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CORRELATION ANALYSIS OF PRELIMINARY BREAKDOWN AND FIRST RETURN STROKE PROCESS IN NEGATIVE GROUND FLASH AS A FUNCTION OF NORTHEAST AND SOUTHWEST MONSOON IN TROPIC

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ABSTRACT

The separation duration of Preliminary Breakdown to the First Return Stroke (PB-RS duration) and the ratio between the highest amplitude pulse of Preliminary Breakdown and the first Return Stroke pulse (PB/RS ratio) were successfully used as a tool by many researchers to determine the relationship between lightning ground flashes and physical changes (latitude, regional and thunderstorm). Malaysia is one of the countries with the highest lightning flash density globally, and the occurrences of ground flashes are mainly due to monsoon seasons. Monsoons in Malaysia are Northeast, Southwest, and two transition periods. However, there is no available information to relate the lightning activities in Malaysia under the influence of all monsoon seasons. The above statements motivated our team to present a new statistical analysis of lightning flashes under two seasons' effects (Northeast and Southwest). 83 out of 332 electric radiation field data (fast fields) from six thunderstorms were selected and analyzed. The data was recorded using a 12-bit high-speed transient recorder (HDO 4024) with a resolution of tens of nanoseconds and sampling of 12.5 MS/s. PB/RS ratio between the monsoons is similar to each other. Whereas, the PB-RS separation, has two factors longer during the Southwest monsoon than during the Northeast monsoon. We classified the PB/RS ratio into four categories (>100%, 50-100%, 20-50%, and < 20%) as an indication of the preliminary breakdown strength. It found that the weakest pulse train (PB/RS ratio is less than 20%) has shown a longer duration of PB-RS and produces higher lightning return strokes in a negative ground flash than the strong one. The results in this study could be evident that the lower strength of preliminary breakdown is correlated to a lower Low Positive Charge Region (LPCR), which means the initial breakdown process only requires low energy to break the LPCR. Hence, these features have shown the highest number of stroke counts compared to pronounced ones. However, it would be more remarkable if one could provide bulky data for this specific study.

Keywords: return stroke, preliminary breakdown, PB/RS ratio, PB-RS duration, northeast monsoon, southwest monsoon.

1. INTRODUCTION

The preliminary breakdown processes of negative ground flashes are the most common type of cloud discharge discussed by many researchers due to their globally high occurrence and yet are one of the most mysterious lightning processes. According to (Clarence & Malan, 1957), the vertical discharge between the negative charge region and the lower positive charge region (LPCR) (Li *et al*., 2020) is the generated mechanism of the preliminary breakdown of negative ground flashes. The magnitude of the LPCR relative to the negative charge region could influence the type of negative initial breakdown discharge produced (Nag & Rakov, 2009b), (Iudin *et al*., 2017). If the LPCR is abnormally dense, it will "block" the progression of the downward step leader from reaching the ground resulting in the step leader to propagates predominantly horizontally. As a result, restricting the return stroke multiplicity (V Cooray & Jayaratne, 2000),(Zikri Abadi Baharudin, 2014) or causing no subsequent event of return stroke to occur (attempted leaders) (Nag & Rakov, 2009b). On the other hand, a smaller magnitude of LPCR causes the step leader to predominantly propagate in a vertical direction. A lower strength of the preliminary breakdown pulse train relative to the first return stroke of negative ground flashes is expected to occur (Wu *et al*., 2020).

The strength of the electric field peak pulse of preliminary breakdown produced by cloud measured to the peak of return stroke (PB/RS ratio) is high in the higher latitudes (V Cooray & Jayaratne, 2000), (Zhu *et al*., 2016), (S. R; Sharma *et al*., 2008), (Isa *et al*., 2021) due to denser LPCR (Gomes *et al*., 1998), (Nag & Rakov, 2009b). Besides latitude, the meteorological state could also influence the characteristics of the lightning discharge. For instance, (Brook, 1992) found the interval between the peak of preliminary breakdown pulse to the first return stroke (PB-RS duration) during winter to be shorter by four factors than during summer. The result was consistent with (Z. A. Baharudin *et al*., 2012) in Malaysia (1°N) and (Gomes *et al*., 1998) in Sri Lanka (6.9°N), which shows

five factors of longer duration during the Southwest monsoon (dry season). Next, the characteristic of the PB/RS ratio of the negative ground flashes reported by (Z. A. Baharudin *et al*., 2012) (27.8%) during the Southwest monsoon shows a slightly similar result to (Gomes *et al*., 1998) (16.5%) during the First intermonsoon. The variation of mentioned studies motivates us to investigate the characteristics of negative ground flashes in Malaysia (tropics region) under the influence of monsoon seasons.

From the perspective of the interaction of lightning events with the power system, there is no specific discussion in this study on how these aspects impact the power system. Nevertheless, understanding the physics behind the electrical discharge pertinent to the discussed phenomena will provide knowledge about the nature of the electromagnetic field that can be coupled with the power system, and protective measures can be designed.

