EMTP MODELLING OF GROUNDING ELECTRODES

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ABSTRACT

In this paper, the capabilities of the Electromagnetic Transients Program (EMTP) are investigated so as to examine the transient behaviour of grounding electrodes under lightning current excitation. Two methods are used, to model the transient response of grounding electrodes, based upon the transmission line approach. The results from the two methods are compares, and general comments regarding the propagation of voltage wave form along the electrode are drawn.

INTRODUCTION

There have been severe attempts to model grounding electrodes under lightning strikes, in the past [1-6]. The advantage of the transmission line approach used here is that the accumulated experience on transmission line modelling can be exploited, since there are similarities between grounding systems and transmission line models under very fast transient conditions, e.g. in lightning.

These techniques are compared in the case of an horizontally and a vertically burried 1m long grounding conductor. Useful results are finally drawn.

THEORETICAL BACKGROUND

The lumped pi-circuits model

Grounding electrodes are characterised by a series resistance R, capacitance C, a series inductance L and a series conductance G. They can be modelled then as series of equivalent pi-circuits, with lumped R-L-C elements, where each pi-equivalent circuit corresponds to a small conductor segment.

A pi equivalent circuit is shown in the figure 1.
The R-L-C parameters of the pi-equivalent circuits are derived from the formulas below [6], based on the well known Sunde's expressions [7]

$$R_{DC} = \rho_c \cdot \frac{4 \cdot dl}{\pi \cdot D^2}, \quad L = \frac{\mu \cdot dl}{2\pi}\left[ln\left(\frac{2l_c}{D}\right) + ln\left(\frac{l_c}{2h}\right)\right],$$

$$G = \frac{2\pi \cdot dl}{\rho_g} \cdot \left[ln\left(\frac{2l_c}{D}\right) + ln\left(\frac{l_c}{2h}\right)\right]^{-1} \quad \text{and}$$

$$C = 2\pi \cdot \varepsilon \cdot \frac{dl}{\left[ln\left(\frac{2l_c}{D}\right) + ln\left(\frac{l}{2h}\right)\right]}$$

The pi equivalents circuit model, is as accurate, as the length of elementary segments decrease, so the effect of segmentation of conductors is quite important.

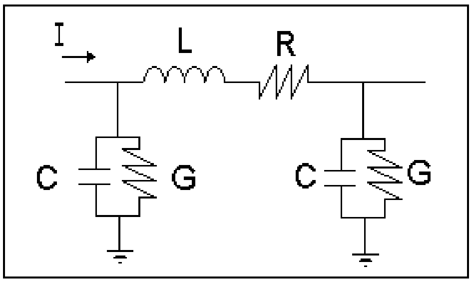

Figure 1 Pi-equivalent circuit

It is adviseable to use a segment length smaller two or three times than the wavelenth in the soil.

In any case, a computationally efficient division, introducing an error within acceptable limits in the range up to 100 kHz, is division into 1m segments.Application into various examples, has shown, that when dividing the electrode into .01 m segments, the results are pretty accurate even in the MHz frequency range.

Frequency Dependent Transmission Line model

This technique, uses the Bergeron' s travelling wave technique. According to this approach, the inherent frequency dependence of the transmission line characteristic impedance Zc(ω) and the corresponding propagation constant A(ω), due to the existence of resistive elements, is taken into account. The functions Zc(ω) and A(ω), the values of which are calculated from the line configuration using a supporting calculation subroutine (LINE CONSTANTS), are expressed in the frequency domain, by rational functions of the form [8]:

$$Q\frac{\prod_{i=1}^{n}(s+z_i)}{\prod_{j=1}^{m}(s+p_j)} = k_0 + \sum_{j=1}^{m}\frac{k_j}{s+p_j}$$

,where the zeros, poles and residues are denoted by z_i, p_j and k_j respectively. This approach is known as JMARTI approach. The advantage of this approximation is that the left hand side of the above equation is transformed in the time domain as quickly damped exponential functions. This facilitates and accelerates the simulation calculations involving convolutions of Zc and A.

