Electric Power Systems Research 118 (2015) 101–109

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Propagation of lightning electromagnetic fields in the presence of buildings

Marcos S. Vieira [a,*], Jorge M. Janiszewski [b]

[a] Engineering School, Mackenzie University, São Paulo, SP, Brazil
[b] Polytechnic School – PTC, University of São Paulo, São Paulo, SP, Brazil

ARTICLE INFO

Article history:
Received 10 March 2014
Received in revised form 19 July 2014
Accepted 21 July 2014
Available online 27 August 2014

Keywords:
Lightning
Buildings
Electromagnetic fields propagation
Computational simulation
Modeling
FDTD

ABSTRACT

Coupling of lightning electromagnetic fields to distribution lines causes overvoltages that can provoke interruption of energy supply and damage to equipment of the power network and consumers.

The propagation of these electromagnetic fields is strongly affected by nearby buildings and the effect depends on both the electric and the geometric parameters of the buildings and on the electric characteristics of the soil.

The influence of the permittivity and conductivity of buildings with different heights on the behavior of lightning electromagnetic fields was studied. First and subsequent strokes and different values of soil parameters were considered. The electromagnetic fields were calculated with the Microwave Studio module of the CST Studio Suite 2013 software.

The results have shown that the vertical electric field is reduced by the presence of buildings, practically in the same way for first and subsequent strokes. PEC buildings cause significantly greater reduction than concrete buildings and the effect is greater for higher buildings. The influence of buildings on the horizontal electric field is very much complex. Depending on the specific condition and type of stroke (first or subsequent stroke), reduction or increase and polarity inversion can be observed, along with negative excursion and oscillation. Regarding magnetic fields, only with subsequent strokes and higher PEC buildings a significant effect was observed due to the occurrence of oscillations.

1. Introduction

Because of their deleterious effects, such as interruptions of energy supply and damage to network or consumer equipment, lightning effects on electric power distribution systems have been extensively studied [1,2].

Although the effect in electrical systems is usually more severe when the lightning hits directly the lines, indirect lightning, responsible for induced voltages on the power lines, deserve more attention due to their higher frequency of occurrence [1,3].

Many studies have been performed by measurements in real and scale models and by computer simulation, mostly focusing on the voltages induced on the distribution lines, with or without protection [4–8].

Calculation of the overvoltages induced on distribution lines requires the evaluation of the electromagnetic fields generated by lightning, followed by the application of a suitable coupling model [9–11].

Lightning electromagnetic fields magnitude and waveform depend on the distance to the point of incidence of the lightning and on the electric parameters of the soil [12–16]. Moreover, the fields show a particular behavior when lightning hits elevated structures [17].

Few studies were developed, however, aiming to evaluate the fields radiated by lightning taking into account both the presence of buildings with different characteristics and the electric parameters of the soil, so as to represent the region near the electric power lines more realistically.

A study developed in a reduced scale model built in USP – University of São Paulo – Brazil [7] has shown that significant changes occur in the values of induced overvoltages on the distribution lines, when nearby buildings distort the field patterns. This study considered soil and buildings as perfect electrical conductors.

Similarly, in Ref. [18] simulation results have shown that buildings affect the lightning electric field and the associated induced overvoltages. In this study, the soil and the buildings were again assumed as perfect electric conductors.

* Corresponding author. Tel.: +55 11976898804.
E-mail addresses: marcos_sv@mackenzie.com.br, mstefanelli.vieira@gmail.com, marcos_sv@mackenzie.br (M.S. Vieira), jorge@lcs.poli.usp.br (J.M. Janiszewski).

http://dx.doi.org/10.1016/j.epsr.2014.07.025
0378-7796/

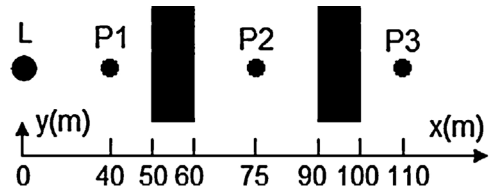

Fig. 1. Top view of the system analyzed. Black rectangles: buildings; L: lightning; P1, P2, P3: field measurement points.

A more realistic analysis of the behavior of vertical and horizontal electric fields was presented in Ref. [19]. The influence of electric and geometric parameters of buildings as well as of soil characteristics was evaluated. The simulations have considered first strokes and the results have shown that, in certain situations, the horizontal electric field in particular presents a complex behavior with polarity inversion or negative excursion. This behavior appears even without buildings, as seen in the results presented in Refs. [8,12–16].

Thus, as the combination of soil and buildings characteristics defines the behavior of the lightning fields, for reliable results the power network region must be realistically represented.

