LIGHTNING SEVERITY IN MALAYSIA AND SOME PARAMETERS OF INTEREST FOR ENGINEERING APPLICATIONS

by

Mohd Zainal Abidin AB-KADIR

Centre for Electromagnetic and Lightning Protection Research, Faculty of Engineering, University Putra Malaysia, Serdang, Malaysia

Original scientific paper
DOI:10.2298/TSCI151026028A

To the electric utility engineer, the parameters of the flash that are of primary interest are the crest current for the first and subsequent strokes, the waveshape of these currents, correlation between the parameters, the number of strokes per flash and flash incidence rates where the ground flash density, denoted as flashes per square km-year and symbolized by N_g. The first three parameters, as we know them today, are to a very large extent based on the measurements of Berger. Berger's masts, 70 and 80 meters high, were mounted atop Mt. San Salvatore (Switzerland), which is 650 meters above Lake Lugano, where it can be readily noted that these 125 records represent one of the best and most extensive set of data available to the industry to date. This paper focuses on the lightning severity scenario in Malaysia, which could also applicable to other tropic countries, and some of the useful parameters for lightning protection system design and forensic study. Some specific engineering applications have also been summarised, taking into account various lightning parameters, available from past and current measurements.

Key words: *lightning, lightning parameters, ground flash density, tropic countries, lightning protection*

Introduction

Lightning is one of the most fantastic natural phenomena in the world. It can result in severe damage to property. Lightning happens when a region of atmosphere acquires a sufficiently large electric charge that is capable of causing an electrical breakdown. It has been reported that there are 2000 thunderstorms in progress at any time resulting in 100 lightning flashes to ground per second; this is 8 million per day. It causes around 100 deaths and 250 injuries in the United States per year, more than from any other weather-related phenomenon. Even though there is no such database regarding the victims or survivors due to the lightning, some cases have been well documented, especially those related to the injuries and the deaths caused by lightning. It has become a significant threat to many countries where the natural phenomenon has previously been treated only as an occasional attacker of careless living beings. Most tropical countries, several southern states of the USA, Japan, and several parts of Australia, experience heavy annual lightning occurrence density [1-12].

It is a fact that Malaysia encounters more than 70% of power outages due to lightning and it is known as the *crown of lightning* in the world. The effects of lightning on elec-

Author's e-mail: mzk@upm.edu.my

trical/communication networks and structures account for equipment damage, downtime/data losses and malfunctioning of control and automated systems that may cost the nation over RM 250 million and thousands of human injuries and deaths. Both lightning and intentionally generated lightning-like microwave pulses may disrupt civil and defense systems giving rise to serious threats to national security

Malaysia has been ranked among the top three in the world in terms of the lightning density, more than any other countries in Asia region. The lives of these people could have been saved if they were given proper education in lightning protection. Apart from human injuries and deaths, another matter of concern is the innumerable deaths of animals caused by lightning every year.

Many cases involve outdoor activities such as fishing, agriculture, recreation and sheltering in an unsafe or unsuitable place [13, 14]. Another issue is related to the economic impact to workers in some areas of south east Asia such as Malaysia, Thailand, and Indonesia, where the planting and harvesting periods of the crops are during the monsoon periods. Experts use the estimate that lightning is fatal in about 1 in 10 lightning-strike victims [15], although it is unknown if the death-to-injury ratio is similar in all countries. Table 1 shows the fatalities and injuries based on the number of victims, which were recorded since 2008 until July 2015. There is no indication at all that the lightning fatalities and injuries have decreased over the years and therefore, much effort is needed to educate and create awareness among the public.

Table 1. Lightning fatalities and injuries recorded in Malaysia from 2008-2015 (as of September 2015)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
2008	3	0	0	3	3	2	0	0	0	0	9	0	20
2009	0	0	0	0	13	6	0	0	0	8	0	5	32
2010	0	0	0	2	0	0	0	0	9	2	0	0	13
2011	1	2	1	0	0	3	3	12	2	1	4	1	30
2012	0	5	1	56	7	1	5	5	1	0	5	0	86
2013	0	12	1	2	0	0	2	1	2	0	0	0	20
2014	0	0	4	1	2	0	0	0	0	2	2	0	11
2015	0	0	0	12	4	0	1	1	5	0	0	0	23
Total	4	19	7	76	29	12	11	11	19	13	20	6	235

This paper highlights the lightning scenario in Malaysia and some parameters of interests for engineering application, based on previous CIGRE documents on the subject published in ELECTRA more than three decades ago by Berger *et al.* [16], and Anderson and Eriksson [17]. Measured lightning generated an electric field with its unique characteristic will be shortly discussed, besides a sample of a case study carried out, taking into account the usefulness of some lightning parameters, obtained from lightning location system.

