Automated Negative Lightning Return Strokes Classification System

F. Abdul Haris¹,², M.Z.A. Ab Kadir¹, S. Sudin³, D. Johari², J. Jasni¹ and S.Z. Mohammad Noor²

¹ Advanced Lightning, Power and Energy Research (ALPER), Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
² School of Electrical, College of Engineering, Universiti Teknologi MARA Shah Alam, 40450, Selangor, Malaysia.
³ Faculty of Electrical Engineering Technology, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia.

faranadia@uitm.edu.my

Abstract.: Over the years, many studies have been conducted to measure and classify the lightning-generated electric field waveform for a better understanding of the lightning physics phenomenon. Through measurement and classification, the features of the negative lightning return strokes can be accessed and analysed. In most studies, the classification of negative lightning return strokes was performed using a conventional approach based on manual visual inspection. Nevertheless, this traditional method could compromise the accuracy of data analysis due to human error, which also required a longer processing time. Hence, this study developed an automated negative lightning return strokes classification system using MATLAB software.

In this study, a total of 115 return strokes was recorded and classified automatically by using the developed system. The data comparison with the Tenaga Nasional Berhad Research (TNBR) lightning report showed a good agreement between the lightning signal detected from this study with those signals recorded from the report. Apart from that, the developed automated system was successfully classified the negative lightning return strokes which this parameter was also illustrated on Graphic User Interface (GUI). Thus, the proposed automatic system could offer a practical and reliable approach by reducing human error and the processing time while classifying the negative lightning return strokes.

1. Introduction

Lightning is a natural phenomenon that develops a sudden electrostatic discharge during thunderstorm days. It occurred between electrically charged regions of the cloud (intra-cloud lightning), between clouds (cloud-to-cloud lightning), and between a cloud and the ground (cloud-to-ground lightning) [1]. High-current produced by lightning about amperes to tens of kilo amperes can harm humankind and damage electronic and electrical systems [2-3]. In addition, the brightness and intensity of lightning flash against the cloud create otherworldly nature phenomena. Lightning can be described, according to Uman (1984), as a transient, high-current (typically tens of kilo amperes) electric discharge in the air whose length is measured in kilometers [3]. About 90 % or more of global cloud-to-ground lightning is accounted for by negative (negative charge is effectively transported to the ground) downward (the initial process begins in the cloud and develops in the downward direction) lightning [4-5].
There are two types of lightning phenomena: ground flashes, where the lightning strike directly connects with the ground. Meanwhile, the other type, which the lightning strike does not reach out to the ground part known as cloud flashes [5]. Out of these two types, the ground flashes of lightning might be the most damaging as it could cause property damage, starts fires, and injures people. The ground flash can further be subdivided into downward ground flash (CG) and upward ground flash (GC), in which the downward CG was initiated from the cloud. In contrast, the upward GC was actuated from a tall structure [5]. Each of these ground flashes consists of Positive and Negative types [6-7]. The negative return stroke is a very bright visible flash from cloud-to-ground caused by the rapid electricity discharge. A complete lightning ground flash includes a sequence of one or more high-amplitude short-duration current impulses or return strokes [8]. Furthermore, downward negative lightning flashes are considered to represent more than 90% of global cloud-to-ground discharge [9-10].

Numerous studies described the lightning electric field's measurement and classification mainly on the negative lightning return strokes in a tropical and non-tropical region [11-15]. However, the classification of negative lightning return strokes was performed using a conventional method based on manual inspection from the naked eye [11-15]. In most of the previous studies, the output waveform was examined manually one by one through zooming in and out features to classify the negative lightning return strokes. The data classification for negative lightning return strokes was recorded manually from the transient recorder system through the conventional method. Hence, this study presents an automated negative lightning return strokes classification system divided into two parts; the first part is the lightning measurement system to detect and measure the lightning-generated electric field signal. The second part involves developing an automated classification system to plot, classify, and record the negative lightning return strokes automatically by using Matlab software.

