Electric and Magnetic Field Measurements at Very Close Range Associated with Lightning Strikes to the Austrian Gaisberg Tower

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Abstract

This paper presents a preliminary analysis of recently obtained experimental data associated with lightning strikes to the Gaisberg Tower in Austria. Electric field changes were measured at distances of 22 m and 170 m from the tower base and the magnetic field was measured at a distance of 20 m. Simultaneously, the lightning return stroke current was measured using a sensor located near the top of the tower. The electric field waveforms feature the typical asymmetrical V-shaped pulses, the bottom of the V being associated with the transition from the leader to the return-stroke. The obtained results confirm the shadowing effect of the tower in reducing the electric fields in the immediate vicinity of the tower.

1.Introduction

Lightning interaction with tall structures has recently been the subject of several studies (e.g. [1, 2]). The effect of the presence of a strike object on the radiated electric and magnetic field depends essentially on the height of the strike object, as well as the distance to the observation point. For observation points located at distances exceeding the height of the tower, the presence of the tower results in a substantial increase of the electric and magnetic field peaks (e.g. [3-5]). On the other hand, theoretical analyses suggest that the presence of the tower at distances of about the height of the tower or less could result in a significant decrease of the electric field peak (e.g. [5-7]), and sometimes in an inversion of polarity [8].

In this paper, we present preliminary results on currents and electromagnetic fields recorded at two close distances for several lightning flashes to the Gaisberg Tower which occurred during the fall 2007.

2. Experimental Set-Up

2.1 Gaisberg Tower Instrumentation

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 [9]. On average, the tower is exposed to about 40 flashes per year. 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 signal 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. Recording time for each event is 800 ms with 15 ms pre-trigger.

2.2 Electromagnetic Field Measuring Systems

The vertical component of the electric field and the azimuthal component of the magnetic field were measured at about 20 m from the Gaisberg Tower. Two active sensors were located on the roof of a one-storey building at about 3 meters above ground: a spherical E-field sensor (TSN 245-E32, Thomson CSF, 1 kHz – 130 MHz) for the E-field and

an H-field loop antenna sensor (TSN 245-H30, Thomson CSF, 4 kHz – 130 MHz) for the H-field. The measured signals from the two sensors were relayed via fiber optic links to the recording system, consisting of a 100-MS/s, 8-bit digitizer with 1 MB memory per channel and a computer controller equipped with a GPS receiver for time stamping. The time scale of the digitizer was set to 20-ns resolution and segmented for recording up to twenty 200-μs long strokes per lightning flash. A 40-MHz low pass filtering was applied to both electric and magnetic field signals.

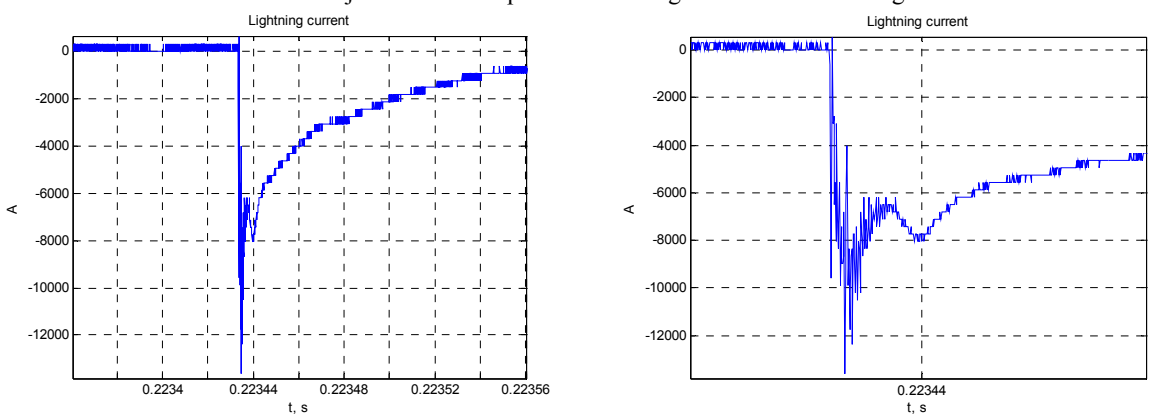
A second measuring station is installed 170 m away from the tower where the vertical electric field is measured using a flat plate antenna with an active integrator. The total bandwidth of the system is from 300 Hz up to 1 MHz. The electrical signal is converted to an optical signal using an optical converter (Isobe 5500, Bandwidth 0 Hz – 25 MHz) and relayed to the recording system (5 MS/s, 12 bit resolution) which is inside an EMC-safe cabinet. Recording time is 5 seconds with two seconds pre-trigger time.

3 Experimental Data

During the period from September 4 to November 10, 2007, the measuring system recorded a total of 42 flashes striking the Gaisberg tower, 18 of which did not show any return strokes. The remaining 24 flashes contained a total number of 272 strokes where 195 were classified as α-pulses and 77 as β-pulses [10] respectively.

A representative set of simultaneously measured return-stroke current and associated electric fields at 22 m and 170 m, and magnetic field at 20 m is reported in this section for the first stroke of a 5-stroke flash which occurred on October 19, 2007 at 11:05:41 UTC.

The return stroke current recorded just below the tip of the Gaisberg tower is shown in Fig.1.



(a) (b)

Fig. 1 – Return-stroke current recorded on the Gaisberg tower: 200-us timescale (a) and 40-us timescale (b).

Some high frequency noise is superimposed to the first peak of the return-stroke current, which is thought resulting from EM interference into the optical converter at the tower top (this speculation is supported by the absence of this noise in the close magnetic field). The current record shows a second, smaller peak of about 8 kA, which is not influenced by the initial noise.

