Journal of Atmospheric and Solar-Terrestrial Physics 70 (2008) 1213–1221

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

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

Isolated breakdown activity in Swedish lightning

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ARTICLE INFO

Article history:
Received 14 August 2007
Received in revised form
19 February 2008
Accepted 3 March 2008
Available online 12 March 2008

Keywords:
Isolated
Breakdown
Lightning
Cloud-flashes
Discharges

ABSTRACT

The initial breakdown processes or preliminary breakdown (PB) processes are generally associated with either cloud or cloud-ground lightning flashes, and hence have been studied mainly in connection with those subsequent activities. However, it has been observed in the summer thunderstorms of Sweden that there are breakdown processes that may not culminate into any subsequent activity. As these processes do not lead to any subsequent activity, they have been termed as isolated breakdown activities. Such isolated breakdown activities involve microsecond-scale pulses with both initial polarities. Based on their polarities, breakdown processes are divided into two groups; the negative breakdown pulses that are similar to the breakdown pulses leading to negative return strokes in ground flashes and the positive breakdown pulses similar to the breakdown pulses generally leading to the cloud flashes. The occurrence of the two types of breakdown processes is found to vary from a thunderstorm day to the other. In the present study, the signatures of isolated breakdown activities have been analyzed and are compared with those leading to the subsequent activities observed during the same measurement campaign. The average duration of the isolated breakdown activity associated with the negative initial polarity pulses is found to be 0.98 ms with average number of pulses 8.5. Similarly, the average duration and number of pulses in the isolated breakdown process with positive initial polarity pulses are 6.9 ms and 3.9, respectively.

1. Introduction

In order that a lightning flash starts within a thundercloud, an electrical breakdown must occur. Such a breakdown process is called the initial or preliminary breakdown (PB) process. However, still little is known about the initiation of the breakdown phenomena within the charged thundercloud.

Two potential hypothetical mechanisms have been, thus far, put forward to answer the inception of the breakdown. The first being the conventional breakdown mechanism, according to which the electric field in the vicinity of small hydrometeors is sufficiently intensified locally which leads to the dielectric breakdown. The second candidate being runaway breakdown mechanism, according to which high-energy electrons accelerate over long distances in the thundercloud electric field, becoming runaways that give rise to huge number of daughter electrons that leads to eventual dielectric breakdown. Both of these mechanisms have some limitations to fully explain the initiation of lightning discharge, the details of which are beyond the scope of this paper and can be found elsewhere in the literature (e.g. Rakov and Uman, 2003; Solomon et al., 2001).

The preliminary or initial breakdown in a cloud-ground flash is the in-cloud process which initiates or leads to an initiation of the downward moving stepped leader. The initial breakdown process in a cloud flash is an initial discharge that leads to the discharge between the two charge regions bridging them together.

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1364-6826/$ - see front matter
doi:10.1016/j.jastp.2008.03.003

Clarence and Malan (1957) suggested that the PB is a vertical discharge between the main negative charge center and lower positive charge pocket. According to Clarence and Malan (1957), the PB is followed by the stepped leader either immediately or after a so-called intermediate stage which may last up to 400 ms and hence the return stroke was considered to be preceded by electric field changes by a combination of breakdown (B), intermediate (I) and leader (L) field changes. They suggested that the (B) stage is due to the electrical breakdown between the main negative charge center and the lower positive charge pocket. The intermediate stage was interpreted by Clarence and Malan (1957) as being due to the negative charging of the vertical channel of the initial breakdown until the field at the bottom of the channel was high enough to launch a stepped leader.

Krehbiel et al. (1979) interpreted the PB as a succession of "breakdown events" with considerable horizontal extent, which occurred prior to the development of a leader to ground. These events were associated in part with the negative charge volume that appeared to be the charge source for the following first stroke, and they effectively transported negative charge away from that volume.

