

Power Line Systems

IT'S ALL ABOUT YOUR POWER LINES

2019 PLS-CADD Advanced Training and User Group

Circuits and Electrical Calculations

by

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Power Line Systems

POWER LINE[®]
S Y S T E M S

IT'S THE SOLUTION

Introduction

- Circuits
 - Defining Circuits
 - Assigning Circuits
- Full Line Constants Calculator
 - Positive and Zero Sequence Impedance and Susceptance with Mutual Coupling
 - Using Circuits for Focused Analysis and Reporting

Circuits

- Benefits of Circuits
 - Visualization
 - Focused Reporting
 - Document Phasing
 - Electrical Analysis
- Legacy Options
 - Section Notes
 - Section Coloring

Defining Circuit Labels

- Sections/Electric/Define Circuits and Phases/Labels...
 - Project Wide
 - Unlimited Number
 - Unique Labels for Each Circuit
 - Labels for 1, 2, or 3 Phases
 - Color and Line Style per Circuit and per Phase
 - Select Line Style of None to Hide Circuit in All Views

Assigning Circuits

- Sections/Electric/Define Circuits and Phases/Table...
 - Line Specific
 - Tracks Every Phase of Every Section
 - Uses Jumpers If Modeled
 - Linking Sections and Assigning Labels
- Graphical Commands
 - Sections/Electric/Define Circuits and Phases/Graphical
 - Sections/Electric/Set Circuit Label

Linking Sections

- Jumpers
 - Section Links Are Like Virtual Jumpers
 - Modeled Jumpers are Fixed Links
 - Supports Transposition
- Rules
 - Must Have Common Structure, Same # Phases, Same Voltage
 - No Loops, No Branches
 - Same Circuit Label For All Linked Sections

Circuit Visualization

- Display Wire Color and Line Style by Circuit or Phase
- Entity Info in Status Bar
- Wire Text Labeling in Drafting and Profile Views
- Section Labeling in Drafting
- Phase Labeling
- Structure Phase Diagrams
- Can Show/Hide Individual Circuits
- Circuit Labels in Reports

Line Constants Overview

Kron Reduction - remove row/column; used to factor out load wires
Each element left $Z_{pq}^{new} = Z_{pq}^{old} - \frac{Z_{pw} \cdot Z_{wq}}{Z_{ww}}$ when removing row/column w

How to get symmetrical components from Phase Impedance Matrix

$$[Z_{012}] = [A_s]^{-1} \cdot [Z_{abc}] \cdot [A_s] = \begin{bmatrix} Z_{00} & Z_{01} & Z_{02} \\ Z_{10} & Z_{11} & Z_{12} \\ Z_{20} & Z_{21} & Z_{22} \end{bmatrix}$$

Z_{00} = zero sequence impedance
 Z_{11} = positive sequence impedance
 Z_{22} = negative sequence impedance
 Diagonal = self impedances (a_1, a_2, a_3)
 Off-diagonal = mutual impedances (a_{12}, a_{13}, a_{23})

$$[A_s] = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a_j^2 & a_j \\ 1 & a_j & a_j^2 \end{bmatrix} \quad [A_s]^{-1} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a_j^2 & a_j \\ 1 & a_j & a_j^2 \end{bmatrix}$$

$$a_j = 1.0 \angle 120^\circ = -0.5 + 0.866j$$

$$a_j^2 = 1.0 \angle 240^\circ = -0.5 - 0.866j = a_j^* \cdot a_j$$

$$1 = 1.0 \angle 0^\circ = a_j^* \cdot a_j$$

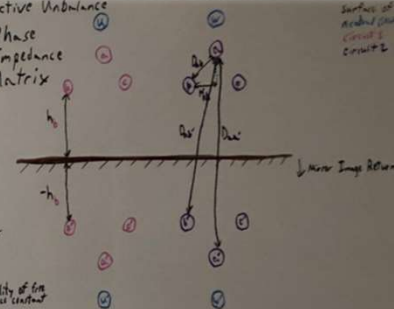
Polar to Rectangular: Real = Mag $\cdot \cos \theta$
Imag = Mag $\cdot \sin \theta$

Phase Quantities Inductive Unbalance

$$\begin{bmatrix} V_1 \\ V_2 \\ V_0 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{10} \\ Z_{21} & Z_{22} & Z_{20} \\ Z_{01} & Z_{02} & Z_{00} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_0 \end{bmatrix}$$

