Wavelet Analysis of the First Pulse of Initial Breakdown Process in Lightning Discharges

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Abstract— Wavelet transformation is used in order to seek for differences in the initial breakdown process between negative cloud-to-ground flash (CG−), positive CG (CG+), cloud flash (IC), and isolated breakdown (IB) processes. 72 waveforms were selected from 885 waveforms recorded between May and August 2010 at the premise of Uppsala University, Uppsala, Sweden. The analysis was conducted only on the first electric field pulse for each lightning process and the output from the wavelet transformation is plotted as normalized power spectrum. The first pulses in CG− are found to radiate intensely in average frequency between 186 and 1637 kHz. The energy radiated by the first pulses of CG+ mainly concentrated in the average frequency between 57 and 599 kHz. As for the IC, the first pulses found to be spread out in the average frequency between 461 and 3570 kHz and for IB, the energy spread out between 44 and 279 kHz. The CG+ and IB flashes tend to radiate at lower frequency region within smaller range compared to CG− and IC. IB has the smallest frequency range around 235 kHz while the frequency range of IC and CG− are more than 10 times and 6 times larger than IB, respectively. Furthermore, IC and CG− have comparable initial-to-overshoot peak ratio with 1.7 and 1.6, respectively, which higher than CG+ and IB at least with a factor of 1.4. It can be speculated that the initial breakdown processes of IC and CG− flashes are most likely initiated from the same discharge process in the thundercloud and differ from the discharge process of CG+ and IB.

1. INTRODUCTION

The most well known breakdown studied in lightning research is known as cloud-to-ground (CG) flashes where such breakdown process is usually started with initial or preliminary breakdown process (PBP) and normally followed by stepped leaders and return strokes. Another breakdown process which is not resulting to return stroke are breakdown process associated with cloud flash (IC) and isolated breakdown (IB). Previously, Ahmad et al. [4] have studied the temporal characteristics of the first electric field pulse for IC and CG− in time domain. In this paper, we are motivated to extend the study by analyzing the first pulse through the wavelet perspective or in the time-frequency domain. Also we extend the analysis further to include CG+ and IB flashes.

2. MEASUREMENT SETUP

The measurements were done in the premise of Ångström Laboratory, Uppsala University, Sweden (59.8°N and 17.6°E) during summer thunderstorm between May and August 2010. The measuring system consists three main parts as shown in Figure 1 namely the parallel plate flat antenna unit, the buffer circuit unit and the recording unit (digital transient recorder) which was the same setup used by Mohd. Esa et al. [3] in their works and explained by Cooray [1]. A broadband antenna system equipped with parallel flat-plate was used to capture fast vertical electric field changes and the decay time constant was fixed at 15 ms that been determined by the impedance values in the buffer circuit unit. The output of the buffer was driven to a 4-channel 12-bit Yokogawa SL1000 Digital Storage Oscilloscope capturing unit. A coaxial cable was used to connect the antenna and buffer circuit and 50 Ω-terminated coaxial cable was used to connect the buffer circuit and the recording unit. The data presented in this paper were recorded at 20 MS/s (50 ns time resolution) with 30 ms delay.

3. RESULTS, ANALYSIS AND DISCUSSIONS

From the total of 885 waveforms, 72 waveforms have been selected to be analyzed and such waveforms are divided into different type of lightning event namely negative ground flash (CG−), positive ground flash (CG+), cloud discharge (IC) and isolated breakdown discharge (IB). The first pulse of each lightning event is then analyzed using wavelet transformation and then plotted in time and

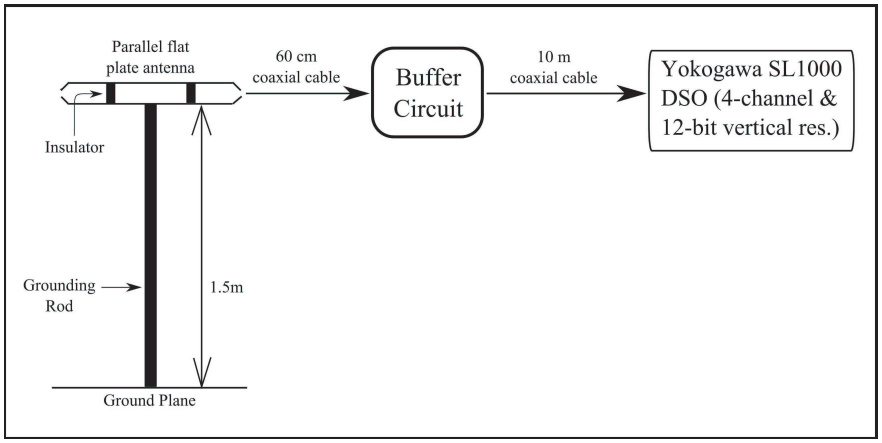

Figure 1: Parallel flat antenna used in the measurements. (Partially adapted from Cooray [1]).

frequency domain as illustrated in Figure 2 below. As have been described by Miranda [2] and Sharma et al. [5], each pulse will have 2 parts or stages; initial and overshoot. To understand the colour distribution in wavelet power spectrum energy radiation, two main regions are utilized in this work; spectral region and spread region. Since power spectrum magnitude has been normalized, spectral region is defined as the energy of power spectrum that radiate above 30% or 0.3 of the maximum magnitude. For the spread region, the power spectrum that radiate more than 90% (or 0.9) of maximum magnitude will be selected. The value which is less than 0.3 will be noted as noise.

