BALKAN JOURNAL OF ELECTRICAL & COMPUTER ENGINEERING, Vol. 13, No. 3, September 2025
Research Article

Lumped-Parameter Transmission Line Modeling Using MATLAB/Simulink

Ilker Ari, Ramazan Menak

Abstract—**Accurate modeling of transmission lines is fundamental for predicting their dynamic behavior under various operating and fault conditions. This study presents a comprehensive investigation into the transient performance of a single-phase lumped-parameter transmission line using MATLAB/Simulink. The research investigates the impact of section number (N) in π-section representations on waveform fidelity and propagation characteristics. A systematic simulation framework was developed to analyze voltage and current waveforms at both sending and receiving ends, capturing key phenomena such as energization-induced oscillations, propagation delays, and the progression toward steady-state conditions. Unlike conventional tools such as ATP-EMTP, the proposed modeling approach enables flexible parameter adjustment without manual reconstruction of circuit topology, offering significant advantages in scalability and computational efficiency. The results provide deeper insight into the relationship between model segmentation and transient accuracy, offering practical guidance for both academic studies and engineering applications in power system design, stability assessment, and protection scheme development.**

Index Terms— **Analysis, Modeling, Simulink, Transients, Transmission line.**

I. INTRODUCTION

ELECTRICAL energy is recognized as a strategic resource that forms the backbone of modern societies' technological, economic, and social infrastructures. In particular, the sustainability of industrial production, transportation systems, information and communication technologies, and daily residential activities is directly dependent on the continuous and high-quality supply of electrical power. Therefore, ensuring the delivery of electrical energy in accordance with the principles of reliability, efficiency, and continuity is of critical importance for both individual consumers and national economies. Contemporary energy systems are complex and expansive structures composed of numerous components that span wide geographic areas from generation points to end-users. These systems require the integrated management of not only electrical quantities but also economic, environmental, and operational parameters. The increasing demand for energy, the integration of renewable resources, and the advancement of smart grid technologies further necessitate the operation of energy infrastructures in a more flexible, observable, and stable manner. In this context, the stages of generation, transmission, and distribution of electrical energy must be approached as interconnected and complementary processes. Enhancing the overall security and performance of the power system can only be achieved through the holistic modeling, monitoring, and optimization of these stages. Analytical, modeling, and optimization studies conducted within the various subfields of electrical engineering play a crucial role in improving system efficiency and ensuring the long-term sustainability of electrical networks.

Transmission lines are essential infrastructure components that enable the reliable and efficient transfer of electrical energy over long distances from generation sources to consumption centers at high voltage levels. The planning and operation of these lines are inherently dependent on numerous engineering parameters that directly influence the overall performance of power systems. To ensure effective energy transmission, factors such as system voltage level, total line length, conductor type and size, reactive power compensation strategies, and system stability must be carefully considered. A holistic evaluation of these variables is crucial for maintaining sustainable and optimal operating conditions. Steady-state analyses are commonly employed in power system studies to assess whether the system can operate under stable and balanced conditions for a given loading scenario. These analyses typically involve the evaluation of voltage profiles, active and reactive power flows, voltage drops, and transmission losses, offering critical insights into the system's operational performance. While steady-state analysis plays a significant role in long-term planning, operational strategy, and power quality assurance, relying solely on these conditions is insufficient for comprehensive system evaluation. In practice, power systems are frequently exposed to transient phenomena induced by external or internal disturbances, such as lightning strikes, short circuits, sudden load variations, and switching operations. These events result in abrupt changes in system behavior, leading to high-magnitude voltage and current surges over very short time intervals. Such conditions can impose significant electrical and

Ilker Ari, is with Department of Motor Vehicles and Transportation Technologies, Siirt University, Türkiye, (e-mail: ilker.ari@siirt.edu.tr).
https://orcid.org/0000-0002-1171-5533
Ramazan Menak, is with Department of Electrical Electronics Engineering, Siirt University, Türkiye, (e-mail: ramazanmenak@siirt.edu.tr).
https://orcid.org/0000-0003-3223-4808
Manuscript received Aug 09, 2025; accepted Sep 09, 2025.
DOI: 10.17694/bajece.1761735

mechanical stresses on system components, potentially threatening system reliability. Therefore, in addition to steady-state performance assessment, the transient behavior of transmission lines must be thoroughly analyzed to ensure the overall integrity and resilience of the electrical grid. In transient regime analyses of transmission lines, modeling the transmission lines is a critical step. The models used to accurately represent transmission lines vary depending on the frequency ranges they focus on and the accuracy of the analysis.

The analysis of transient regimes occurring in transmission lines is carried out in both the time and frequency domains in order to accurately reveal the dynamic responses of the system. Time domain analyses allow for the observation of the direct time-dependent effects of transient events, while frequency domain approaches are important for examining the system's responses to its frequency components. Frequency domain methods are particularly effective in determining frequency-dependent parameters, and calculations performed in this domain are often converted back to the time domain using inverse Fourier or inverse Laplace transforms. This enables the analysis of time-sensitive effects such as sudden voltage changes, reflections, and refractions in transmission lines with high accuracy through frequency-based modeling. The complementary use of these two fields enables a more robust interpretation of transient regimes, both physically and mathematically. It is also important to model the transmission line correctly in order to perform transient regime analyses. In this context, transmission lines are modeled as lumped or distributed parameters.

