Computational Tool for Determining the Model in Sequence Components of Overhead Transmission Lines

Luis Imbachi Guerrero, Fredy Jiménez Rubio, Mario Rodríguez Barrera, Diego Giral Ramírez
Universidad Distrital Francisco José de Caldas. Colombia.
lfimbachig@correo.udistrital.edu.co, fajimenezr@correo.udistrital.edu.co, marodriguezb@udistrital.edu.co, dagiralr@udistrital.edu.co

Abstract. An indispensable element in addressing the current problem of non-ionizing electromagnetic pollution in the environment is a review of the levels of exposure to the electric and magnetic fields produced by the lines of electric power transmission and distribution systems. In order to establish the exposure levels, it is necessary to determine the model of the lines. Considering that a computational simulation is a helpful tool for power system analysis, this article presents a computational tool developed in Matlab App Designer for the model-in-sequence components of the parameters that make up a transmission line. This tool allows the user to work in a friendly and parameterizable environment according to the performed tests. In order to verify the tool’s performance, two case studies are implemented. The first one is for a transposed transmission line and the second one for a non-transposed transmission line. The results obtained are compared with commercial software, acquiring a maximum error of 0.16402 %.

1. Introduction
In order to supply electric power to a given territory, it is necessary to implement an electric power system, which is made up of a generation, transmission, and distribution stage [1]–[3]. A transmission system is mainly formed by overhead lines that transport power to a large part of the territories [4]–[7]. Thus, it is of utmost importance to analyze the electrical parameters and characteristics in the conductors of the lines since these include impedance and admittance parameters, which are essential for load flow analysis, short-circuit studies, coordination of protections, among others [8]–[10].

Based on the above, it is considered essential to determine the model in sequence components of the parameters that make up a transmission line [8], [9]. This article aims to present a computational tool developed in Matlab App Designer for transmission line modeling. The results are compared with the software for the study of power systems NEPLAN.

As there is significant interest in the modeling of transmission lines, computational tools have been developed to facilitate the learning process or accompany it as a working tool [11], [12]. The following are the most relevant documents associated with the development of non-commercial simulation tools.

In [13], the authors present a computer program called CELTIO developed with MATLAB software, which allows simulating the electric field of a transmission line under the finite element method, which is applied to electrostatic problems that allow obtaining the electric field induced under a transmission line.

In [6], the authors relate the methods for the calculation of basic electrical parameters in a transmission line, which are resistance, inductance, and capacitance. The authors of the document developed a computational tool in MATLAB with a graphical interface named CPEL, which is
responsible for guiding the user in the process of determining the values of the electrical parameters of a transmission line. Likewise, the authors reflect in the document explanatory exercises to give an accompaniment to the reader.

This paper is organized and presented in five sections. Section 2 describes the mathematical formulation. Section 3 presents the methodology describing the modules that make up the application. Section 4 analyzes the results obtained for two case studies. Section 5 establishes the general conclusions of the work.

2. Mathematical Formulation

The software developed is focused on the imaging method. This method allows determining the series model and the capacitances per phase; later, by applying the Kron reduction and the similarity transformation, the equivalent in sequence components, and finally, the equivalent circuit is obtained. The following is the mathematical formulation for the modeling of non-transposed transmission lines, a formulation that is easily adaptable to a transposed transmission line.[14]–[16].

2.1. Non-transposed line: Matrix $Z_{abc}$ (Series model per phase)

In a non-transposed transmission line with $n$ guard wires, the self-impedances $Z_{ii}$ are equal; the impedances $Z_{ij}$ are different from each other, their calculation is done by equations (2) and (3), for the remaining positions of the matrix $Z_{abc}$ use is made of equations (4), (5), (6), (7), and (8) as appropriate.

$$
[Z_{abc}] = \begin{bmatrix}
Z_{aa} & Z_{ab} & Z_{ac} & Z_{au} & \cdots \\
Z_{ba} & Z_{bb} & Z_{bc} & Z_{bu} & \cdots \\
Z_{ca} & Z_{cb} & Z_{cc} & Z_{cu} & \cdots \\
Z_{ua} & Z_{ub} & Z_{uc} & Z_{uu} & \cdots \\
& & & & \vdots
\end{bmatrix}
$$

(1)

