Analysis of the Response of Transmission Line Network under Electromagnetic Pulse

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Abstract. Power system transmission line is a very complex network. The response of cable terminal is very different from that of single line. In order to accurately predict the terminal response of the cable under the nuclear electromagnetic pulse, a convenient method is needed to calculate the response of complex network. Based on the state equation method and the extrapolation method, the transmission line is equivalent to the current source or voltage source. Matlab program and Simulink are used to calculate the induced current generated by the cable terminal. The results are compared with those of CST cable studio. The results of CST show that the method is correct.

Keywords: Hemp, Simulink, Transmission line, State-variable formulation.

1. Introduction
There are complex Internet connections on chips or power systems, which also interfere with each other when an external electromagnetic pulse arrives. The response to the load of the Internet is solved, and the law of its variation with para-meters is analyzed. The important problem of electromagnetic pulse protection design is also discussed.

At present, there are many methods to solve the time domain of the Internet. In this paper [1], it proposes a method to set up so-me state variable equations as terminal conditions. The defect is that the state equations of circuits containing capacitive inductors or nonlinear elements are very complex. By establishing t T-type circuit model of transmission line [2], then using SPICE software to analyze, the defect is that it can only be used for lossless and small-scale cable network calculation. By constructing the scattering parameter model of transmission line, the total scattering parameter model of cable network is obtained to analyze the cable network [3-4]. In this paper, a two-port equivalent circuit of each cable is established [5], the transmission line is solved by FDTD method, and the circuit equations are analyzed by MNA method.

In this paper, the two-port equivalent network of cable is established, the extrapolation formula of terminal current is derived firstly, and then the circuit is solved by SIMULINK.

In the second section, we give a concrete formula and computational model, and in the third section, we calculate the induced current on the transmission line and compare it with CST.
2. Computational model

The lossy MTL are taken into account in this article [6], generally the per-unit-length parameter matrices \( G \) (conductance) are very small, so \( G \) can be neglected. The time-domain MTL equation are:

\[
\frac{\partial}{\partial z} V(z,t) + Z(t) * I(z,t) + L \frac{\partial}{\partial t} I(z,t) = - \frac{\partial}{\partial z} E_r(z,t) + E_L(z,t)
\]

(1)

\[
\frac{\partial}{\partial z} I(z,t) + C \frac{\partial}{\partial t} I(z,t) = -C \frac{\partial}{\partial t} E_r(z,t) + E_L(z,t)
\]

(2)

Where \( V \) and \( I \) are \( n \times 1 \) vectors of the line voltages (with respect to the reference conductor) and line currents, respectively. The position along the line is denoted by \( z \), and \( N \) is the number of the spatial segments. The line voltages and currents are functions of \( z \) and time \( t \). The line cross-sectional dimensions are contained in the per-unit-length parameter matrices \( L \) (inductance) and \( C \) (capacitance), the conductor losses are represented by \( Z \); \( E_r \) and \( E_L \) are the \( n \times 1 \) vector describing the incident field excitation. The model of the MTL is shown as Fig.1.

![Figure 1. The model of the MTL](image)

The model of multi-conductor transmission lines connected by the arbitrary load networks is shown as Fig.2. The per-unit-length parameters of the MTL1 and MTL2 are \( L_1 \), \( C_1 \) and \( L_2 \) respectively.

![Figure 2. The model of multi-conductor transmission lines connected by arbitrary load networks](image)

The boundary conditions of the transmission line equation are as follows [7]:

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\[ \frac{\Delta z}{2\Delta t} C_1 V_{1,N+1}^{n+1} = \frac{\Delta z}{2\Delta t} C_1 V_{1,N+1}^n - \left( I_{T1}^{n+1/2} - I_{T1}^n \right) \]

\[ - \frac{\Delta z}{2\Delta t} C_1 \left( E_{1T,N+1}^{n+1} - E_{1T,N+1}^n \right) \]

\[ \frac{\Delta z}{2\Delta t} C_2 V_{2,1}^{n+1} = \frac{\Delta z}{2\Delta t} C_2 V_{2,1}^n - \left( -I_{T2}^{n+1/2} + I_{T2}^n \right) \]

\[ - \frac{\Delta z}{2\Delta t} C_2 \left( E_{2T,1}^{n+1} - E_{2T,1}^n \right) \]

The currents on the two sides of the T network are denoted by \( I_{T1} \) and \( I_{T2} \).

\[ I_{T1}^{n+1/2} = \frac{I_{T1}^{n+1} + I_{T1}^n}{2} \]

\[ I_{T2}^{n+1/2} = \frac{I_{T2}^{n+1} + I_{T2}^n}{2} \]

The key is to use the central difference to need \( n + 1 \)-time voltage value, to use the state variable equation solution will be very complex, the use of extrapolation method solution can be obtained.

\[ I_{T1}^{n+1/2} = \frac{3I_{T1}^n - I_{T1}^{n-1}}{2} \]

\[ I_{T2}^{n+1/2} = \frac{3I_{T2}^n - I_{T2}^{n-1}}{2} \]

According to the FDTD calculation rules, it is assumed that the current values of \( n \) and \( n-1 \) time are known, and the transmission line is equivalent to a current source or a voltage source is calculated in simulink:
3. Numerical results

The ideal double conductor transmission lines are used in the article for convenience. The parameters of the model in Fig.5 and Fig.6 are: \( R_s = R_t = 50\Omega \), \( a_1 = a_2 = 0.0015m \), \( L_1 = L_2 = 2m \), \( h_1 = h_2 = 0.1m \). The configuration of connection are shown as Fig. 5 and Fig.6, where are the resistance, inductance and capacitance of the networks respectively. The values of these parameters are: \( R_{r_1} = 150\Omega \), \( L_r = 100\mu\text{H} \).
Figure 5. The configuration of the transmission lines connected by the resistance

Figure 6. The configuration of the transmission lines connected by the arbitrary load

The incident electromagnetic wave is used here. The incident electromagnetic wave is the exponential wave. its expression is $E_{inc}(t) = 1.3 \times 50000 \left(e^{-4 \times 10^7 t} - e^{-6 \times 10^7 t}\right)$ V/m, shown as Fig.7.

Figure 7. The waveform of the double exponential pulse

The numerical results of the MTLs of the configuration of Fig.5 and Fig.6 are shown as Fig.8 and Fig.9.
Figure 8. The terminal induced current of the nonuniform lossy transmission lines connected by the resistance

Figure 9. The terminal induced current of the nonuniform lossy transmission lines connected by the arbitrary load

It can be seen that the results of CST are consistent with the peak value of the proposed method, and the period is slightly different from that of the proposed method, whether it is the connection resistance or the connection resistance and inductance of the transmission line. This is due to CST considering the vertical segment and the difference between the full-wave algorithm and the one-dimensional algorithm.

4. Conclusion
In this paper, the terminal current of transmission line is obtained by extrapolation without solving the state equation. By connecting the transmission line as voltage source or current source to Simulink, the visual complex circuit design is realized. Compared with CST, this method is proved to be effective.

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