Some lightning parameters of interest

Ground flash density

This is a fundamental parameter, providing the basis for any estimation of the frequency of lightning effects on the electrical system. The ground flash density N_g, is often viewed as the primary descriptor of lightning incidence, at least in lightning protection studies. Ground flash density has been estimated from records of (1) lightning flash counters (LFC) and (2) lightning locating systems (LLS) and can potentially be estimated from records of satellite-based optical or radio-frequency radiation detectors. It is worth noting that satellite detectors cannot distinguish between cloud and ground discharges and, hence, in order to obtain N_g maps from satellite observations, a spatial distribution of the fraction of discharges to ground relative to the total number of lightning discharges is needed. IEEE Std 1410-2010 [18] recommends, in the absence of ground-based measurements of N_g, to assume that N_g is equal to one-third of the total flash density (including both cloud and ground discharges) based on satellite observations.

The ground flash density N_g for temperate areas may be estimated from T_d, the keraunic level, using eq. (1) from Anderson *et al*. [19]:

$$N = 0.04T_d^{1.25} \tag{1}$$

where
- N_g is the ground flash density in flashes per km^2 per year, and
- T_d is the number of days with thunder per year.

Torres *et al.* [20] noted that this expression has unacceptably large errors in tropical areas, recommending the alternative expressions for eq. (1), as tabulated in tab. 2.

Table 2. Alternative expressions for eq. (1) for tropical areas

Country	Alternative expression for Equation (1)
Mexico	$N = 0.024T_d^{1.12}$
Brazil	$N = 0.030T_d^{1.12}$
Columbia	$N = 0.0017T_d^{1.56}$

Figure 1. Malaysian lightning density map given in terms of thunder days per year (adopted from [22])

Figure 1 shows isokera-unic level (thunder days per year) in Malaysia. The western coast, especially the Klang valley, records highest lightning densities. These values are almost an order of magnitude greater than the global average. MS IEC 62305-2:2007 [21] specifies the approximate relationship of the lightning density N_g with keraunic level or thunder days per year (T_d) for temperate land only:

$$N_g = 0.1\ T_d$$

where
– N_g is the ground flash density in flashes per km^2 per year and
– T_d is the number of days with thunder per year.

Peak current – classical distribution

Basically, all national and international lightning protection standards (*e. g.*, IEEE Std 1410-2010 [15]; IEEE Std 1243-1997 [23]; IEC 62305 series [24-27]) include a statistical distribution of peak currents for first strokes in negative lightning flashes (including single-stroke flashes). This distribution, which is one of the foundations of most lightning protection studies, is largely based on direct lightning current measurements conducted in Switzerland from 1963 to 1971.

It is worth noting that directly measured current waveforms of either polarity found in the literature do not exhibit peaks exceeding 300 kA or so, although inferences from remotely measured electric and magnetic fields suggest the existence of currents up to 500 kA and even higher.

For the CIGRE distribution, 98% of peak currents exceed 4 kA, 80% exceed 20 kA, and 5% exceed 90 kA. For the IEEE distribution, the *probability to exceed* values are given by the following eq. (2):

$$P(I) = \frac{1}{1 + \left(\frac{I}{31}\right)^{2.6}} \tag{2}$$

where $P(I)$ is in per unit and I is the first return stroke peak current in kA. Note that this equation applies to values of I up to 200 kA.

According to Hileman [28], this equation, usually assumed to be applicable to negative first strokes, is based on the data for 624 strokes analyzed by Popolansky [29], whose sample included both positive and negative strokes, as well as strokes in upward lightning.

Whilst the distribution of subsequent-stroke peak current values is approximated in eq. (3) by (IEEE Std 1243-1997) [23]:

$$P(I) = \frac{1}{1 + \left(\frac{I}{12}\right)^{2.7}} \tag{2}$$

Sample sizes for *global* peak current distributions for negative first strokes and the IEEE peak current distributions can be referred to CIGRE technical brochure (TB) 549 [30].

Table 3 shows the global peak current distribution derived from eq. (2) and (3). However, these distributions are not much different from the direct current measurement by Berger *et al.* [31] which are still regarded to be the most reliable ones. Reference [30] further discusses a few other concerns related to this global peak distribution.