- $Z_{ii} = \left[ (r_a + r_e) + j0,0754 \cdot \ln \left( \frac{D_{RMG}}{R_{lij}} \right) \right] \Omega/km$ (2)
- $Z_{ij} = \left[ r_e + j0,0754 \cdot \ln \left( \frac{D_{RMG}}{R_{lij}} \right) \right] \Omega/km$ (3)
- $Z_{au} = Z_{ua} = \left[ r_e + j0,0754 \cdot \ln \left( \frac{D_{RMG}}{R_{lij}} \right) \right] \Omega/km$ (4)
- $Z_{bu} = Z_{ub} = \left[ r_e + j0,0754 \cdot \ln \left( \frac{D_{RMG}}{R_{lij}} \right) \right] \Omega/km$ (5)
- $Z_{cu} = Z_{uc} = \left[ r_e + j0,0754 \cdot \ln \left( \frac{D_{RMG}}{R_{lij}} \right) \right] \Omega/km$ (6)
- $Z_{uu} = \left[ (r_u + r_e) + j0,0754 \cdot \ln \left( \frac{D_{RMG}}{R_{lij}} \right) \right] \Omega/km$ (7)
- $Z_{su} = \left[ r_e + j0,0754 \cdot \ln \left( \frac{D_{RMG}}{R_{lij}} \right) \right] \Omega/km$ (8)

Where $D_{lij}$: Distance between phase i and phase j

2.1.1. Kron Reduction Matrix $Z_{abc}$

$$
[Z_{abcRK}] = [Z_1] - [Z_2][Z_4]^{-1}[Z_3]
$$

(9)
Where:

\[
[D_1] = \begin{bmatrix}
Z_s & Z_m & Z_m \\
Z_m & Z_s & Z_m \\
Z_m & Z_m & Z_s
\end{bmatrix} \quad [D_2] = \begin{bmatrix}
Z_{su} & \cdots \\
Z_{su} & \cdots \\
Z_{su} & \cdots
\end{bmatrix} \quad [D_3] = \begin{bmatrix}
Z_{su} & Z_{su} & Z_{su} \\
\vdots & \ddots & \vdots \\
\vdots & \vdots & \vdots
\end{bmatrix} \quad [D_4] = \begin{bmatrix}
\vdots & \ddots & \vdots \\
\vdots & \vdots & \vdots
\end{bmatrix}
\] (10)

2.1.2. Matrix $Z_{012}$ (Serial model in sequence components)

\[
[Z_{012}] = [A]^{-1} \cdot [Z_{abc_{RK}}] \cdot [A]
\]

\[
[Z_{012}] = \begin{bmatrix}
Z_s + 2Z_m & 0 & 0 \\
0 & Z_s - Z_m & 0 \\
0 & 0 & Z_s - Z_m
\end{bmatrix} \begin{bmatrix}
\Omega \\
\text{[km]}
\end{bmatrix}
\]

2.2. Matrix $C_{abc}$ (Matrix of capacitances per phase)

In a transposed transmission line with n guard wires, the maxwell coefficients $P_i$ are equal; and the maxwell coefficients $P_j$ are different from each other, their calculation is performed through Equations (13) and (14), for the remaining positions of the matrix $P_{abc}$ we make use of equations (15), (16), (17), (18) as appropriate.

\[
[P_{abc}] = \begin{bmatrix}
P_{aa} & P_{ab} & P_{ac} & P_{au} & \cdots \\
P_{ba} & P_{bb} & P_{bc} & P_{bu} & \cdots \\
P_{ca} & P_{cb} & P_{cc} & P_{cu} & \cdots \\
P_{ua} & P_{ub} & P_{uc} & P_{uu} & \cdots
\end{bmatrix}
\]

(12)

\[
P_i = \frac{1}{2\pi\varepsilon_0} \ln \left(\frac{h_i}{\text{RMG}_i}\right) \left[\text{mF}\right]
\]

(13)

\[
P_j = \frac{1}{2\pi\varepsilon_0} \ln \left(\frac{l_j}{D_{ij}}\right) \left[\text{mF}\right]
\]

(14)

\[
P_{uu} = \frac{1}{2\pi\varepsilon_0} \ln \left(\frac{h_u}{\text{RMG}_u}\right) \left[\text{mF}\right]
\]

(15)

\[
P_{ua} = P_{au} = \frac{1}{2\pi\varepsilon_0} \ln \left(\frac{l_{ua}}{D_{ua}}\right) \left[\text{mF}\right]
\]

(16)

\[
P_{ub} = P_{bu} = \frac{1}{2\pi\varepsilon_0} \ln \left(\frac{l_{ub}}{D_{ub}}\right) \left[\text{mF}\right]
\]

(17)

\[
P_{uc} = P_{cu} = \frac{1}{2\pi\varepsilon_0} \ln \left(\frac{l_{uc}}{D_{uc}}\right) \left[\text{mF}\right]
\]

(18)

Where:

$l_{ua}$: Distance between the phases and the guard wire image.

