PAPER • OPEN ACCESS

Morphological characteristics of preliminary breakdown pulses of hybrid intra cloud–negative cloud-to-ground lightning at low lattitude

To cite this article: P Emeraldi *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **602** 012020

Morphological characteristics of preliminary breakdown pulses of hybrid intra cloud–negative cloud-to-ground lightning at low lattitude

P Emeraldi[1], M I Hamid[1], and A Hazmi[1]

[1]Electrical Engineering Department, Andalas University, Padang, Indonesia

Email: ariadi@eng.unand.ac.id

Abstract. Preliminary breakdown (PB) pulses can represent the propagation path of lightning initiation and can be used to model the charge structure of a thundercloud. The characteristics of PB pulses from the lightning initiation process depend on the charge structure of the lightning cloud. This study presents the PB pulse morphology and charge structure of thunderclouds from hybrid intracloud–negative cloud-to-ground (hybrid IC-NCG) lightning in Padang, Indonesia. PB pulses were obtained from lightning radiation electric field observation. A total of 41 PB pulse waveforms of hybrid IC-NGC flashes were analyzed. Three types of PB pulse characteristics occurred in association with three different types of hybrid IC-NCG lightning morphologies. Hybrid IC-NCG lightning can be initiated from the main negative cloud charge to the upper positive cloud charge or vice-versa. The propagation direction of the initial PB pulse train of hybrid IC-NCG flashes is either upward or downward.

1. Introduction

Preliminary breakdown (PB) pulse characteristics of lightning are important for understanding the initial process mechanism that triggers lightning strikes, both of intracloud (IC) and cloud-to-ground (CG) lightning. The process of lightning initiation occurs in the cloud so that it cannot be observed optically using a camera. Observation of the lightning initiation process is done by detecting electromagnetic radiation from lightning strikes [1-3]. This observation yields PB pulses, which can represent the propagation path of lightning initiation and can be used to model the charge structure of a thundercloud [4-5].

The initial process of CG lightning strike involves three stages: the breakdown stage (B), the intermediate stage (I) and the stepped leader stage (L), as represented in the so-called BIL model. The lightning initiation process begins with the initial breakdown stage, characterized by intense electromagnetic radiation for several milliseconds, followed by the intermediate stage for hundreds of milliseconds, with fewer electromagnetic radiation pulses, and ends with the stepped leader stage, which lasts several milliseconds and is characterized by very intense electromagnetic radiation pulses. The waveform of PB pulses can be positive, negative or bipolar [6-7].

The characteristics of the PB pulses from the lightning initiation process depend on the charge structure of the thundercloud. The location and propagation path of the lightning initiation process will determine the waveform of the PB pulses obtained from electromagnetic radiation observation. A CG lightning strike is initiated between the main negative charge regions and regions in a thundercloud with a lower positive charge, while the typical IC lightning flash is initiated between the main negative charge region and the upper positive charge region [8-9].

Another type of lightning flash is hybrid IC–negative CG (hybrid IC-NCG) lightning, which begins as IC lightning and then produces one or more negative CG strokes. This type of lightning is categorized as abnormal. A previous study has identified a morphology of hybrid IC-NCG lightning in regions at high latitude (35.97° N) [4]. However, it did not provide the characteristics of the initial PB pulses of the lightning flash. In this paper, we analyze the characteristics of PB pulses and model the charge structure of thunderclouds from hybrid IC-NCG lightning in Padang, Indonesia, which is located at a low latitude (0° N). PB pulses were obtained from lightning radiation electric field observation. The PB pulse waveforms were categorized into several types based on the polarity of the pulses. The lightning morphology, which shows the charge structure of the thundercloud and the lightning strike propagation path, was obtained from analysis of the PB pulse waveforms.

2. Instrumentation and Data

Measurements of the electric fields of lightning strikes were conducted between January and August 2015 at the Observatory Station in Electrical Engineering Department Building of Andalas University, Padang, Indonesia (0° N). The measuring system was situated on top of the department building, which is located at 137 m above sea level. The measuring system consisted of three main parts, namely a flat plate antenna unit, an integrator amplifier unit and a recording unit (digital storage oscilloscope), as shown in Figure 1.

