An Improved Soil Ionization Representation to Numerical Simulation of Impulsive Grounding Systems

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This paper presents an extended methodology based on the transmission line modeling method (TLM) to represent soil ionization for the simulation of grounding systems. This natural phenomenon can be better represented by taking into account the variation of the conductive components present in the TLM circuit and considering the residual resistivity remaining in the soil. The proposed analytical formulation is developed with a focus on the computational implementation of the method. Simulations are carried out considering a typical horizontal electrode for soils with different characteristics. The model is validated by comparing the results with other numerical models and measured data. The results demonstrate that the proposed method offers good accuracy.

***Index Terms*— Grounding, lightning, numerical modeling, soil ionization, transmission line modeling method TLM.**

I. Introduction

OVER the past decades, much effort has been made to improve the performance of grounding systems for electric current dissipation. In this context, mathematical modeling and computer simulation are valuable approaches to provide a clear understanding of soil behavior, grounding systems and their interaction with human beings.

Grounding systems are one of the main resources responsible for dissipating the current originating from a lightning to the earth, functioning as an important component for protection and safety. Although it is known that the performance of a lightning protection system (LPS) can be improved by using elaborated grounding meshes, the implementation of simple structures composed of horizontal or vertical electrodes is a common practice adopted by the power utilities both in distribution and transmission networks. Usually, the practical implementation of these basic grounding components using a minimum of material to obtain low values of grounding impedance is justified either by physical constraints, especially in the case of urban areas, or by financial constraints. The transmission line modeling method can be a powerful tool to analyze the transients generated by a lightning striking a LPS composed by these grounding structures.

During the process of current dissipation through the grounding system, if the voltage in the electrodes is high enough with consequent generation of an electric field exceeding a given threshold – critical electric field – the rupture of the soil dielectric around the electrodes up to a certain radial distance may occur. This region, referred to as ionized, can be interpreted as a type of irregular wrap of conductivity around the grounding conductors.

Several researches concentrated on the study of this phenomenon with consequent development of representative models, general or not, with distinct approaches. Methods like those developed by Liew, Darveniza and Wang [1]-[2], Sekioka *et al*. [3] focus on the nonlinear variation of the resistivity in the ionized region. In [4] Liu represents the soil ionization based on a soil residual resistivity produced in the ionized region. Velasquez and recently Gazzana *et al*. [5]-[6], in their equation, adopt the concept of increasing the electrode radius during the soil breakdown period.

In this context, this paper aims at presenting a hybrid formulation, based on increasing the electrode radius and the produced residual resistivity, in order to consider the soil ionization process taking into account a TLM algorithm. The objective is to improve the representation of the grounding electrodes and their interaction with the surrounding medium.

II. Numerical Implementation

Based on the concept that the soil ionization produces an increase in the electrode radius [5], this increment leads to an increase in the G conductance value of the TLM line segments.

In accordance with the principle that the soil retains some residual resistivity in the ionization region [4] and considering several measurements, the percentage of residual resistivity in the ionization region for the soils with resistivity ranging from 50 Ωm to 827 Ωm can be estimated, as can be seen in Fig.1.

Considering the proposed hybrid technique (variation in the electrode radius and the residual resistivity), the soil ionization can be inserted into a classic TLM algorithm described as shown in the flowchart in Fig. 2.

To sum up, the soil ionization phenomenon can be represented in the TLM code by following two steps. Initially, the electric field on each node J must be determined. Then, the electric field on a line segment represented by a node *J* can be established. In the second step, a verification is carried out for each node *J* so as to check whether the electric field *E(J,t)* exceeds the critical value of electric field E_{cr}. If so, the new values of *G(J,t)* obtained on a node *J* are recalculated representing the soil ionization along the associated segment.

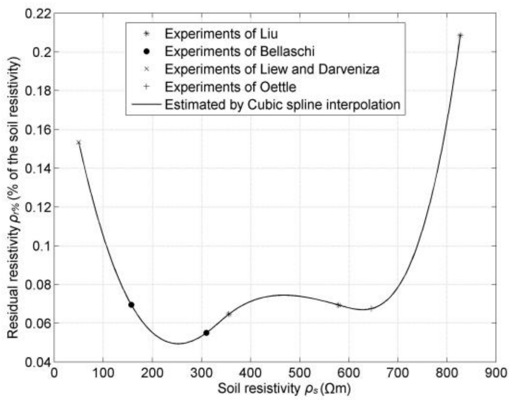

Fig. 1. Residual resistivity in the ionization region.

