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Focus Review Article

Effects of Soil Ionization and Lightning Impulse Corona on Lightning Current Strike

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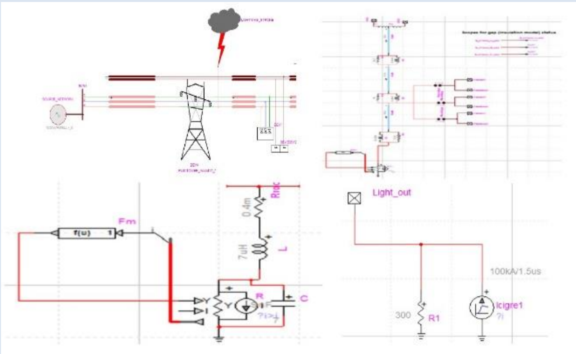
Abstract:
This work investigates the 1000-KV UHV transmission line under the 100KA lightning impulse on the overhead guard wire with considering the corona and soil ionization in high frequency grounding system. In this study, four cases of transient electromagnetic current status of the transmission line power system have been analyzed using the EMTP-RV software. The results depicted that the soil ionization in the absence of the corona can be caused an attenuation of the lightning current waves. However, with considering the corona phenomena and soil ionization, all together, this reduction of the resultant waves propagation from a lightning strike on a 1000-KV UHV transmission line is not visible due to high charging of the corona phenomena.

Keywords: Soil ionization; Corona; Lightning current; Electromagnetic transients; EMTP-RV software

Graphical Abstract:



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Introduction

The grounding system, containing a network of horizontal and vertical conductors, is an important part of any distributed electrical system such as electrified railway system, communication tower, power system, and large building. Often it is required to estimate the influence of the grounding system on the spread of voltage and current within the electrical system during lightning impulse. In this purpose, many researchers have developed different models to analyze the transient signals behavior of the grounding system under the lighting impulse. These models can be classified as circuit approach [1-4]. Transmission line approach can be either in time domain or in frequency domain, including all the mutual coupling between the different parts of the earth wires, and at the same time could predict surge propagation delay. For the UHV transmission-line approach, the authors in [5] and [6] applied the UHV transmission-line concept only to each of the small segments of the grounding conductors in order to derive the equivalent resistive matrix for solving the circuit equation conductor as equivalent x-circuits made up of lumped R-L-C elements [7-12]. The coupling of grounding conductors can be taken into account by mutually coupled inductances. Among others, Velazquez and Mukhedkar described the procedure [13-16]. The electromagnetic field approach exhibits the most rigorous theoretical background of all three approaches. Strictly based on the theorems of electromagnetism and with the least neglects possible, the problems are defined in terms of retarded potentials, and among the possible strategies for their solution, the method of moments proved to be most efficient. Dawalibi could translate the highly complex relationships into practical, engineering program [17-21].

Releases waves resulting from lightning have an important role in the design of UHV transmission lines. Many studies of lightning strikes have been carried out in view of the corona. Corona reduces the impedance of the conductor and increases the coupling factor between the lines [22-25]. When the voltage in the conductor goes beyond the corona inception voltage, electric charging data not only is on the surface of the conductor but also production in the adjacent conductor [26].

Typically, the electrical charging in Q-V curve, used to show the characteristics of the Corona phenomena impulses [27-30]. Many studies on Corona characteristics impulse were done on contactors cages [31-33]. However, various experiments are done on lightning impulse on the 1000-KV UHV transmission lines under positive and negative polarity [34]. In the study of high-voltage transmission line project, electromagnetic environments are considered as the key technical problems. One of the electromagnetic environments is corona characteristics in the power system transmission line [35].

This work examines the effects of corona and soil ionization on the charging data caused by 100KA lightning strike in 1000-KV UHV transmission line. Also be able to fully understand of corona impulse characteristics and understanding the actual wave processes and understand a proper design of electromagnetic transient of power system.