The impedance Z' and the susceptance Y' per unit length of an horizontally buried or a vertical bare electrode are obtained by:

$$Z' = Z_i' + Z_e' \qquad Y'^{-1} = Y_i'^{-1} + Y_e'^{-1}$$

where the internal impedance and susceptance of a cylindrical electrode are given by the well known relationships, given by Sunde :

$$Z_i' = \frac{jw\mu_c I_o(\gamma_c a)}{2\pi a \gamma_c I_1(\gamma_c a)} \quad \text{with}$$

$$\gamma_c = \sqrt{jw\mu_c(\sigma_c + jw\varepsilon_c)}$$

$$Y'^{-1}_i = 0$$

once there is no insulation coating, as in the cases examined here.

In the case of a horizontal electrode buried at h m depth in the ground

$$Z'_e = \frac{jw\mu_o}{2\pi}\log\frac{1.85}{\sqrt{\gamma^2+\Gamma^2}\sqrt{2ah}} \quad ,$$

$$Y'^{-1}_e = \frac{1}{\pi(\sigma_E + jw\varepsilon_o\varepsilon_{r,E})}\log\frac{1.12}{\gamma\sqrt{2ah}}$$

with

$$\Gamma = \sqrt{jw\mu_o(\sigma_E + jw\varepsilon_o\varepsilon_{r,E})} \quad \text{and}$$

$$\gamma = \sqrt{Z'(\gamma)Y'(\gamma)}$$

while in the case of a vertical electrode [9]

$$Z'_e = \frac{jw\mu_o}{2\pi}\log\frac{1.12}{\sqrt{\gamma^2+\Gamma^2}a} \quad ,$$

$$Y'^{-1}_e = \frac{1}{2\pi(\sigma_E + jw\varepsilon_o\varepsilon_{r,E})}\log\frac{a\sqrt{\gamma^2+\Gamma^2}}{3.56}$$

Frequency dependent transmission line model, has the advantage of being suitable, for a wide range of frequencies examined, so it can be accurate enough in the case of examining the effects of lightning.

Model of the Lightning current

EMTP simulation of current sources, gives the ability to model lightning strike current as a double exponential waveform current source of type 15.

Two test current sources have been used here: a 30 kA 3/10 μs , and a 3.3kA 8/20 μs one.

EMTP Implementation-Interpretation of results

The two methods described, are applied in the case of an horizontally and a vertically burried 1m long grounding conductor, under a 30kA, 3/10 test current. The conductor is made of copper (radius=.0039m), and is buried in 100 Ohm m soil, in .5 m (in the first case).

Results are comparatively presented in figures 2 and 3, below.

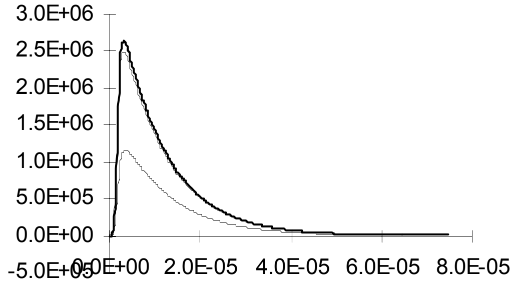

Figure 2 Voltages at start (1) and end (2) points of the grounding conductor, using the lumped pi-equivalent (a) and the frequency dependent (b) line model

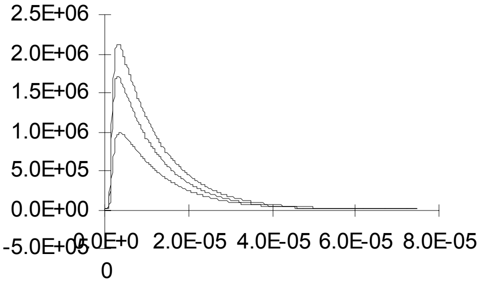

Figure 3 Voltages at start (1) and end (2)points of the grounding rod, using the lumped pi-equivalent (a), and the frequency dependent (b) line model.

An horizontally buried 100m-long grounding conductor, is also examined. The conductor, is made of copper, in 20 Ohm m soil, and 60cm, below the surface. Test current source used, is a 3.3kA 8/20 μs source. Lightning current is injected in the end of the conductor (0m).

Voltages obtained using EMTP simulation, are presented in figures 4-5, that follow.

