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Preliminary measurements and analysis of lightning electric field recorded at the observation station in the South-east part of Poland

Abstract. *In this paper we have presented preliminary measurements and analysis of lightning electric field recorded at a new lightning observation station installed at Rzeszow University of Technology, Poland. Parameters of the lightning electromagnetic field are determined based on the power spectrum density obtained from the short-time Fourier transform. Typical lightning electric field waveform recorded during summer season 2013 was analyzed for different frequency ranges and parameters of the transformation. The most important features of the analyzed electric field waveform generated by the far lightning return stroke can be determined based on the dynamic spectrum the upper frequency of which does not exceed 25 kHz. The obtained results can be applied for location and warning systems purposes to develop effective algorithms of lightning parameters recognition.*

Streszczenie. *W artykule przedstawiono pierwsze wyniki pomiarów oraz analizę piorunowego pola elektrycznego zarejestrowanego na stacji obserwacji wyładowań atmosferycznych Politechniki Rzeszowskiej, w Polsce. Parametry pola elektrycznego zostały wyznaczone w oparciu o spektrogramy gęstości widmowej mocy otrzymane z wykorzystaniem krótkoczasowej transformaty Fouriera. Analizie poddano typowy przebieg piorunowego pola elektrycznego zarejestrowany podczas sezonu burzowego w 2013 roku. Przebiegi były badane dla różnych zakresów częstotliwości oraz parametrów transformaty. Najważniejsze cechy analizowanego pola elektrycznego pochodzącego od dalekiego wyładowania głównego mogą być określone na podstawie dynamicznego spektrum, którego górna granica częstotliwości nie przekracza 25 kHz. Otrzymane rezultaty mogą być zaimplementowane w nowych algorytmach identyfikacji parametrów piorunowych, głównie na potrzeby systemów lokalizacji oraz wczesnego ostrzegania przed burzami.* ***(Wstępne pomiary i analiza piorunowego pola elektrycznego zarejestrowanego na stacji obserwacyjnej w południowo-wschodniej części Polski).***

Keywords: lightning observation station, lightning electric field waveforms, fast video recording, lightning protection
Słowa kluczowe: stacja obserwacji wyładowań, piorunowe pole elektryczne, szybka rejestracja wideo, ochrona odgromowa

doi:10.12915/pe.2014.04.21

Introduction

Lightning is one of the most interesting and unpredictable natural phenomena. Its features are studied worldwide by different groups of researchers [1, 2, 3]. Typical physical parameters of lightning discharges are obtained with application of advanced measuring equipment. Most of them are determined based on measurements of slow and fast electric field waveforms [4, 5, 6, 7]. Different indirect methods of current estimation and lightning channel location are widely used in different detection networks and commercial warning systems [8, 9, 10, 11, 12]. Typical identification algorithms work in the time domain. However, such algorithms can be carried out on the basis of the frequency domain of the registered electric field waveforms. For example, the hybrid analysis using the short-time Fourier transform (STFT) has many advantages. The STFT can be used to compute the power spectrum density (PSD) of the signal in order to estimate and identify particular flash events as preliminary breakdowns (PB), return strokes (RS), continuous currents (CC), and inter-cloud discharges (IC). Also, the lightning parameters computed with application of the PSD analyses can be used for overvoltage protection purposes [13,14].

The lightning observation station operated at Rzeszow University of Technology (RUT) is designed to perform such analyzes [15,16]. Recording process is based on slow (up to 10 Hz) and fast electric field (up to 3 MHz) antennas [Fig.1]. Power supply and signal registration system is switched on automatically by trigger signal transmitted from the antenna. The electric field data together with the corresponding video recorded by the high-speed camera Photron SA5 in HD quality with speed 7000 fps is stored in the information system. The time is synchronized by the GPS sensor. The entire system is automatically switched off when the storm activity is finished.

