32nd URSI GASS, Montreal, 19-26 August 2017

Study of the Impaction by Lightning Strike on Communication Cable Based on Time-domain Finite Element Method

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Abstract

Lightning strikes at converter station will threaten the safety and reliability of communication equipment by rising the substation grounding grid potential and radiation field. This paper analyzes the coupling mechanism of communication signal line based on E1 signal cable model and transient solution method when a lightning strike occurs. This paper established frequency variable transmission line model of the E1 signal cable, and achieved the E1 line transient calculation under the excitation of lightning radiation field based on the time-domain finite- element method. While the design of RF conduction disturbance tests system, the measurements and the simulation results are comparable and verified the correctness of the model. Based on the model, the transient voltage of communication cable is analyzed and calculated under lightning. The coupling mechanism was revealed. The generated influence of communication data is predicted when a lightning strike occurs. At the same time in order to inhibit the interference effects, the filter and single point grounding of the protective measures effective is provided.

1. Introduction

With the development of smart grid, the reliability of communication system in power system receives much attention. When lightning strikes the line, frame and control building in the lighting protection system to create a strong transient current, thus causing electromagnetic interference and other issues. For long distance communication cable, there is possible to have a double side way when unable to connect to the same grounding body, and due to the presence of the resistance of the ground network to produce a transient current flowing through the mesh of the conductive layer, thus inducing disturbance voltage in communication cable core[1, 2].

In this paper, the simulation calculated when lightning strikes control building, under the condition of the ground potential difference between communication cable E1 line ends and the case of E1 line around the radiated interference, the amount of interference coupled to the E1 line. Through the calculation, verifies under the case of taking corresponding measures, the inhibiting effect on the amount of interference.

2. E1 Line Model

E1 is a digital transmission system for one group standard (i.e., PCM30), developed by ITU-T and named by the European postal and Telecommunications Association (CEPT), and is a time division multiplexing form. The structure of the E1 line as showed in Figure 1, from inside to outside is divided into four layers: copper center, plastic insulation, mesh conductive layer and wire sheath. Copper center and mesh conductive layer form the current loop. In the process of lying, both ends of the cable through the connecting head are connected in communication equipment, and communication equipment shell is linked by the nearest ark grounding line. That is, communication cable connects the grounding grid in a way of double end grounding.

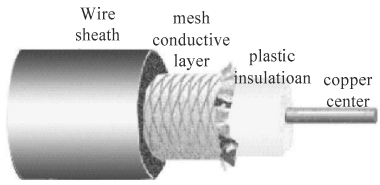

Figure 1. E1 line structure.

For the E1 line, whose lying of the line length is more than 30 meters, to study the problem of lightning, need to use the distributed parameter circuit, as shown in Figure 2, R_0, G_0 , L_0, C_0 is per unit length parameters.

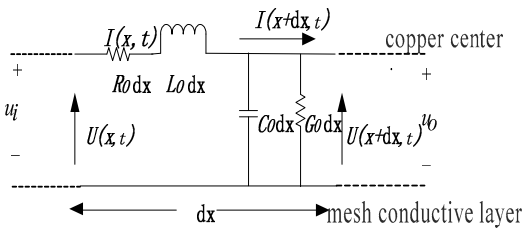

Figure 2. The unit equivalent circuit of E1 line.

Using the impedance analyzer, measuring the impedance in open circuit, short circuit of an E1 line, and calculate and determine the values of R_0, G_0 , L_0, C_0 changing with frequency , which are showed in [3].

3. Coupling Mechanism

When lighting the arresters of Converter Station's Main Control Building, there will exist currently in the grounding structures of the building and produce comprehensive radiation interference. Simultaneously, there will be a large current into the grounding grid , making the potential of grounding point and even grounding grid rises ,and there are some differences in electric potential difference of different grounding point to infinity（0V）,causing the grounding points of both ending of E1 have distinct potential , shown in Figure 3, $u_a \neq u_b$ .So, transient current will flow mesh conductive layer and voltage will be induced in the center of the copper wire. As a result, interferences that E1 has mainly from the following aspects: radiated interference and ground potential rise interference. Then influence of both aspects needs to be considered when analyzing the coupling mechanism affected by lighting. So, this paper using multiple conductor time-domain finite element method which considering frequency variable impedance parameters to analyze the coupling efficiency.