In figures 6-10, voltages vs conductor length, are plotted, in various time moments. In the first 3.5 μs, voltage values are observed in the first 20 m of the conductor while in the next 10 μs, voltage values appear in 30 m from the injection point. Similarly, voltage values appear in the next 10m during the next 8 μs.In figures 8-10, lower voltage values appear in 0 and 10 m of conductor, due to travelling wave.

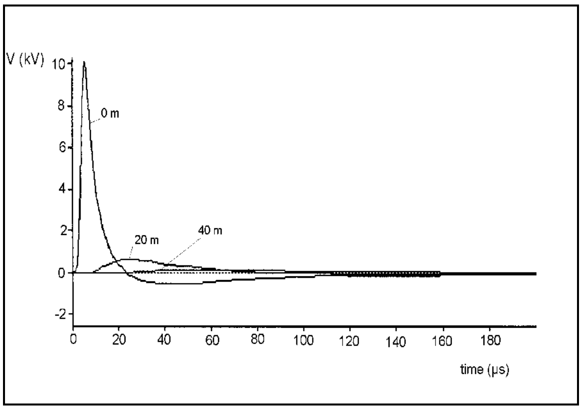

Figure 4 Voltage of conductor points vs. Time (0-40 m)

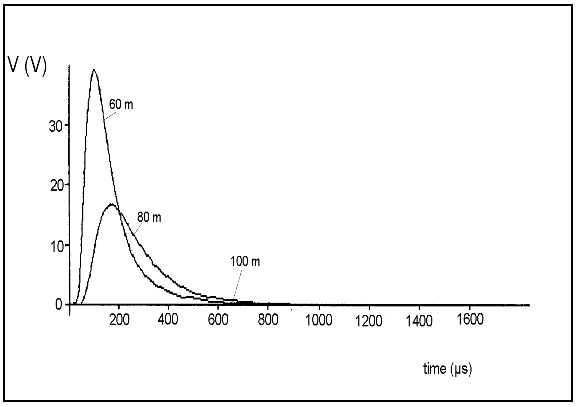

Figure 5 Voltage of conductor points vs. Time (60-100m)

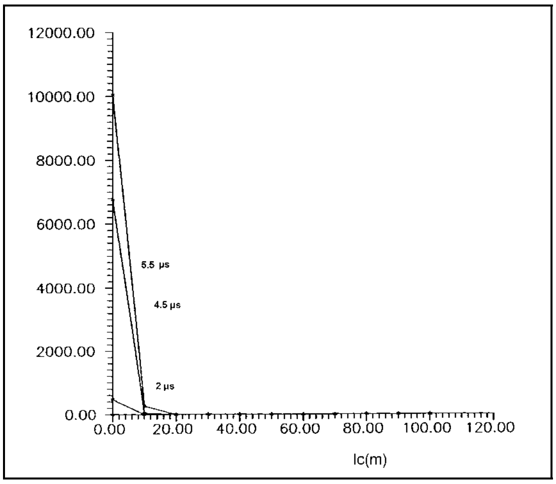

Figure 6 Voltage vs. conductor length (time=0-2μs)

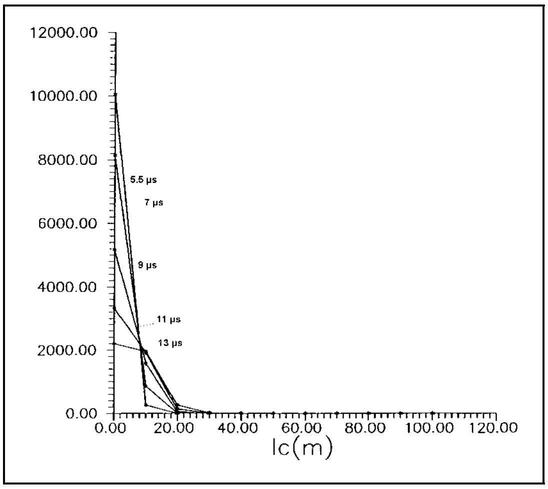

Figure 7 Voltage vs. conductor length (time=3.5-13μs)

