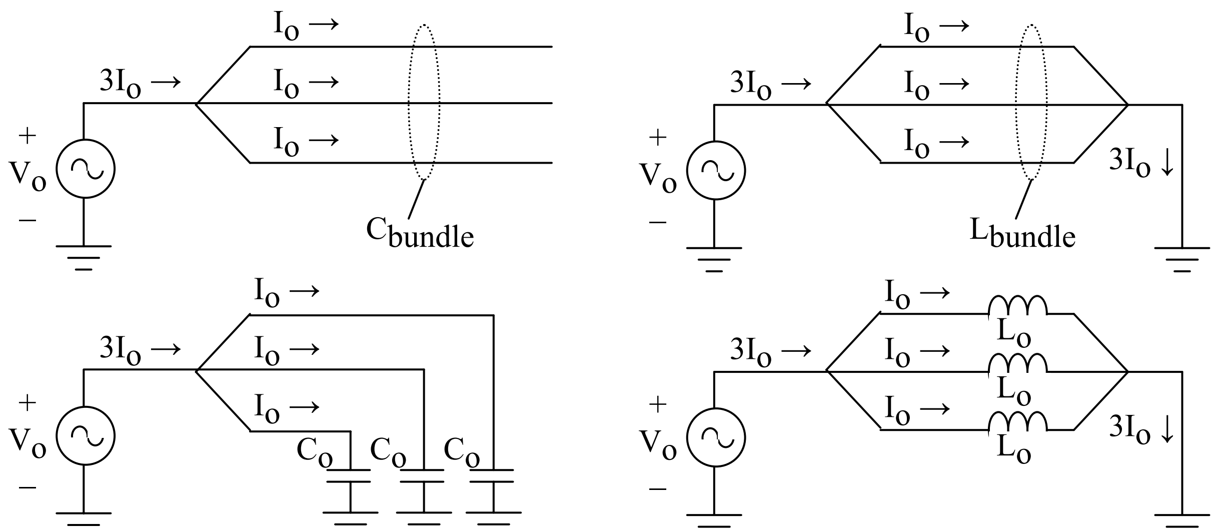


ZERO SEQUENCE CALCULATIONS

Assumptions

Ground wires are ignored. The a-b-c phases are treated as one bundle. If individual phase conductors are bundled, they are treated as single conductors using the bundle radius method. For capacitance, the Earth is treated as a perfect conductor. For inductance and resistance, the Earth is assumed to have uniform resistivity ρ. Conductor sag is taken into consideration, and a good assumption for doing this is to use an average conductor height equal to (1/3 the conductor height above ground at the tower, plus 2/3 the conductor height above ground at the maximum sag point).

The zero sequence excitation mode is shown below, along with an illustration of the relationship between bundle C and L and zero sequence C and L. Since the bundle current is actually $3I_o$, the zero sequence resistance and inductance are three times that of the bundle, and the zero sequence capacitance is one-third that of the bundle.



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Computation of zero sequence capacitance

$$C_0 = \frac{1}{3} \bullet \frac{2\pi\varepsilon_o}{\ln \dfrac{GMD_{C0}}{GMR_{C0}}}$$ farads per meter,

where GMD_{C0} is the average height (with sag factored in) of the a-b-c bundle above perfect Earth. GMD_{C0} is computed using

$$GMD_{C0} = \sqrt[9]{D_{aa^i} \bullet D_{bb^i} \bullet D_{cc^i} \bullet D^2_{ab^i} \bullet D^2_{ac^i} \bullet D^2_{bc^i}}$$ meters,

where D_{aa^i} is the distance from a to a-image, D_{ab^i} is the distance from a to b-image, and so forth. The Earth is assumed to be a perfect conductor, so that the images are the same distance below the Earth as are the conductors above the Earth. Also,

$$GMR_{C0} = \sqrt[9]{GMR^3_{C+/-} \bullet D^2_{ab} \bullet D^2_{ac} \bullet D^2_{bc}}$$ meters,

where $GMR_{C+/-}$, D_{ab}, D_{ac}, and D_{bc} were described previously.

Computation of zero sequence inductance

$$L_0 = 3 \bullet \frac{\mu_o}{2\pi} \ln \frac{D_e}{GMR_{L0}}$$ henrys per meter,

where $D_e = 658.4\sqrt{\dfrac{\rho}{f}}$ meters (see Bergen), ρ is the resistivity of the Earth (a good assumption is 100Ω-m), and f is the frequency (Hz). D_e takes into account the fact that the Earth is resistive and that zero sequence currents flow deep in the Earth. In most cases, D_e is so large that the actual height of the conductors makes no difference in the calculations. For example, for 60Hz and ρ = 100Ω-m, D_e = 850m.

