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Wavelet Analysis for Negative Return Stroke and Narrow Bipolar Pulses

Z.Zakaria, N.A.Ahmad, Z. C.L.Wooi, M.R.M.Esa, Abdul-Malek
Institute of High Voltage and High Current,
Fakulti Kejuruteraan Elektrik,
Universiti Teknologi Malaysia,
81310 Johor Bharu, Malaysia.
ee_zai89@yahoo.com

Z.Zakaria
Institute of High Voltage and High Current,
Fakulti Kejuruteraan Elektrik,
Universiti Teknologi Malaysia,
81310 Johor Bharu, Malaysia.
ee_zai89@yahoo.com

***Abstract*—Lightning generates electric fields are known to have negative consequences. In this study, two types of lightning electric fields which are Negative Return Stroke (NRS) and Narrow Bipolar Pulses were thoroughly analyzed using wavelet analysis. Hence, analysis on the wavelet and frequency spectrum reveal that the energy spectrum for NBP concentrates at high frequency (200 kHz to 500 kHz) with average peak power of the initial stage for NNBP and NPBP are 76,650 $(V/m)^2$ and 76309$(V/m)^2$ respectively. However, the initial stage peak power corresponding to NRS is about 118,931$(V/m)^2$ with lower frequency spectrums (60 kHz). The results suggest that NBP radiates energy at high frequency region compared to NRS. Hence it can be concluded that, electric field pulse for NBP experience more extensive and rapid ionization process compared to NRS.**

Keywords-Negative Return Stroke; Narrow Bipolar Pulses; Wavelet; .Spectrum.

I. Introduction

Lightning generates electric fields are known to have negative consequences. Therefore, the electric field characteristics of different types of lightning activities are at extremity to be studied and analyzed.

Studies of lightning characteristics have been carried out by a lot of researcher especially lightning related to ground flash since it is one of the fascinating natural phenomenon's on earth[9]. However, many aspects of lightning are still not well understood due to complexity of lightning characteristics. Two type of lightning that have been discussed in previous study are cloud flash and ground flash[1][5]. Studies on ground flash have been carried out in a great detail. However, due to increasing number of accidents caused by ground flash type of lightning strike, the need and awareness to have further research on the characteristic of lightning flash has become increased as well.

The theory of wavelet analysis and its usage in a wide range of applications have been well documented in the past decades. Hence, wavelet tools can be considered as a robust tool in order to investigate the behavior of the real signal in frequency domain. The wavelet transform is very useful in analyzing transient phenomena due to its ability to extract time and frequency information from the transient signal. The theory of wavelet analysis and comparison made using Fourier analysis has been documented in[11][7][2]. Wavelet transform was developed, and it has been used in many studies related to lightning.

A. Wavelet Theory

The theory of wavelet analysis and its usage in a wide range of applications have been well documented in the past decades. Hence, wavelet tools can be considered as a robust tool in order to investigate the behavior of the real signal in frequency domain. The wavelet transform is very useful in analyzing transient phenomena due to its ability to extract time and frequency information from the transient signal. The theory of wavelet analysis and comparison made using Fourier analysis have been documented in [11]. A wavelet analysis for geophysical application and practical guide to wavelet function have been explained and the details of analysis wavelet are presented as in [6][13]. One of the commonest continuous wavelets is Morlet, Paul and Derivative of Gaussian (DOG) wavelet. This type of wavelet can either be real or complex. The DOG wavelet is categorized as real, while the Morlet and Paul are under complex wavelet.

II. Methodology

The measurement was conducted during the northeast period in Malaysia. Twelve measurements were conducted on 23rdNovember, 27th to 30th November, 3rd December, 6th December, 10th December, 12th December, 13th December, and 19th December 2012. The measurements were performed in the vicinity of Universiti Teknologi Malaysia (UTM), Johor located at the southern tip of peninsular Malaysia (1.562^{o}N, 103.636^{o}N), very close to the equator. The measuring station was situated on top of a hill which was 132 m above the sea level and about 30 km away from the Tebrau Strait.