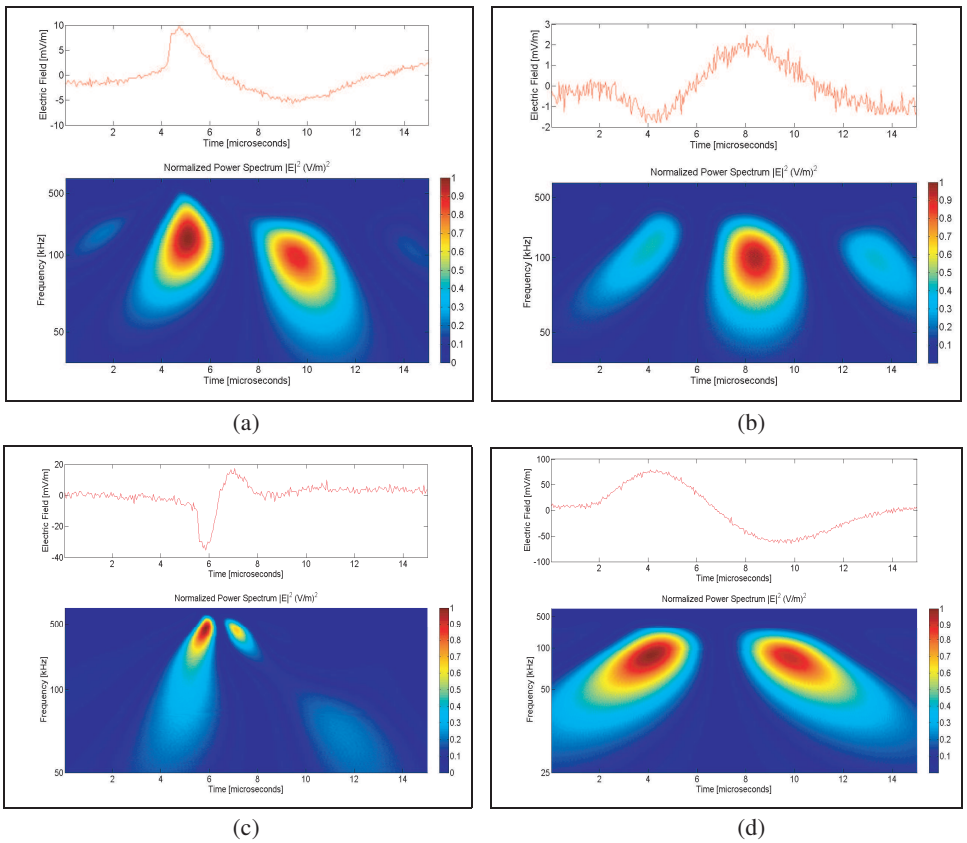

Figure 2: Wavelet power spectrum of the first pulse with single peak pulse and single spread wavelet transformation pertinent to (a) negative CG (CG−), (b) positive CG (CG+), (c) cloud Flash (IC) and (d) isolated Breakdown discharge (IB).

It is discovered that about 23 are from CG−, 12 are contributed by CG+, 28 IC and 11 IB. For

example, Figure 1(a) shows that the spectral region for both initial and overshoot stages are lying from 50 to 500 kHz. Whereas, the spread region are approximately between 100 kHz to 200 kHz and 80 kHz to 120 kHz for initial and overshoot stages, respectively. The example for CG+, IC and IB single peak pulse and single spread power spectrum can be seen in Figures 1(b), 1(c) and 1(d), respectively.

In Table 1, it can be observed that the order from the highest to the lowest average values (both maximum and minimum) starts with IC followed by CG−, CG+ and IB in both spectral and spread regions which is also covers during both initial and overshoot stages. It seems that, both the average maximum and minimum frequencies for IC are at least double than CG− average values and about 10 and 6 times higher than IB and CG+, respectively. It shows that IC seems to start the process of initiation at higher frequency which in average it starts to radiate intensely at more than 450 kHz and possible to radiate up to higher microwave region. On the other hand, IB's first pulse shows that it only requires in average about 40 kHz in order to start the initiation process.

Table 1: Statistic for first pulse of different type of lightning events.