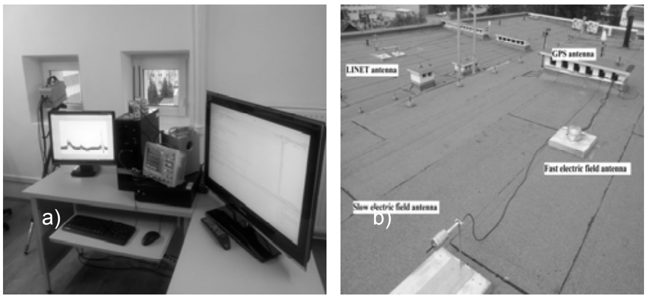

Fig.1. Lightning observation station in Rzeszow. Equipment installed in the laboratory – a). Antennas located on the roof of the building of Electrical and Computer Engineering Department – b).

Algorithms used at the station are supported by Matlab and the Windows Standalone Applications.

High level automation of all operations should increase the number of registrations and prevent measuring equipment from overload. Currently, some storm statistics, including number of electric field recorded, video registrations and precise time of particular flashes can be delivered to the specified e-mail address.

Data processing and analysis

In this section analysis of the preliminary registration is carried out in the time-frequency domain. In 2013, that is, in the first year of operation of the station, only few electric field waveforms have been collected. This is because further improvements and adjustments were necessary to system, and also, there was extremely low thunderstorm activity in South-east part of Poland in the summer season 2013.

The lightning electric field waveform selected to the analyses were registered on August 13, 2013 at 13:35:58.230573 (UTC). This is the time of the trigger event indicated as the beginning of the first significant flash in

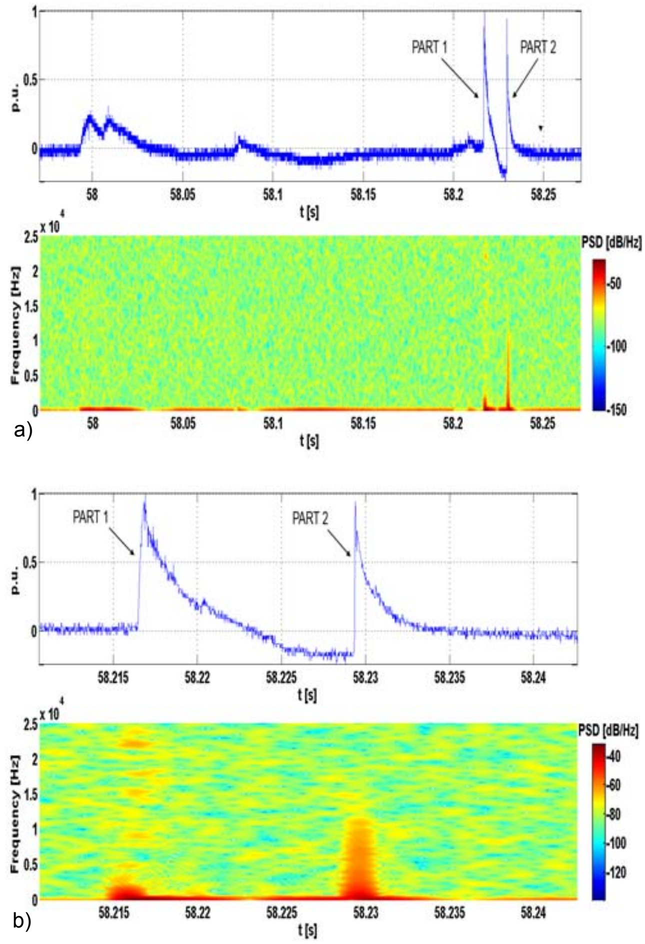

Fig.2. Electric field recordings with the corresponding PSD analysis. Lightning electric field waveform recorded at RUT in 300 ms time scale – a). Part of the same waveform in 35 time scale – b). PSD was done up to 25 kHz; the STFT parameters: window: 128 probes, overlap: 120 probes, sampling frequency: 50 kHz.