Corona phenomena and Q-V curve characteristics

Corona model explained based on Q-V curve. When the voltage of the air around the conductor increases a specific value, corona voltage is generated and the air around the conductor ionized and the electrical charge stored. This phenomenon is called Corona which may involve in the transmission line and increase the capacitance of transmission lines. The characteristics of this phenomena showed by Q-V curve. Some models presented in the form of equivalent circuit and others are in the form of linear approximation of the Q-V curve. All of these are dependent on the instantaneous voltage line. The experimental results shows that the corona effect on the slope of the voltage waveform.

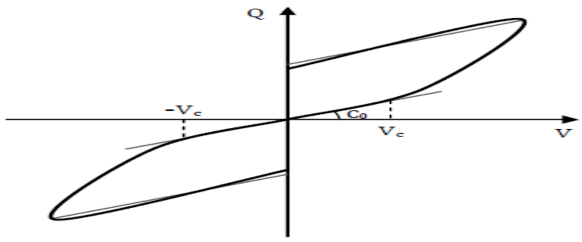

Figure 1. Q-V curve characteristics of transmission line

Corona impact analysis on the performance of lightning UHV transmission lines has been paid by using the EMTP-RV software. In some areas with frequent lightning strikes and high resistance soil, there is more possibility of a lightning strike to the transmission line. In this method as an economy result, increase the probability of a lightning strike caused an increase of among of electrical charging and electrical discharge. Therefore detailed assumptions lightning protection function and improve power system stability important for the design of ultra high voltage transmission lines [36].

3-phase of corona phenomena runs in EMTP-RV software. In Figure 2, C_{22}, C_{23} and C_{24} are coupling capacitance between phases in the model are the corona. In the proposed model C_{14}, C_{17}, C_{26} showed capacitance between the line and the corona and C_{15}, C_{18}, C_{21} demonstrated the capacitance between the corona and earth. In the simulation L and R have assumed as series. DC_5, DC_6, DC_7 are starting voltage of corona. Before the voltage of transmission line reached to the corona starting voltage, Diode is switch off and dose not conduct but when the voltage of transmission line exceed from starting voltage, diode is switched on and conducts. In this simulation, each 100 m corona model will be added to Ultra high voltage transmission line. Figure 3 illustrates the section of transmission line with corona model. In this corona model L=0.064 mH and R=16 Ω [37-41].

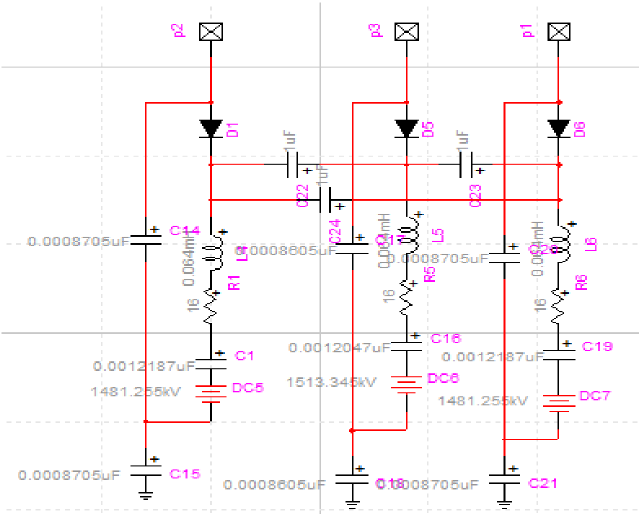

Figure 2. Corona 3-phase equivalent circuit in a transmission line

Ultra-high voltage alternating current transmission line is divided into different sections and non-linear circuit capacitive added to the electromagnetic transient models. The proposed corona model, if the discretization of ultra-high voltage transmission line is not choosing correctly the corona model may cause wave deformation. So to get accurate results, the transmission line is divided into sections of 100 meters.