Statistics		Initial Stage		Overshoot Stage		Ratio of power peak of initial stage and overshoot stage
		Spectral range (kHz)	Spread region (kHz)	Spectral range (kHz)	Spread region (kHz)	
CG−	Minimum	23	42	22	35	0.67
	Maximum	7645	3987	5714	4198	3.12
	Average	186–1637	475–821	391–1020	572–730	1.6
CG+	Minimum	26	51	23	37	0.44
	Maximum	2174	758	893	649	1.84
	Average	62–599	148–243	57–278	107–166	1.06
IC	Minimum	20	41	21	42	0.6
	Maximum	12195	7418	9141	6329	2.93
	Average	461–3570	1007–1744	663–2067	919–1439	1.7
IB	Minimum	22	46	13	30	0.73
	Maximum	1064	595	926	495	2.29
	Average	45–279	97–146	44–218	92–122	1.17

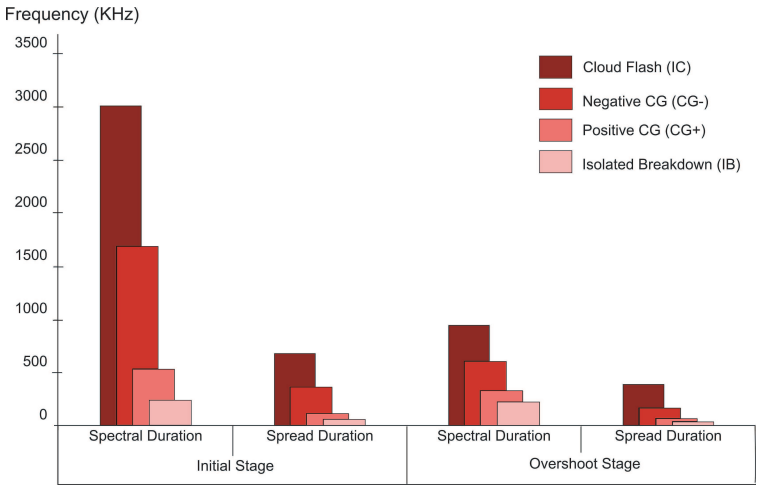

Figure 3: Frequency differences pertinent to lightning events.

Figure 3 illustrates the frequency differences or bandwidth, where frequency difference implies the difference between mean maximum frequency and mean minimum frequency. It is discovered that the highest bandwidth to the lowest bandwidth are following the same trend as observed in previous parameters. In comparison, the frequency difference of IC is found to be more than twice

compared to CG− and more than CG+ at least with the factor of 6. It is speculated that the energy radiated by the first pulse of IC is overwhelmingly high.

The highest mean ratio of initial peak to overshoot peak is gained by IC which is a slightly higher than CG− with 1.7 and 1.6, respectively. The average ratio gained by first CG− pulse in this paper is found to be slightly lower than the average ratio reported by Sharma et al. [5] where the average ratio of initial to overshoot power peak for the first 200 µs of preliminary breakdown pulses was 1.8. As for IB, it is found to be lower than the first two lightning events' mean ratio but almost comparable with CG+; 1.17 and 1.06, respectively. It shows that in all type of lightning events the energy radiated by initial is stronger than overshoot energy. This is maybe due to the effect of propagation which is prone to overshoot stage as speculated by Miranda [2]. However, due to the ratio gained by IC and CG− is at least 1.4 higher than CG+ and IB, it can be speculated that the intensity of energy radiated from IC is similar to CG− but differ from CG+ and IB.

4. CONCLUSION

Wavelet transformation has been done to 72 first pulses' concerning to CG−, CG+, IC and IB in order to understand and identify any distinctive features between these lightning events. It is found that IC dominates in all four selected parameters such as mean maximum and minimum frequencies, frequency difference and initial-to-overshoot ratio with at least twice higher than CG− and higher than CG+ with the factor of 6. It is also observed that IB gained the lowest in all parameters except in the initial-to-overshoot peak ratio. It is found that in average the energy radiated during initial stage is always higher than during the overshoot stage with at least the factor of 1.06 which is gained by CG+.

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REFERENCES

1. Cooray, V., "The mechanism of lightning flash," *The Lightning Flash*, V. Cooray, ed., 214–215, The Institutions of Electrical Engineers (IEE), London, 2003.
2. Miranda, F. J., "Wavelet analysis of lightning return stroke," *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 70, 1401–1407, 2008.
3. Mohd. Esa, M. R., M. R. Ahmad, V. Cooray, and M. Rahman, "Distinctive features of initial breakdown process between ground and cloud discharges," *16th Asean Conference on Electrical Discharges (ACED)*, Johor Bahru, Malaysia, December 10–12, 2012.
4. Ahmad, N. A., M. Fernando, Z. A. Baharudin, M. Rahman, V. Cooray, Z. Saleh, J. R. Dwyer, and H. K. Rassoul, "The first electric field pulse of cloud and cloud-to-ground lightning discharges," *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 72, 143–150, 2010.
5. Sharma, S. R., V. Cooray, M. Fernando, and F. J. Miranda, "Temporal features of different lightning events revealed from wavelet transform," *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 73, 507–515, 2011.