In this study, we analyzed the electric radiation field data during the Northeast Monsoon (rainy season) and compared the results with the Southwest monsoon reported by (Z. A. Baharudin *et al*., 2012). The study presents the ratio of the highest pulses of preliminary breakdown to the first return stroke (PB/RS ratio), the interval of the highest peaks of the preliminary breakdown to the first return stroke (PB-RS duration), the duration of the first pulse of the PB pulse train to the first return stroke (pre-RS duration), stroke count, B, I, L and B, L type and the classification of the highest peak of the preliminary breakdown to that of the first return stroke ratio of four categories (>100%, 50-100%, 20-50% and < 20%). The results were compared to other researchers of the same region with different monsoon seasons.

2. METHODOLOGY

The measurements of the electric fields generated by the lightning flash were at Paya Rumput, Melaka Malaysia. The electric field measurements of the whole lightning flashes were recorded from 6th until 11th November 2019 during the Northeast monsoon in the southern part of Peninsular Malaysia near the equator. The Paya Rumput is at the latitude: 2°18'07, 6"N, Longitude: 102°12'13.4"E. The electric field measuring sensors are similar to the measurement layout performed by (Isa *et al*., 2020) and (Z. A. Baharudin *et al*., 2014). The operations of the antennas for electric field radiation (fast field) are shown in (Zikri Abadi Baharudin, 2014) (see Figure-1).

Two parallel flat plate antennas are used to detect the broadband radiation electric field (or fast field). A flat antenna used to sense the vertical electric field. The plane of the antenna is adjusted perpendicular to the electric field vector, or in other words, parallel to the ground to avoid the horizontal component of the electric field. The physical height and effective height of the antenna is 1.5m and 0.25 m, respectively. The antenna was connected to the electronic buffer circuit using a 60 cm long coaxial cable (RG58). The signal from the antenna is transmitted into a 12-bit digital transient recorder (Lecroy HDO4024) equipped with a 200 MHz High-Definition Oscilloscope using the 10 m long coaxial cable (RG-58). The sampling rate set to 12.5 MS/s, and the total duration of electric field waveform recorded was 2 s. The trigger setting of the oscilloscope is able to capture the signals of positive and negative polarities. The trigger level is set to either 50 mV to 500 mV for the far flashes or 500 mV to 2 V for the closer one. The transient recorder operated at a 300 ms pre-trigger mode while the rise time of the broadband antenna system (fast field) for step input pulses was less than 30 ns, and the decaying time constant was set to approximately 17.5 ms.

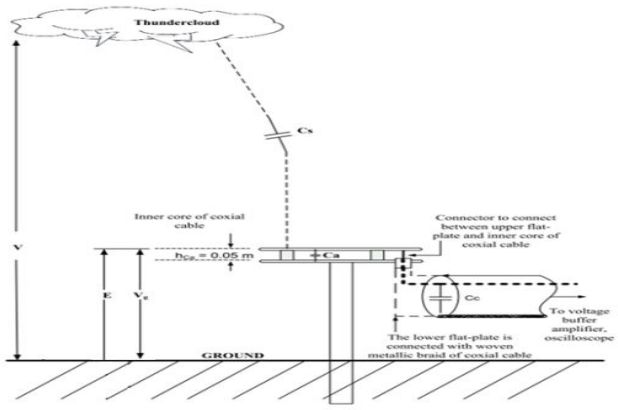

Figure-1. Flat-plate antenna for the fast field measurement, depicted in (Zikri Abadi Baharudin, 2014).

Any ambiguity of the whole flashes event, such as two flashes event for the ground flashes and unclear profile of preliminary breakdown processes was discarded in the analysis. Figure-2 shows the overall methodology features begin with the electric measurement and recording, followed by the analysis work. Further, the terminal point of the flat plate antenna is connected to the input of the electronic drive circuit (buffer). The electric radiation field (fast field) is determined in such way that the system allows it to operate under lightning frequency operation of hundreds kHz to tens of MHz.

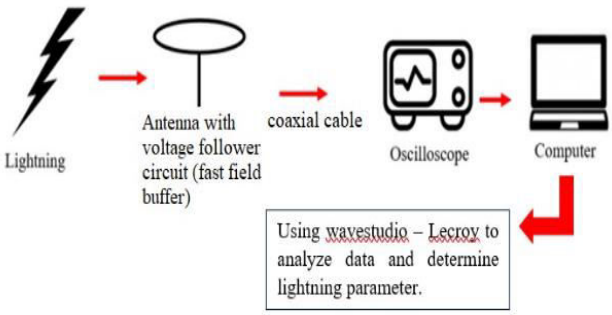

Figure-2. Overall methodology featuring the electric field measurement, recording and analysis.

To get the sufficient frequency operation mentioned above, the decay time constant of the buffer was set at 17.5 x 10-3 s for far lightning distance, while the close distance was 87.5 x 10-6 s. Next, the output of the buffer was fed to the oscilloscope (Lecroy HDO4024)

using a 15-meter coaxial cable (impedance=50 W). The recording duration was 2 seconds to capture the whole processes in the lightning flashes. The sampling, trigger level, and pre-trigger duration setting of the oscilloscope were 12.5 Mega Sample per second, 300 mV, and 500 ms, respectively. Figure-3 ilustrate the definition of PB-RS duration, pre-RS duration, and PB/RS ratio.