$h_u$: Distance between guard wires and their image.

$h$: Distance between the phase and its image.

$l$: Distance between the phase and the image of the other phases.

$h_{uk}$: Distance between the phase and the image of the guard wire.

$D_{lu}$: Distance between the phase and the guard wire.

$l_{lu}$: Distance between the phase and the image of the guard wire.
2.2.1. *Kron Reduction Matrix* $P_{abc}$

$$[P_{abc}] = [P_1] - [P_2][P_4]^{-1}[P_3]$$ \hspace{1cm} (19)

Where:

$$[P_1] = \begin{bmatrix} P_s & P_m & P_m \\ P_m & P_s & P_m \\ P_m & P_m & P_s \end{bmatrix} \quad [P_2] = \begin{bmatrix} P_{mu} \cdots \\ P_{mu} \cdots \\ P_{mu} \cdots \end{bmatrix} \quad [P_3] = \begin{bmatrix} P_{um} & P_{um} & P_{um} \\ P_{um} & P_{um} & P_{um} \end{bmatrix} \quad [P_4] = \begin{bmatrix} P_{su} \cdots \\ P_{su} \cdots \end{bmatrix}$$ \hspace{1cm} (20)

2.2.2. *Matrix $C_{abc}$ (Matrix of capacitances per phase)*

$$[C_{abc}] = [P_{abc}]^{-1}$$ \hspace{1cm} (21)

2.2.3. *Matrix $C_{012}$ (Matrix of capacitances in sequence components)*

$$[C_{012}] = [A]^{-1} \cdot [C_{abc}] \cdot [A]$$

$$[C_{012}] = \begin{bmatrix} C_0 & 0 & 0 \\ 0 & C_1 & 0 \\ 0 & 0 & C_2 \end{bmatrix} \begin{bmatrix} \Omega \\ \text{[km]} \end{bmatrix}$$ \hspace{1cm} (22)

**Remark:** In order to determine the model of sequence components in transposed lines, there are two alternatives. The first uses the same formulas, as for a non-transposed line, with the difference that for a transposed line the $D_{ii}$, $h_{ij}$ and $l_{ij}$ are changed by equivalent average distances. And the second way is to determine the average of the diagonal and off-diagonal elements as shown in equations (23) and (24).

$$[Z_{abc}]_{\text{Transposed}} = \begin{bmatrix} \frac{Z_{aa} + Z_{bb} + Z_{cc}}{3} & \frac{Z_{ab} + Z_{ca} + Z_{bc}}{3} & \frac{Z_{ab} + Z_{ca} + Z_{bc}}{3} \\ \frac{Z_{ab} + Z_{ca} + Z_{bc}}{3} & \frac{Z_{aa} + Z_{bb} + Z_{cc}}{3} & \frac{Z_{ab} + Z_{ca} + Z_{bc}}{3} \\ \frac{Z_{ab} + Z_{ca} + Z_{bc}}{3} & \frac{Z_{ab} + Z_{ca} + Z_{bc}}{3} & \frac{Z_{aa} + Z_{bb} + Z_{cc}}{3} \end{bmatrix}$$ \hspace{1cm} (23)

$$[P_{abc}]_{\text{Transposed}} = \begin{bmatrix} \frac{P_{aa} + P_{bb} + P_{cc}}{3} & \frac{P_{ab} + P_{ca} + P_{bc}}{3} & \frac{P_{ab} + P_{ca} + P_{bc}}{3} \\ \frac{P_{ab} + P_{ca} + P_{bc}}{3} & \frac{P_{aa} + P_{bb} + P_{cc}}{3} & \frac{P_{ab} + P_{ca} + P_{bc}}{3} \\ \frac{P_{ab} + P_{ca} + P_{bc}}{3} & \frac{P_{ab} + P_{ca} + P_{bc}}{3} & \frac{P_{aa} + P_{bb} + P_{cc}}{3} \end{bmatrix}$$ \hspace{1cm} (24)

**Remark:** To determine $Z_{abcRk}$, $Z_{012}$, $C_{abc}$ and $C_{012}$ the same procedure is followed for a non-transposed line.