The circular plate antenna with a diameter of 30 cm was connected via a short 50 cm shielded coaxial cable to an integrator amplifier circuit in a protected metal case. The antenna was used to record the incident vertical electric fields from the lightning strikes. The time-varying electric field produced by lightning causes a current to flow to and from the plate antenna. This current is proportional to the time derivative of the electric field. Integrating the current gives an output signal that is proportional to the electric field. The integrator amplifier circuit had a time constant of 100 ms. The output of the integrator amplifier circuit connected to a picoscope as the recording unit with a sample rate variation from 1 MS/s to 4 MS/s and a record length of 250 ns-1 s. The recording unit was triggered using window trigger mode at a trigger level of 1 V and a pre-trigger time of 30% of the record length. The electric field data were stored on a personal computer. The electric field measurement system used was similar to the one used in [10-11]. A total of 4419 waveforms were recorded during this measurement campaign, from which 41 waveforms of PB pulses of hybrid IC-NCG lightning were analyzed.

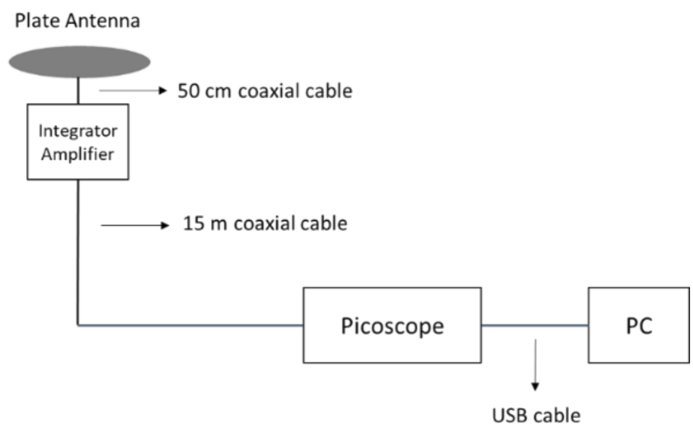

Figure 1. The electric field measurement system

3. Result and Analysis

The 41 PB pulse waveforms of hybrid IC-NGC flashes were grouped into three distinct types, called types A, B and C, which were then categorized into three types of lightning morphology, as shown in

Figure 2. Type A of PB pulse trains contains individual pulses with positive polarity, as shown in Figure 3. The morphological characteristics of type A of PB pulses are similar to those of hybrid IC-NCG lightning [4], where flashes are initiated between the main negative charge region and the upper positive charge region. However, the positive polarity of the PB pulses shows that the discharge started from a positively charged region going towards the main negatively charged region with downward propagation. This positive IC flash is then followed by a return stroke of the NCG flash. The morphological characteristics of type A of PB pulses are shown in Figure 2a.

Contrary to type A, type B of PB pulses have a negative polarity, as shown in Figure 4. The flashes are initiated by an upward discharge from the main negative charge region to the upper positive charge regions. The negative IC flash is then followed by a negative CG flash. This corresponds to the morphology of hybrid IC-NCG lightning [4]. The morphological characteristics of type B of PB pulses are shown in Figure 2b. Type C of PB pulse trains have a changing polarity. They start with a positive polarity pulse cluster followed by a negative polarity pulse cluster or vice versa, as shown in Figure 5. The direction of discharge propagation changes for each cluster of PB pulses between the main negative charge region and the upper positively charged regions. Type C of PB pulse characteristics correspond to the morphology of class III negative CG lightning [5]. The morphological characteristics of type C of PB pulses are shown in Figure 2c.

