Evaluation of the Existence of Initial Breakdown Process for Cloud-to-Ground Flashes

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Abstract— **In this paper, we are motivated to evaluate the existence of Initial Breakdown (IB) process in Cloud-to-Ground (CG) flashes of a tropical storm by using both broadband E-field and B-field antenna systems. It is important to note here that all previous studies were using only broadband E-field antenna system. In this study, the evaluation of existence of IB process was done based on both broadband E-field and B-field antenna systems. The data of lightning flashes were collected on June 3rd 2016 by our station in Malacca, Malaysia. We analyzed 50 CG flashes from a tropical storm happened in Kuala Lumpur area. The data recorded by broadband E-field antenna system shows that 94% of CG flashes were preceded by IB process. On the other hand, by using B-field antenna system, all CG flashes have been observed to be preceded by IB process. This finding is very significant because we can conclude that all CG flashes are initiated by IB process. The average pulse duration of the first, second, third, and the largest IB pulses are 33.52 µs, 36.08 µs, 37.76 µs, 43.02 µs, respectively. The average peak amplitude of the first, second, third, and the largest IB pulses are 179.60 mV, 261.90 mV, 272.94 mV, 609.57 mV, respectively.**

Keywords- electromagnetic field; ground flash; initial breakdown; lightning.

I. INTRODUCTION

Lightning flash is an electrical discharge that emits Electromagnetic (EM) fields across very wide frequency bands and also optical radiation. There are four common types of lightning flashes namely Negative Cloud-to-Ground (-CG), Positive Cloud-to-Ground (+CG), Intra-cloud (IC) and Narrow Bipolar Event (NBE).

Most of lightning flashes (except NBE) have been observed to begin with a series of bipolar pulses, known as Initial Breakdown (IB) process [1-7]. Initial breakdown pulses (radiation field) have the following characteristics such as the shape is bipolar, duration of IB pulses are around 10 µs to greater than 200 µs, and in the process usually started with some little pulses then it continues to largest pulse and ended with the decreasing amplitude in the last pulse.

Narrow bipolar event is a special type of flash without detectable IB process and has been believed to be emitted by fast positive streamer and initiating IB process [8]. Consequently, NBE is latitude dependent [9]. Recent high speed camera observation by [10] has revealed that the occurrence of the first IB pulse of 15 flashes (12 CGs and 3 ICs) have been accompanied by visible light. This result is a strong indication that the first IB pulse is a leader process rather than streamer process.

In [11], IB process that preceded the first Return Stroke (RS) in Sweden and Sri Lanka has been studied. They found that all (41) –CG flashes in Sweden were preceded by IB process while on the other hand, only 9 out of 47 –CG flashes from tropical storms in Sri Lanka were preceded by IB process. Another study conducted by [12] in Malaysia and

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Florida revealed that all (100) –CG flashes in Florida had detectable IB process, while not all –CG flashes of tropical storms in Malaysia preceded by IB process. They found that only 97% of –CG flashes were preceded by IB process. It seems that only tropical flashes are lack of IB process. More recent study by [13] in Florida found that every flash they observed were preceded by IB process; in perfect agreement with the study conducted by [12].

In this paper, we are motivated to evaluate the existence of IB process in CG flashes of a tropical storm by using both broadband E-field and B-field antenna system. We think that low sensitivity E-field antenna system has led to the case where IB process is undetectable. The B-field system used in this study is more sensitive than the E-field system. There are some aspects considered in measuring the characteristics of IB pulses and first RS, both are identified to reach the purpose of the study.

II. Data and Instrumentation

The results of measurements were obtained from a single station consists of a broadband E-field change system with decay time constant of 13 ms, a High Frequency (HF) E-field system tuned at 3 MHz, and a pair of orthogonal wideband B-field system ([14-15]. The station is located at the Universiti Teknikal Malaysia Melaka (UTEM), Melaka, Malaysia (2°18′50.41″N, 102°19′6.9″E). Radar reflectivity data (CAPPI format at 2 km altitude) has been obtained from the Malaysia Meteorological Department (MMD).

The output from antennas is digitized at rates of 2 MHz and 80 MHz with a resolution of 12 bits. Data records were event-triggered and were 2 s long. The timing for each event was provided by a Global Positioning System (GPS) with accuracy of ±6 ns. Additional details of the E-field instrumentation are given in [16-17]. The observations presented here were obtained from a single storm that formed in Bukit Jalil, Kuala Lumpur on June 3rd, 2016.