3. **Methodology**

The methodology used for the development of the tool is presented below. The first part describes the algorithms used for the operation process, and the second part describes the module structure used.
3.1. Operation process
The computational tool developed in Matlab App Designer allows the user to progressively advance in the configuration of the problem to be solved. This process is described below, using the flowchart shown in Figures 1, 2, and 3.

Figure 1 shows five operation blocks that represent the panels that the user must configure in the computational tool according to the information contained in the problem to be solved.

![Flow chart for the characteristics of the line model](image)

Figure 1. Flow chart for the characteristics of the line model

Figure 2 shows the mathematical process followed by the computational tool to determine the model in sequence components of a transposed transmission line. Additionally, a decision block can be observed that will allow showing in a later section the mathematical process followed by the computational tool to determine the model in sequence components of a non-transposed transmission line. It is relevant to note that once the program has calculated the model of the line, it can export the results in .xlsx or .txt files and to visualize the equivalent circuit for zero, positive and negative sequences.

Figure 3 reference source not found shows the mathematical process followed by the computational tool to determine the model in sequence components of a non-transposed transmission line, and for a transposed line, the tool allows exporting the results in .xlsx or txt format files and visualizing the equivalent circuit for zero, positive and negative sequences.
Figure 2. Flow chart for the transposed transmission lines model

Calculation of $[C_{abc}]$

$$[C_{abc}] = \text{inv}([A]) [C_{abc}] [A]$$

Calculation of $[Z_{012}]$

$$[Z_{012}] = \text{inv}([A]) [Z_{abc}] [A]$$

Export Results

Information: *xlsx, *.txt

Figure 3. Flow chart for the non-transposed transmission lines model

Calculation of $[C_{abc}]$

$$[C_{abc}] = \text{inv}([A]) [C_{abc}] [A]$$

Calculation of $[Z_{abc}]$

$$[Z_{abc}] = \text{inv}([A]) [Z_{abc}] [A]$$

Export Results

Information: *xlsx, *.txt
3.2. Modular structure
The computational tool was developed in MATLAB R2020b App Designer. It consists of two modules that allow parameterizing the input variables and obtaining the model in sequence components, for transposed and non-transposed transmission lines.

3.2.1. Module 1: Transmission Line Characteristics and Geometry
This module is presented as the first graphical window that the user will see when running the computational tool. In this space, the user must configure the operating frequency and the characteristics of the line (length, sag, number of conductors per beam, and distance between the conductors of the beam). Subsequently, the user will have to configure the parameters of the phase and guard conductors, if the effect of the latter is considered, for this the user will have the possibility to choose between entering the information related to (RMG and Electrical Resistance at 75°C) or choosing a conductor from the manufacturer's library available in the tool. Finally, the user will have to configure the line geometry according to the adopted reference frame. Figure 4 shows the block diagram of the Transmission Line Characteristics and Geometry module.

This module is presented as the second graphical window that the user will see when running the computational tool. In this space, the type of line (transposed or not transposed) and the soil resistivity must be configured, for the latter the user will have the possibility to choose between the different types of soil available in the tool or to configure the value directly. Finally, the user will be able to choose the units in which wants the results to be presented, and clicking on the calculate button will show the results for $Z_{abc}$, $C_{abc}$, $Z_{012}$, $C_{012}$ and the equivalent circuit for the zero, positive and negative sequences. Additionally, the panel to export the data in .xlsx or .txt formats will be activated. Figure 5 shows the block diagram of the Results module.

Figure 4. Structure of module 1 Characteristics and geometry of the transmission line.

Figure 5. Structure of module 2 Results
4. Results
This section aims to evaluate the accuracy of the computational tool developed in Matlab App Designer. Therefore, two case studies are presented, and through a comparative analysis with the NEPLAN tool, the accuracy of the developed application is evaluated.

4.1. Graphic interface
Figure 6 shows the graphical interface of the computational tool developed in Matlab App Designer for a particular case study where the different graphical windows that the user will have to configure to obtain the model in sequence components of the transmission line of interest can be observed.

