Lightning Return Strokes to Tall Towers: Ability of Engineering Models to Reproduce Nearby Electromagnetic Fields

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Abstract

We present measurements of nearby vertical and horizontal electric fields from leaders and return strokes associated with lightning strikes to the 100-m tall Gaisberg Tower in Austria obtained in 2007 and 2008. The fields were measured at a distance of about 20 m from the tower's vertical axis. Simultaneously with the fields, return-stroke currents were also measured at the top of the tower. The measured data are used to test engineering models for the return stroke. In general, the agreement between measured waveforms and model-predicted ones are satisfactory.

1. Introduction

The knowledge of the characteristics of electromagnetic fields produced by lightning discharges is needed for studying the coupling of lightning fields to various electrical circuits and systems, as well as sensitive electronic circuits. On the other hand, measured electric and magnetic fields can be used for the indirect estimation of lightning parameters and for testing lightning models.

Bermudez et al. [1] made simultaneous recordings, gathered during the summers of 2000 and 2001, of the return-stroke current and its associated electric and magnetic fields measured at two distances, namely, 2 km and 16.8 km, related with lightning strikes to the CN Tower. During the summer of 2005, Pavanello et al. [2] measured the vertical component of the electric field and the azimuthal component of the magnetic field produced by lightning strikes to the CN Tower at three distances, 2.0, 16.8, and 50.9 km, from the tower. Pavanello et al. [2, 3] compared the measured waveforms with predictions of the engineering return-stroke models extended to include the presence of the strike object. A reasonable agreement was found for all the models for the magnetic field waveforms at the three considered distances, although the peak values of the computed fields were systematically about 25% lower than the measured values [2]. None of the models, however, was able to reproduce either the initial double-peak, the early zero crossing and the narrow undershoot, seen in the measured field waveforms, or the typical zero-crossing of the far field. As far as the electric field was concerned, larger differences were observed between simulations and measurements. These differences were attributed to the enhancement effect of the metallic structures of the buildings on which measuring sensors were located [2]. More recently, Mosaddeghi et al. [4] proposed an extension of the engineering return-stroke models for lightning strikes to tall structures that takes into account the presence of possible reflections at the return stroke wavefront and the presence of an upward connecting leader. Simulation results for the magnetic fields were compared with experimental waveforms associated with lightning strikes to the CN Tower (553 m) and it was shown that the extended model was able to reproduce all the aforementioned features of the electromagnetic fields.

The aim of this paper is to test the ability of engineering models to reproduce the electric fields at very close distance ranges from a tower struck by lightning. To do this, we will use recent measurements of nearby vertical and horizontal electric fields from lightning strikes to the 100-m tall Gaisberg Tower in Austria obtained in 2007 and 2008 [5]. The fields were measured at a distance of about 20 m from the tower's vertical axis. Simultaneously with the fields, return-stroke currents were also measured at the top of the tower.

2. Experimental Setup and Data

The Gaisberg Tower is a 100-m tall radio tower located 1287 m above sea level on the top of a mountain 5 km east of the city of Salzburg, Austria. On average, the tower is exposed to about 60 upward initiated flashes per year [6].

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The current at the tower top is measured with a current viewing shunt with 0.25 mΩ and a total bandwidth of 0 Hz to 3.2 MHz. The electrical signal is split into two channels with a measuring range of ±2 kA and ± 40 kA, respectively. The signals of these two channels are routed to the bottom of the tower via fiber optic links (Isobe 3000, bandwidth 0 Hz – 15 MHz) to the recording system consisting of a two-channel 20 MS/s, 8-bit digitizer. The recording time for each event is 800 ms with a 15-ms pre-trigger.

Radial electric fields at 20-m distance from the tower center axis were measured using an active spherical electric field sensor (TSN 245-E30, Thomson CSF, 1 kHz – 150 MHz). A similar sensor but with a different sensitivity (TSN 245-E31, Thomson CSF, 1 kHz – 150 MHz) was used to measure the vertical electric field at 22 m. All the sensors were located on the metallic roof of a one-storey building at a height of about 3 meters above ground. The measured signals from the sensors were relayed via fiber optic links to the recording system, which consisted of a 100-MS/s, 8-bit digitizer with 1 MB memory per channel and a computer controller with local clock. A 40-MHz low pass filtering was applied to both electric and magnetic field signals to reduce high frequency noise and to minimize aliasing.