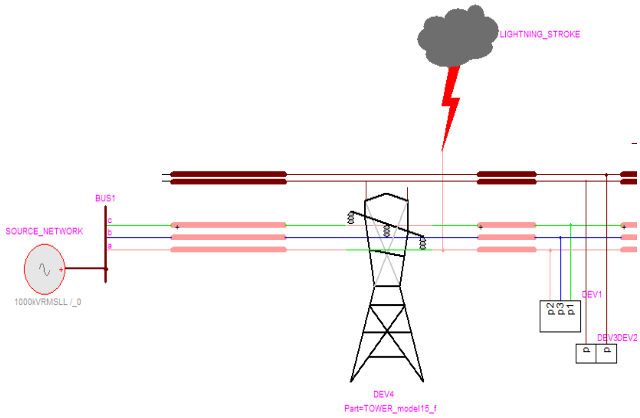

Figure 3. A 100-meter section of the simulation model

High Frequency Grounding system with soil ionization

In general, the methods of analyzing the high-frequency model of the grounding system and dynamic behavior in the discharge of lightning current, classified to the three methods:

1. Circuit theory method;
2. Transmission line theory method;
3. Electromagnetic field theory.

In this work, the circuit theory method was used. A simple method as shown in Figure 4 was used to model the grounding system in high frequency with considering the soil ionization.

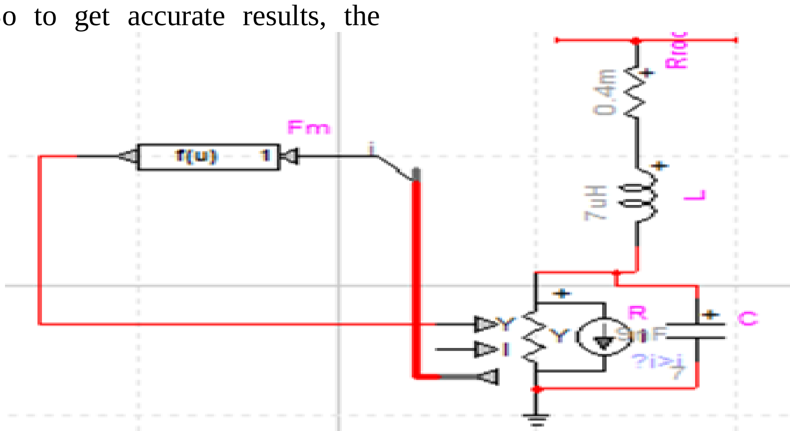

Figure 4. Grounding electrode impedance circuit model considering the effect of soil ionization

In this study, vertical copper electrode is used. Calculate the electrical resistance, capacitance and inductance is defined as follows:

$$RT(t) = \frac{R0}{\sqrt{1+\frac{i(t)}{Ig}}} \quad (1)$$

$$Ig = \frac{Eo\ \rho}{2\pi R0^2} \quad (2)$$

$$C(F) = \frac{2\pi \varepsilon l}{\ln(\frac{4l}{a}) - 1} \quad (3)$$

$$L(H) = \frac{\mu l}{2\pi}\left(\ln\frac{4l}{a} - 1\right) \quad (4)$$

where the (R_t) low flow resistance base and (I_g) is current limiting to start soil ionization. I_g related to soil ionization gradient (E_g) and also soil resistance (P_h). In this research, the electrode diameter was 16 mm and the electrode length was 2 m. Also the depth of electrode burial was 0.5 m. It should be noted that in this study the high-frequency grounding systems use vertically buried [42-44].

Components of 1000-KV UHV Transmission Line

Specifications of the transmission line is 1.6 km, consists of three two-bundle conductor with FD LINE model. Space bundle is 400 mm, conductor radius is 30 mm. air coefficient specific gravity (δ=1) and Conductor surface roughness coefficient (m=0.82). The guard wire was considered with a 16 mm radius. In transmission line suspension heights of sag have been considered, 17 meters and in the guard wire, 15 m [45-47].