In [1], both lumped parameter line and distributed parameter line models were used to model the transmission line. The state-space method was used to model the lumped parameter line, while the inverse Laplace transform was used to model the distributed parameter line. In [2], a lumped parameter transmission line was modeled using the state-space method. Inductor currents and capacitor voltages were selected as state variables. The modeling was performed by adding corona loss to the line used in the study. In [3], a modified lumped parameter line model was used for transient regime analysis. In the study, a damping resistance was added to the traditional lumped parameter model to reduce numerical oscillations. The damping resistance was connected in series to the shunt capacitor in the π-segment. In [4], a study was conducted to include the frequency dependence of longitudinal parameters in the lumped parameter line model. The state-space method was used to calculate the voltage and current values of the line consisting of cascaded π circuits. EMTP was used to verify the model and method used in the study, and the results were found to be consistent with each other. In [5], transient regime analysis of non-uniform single-phase bulk parameter lines was performed using the state variable method. The state equations were obtained as a linear set of first-order differential equations and solved using MATLAB to obtain the transient response in the time domain. The results of the proposed method were validated using s-domain simulations of the distributed parameter transmission line and results obtained using the inverse Laplace transform. In [6], a single-phase transmission line was modeled in two different ways, namely as a lumped parameter model and a distributed parameter model, and the two models were compared. The results of the study indicate that the performance of the lumped parameter line model depends on the line length, number of segments, and frequency band in the simulations. Additionally, it was observed that spurious oscillations were present in the lumped parameter model, whereas no such oscillations were detected in the distributed parameter model. In [7], a method in the frequency domain was proposed for transient regime analysis in power distribution networks. The working methodology is based on modeling electrical components in the frequency domain and adding the corresponding admittance to the system matrix. Depending on the size of the system matrix, simulations can take several hours, so network reduction techniques were applied. This has simplified the system and accelerated simulation times. The Kron reduction method was used to reduce the admittance matrix. After the matrix reduction process, the numerical inverse Laplace transform was applied to obtain the system's response in the time domain. When the results of the proposed method were compared with those obtained from ATP-EMTP, it was found that the results were consistent with each other. In [8], a modified implementation of the Folded Line Equivalent (FLE) model for three-phase transmission lines in ATP-EMTP is introduced. By employing an orthogonal transformation matrix and mode decomposition via Clarke’s matrix, the proposed Modified FLE (MFLE) allows bidirectional transformations using ideal transformers. Unlike traditional models derived from the method of characteristics, MFLE enables accurate simulations even with time steps larger than the line’s propagation delay. Comparative results with the JMarti and Universal Line Model demonstrate that MFLE maintains accuracy while significantly reducing computational time, making it well-suited for transient analysis of short lines in large-scale networks. In [9], the Descriptor State-Space (DSE) approach was proposed for formulating circuit equations in EMT simulations. This method has enabled the automatic derivation of equations from netlist data without requiring intermediate matrix operations, thereby making it suitable for large-scale systems. Compared to the traditional Companion Circuit (CC) method, the DSE approach has allowed direct analysis of the system’s eigenvalues; however, it has also been noted to require longer simulation times. In addition, a no-delay interface between DSE-based modules and CC-based solvers has been developed, providing support for modular and parallel simulation frameworks. In [10], A nonlinear system of equations has been proposed to estimate the parameters of a generic three-phase transmission line by utilizing modal-phase relations and terminal phasor measurements. The approach employs the Newton–Raphson method to solve the system and determine the transmission line parameters (TLPs) with high accuracy. The relative error analysis has confirmed the effectiveness of the method and highlighted the impact of lumped element modeling. Simulation results have shown that the technique is both robust and efficient across lines of varying lengths. In [11], modeling techniques for transmission lines loaded with time-varying series capacitors have been explored using both the FDTD method and a block-diagram-based approach implemented in MATLAB Simulink. In the FDTD method, the incremental transmission line model has been modified to include lumped capacitors with time-varying characteristics. In parallel, the RF Blockset library in Simulink has been used to design RF circuits with variable lumped elements. The comparison of both methods has revealed consistent and promising results. Furthermore, the time-varying capacitor-loaded line has been utilized to demonstrate mixing behavior, and the influence of physical parameters on modulation performance has been analyzed. In [12], a transmission line with distributed parameters was modeled using the state-space method, and a transient regime analysis was performed. In this study, capacitor voltages and inductor currents were selected as state variables. A disc-type transformer was connected to the end of the transmission line, and the voltage distribution across the transformer windings was examined under different conditions. The proposed method was compared with ATP-EMTP, and it was found that the results were in agreement with each other.

When reviewing the literature, it is observed that transmission line modeling and transient regime analysis have been important research topics from the past to the present. Based on this point, in this study, a lumped parameter transmission line was modeled and analyzed using MATLAB/Simulink. The study consists of the following main sections: introduction, transmission lines, modeling of transmission line, results, and conclusions.

II. TRANSMISSION LINES

A. *Transmission Line Parameters*

The conductors that make up power transmission lines have specific resistance (r), inductance (l), capacitance (c), and conductance (g) values per unit length. These line parameters are not concentrated at specific points but are distributed continuously and evenly along the transmission line.

The effective resistance value of a transmission line is calculated as given in equation (1).

$$R_{AC} = \frac{P_{loss}}{I^2}\,\Omega \tag{1}$$

The effective resistance value is obtained by dividing the power loss in the conductor by the square of the current. The resistance value of the conductor against direct current is calculated as shown in equation (2).

$$R_{DC} = \rho \frac{d}{A}\,\Omega \tag{2}$$

In equation (2), A represents the cross-sectional area of the conductor, d represents the length of the conductor, and ρ represents the resistivity of the conductor.

The inductance of a transmission line depends on the type of material used, the structure of the conductors, and the relative positions of the phase conductors. The inductance of one phase of the transmission line is calculated as follows.

$$l = 2x10^{-7}\left(\ln \frac{D}{r'}\right)\left[H/m\right] \tag{3}$$

In Equation (3), D and r' represent the distance between conductors and the effective radius of the conductor, respectively. If three phase conductors are placed in an equilateral triangle on a pole, no transposition is required, and the geometric mean distance (GMD) is equal to the distance between the phases. However, if the phase conductors are not arranged in an equilateral triangle, transposition is applied for lines longer than 50 km. After calculating the GMD using Equation (4), the inductance of each phase of the bundle conductor line is calculated using Equation (5). The GMR given in the equations represents the geometric mean radius of the conductors.

$$GMD = \sqrt[3]{D_{ab}D_{bc}D_{ac}} \tag{4}$$

$$l = 2x10^{-7}\left(\ln \frac{GMD}{GMR}\right)\left[H/m\right] \tag{5}$$

The unit capacitance per phase in three-phase lines with transposed bundle conductors is calculated as follows.

$$c = \frac{2\pi\varepsilon_0}{\ln \frac{GMD}{GMR}}\left[F/m\right] \tag{6}$$

Transmission lines have a certain amount of leakage conductivity. This leakage conductivity represents the power loss between conductors and between the conductor and the ground. Leakage current and corona in insulators are some of the causes of these power losses. The value of leakage conductivity varies depending on the insulating material used, frequency, and atmospheric conditions [13].