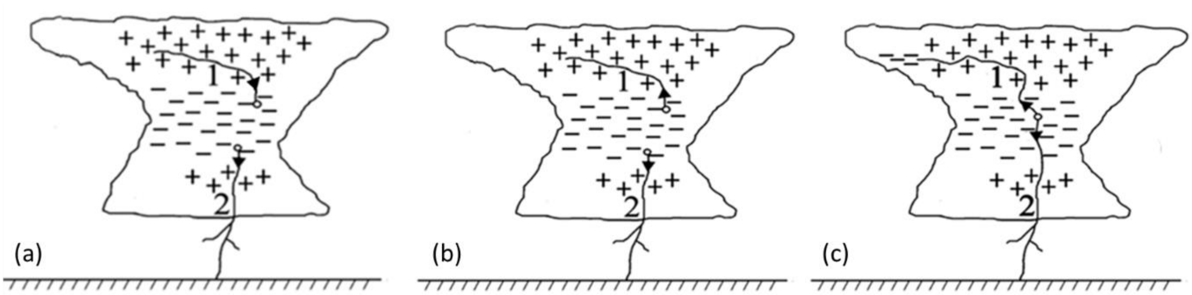

Figure 2. Schematic illustration of hybrid IC-NCG lightning morphologies: (a) type A, (b) type B, and (c) type C of PB pulses. The curve represents the propagation path. Arrows represent the propagation direction

