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Investigation of Zero Crossing Detection for First Return Stroke in Negative Cloud-to-Ground Lightning Flash

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Abstract: This paper aims to investigate the minimum threshold for zero crossing detection of the first return stroke in negative cloud-to-ground lightning flashes. The uncertainty for a minimum threshold to be set into a programmed software for an automatic zero crossing detection motivated the author to overcome the problem. The software was built-in MATLAB. The development of the software considered the important parameter of lightning strike from the preliminary breakdown stages until the first return strokes. A single station measurement was setup in Ayer Keroh, Malacca. 41 samples of duration of the zero crossing time were recorded by using Lecoy HDO4024 with 5 MS/s. The results showed that the minimum threshold for zero crossing detection was 40µs with 82.9% accuracy. In conclusion, the minimum threshold of zero crossing detection of the first return stroke in negative cloud-to-ground was determined.

Keywords: minimum threshold, MATLAB; first return stroke; zero crossing

1. Introduction

Lighting strike is one of the mysterious phenomenon in this world. Lightning strike has many structural components such as preliminary breakdown pulses, first return stroke and subsequent return strokes. The first return stroke is the main structural component of the lightning strike. Zero crossing of the first return stroke lies in the first return stroke component.

This paper only focused on zero crossing detection for lightning detection system. In this paper, zero crossing is referring to the value of the duration of the zero crossing of the first return stroke in negative cloud-to-ground lightning flashes.

Zero crossing was defined by Haddad and his co-worker as the time from where the initial deflection rise part from the reference line to the point where it crosses the reference line again [1]. Zero crossing carries information about the duration of the pulse width, the fast transition time, the slow front transition time and the peak amplitude of the lighting strike. These parameters are the information contains in the first return stroke in negative cloud-to-ground flashes.

Zero crossing is usually calculated in tens of microseconds range. Shoory and his co-workers [2] reported zero crossing was calculated in tens microseconds range. The objective of their research was to investigate the reasons why some return-stroke model did not reproduce the far-field inversion of polarity with zero crossing occurring in the tens of microseconds range. The findings suggested to predict a zero-crossing occurring in the tens microseconds range for existing lightning stroke channel models.

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The duration of the zero crossing must be less than 100μs [3]. In 1979, Lin et al. (1979) found the duration of the zero crossing at distance of (1 – 200km) lies within the range 35-60μs in Florida [4]. In Sweden, duration of the zero crossing values reported was 49μs while in Sri Lanka the duration of the zero crossing was 90μs by Cooray and co-workers in 1985 [5]. This shows the geographical area of the study affected the duration of the zero crossing. The increase in distance of the lightning strike caused lower duration of the zero crossing. Gomes and Cooray reported the duration of the zero crossing lies in between 35-60μs [6]. Despite there are numerous duration of zero crossing values reported but the duration of zero crossing still lies in the range of tens microseconds.

Besides that, many durations of the zero crossing were reported in tens of microseconds range [2 - 6], there was a case in which some researchers found the duration of zero crossing was not in the tens of microseconds range. The unusual case was reported by Hamzah and his co-worker in 2014 [7]. The investigation was done by measuring a total 207 lightning cloud-to-ground flashes in Malaysia. The majority of the first return strokes consisted about 40 – 70 μs of the duration of zero crossing but on the other hand, the unusual long durations of zero crossing were also reported in the study and were categorized into 0.66ms to 7.96ms. The conclusion for the unusual long duration of the duration of zero crossing was explained by the neutralization process. The slower the neutralization process the higher the length of the vertical channel, the higher the zero crossing and vice versa.

The inconsistent value of the duration of zero crossing caused the prediction is hard to make unless there is a software which can measure the duration of the zero crossing. The creation of the software could help to predict the duration of the zero crossing for data measurement in the future.

Thus, the main problem in this research is because there is no software created to measure and calculate the duration of the zero crossing of the negative return strokes of the lightning strike. Furthermore, to the best of our knowledge the current method to determine the duration of the zero crossing was by using a manual measurement and calculation to analyze the duration of the zero crossing of the first return stroke. Therefore, the objective of this study is to identify the minimum threshold for the start point of the duration of the zero crossing of the first return stroke by using MATLAB for lightning detection system in southern peninsular of Malaysia.