4.2. Case studies
Two case studies are presented below; the first one corresponds to the model of a transposed transmission line, and the second one to a non-transposed line.

4.2.1. Case 1: Transposed transmission line
There is a transmission line with the configuration shown in Figure 2, which operates at a frequency of 60 [Hz]. The line is composed of 3 bundle conductors and two guard conductors. Table 1 shows the characteristics of the phase conductors, and Table 2 shows the guard conductors’ characteristics. For this exercise, the length will be 1 [km] and the average resistivity 100 [Ω-m], which corresponds to a ground with a wet soil type (medium soil).

Figure 7. Transmission Line Case Study 1 (3 Conductor per bundle configuration)
Table 1. Characteristics of phase conductors (Case study 1)

| Phase Conductors | Cable Type | Code | AWG / kcmil | RMG [mm] | Electrical Resistance 75°C [Ω/km] |
|------------------|------------|------|-------------|----------|-----------------------------------|
| ACSR (6/1) Sparrow | 2 | 2,58 | 1,10 |

Table 2. Characteristics of guard conductors (Case study 1)

| Guard Conductors | Cable Type | Code | AWG / kcmil | RMG [mm] | Electrical Resistance 75°C [Ω/km] |
|------------------|------------|------|-------------|----------|-----------------------------------|
| AAC (7) Aster | 2/0 | 3,81 | 0,521 |

Using the computational tool developed in Matlab App Designer, the sequence component model and the equivalent circuit for the transmission line shown in Figure X are determined. The results obtained by the computational tool are compared with the results provided by NEPLAN.

- Sequence Component Matrix $Z_{012}$ (NEPLAN)
  \[
  Z_{012} = \begin{bmatrix}
  0,59847 + j0,88511 & 0 & 0 \\
  0 & 0,36667 + j0,35418 & 0 \\
  0 & 0 & 0,36667 + j0,35418 \\
  \end{bmatrix} \text{[} \frac{\Omega}{\text{km}} \text{]} \quad (25)
  
- Matrix of sequence components $Z_{012}$ (MATLAB Computational Tool)
  \[
  Z_{012} = \begin{bmatrix}
  0,59847 + j0,88511 & 0 & 0 \\
  0 & 0,36667 + j0,35418 & 0 \\
  0 & 0 & 0,36667 + j0,35418 \\
  \end{bmatrix} \text{[} \frac{\Omega}{\text{km}} \text{]} \quad (26)
  
- Capacitance matrix in sequence components $C_{012}$ (NEPLAN)
  \[
  C_{012} = \begin{bmatrix}
  7,49870 & 0 & 0 \\
  0 & 11,96924 & 0 \\
  0 & 0 & 11,96924 \\
  \end{bmatrix} \text{[} \frac{nF}{\text{km}} \text{]} \quad (27)
  
- Capacitance matrix in sequence components $C_{012}$ (MATLAB Computational Tool)
  \[
  C_{012} = \begin{bmatrix}
  7,511 & 0 & 0 \\
  0 & 11,9611 & 0 \\
  0 & 0 & 11,9611 \\
  \end{bmatrix} \text{[} \frac{nF}{\text{km}} \text{]} \quad (28)
  
Table 3 shows the calculation of the percentage errors calculated for $Z_{012}$ and $C_{012}$

Table 3. Calculation of percentage errors of Z012 and C012 (Case of study 1)

|                | NEPLAN            | MATLAB Computational Tool | Error (%) |
|----------------|-------------------|---------------------------|-----------|
| $Z_0$          | $0,59847 + j0,88511$ | $0,59847 + j0,88511$     | 0         |
| $Z_1$          | $0,36667 + j0,35418$ | $0,36667 + j0,35418$     | 0         |
| $Z_2$          | $0,36667 + j0,35418$ | $0,36667 + j0,35418$     | 0         |
| $C_0$          | 7,49870           | 7,511                     | 0,16402   |
| $C_1$          | 11,96924          | 11,9611                   | 0,06800   |
Figures 8, 9, and 10 display the equivalent circuit for the zero, positive, and negative sequences provided by the computational tool developed in Matlab App Designer.

| NEPLAN     | MATLAB Computational Tool | Error (%) |
|------------|---------------------------|-----------|
| $C_2$      | 11,96924                  | 11,9611   | $0.06800$ |