Table 3. The IEEE peak current distributions (adopted from [30])

Peak current, I, kA		5	10	20	40	60	80	100	200
Percentage exceeding tabulated value, P (I) 100 %	First strokes	99	95	76	34	15	7.8	4.5	0.78
	Subsequent strokes	91	62	20	3.7	1.3	0.59	0.33	0.050

In the protection concerns, the lightning current has been divided into two parts in order to represent the impulse component and the long continuing current.

The two components are:

(1) Short strokes (impulse) with a duration less than 2 ms fig. (2) and

(2) Long strokes with a duration longer than 2 ms and less than 1 second fig. (3).

In IEC 62305-1 [24], test current waveform with T_1= 8 µs and T_2 =20 µs (known as 8 / 0 µs impulse) and another with T_1= 10 µs and T_2=350 µs (known as 10 / 350 µs impulse) have been recommended.

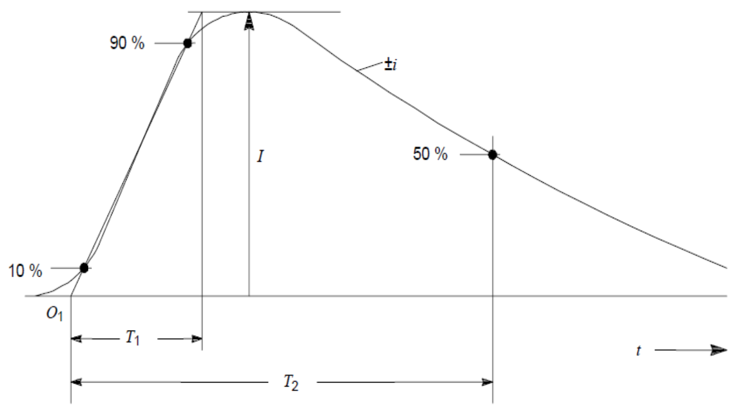

Figure 2. The short stroke current (impulse) as specified in IEC 62305-1

Figure 3. The long stroke current (continuing current) specified in IEC 62305-1:2010. T_{long} can vary between 2-1000 ms

Peak current – direct measurement

Recently, direct current measurements on instrumented towers were carried out in Russia, South Africa, Canada, Germany, Brazil, Japan, Austria, and again in Switzerland (on a different tower). The important results from the Brazilian, Japanese, and Austrian studies are reviewed and compared with Berger's data. In addition, recent direct current measurements for rocket-triggered lightning are also considered. Tables 4 and 5 summarise the distributions of lightning peak currents from individual studies (obtained from direct measurements only) and those synthesized by combining different measurements for first and subsequent strokes [30].

Table 4. Comparison of return-stroke peak currents (the largest peak, in (kA) for first strokes in negative downward lightning (adopted from [30])

References	Location	Sample size	Percent exceeding tabulated value			$\sigma_{\lg}I$	Remarks
			95%	50 %	5 %		
Berger *et al.* [31]	Switzerland	101	14	30 (~30)	80	0.265	Direct measurements on 70-m towers
Anderson and Eriksson [17]	Switzerland	80	14	31	69	0.21	Direct measurements on 70-m towers
Dellera *et al.* [32]	Italy	42	–	33	*	0.25	Direct measurements on 40-m towers
Geldenhuys *et al.* [33]	South Africa	29	7*	33 (43)	162*	0.42	Direct measurements on 60-m towers
Takami and Okabe [34]	Japan	120	10	29**	85	0.28**	Direct measurements on 40- to 140-m transmission-line towers
Visacro *et al.* [35]	Brazil	38	21	45	94	0.20	Direct measurements on a 60-m mast
Anderson and Eriksson [17]	Switzerland (*N* = 125), Australia (*N* = 18), Czechoslovakia (*N* = 123), Poland (*N* = 3), South Africa (*N* = 11), Sweden (*N* = 14), and USA (*N* = 44)	338	9*	30 (34)	101*	0.32	Combined direct and indirect (magnetic link) measurements
CIGRE Report 63 [36]	Switzerland (*N* = 125), Australia (*N* = 18), Czechoslovakia (*N* = 123), Poland (*N* = 3), South Africa (*N* = 81), Sweden (*N* = 14), and USA (*N* = 44)	408	–	31 (33)	*	0.21	Same as Anderson and Eriksson's [17] sample plus 70 additional measurements from South Africa

The 95%, 50%, and 5% values are determined using the lognormal approximation to the actual data, with 50% values in the parentheses being based on the actual data.
$\sigma_{\lg}I$ is the standard deviation of the logarithm (base 10) of peak current in kA; $\beta = 2.3026\ \sigma_{\lg}I$.
* As reported by Takami and Okabe [34].
**26 kA and 0.32 after compensation for the 9-kA lower measurement limit.