B. *Lumped Parameter Transmission Lines*

When modeling lumped-parameter transmission lines, they are divided into numerous sections. Each section consists of its own total series resistance (*R*), series inductance (*L*), shunt capacitance (*C*), and shunt conductance (*G*) parameters [1]. The sections are identical and are modeled as cascades. Transmission lines of this type can be modeled in four different ways: T, Π, Γ, and Ꞁ, as shown in Fig. 1.

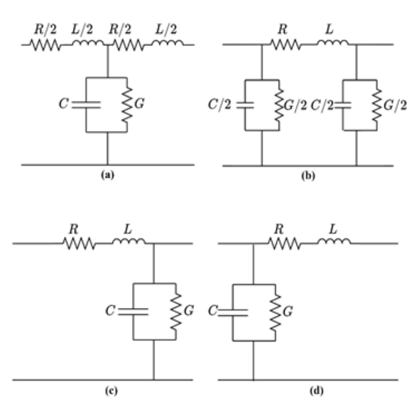


Fig. 1. Lump parameter line models (a) T-circuit (b) Π-circuit (c) Ꞁ -circuit (d) Γ-circui

Let us assume that a transmission line with lumped parameters consists of *N* sections, each of which consists of a Π-type circuit. In this case, the resulting circuit model is shown in Fig. 2.

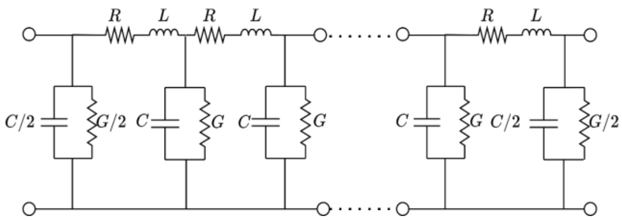


Fig. 2. Lumped parameter transmission line model obtained using Π-circuit

When modeling transmission lines with lumped parameters, the *R, L, C*, and *G* values for each section are obtained by dividing the total resistance, inductance, capacitance, and conductivity values of the line by the number of sections, or in other words, by dividing them by the number *N*. Therefore, the line parameter value in each section will change depending on the change in the number *N*.

Transmission lines are divided into three categories based on their length: short, medium, and long lines. Transmission lines with a length between 0 and 80 km are referred to as short transmission lines. When modeling this type of short transmission line, the shunt capacitance is neglected, and the line is modeled using only the series impedance value consisting of resistance and inductance. This model is generally used to represent electrical distribution networks. The two-port equivalent circuit of the short transmission line is shown in Fig. 3.

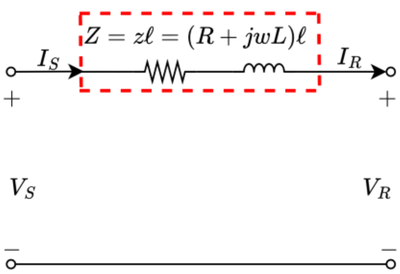


Fig. 3. Equivalent circuit of a short transmission line model

V_s, V_r, I_s, and I_r in the Fig. 3. represent the sending end voltage, receiving end voltage, sending end current, and receiving end current of the line, respectively. The equation for the given line model is as follows.

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{7}$$

The ABCD parameters of the short transmission line are as follows.

$$A = D = 1$$
$$B = Z \tag{8}$$
$$C = 0$$

Transmission lines with a length of more than 80 km and less than 250 km are referred to as medium-length transmission lines. As the length of the transmission line increases, the line charging current becomes significant, and shunt capacitance is taken into account. Therefore, a medium-length transmission line is modeled using the total shunt admittance and total impedance connected in series to the circuit. Medium-length transmission lines with lumped parameters are modeled in two ways: the Nominal Π-circuit model and the Nominal T-circuit model. In the nominal Π-circuit representation, the total series impedance is placed in the middle of the line, while the shunt admittance is divided into two equal parts and placed at both ends of the line. The equivalent circuit of the Π-circuit model is shown in Fig. 4.

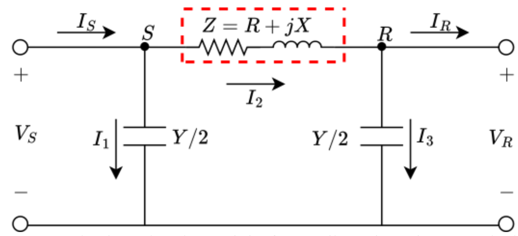


Fig. 4. Nominal Π-circuit model of a medium-length transmission line

The equations obtained by applying Kirchhoff's current and voltage laws to the equivalent circuit shown in Fig. 4. are given below.

$$V_S = ZI_2 + V_R = Z\left(V_R \frac{Y}{2} + I_R\right) + V_R = \left(\frac{YZ}{2} + 1\right)V_R + ZI_R \tag{9}$$

$$I_S = I_1 + I_2 = I_1 + I_3 + I_R = \frac{Y}{2}V_S + \frac{Y}{2}V_R + I_R \tag{10}$$

Substituting equation (9) into equation (10), equation (10) is rearranged to become equation (11).

$$I_S = \frac{Y}{2}\left[\left(\frac{YZ}{2} + 1\right)V_R + ZI_R\right] + \frac{Y}{2}V_R + I_R = Y\left(\frac{YZ}{4} + 1\right)V_R + \left(\frac{YZ}{2} + 1\right)I_R \tag{11}$$

The ABCD parameters of the nominal Π-circuit are written as shown below.

$$A = D = \left(\frac{YZ}{2} + 1\right)$$
$$B = Z \tag{12}$$
$$C = \left(\frac{YZ}{4} + 1\right)$$

Transmission lines that are 250 km or longer are called long transmission lines. Long transmission lines are generally modeled as distributed parameters, but they can also be modeled using Π equivalent circuits. For the equivalent Π circuit of the long transmission line model, Z' and Y' are used instead of Z and Y in the nominal Π circuit representation. A visual representation of this model is provided in Fig. 5.