Proctor et al. (1988) interpreted the BIL-type electric field changes prior to the first return stroke as being associated with the development of stepped leaders. Some of these leaders were preceded or accompanied by cloud discharge starting from approximately the same origin as the leaders. The breakdown (B) portion of the BIL waveform was interpreted by Proctor et al. (1988) as the start of the leader, while the intermediate (I) portion was found to occur sometimes owing to inadequacies in the rate of supply of charge at the source, sometimes due to geometry of the stepped leader and sometimes due to overlapping cloud discharges. They further claim that if the initial breakdown is not a unique process but merely the start of the stepped leader, the intermediate portion of the BIL electric field change may be due to slowing of the negative leader as it encounters a positively charged region.

The PB pulses in negative ground flashes are reported generally to be bipolar, the initial polarity in most of the cases being the same as that of the following return stroke pulse. However, Ogawa (1993) reported some trains with initial polarity opposite to that of the following return stroke.

On the other hand, cloud flashes have been observed by many researchers (e.g. Bils et al., 1988; Villanueva et al., 1994; Rakov et al., 1996; Shao and Krehbiel (1996); Weidman and Krider (1979); Willett et al. 1990) as being composed of two stages, the initial breakdown stage and late or final stage. The breakdown activity pertinent to cloud flashes involves large microsecond-scale bipolar pulses with an initial polarity opposite to that of negative return stroke lowering the negative charge to ground. However, cloud flashes with breakdown pulses having the same initial polarity as that of negative return strokes have also been observed in the present study.

As mentioned earlier in this paper, breakdown-type activities that do not lead to any subsequent activity and accompanied by large microsecond-scale pulses have been frequently observed during the measurement campaign in summer 2006, conducted in Uppsala, Sweden. Similar activities, not leading to any subsequent activity, have been reported by Norinder and Knudsen (1956) from the same geographical location as that of the present study. Recently, Nag and Rakov (2006) have also reported similar PB discharge activities that are not followed by the return stroke pulses. It is apparent that their study is mainly concerned to the breakdown pulses that have the same initial polarity as that of the negative return stroke. Nevertheless, study pertaining to such isolated activities is very scarce in the literature. The signatures of isolated breakdown pulses have been analyzed and compared with those of initial breakdown pulses leading to ground and cloud flashes observed during the same measurement campaign in this study.

2. Measurement

The measuring system was placed in an electrically shielded wagon and the data were recorded in LeCroy wave-pro (7100A) 4 channel Digital Storage Oscilloscope (DSO) operated in pre-trigger mode placed inside the wagon. The electric and magnetic field sensors were mounted on the rooftop of the wagon. The vertical electric fields sensed by parallel plate antenna were sent to a buffer amplifier circuit through a short (60 cm) RG-58 coaxial cable. The buffer circuit is identical to what has been described by Sharma et al. (2005) except for the buffer amplifier (LH0033), which has been replaced by MSK0033 with a larger bandwidth of 140 MHz. The zero-to-peak rise time of the antenna system for a step pulse was less than 30 ns. The output of the buffer amplifier was fed to the DSO through a properly terminated RG-58 coaxial cable. The electromagnetic fields of lightning were recorded on different thunderstorm days during the summer (June–August) 2006 at the premise of Ångstrom Laboratory, Uppsala, Sweden (59.8°N and 17.6°E). The data were recorded either at 100 Ms/s for 200 ms with a delay of 40 ms or at 50 Ms/s for 500 ms with a delay of 100 ms. The data to be presented here were recorded on different days of July and August, and on different times of the days.

3. Data and results

The isolated breakdown activities that do not lead to any subsequent activity have been frequently observed during the measurement campaign. In an agreement with Gomes et al. (1998), on many occasions, the initial breakdown pulses leading to the ground flashes are so pronounced that the system often gets triggered by the breakdown pulses itself. The time window was set to 500 ms with a pre-trigger delay of 100 ms also in order that no subsequent activity would be missed.

Observed breakdown activities could be divided into three categories based on the subsequent activities as (1) breakdown activity leading to ground-flash return strokes, (2) breakdown activities leading to cloud flash and (3) breakdown activity not leading to any subsequent