EMTP MODELLING OF GROUNDING ELECTRODES

M.I.Lorentzou  N.D.Hatzigargyriou
National Technical University of Athens, Greece

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 compared, 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 buried 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 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 advisable to use a segment length smaller two or three times than the wavelength 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 $Z_c(\omega)$ and the corresponding propagation constant $A(\omega)$, due to the existence of resistive elements, is taken into account. The functions $Z_c(\omega)$ and $A(\omega)$, 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]:

$$\prod_{i=1}^{n} \frac{s + z_i}{s + p_i^j} = \prod_{j=1}^{m} \frac{s - k_j}{s + p_j^i}$$

where the zeros, poles and residues are denoted by $z_i$, $p_j^i$ 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 $Z_c$ and $A$.

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

$$Z' = Z'_{i} + Z'_{e}$$
$$Y'^{-1} = Y'^{-1}_{i} + Y'^{-1}_{e}$$

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

$$Z_{i} = \frac{jw\mu_{i}}{2\pi av_{c}} (y_{c}a)$$
$$Y_{e} = \sqrt{jw\mu_{e}(\sigma_{e} + jw\varepsilon_{e})}$$

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

$$Z_{e} = \frac{jw\mu_{e}}{2\pi} \log \frac{185}{\sqrt{1 + \Gamma^2\sqrt{2ah}}}$$
$$Y_{e}^{'-1} = \frac{1}{\pi(\sigma_{e} + jw\varepsilon_{e}^{r_{e}})} \log \frac{112}{\sqrt{2ah}}$$

with

$$\Gamma = \sqrt{jw\mu_{o}(\sigma_{E} + jw\varepsilon_{o}^{r_{E}})}$$
$$\gamma = Z(\gamma)Y'(\gamma)$$

while in the case of a vertical electrode [9]

$$Z_{e} = \frac{jw\mu_{e}}{2\pi} \log \frac{112}{\sqrt{1 + \Gamma^2 a}}$$
$$Y_{e}^{'-1} = \frac{1}{2\pi(\sigma_{e} + jw\varepsilon_{e}^{r_{e}})} \log \frac{a\sqrt{1 + \Gamma^2}}{356}$$

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 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.

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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AUTHOR'S ADDRESS

Department of Electrical and Computer Engineering
National Technical University of Athens
42, Patission Str., 10682 Athens, Greece
email: lorentz@power.ece.ntua.gr