TLM modeling in electrical grounding problem including the soil dispersive behavior through the Debye equation in lightning situations

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Abstract — A proposal for developing numerical simulations of grounding topologies, considering the dispersive behavior of the soil in lightning situation is presented. For this, it is employing a computer code with the implementation of 3D-TLM method adapted by using Z-transform techniques for processing dispersive media in the time domain. After the simulations in lightning situation, it is shown the behavior of the curve Transient Grounding Resistance (TGR). The results show that the values in steady state are acceptable and meet the practical measurement.

I. INTRODUCTION

A special attention must be paid to the grounding if a proper performance and safety of the complete electric system is wanted. For the conditions of low frequency and not very high current values, the soil dispersive effects and the soil ionization are negligible, and then the grounding behaves as a linear resistance. Normally the supposition of soils constant parameters is adopted in a conservative approach, but experimental researches developed in the last decades have shown that the soil resistivity and permittivity are strongly frequency dependent [1]-[3].

Hence, this dispersive behavior must not be ignored when the ground is subjected occurrences associated with fast transients and high intensity phenomena, such as the current and voltage surges from the lightning.

In this way, this paper includes numerical simulations of the performance of the grounding topologies subject to lightning, considering the soil dispersive behavior and its influence on the transient grounding resistance (TGR). Specifically, it is proposed Debye equation as a mathematical model for the representation of the variation in frequency of the soil electrical parameters, for the typical grounding systems conditions.

Debye equation can be incorporated in the formulations of time-domain numerical methods (e.g. FDTD and TLM), as long as those are adapted to consider dispersive materials [4]. In this paper, it was used TLM-3D method, with the formulation changed to include the soil dispersive behavior. Some results are presented – from TLM codes created – of some typical grounding topologies on lightning conditions.

II. SOIL ELECTROMAGNETIC BEHAVIOR MODEL

From a macroscopic standpoint, the soil can be treated as a lossy dielectric material with linear (when the ionization phenomenon does not happen), isotropic and frequency-dependent behavior. This last factor is precisely the most important to be considered in the fast transitory phenomena study.

The soil can be classified as a first multiple order terms dielectric material. So, the well-known Debye equation was used as a mathematical approach for soil modeling [3],[4].

$$\varepsilon_r(\omega) = \varepsilon_\infty + \sum_{n=1}^{N} \frac{\varepsilon_{sn} - \varepsilon_\infty}{1 + j\omega\tau_n} . \qquad (1)$$

Where n is the electrical dispersion region index; ε_∞ is the dielectric constant in the infinite or optical relative permittivity, for $f \to \infty$; ε_s is the static dielectric constant, for $f \to 0$; τ is the dielectric relaxation time constant and ω is the angular frequency.

III. TLM METHOD CONSIDERING THE DISPERSIVE EFFECT

In this work, the TLM formulation developed by [4], was used. The differential equations of electrical circuits (in time domain) that describe the relationships between voltages and currents in the cells of TLM mesh are first transformed to s domain. After algebraic manipulations for the development of the impulses scattering process in the mesh and obtain the expressions to the total voltages and currents, the system is transformed to z domain, where the material dispersive characteristics material is equated with *Z-Transform techniques*. Finally, expressions are transferred to the discrete time domain ($t = k{\cdot}\Delta t$). A simplified schematic of this process is showed in Fig. 1:

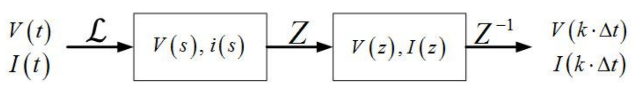


Fig. 1. Representation of the use of TLM method modified for the treatment of dispersive materials.

IV. TLM MODELING OF GROUNDING SYSTEM CONSIDERING THE SOIL DISPERSIVE EFFECT

Some simulations were made of typical grounding topologies on lightning conditions. As example, in this paper is shown the results for triple grounding electrodes in line system (see Fig. 2).