Table 5. Comparison of return-stroke peak currents (in kA) for subsequent strokes in negative lightning (adopted from [30])

References	Location	Sample size	Percent exceeding tabulated value			$\sigma_{lg}I$	Remarks
			95%	50%	5%		
Berger *et al.*[31]	Switzerland	135	4.6	12	30	0.265	Direct measurements on 70-m towers
Anderson and Eriksson [17]	Switzerland	114	4.9	12	29	0.23	Direct measurements on 70-m towers
Dellera *et al.* [32]	Italy	33	–	18	–	0.22	Direct measurements on 40-m towers
Geldenhuys *et al.* [33]	South Africa		–	7-8	–	–	Direct measurements on a 60-m mast
Visacro *et al.* [35]	Brazil	71	7.5	18	41	0.23	Direct measurements on a 60-m mast
Diendorfer *et al.* [37]	Austria	615	3.5	9.2	21	0.25	Direct measurements on a 100-m tower; upward lightning
Schoene *et al.* [38]	Florida	165	5.2	12	29	0.22	Direct measurements; rocket-triggered lightning

The 95%, 50%, and 5% values are determined using the lognormal approximation to the actual data. $\sigma_{lg}I$ is the standard deviation of the logarithm (base 10) of peak current in kA; $\beta = 2.3026\ \sigma_{lg}I$. Data for strokes in upward and rocket-triggered flashes are included because those strokes are similar to subsequent strokes in natural downward flashes.

Other parameters of Interests

Apart from those basic parameters discussed earlier, there are several other lightning parameters needed in engineering applications which include maximum current derivative, average current rate of rise, current rise time, current duration, charge transfer, and specific energy (action integral), which are all derivable from direct current measurements. The distributions of these parameters presently adopted by CIGRE are based on direct measurements by Berger *et al.* [31] in Switzerland. There are also more recent direct current measurements available which are obtained using instrumented towers in Austria, Brazil, Canada, Germany, Japan, Russia, and Switzerland, as well as those obtained in several countries using rocket-triggered lightning. Furthermore, modern lightning locating systems report peak currents estimated from measured magnetic or electric field peaks. Additionally, lightning parameters such as the number of strokes per flash (multiplicity), interstroke interval, number of channels per flash, relative intensity of strokes within a flash, return-stroke speed, and equivalent impedance of the lightning channel, as well as the characteristics of continuing currents and M-components are among other parameters to be considered. Table 6 shows the lightning current parameters (based on Berger's data) recommended by CIGRETB 63 [39] and IEEE Std 1410-2010 [18].

Table 6. Lightning current parameters (based on Berger's data) recommended by CIGRE TB 63 [39] and IEEE Std 1410-2010 [18]

Parameters of long-normal distribution for negative downward flashes				
Parameter	First stroke		Subsequent stroke	
	M, Median	ß, logarithmic (base e) standard deviation	*M*, Median	ß, logarithmic base standard deviation
Front time [μs]				
t_d 10/90 = T_{10}/90/0.8	5.63	0.576	0.75	0.921
t_d 10/90 = T_{30}/90/0.6	3.83	0.553	0.67	1.013
$t_m = I_F / S_m$	1.28	0.611	0.308	0.708
Steepness [kA/μs]				
S_m, maximum	24.3	0.599	39.9	0.852
S_{10}, at 10%	2.6	0.921	18.9	1.404
S_{10}/90, 10-90 %	5.0	0.645	15.4	0.944
S_{30}/90, 30-90 %	7.2	0.622	20.1	0.976
Peak (crest) current [kA]				
I_i, initial	27.7	0.461	11.8	0.530
I_F, final	31.1	0.484	12.3	0.530
Ratio I_i/I_F	0.9	0.230	0.9	0.207
Other relevant parameters				
Tail time to half value, t_h (μs)	77.5	0.577	30.2	0.933
Number of strokes per flash	1	0	2.4	0.96 based on median N total=3.4
Stroke charge, Q (Coulomb)	4.65	0.882	0.938	0.882
$\int I^2 \mathrm{d}t((kA)^2 s)$	0.057	1.373	0.0055	1.366
Interstroke interval (ms)	–	–	35	1.066

Measured lightning generated electric field in Selangor, Malaysia

Since the early 1930s, the breakdown process in the cloud discharge has been studied in a structured fashion in order to understand the lightning initiation mechanism. There is another method for considering lightning effects by visually observing the discharged process of the cloud. Some valuable information on the initiation of the process could be provided by the electric field remote sensor.