Parallel plate antenna was used to sense the vertical electric field. The parallel plate was placed at 12 meters from the control room where the recording system was kept. Output of the buffer amplifier was driven to a LeCroy Wave Runner 400MHz oscilloscope. This oscilloscope operated at 8 bit resolution with bandwidth of 20 MHz to 200 MHz. A 60 cm RG58 coaxial cable was used to connect the antenna and buffer circuit. About 10 m RG58 coaxial cable was used to connect the output of the buffer circuit and the oscilloscope

Wavelet tool are used to get the lightning behavior of frequency content and their relative energies. In this study, the Derivative of Gaussian (DOG) wavelet was used. This algorithm was used because this type are more stable for computation of wavelet power spectrum[8].

III. RESULTS AND DISCUSSION

Wavelet analysis is a powerful tool to analyses data because it can extract information from data both in time and frequency domain. A total of 70 data were measured and analyzed during northeast monsoon period in Malaysia in 2012 using wavelet transformation. A set of data with a very fine structure of waveform was selected and grouped into three different lightning activities; a) negative return stroke (no of sample selected : 27), b) NNBP (no of sample selected : 13) and c) NPBP (no of sample selected : 30). Note that all data were normalized to 50 km distance.

Figure 1, Figure 2 and Figure 3 depict the time domain events and wavelet transform in frequency domain for NPBP, NNBP and NRS with the window sizes of 200µs, respectively. In each Figure, the upper plot shows the time domain electric field of NPBP, NNBP and negative return stroke, while the lower plot indicates the wavelet transform analysis. The intensity of power spectrum is shown based on color contour. In this analysis, the frequency region and power radiation of negative return stroke, NPBP, and NNBP were divided into sections, which were initial and overshoot (later) stages, as shown in Figure 1.The initial stage was basically determined from the onset of the waveform to the zero crossing point, while the overshoot stage was determined from the onset of the overshoot to the point where the signal would be coming back to zero level, as shown in Figure 1.

The vertical color bar on the right hand side in the lower plot shows the scale of power spectrum. This power spectrum displayed that the spread region was bounded by the dark-red colour contour, while the spectral region was bounded by the light-blue colour contour. Spectral region is a region where predominant energy radiates, and is bounded by the light-blue colour contour. Spread region is defined as part of the spectral region where the most intense energy radiates and is bounded by the dark red colour contour.