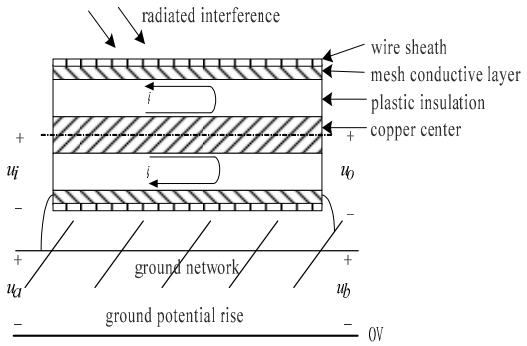

Figure 3. The coupling path that lighting to E1.

The equivalent circuit shown in Figure 4.

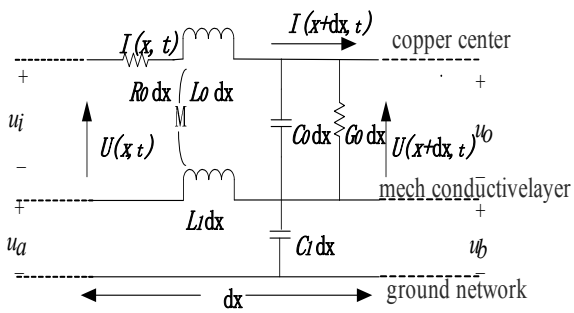

Figure 4. The equivalent circuit of Figure 4.

The time-domain model not considering the frequency variable parameters Agrawal coupled model [4~8].

$$\begin{cases} \dfrac{\partial u(x,t)}{\partial x} + R_0 i(x,t) + L_0 \dfrac{\partial i(x,t)}{\partial t} = 0 \\ \dfrac{\partial i(x,t)}{\partial x} + G_0 i(x,t) + C_0 \dfrac{\partial u^s(x,t)}{\partial t} = 0 \end{cases} \quad (1).$$

The $u^s(x,t)$, $u(x,t)$, $i(x,t)$ in the above formula respectively represent induced voltage, total voltage and total current.

Using the Galerkin method, the voltage of each node on the moment can be further derived as formula (2)

$$\begin{aligned} &\mathbf{A_1 u_{n+1}} + \mathbf{B_2}\left(-\mathbf{D_1^{-1} C_1 u_{n+1}} + \mathbf{D_1^{-1} C_2 u_n} + \mathbf{D_1^{-1} D_2 i_n}\right) \\ &= \mathbf{A_2 u_n} + \mathbf{B_2 i_n} + \mathbf{u_F} \\ &\Rightarrow \left(\mathbf{A_1} - \mathbf{B_2 D_1^{-1} C_1}\right)\mathbf{u_{n+1}} \\ &= \left(\mathbf{A_2} - \mathbf{B_2 D_1^{-1} C_2}\right)\mathbf{u_n} + \left(\mathbf{B_2} - \mathbf{B_2 D_1^{-1} D_2}\right)\mathbf{i_n} + \mathbf{u_F} \\ &\Rightarrow \mathbf{u_{n+1}} = \left(\mathbf{A_1} - \mathbf{B_2 D_1^{-1} C_1}\right)^{-1}\left[\left(\mathbf{A_2} - \mathbf{B_2 D_1^{-1} C_2}\right)\mathbf{u_n}\right] \\ &+ \left(\mathbf{A_1} - \mathbf{B_2 D_1^{-1} C_1}\right)^{-1}\left[\left(\mathbf{B_2} - \mathbf{B_2 D_1^{-1} D_2}\right)\mathbf{i_n} + \mathbf{u_F}\right] \end{aligned} \quad (2).$$

In order to verify using the above method to calculate the influence which the communication cable on the signal in outfield alone, this paper designed the RF conduction disturbance test system, as show in Figure 5. Putting the 82.4MHz, 80% modulation waves and interference intensity of 10 V/m produced by RF transmitter device on E1 around by coupling clamp (total length of 0.6m), E1 since the ring in error instrument of sending and receiving ends. Using the oscilloscope observes the voltage waveform of error instrument's accept port, comparing with the results calculated using the above methods, as showed in Figure 6, verifying the feasibility of the above method.

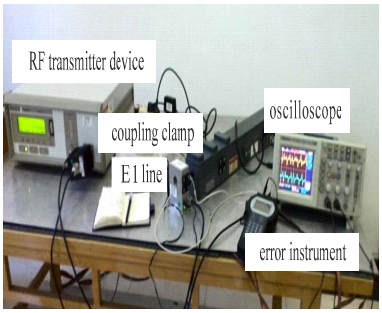

Figure 5. Test system.