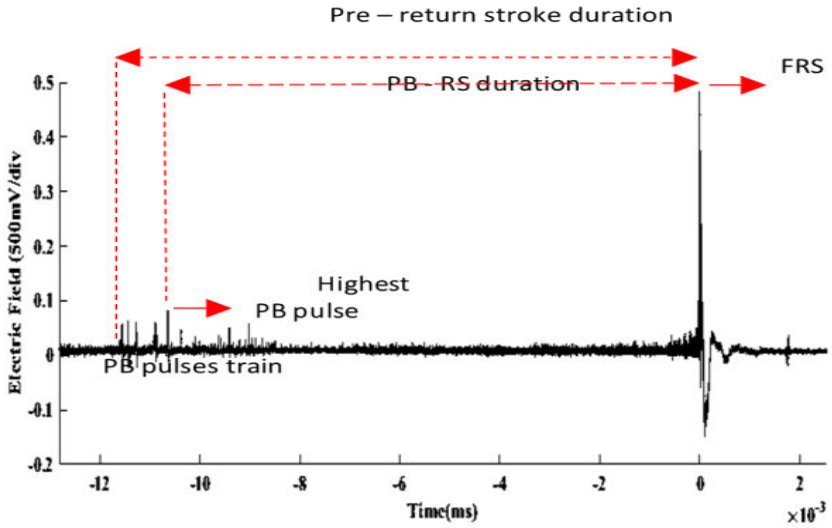

Figure-3. Electric radiation field of the of negative preliminary breakdown polarity followed by negative return stroke recorded on 7th November 2019.

2.1 Northeast Monsoon

A total of 332 electric fields of lightning flashes data from six different thunderstorms in Melaka, Malaysia (2.1896° N, 102.2501° E) during the Northeast monsoon (6th until 11th of November 2019) were recorded. Samples of 88 electric fields ground flashes are selected. The Northeast monsoon occurs between November and March and brings more rainfall than other monsoons. The negative ground discharge consists of the preliminary breakdown pulses of the same (N=83) and opposite (N=5) polarity to the subsequent event of the return stroke. The current study only focuses on the negative polarity of the preliminary breakdown of negative ground flashes.

Table-1. The analysis results of negative cloud-to-ground flashes in Malaysia.

Total flashes	No. sample	PB / RS ratio (%)			PB - RS separation (ms)			Pre - return stroke (ms)			Stroke count
		Arithmetic Mean	Min	Max	Arithmetic Mean	Min	Max	Arithmetic Mean	Min	Max	Arithmetic Mean
89	83	27.70	7.5	191	27.74	1.84	113	28.92	2.3	114	4

2.2 Southwest Monsoon

The PB/RS ratio percentage and PB-RS duration of negative ground flash during Southwest monsoon were adapted from (Z. A. Baharudin *et al*., 2012) and compared with the present result. The Southwest monsoon starts in May and sustains until September. The weather is relatively drier during this period. A similar electric field measurement was used in the present study. The author presents the measurement recorded from April until 2009 of 97 analyzed data during the Southwest monsoon in Johor Malaysia.

3. RESULTS AND DISCUSSIONS

The preliminary breakdown process is a sequence of train pulses expending arbitrarily downward as a step leader in a random direction and then bridging with the upward step leader before producing a return stroke (Wang *et al*., 2018), (Qie *et al*., 2002). All the preliminary breakdown processes of negative CG flashes gathered in this work were analyzed based on (Nag & Rakov, 2009a) and the electric fields exhibited as typical were assumed bipolar pulses.

3.1 The Characteristic of the Negative CG Lightning Flashes under the Influence of the Northeast Monsoon

In this study, the arithmetic means of the PB/RS ratio of 83 data sets of -CG flashes were 27.70%, where the maximum and minimum percentages are between 7.5% and to191%. Next, the arithmetic means PB-RS duration and pre-RS duration were 27.74 ms (range: 1.84-113 ms) and 28.92 ms (range: 2.3-114 ms), respectively. Note that the arithmetic means of stroke count in this study were 4. This information is a crucial parameter of electrical engineering to design the relay of a circuit

breaker (Arshad *et al*., 2014), (S. R. Sharma *et al*., 2011). Table 1 presents the summary of the analysis.

3.2 The Comparison of PB/RS Ratio during Northeast and Southwest Monsoon

To investigate the correlation of PB/RS ratio relative to the influence of monsoon, a comparison of data during the present study and Southwest monsoon reported by (Z. A. Baharudin *et al*., 2012) is illustrated in Figure-4. The data between the Northeast and Southwest monsoon of similar latitude are compared. The present result shows that, only three sets of PB pulse train of -CG flashes during Northeast monsoon exceeded that of the first return stroke (PB/ RS ratio of more than 100%).

In other word, only three pronounced preliminary breakdowns observed during Northeast monsoon. On the other hand, the data during the Southwest monsoon shows a higher percentage of ratios exceeding 100%, indicating pronounced preliminary breakdown were more often occur during the Southwest monsoon. Although the PB/RS ratio in the previous study decreased as the latitude decreased (T. Marshall, W. Schulz, N. Karunarathna, S. Karunarathne, M. Stolzenburg, C. Vergeiner, 2014), the arithmetic means ratio for both studies is similar (27.7% and 27.8%) despite under the influence of different monsoon. Overall, majority of the data shows weak PB/ RS ratio (<20%). A summary of the PB/RS ratio during Northeast and Southwest monsoon is in Figure-4.