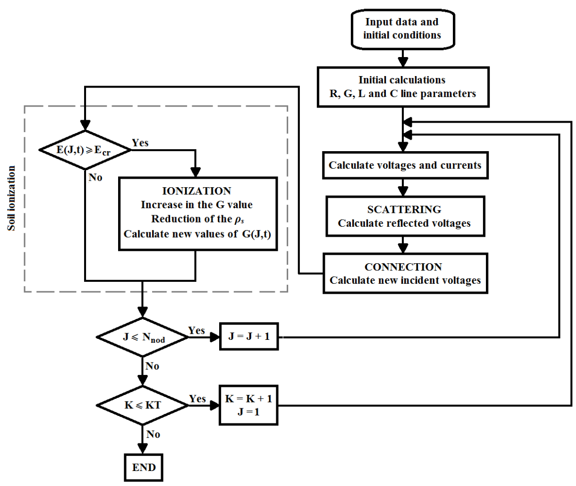

Fig. 2. Flowchart of the TLM algorithm considering the soil ionization phenomenon.

III. Simulation Results

A horizontal electrode with 12 m length, radius of 0.0065 m buried at 0.5 m depth in homogeneous soil with different properties was considered in the simulations. The lightning was represented by a double exponential wave of 50 kA (8 x 20) µs injected in one of the conductor extremities.

The behavior of the grounding electrode buried in the rocky soil can be seen in Fig. 3. In this case, the soil was represented by its resistivity ρ_s = 530 Ωm and relative permittivity ε_r = 10.

Fig. 3 shows that for a soil with such characteristics, the ionization has a significant influence regarding the generated potential on the electrode. A decrease of 18.2% in the maximum magnitude is identified, highlighting the importance of considering this phenomenon in the computational representation. Additionally, a mean decrease of 10.13% can be estimated during the transient period.

In order to validate the proposed model, comparisons were made using as a reference results from other simulation models and experimental results, as presented in Fig. 4.

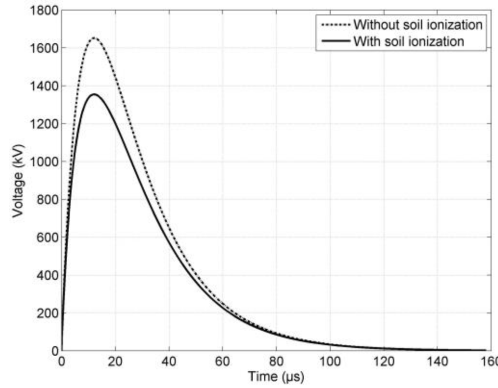

Fig. 3. Voltage at the origin of the electrode (ρ_s = 530 Ωm, ε_r = 10).

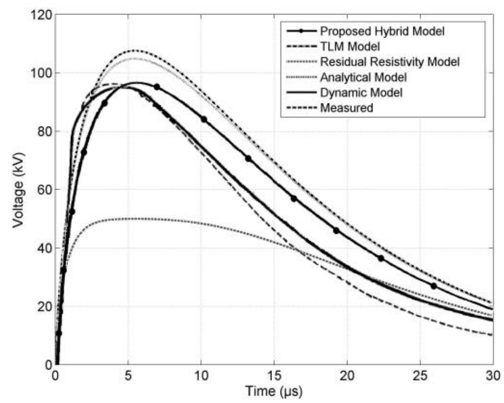

Fig. 4. Comparison between models. Voltage at the origin of the electrode.

IV. Conclusions

In this work a methodology for the numerical representation of soil ionization was introduced. Taking as reference the main models developed so far, a novel solution to the problem was sought in order to offer a general procedure to evaluate the performance of grounding systems.

Additionally, in the proposed technique there is no need to use any constants obtained experimentally. The effective radius of the electrode in the ionization region is obtained as a result of the variation in the resistive elements in the model, where the radius values are physically acceptable. The method is not subject to divergent solutions, being numerically stable.

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