1.1 Negative cloud to ground lightning

Negative cloud to ground lightning is commonly used to investigate the lightning events. This lighting occurred when there were interactions between the negatively charged ions and the positively charged ions within the area of the cloud and the ground in the earth. The formations of the negative cloud to ground quoted from [8] occurred when the stepped leader shown in Fig. 1 created a conducting path between the cloud negative charge region and ground. Then, the negative charged ions deposited along this path and as response the return stroke traversed the leader path upward from ground to the cloud charge region. As a result, this interaction neutralized the negative leader charge. Thus, both leader and return stroke processes contributed to transporting negative charge from cloud to ground. This was the sequences for the negative cloud to ground lightning flash occurred and emits electromagnetic wave. Negative cloud to ground was chosen to be investigated in this study because there were many cases or scenarios in the lightning and protection field involving this kind of lightning to be explored. The data of this lightning may help the engineers out there to simulate and create artificial lightning to build new protection system for electrical tools. Since the data of negative cloud to ground is important, this study selected this type of lightning to be investigated.

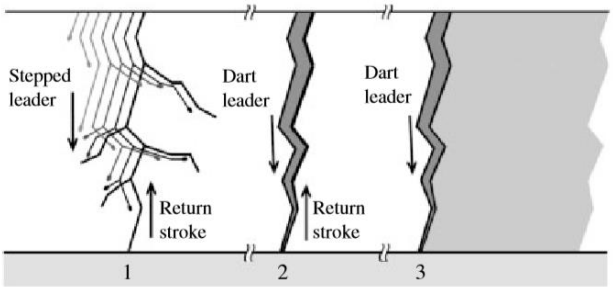

Fig. 1 - The formations of the negative cloud to ground lightning flash [8]

2. Data and Methodology

A measurement setup was in Southern Peninsular of Malaysia. The exact location was in Industrial Campus of Universiti Teknikal Malaysia Melaka, Ayer Keroh, Melaka. A single station measurement construction consists of a buffer circuit, a parallel flat plate antenna and an oscilloscope. The measurement for the lightning strike was conducted in March 2017. The collected data were consisted of 41 samples of the duration of zero crossing. The data was filtered and chosen based on the duration of zero crossing in the range of tens microseconds. The measurement setups were shown in Fig. 2 , Fig. 3 and Fig. 4.

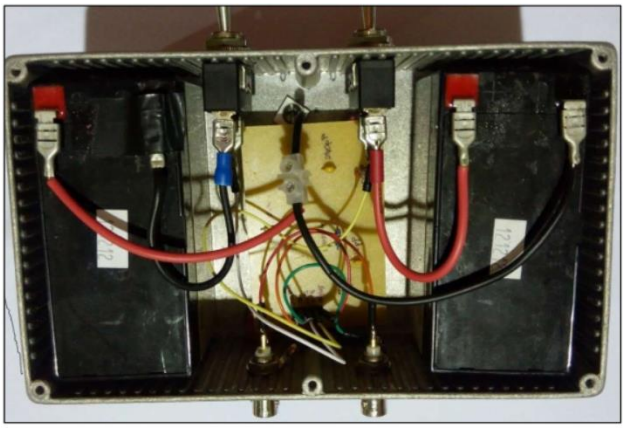

Fig. 2 - The buffer circuit to capture the lightning signal.

Fig. 3 - The antenna of parallel flat plate antenna was used in this study.

Fig. 4 - LeCroy HDO 4024 used to display the captured signal.

2.1 MATLAB

The program built in MATLAB. The program was to read the duration of the zero crossing of negative cloud to ground lightning flash. This study was essential to determine the minimum threshold for this program to create an algorithm for zero crossing detection of the cloud to ground lightning flash. The software will be used in the future to solve misidentification of lightning flash for lightning detection system.

2.2 First return stroke

Fig. 5 shown the signal of the first return stroke read in this software.

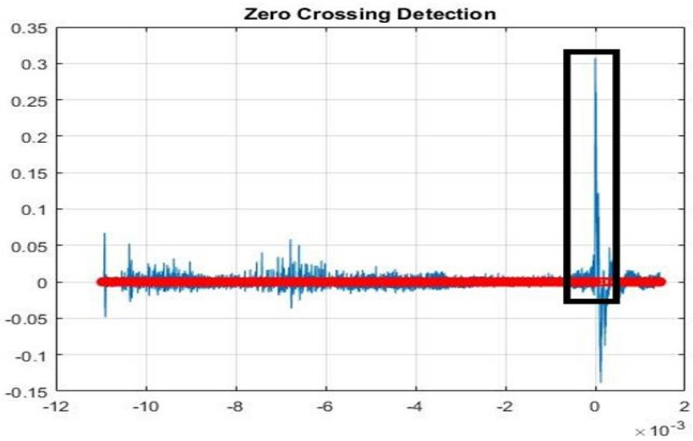

Fig. 5 - The figure shows the whole event starting from the preliminary breakdown pulses until the first return stroke. The rectangular box marker highlighted in black is the first return stroke signal.

2.3 Duration of zero crossing

Fig. 6 shown the definition of the duration of the zero crossing of the cloud to ground lightning flash.