III. Results and Analysis

The lightning events focusing on CG flashes were measured in Kuala Lumpur where the flashes taken place. We examined 50 CG flashes that were collected on June 3rd 2016 by our station in Melaka, Malaysia. The data showed that based on their polarity and the criteria of lightning initiation parts, out of 50 flashes, 45 of them were –CG flashes with 38 were Breakdown-Intermediate-Leader (BIL) type and 7 were Breakdown-Leader (BL) type. On the other hand, there are 5 +CG flashes with 4 BIL type and only 1 BL type.

From the B-field data, all 50 CG flashes were preceded by IB process. On the other hand, from the E-field data, only 47 CG flashes were preceded by IB process. The 3 CG flashes that were not preceded by IB process are all –CG and BIL type. This result is a clear indication that all lightning flashes are initiated by IB process and E-field antenna system has limitation to detect small IB pulses.

Fig. 1 shows the first RS in one of the 3 -CG flashes that not preceded by IB process. The sample has been recorded by using both E-field and B-field antenna systems. The E-field RS is illustrated by using blue plot while the B-field RS is illustrated by using gold plot. The polarity of the B-field RS is oppose the polarity of E-field RS. This means that the polarity of IB pulses for B-field must follow the polarity of the B-field RS which is negative. The zero crossing time and total pulse duration are 15.25 μs and 71.58 μs, respectively. The peak amplitude of E-field and B-field are 0.35 V and 3.29 V, respectively. Obviously, the amplitude of B-field is almost 10 times larger than the amplitude of E-field. The average pulse duration and B-field peak amplitudes for all 50 CG flashes are 104.30 μs and 4.66 V, respectively.

Figs. 2 to 4 show the IB pulses from B-field data (gold plot) that preceded the first RS that shown in Fig. 1. It is clear from the figures that no IB pulses can be seen from E-field data (blue plot). The polarity of IB pulses is identical to the polarity of the B-field RS (Fig. 1). The pulse duration of the first, second, and third IB pulses (shown in Fig. 2) are 115.69 μs, 127.00 μs and 122.60 μs, respectively. The peak amplitudes are 53.05 mV, 66.00 mV and 63.50 mV, respectively. The average pulse duration of the first, second, third, and the largest IB pulses are 33.52 μs, 36.08 μs 37.76 μs, 43.02 μs, respectively. The average peak amplitude of the first, second, third, and the largest IB pulses are 179.60 mV, 261.90 mV, 272.94 mV, 609.57 mV, respectively.

IV. Conclusion

In this paper, we have evaluated the existence of IB process preceded the first RS for 50 CG flashes in a tropical storm located in Kuala Lumpur, Malaysia by using both broadband B-field and E-field antenna systems. We found that IB process preceded the first RS in all B-field data while only 94% IB process preceded E-field data. The IB process of the remaining 6% of E-field data were undetectable (below noise level) although their counterpart B-field IB process were detectable. By using better sensitivity B-field antenna system, we can conclude that all CG flashes are initiated by IB process, thus reject the earlier claims (observations from Sri Lanka and Johor, Malaysia) that some CG flashes were not initiated by IB process.

Acknowledgment

The authors would like to acknowledge the support provided by Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer (FKEKK), Universiti Teknikal Malaysia Melaka (UTeM). This project is funded by Short Term Grant (Projek Jangka Pendek PJP) in FKEKK, UTeM (PJP/2018/FKEKK/(3B)/S01615). This project is partially funded by Universiti Teknologi Malaysia (UTM) under Vote No. 04G19 and Ministry of Education (MOE) under 4F966 research grants (FRGS). We thank Malaysia Meteorological Department (MMD) for providing CAPPI radar reflectivity data on the website.