The magnetic and the electric fields at the nearest measuring station are presented in Fig. 2.a and Fig 2.b, respectively. The electric field waveform recorded at 200 m is represented in Fig. 3.

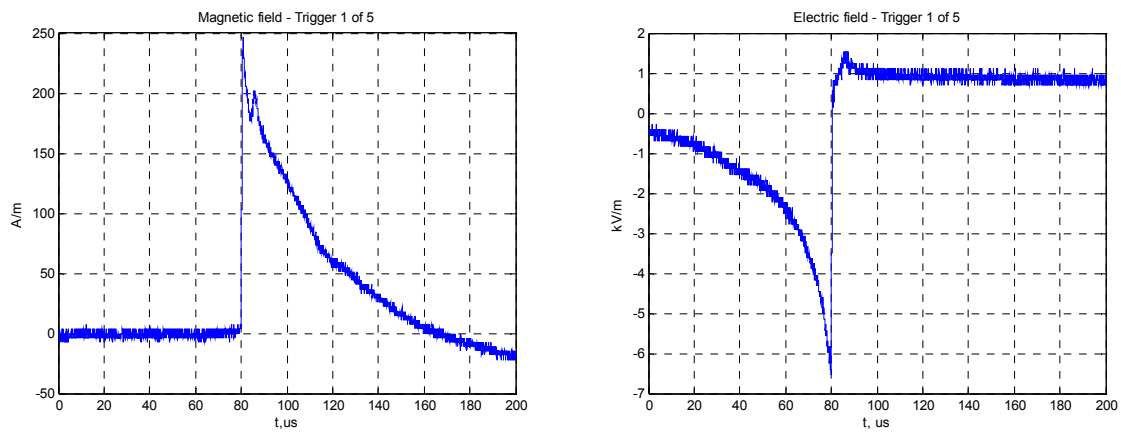
The magnetic field is characterized by a wave shape similar to that of the incident current. The overall (leader + return-stroke) electric field waveforms appear as asymmetrical V-shaped pulses [11] with a width at half peak of about 15 μs at 22 m and about 40 μs at 170 m. The initial, relatively slow, negative electric field change[1] is due to the downward leader and the following fast positive field change is due to the return stroke phase of the lightning discharge.

The following comments can be made on the obtained data:

1. The magnetic field appears to be a factor of about 2.5 larger than the value predicted by the Ampere's law, which should in principle be applicable at the considered distance [12]. This enhancement could be due to several possible causes such as the proximity to the tower base and other close-by metallic structures, and also to the presence of a horizontal ground wire connected to the base of the tower which runs close to the magnetic field sensor and might give a non-negligible contribution to the overall magnetic field.

[1] The atmospheric electricity sign convention is used throughout this paper, according to which a downward-directed field is defined as positive.

2. The return-stroke electric field change at 22 m appears to be significantly smaller than similar measurements obtained using triggered lightning. Crawford et al. [13] present electric field waveforms featuring return-stroke field changes in the order of 40 kV/m at a distance of 20 m from a triggered lightning discharge with a current peak of 11 kA. This is presumably due to the shadowing effect of the tower which results in a significant decrease of the electric field at distances of about the height of the tower or less (e.g. [5-7]).
3. It is also interesting to observe that the electric field change at 22 m is even smaller than that measured at 170 m. This can be partially due to the shadowing effect of the tower which results in the flattening, and even slight attenuation of the E-field peak when the observation point approaches the tower [14, 15]. Note also that the two electric field sensors are located on the top of metallic structures which could result in a local enhancement of the electric field of a factor typically ranging from 1.5 to 2.5 [16-18].



(a) (b)

Fig. 2 – Magnetic field at 20 m (a) and Electric field at 22 m (b) from the tower base.

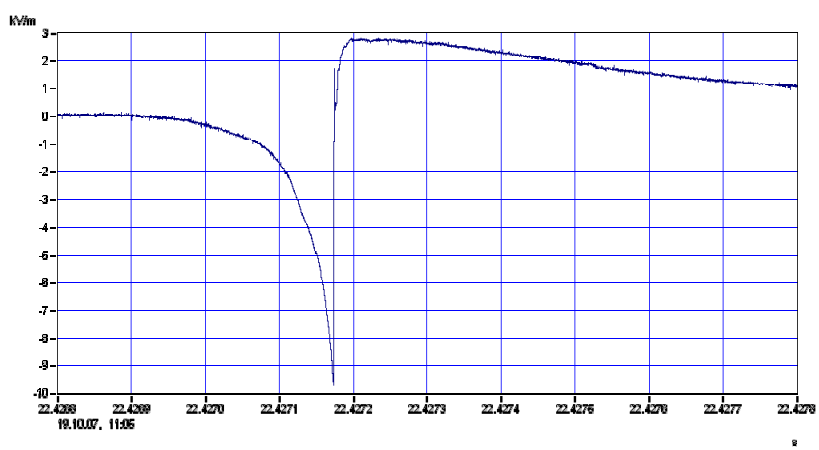


Fig. 3 – Electric field at 170 m over a time window of 1 ms.

4. Conclusion

A preliminary analysis of recently obtained experimental data associated with lightning strikes to the Gaisberg Tower in Austria was presented. The data consist of simultaneously recorded waveforms of lightning return stroke current on the tower, electric fields at 22 m and 170 m from the tower, and magnetic field at 20 m from the tower.

The electric field waveforms are characterized by the typical asymmetrical V-shaped pulses, the bottom of the V being associated with the transition from the leader to the return-stroke.

The obtained results confirm the shadowing effect of the tower in reducing the electric fields in the immediate vicinity of the tower.

5. Acknowledgments

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