The study of the remote sensing of lightning cloud discharge can be found in literature, for example in Weidman and Krider [40], Le Vine *et al.* [41], Cooray and Lundquist [42], and Villanueva *et al*. [43].

Based on previous studies, it was found that large microsecond scale pulses typically observed at the beginning of the cloud discharge could be related to the breakdown process initiation. Detailed analyses of the pulses in the first 10 ms of cloud discharge were performed by Sharma *et al.* [44] and Bodhika *et al.* [45] with the absence of the first electric field pulse. Motivated by their analysis on the pulse duration, zero crossing time, and rise time, Ahmad *et al.* [46] conducted an experiment to include the first electric field pulse of the cloud discharge.

Over the years, various researchers have done reliable works to measure and model various features and effects of lightning discharge with varied success. These works served to improve our understanding of the physical meaning of the lightning processes and the role of lightning in the global circuit.

The measurement of the electric field was recorded on November 2013 at the University Putra Malaysia (UPM) (2°59'19.9"N 101°43'29.8"E) in Serdang Selangor area during the monsoon period. Selangor has a tropical rainforest climate with monsoon rain from November to February blowing to Strait of Malacca. From a total of 172 lightning ground flash records analyzed, 57 flashes contained positive lightning with a number of them having high numbers of subsequent return strokes which is somewhat unusual considering the observations in other locations. In contrast to the majority of positive lightning return strokes that have been recorded previously, where the average multiplicity, M_{AVG}, is one, this study showed a high average multiplicity which is almost four times higher than usually observed. Table 7 generalizes the studies that have been experimented on positive lightning in the past for their respective number of strokes and average multiplicity, M_{AVG}. This is one of the examples of positive lightning, which intends to highlight the distinctive features of these measured electric fields.

Table 7. Occurrence of positive return strokes in flashes and M_{AVG} of numerous studies [47]

Study	Number of flashes	Percentage of different number of strokes in flashes					Average multiplicity
		One stroke	Two strokes	Three strokes	Four strokes	More than 4-strokes	
Qie *et al.* [48]	185	175 (94.59%)	9 (4.86%)	1 (0.55%)	0	0	1.06
Nag and Rakov [49]	52	42 (81%)	9 (17%)	1 (2%)	0	0	1.2
Saba *et al.* [50]	103	83 (80%)	19 (18%)	1 (2%)	0	0	1.2
Fleenor *et al.* [51]	204	195 (96%)	9 (4%)	0	0	0	1.04
Heidler and Hopf [52]	44	33 (75%)	8 (18%)	2 (5%)	1 (2%)	0	1.34
Our study	57	9 (15.79%)	14 (24.56%)	10 (17.54%)	9 (15.79%)	15 (26.32%)	3.86

Figure 4 shows one of the recorded flashes that occurred at 15:22:54 on 31/10/13. Nine positive RS were found to be present in the flash with a small intensity PBP preceding the first positive return stroke.