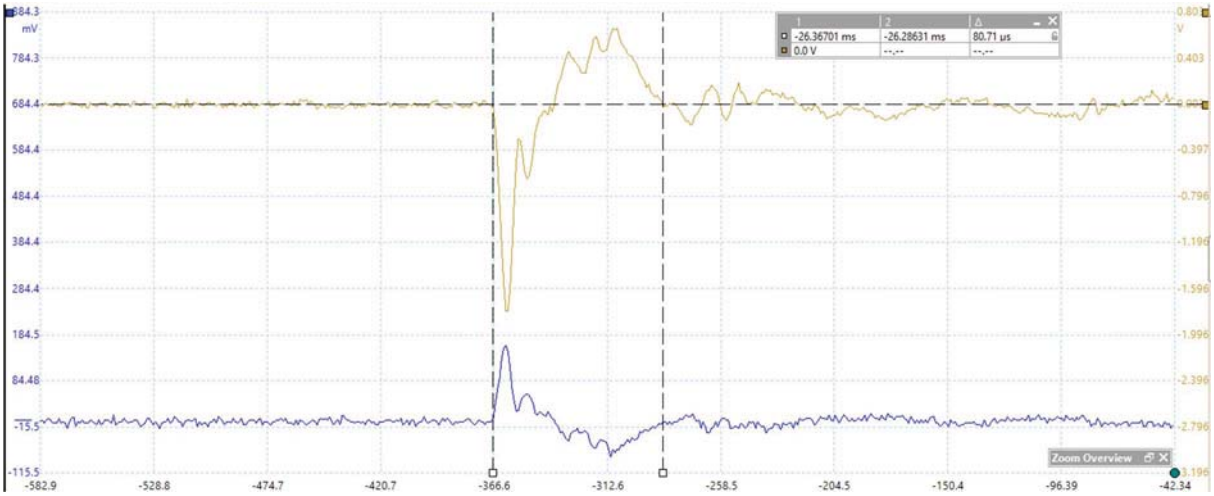

Figure 1. The first Return Stroke (RS) of Negative Cloud-to-Ground (–CG) flash that not preceded by E-field Initial Breakdown (IB) pulses. E-field RS is illustrated by blue plot and B-field RS is shown by gold plot.

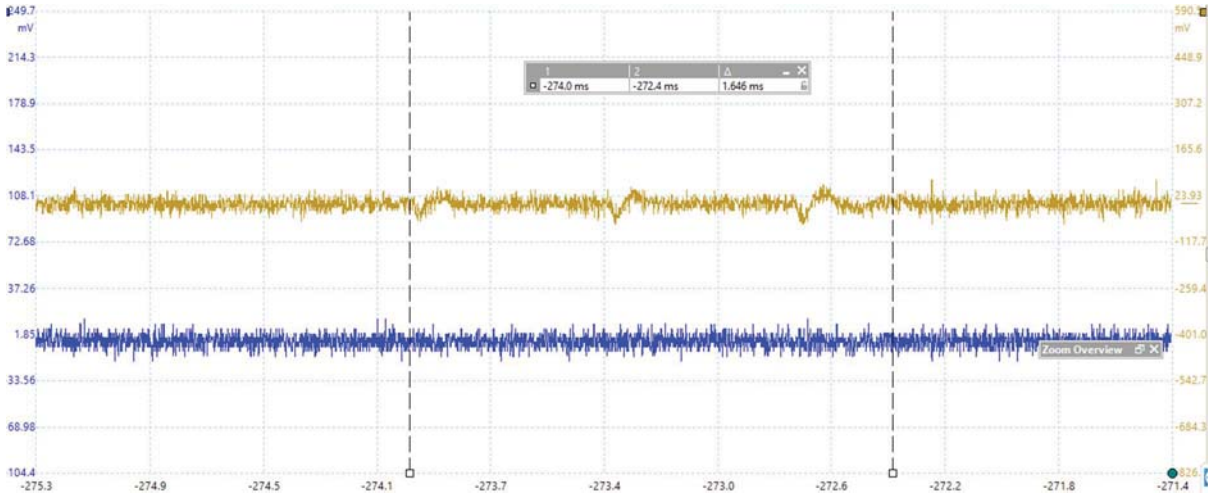

Figure 2. The first 3 IB pulses (gold plot) preceded B-field RS in Fig. 1. No IB pulses cannot be observed from E-field (blue plot).