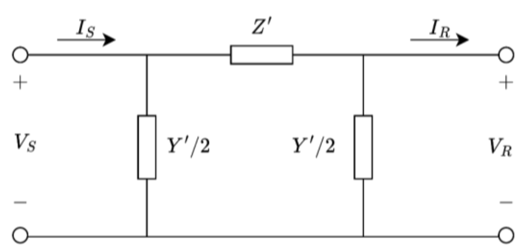


Fig. 5. Nominal Π-equivalent circuit of a long transmission line

The ABCD parameters of the Π-circuit model of the long transmission line are as follows:

$$A = D = 1 + \frac{Y^{'}Z^{'}}{2}$$
$$B = Z^{'} \quad (13)$$
$$C = Y^{'}\left(1 + \frac{Y^{'}Z^{'}}{4}\right)$$

Here;

$$Z^{'} = Z_C \sinh(\gamma d) = Z\frac{\sinh(\gamma d)}{\gamma d}$$
$$\frac{Y^{'}}{2} = \frac{1}{Z_C}\tanh(\gamma d/2) = \frac{Y}{2}\frac{\tanh(\gamma d/2)}{(\gamma d/2)} \quad (14)$$

In the equations given above, z and y are unit length parameters, while $Z=zd$ and $Y=yd$.

C. Reflection and Refraction in Traveling Waves

When a traveling wave on a transmission line encounters an impedance discontinuity at a specific point, a portion of the wave is reflected while the remainder continues to propagate into the new medium. Part of the wave remains in the original medium, whereas the other part advances through the region with different electrical characteristics. The phenomenon of wave refraction arises due to variations in material properties as the wave transitions from one segment of the line to another. If multiple impedance regions are present along the line, the wave may undergo changes in direction and exhibit variations in amplitude. The equations governing wave reflection and refraction are presented below.

$$\Gamma = \frac{Z_L - Z_C}{Z_L + Z_C} \quad (15)$$

$$T = \frac{2Z_L}{Z_L + Z_C} \quad (16)$$

Here;
Γ: Reflection coefficient,
T: Transmission coefficient,
Z_L: Load impedance at the end of the transmission line.
Z_C: Characteristic impedance of the transmission line.

The impedance observed at the input of an infinitely long transmission line is referred to as the characteristic impedance. This impedance is inherently determined by the physical structure of the line, and these physical properties can be expressed in terms of electrical quantities. By taking the line parameters into account, the characteristic impedance can be accurately calculated. According to equations (15) and (16), if $Z_L=Z_C$, the entire wave is transmitted and no reflection occurs. However, if $Z_L \neq Z_C$, a reflection occurs and part of the wave is returned. If there is an open circuit or short circuit at the end of a transmission line, total reflection occurs. In the case of an open-circuit termination $(Z_L \rightarrow \infty)$, the reflected voltage wave has a positive polarity $(\Gamma=+1)$, whereas in the case of a short-circuit termination $(Z_L=0)$, the reflected voltage wave exhibits a negative polarity $(\Gamma= -1)$. To analyze wave reflection and transmission phenomena, different methods can be employed in both the time and frequency domains. In the time domain, the instantaneous variations of voltage and current waves can be observed directly. In contrast, the frequency domain analysis, typically conducted using the Fourier transform, allows for examination of how the wave is decomposed into its constituent frequency components. Wave propagation and reflections can also be examined graphically. Using the Bewley Lattice Diagram method, the behavior of wave packets at specific locations along the line can be tracked by employing a time-position coordinate system. This graphical technique provides a clear visualization of how incident and reflected waves interact at impedance discontinuities over time.

III. MODELING OF TRANSMISSON LINE

Various methods and simulation programs are used for transmission line modeling and transient regime analysis. Programs such as PSS®E (Power System Simulator for Engineering), RTDS (Real-Time Digital Simulator), PSCAD (Power Systems Computer-Aided Design), and ATP-EMTP (Alternative Transients Program–Electromagnetic Transients Program) are some of the programs used for simulation and analysis. In addition, modeling can also be performed using the state-space method. In this study, the MATLAB/Simulink program is used for modeling transmission lines with lumped parameters.

In this study, a single-phase lumped parameter transmission line was used, and an R-L load was connected to the end of the line. The equivalent circuit of the transmission line used for modeling is shown in Fig. 6.