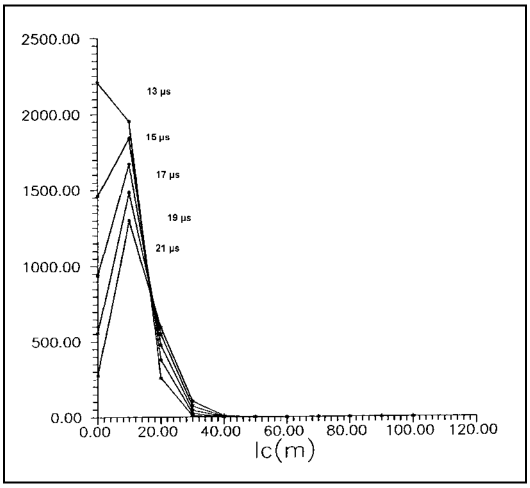

Figure 8 Voltage vs. conductor length (time=13-21μs)

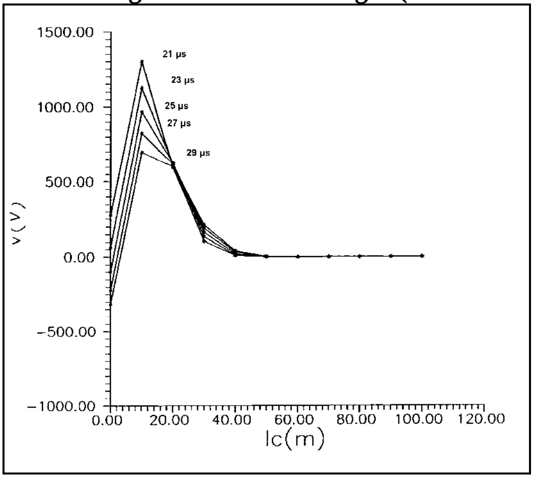

Figure 9 Voltage vs. conductor length (time=21-29μs)

Comments that follow, hold in both the cases of grounding electrodes and grounding rods examined.

Generally, application of the frequency dependent transmission line model, result lower voltage values, in the whole time range the phenomenon is examined. This can be explained, because in the case of the lumped pi-equivalents circuits transmission line model, there is an error introduced in the high frequency response of the electrodes.

In addition, lumped parameters pi-circuits model, results almost no difference between injection point and end point voltages. Frequency dependent transmission line model results, important decrease of voltage along the conductor, thus there is mentionable difference between start and end point voltages.

Generally, transmission line model is computationally less efficient, in cases that both models can give enough accurate results, due to the small integration step used. Appropriate segmentation of the conductor, can give accurate results, even in the MHz frequency range

In the case of long horizontal electrode examined, there can observed the time dependence of the maximum voltage wave front position.

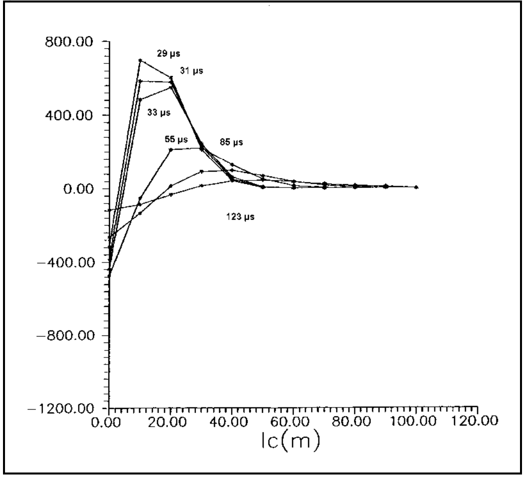

Figure 10 Voltage vs. conductor length (time=29-123µs)

CONCLUSIONS

Grounding electrodes are more frequency dependent than transmission lines. Shunt conductance that is negligible in transmission lines, is the dominant component of the circuit model of a grounding electrode. Distributed capacitance is often non-existent as the grounding electrodes are rarely insulated.

Grounding resistance slightly decreases, when the grounding electrode is vertically buried from the value obtained when it is buried horizontally.

Earth conductivity, is of primary importance, as it acts as a diffusion means leaking the currents flowing in the grounding system.

It is preferable to use the lumped pi-circuits model in case low frequency phenomena are examined, and when the computational memory used (dividing the electrode into small segments) does not exceed a limit.

The frequency dependent transmission line model is accurate, because it is considering the response, in the whole frequency range.
The two EMTP methods used to simulate grounding electrodes transient behaviour, give similar results.

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