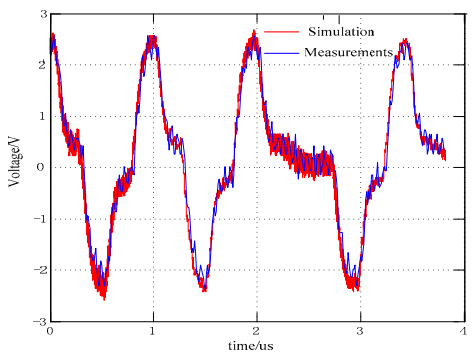

Figure 6. The calculation result.

4. Considering Coupling Effect under the Ground Potential Rise

Ground potential rise (GPR) is due to when the converter station failure or the occurrence of lightning, grounding system will be injected into very high frequency large inrush current, generating the phenomenon of high voltage potential gradient distribution along the ground. There exists a potential difference between the communication cable end places, causing the ground loop current. The thesis simulates a converter station in lightning case communication cable at both ends of the ground potential rise waveform. As shown in Figure 4, the grounding grid consists of 490 galvanized flat steel buried underground 0.8m, 125 ground piles buried by the main grounding grid 3.8m deep underground. The rod body diameter is 24mm. The red line in Figure 7 indicates is E1 line (35 meters) position in the converter station.

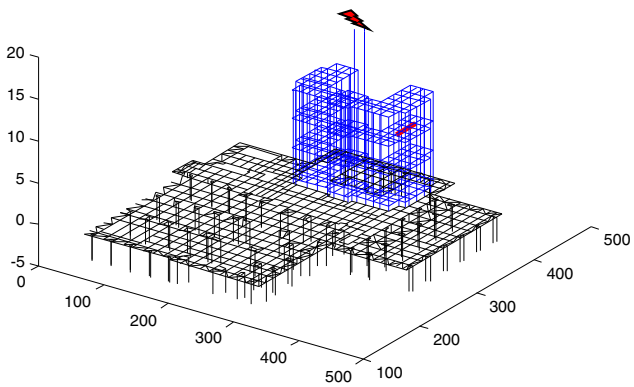

Figure 7. A substation main grounding network.

Peak 1000kV, 8/20 lightning hit the red arrow in Figure 7, getting E1 line ends ground a,b potential waveforms, through the simulation calculation, as showed in Figure 8.

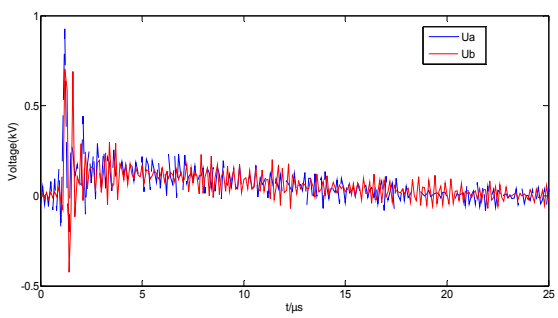

Figure 8. Ground potential rises simulation diagram.

Under normal circumstances, the signal waveform E1 line is shown in Figure 9, Level range changes -2.75~2.75V.

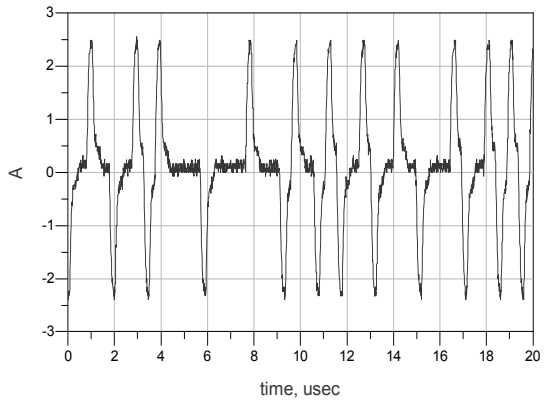

Figure 9. E1 signal waveform.

By using time-domain finite element method, the calculation of the interaction effect of radiation and ground potential rise for communication signal is shown in Figure 10. Level range changes from the original -2.75~2.75V into -1~5V, unable to transfer signal correctly, generating a logic error.