The geometric mean bundle radius is computed using

$$GMR_{L0} = \sqrt[9]{GMR^3_{L+/-} \bullet D^2_{ab} \bullet D^2_{ac} \bullet D^2_{bc}}$$ meters,

where $GMR_{L+/-}$, D_{ab}, D_{ac}, and D_{bc} were shown previously.

Computation of zero sequence resistance

There are two components of zero sequence line resistance. First, the equivalent conductor resistance is the 60Hz resistance of one conductor if the line has one conductor per phase. If the line has symmetric phase bundles with N conductors per bundle, then divide the one-conductor resistance by N.

Second, the effect of resistive Earth is included by adding the following term to the conductor resistance:

$3 \bullet 9.869 \bullet 10^{-7} f$ ohms per meter (see Bergen),

where the multiplier of three is needed to take into account the fact that all three zero sequence currents flow through the Earth.

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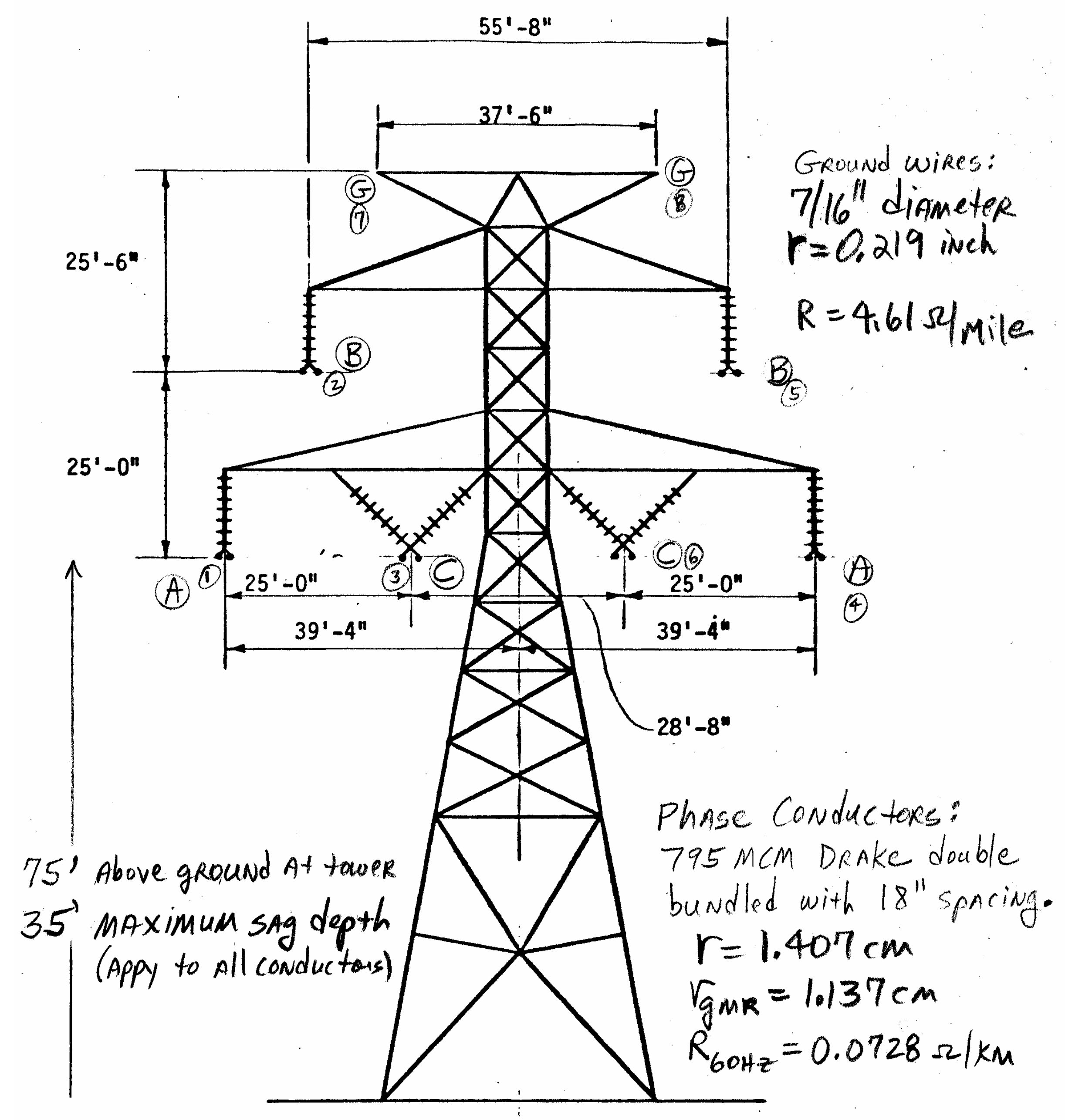
Practice Problem – a 345kV double-circuit configuration that is commonly used in Texas



345 KV CONST.
FIG. 43