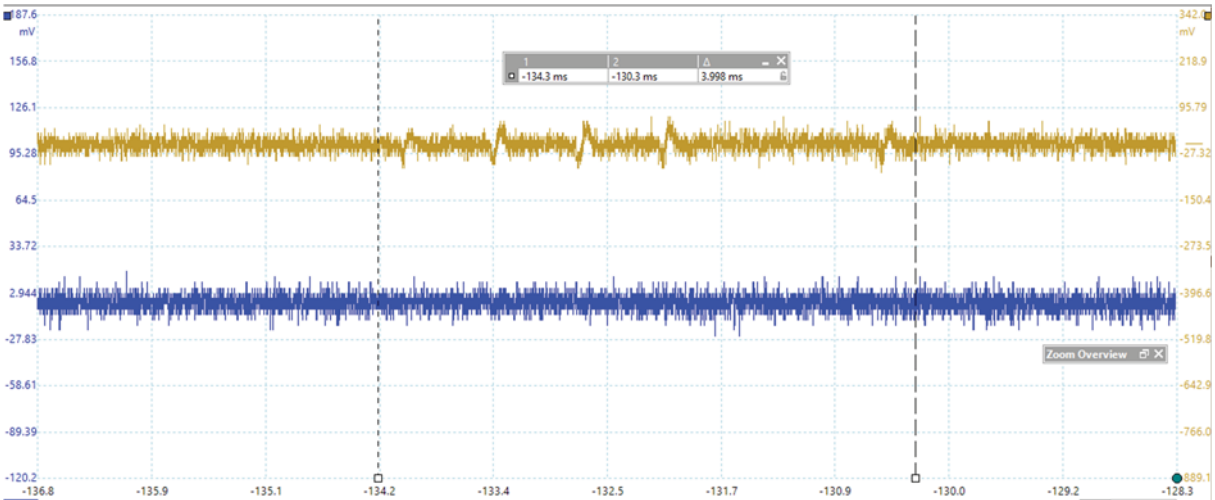

Figure 3. The subsequent IB pulses that following the IB pulses in Fig. 2. There are 5 IB pulses in this sequence. No IB pulses cannot be observed from E-field (blue plot).

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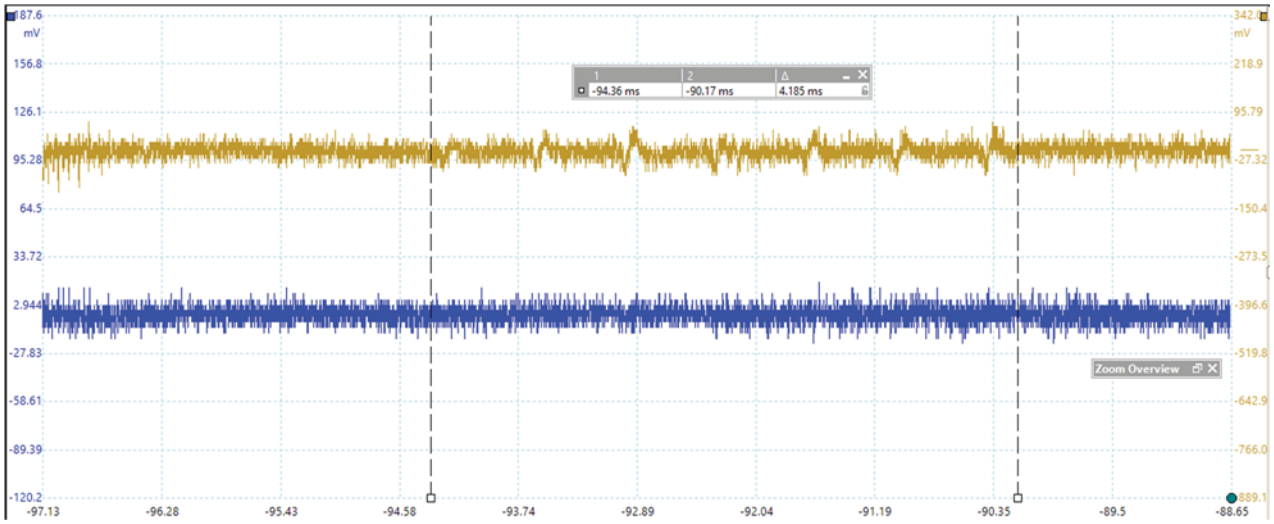

Figure 4. The subsquent IB pulses that following the IB pulses in Fig. 3. There are 7 IB pulses in this sequence. No IB pulses cannot be observed from E-field (blue plot).