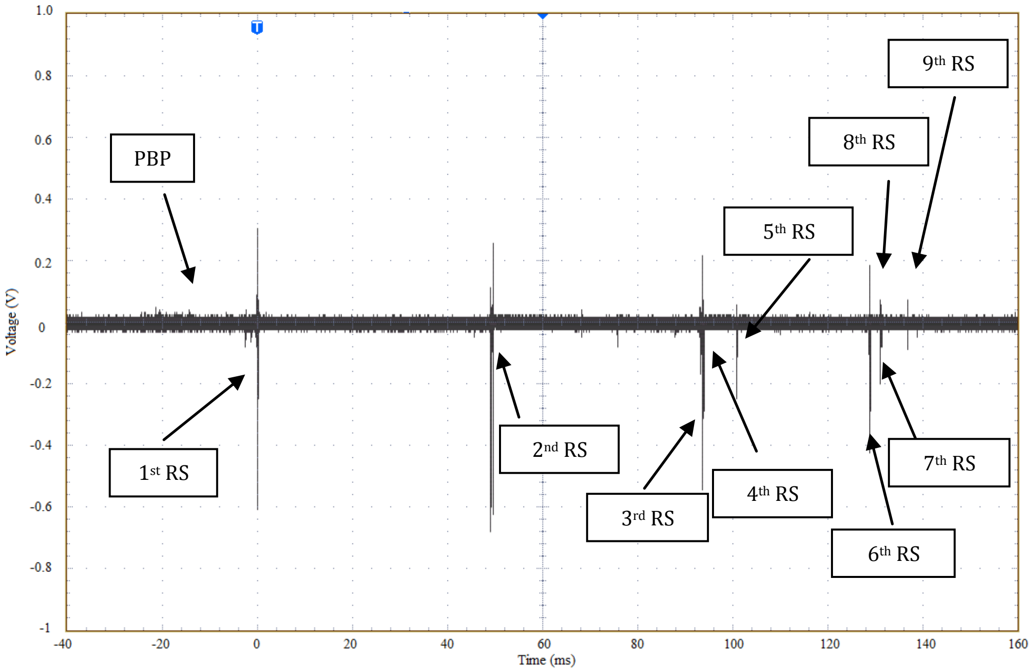

Figure 4. The electric field return stroke waveform of flash with a timeframe of 20 ms [47]

Lightning parameters for forensic study: Lukut incident

This section details the incident that caused death to a man living in the palm estate area in Lukut Negeri Sembilan. That incident was covered in most of the newspaper in Malaysia and was reported to have happened around 5.30 p. m. (local time) on 27 November 2011. There are few issues here *i. e.* the death incident, the electrical shock to personnel and the damage to equipment. While the death is very rare in this case (where family claimed to see the red flash came from the front door), it is believed that it was due to the flashover from the roof to the victim that happened within a fraction of second, as seen by family members.

Some information that we received from the electrical utility showed that between 4.00-6.00 p. m. on the 27 Nov 2011 (the date where the incident happened), there were about 155 lightning strikes within 10 km radius from the locations of the accident with two strikes that carried 105 kA (6.01 p. m.) and 114 kA (5.35 p. m.). This is a tremendous amount of current that was more than enough to cause damage to the personnel and equipment (from various mechanisms). Figure 5 shows the number of lightning strikes at 10 km radius from the incident location, recorded for the period of 45 days, from 1 Nov 2011 till 15 Dec 2011. Due to the difficulty in getting the coronary report, it was unable to discuss further details of the incident from the medical point of view. Nevertheless, there were very good ideas on the technical perspective, such as on the peak current, the location from the incident and the number of strikes which definitely would be useful in designing the lightning protection system. This is a very good example of how we can utilize these lightning parameters to investigate the details pertaining to the incident, which in this case was found to be very informative.