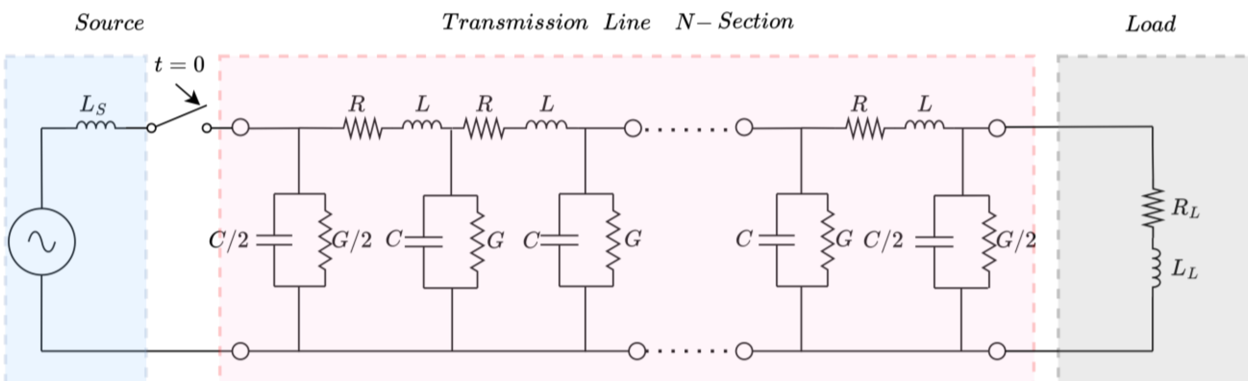


Fig. 6. Equivalent circuit of transmission lines with lumped parameters

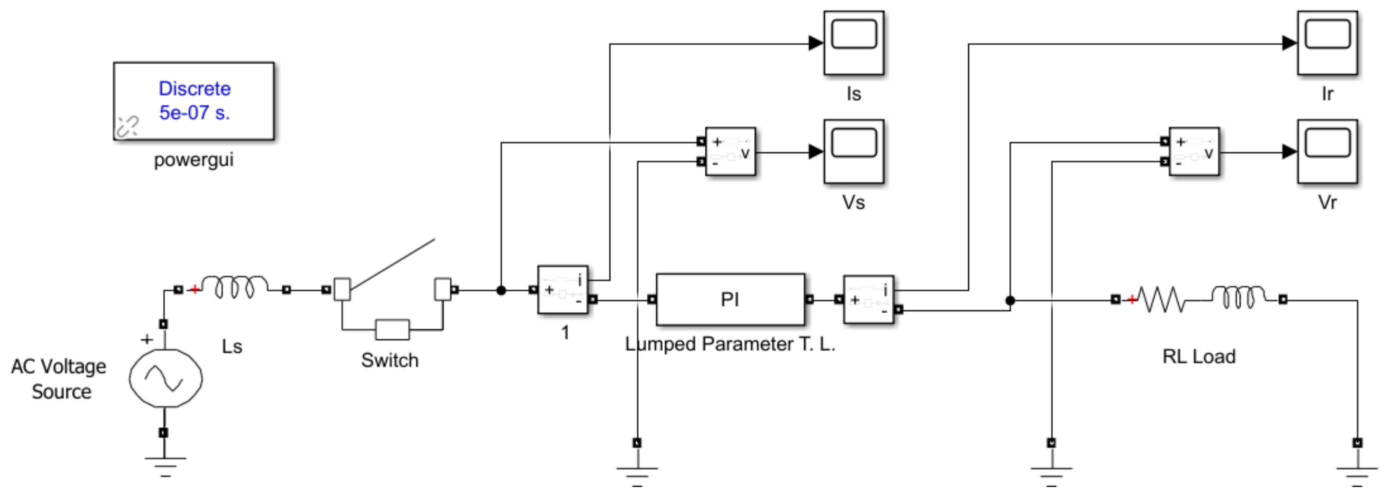


Fig. 7. MATLAB/Simulink model of a lumped parameter line

As can be seen in Fig. 6, the circuit used in the model consists of a cascade connection of multiple π-circuits. Each π-circuit represents one section. The number of sections is expressed by *N*. The L_S, R_L, and L_L in the circuit represent the source inductance, load resistance, and load inductance, respectively. An AC source was used as the voltage source. The equivalent circuit used in the study, modeled in MATLAB/Simulink, is shown in Fig. 7. According to the circuit, at $t=0\ s$, the switch closes and the transmission line is energized. The parameters used in the model are given in Table I.

TABLE I
MODEL PARAMETERS

d	*180 km*
r	*0.045 Ω/km*
l	*0.76 mH/km*
c	*11 nF/km*
R_L	*1.1 k Ω*
L_L	*0.45 H*
L_S	*50 mH*
Source	*154 kV AC*
f	*50 Hz*
N	*1, 5, 20, 50*

In Table I, the parameters *d, r, l*, and *c* represent the length of the transmission line, series resistance, series inductance and shunt capacitance, respectively, while *f* represents the frequency and *N* represents the number of sections in the line. The step length (Δx) is 50 μs and The Tustin/Backward Euler (TBE) solver type has been used for the simulation.

When modeling in MATLAB/Simulink, there is no need to draw separate sections for each pi circuit. Modeling can be performed by entering the desired number of sections in the block parameter section. This provides an advantage when compared to a generally accepted transient regime simulation program such as ATP-EMTP. This is because in the ATP-EMTP program, when modeling transmission lines with lumped parameters, sections must be added manually for each π-circuit. The number of sections entered into the block parameters and the number of sections represented in the ATP-EMTP program are shown in Fig.8., Fig. 9. and Fig. 10.

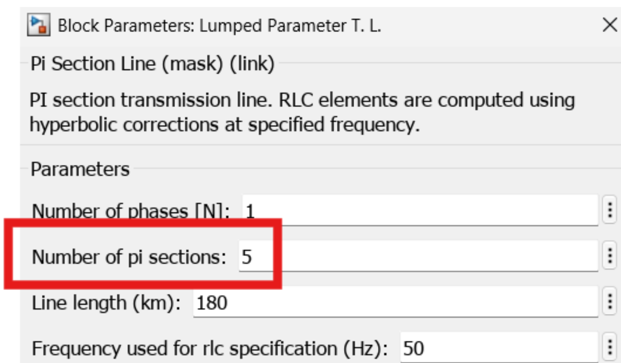


Fig. 8. PI block parameters in MATLAB/Simulink

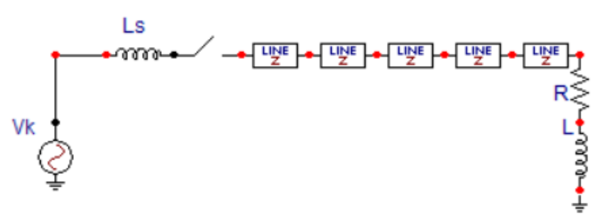


Fig. 9. ATP-EMTP model of a transmission line consisting of 5 sections

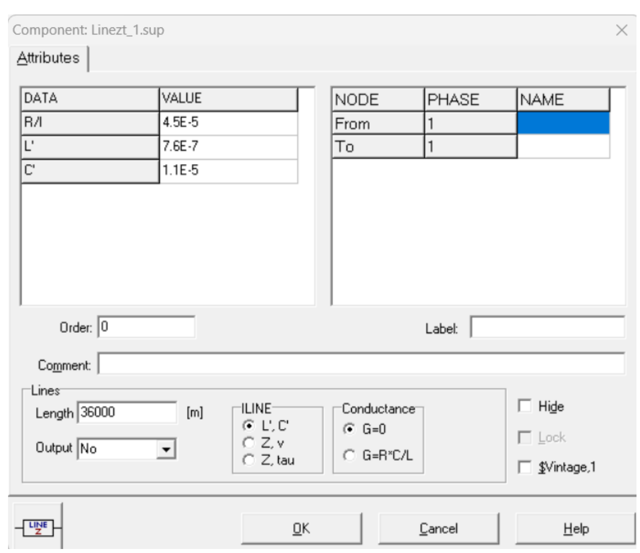


Fig. 10. Block parameters in ATP-EMTP

When examining Fig. 9. and Fig. 10., it can be seen that five π-circuits must be manually added to the circuit to model a line consisting of five sections, and that the line length for each π-circuit must be entered according to the *d/N* formula. Here, *d* is the total line length and *N* is the number of π-circuits. For a circuit consisting of 180 km and 5 sections, the line length should be entered as 180/5, which is 36 km. In this study, simulations were performed for different *N* values. Therefore, the use of MATLAB/Simulink is more advantageous for large *N* values.