Fig. 2. Preceding events were below trigger sensitivity. Fig. 2a includes a sequence of several negative lightning discharges (negative charge transferred to the ground) with different peak values. Note that the peak values and polarity were normalized to the highest peak occurring in the registered waveform.

Discrete short-time Fourier transform (1) is used to compute the power spectrum density of the electric field signal [17,18].

$$STFT\{E[n]\}(m,\omega) = X(m,\omega) = = \sum_{n=1}^{L} E[n]w[n-m]e^{j\omega n} \quad (1)$$

where: $STFT$ – the short-time Fourier transform of the discrete electric field signal $E[n]$, n – number of subsequent electric field samples, L – total number of electric field samples, m – discrete variable, $w[n]$– discrete Hamming window, ω – specified pulsation of the signal.

The power spectrum density of the electric field waveform is related to the squared magnitude of the STFT described by (1). In Matlab, the PSD definition is as follows (2) [19].

$$PSD_{LIN} = \frac{\left|STFT\{E[n]\}(m,\omega)\right|^2}{F_S \sum_{n=1}^{L} \left|w[n]^2\right|} \quad (2)$$

where: PSD_{LIN} – the power spectrum density of the electric field signal related to the sampling frequency F_S. Note that the subscript *LIN* indicates the PSD in linear scale in W/Hz.

Since the dynamics of the lightning electric field is significant (Fig.2) it is a good practice to present the PSD in logarithmic scale in dB/Hz. Note that the reference power equal to 1 W used in this paper, the same as in Matlab, is a relatively large value for lightning electric field power generated by far lightning discharges, and therefore, the scales of vertical bars in presented plots are within -150 dB/Hz and -40 dB/Hz (see Figs 2 and 3).

In the further analysis only two highest peaks called Part 1 and Part 2 visible in Fig 2a in 300 ms time scale are taken into account. These parts of the recorded electric field waveform are presented in Fig. 2b in 35 ms time-scale. Time interval between Part 1 and Part 2 is about 13 ms. This is too short time interval as two consecutive return strokes in the same flash [1]. The rise time of the electric field waveform depicted in Fig. 3a is about 350 μs and looks like lightning discharge inside cloud (Part 1) or return stroke signature generated by another flash. The latter waveform shows in Fig. 3b (Part 2) is caused by return stroke because the wavefront is typical for such events. Apart from, the rise time is about 43 μs and the time duration of this part of the electric field waveform is less than 3 ms. Additionally, the tail is very similar to those generated by return strokes. Both electric field pulses (Part 1 and Part 2) are generated by relatively far lightning discharges.

Corresponding PSD analysis was done for entire electric field waveform presented in Fig 2a and for particular lightning events (Figs 2b, 3a, and 3b). The analysis was performed for two different sets of parameters of the STFT and two frequency ranges. First, the PSD of the entire available recording was computed in the lower frequency range up to 25 kHz (Fig. 2a). The waveform was downsampled from 25 MHz to the 50 kHz. The reason of this was relatively large amount of data which lead to time consuming computations and lack of PC memory. The same sampling time was used in local lightning location system operated in Warsaw, Poland [20]. It enables to make comparison and validate results collected from two different location in Poland. Other parameters of the STFT remain the same for all computations and were selected to obtain a good resolution of final PSD's. The color bar scales are similar for all plots. In case of lightning discharges marked as Part 1 and Part 2 the variations of dynamic spectra are easily visible in Fig. 2a and Fig. 2b. Despite similar shapes the PSD's are different for these two parts of the electric field waveform. PSD for Part 1 is solid up to about 2 kHz (the main waveform) and has scattered part from 2 kHz to 25 kHz (high frequency EM disturbances imposed on the main waveform). PSD for Part 2 is solid up to 10 kHz which responds to frequency range of the most energetic parts of the lightning return stroke events. Note that the Part 2 is without scattered high frequency components. Additional analysis of the PSD up to 1.25 MHz was done and presented in Fig. 3. In this case the sampling frequency is 2.5 MHz. The aim of this analysis is to check if there is any spectrum variation in the higher frequency range. For both analyzed electric field waveforms no significant changes are observed. Only in case of Part 2 the spectrum variation is extended up to about 200 kHz. The reason of the presence only relatively low frequency components within the dynamic spectra is a long distances from registered lightning discharges. The high frequency components of electric field waveform propagated over the lossy ground are attenuated, and therefore, the rise time of the wavefront lengthens.