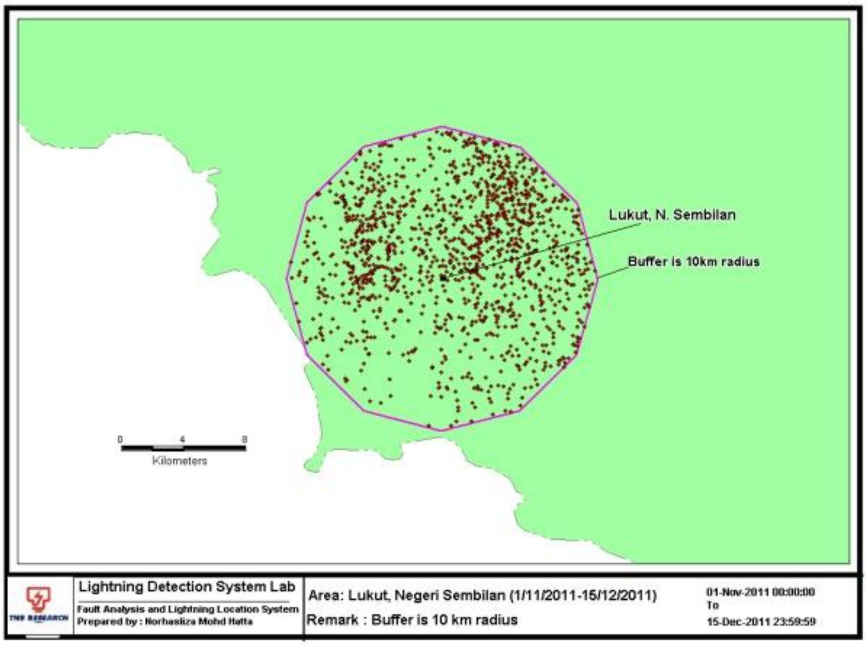

Figure 5. Lightning recorded data within 10 km radius from the incident location

Summary of some engineering applications

Lightning parameters are of interest in different fields of research and engineering applications, such as airborne vehicles, construction and oil industry engineering, power network components and wind turbines. The protection against lightning for each application follows specific standards. Several aspects have been covered by previous CIGRETB 63 [39],TB 118 [53], TB 172 [54], TB 360 [55],TB 287 [56], TB 441 [57] and by the ongoing activities of other working groups (*e. g.* WG C4.408 Lightning Protection of Low-Voltage Networks, WG C4.409 Lightning Protection of Wind Turbine Blades, WG C4.410 Lightning Striking Characteristics for Very High Structures, WG C4.23 Guide to Procedures for Estimating the Lightning Performance of Transmission Lines, WG C4.26 Evaluation of Lightning Shielding Analysis Methods for EHV and UHV DC and AC Transmission Lines).

In the case of transmission lines, for instance, the protection is mainly based on the use of shield wires (or overhead ground wires) and selective use of surge arresters. Some special methods have also been successfully used for improving the lightning performance [23]. The grounding system generally has a great influence on the effectiveness of the protection means. In the IEC 62305 series, those parameters are the basis for the developed standard for the protection of structures, living beings and electrical and electronic systems against lightning.

Effective shield wire protection is characterized by the low probability of both shielding failures and back flashovers. Modeling and procedures for the estimation of these probabilities have been addressed by both CIGRE document [39] and IEEE Standards [18, 23].

Conclusion

This paper has presented lightning severity in Malaysia and has summarized some of the basic lightning parameters that are needed in power engineering calculations, along with the relevant references to standards and the recent literature on the subject. Looking at several engineering applications with regards to the obtained parameters, the use of these parameters in the standard series IEC 62305 and several IEEE standards, for instance, are mainly based on the direct measurements by Berger *et al.* in Switzerland. Meanwhile, more recent direct current measurements were obtained from instrumented towers in Austria, Germany, Russia, Canada, and Brazil, as well as from rocket-triggered lightning. In addition, modern LLS report peak currents estimated from measured electromagnetic field peaks, which can lead to many improvements of the existing research and technologies. In the meantime, new perspectives of lightning research could also possibly be explored.

References

[1] Murty, O. P., *et al.*, Fatal Lightning Strikes in Malaysia: A Review of 27 Fatalities, *Amer. J. Forensic Medicine & Pathology*, *30* (2009), 3, pp. 246-251
[2] Chao, T. C., *et al.*, A Study of Lightning Deaths in Singapore, *Singapore Medical J*., *22* (1981), June, pp. 150-157
[3] Rakov, V. A., Uman, M A., *Lightning: Physics and Effects*. Cambridge Univ. Press, Cambridge, UK, 2007
[4] Hidayat, S., *Characteristic of Lightning in Indonesia Observed by Lightning Location System*, Ph.D. thesis, Dept. of Electrical Engineering, University of Tokyo, Tokyo, 1996
[5] Hamid, E. Y., *et al.*, TRMM/LIS Observations of Lightning Activity over Indonesia and Comparison with Ground-based Measurement Around Java Island, *J. Atmos. Electr*., *19* (1999), 2, pp. 153-164
[6] Manohar, G. K., Kesarkar, A. P., Climatology of Thunderstorm Activity over the Indian Region: A Study of East-West Contrast, *Mausam*, *54* (2003), 4, pp. 819-828
[7] Manohar, G. K., Kesarkar, A. P., Climatology of Thunderstorm Activity over the Indian Region: II. Spatial Distribution, *Mausam*, *54* (2004), 1, pp. 31-40
[8] Gomes, C., Kadir, Z., A Theoretical Approach to Estimate the Annual Lightning Hazards on Human Beings, *Atmospheric Research*, *101* (2011), 3, pp. 719-725
[9] Asha, N., *et al.*, A Study of Lightning Activity over Land and Oceanic Regions of India, *J. Earth System Science*, *118* (2009), 5, pp. 467-481
[10] Mir, H., *et al.*, Analysis of Thunderstorms Activity over Pakistan during (1961-2000), *Pakistan J. Meteorology*, *3* (2006), 5, pp. 13-34
[11] Gomes, C., *et al.*, Lightning Accidents and Awareness in South Asia: Experience in Sri Lanka and Bangladesh, *Proceedings*, 28th Int. Conf. Lightning Protection (ICLP), Kanazawa, Japan, 2006
[12] Shwehdi, M. H., Thunderstorm Distribution and Frequency in Saudi Arabia, *J. Geophysical Eng*., *2* (2005), Aug., pp. 252-267
[13] Ferrett, R. L., Ojala, C. F., The Lightning Hazard in Michigan, *Michigan Academician, 24* (1992), pp. 427-441
[14] Elsom, D. M., Deaths and Injuries Caused by Lightning in the United Kingdom: Analyses of Two Databases, *Atmospheric Research*, *56* (2001), 1, pp 325-334
[15] Gomes, C,. *et al.*, Lightning Accidents and Awareness in South Asia: Experience in Sri Lanka and Bangladesh, *Proceedings*, 28th International Conference on Lightning Protection (ICLP), Kanazawa, Japan, 2006
[16] Berger, K., *et al.*, Parameters of Lightning Flashes, *ELECTRA*, *41* (1975), 1, pp. 23-37
[17] Anderson, R. B., Eriksson, A. J., Lightning Parameters for Engineering Application, *ELECTRA*, *69* (1980), 1, pp. 65-101
[18] ***, IEEE Standard 1410-2010, IEEE Guide for Improving the Lightning Performance of Electric Power Overhead Distribution Lines, 2010
[19] Anderson, R. B., *et al.*, Lightning and Thunderstorm Parameters, *IEE Conference Publication no. 236, Lightning and Power Systems*, London, 1984, pp. 57-61

