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EE374 Term Project Phase 2

Introduction

Transmission lines play a significant role in the modern power grid's ability to move electricity from power plants to customers. For the maintenance of a steady and safe power supply, it is essential to guarantee the effectiveness and dependability of these lines. In this research, we specifically focus on the resistance (R), reactance (X), and susceptance (B) of the overhead line in per-unit amounts to examine the electrical properties of a particular transmission tower. We'll use a two-step method to accomplish this, using Python's processing capabilities to analyze the raw input data and determine the needed values.

In Phase 1, I prepared a Python function to read and preprocess the raw input data provided in a text file, which includes the transmission tower's specifications and a library of ACSR conductors. This function extracts the necessary information about the conductor type, such as outside diameter, AC resistance at 20°C, and GMR, and converts all lengths to SI units. The function takes the input file and library paths in string format as its inputs.

Phase 2 enhances Phase 1 by improving the Python function used to determine the line's electrical properties, such as series resistance & reactance (Ω) and shunt susceptance (℧) while considering the Earth's influence on shunt capacitance calculations. We calculate these amounts per unit using the base values in the raw input text file. Finally, the final values are converted to per-unit versions, as requested in Phase 2.

The Effect of Number of Bundles Per Phase

In power transmission lines, the number of sub-conductors per phase, or bundles, is crucial when determining the Geometric Mean Radius (GMR) and the equivalent resistance (Req) of the bundled conductors. Conductor bundling can increase the transmission line's efficiency by lowering inductive reactance.

The GMR of a single conductor ($GMRs$) and the separation between sub-conductors in the bundle (D or simply bundle distance) must be considered when calculating a bundled conductor's GMR. The GMR of a bundle (GMR_{bundle}) is calculated as follows for 2 bundles per phase:

$$GMR_{bundle\ (2)} = \sqrt{GMR_s \times D}$$

From the lecture notes, we can observe the GMR_{bundle} formulas up to 4 number of bundles per phase.

1 bundle per phase:

$$GMR_{bundle\ (1)} = GMR_s$$

3 bundles per phase:

$$GMR_{bundle\ (3)} = \sqrt[3]{GMR_s \times D^2}$$

4 bundles per phase:

$$GMR_{bundle\ (4)} = 1.09\ \times \sqrt[4]{GMR_s \times D^3}$$

Since we expect up to 8 bundles per phase, we need to determine the formulas for 5-8 bundles per phase. In order to accomplish, we utilized the diagonal values of pentagon, hexagon, heptagon, and octagon to determine the GMR_{bundle}.

The diagonal for pentagon and the $GMR_{bundle(5)}$:

$$Diagonal = \ diag_5 = \frac{D}{2 \times (\sqrt{5} + 1)}$$

$$GMR_{bundle\ (5)} = \sqrt[5]{GMR_s \times \ diag_5^2 \ \times D^2}$$

The diagonals for hexagon and the $GMR_{bundle(6)}$:

$$Small\ Diagonal = \ diag_{s6} = D \times \ \sqrt{3}$$
$$Large\ Diagonal = \ diag_{l6} = 2 \times D$$
$$GMR_{bundle\ (6)} = \sqrt[6]{GMR_s \times \ diag_{s6}^2 \ \times diag_{l6} \times D^2}$$

The diagonals for heptagon and the $GMR_{bundle(7)}$:

$$Small\ Diagonal = \ diag_{s7} = 2 \times \ D \ \times \cos\left(\frac{180}{7}\right)$$
$$Large\ Diagonal = \ diag_{l7} = \frac{D}{2 \times \sin\left(\frac{90}{7}\right)}$$
$$GMR_{bundle\ (7)} = \sqrt[7]{GMR_s \times \ diag_{s7}^2 \ \times diag_{l7}^2 \times D^2}$$

The diagonals for octagon and the $GMR_{bundle(8)}$:

$$Small\ Diagonal = diag_{s8} = D \times \sqrt{2+\sqrt{2}}$$
$$Medium\ Diagonal = diag_{m8} = D \times (1 + \sqrt{2})$$
$$Large\ Diagonal = diag_{l8} = D \times \sqrt{4+2\sqrt{2}}$$
$$GMR_{bundle\ (8)} = \sqrt[8]{GMR_s \times diag_{s8}^2 \times diag_{m8}^2 \times diag_{l8} \times D^2}$$

Similarly, the equivalent resistance ($r_{eq_{bundle}}$) is calculated as follows for 2 bundles per phase. D is bundle distance.

$$r_{eq} = \frac{Diameter}{2}$$
$$r_{eq_{bundle}\ (2)} = \sqrt{r_{eq} \times D}$$

Following the same procedure, we can determine the remaining $r_{eq_{bundle}}$ values:

1 bundle per phase:

$$r_{eq_{bundle}} = r_{eq}$$

3 bundles per phase:

$$r_{eq_{bundle}\ (3)} = \sqrt[3]{r_{eq} \times D^2}$$

4 bundles per phase:

$$r_{eq_{bundle}\ (4)} = 1.09 \times \sqrt[4]{r_{eq} \times D^3}$$

5 bundles per phase (use pentagon diagonal from GMR calculation):

$$r_{eq_{bundle}\ (5)} = \sqrt[5]{r_{eq} \times D^2 \times diag_5^2}$$

6 bundles per phase (use hexagon diagonals from GMR calculation):

$$r_{eq_{bundle}\ (6)} = \sqrt[6]{r_{eq} \times D^2 \times diag_{s6}^2 \times diag_{l6}}$$

7 bundles per phase (use heptagon diagonals from GMR calculation):

$$r_{eq_{bundle}\ (7)} = \sqrt[7]{r_{eq} \times D^2 \times diag_{s7}^2 \times diag_{l7}^2}$$

8 bundles per phase (use octagon diagonals from GMR calculation):

$$r_{eq_{bundle}}(8) = \sqrt[8]{r_{eq} \times D^2 \times diag_{s8}^2 \times diag_{m8}^2 \times diag_{l8}^2}$$

Earth Effect Calculation

The term "earth effect" describes a phenomenon in which a tiny amount of current flows directly to the ground as a result of the capacitance of power transmission cables to the ground. This affects fault currents, causes non-uniform voltage distribution, causes power losses, and poses insulation problems. Shield wires, better insulation, and appropriate grounding methods are mitigation measures. Power transmission that is effective and reliable must be understood and managed.

Shunt capacitance per meter without considering earth effect:

$$C = \frac{2\pi \times 8.854 \times 10^{-12}}{\ln\left(\frac{GMD}{r_{eq_{bundle}}}\right)}$$

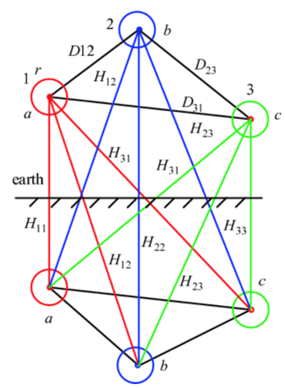

Figure 1. Shows the sample for Earth effect in geometry
Source: https://media.springernature.com/lw685/springer-static/image/chp%3A10.1007%2F978-981-15-3212-2_4/MediaObjects/469422_1_En_4_Fig33_HTML.png

After taking into account of earth effect, new formula becomes:

$$C = \frac{2\pi \times 8.854 \times 10^{-12}}{\ln\left(\frac{GMD}{r_{eq_{bundle}}}\right) - \ln\left(\frac{\sqrt[3]{H_{12} \times H_{13} \times H_{23}}}{\sqrt[3]{H_{11} \times H_{22} \times H_{33}}}\right)}$$

Effect of the Parameters

Parameter	Total Series Resistance	Total Shunt Susceptance	Total Series Reactance
Number of bundles (6->7)	Decrease	Increase	Decrease
Bundle Distance (0.5m -> 2m)	Same	Increase	Decrease
Sbase (100 MVA -> 150 MVA)	Increase	Decrease	Increase
Vbase (154 KV -> 254 KV)	Decrease	Increase	Decrease
Length of line (125 km -> 50 km)	Decrease	Increase	Decrease

The line parameters of transmission lines have a direct effect on the total series resistance, total shunt susceptance, and total series reactance. Changes in parameters result in corresponding changes in the line characteristics. Here is a summary of the effects given in *Table 1*:

Modifying transmission line parameters has a substantial impact on performance. Total series resistance, total shunt susceptance, and total series reactance all drop as the number of bundles increases. Series resistance is not influenced by changing the bundle distance, while shunt susceptibility and series reactance are both increased. Series resistance, shunt susceptance, and series reactance all rise with an increase in base power level. Series resistance, shunt susceptance, and series reactance all drop as base voltage level is raised. Series resistance, shunt susceptance, and series reactance are all reduced as line length is decreased. Optimizing the performance of transmission lines requires a thorough understanding of these interactions.

In summary, this project demonstrates how to use Python to process data inputs and determine electrical characteristics in transmission towers. The created Python function efficiently preprocesses unprocessed data, retrieves pertinent data, and computes resistance, reactance, and susceptance per unit quantities. The report's findings offer insightful information about the variables affecting electrical parameters in transmission lines, serving as a foundation for further investigation and power transmission initiatives for optimization. We can improve the effectiveness and dependability of the electricity grid for the benefit of both the industry and consumers by understanding and examining these characteristics.