In this context, this paper presents the analysis of the influence of buildings of different heights and with different permittivity and conductivity of soil and buildings on the lightning electric and magnetic fields at various points, for first and subsequent strokes.

2. Methodology

Although the phenomena involved in the problem are well understood, the system to be analyzed is not of simple configuration, therefore a computational solution is recommended.

The analysis of electromagnetic fields was performed by the Microwave Studio module of the software CST Studio Suite 2013 [20], using its Time Domain Solver based on the Finite Integration Technique – FIT, with hexahedral mesh and Open Boundary condition at the boundaries of the simulation domain. The analyzed configuration is depicted in Fig. 1, where the buildings (represented by black rectangles) have width and depth of 40 m and 10 m respectively. The lightning stroke is supposed hitting the point indicated by L, generating electromagnetic waves that propagate toward the buildings.

The lightning channel, 500 m long, was simulated by a conducting wire (current propagation velocity c), which is of simple implementation in the software. For lower channel propagation velocities, the vertical electric field at the distances considered in the study would present a higher peak value and a longer front time, which, as shown in Section 3.1, do not affect the conclusions obtained. On the other hand, for lower velocities, at the distances considered and with the soil conductivities assumed in the study, the horizontal electric field would present a greater positive peak value and a smaller negative excursion, but the changes on the waveforms would not be significant [21]. For excitation of the channel a current source was selected in the CST options.

Two different situations were considered: a first stroke current with front time 3.8 μs and amplitude 31.0 kA, and a subsequent stroke with front time 0.7 μs and amplitude 12.3 kA. The subsequent stroke was supposed with a 21.0 μs tail time, value similar to that adopted in Ref. [18], and for the first stroke the tail time was assumed as 28 μs. These are short values, but they did not influence significantly the conclusions because in the analysis only the initial part of the waveforms was considered and the effect of buildings was evaluated by comparing the field waveforms (peak values) with and without buildings for the same stroke current.

Three values of building heights were considered: $h = 5$ m, $h = 15$ m and $h = 45$ m.

The points for calculation of the fields were considered at 10 m above the soil level and are indicated by P1, P2 and P3.

All the analyses were performed in a parallelepiped 500 m high, extending 600 m and 500 m in the x and y directions, respectively. To avoid undesired reflections at the boundaries, all faces of this computational domain were defined in the software as Perfectly Matched Layers. Buildings material was assumed to be concrete forty years old as defined in the CST [20] with given frequency dependent real and imaginary parts of the permittivity, while the soil was assumed with a depth of 30 m and two different values of conductivity and permittivity: Soil 1 ($\sigma = 0.0005$ S/m and $\varepsilon r = 3$) and Soil 2 ($\sigma = 0.002$ S/m and $\varepsilon r = 10$). Soils with greater depths and buildings of concrete one year old (with parameters defined in the software) were also considered in the simulations with negligible changes observed in the results. In order to illustrate a limit condition, the buildings and the soil were also considered as perfect conductors (PEC).

The spatial discretization adopted has resulted in approximately 0.5×10^6 points for situations with Soil 1 and Soil PEC and 1.2×10^6 points for Soil 2. It was verified that further refinement of the discretization did not provoke significant differences on the calculated fields. In all cases, the used time step was approximately 3.8 ns.

A large number of computational simulations were performed according to the parameters proposed. In the next section, results are presented with relevant considerations.

3. Results and discussion

The results of simulations are presented considering the vertical and horizontal components of the electric field and the horizontal magnetic field observed at 10 m above the soil level.

Values corresponding to points P1, P2 and P3 are shown in detailed form in Tables 1–4. Additional simulations were performed at points situated at the same x-coordinates as P1, P2 and P3, but shifted in the y direction 20 m and 40 m, to evaluate the effect at the vicinity of the buildings. For these points some pertinent commentaries are presented at the end of the text relative to each

Table 1
Relative peak values – vertical electric field.

Subsequent stroke										
Soil type	Building material	Building height = 5 m			Building height = 15 m			Building height = 45 m		
		P1	P2	P3	P1	P2	P3	P1	P2	P3
Soil 1	Concrete	0.99	0.96	0.97	0.90	0.82	0.83	0.88	0.84	0.86
Soil 1	PEC	0.99	0.95	0.97	0.79	0.61	0.65	0.50	0.11	0.20
Soil 2	Concrete	0.99	0.96	0.97	0.89	0.82	0.83	0.88	0.84	0.86
Soil 2	PEC	0.98	0.94	0.96	0.79	0.61	0.64	0.49	0.09	0.22
Soil PEC	Concrete	0.99	0.96	0.98	0.89	0.82	0.82	0.88	0.84	0.86
Soil PEC	PEC	0.99	0.94	0.96	0.80	0.62	0.65	0.50	0.08	0.22