REFERENCES

[1] Appleton, E. V., and F. W. Chapman (1937), On the nature of atmospherics, 4, Proc. R. Soc. London, Ser. A, 158, 1–22.

[2] Clarence, N. D., and D. J. Malan (1957), Preliminary discharge processes in lightning flashes to ground, Q. J. R. Meteorol. Soc., 83, 161–172.

[3] Weidman, C. D., and E. P. Krider (1979), The radiation field waveforms produced by intracloud lightning discharge processes, J. Geophys. Res., 84(C6), 3159–3164, doi:10.1029/JC084iC06p03159.

[4] Beasley, W. H., M. A. Uman, and P. L. Rustan (1982), Electric fields preceding cloud-to-ground lightning flashes, J. Geophys. Res., 87, 4883–4902, doi:10.1029/JC087iC07p04883.

[5] Bils, J. R., E. M. Thomson, M. A. Uman, and D. Mackerras (1988), Electric field pulses in close lightning cloud flashes, J. Geophys. Res., 93, 15,933–15,940, doi:10.1029/JD093iD12p15933.

[6] Esa, M.R.M., Ahmad, M.R., Cooray, V., 2014. Wavelet analysis of the first electric field pulse of lightning flashes in Sweden. Atmos. Res. 138, 253–267, doi:10.1016.j.atmosres.2013.11.01.

[7] Esa, M.R.M., Ahmad, M.R., Rahman, M., Cooray, V., 2014. Distinctive features of radiation pulses in the very first moment of lightning events. J. Atmos. Sol. Terr. Phys. 109, 22–28.

[8] W. Rison *et al.*, “Observations of narrow bipolar events reveal how lightning is initiated in thunderstorms,” *Nat. Commun.*, vol. 7, p. 10721, 2016.

[9] Ahmad, M.R., Esa, M.R.M., Cooray, V.,Baharudin, Z.A., Hettiarachchi, P.,2015. Latitude dependence of narrow bipolar pulse emissions. J. Atmos. Sol. Terr. Phys. 128, 40-45.

[10] Stolzenburg, M., T. C. Marshall, S. Karunarathne, N. Karunarathna, L. E. Vickers, T. A. Warner, R. E. Orville, and H.-D. Betz (2013), Luminosity of initial breakdown in lightning, J. Geophys. Res. Atmos., 118, 2918–2937, doi:10.1002/jgrd.50276.

[11] Gomes, C., Cooray, V., Jayaratne, C., 1998. Comparison of preliminary breakdown pulses observed in Sweden and Sri Lanka. J. Atmos. Sol. Terr. Phys. 60, 975–979.

[12] Z. A. Baharudin, N. A. Ahmad, M. Fernando, V. Cooray, and J. S. Mäkelä, “Comparative study on preliminary breakdown pulse trains observed in Johor, Malaysia and Florida, USA,” *Atmos. Res.*, vol. 117, pp. 111–121, 2012.

[13] R. Chapman, T. Marshall, S. Karunarathne, and M. Stolzenburg, “Initial electric field changes of lightning flashes in two thunderstorms,” *J. Geophys. Res. Atmos.*, vol. 122, no. 7, pp. 3718–3732, 2017.

[14] Lu, G., R. Jiang, X. Qie, H. Zhang, Z. Sun, M. Liu, Z. Wang, and K. Liu (2014), Burst of intracloud current pulses during the initial continuous current of a rocket-triggered lightning flash, *Geophys. Res. Lett.*, doi:10.1002/2014GL062127.

[15] Zhang, H., Lu, G., Qie, X., Jiang, R., Fan, Y., Tian, Y., Sun, Z., Liu, M., Wang, Z., Liu, D., Feng, G., Locating narrow bipolar events with single-station measurement of low-frequency magnetic fields, J. Atmos. Sol. Terr. Phys. 143-144, 88-101.

[16] Ahmad, M.R., Esa, M.R.M., Cooray, V., Dutkiewicz, E., 2014. Interference from cloud-to-ground and cloud flashes in wireless communication system. Electr. Power Syst. Res. 113, 237–246.

[17] Ahmad, M. R., Esa, M. R. M., Cooray, V., Baharudin, Z. A., & Hettiarachchi, P. (2015). Latitude dependence of narrow bipolar pulse emissions. Journal of Atmospheric and Solar-Terrestrial Physics, 128, 40-45.