IV. RESULTS

Transient simulations were performed using the lumped parameter transmission line model shown in Fig. 7. At *t=0*, the switch closes and the transmission line is energized. The sending end voltage (V_S) profile of the lumped parameter transmission line is shown in Fig. 11.

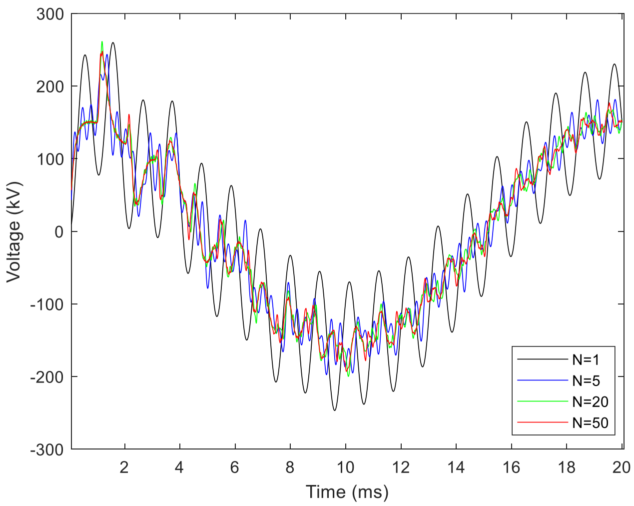


Fig. 11. Sending-end voltage waveforms for different N values

When examining Fig. 11., it is observed that different waveforms are produced for different N values. For N=1, the oscillation frequency in the wave is lower and the peak voltage value is higher than other N values. Here, it can be seen that as the N value increases, the voltage amplitude in the waveforms decreases. Despite using a voltage source of 154 kV, it was found that the sending-end voltage reached approximately 260 kV within the first few milliseconds after energization.

The voltage profile at the receiving-end (V_R) of the line is shown in Fig. 12. When the voltage-time profile at the receiving end of the line was examined, it was found that, unlike the voltage profile at the sending-end, the voltage wave reached the end of the line with a certain delay. This delay is related to the line length, wave propagation speed, and number of sections. The wave propagation speed depends on the line parameters. When examining waveforms, the time it takes for the wave to reach the end of the line varies as the N value changes. The voltage wave reached the end of the line after 0.11 ms for N=1, 0.31 ms for N=5, 0.44 ms for N=20, and 0.49 ms for N=50. The receiving-end voltage has taken values between 300 kV and 264 kV up to 2 ms for different N values. In the following period, these peak values have shown a decreasing trend.

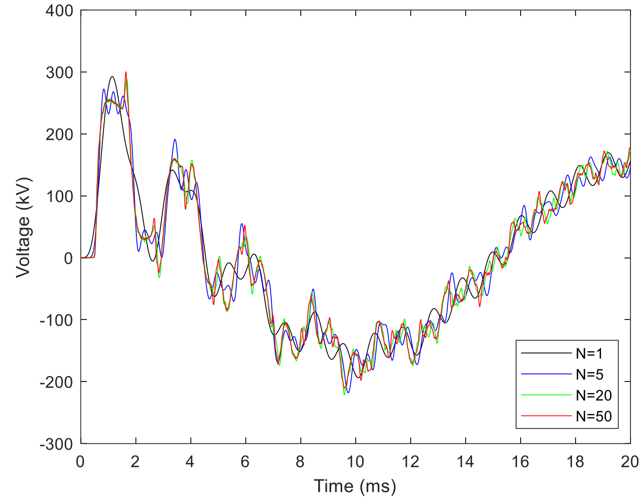


Fig. 12. Receiving-end voltage waveforms for different N values

The current (I_s) profile at the sending-end of the line is shown in Fig. 13.

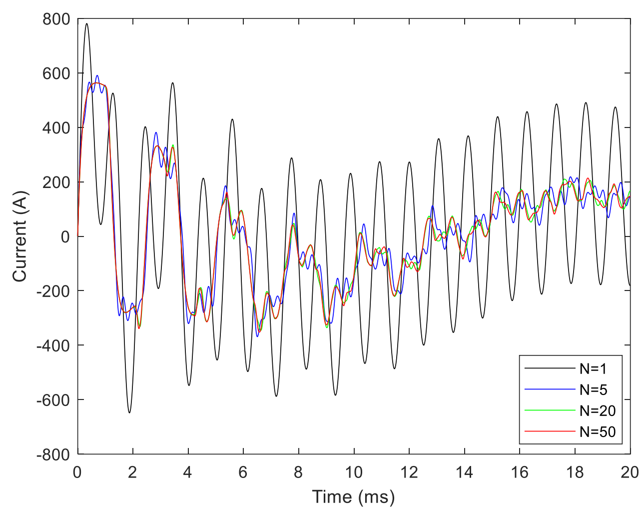


Fig. 13. Sending-end current waveforms for different N values

When the sending-end current waveform was examined, it was determined that peak current values were reached between approximately 500 A and 780 A for different N values. Over time, these peak values decreased significantly, especially for N=5, 20, and 50.

The receiving-end current (I_R) profile of the transmission line is shown in Fig. 14. When examining the receiving-end current waveforms, it was determined that the wave reached the receiving end of the line with a certain delay. After energization, the current waveform suddenly reached peak values of 204 A to 214 A after the delay for all N values. Here, the current waveforms for N=1 and N=50 are more similar to each other compared to the sending-end current profile. Current waves remain unstable for approximately the first 10 ms, but after 10 ms, the waves attempt to stabilize. Stabilization will occur over time.