It is worth noting that the electric field sensors being located on the top of metallic structures could result in a local enhancement of the electric field. However, a calibration campaign aiming at evaluating such an enhancement effect was carried out in the Summer of 2008, measuring waveforms associated with distant lightning return strokes and using as reference a flat plate antenna located on the surface of the ground. The campaign revealed that the enhancement effect of the metallic structures on the measured electric fields was minimal (about 1.1). More details on the experimental setup and the obtained data can be found in [5].

Two representative data sets have been selected for the simulation and comparison (see Figs. 1 and 2). Note that, as discussed in [5], a 750-kHz low pass Butterworth filter was applied to the measured current waveforms to filter out the high frequency oscillations visible in the early time response of the current and whose origin is currently unknown. The filter used was chosen because the resulting current waveforms have similar early-time waveshapes to those of the corresponding magnetic fields measured at 20 m.

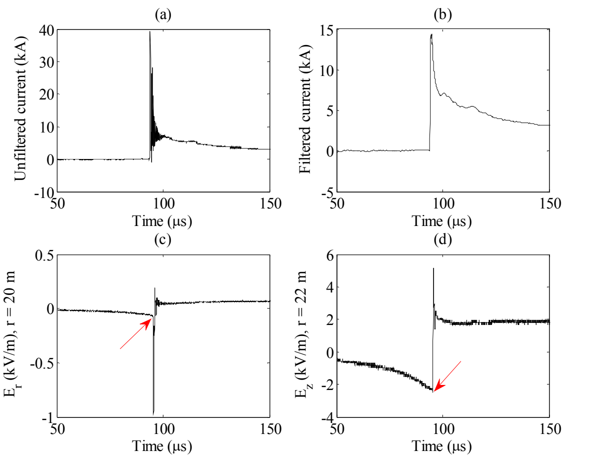

Fig. 1. Representative waveforms of the data recorded on 2008-07-20, (a) tower top unfiltered current, (b) tower top 750 kHz filtered current, (c) radial electric field at *r* = 20 m, and (d) vertical electric field at *r* = 22 m (flash 682, stroke 2 of 3). The arrows in the plots represent transition from leader to return stroke.

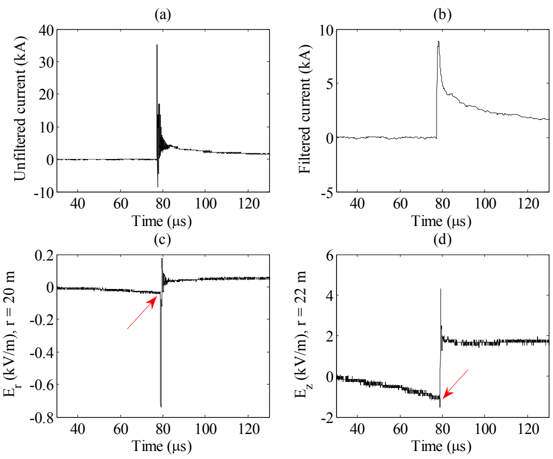

Fig. 2. Representative waveforms of the data recorded on 2008-07-20, (a) tower top unfiltered current, (b) tower top 750 kHz filtered current, (c) radial electric field at r = 20 m, and (d) vertical electric field at r = 22 m (flash 682, stroke 3 of 3). The arrows in the plots represent transition from leader to return stroke.

The vertical and radial electric field waveforms appear as asymmetrical V-shaped pulses. For the vertical electric field, the initial, relatively slow, negative electric field change is due to the downward leader and the following fast positive field change is due to the upward return stroke phase of the lightning discharge. For the horizontal electric fields, however, the bottom of the V is not associated with the transition from the leader to the return stroke. The horizontal field change due to the return stroke is characterized by a short negative pulse of the order of 1 microsecond or so, starting with a fast negative excursion followed by a positive one [5].