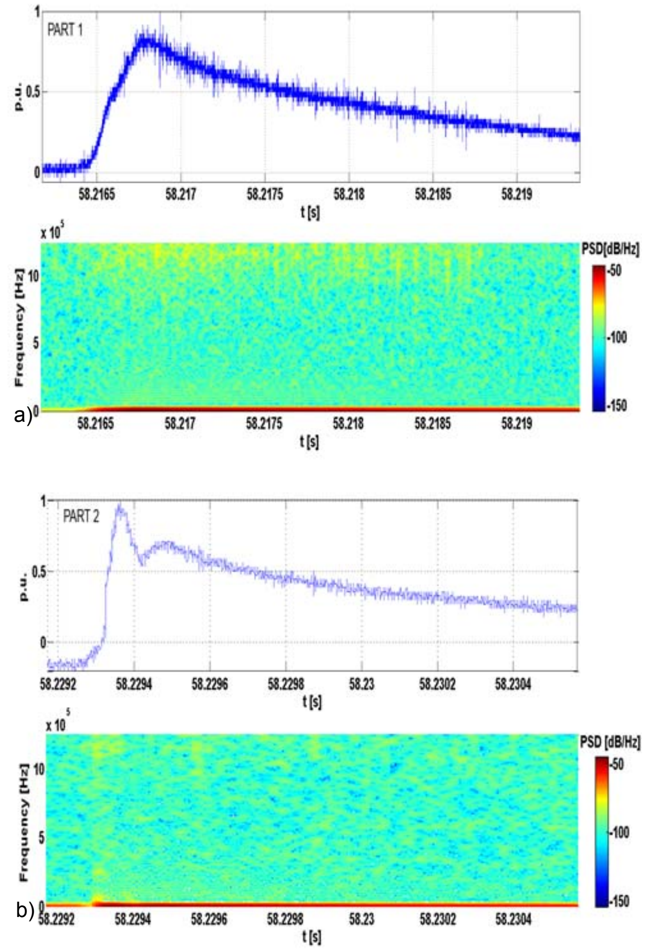

Fig.3. PSD of waveforms depicted in Fig.2b. The Part 1 of recorded waveform – a). The Part 2 of waveform – b). The PSD is computed up to 1.25 MHz; the STFT parameters: window: 128 samples, overlap: 120 samples, sampling frequency: 2.5 MHz.

Conclusions and final remarks

In the paper, lightning electric field waveform is presented and analyzed in the time-frequency domain. The preliminary recordings were carried out fully automatically at the lightning observation station operated in Rzeszow, Poland. Typical lightning electric field waveform recorded during summer season 2013 was analyzed for different frequency ranges and parameters of the transformation. The most important features of the analyzed electric field waveform generated by far lightning return stroke can be determined based on the dynamic spectrum which upper frequency does not exceed 25 kHz. Thanks to this, algorithms based on frequency domain can work faster and with lower consumption of PC resources. In consequence detection and warning systems may process data rapidly. The obtained results can be applied for location and warning systems purposes to develop new algorithms of lightning parameters recognition. Further measurements in the forthcoming thunderstorm season are planned together with the expanding of the functionality and automation of the observation station in cooperation with the Institute of Geophysics, Polish Academy of Sciences, and the Institute of Electronic Systems, Warsaw University of Technology. We will implement a new automated procedure to assist in searching of events for detailed investigation.

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