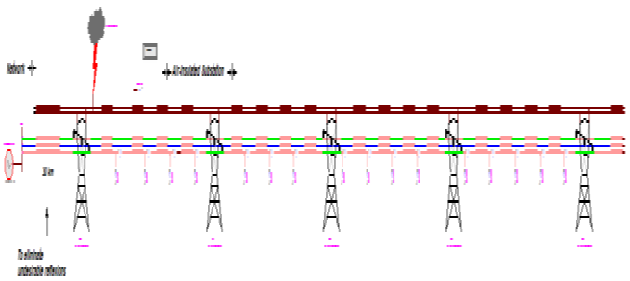

Figure 5. Transmission line simulated by software EMTP-RV

The model of injection lightning current

In this simulation of lightning current, double exponential function 50/2.5 µs is used. Lightning current source model is intended 100 KA.

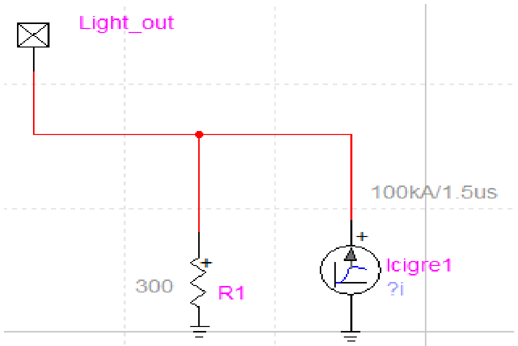

Figure 6. 100 KA Lightning model on guard wire

UHV transmission line tower and insulator back flashover models

Ultra-high voltage tower model is of type multi-wave impedance model which contains three sub-layers and each sub-layer of tower include resistance and parallel inductance. The multi-wave impedance model towers components in high voltage alternating current transmission line attenuation constant (γ=0.7) and Damped liquidity ratio (∅=1) according to reference [48]. In the software EMTP-RV insulator back flashover phenomena are simulated with a switch that consists of input and output signal. The maximum electrical discharge voltage of Insulation filament considered 6MV [49-51].

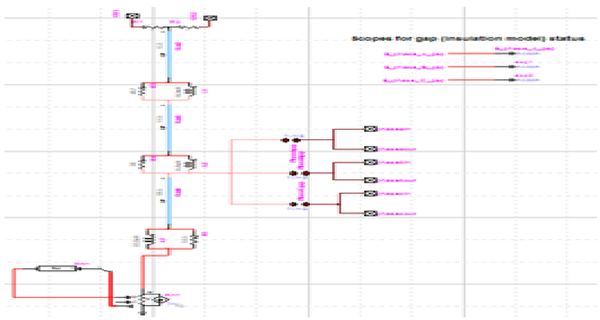

Figure 7. Insulator back flashover of Insulation filament and UHV tower models

Analysis of injection lightning current on UHV transmission line

Assessment of the current in 1000KV UHV transmission line with the length of 1.6 km was done with EMTP-RV software. In this study, four tests in different modes of current with 100, 300, 600, 900, 1200 meters distance of the Point lightning strike with 100KA was done in power transmission line system [52-55].

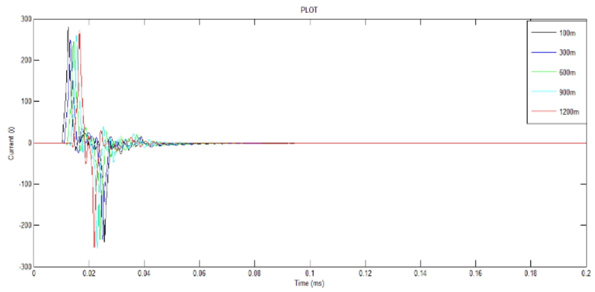

Figure 8. Current of UHV transmission line without soil ionization and corona phenomena