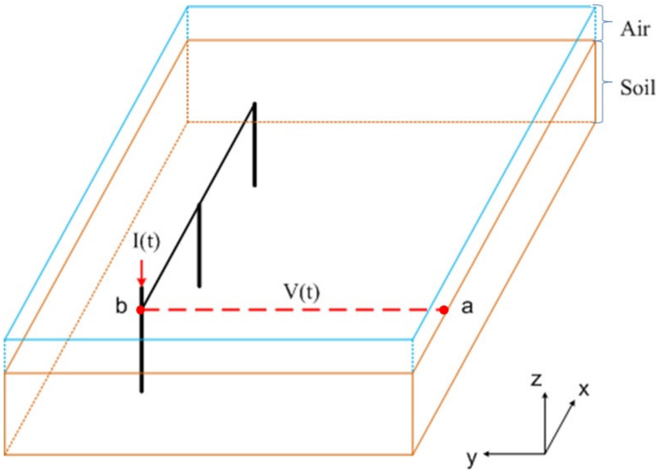
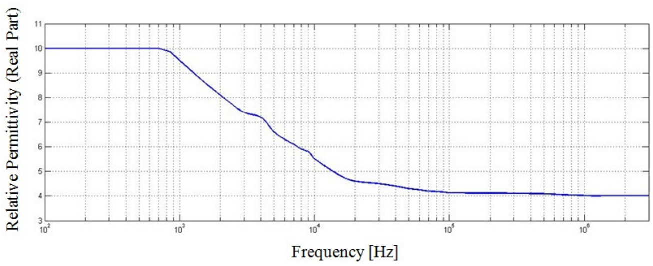
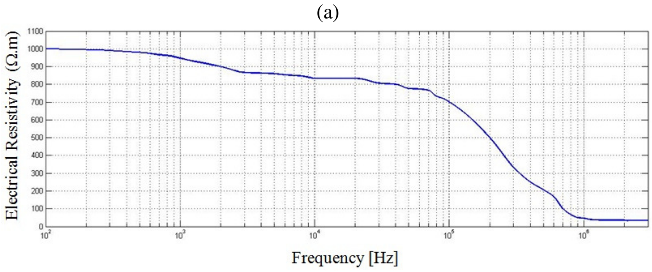


Fig. 2. Grounding topology modeling.

The conductors were represented by cooper, considering 2,4m length. To represent the soil dispersive behavior was used the Debye formulation. Tab. I shows the Debye parameters, obtained from the soil curves shown in Fig. 3.



(a)



(b)

Fig. 3. Curves of the soil dispersive parameters employed in this article: (a) Relative permittivity; (b) Electrical resistivity.

TABLE I
DEBYE PARAMETERS OF THE DISPERSIVE SOIL

Parameters	**Dispersive region - *n***		
	1	**2**	**3**
ε_{sn}	10.0	4.1590	4.0195
τ_n(s)	$3.5765\cdot 10^{-5}$	$2.4478\cdot 10^{-7}$	$5.3053\cdot 10^{-8}$
ε_∞	4.0		
$\sigma_s(mS/m)$	$1.0\cdot 10^{-3}$		

The well-known double exponential 1 kA (1.2μs/50μs) function was used to represent the current impulse excitation.

The voltage was obtained by integrating the electric field, from the point of current injection to the absorbing boundary of the TLM mesh. The TGR was calculated by the ratio between the voltage and the current variation in time.

Fig. 4 shows the TGR curve obtained from the simulation. It is observed that the steady value is about 114Ω, very close to the value measured at low frequency techniques.

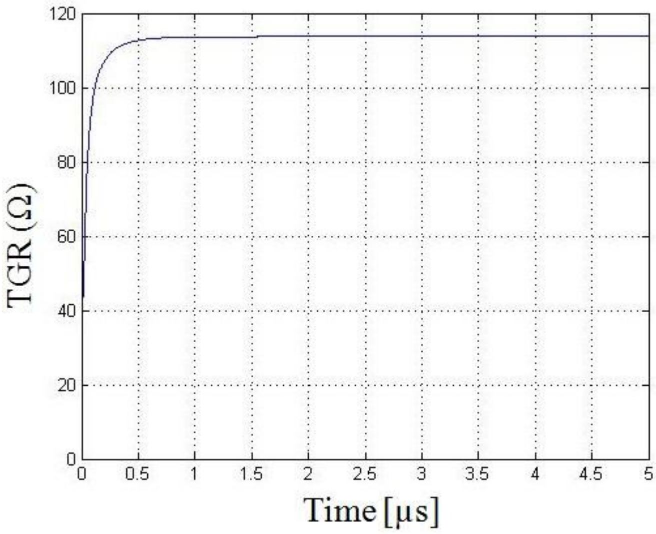


Fig. 4. Transient Grounding Resistance curve.

More results will be presented in the full paper.

V. CONCLUSION

The Debye parameters represent the characteristic curves of the soil behavior. Applying these terms to modified TLM code by employing Z-Transform techniques it was possible to calculate the TGR curves.

The TGR results are considered adequate**.** The values tend to an acceptable steady-stated which is consistent with those obtained from experimental techniques in low frequency.

VI. REFERENCES

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