Fig. 15. shows how the sending-end voltages attempt to steady state.

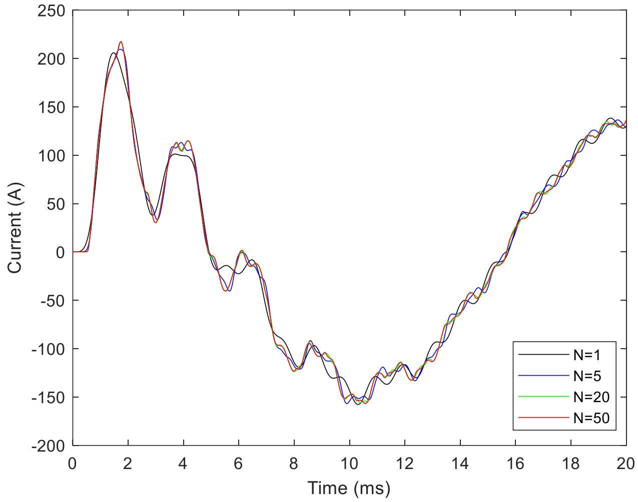


Fig. 14. Receiving-end current waveforms for different N values

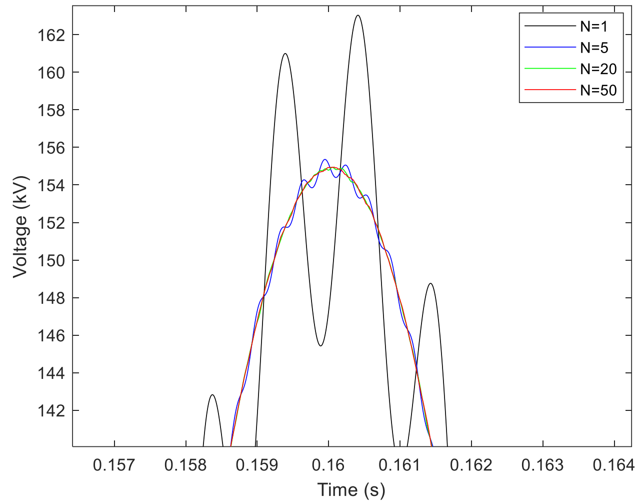


Fig. 16. Closer view of sending-end voltage waveforms for steady state

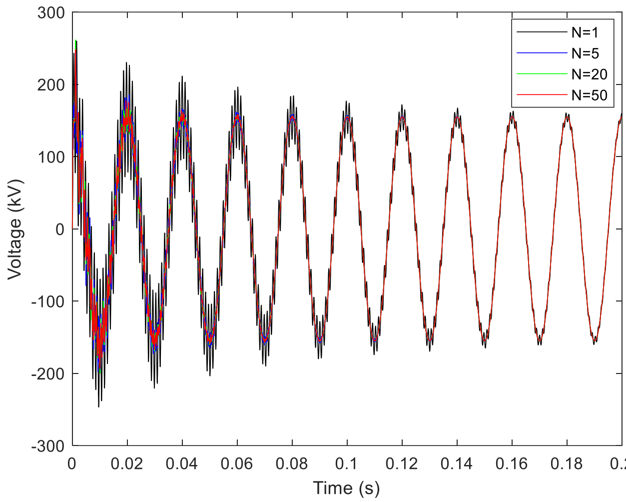


Fig. 15. Sending-end voltage waveforms for steady state

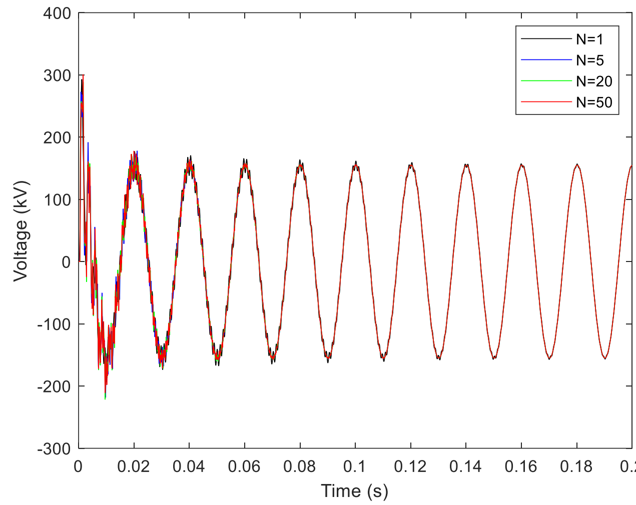


Fig. 17. Receiving-end voltage waveforms for steady state

When Fig. 15. is examined, it can be seen that all N values transitioned to a steady state at different times. The simulation time was set to 0.2 s in order to observe the steady state. Simulations were performed at the ms level for the analysis of transient states.

A closer view of the steady-state voltages at the sending-end is shown in Fig. 16. When the figure is examined, it is observed that the voltage waveform at the sending-end for N=50 reaches a steady state approximately 0.16 s later. The voltage level at this point is approximately 154 kV. At 0.16 s, the voltage waveform for N=1 has not yet reached a steady state and continues to oscillate at high amplitude. When examining the voltage waveforms for N=5 and N=20, it was observed that they had not yet transitioned to a steady state but were very close to it. The oscillations here, however, have lower amplitudes.

Fig. 17. shows how the receiving-end voltages attempt to steady state. When examining the steady-state form of the receiving-end voltage waveforms, oscillations were observed in the first milliseconds, with very high peaks detected. After approximately 0.16 seconds, it was determined that N=50 had reached a steady state, while other N values were close to a steady state.

When both the sending-end and receiving-end waveforms are examined, it is observed that oscillations occur along the line. The reason for these oscillations is that the line exhibits an LC filter effect. The delay time of the waves in the graphs, on the other hand, is related to the wave propagation speed and the length of the line.