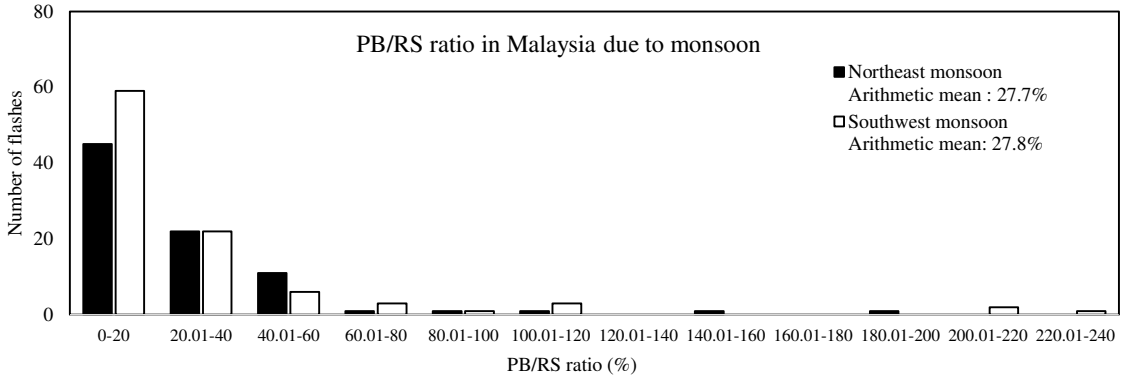

Figure-4. The distribution of PB/RS ratio during Northeast monsoon and Southwest monsoon of negative cloud-to-ground flashes in Melaka, Malaysia.

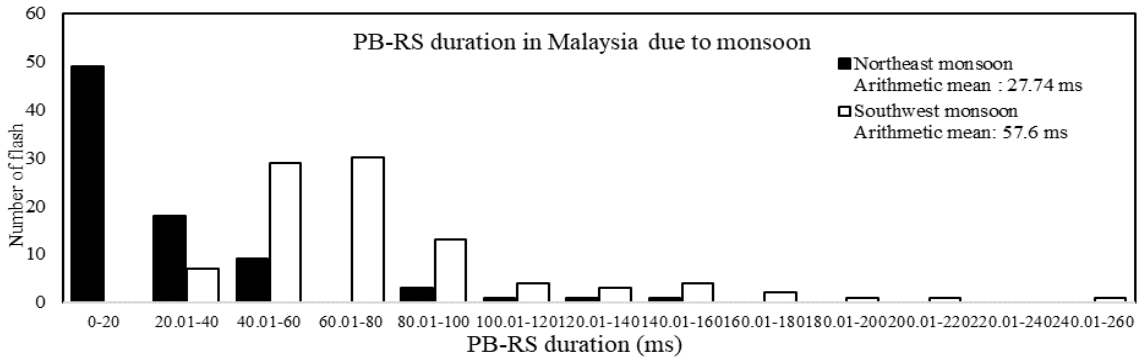

Figure-5. The distribution of PB-RS duration during Northeast monsoon and Southwest monsoon of negative cloud-to-ground flashes in Melaka, Malaysia.

3.3 The Comparison of PB-RS duration during Northeast and Southwest Monsoon

On the other hand, the comparative study between the Northeast monsoon from the current study and the Southwest monsoon by (Z. A. Baharudin *et al*., 2012) showed the inconsistency of PB-RS duration, as shown in Figure-5. Despite the measurement conducted in the same latitude, both result from the Northeast and Southwest monsoon are inconsistent. Most negative CG flashes during the Northeast monsoon data have a range of PB-RS duration of less than 20 ms. There were no data during the Southwest monsoon demonstrate PB-RS duration of less than 20 ms. It implies that the interception process occurs faster during the Northeast monsoon, or it could be due to higher cloud base height during the Southwest monsoon. Moreover, the Northeast monsoon indicates only 3 data of PB-RS duration than 100 ms, unlike the data from the Southwest monsoon, a higher number of data exceeding 100 ms duration for the PB-RS duration. In addition, the arithmetic means of PB-RS duration during Northeast monsoon (27.74 ms) is two factors shorter than during the Southwest monsoon (57.6 ms).

3.4 The Classification of PB/RS Ratio

The ratio between the highest peak of PB pulses to the first return stroke during the Northeast monsoon is grouped into four, as shown in Table-2. Most of the data exhibit a low PB/RS ratio percentage indicating the strength of the preliminary breakdown in this study, in general, is weak, similar to (Arshad *et al*., 2014), (Kumar & Kamra, 2010), (Salimi, Mehranzamir, *et al*., 2014), (Salimi, Abdul-malek, *et al*., 2014). Three data with high PB/RS ratio percentages were observed (103%, 145%, and 191%), the arithmetic means of PB-RS duration and pre-RS duration being 20.55 and 21.26, respectively. All three data with the stroke average of 3, exhibiting B, I, L type according to (Clarence & Malan, 1957), who has sorted out the PB into three successive and distinct discharge processes, termed as breakdown stage (B), intermediate stage (I), and the leader stage (L). The author suggests that B and I are inside the cloud process before launching the step leader (L)). The sample of the mentioned preliminary breakdown is in Figure-6.

