Lightning Characteristics Analysis of Grounding Devices by Modified Partial Element Equivalent Circuit Method

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***Abstract*—This paper proposes a time-domain method for the lightning transient performance of the grounding device. Based on the partial element equivalent circuit method, it considers the frequency-dependence in the time-domain, and refers to the alternating direction implicit difference scheme for the unconditionally stable solution.**

Keywords- grounding; partial element equivalent circuit (PEEC); time-domain; frequency-dependent; lightning.

I. Introduction

The lightning transient characteristic of the grounding device plays an important role in the lightning protection [1]. For evaluating and analyzing, simulation is a very effective approach. There are several kinds of methods such as the transmission line method, the finite-different time-domain method, the method of moment and the PEEC method. Compared with the former three, PEEC gives consideration to both efficiency and accuracy [2].

In this paper, a modified PEEC method is proposed with following characteristic: a) bases on the electromagnetic quasi-static (EMQS) hypothesis and time-domain analysis; b) considers the frequency-dependence, as well as the multi-layer soil and the mutual coupling; c) refers the ADI difference scheme for the unconditionally stable solution.

II. General Principle of Method

Firstly, for conductors buried in the lossy ground, the node voltages $\boldsymbol{V}$ and the branch currents $\boldsymbol{I}$ are arranged alternatively, $\boldsymbol{V}$ are located at the nodes, and $\boldsymbol{I}$ are located at the middle of the branches. Then, the EMQS equivalent circuit is established in the frequency domain, which considers the frequency-dependence, as well as the multi-layer soil and the mutual coupling.

$$\begin{cases} \boldsymbol{Y}_r * \boldsymbol{V} - \boldsymbol{A}\boldsymbol{I} = \boldsymbol{I}_s \\ \boldsymbol{Z}_a * \boldsymbol{I} + \boldsymbol{A}^T\boldsymbol{V} = 0 \end{cases} \tag{1}$$

where $\boldsymbol{I}_s$ is the current source vector, $\boldsymbol{A}$ is the incidence matrix, $\boldsymbol{Y}_r$ and $\boldsymbol{Z}_a$ are respectively the admittance and the impedance, which are full matrixes. By the vector fitting method [4], each of the frequency-dependent elements can be approximated as a rational function in the complex frequency (s) domain:

$$\begin{cases} \boldsymbol{Y}_r = s\boldsymbol{C}_r + \boldsymbol{G}_r + \sum_{q=1}^{Q_r}\left[\boldsymbol{k}_r^q / \left(\boldsymbol{s} + \boldsymbol{p}_r^q\right)\right] \\ \boldsymbol{Z}_a = s\boldsymbol{L}_a + \boldsymbol{R}_a + \sum_{q=1}^{Q_a}\left[\boldsymbol{k}_a^q / \left(\boldsymbol{s} + \boldsymbol{p}_a^q\right)\right] \end{cases} \tag{2}$$

Then, by the inverse Laplace transformation, (1) can be transferred from the frequency domain into the time domain as:

$$\begin{cases} \boldsymbol{C}_r\, d\boldsymbol{v}/dt + \boldsymbol{G}_r\boldsymbol{v} + \boldsymbol{B}_r - \boldsymbol{A}\boldsymbol{i} = \boldsymbol{i}_s \\ \boldsymbol{L}_a\, d\boldsymbol{i}/dt + \boldsymbol{R}_a\boldsymbol{i} + \boldsymbol{B}_a + \boldsymbol{A}^T\boldsymbol{v} = 0 \end{cases} \tag{3}$$

where $\boldsymbol{B}_r$ and $\boldsymbol{B}_a$ are the infinite integral items resulted, and can be calculated by the recursive convolution method [3].

Lastly, by the ADI difference scheme [4], one traditional time step is split into two sub-time steps as (4) and (5). Then, the implicit and explicit difference schemes are respectively applied.

$$\begin{cases} \boldsymbol{C}_r \dfrac{\boldsymbol{v}^{n+1/2} - \boldsymbol{v}^n}{\Delta t/2} + \boldsymbol{G}_r \dfrac{\boldsymbol{v}^{n+1/2} + \boldsymbol{v}^n}{2} + \boldsymbol{B}_r - \boldsymbol{A}\boldsymbol{i}^{n+1/2} = \dfrac{\boldsymbol{i}_s^{n+1} + 3\boldsymbol{i}_s^n}{4} \\ \boldsymbol{A}^T\boldsymbol{v}^{n+1/2} + \boldsymbol{L}_a \dfrac{\boldsymbol{i}^{n+1/2} - \boldsymbol{i}^n}{\Delta t/2} + \boldsymbol{R}_a \dfrac{\boldsymbol{i}^{n+1/2} + \boldsymbol{i}^n}{2} + \boldsymbol{B}_a = 0 \end{cases} \tag{4}$$

$$\begin{cases} \boldsymbol{C}_r \dfrac{\boldsymbol{v}^{n+1} - \boldsymbol{v}^{n+1/2}}{\Delta t/2} + \boldsymbol{G}_r \dfrac{\boldsymbol{v}^{n+1} + \boldsymbol{v}^{n+1/2}}{2} + \boldsymbol{B}_r - \boldsymbol{A}\boldsymbol{i}^{n+1/2} = \dfrac{3\boldsymbol{i}_s^{n+1} + \boldsymbol{i}_s^n}{4} \\ \boldsymbol{A}^T\boldsymbol{v}^{n+1/2} + \boldsymbol{L}_a \dfrac{\boldsymbol{i}^{n+1} - \boldsymbol{i}^{n+1/2}}{\Delta t/2} + \boldsymbol{R}_a \dfrac{\boldsymbol{i}^{n+1} + \boldsymbol{i}^{n+1/2}}{2} + \boldsymbol{B}_a = 0 \end{cases} \tag{5}$$

III. Validation and Conclusion

A typical tower footing device, shown in Fig.1, is tested and simulated by the proposed method. It can be seen that they have quite a good agreement.

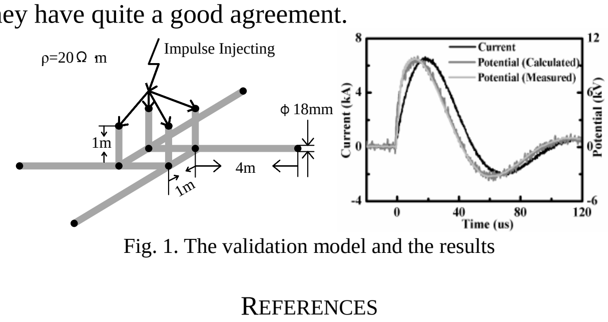

Fig. 1. The validation model and the results

References

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