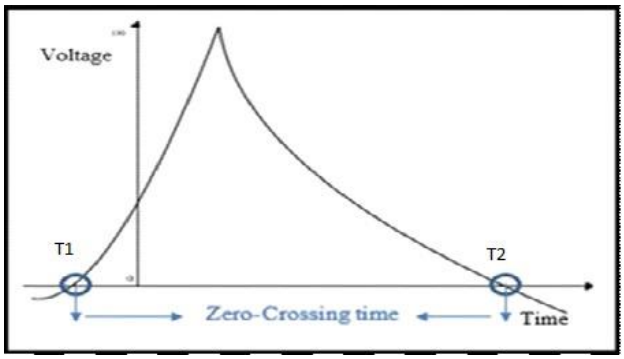

Fig. 6 - The diagram to calculate the duration of the zero crossing.

The formula (1) to calculate the duration of zero crossing used this formula:

$$Tzc = T2 - T1 \quad (1)$$

where Tzc is the duration of the zero crossing. T1 is the first intersection point between signal and offset. T2 is the second intersection point between signal and offset. The difference between T2 -T1 is the duration of the zero crossing of the lightning flash.

2.4 Automatic zero crossing detection

The diagram in Fig. 7 shown the automatic zero crossing detection.

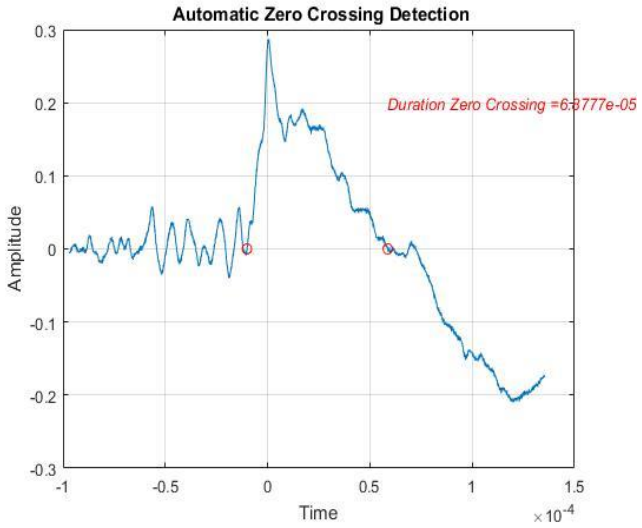

Fig.7 - The automatic zero crossing detection detected the duration of the zero crossing automatically.

The red dotted indicate the starting time detection and ending time detection for measuring the duration of zero crossing detection. The duration of zero crossing is 60.6 µs measured automatically from the software.

3. Results and Discussion

The finding of the results elaborated in this section. The duration of the zero crossing and the minimum threshold accuracy were analyzed in this section. Table 1 below shown the data of the samples used in this study.

Table 1. Data of 41 samples of cloud to ground lightning flashes

Tag	Start Time Point (µs)	End Time Point(µs)	Duration of Zero Crossing (µs)	Tag	Start Time Point (µs)	End Time Point(µs)	Duration of Zero Crossing (µs)
Z1D001	-9.5	76.1	85.5	Z1D022	-4.6	56.3	60.9
Z1D002	-6.3	21.0	27.2	Z1D023	-16.0	59.3	75.3
Z1D003	-41.2	46.1	87.3	Z1D024	-11.1	57.6	68.6
Z1D004	-6.0	64.2	70.2	Z1D025	-14.6	54.8	69.5
Z1D005	-6.8	40.9	47.7	Z1D026	-5.4	55.2	60.6
Z1D006	-10.1	58.7	68.8	Z1D027	-3.9	79.3	83.2
Z1D007	-12.0	57.3	69.3	Z1D028	-4.1	61.9	66.1
Z1D008	-5.9	29.9	35.7	Z1D029	-4.0	44.9	49.0
Z1D009	-5.4	51.0	56.4	Z1D030	-12.2	61.0	73.3
Z1D010	-9.0	45.3	54.2	Z1D031	-8.7	71.3	80.0
Z1D011	-8.6	18.7	27.3	Z1D032	-9.2	75.8	85.0
Z1D012	-5.5	53.5	59.0	Z1D033	-6.6	8.0	14.6
Z1D013	-8.6	44.4	53.1	Z1D034	-9.9	66.4	76.3
Z1D014	-4.7	36.8	41.6	Z1D035	-10.8	61.7	72.5
Z1D015	-8.4	23.8	32.2	Z1D036	-10.3	77.1	87.4
Z1D016	-5.4	74.6	80.0	Z1D037	-9.6	29.7	39.2
Z1D017	-5.2	36.4	41.5	Z1D038	-7.4	55.2	62.6
Z1D018	-65.8	29.8	95.6	Z1D039	-14.4	66.0	80.4
Z1D019	-4.8	22.3	27.1	Z1D040	-3.4	64.8	68.1
Z1D020	-5.5	69.7	75.2	Z1D041	-4.8	39.4	44.1
Z1D021	-12.6	54.1	66.7	-	-	-	-

Table 1 shown the result of the duration of zero crossing from this research. The analysis from the result consisted the minimum duration of the zero crossing, the maximum duration of the zero crossing, the median value, the arithmetic mean and the geometric mean.

