STSM Cost Action P18 The Physics of Lightning Flash and its Effects

Modeling lightning strikes to tall structures and the associated EM radiation

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1. Propagation effects of electromagnetic field radiated by lightning to tall structures

This STSM allowed the participant to improve his knowledge of the propagation effects on the electromagnetic field radiated from a lightning strike. In particular, starting from a previous work already done before participating to this STSM regarding the investigation of the propagation effects on the vertical electric field radiated by a lightning strike to ground (or to a tall structure) at far distances, the problem to be solved during this mission was to extend the computation of the propagation effects to closer distances.
The convolution integral between the field radiated under perfect ground conditions and the attenuation function for homogeneous ground characterized by its finite conductivity, available in the literature, depends on the angle between the elemental current dipole and the observation point.
While at far distances this convolution integral could be performed only once because that angle varies slightly when the current dipole moves along the lightning channel, at closer distances from the impact point this convolution must be performed for each position of the elemental current dipole.
Considering the large amount of convolution integrals to be performed to obtain the solution for small distances, one needs an approach optimized in terms of memory storage and computation time.
This optimization has been found in the recursive convolution, whose advantage is that one could calculate the fields due to lossy ground at the same time when he calculates the fields from the return stroke and there is no need to store the field for the entire time and later do a convolution. Storing the fields for the entire time and later doing the convolution is indeed computationally inefficient.
In the case of tower lightning electromagnetic fields, we look at the function to be fitted for the application of recursive convolution.

$$E_z(s) = E_0(s) \cdot F(p) \qquad (1)$$

F(p) is the attenuation function due to Sommerfeld and Norton and it is unity when the ground is perfectly conducting [1].

$$F(p) \equiv 1 - i \cdot \sqrt{p} \cdot e^{-p} \cdot erfc\left(i \cdot \sqrt{p}\right) \qquad (2)$$

$$\left.\begin{array}{l} p(s) \cong -\dfrac{s^2 \cdot \rho}{2 \cdot \sigma_g \cdot \mu_0 \cdot C^3 \cdot (1+\delta)} \cdot \left(1 - \dfrac{s}{\sigma_g \cdot \mu_0 \cdot C^2 \cdot (1+\delta)}\right) \\ \delta = \dfrac{\varepsilon_g \cdot s}{\sigma_g}, \quad C = 3 \times 10^8 \end{array}\right\} \qquad (3)$$

Let us consider the attenuation function ***F(p)***: it can be fitted using the Vector fitting equation (4),

$$F_{fit}(s) = \sum_{i=1}^{n} \frac{c_i}{s + a_i} + d + s \cdot e \qquad (4)$$

It can be demonstrated that the recursive convolution works fine if the parameters ***d*** (constant part) and ***e*** (proportional part) in the above equation are negligible. In the above equation, c_i and a_i are the residues and poles of the function respectively so that,

$$F_{fit}(s) = \sum_{i=1}^{n} \frac{c_i}{s + a_i} \Rightarrow \sum_{i=1}^{n} c_i \cdot e^{-a_i \cdot t} \qquad (5)$$

It was found that there is a perfect fit for the attenuation function ***F(p)***, with negligible constant and proportional parts. Note that the poles and residues are both types real and complex conjugates. But even with complex arguments the recursive convolution can be used. One might wonder that there could be complex values for fields after convolution. It can be mathematically shown in time domain the imaginary parts will perfectly cancel each other and leave alone the real parts. This shows the primary advantage of recursive convolution in lightning propagation related problems as the ground losses can be easily handled by fitting.
The convoluted final waveforms obtained using recursive convolution have been found to be identical to the ones presented in [2] and shown in fig. 1, where the current distribution from the tower and the channel were first calculated and the field for perfect ground case was calculated and then stored. The stored field was then convoluted with the attenuation function in time domain using the so-called step function method.
That paper investigated the case of an observation point located at a distance of 100 km from the channel. To demonstrate the time saving and computation efficiency we need to do an example close to the tower in the future.

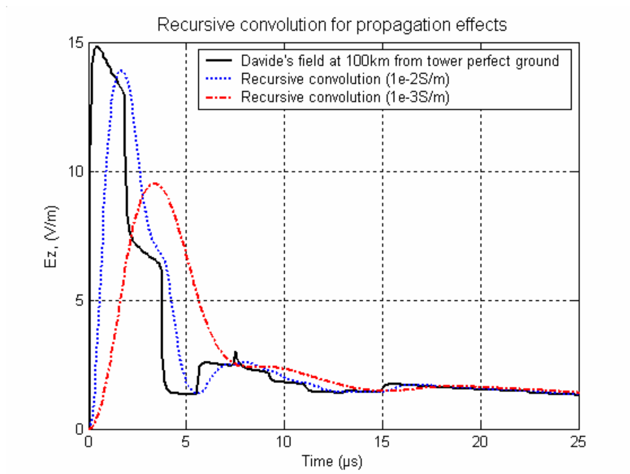

fig.1 – Propagation effects for a distance of 100 km using recursive convolution

2. **Electromagnetic environment of a tall structure struck by lightning**

Less time has been devoted to this second subject.
In particular, the recent measurements gathered in Toronto of return stroke current and radiated electromagnetic field from lightning striking the CN tower have been observed carefully in order to determine suitable parameters for reproduce them with an engineering model.
The current peaks, in particular, appeared after a first look to be few times lower than expected.
Further investigation is needed in this direction.

References

[1] Wait, *"Propagation effects for electromagnetic pulse transmission"*, IEEE Proceedings, Vol.74, Sept 1986.

[2] Pavanello et al., *"Propagation effects on the electromagnetic field radiated by lightning to tall towers", SIPDA 2005, Brazil.*

Acknowledgements

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