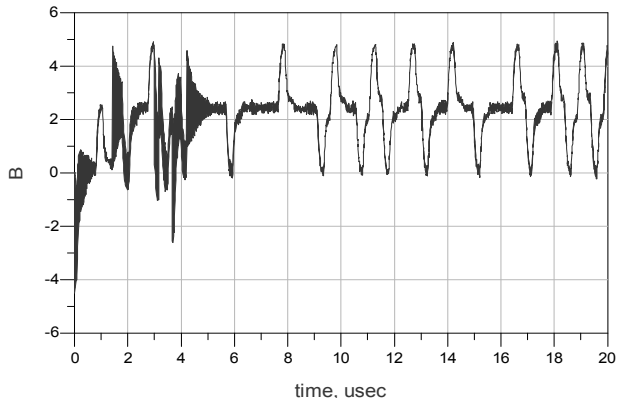

Figure 10. Logic error waveform.

Shown to increase between 0.1 μF capacitor can solve the conductive layer and the mesh network can be used to Figure 11.

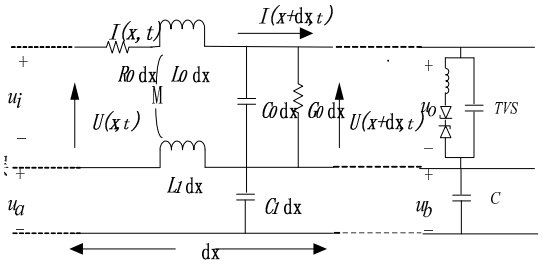

Figure 11. Measures taken by the circuit.

Single increase in case of the capacitance waveform shown in Figure 12.

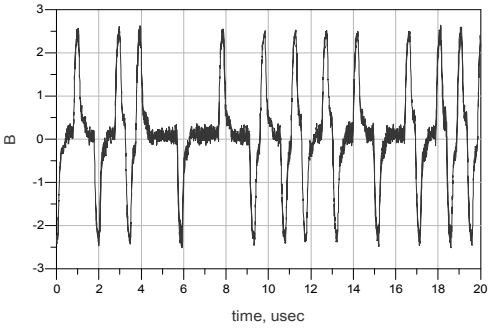

Figure 12. Effect of increasing capacitance.

In the electronic device port protection, usually adopts the breakdown characteristics of TVS Zener diode quickly discharge impulse current, rising clamp impulse voltage to the breakdown voltage level to make a safe protection of the follow-up circuit work. Single increase in case of the TVS waveform shown in Figure 13.

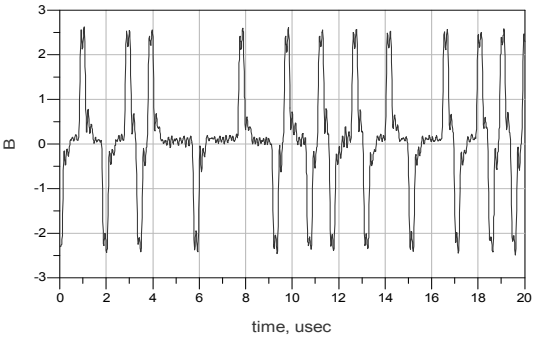

Figure 13. Effect of increasing TVS.

For the length of the short communication lines, the best way is a single point grounding method, the effect shown in Figure 14.

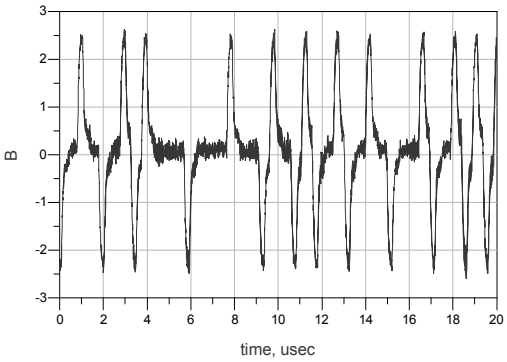

Figure 14. Effect of single-point ground.

5. Conclusion

The time-domain finite element method can be used in the research of coaxial cable by lightning strikes. This method can also consider the effect of the external field and the ends of being ground potential rise situation. The simulation results provide a theoretical basis for the further protection measures. For electronic equipment's' lightning protection measures in building, in addition to the use of three stage lightning proof device in the building construction, we can also use the equipotential connection, installation of lightning protection devices and other measures to have a further protection for electronic equipment.

6. Acknowledgement

This work is supported by the Fundamental Research Funds for the Central Universities (2016MS102).

7. Reference

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