V. CONCLUSION

In this study, a single-phase 154 kV lumped-parameter transmission line with an RL load was modeled and energized at t = 0 s. The advantages of the modeling approach used in this work over ATP-EMTP were highlighted. Voltage and current waveforms at both the sending and receiving ends of the line were analyzed. It was observed that oscillations occurred in the initial time interval due to energization, and that the waveforms approached a steady-state condition approximately 0.16 s after energization. Owing to the inherent characteristics of the line, the voltage and current waves reached the receiving end with a certain propagation delay. The lumped-parameter model of the transmission line inherently consists of multiple π-sections, each representing one segment of the line. To investigate the effect of the number of sections on transient analysis, four different values of N were employed. The results indicate that increasing the number of sections yields more accurate results, producing waveforms that more closely match the expected physical behavior. MATLAB/Simulink provides significant convenience in modeling transmission lines and in the design of power systems. The program allows for the analysis of various load conditions and delayed switching operations. Future research directions may include extending the lumped-parameter transmission line model to a three-phase configuration, simulating the impact of lightning impulses on the line, integrating a transformer at the receiving end, investigating short-circuit faults at specific points along the line, and performing comparative studies with distributed-parameter line models.

REFERENCES

[1] M. Koksal, M. S. Mamis, “Remark on the Lumped Parameter Modeling of Transmission Lines.” Electr. Mach. Power Syst., vol. 28, no. 6, pp. 565–575, Jun. 2000, doi: 10.1080/073135600268180.

[2] M. S. Mamis, “State-Space Transient Analysis of Single-Phase Transmission Lines with Corona,” Proc. Int. Conf. Power Syst. Transients 2003 (IPST 2003), 2003.

[3] J. S. L. Colqui, A. R. J. De Araújo, and S. Kurokawa, “Improving the performance of a lumped transmission line model used in electromagnetic transient analysis,” IET Gener. Transm. Distrib., vol. 13, no. 21, pp. 4942–4951, Nov. 2019, doi: 10.1049/iet-gtd.2018.6301.

[4] S. Kurokawa, F. N. R. Yamanaka, A. J. Prado, and J. Pissolato, “Inclusion of the frequency effect in the lumped parameters transmission line model: State space formulation,” Electr. Power Syst. Res., vol. 79, no. 7, pp. 1155–1163, Jul. 2009, doi: 10.1016/j.epsr.2009.02.007.

[5] M. S. Mamis, “Lumped-parameter-based electromagnetic transients simulation of non-uniform singlephase lines using state variable method,” IET Gener. Transm. Distrib., vol. 14, no. 23, pp. 5626–5633, Dec. 2020, doi: 10.1049/iet-gtd.2020.0454.

[6] A. R. J. Araújo, R. C. Silva, and S. Kurokawa, “Comparing Lumped and Distributed Parameters Models in,” in 2014 Ieee Pes T&d Conference And Exposition, 2014, pp. 1–5.

[7] G. Bilal, P. Gomez, R. Salcedo, and J. M. Villanueva-Ramirez, “Electromagnetic transient studies of large distribution systems using frequency domain modeling methods and network reduction techniques,” Int. J. Electr. Power Energy Syst., vol. 110, no. January, pp. 11–20, Sep. 2019, doi: 10.1016/j.ijepes.2019.02.043.

[8] J. S. L. Colqui, L. C. Timaná, P. T. Caballero, S. Kurokawa, and J. P. Filho, “A modified implementation of the Folded Line Equivalent transmission line model in the Alternative Transient Program,” Electr. Power Syst. Res., vol. 211, no. November 2021, p. 108185, Oct. 2022, doi: 10.1016/j.epsr.2022.108185.

[9] A. Sinkar, H. Zhao, B. Qu, and A. M. Gole, “A Comparative Study of Electromagnetic Transient Simulations using Companion Circuits, and Descriptor State-space Equations,” Electr. Power Syst. Res., vol. 198, no. April, p. 107360, 2021, doi: 10.1016/j.epsr.2021.107360.

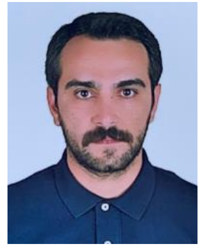
[10] J. T. R. Pineda and S. Kurokawa, “Application of modal-phase domain relations to estimate transmission line parameters,” IET Sci. Meas. Technol., vol. 13, no. 5, pp. 684–691, Jul. 2019, doi: 10.1049/iet-smt.2018.5428.

[11] A. Kumar, J. C. Dash, and D. Sarkar, “Computational Techniques for Design and Analysis of Time-Varying Capacitor Loaded Transmission Lines Using FDTD and Simulink,” IEEE J. Multiscale Multiphysics Comput. Tech., vol. 7, pp. 228–235, 2022, doi: 10.1109/JMMCT.2022.3202990.

[12] İ. Arı and M. S. Mamiş, “Voltage Distribution on Transformer Windings Subjected to Lightning Strike Using State-Space Method,” Appl. Sci., vol. 15, no. 3, p. 1569, Feb. 2025, doi: 10.3390/app15031569.

[13] D. Akmaz, “İletim Hatlarinda Ariza Yeri Ve Türünün Geçici Rejim Sinyalleri Ve Makine Öğrenme Algoritmalari İle Belirlenmesi,” Ph.D. Dissertation, İnönü Universtiy, 2017.

BIOGRAPHIES



Dr. Ilker ARI was born in Siirt, Türkiye, in 1989. He received the B.Sc. degree in Electrical and Electronics Engineering from Çukurova University, Adana, Türkiye, in 2014, the M.Sc. degree in Electrical and Electronics Engineering from Siirt University, Siirt, Türkiye, in 2018 and Ph.D. degree in Electrical and Electronics Engineering from İnönü University, Malatya, Türkiye, in 2025. Since 2020, he has been a Lecturer with the Department of Motor Vehicles and Transportation Technologies, Siirt University. His research interests include power systems, line modeling and analysis.

Dr. Ramazan MENAK was born in Siirt, Türkiye, in 1993. He received the B.Sc. degree in Electrical and Electronics Engineering from İnönü University, Malatya, Türkiye, in 2015, the M.Sc. degree in Electrical and Electronics Engineering from Siirt University, Siirt, in 2018 and Ph.D. degree in Electrical and Electronics Engineering from İnönü University, Malatya, Türkiye, in 2025. Since 2017, he has been a Research Assistant with the Department of Electrical and Electronics Engineering, Siirt University. His research interests include control system design, robust controller design, and H-∞ norm based controller design.