2. Methodology

2.1 Lightning Measurement System

A pictorial diagram of the lightning measurement system composed of the parallel plate antenna, buffer electronic circuit, and the developed monitoring system to classify the negative lightning return strokes is shown in figure 1. The lightning-generated electric waveform is measured using a parallel plate antenna with 0.555 metres height and a 0.25 metres diameter. The buffer electronic circuit is constructed by RC filter, MSK0033 buffer amplifier, and impedance matching circuit for the fast field of electric field measurement. This circuit is connected to the transient recorder system (PC Oscilloscope 4000 Series) with 25 MS/s (Mega samples per second) through 15 metres long RG58 coaxial cable. Then, the monitoring system is developed based on the waveform/signal measured by this transient recorder system using Matlab software.

![Figure 1. Pictorial Diagram of Lightning Measurement System](image-url)
2.2 Automated Classification System

A flowchart of the overall process for automated classification system strokes by using Matlab software is shown in figure 2. In this system, the real-time lightning activity was measured by the lightning measurement system, as highlighted in the previous part. Then, the real-time data (raw data) is fetched from the transient recorder system, which refers to the Picoscope software. The system will normalize and convert the data captured by the Picoscope into numerical, and plot in a full spectrum configuration. The developed system will find the peak amplitude from the full spectrum of the output waveform, and then it will compare the positive and negative peak amplitude values. In this part, if the positive peak amplitude (+ve) is greater than the negative peak amplitude (-ve), the system will be classified as negative return strokes; otherwise, it will be classified as others.

In this system, the peak amplitude was identified by implementing a comparative concept where the value of each raw data is compared to determine a maximum value of the plotted waveform. This concept can be further explained based on figure 3, in which the variable $a_n$ is assumed starting at point zero; meanwhile, the $a_{n+1}$ variable is referred to as any point other than zero. The system works when the value of variable $a_n$ is less than the $a_{n+1}$; then the peak indicate as $P$ is equal to $a_{n+1}$. Then, the looping process continued until the value of $a_n$ is greater than $a_{n+1}$. Hence, the highest value of $a_{n+1}$ variable became the peak value ($P$). Meanwhile, the $t_P$ variable indicates the time at the peak amplitude. The flowchart of the pseudocode can be simplified, as shown in figure 4.

![Flow Chart of the Developed Automated Negative Lightning Return Strokes Classification System](image1)

![Peak Amplitude of Negative Lightning Return Strokes](image2)
3. Results and Discussion

A total of 115 negative lightning return strokes have been successfully identified from the 205 lightning signals. The recorded lightning signal was compared with the TNBR (Tenaga Nasional Berhad Research) historical lightning stroke report. The TNBR works as an in-house solution provider in terms of technical solutions and innovation for the largest electricity utility company in Malaysia, recognized as Tenaga Nasional Berhad (TNB). The measured signal was compared with the TNBR Lightning Detection System (LDS), where the system detects a real-time lightning activity in Peninsular Malaysia. The location of the developed lightning measurement system (blue placemark) at the college of engineering building rooftop at UNITEN, where its proximity to the equator is given by geographic coordinates of latitude and longitude 2.973270N and 101.728536E, as shown in figure 5.

Meanwhile, the yellow placemark indicates the lightning activity recorded by the TNBR system from Google Earth. Based on the same figure, the lightning signal measured from this study was validated with the lightning signal detected by the TNBR within 10 kilometres radius on 26th September 2019. Table 1 presents the measured time of the lightning signal and the distance of the detected lightning activity from the location of the developed measurement system. It was observed that the measured time of the lightning signal detected from the developed lightning measurement system is similar to those signals detected from the TNBR, as shown in table 1.

The developed Graphic User Interface (GUI) for an automated monitoring system is illustrated from figure 6, by displaying a full spectrum lightning-generated electric waveform and classifying the negative lightning return strokes through Matlab software. In addition, the value of the negative return...
strokes parameters such as peak amplitude (P) and tp (time at peak amplitude) are also presented from this GUI. Apart from that, all the raw data for each waveform was stored in the excel file with the format of .xlsx.