Table-2. The classification of PB/RS ratio.

PB/RS ratio (%)	Sample (N)	PB-RS duration (ms)	Pre-RS duration (ms)	Stroke average	B, I, L type (N)	B, L type (N)
>100	3	20.55	21.26	3	3	-
50-100	4	25.59	26.20	4	4	-
20-50	31	17.71	18.45	4	28	3
< 20	45	35.33	36.87	5	37	8

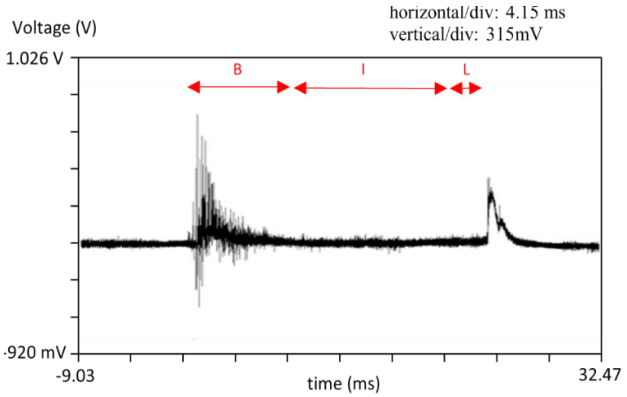

Figure-6. The electric radiation fields of negative ground flash with a pronounced preliminary breakdown (PB/RS ratio: 191%) met the description of B, I, L type.

Next, the PB/RS ratio percentages ranged from 50-100% (N=4) and 20-50% (N=31), the PB-RS and pre-RS duration were slightly comparable. The arithmetic means of stroke count for both ranges were 4. Most of the data from both ranges exhibited B, I, L type, and only three data of PB/RS ratio range from 20 to 50 percent exhibits B, L type. The example of electric radiation field of B, I, L type of PB/RS ratio ranges from 50 to 100 percent is shown in Figure-7, while the sample of B, I, L and B, L type of PB/RS ratio ranges from 20 to 50 percent is shown in Figure 8 a) and b).

Further, 45 sets of data with a PB/RS ratio of less than 20% demonstrate the highest arithmetic means of PB-RS and pre-RS duration; 35.33 ms and 36.87 ms, which were two factors more than the duration of PB-RS and pre- RS exhibited by other group ranges. The arithmetic means of stroke count for the PB/RS ratio with a range less than 20% is 5. The electric field of negative ground flashes within this range was most exhibit B, I, L type, and only eight data met the description of B, L type as shown in Figures 9 a) and b). A summary of the PB/RS ratio classification analysis is in Table-2.

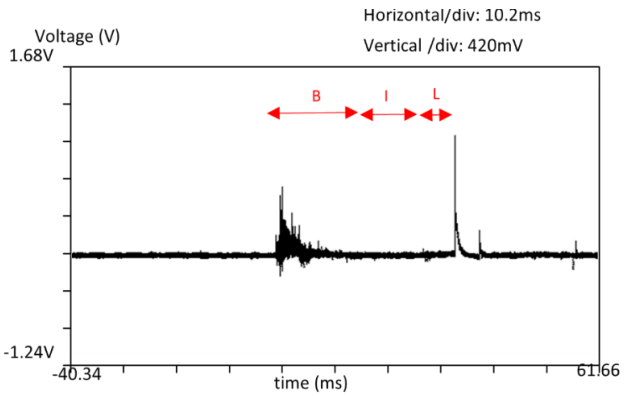

Figure-7. The electric radiation fields of negative ground flash with PB/RS ratio of 60% met the description of B, I, L type.