3. Simulations and Comparison with Experimental Data

In this work, we used the extension of the MTLE engineering model, as proposed by Mosaddeghi et al. [4], which is based on a distributed-source representation [7]. Note that an equivalent representation based on a lumped voltage source at the junction point between the channel and the strike object has been proposed by Baba and Rakov [8].

A value of 2 km was assumed for the current decay constant λ, and the return stroke speed was assumed to be v = 120 m/μs.

For each event, the so-called 'undisturbed current' [7] is represented using the sum of two Heidler's functions [9]. The parameters of the Heidler's functions were determined for each event using a trial-and-error approach to obtain the best match with the filtered recorded currents. The strike object is characterized by the reflection coefficients on the top and button of the tower, ρ_t = -0.35, and ρ_g = 0.9, respectively. These values resulted in the best agreement with the measured current waveforms on the top of the tower. Figs 3a and 4a present, for the two considered events, the filtered current waveforms as well as the waveforms obtained using the adopted representation using Heidler's functions.

Figures 3b,c and 4b,c show the comparisons between the measurements and the simulations for the vertical and horizontal electric fields of the return stroke phase of the two events. It can be seen that the model-predicted electric field waveforms are in reasonable agreement with measured waveforms.

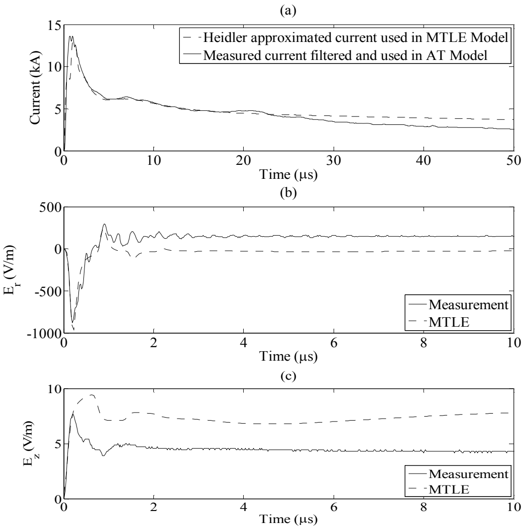

Fig. 3. (a) current on the top of the tower, (b) radial electric field, (c) vertical electric fields (measured and MTLE)

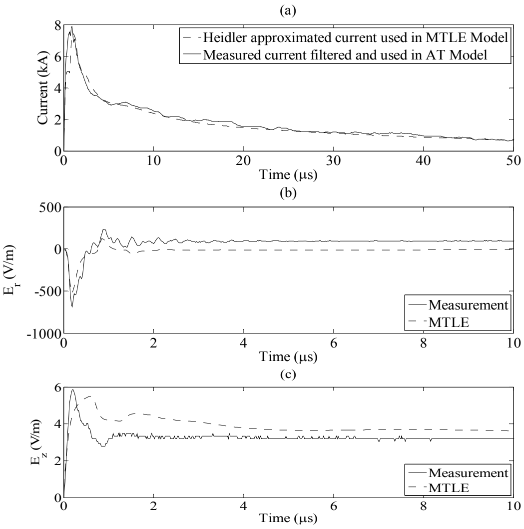

Fig. 4. (a) current on the top of the tower, (b) radial electric field, (c) vertical electric fields (measured and MTLE)

3. Conclusions

We presented recent measurements of nearby vertical and horizontal electric fields from leaders and return strokes associated with lightning strikes to the 100-m tall Gaisberg tower in Austria obtained in 2007 and 2008. The fields were measured at a distance of about 20 m from the tower's vertical axis. Simultaneously with the fields, return-stroke currents were also measured at the top of the tower. The measured data were used to test engineering models for the return stroke. The extended MTLE engineering model was used in the study. The parameters of the undisturbed current, represented using Heidler's functions, were determined for each event using a trial-and-error approach to obtain the best match with the recorded currents on the tower top. In general, the agreement between measured waveforms and model-predicted ones were found to be satisfactory.

4. Acknowledgments

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5. References

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