Phase Impedance Matrix

$$[V] = [Z][I]$$



Carson's Equations

$$Z_{mn} = R_m + 4\pi \cdot 10^{-7} f \left(j \ln \left(\frac{D_{mn}}{GMR_m} \right) + 2(P + jQ) \right) \Omega/m$$

permeability of free space μ_0
AC Resistance R_m
frequency f

$$Z_{mn} = 4\pi \cdot 10^{-7} f \left(j \ln \left(\frac{D_{mn}}{GMR_m} \right) + 2(P + jQ) \right) \Omega/m$$

$$P = \frac{\pi}{8} - \frac{1}{2\sqrt{2}} K \cos \theta + \frac{K^2}{16} \cos 2\theta \left(0.6728 \ln \left(\frac{D_{mn}}{GMR_m} \right) \right) + \frac{K^2}{6} \theta \sin 2\theta + \frac{K^2 \cos 2\theta}{15.78} - \frac{\pi K^2 \cos \theta}{15.78}$$

$$Q = -0.0346 + \frac{1}{2} \ln \left(\frac{D_{mn}}{GMR_m} \right) + \frac{1}{2\sqrt{2}} K \cos \theta - \frac{K^2}{16} \cos 2\theta + \frac{K^2 \cos 2\theta}{15.78} - \frac{K^2 \theta \sin 2\theta}{2\sqrt{2}} - \frac{K^2 \cos \theta}{2\sqrt{2}} \left(\ln \frac{2}{\pi} + 1.0215 \right)$$

if $m=n$, $K = 2.81 \cdot 10^{-2} D_{mn} \sqrt{\frac{f}{\rho}}$; $\theta = 0$

if $m \neq n$, $K = 2.81 \cdot 10^{-2} D_{mn} \sqrt{\frac{f}{\rho}}$; $\theta = \arcsin \left(\frac{D_{mn}}{GMR_m} \right)$

$$2\text{-Phase: } [Z_{abc}] = \begin{bmatrix} Z_{aa} & 0 & Z_{ac} \\ 0 & 0 & 0 \\ Z_{ca} & 0 & Z_{cc} \end{bmatrix}$$

$$1\text{-Phase: } [Z_{abc}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & Z_{bb} & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

P = resistivity of earth Ωm

PLS Line Constants History

- Simple Line Constants Calculator in v14.00
 - Positive Sequence Only
- Full Line Constants Calculator in v15.50
 - Positive and Zero Sequence
 - Mutual Coupling per Span in Phase Domain Only
- Update in v15.61 (beta) and v16.00
 - Zero Sequence Mutual Impedance Summary

PLS Advantages

- Ease of Use
 - Automatically Determines Wire Positions and Height
 - Can Calculate Several Circuits at Once
 - Changing Operating and Weather Conditions
- Accuracy
 - Resistance Calculated per Section Using Weather Case
 - Wire Positions Calculated Using Weather Case and Condition
 - Height Calculated Using Ground TIN
 - Several Measurements per Span

Full Line Constants Requirements

- Modeled Line with Circuit Labels Assigned
 - Correct cables, voltage, weather case
 - If bundled conductors, must have total bundle diameter
- Cable Files Updated
 - Must have diameter, AC resistance, GMR
- Ground TIN
 - Must cover entire line being analyzed

Full Line Constants Calculator

- Standard Report
 - Effective Resistance, Radius, and GMR of Every Cable
 - Positive and Zero Sequence Impedance and Susceptance
 - Average Per Distance, Total, and Per-Unit
 - By Span and Summarized by Circuit
- Zero Sequence Mutual Impedance
 - Per Coupled Circuit on Common Spans
 - Results Per Span and Per Overlapping Region

Report Options

- Whole Circuit Matrices
 - Impedance in Phase or Sequence
 - Capacitance/Susceptance in Phase or Sequence
- Span Matrices
 - Combined (with Optional Ground Wires) or Per Circuit
 - Impedance in Phase or Sequence
 - Capacitance/Susceptance in Phase or Sequence
 - Mutual Couple in Phase or Sequence
 - Average Heights and Distances Per Wire

PLS Resources

- Website: www.powerlinesystems.com
- Videos
 - “Defining and Labeling Circuits and Electrical Phasing”
 - “Creating Phasing Diagrams”
- Tech Notes
 - “Defining and Labeling Circuits and Electrical Phasing”
 - “Full Line Constants Feature”

Future Improvements

- Mutual Impedance Across Adjacent Spans
- Improved EMF
- Improved Lightning Protection
- Improved Performance

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Advanced Sag & Tension
NESC
Structural Analysis
Pole Analysis
Transmission
NERC Ratings
Line Optimization
GO95
Company Logo
Contact Information
Drafting
Storm Hardening
Line Ratings
TOWER
IEEE
1000+ Users in 100+ Countries
Vegetation Management
FAC 003
ASCE
Joint Use
PLS-POLE
GO95
CSA
Distribution
LiDAR Modeling
FAC 008/009
CENELEC
Materials Management
IEC
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Questions?

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