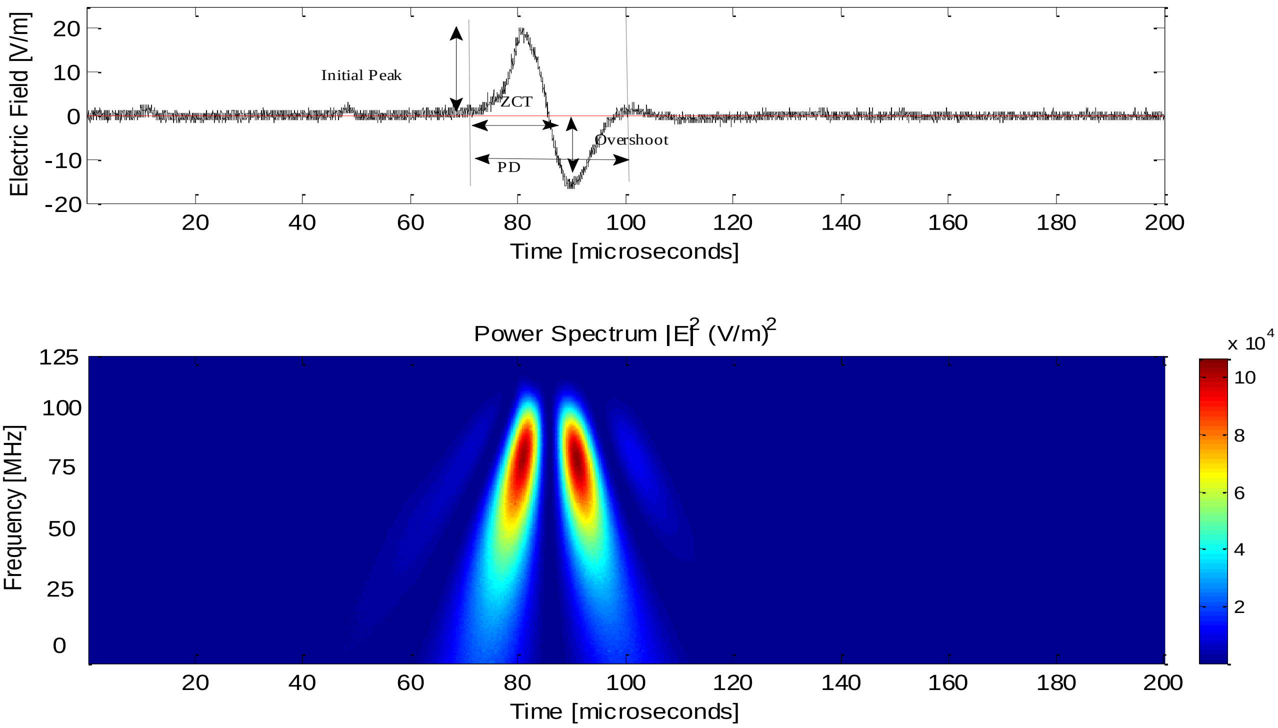

Figure 1. Typical NPBP recorded on 28 December 2012; (a) Electric field in time domain, (b) Wavelet power spectrum in frequency domain

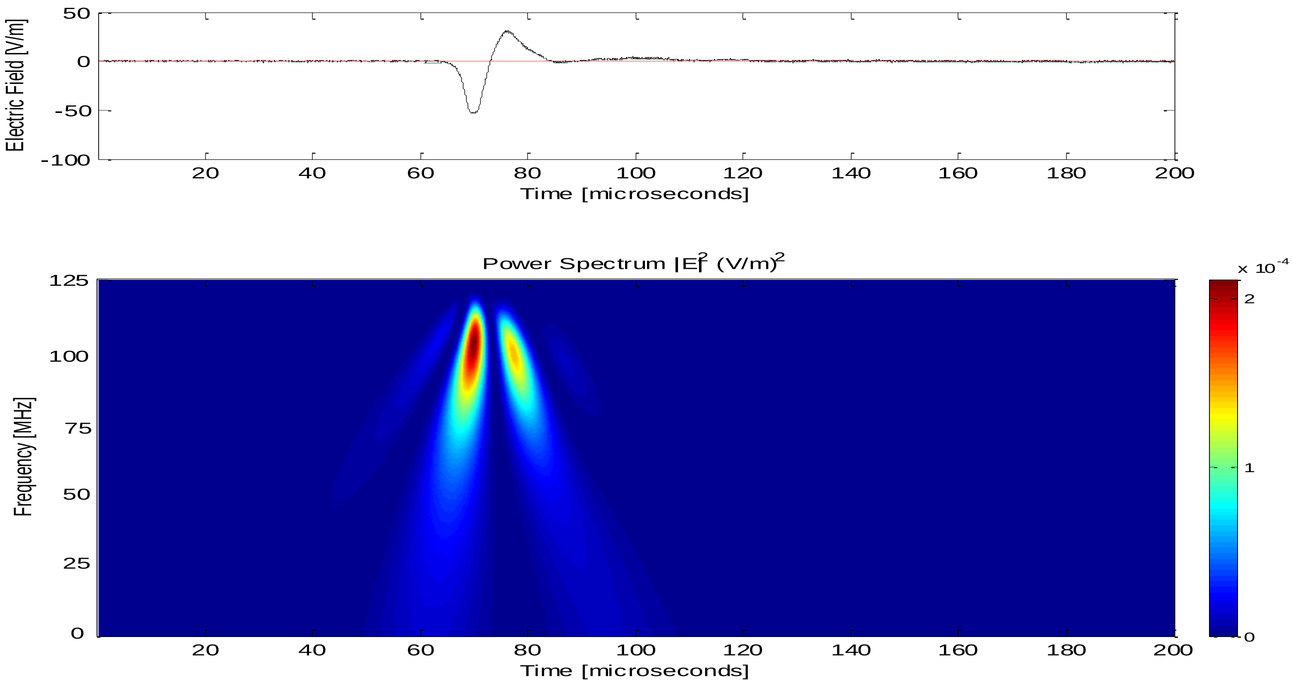

Figure 2. Typical NNBP recorded on 23 December 2012; (a) Electric field in time domain, (b) Wavelet power spectrum in frequency domain