The minimum duration of zero crossing for 41 samples was 14.6 µs and the maximum duration of zero crossing was 95.6 µs. The calculated median value, arithmetic mean and geometric mean were 66.7 µs, 61.4 µs and 57.4 µs respectively. Fig. 8 provided about the histogram of duration of zero crossing detected in this study.

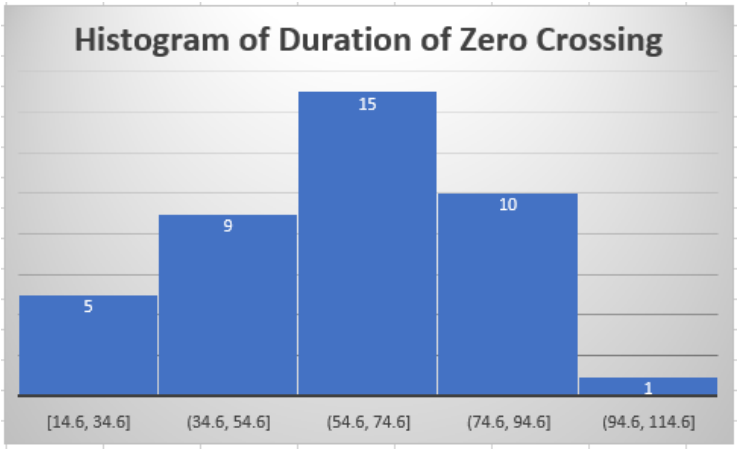

Fig. 8 - The histogram of the duration of zero crossing

Fig. 8 shown the highest frequency was 15 in the range of {54.6,74.6} which means the most distributions of the durations of zero crossing lies in the range of 54.6us until 74.6us within 41 samples of negative cloud to ground lightning flashes. The least frequency was in the range of {94.6,114.6} with only 1 frequency detected. The minimum threshold accuracy discussed in the next section for further explanation.

3.1 Threshold accuracy

In this section, the threshold of the study discussed and provided. Table 2 shown the result for minimum threshold accuracy.

Table 2. The minimum threshold accuracy

Minimum Threshold	Threshold Accuracy (%)
35µs	-
40 µs	82.9
45 µs	75.6
50 µs	70.7
55 µs	65.6
60 µs	61.0
65 µs	53.7
70 µs	36.6

The Fig. 9 shown the minimum threshold accuracy decreasing over the increasing value of minimum threshold.

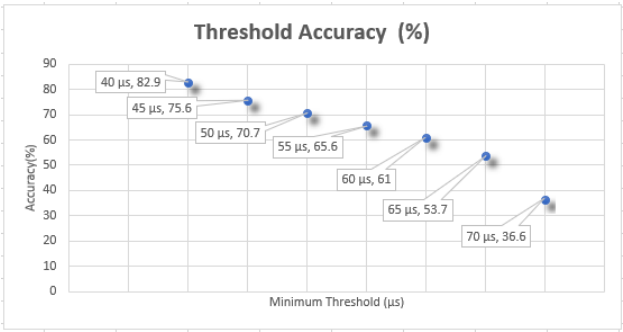

Fig. 9 - The Minimum Threshold Accuracy

The minimum threshold was chosen based on the literature review by the author from the result of previous researchers [6 – 7]. The minimum threshold of 35µs was neglected because duration of zero crossing detected before the first return strike. Thus, the threshold was not chosen to be the best and not to be selected as the software threshold because the software detected the duration of the zero crossing before the first return stroke. This is considered as the limitations of the study. So, the value of 35us minimum threshold was ignored and cannot be used as the minimum threshold.

Alternatively, the default setting for minimum threshold to detect the duration of the zero crossing was changed to 40µs. This was because 40µs is the highest accuracy for detection of duration of zero crossing. The threshold accuracy was 82.9% when the threshold was set to 40µs. All durations of zero crossing were detected at the first return stroke. In conclusion, the 40µs was chosen to be the minimum threshold for the software for zero crossing detection.

4. Conclusion

The minimum threshold for zero crossing detection was analyzed and determined. The research produced a result to use 40 µs as the minimum threshold for zero crossing detection. The minimum threshold used in the programmed software in MATLAB for the future use. The limitation for in this research was the measurement location to measure the data. The recommendation to increase the accuracy of the research is to use multiple station for lightning strike detection.

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