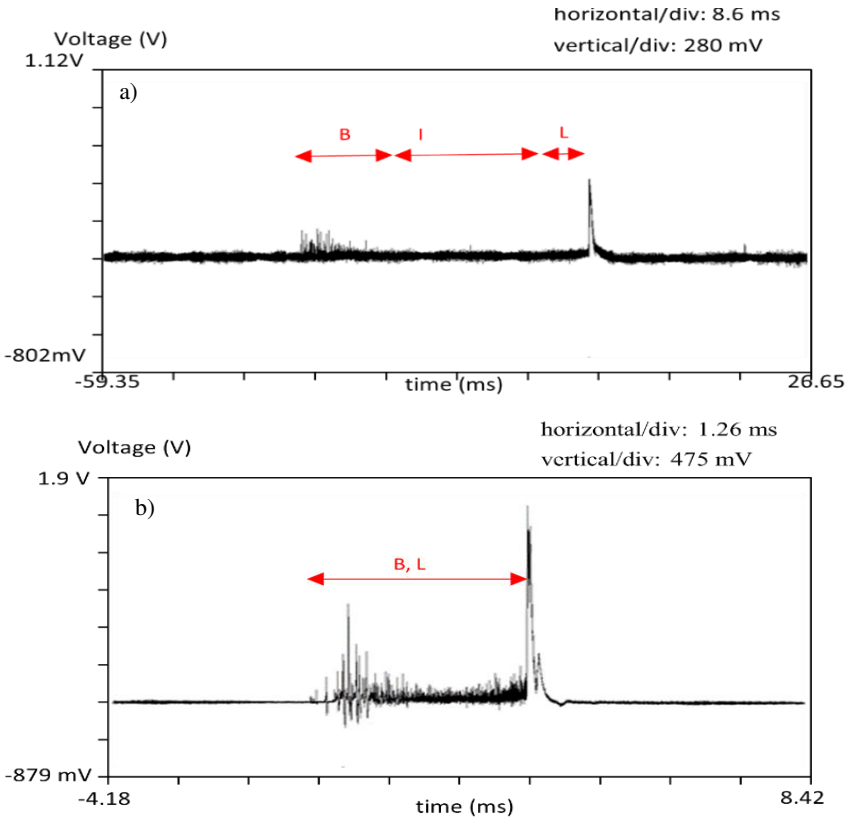

Figure-8. The electric radiation fields of negative ground flash with PB/RS ratio of a) 36.5% described as B, I, L type and b) 49% described as B, L type.

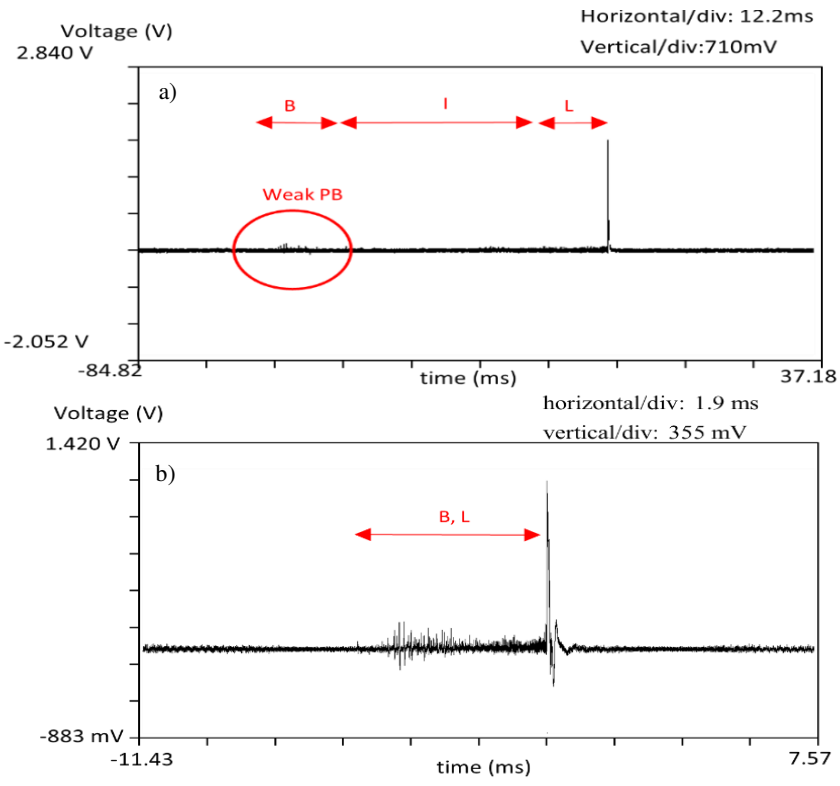

Figure-9. The electric radiation fields of negative ground flash of weak preliminary breakdown with PB/RS ratio of a) 9% described as B, I, L type and b) 17% described as B, L type.

3.5 The Strength of the PB Process Relative to the PB-RS Duration and Stroke Count

Figures 10 a), b), c), and d) shows the waveform of negative ground flashes with PB/RS ratio of; a i) 145%, b i) 60%, c i) 37%, and d i) 9%, and the expanded part of preliminary breakdown pulses to the first return stroke with PB-RS duration of; a ii) 15 ms, b ii) 33.44 ms, c ii)33.36 ms and d ii) 58.24 ms. From Figure 10, the preliminary breakdown of those with a small ratio of PB/RS (weak PB), exhibits a longer duration of PB-RS and a higher return stroke count average than the strong one. In other words, the pronounced preliminary breakdown shows shorter arithmetic means of PB-RS duration and lower return stroke count average than the weak PB pulse train.

Next, the correlation between the PB/RS ratio, PB-RS duration, and stroke count average is in Figure-11. From Figure-11, the PB-RS duration, and arithmetic means of stroke count increase with the decrement of the PB/RS ratio. It implies that the stroke average of the negative CG flashes increased with the decrease of preliminary breakdown strength. This result is consistent with the information reported by (V Cooray & Jayaratne, 2000) and (Zikri Abadi Baharudin, 2014), as the pronounced PB (PB/RS ratio is higher than 100%) is produced with the presents of dense LPCR and restricting the multiplicity of return stroke. The information on stroke average is very important, especially for the electrical circuit breaker setting.