![Lightning activity map](image)

**Figure 5.** Location of the developed lightning measurement system and lightning activities on 26th September 2019.

| No | Date       | Measured Time (This Study) | Measured Time (TNBR) | Distance (km) |
|----|------------|-----------------------------|----------------------|---------------|
| 1  | 26/09/2019 | 3:04 PM                     | 3:04:02 PM           | 6.91          |
| 2  | 26/09/2019 | 3:04 PM                     | 3:04:03 PM           | 8.13          |
| 3  | 26/09/2019 | 3:55 PM                     | 3:56:09 PM           | 6.14          |
| 4  | 26/09/2019 | 5:57 PM                     | 5:57:03 PM           | 4.00          |
| 5  | 26/09/2019 | 6:15 PM                     | 6:15:38 PM           | 6.85          |
| 6  | 26/09/2019 | 6:17 PM                     | 6:17:17 PM           | 7.72          |
| 7  | 26/09/2019 | 6:21 PM                     | 6:21:24 PM           | 8.42          |
| 8  | 26/09/2019 | 6:28 PM                     | 6:28:01 PM           | 7.71          |
| 9  | 26/09/2019 | 6:30 PM                     | 6:30:25 PM           | 5.24          |
| 10 | 26/09/2019 | 7:08 PM                     | 7:08:47 PM           | 6.19          |
| 11 | 26/09/2019 | 7:28 PM                     | 7:27:28 PM           | 10.51         |
| 12 | 26/09/2019 | 8:33 PM                     | 8:33:21 PM           | 9.38          |
| 13 | 26/09/2019 | 8:54 PM                     | 8:54:29 PM           | 6.11          |
| 14 | 26/09/2019 | 8:55 PM                     | 8:55:25 PM           | 9.76          |
| 15 | 26/09/2019 | 9:01 PM                     | 9:01:37 PM           | 8.44          |
4. Conclusion

This study demonstrated an automated negative lightning return strokes classification system for electric field signals by using MATLAB software. A total of 115 lightning-generated electric field signals were recorded and classified automatically by using this system. Based on the data comparison and validation with the TNBR lightning activity report on 26th September 2019, it shows the capability of the lightning measurement system to capture and measure the lightning-generated electric field waveforms. Apart from that, the conventional method that has been adopted from the previous studies to record and analyse the negative lightning return strokes could compromise the accuracy of data analysis due to human error. Moreover, through manual inspection, the procedure of classification and recording for each raw data or waveform required a longer time to process. Hence, the developed automated classification system can provide a reliable monitoring system for negative lightning return strokes parameters by reducing the processing time and reducing the non-uniformity among users. For future work, apart from the automated classification on negative lightning return strokes, this system can be employed to characterise automatically mainly on seven parameters of negative return strokes, i.e., on zero-to-peak rise time, 10-to-90% rise time, zero-crossing time, slow front time, slow front amplitude relative to peak, fast transition 10-to-90% rise time, and width dE/dt pulse at half peak value.
References