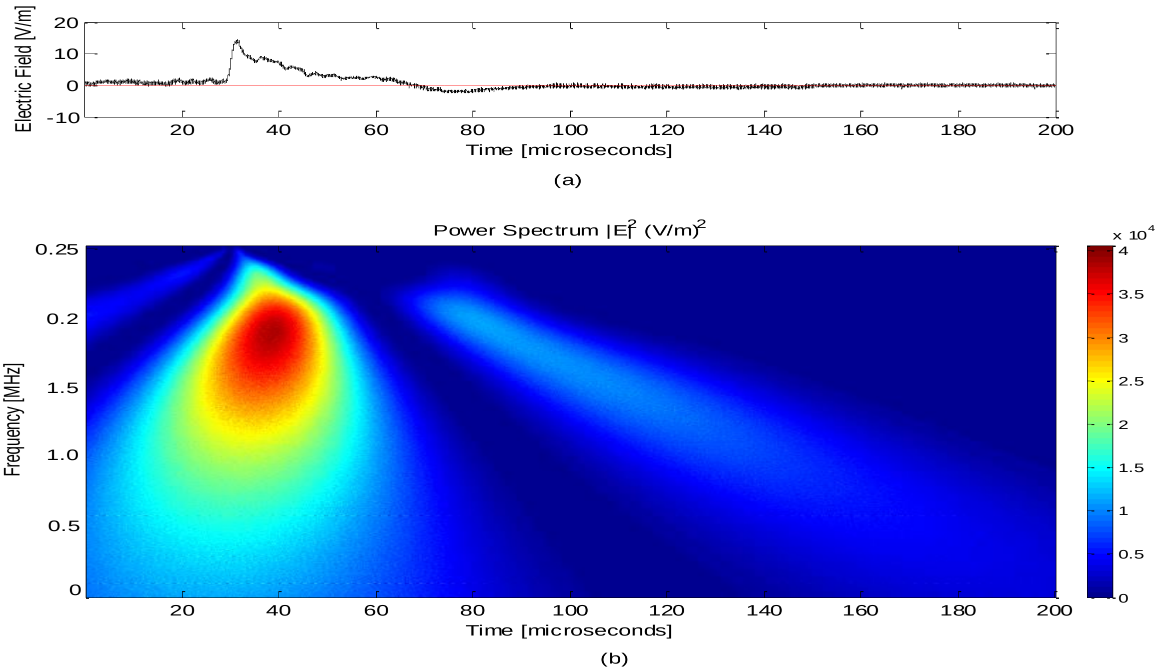

Figure 3. Typical (NRS) recorded on 23 December 2012; (a) Electric field in time domain, (b) Wavelet power spectrum in frequency domain

Table I shows the statistics for the power spectrum of narrow negative bipolar pulses (NNBP). It can be seen from the result that the spectral region for the initial stage was in the range of 233.31 kHz to about 411.43 kHz, while the spread distribution of initial stage ranged between 59.38 kHz to 102.07 kHz. The average range for spectral region and spread region for initial stage were at 327 kHz and 82 kHz, respectively. The range 126.8 kHz to 245.89 kHz was present for spectral range of overshoot stage. However, the spread region for overshoot had a smaller frequency range (0 kHz to 41.82 kHz). Some of the waveform data for NNBP did not radiate at spread region for overshoot stage. This is in agreement with results in [4] where it was mentioned that NBPs radiate energy mostly in the range of 200 kHz to 500 kHz. As reported in [3] spread region for the initial range lower than in this study. However, the spread region for the overshoot stage was within the range, as reported in [3].

The peak power spectrum for NNBP in the initial stage had a minimum of 34611(V/m)^2, a maximum of 169860 (V/m)^2 and average of 76650.85(V/m)^2. The peak power spectrum for the overshoot had a minimum of 13934(V/m)^2, a maximum of 89140 (V/m)^2 and average of 42632.23(V/m)^2.

TABLE I. STATISTIC OF THE WAVELET POWER SPECTRUM OF NNBP

Statistics (NNBP)	**Spectral region for the initial stage (kHz)**	**Spread region of initial stage (kHz)**	**Spectral region for the overshoot (kHz)**	**Spread region of overshoot (kHz)**	**Peak power spectrum for the initial stage (V/m)^2**	**Peak power spectrum for the overshoot (V/m)^2**
Minimum	233.31	59.379	126.80	0	34611	13934
Maximum	411.43	102.07	245.89	41.816	169860	89140
Average	326.70	81.82	176.86	1.176	76650.85	42632.23