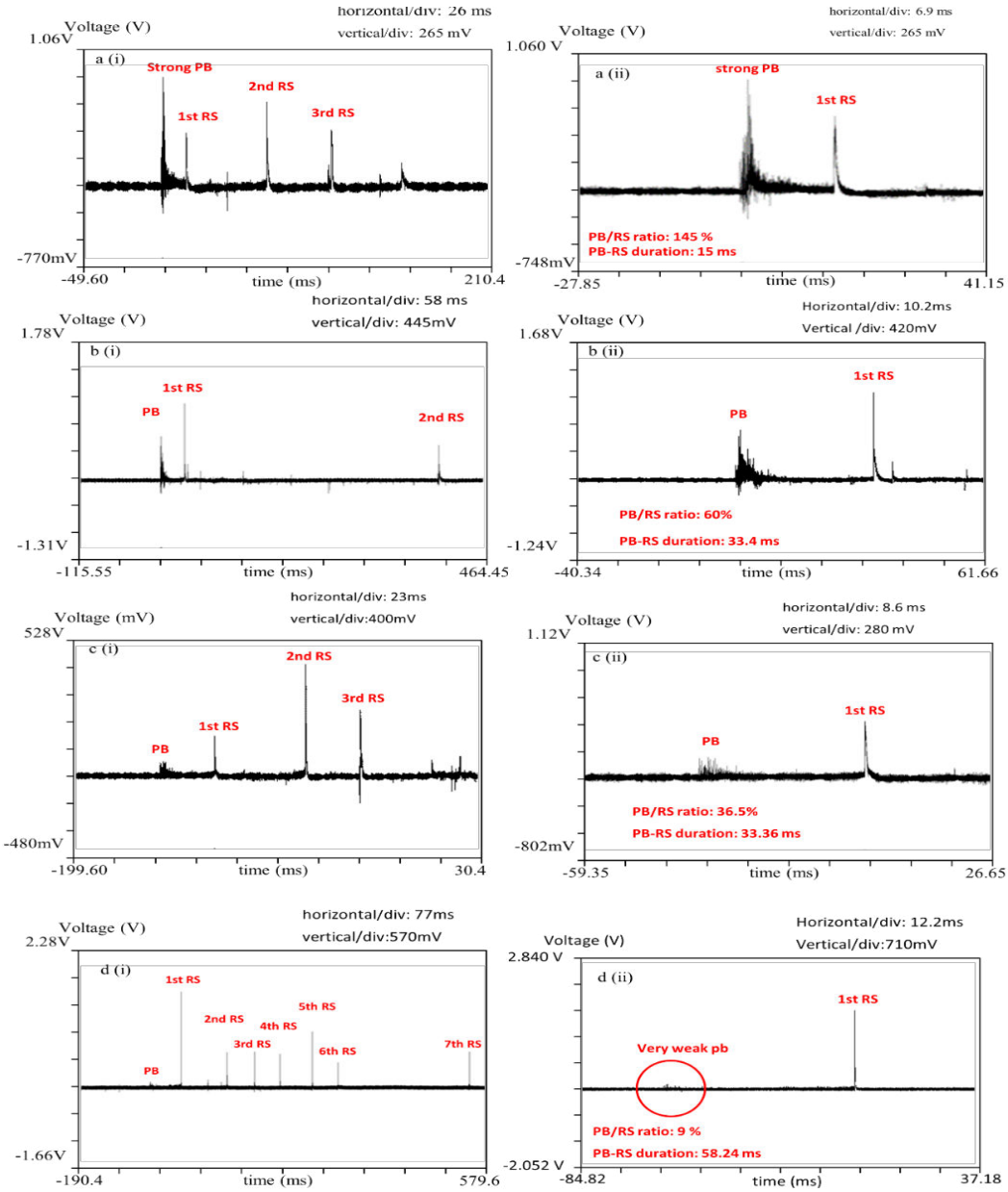

Figure-10. The variation of PB/RS ratio relative to the PB-RS duration. The PB/RS ratio and PB-RS duration of a) 145 %, 15 ms, b) 60 %, 33.4 ms, c) 36.5 % and 33.36 ms, and d) 9 %, 58.24 ms. The atmospheric electricity sign convention is used here.

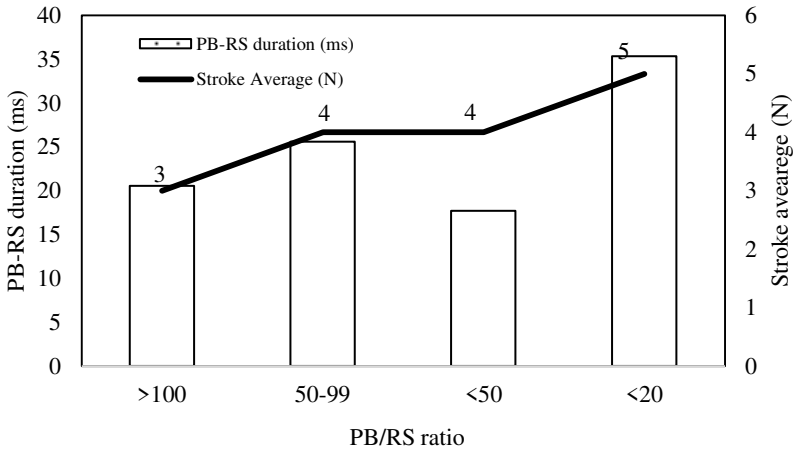

Figure-11. The correlation of PB-RS duration to stroke count average.