[1] S.Shivalli 2016 Lightning Phenomenon, Effects and Protection of Structures from Lightning IOSR Journal of Electrical and Electronics Engineering. 11 pp. 44-50.
[2] V. A. Rakov and M. A. Uman 2003 Lightning: Physics and Effects Cambridge Univ. Press, New York
[3] M. A. U. Joseph R. Dwyer 2014 The physics of lightning Phys. Rep. 534 pp. 147–241
[4] V. A. Rakov 2012 The Physics of Lightning parameters of engineering interest Light. Prot., Institution of Engineering and Technology 21 pp. 15–96.
[5] V. Cooray 2015 Charge Generation in Thunderclouds and Different Forms of Lightning Flashes, in: An Introd. to Light., Springer Netherlands pp. 79–89.
[6] V. Cooray 1996 A Model for Negative First Return Strokes in Lightning Flashes Institute of High Voltage Research, University of Uppsala, Sweden. pp. 119-128.
[7] H.Rojas, A.Cruz, C.Cortez 2017 Characteristics of Lightning-generated electric fields measured in the Colombia Department of Electrical Engineering, Colombia. pp. 243-251.
[8] G. Chi, Y. Zhang, D. Zheng, W. Lu and Y. Zhang 2014 Characteristics of lightning activities in Potala Palace region of Tibet International Conference on Lightning Protection (ICLP), Shanghai. pp. 1992-1994
[9] A.R.Jacobson, W.Boeck 2006 Comparison of Narrow Bipolar Events with Ordinary Lightning as Proxies for the Microwave-Radiometry Ice-Scattering Signature American Meteorological Society. 135 pp. 1354-1363.
[10] M. Izadi, M. Z. Abidin Ab Kadir, M. Hajikhani and C. Gomes 2016 Evaluation of lightning location and lightning current wave shape using measured lightning magnetic fields at two stations 33rd International Conference on Lightning Protection (ICLP), Estoril pp. 1-6
[11] Heidler, F., Hopf, C. 1998 Measurement Results of the Electric Fields in Cloud-to-Ground Lightning in Nearby Munich, Germany. IEEE Trans. Electromagnetic Compatibility 4 463–443
[12] Azlinda Ahmad, N.; Fernando, M.; Baharudin, Z. A.; Cooray, V.; Ahmad, H.; Abdul Malek, Z. Characteristics of Narrow Bipolar Pulses Observed in Malaysia 2010 J. Atmos. Solar-Terrestrial Phys 72 pp.534-540
[13] Wooi, C. L.; Abdul-Malek, Z.; Ahmad, N. A.; El Gayar, A. I. 2016 Statistical Analysis of Electric Field Parameters for Negative Lightning in Malaysia. J. Atmos. Solar-Terrestrial Phys. 146 pp.69-80
[14] Santamaria, F.; Gomes, C.; Roman, F. 2006 Comparison Between the Signatures of Lightning Electric Field Measured in Colombia and That in Sri Lanka 28th International Conference on Lightning Protection (ICLP). 1 pp. 12-18
[15] Hazmi, A.; Emeraldi, P.; Hamid, M. I.; Takagi, N. 2016 Research on Positive Narrow Bipolar Events in Padang 3rd International Conference on Information Technology, Computer, and Electrical Engineering, ICITACEE 2016 pp. 156-159
[16] Li Cai, Qiang Hu, Jianguo Wang, Xin Zou, Quanxin Li, Yadong Fan. 2021 Characterization of electric field waveforms from triggered lightning at 58 m. Journal of Electrostatics. Volume 109
[17] H. N. A. K.Mehranzamir, “Hardware Installation of Lightning Locating System Using Time Difference of Arrival Method,” Int. Conf. Electr. Eng. Comput. Sci., pp. 29–34, 2012.
[18] M. F. U.Sonnadra, V.Corray, “The Lightning Radiation Field Spectra of Cloud Flashes in the Interval from 20 kHz to 20 MHz,” IEEE Trans. Electromagn. Compat., vol. 42, no. 1, pp. 234–239, 2006.
[19] C. C. H.Rojas, a. Cruz, “Characteristics of lightning-generated electric fields measured in the Bogota Savanna, Colombia,” Electromagnetic Compatibility. vol. 16, no. 2, pp. 243–252, 2017.
[20] M. R. Ahmad et al., “Emission heights of narrow bipolar events in a tropical storm over the Malacca Strait,” Int. Conf. Electr. Eng. Comput. Sci., pp. 305–309, 2017.

[21] Z. Z. and M. R. A. C. Wooi, Z. Abdul-Malek, N. A. Ahmad, M. R. M. Esa, “Wavelet analysis of chaotic pulse trains prior to subsequent return strokes in Malaysia,” 33rd Int. Conf. Light. Prot., pp. 1–6, 2016.

[22] V. C. and M. R. M. E. M. R. M. Esa, M. R. Ahmad, “Time-Frequency profile of discharge processes prior to the first return stroke,” 2014 Int. Conf. Light. Prot., pp. 1134–1137, 2014.