4.2.2. Case 2: Non-transposed transmission line
There is a transmission line with the configuration shown in Figure 11, which operates at a frequency of 60 [Hz]. Table 4 shows the characteristics of the phase conductors. For this exercise, the length will be 1[km] and the average resistivity 100[Ω-m], which corresponds to a ground with a wet soil type (medium soil).
Figure 11. Transmission line case study 2

Table 4. Characteristics of phase conductors (Case Study 2)

| Phase Conductors | Cable Type | Code | AWG / kcmil | RMG [mm] | Electrical Resistance 75°C [Ω/km] |
|------------------|------------|------|-------------|----------|-----------------------------------|
| ACSR (30/7)      | Eagle      | 556,5| 10,00       | 0,121    |

Using the computational tool developed in Matlab App Designer, the sequence component model and the equivalent circuit for the transmission line shown in Figure 11 is determined. The results obtained by the computational tool are compared with the results provided by NEPLAN.

- Sequence Component Matrix $Z_{012}$ (NEPLAN 5.3.3)

\[
Z_{012} = \begin{bmatrix}
0.29865 + j1.73358 & 0.01509 - j0.00871 & -0.01509 - j0.00871 \\
-0.01509 - j0.00871 & 0.12100 + j0.41690 & -0.03017 + j0.01742 \\
0.01509 - j0.00871 & 0.03017 + j0.01742 & 0.12100 + j0.41690
\end{bmatrix} \text{ [Ω/km]}
\]  

(29)

- Matrix of sequence components $Z_{012}$ (MATLAB Computational Tool)

\[
Z_{012} = \begin{bmatrix}
0.29865 + j1.7336 & 0.015087 - j0.0087103 & -0.015087 - j0.0087103 \\
-0.015087 - j0.0087103 & 0.121 + j0.4169 & -0.030174 + j0.017421 \\
0.015087 - j0.0087103 & 0.030174 + j0.017421 & 0.121 + j0.4169
\end{bmatrix} \text{ [Ω/km]}
\]  

(30)

- Capacitance matrix in sequence components $C_{012}$ (NEPLAN 5.3.3)

\[
C_{012} = \begin{bmatrix}
6,35959 & 0,60830 & 0,60830 \\
0,60830 & 10,31692 & -0,27508 \\
0,60830 & -0,27508 & 10,31692
\end{bmatrix} \text{ [nF/km]}
\]  

(31)

- Capacitance matrix in sequence components $C_{012}$ (MATLAB Computational Tool)

\[
C_{012} = \begin{bmatrix}
6,3553 & 0,60789 & 0,60789 \\
0,60789 & 10,3099 & -0,2749 \\
0,60789 & -0,2749 & 10,3099
\end{bmatrix} \text{ [nF/km]}
\]  

(32)
Table 5 shows the calculation of the percentage errors calculated for \( Z_{012} \) and \( C_{012} \)

|       | NEPLAN             | MATLAB Computational Tool | Error (%) |
|-------|--------------------|----------------------------|-----------|
| \( Z_0 \) | 0,29865 + j1,73358 | 0,29865 + j1,7336          | 0         |
| \( Z_1 \) | 0,12100 + j0,41690 | 0,121 + j0,4169             | 0         |
| \( Z_2 \) | 0,12100 + j0,41690 | 0,121 + j0,4169             | 0         |
| \( C_0 \) | 6,35959           | 6,3553                      | 0,06745   |
| \( C_1 \) | 10,31692          | 10,3099                     | 0,06804   |
| \( C_2 \) | 10,31692          | 10,3099                     | 0,06804   |

It is important to note that in order to construct the equivalent in sequence components and the respective equivalent circuit, for a non-transposed line, the effect of the off-diagonal positions is ignored, and only the power of the diagonal positions is considered as in the transposed line.

Figures 12, 13, and 14 show the equivalent circuit for the zero, positive, and negative sequences provided by the computational tool developed in Matlab App Designer.