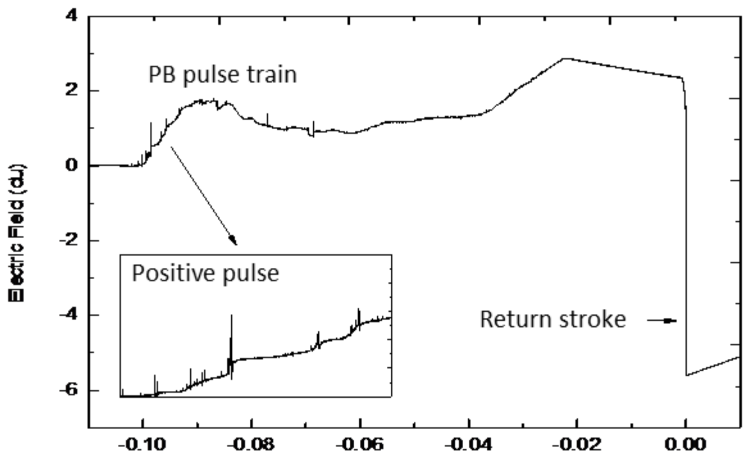

Figure 3. Electric field waveform of type A of PB pulses

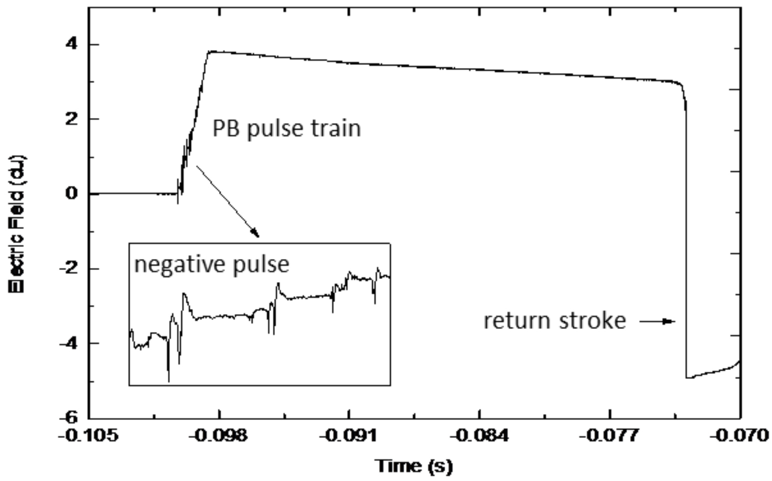

Figure 4. Electric field waveform of type B of PB pulses

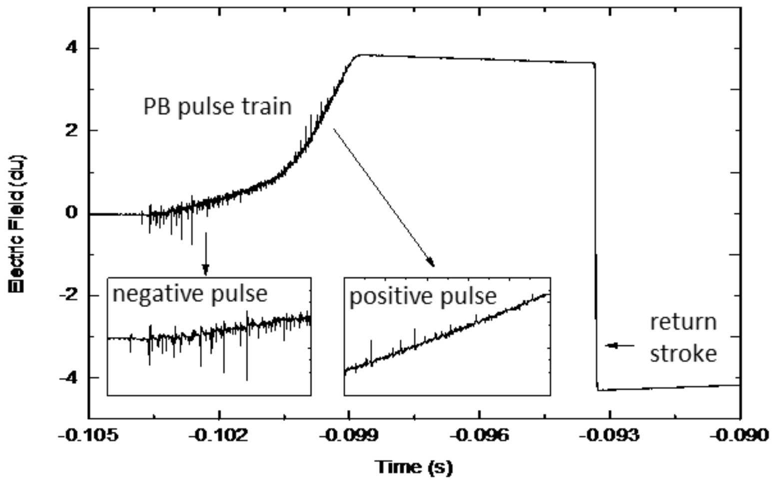

Figure 5. Electric field waveform of type C of PB pulses.

4. Conclusion

A total of 41 PB pulse waveforms of hybrid IC-NGC flashes were analyzed. Three types of PB pulse characteristics occurred in association with three different types of hybrid IC-NCG lightning morphologies. Type A of PB pulse trains contains individual pulses with positive polarity. Contrary to type A, type B has a negative polarity pulse. Type C of PB pulse trains have different pulse polarities for each pulse cluster. The morphologies show that hybrid IC-NCG lightning can be initiated from the main negative charge region to the upper positive charge regions, or vice-versa. The propagation direction of the initial PB of hybrid IC-NCG flashes is either upward or downward.

Acknowledgment

This work is supported by Universitas Andalas of KRP2GB-PDU scheme, with grant no. 03/UN.16.17/PP.PDUPT.K/LPPM/2018.

IOP Conf. Series: Materials Science and Engineering **602** (2019) 012020 doi:10.1088/1757-899X/602/1/012020

References

[1] Baharudin Z A, M Fernando, N A Ahmad, J Mäkelä, M Rahman and V Cooray 2012 Electric field changes generated by the preliminary breakdown for the negative cloud-to-ground lightning flashes in Malaysia and Sweden *J Atmos Sol Terr Phys* **84** 15–24

[2] Marshall T, W Schulz, N Karunarathna, S Karunarathne, M Stolzenburg, C Vergeiner and T Warner 2014 On the percentage of lightning flashes that begin with initial breakdown pulses *J. Geophys. Res. Atmos*. **119** 445–60

[3] Marshall T, M Stolzenburg, N Karunarathna and S Karunarathne 2014 Electromagnetic activity before initial breakdown pulses of lightning *J. Geophys. Res. Atmos.* **119** 12 558-12 574

[4] Lu G, S A Cummer, R J Blakeslee, S Weiss and W H Beasley 2012 Lightning morphology and impulse charge moment change of high peak current negative strokes *J. Geophys. Res.* **117**

[5] Wu B, G Zhang, J Wen, T Zhang, Y Li and Y Wang 2016 Correlation analysis between initial preliminary breakdown process, the characteristic of radiation pulse, and the charge structure on the Qinghai-Tibetan Plateau *J. Geophys. Res. Atmos.* **121** 12 434–12 459

[6] Clarence N and D Malan 1957 Preliminary discharge processes in lightning flashes to ground *Q. J. R. Meteorol. Soc.* **83**(356) 161–72

[7] Rakov V A and M A Uman 2003 Lightning: Physics and Effects (Cambridge, U K: Cambridge Univ Press)

[8] Nag A and V A Rakov 2009 Electric field pulse trains occurring before the first stroke in the negative cloud to ground lightning *Electromagn. Compact. IEEE Trans.* **51**(1) 147–50

[9] Marshall T, S Karunarathne, M Stolzenburg, M Briggs, E S Cramer, B G Mailyan, S McBreen, O J Roberts and M Stanbro 2017 Electric field change measurements of a terrestrial gamma-ray flash *J. Geophys. Res. Atmos.* **122** 5259–66

[10] Hazmi A, Emeraldi P, Hamid M I and Takagi N 2016 Some characteristics of multiple stroke negative cloud-to-ground lightning flashes in Padang *Int. J. on Elec. Eng. and Infor.* **8** 2 438-50

[11] Emeraldi P and Hazmi A 2017 Observed preliminary breakdown pulses of intracloud discharges *Int. Conf. on High Vol. Eng. and Power Sys. (ICHVEPS)* 488-92