3.6 Comparison with the Previous Study

As discussed earlier, the arithmetic means of PB/RS ratio during Northeast monsoon and Southwest monsoon show consistency with one another despite different monsoons of measurement conducted. However, the parameter for PB-RS duration of both monsoons shows dissimilarity as the data during the Southwest monsoon demonstrate two factors longer than the present study (see Figure-5). To investigate the PB-RS duration of the negative ground flashes under the influence of monsoons, a comparison of three different monsoons from previous studies of the same region is presented. Table-3 shows the arithmetic means of PB/RS ratio and PB-RS duration of similar latitudes but different monsoons.

Table-3. Comparison with the previous study of the same region.

Research	Monsoon	Sample Size (N)	PB / RS ratio (%)		PB-RS separation (ms)		Pre- RS duration (ms)	
			Arithmetic means	Range	Arithmetic means	Range	Arithmetic means	Range
Present Study	Northeast	83	27.7	7.5-191	27.74	1.84 -113	28.92	2.3-114
Malaysia, (Z. A. Baharudin *et al*., 2012)	Southwest	97	27.8	2.6-228.1	57.6	8.3 -227.3	62	-
Sri Lanka, (Gomes *et al*., 1998)	Northeast & First Inter-monsoon	9	16.5	6.2-26.4	11.9	3.5-25.3	-	-
Padang, (Hazmi *et al*., 2016)	Second Inter-monsoon	100	13	3-37	8.23	3.79-19.08	-	-

The characteristic study of negative ground flashes during the First Inter-monsoon in Sri Lanka by (Gomes *et al*., 1998) and Second Inter-monsoon in Padang by (Hazmi *et al*., 2016), shows that the arithmetic means of PB/RS ratio were two factors less than the present study. Overall, the PB/RS ratio reported by (Z. A. Baharudin *et al*., 2012), (Gomes *et al*., 1998), (Hazmi *et al*., 2016) and the present study indicates that the preliminary breakdown in lower region is relatively weak regardless of which monsoon were the data measured. The lowest PB/RS ratio from tropics was during Second Intermonsoon reported by (Hazmi *et al*., 2016). Overall, the PB/RS ratio during the Northeast monsoon are similar. On the other hand, the PB/RS ratio between the Northeast and Southwest monsoon were higher than during the two intermonsoon.

However, the PB-RS during the Southwest monsoon shows a significantly higher duration than the other monsoon reported by (Gomes *et al*., 1998) and (Hazmi *et al*., 2016). Overall, the PB-RS duration between the Northeast monsoon were two factors shorter than during the Southwest monsoon. Whereas, in contrast the PB-RS duration between the Northeast and Southwest monsoon were much longer than during the two intermonsoon.

The longer duration of PB-RS of negative ground flashes during the Southwest monsoon compared to the Northeast monsoon, First Inter-monsoon and Second Inter-monsoon indicating the uprising process are effected by the seasons and locations (Zoro, 1999), (Kraaij *et al*., 2013), (Wooi *et al*., 2016), (Wooi *et al*., 2015), (Vernon Cooray, 2015). The air rose into the unstable atmosphere

forming a convective cell before the thunderstorms formed. The drier weather during the Southwest monsoon (dry monsoon) might cause the thunderstorm to formed in higher altitude (high cloud base) compared to other monsoons (Xie *et al*., 2018), (Hazmi *et al*., 2019). In results, a higher PB-RS duration occur.

CONCLUSIONS

The meteorological state could influence the lightning discharge characteristics. In the current study, 83 data of negative CG lightning flashes recorded on 6th to 11th of November 2019 were analyzed. The arithmetic means of PB/RS ratio, PB-RS duration, pre-RS duration and stroke count under the influence of Northeast monsoon were 27.70%, 27.74 ms, 28.92 ms and 4, respectively. In general, the preliminary breakdown of -CG flashes during the Northeast monsoon in the present study are weak and demonstrate some interesting correlation with the PB-RS duration and stroke average. The stroke average of -CG flashes increased with the decreased of PB/RS ratio implies that the low strength of preliminary breakdown attribute as a lower Low Positive Charge Region (LPCR), which means that the preliminary breakdown process only requires low energy to break the LPCR. Compared to the previous study, PB/RS ratio from the Northeast monsoon (present study), Southwest monsoons, First Inter-monsoon, and Second Inter-monsoon in the same region is considered low despite different monsoons of the data measured. In other words, preliminary breakdown in lower region is relatively weak regardless of which monsoon the data measured. It implies that the meteorological of tropic region state does not much influence the PB/RS ratio or the strength of preliminary breakdown of negative ground flashes. However, the PB-RS duration shows an inconsistent result due to monsoons variation. The PB-RS duration of negative ground flashes was longer during the Southwest monsoon compared to Northeast monsoon, First and Second Inter-monsoon. The inconsistency might be due to higher cloud base during Southwest monsoon compared to another monsoon.

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