![Figure 12](image12.png)

**Figure 12. Equivalent Circuit (Zero Sequence) Case Study 2**

![Figure 13](image13.png)

**Figure 13. Equivalent Circuit (Positive Sequence) Case Study 2**

![Figure 14](image14.png)

**Figure 14. Equivalent Circuit (Negative Sequence) Case Study 2**
5. Conclusions

In order to obtain the models in sequence components of the two case studies, computational tools such as Matlab and NEPLAN were used. The obtained results present practically negligible variations if it is considered approximations to 5 or 6 decimal places in calculations such as the serial model of the line. But the capacitance calculations present somewhat more significant variations. However, the data is closed between one software and the other.

The computational tool developed in Matlab allows obtaining the matrices in sequence components and the equivalent circuit for any transmission line regardless of its geometry, as long as it has a maximum of 2 guard wires. It also allows exporting the data obtained in Excel or TXT formats, which differs from some tools for power system analysis such as NEPLAN.

References

[1] Lv J. Transient stability assessment in large-scale power systems using sparse logistic classifiers. Int J Electr Power Energy Syst [Internet]. 2022;136:107626. Available from: https://www.sciencedirect.com/science/article/pii/S0142061521008589

[2] Li J, Yu T, Zhang X. Coordinated automatic generation control of interconnected power system with imitation guided exploration multi-agent deep reinforcement learning. Int J Electr Power Energy Syst [Internet]. 2022;136:107471. Available from: https://www.sciencedirect.com/science/article/pii/S0142061521007109

[3] Moradi R-A, Zeinali Davarani R. Introducing a new index to investigate voltage stability of power systems under actual operating conditions. Int J Electr Power Energy Syst [Internet]. 2022;136:107637. Available from: https://www.sciencedirect.com/science/article/pii/S0142061521008693

[4] Stracqualursi E, Araneo R, Faria JB, Andreotti A. Protection of distribution overhead power lines against direct lightning strokes by means of underbuilt ground wires. Electr Power Syst Res [Internet]. 2022;202:107571. Available from: https://www.sciencedirect.com/science/article/pii/S0378779621005526

[5] Kurokawa S, Daltin RS, Prado AJ, Pissolato J. An alternative modal representation of a symmetrical nontransposed three-phase transmission line. IEEE Trans Power Syst. 2007;22(1):500–1.

[6] Calderon EY, Quiroga DE. Cálculo de parámetros en líneas de transmisión de energía eléctrica aéreas en corriente alterna. Universidad Industrial de Santander; 2017.

[7] Mustafa T, Cabral SHL, Almaguer HAD, Meyer LH, Puchale LHB, Cereja JE, et al. A practical application of an analytical method for modeling power transmission lines. In: 2017 International Symposium on Electromagnetic Compatibility-EMC EUROPE. IEEE; 2017. p. 1–4.

[8] Gaur VK, Bhalja BR, Saber A. New ground fault location method for three-terminal transmission line using unsynchronized current measurements. Int J Electr Power Energy Syst [Internet]. 2022;135:107513. Available from: https://www.sciencedirect.com/science/article/pii/S0142061521007523

[9] Liu Y, Wang B, Zheng X, Lu D, Fu M, Tai N. Fault location algorithm for non-homogeneous transmission lines considering line asymmetry. IEEE Trans Power Deliv. 2020;35(5):2425–37.

[10] Niu G, Xiao T, Pei W, Zhu M, Yan Z, Zhou L, et al. Fault analysis of power transmission line in a generalized state-space model perspective. In: IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics Society. IEEE; 2017. p. 239–43.

[11] Henke HTJ, Gardumi F, Howells M. The open source electricity Model Base for Europe - An engagement framework for open and transparent European energy modelling. Energy [Internet]. 2022;239:121973. Available from: https://www.sciencedirect.com/science/article/pii/S0360544221022210

[12] Andreev M, Suvorov A, Askarov A, Rudnik V, Bhalja BR. Novel approach for relays tuning using detailed mathematical model of electric power system. Int J Electr Power Energy Syst [Internet]. 2022;135:107572. Available from: https://www.sciencedirect.com/science/article/pii/S0142061521008061
[13] Correa J, Chacon J. Campo eléctrico inducido en objetos cercanos a una línea de transmisión de alta tensión. Universidad Industrial de Santander; 2017.

[14] Bayliss CR, Bayliss C, Hardy B. Transmission and distribution electrical engineering. Elsevier; 2012.

[15] Gonen T. Modern power system analysis. CRC Press; 2013.

[16] Das JC. Understanding symmetrical components for power system modeling. John Wiley & Sons; 2016.