TABLE II. STATISTIC OF THE WAVELET SPECTRUM OF NPBP

Statistics (NPBP)	**Spectral region for the initial stage (kHz)**	**Spread region of initial stage (kHz)**	**Spectral region for the overshoot (kHz)**	**Spread region of overshoot (kHz)**	**Peak power spectrum for the initial stage (V/m)^2**	**Peak power spectrum for the overshoot (V/m)^2**
Minimum	63.97	3.3	7.79	0.00	5259	2039
Maximum	471.49	113.02	199.38	13.46	307640	110970
Average	289.89	67.31	79.50	0.83	76309.23	35013

TABLE III. STATISTIC OF THE WAVELET SPECTRUM OF NPBP

Statistics (NRS)	**Spectral region for the initial stage (kHz)**	**Spread region of initial stage (kHz)**	**Spectral region for the overshoot (kHz)**	**Spread region of overshoot (kHz)**	**Peak power spectrum for the initial stage (V/m)^2**	**Peak power spectrum for the overshoot (V/m)^2**
Minimum	10.392	0.773	0	-	12489	0
Maximum	122.96	9.634	18.166	-	280980	163920
Average	54.077	3.690	6.447	-	118931	51855

Table II shows the statistic of the wavelet spectrum for NPBP. The spectral region for initial stage had a minimum of 63.97 kHz and maximum value of 471.49 kHz with average 289.89 kHz. The spread region of initial stage fell in the range of 3.3 kHz to 113.02 kHz with average of 67.31 kHz. Hence, the frequency region for spectral distribution of overshoot was 7.79 kHz to 199.38 kHz with average value 0.83 kHz. Further, the spread distribution of overshoot ranged between 0 kHz to 13.46 kHz with average of 0.83 kHz. Peak power spectrum for NPBP in the initial stage had a minimum of 5259(V/m)^2, a maximum of 309640 (V/m)^2 and average of 76309.23(V/m)^2. The peak power spectrum for the overshoot had a minimum of 2039(V/m)^2, a maximum of 110970 (V/m)^2 and average of 35013(V/m)^2. When compared between NNBP and NPBP, the initial pulses had similar energy in the initial, whereas the overshoot seemed to be slightly more energetic in NNBP.

In wavelet analysis of NRS, the spread distribution of overshoot was zero because the overshoot stage for negative return stroke was too small. As reported in [8], the cases of intermediate and near field overshoot are not common. The initial peak of NRS pulses was found to radiate predominantly in the average spectral of 54.077 kHz with a minimum value of 10.392 kHz to maximum value of 122.96 kHz. The spread distribution of initial radiated in the average of 3.89 kHz with a minimum value of 0.773 kHz and maximum value of 9.634 kHz. The peak power spectrum for negative return stroke (NRS) in the initial stage had a minimum of 12489 $(V/m)^2$, a maximum of 280980 $(V/m)^2$ and average of 118931 $(V/m)^2$.

As comparison between NRS, NNBP and NPBP, the wavelet analyses showed that NRS radiated energy at lower frequency. As reported in [12], return strokes have the strongest source of energy at lower frequency below 10 kHz. In this study, NRS radiated energy at lower frequency below 60 kHz, as compared to NBPs radiated energy, mostly in the range of 200 kHz to 500 kHz. In specific comparison, as mention in [10]found that between CG and IC flashes, both temporal and wavelet analyses suggested that the first electric field pulse of IC radiated energy at higher energy compared to negative CG flash.

IV. Conclusion

Wavelet analysis had also been used to analyses the energy behavior of both types of discharges, NBPs and NRS. A specific comparison between NRS, NNBP and NPBP has been done. Wavelet analysis shows that NBPs radiate at high frequency (200 kHz to 500kz) with average peak power spectrum for NNBP at initial stage is 76,650 $(V/m)^2$ and overshoot stage is 42,632 $(V/m)^2$. After that, power spectrum for NPBP at initial stage is 76,309 $(V/m)^2$ and peak power spectrum for the overshoot stage is 35,013 $(V/m)^2$. However, the peak power corresponding for NRS is approximately 118,931$(V/m)^2$ at overshoot stage and 51,855$(V/m)^2$ at initial for frequency spectrum below 60 kHz. It is found that NRS is the strongest source of energy at lower frequency which in line with the comparison between negative CG and IC flashes obtained in [10] and [12].

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