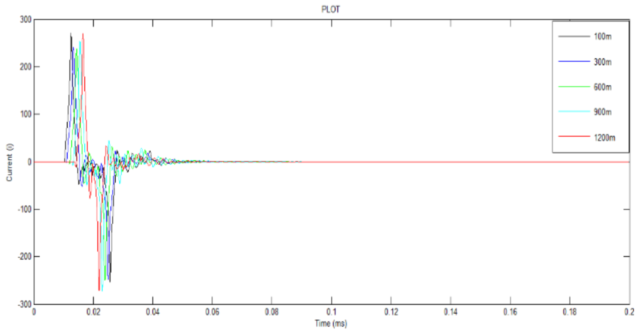

Figure 9. Current of UHV transmission line with soil ionization and without corona phenomena

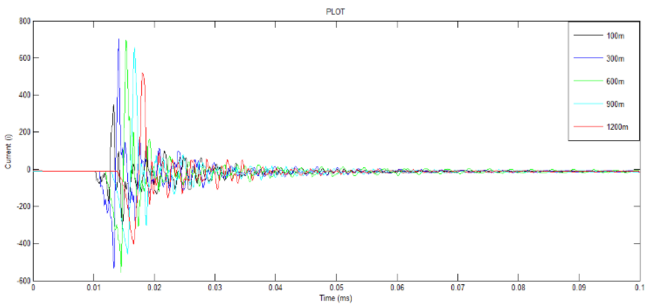

Figure 10. Current of UHV transmission line with soil ionization and corona phenomena

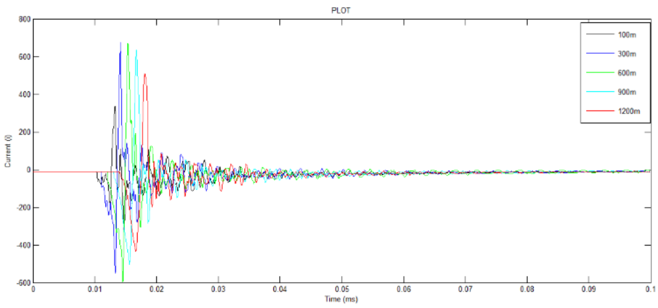

Figure 11. Current of UHV transmission line with corona phenomena and without soil ionization

For a more detailed analysis of the output of the transmission line under lightning impulse 100 KA, Table. 1 was prepared by ampere. This table current analysis in a variety condition of soil ionization in the high-frequency grounding system and corona phenomenon in distances of 100, 300, 600, 900 and 1200 meters from the point of lightning strike [56-59].

The results demonstrated that the soil ionization of the absence of ionization in grounding systems, damped and attenuation in the signal current creates alternating current transmission line. However, the attenuation in the soil ionization with corona phenomenon due to the corona charging data cannot be seen [60-63].

Table 1. Analysis of the injection current of 1000-KV UHV transmission line

	100m	300m	600m	900m	1200m
Current with soil ionization and corona	346.84	702.70	697.14	656.06	520.91
Current with soil ionization and without corona	270.83	241.15	235.54	254.33	269.40
Current with corona and without soil ionization	337.93	674.75	669.72	635.37	509.14
Current without corona and soil ionization	279.11	248.64	245.35	259.23	272.84

Conclusion

In this work, various analyzes was done on the injected current 100 KA from a lightning strike in alternative high-voltage transmission lines 1000-KV UHV by EMTP-RV software. In this simulation, injection current releases in the transmission line with considering the various status of soil ionization in the high-frequency grounding system and corona phenomena was evaluated in distances of 100, 300, 600, 900, and 1200 m from the point of lightning strike. The output from the transient electromagnetic current of power system transmission line showed that considering the soil ionization in the high-frequency grounding system in UHV transmission line will reduce the current. However, with considered the soil ionization in the high-frequency grounding system and corona phenomena, attenuation and reduce the amplitude in the transmission line was not observed. The reason for this lack of attenuation was the high charging of corona phenomena around conductor which prevents soil ionization influence on the propagation waves.

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