[20] ***, CIGRE Task Force C4.01.02-B, Torres, H. (Chair), Ground Flash Density: Definition of the Appropriate Grid Size and a Proposal of Relationship Ng vs. Td for Tropical Zones, *Activity Report*, CIGRE WG C4.01 Meeting, Dallas, Texas, Sept. 2003
[21] ***, MS IEC Standard 62305-2. Protection against Lightning, Part 2: Risk Management, 2007
[22] ***, Energy Commission of Malaysia. Guide on Lightning Protection System for Buildings. ISBN:978-967-12023-4-0. 2014
[23] ***, IEEE Std 1243-1997. IEEE Guide for Improving the Lightning Performance of Transmission Lines, 1997
[24] ***, IEC Standard 62305-1: 2010. Protection against Lightning, Part 1: General Principles, Edition 2.0., 2010
[25] ***, IEC Standard 62305-2: 2010. Protection against Lightning, Part 2: Risk Management, Edition 2.0., 2010
[26] ***, IEC Standard 62305-3: 2010. Protection against Lightning, Part 3: Physical Damage to Structures and Life Hazard, Edition 2.0., 2010
[27] ***, IEC Standard 62305-4: 2010. Protection against Lightning, Part 4: Electrical and Electronic Systems within Structures, Edition 2.0., 2010
[28] Hileman, A. R. *Insulation Coordination for Power Systems*, Marcel Dekker, New York, SAD, 1999
[29] Popolansky, F., Frequency Distribution of Lightning Currents, *Electra, 22* (1972), 2, pp. 139-147
[30] ***, CIGRE WG C4.407, Technical Brochure 549. Lightning Parameters for Engineering Applications, 61 p., 2013
[31] Berger, K., *et al.*, Parameters of Lightning Flashes, *Electra, 80* (1975), 1, pp. 23-37
[32] Dellera, L., *et al.*, Lightning Protection of Structures. Part IV: Lightning Current Parameters, *Energia Elettrica*, *62*(1985), 11, pp. 447-461
[33] Geldenhys, H. T., *et al.*, Fifteen Years of Data of Lightning Current Measurements on 60 m mast. *South African Institute of Electrical Engineers. Transactions*, *80* (1989), 1, pp. 98-103
[34] Takami, J., Okabe, S., Observational Results of Lightning Current on Transmission Towers, *IEEE Transaction on Power Delivery*, *22* (2007), 1, pp. 547-556
[35] Visacro, S., *et al.*, Updated Statistics of Lightning Currents Measured at Morro do Cachimbo Station, *Atmospheric Research*, *117* (2012), Nov, pp. 55-63
[36] ***, CIGRE WG 33.01, Report 63. Guide to Procedures for Estimating the Lightning Performance of Transmission Lines, 1991
[37] Diendorfer, G., Some Parameters of Negative Upward-Initiated Lightning to the Gaisberg Tower (2000–2007), *IEEE Transactions on Electromagnetic Compatibility*, *51* (2009), 3, pp. 443-452
[38] Schoene, J., *et al.*, Characterization of Return-Stroke Currents in Rocket-Triggered Lightning, *Journal of Geophysical Research*, *114* (2009), D3, pp. D03106
[39] ***, CIGRÉ Working Group 33.01, Technical Brochure 63. Guide to Procedures for Estimating the Lightning Performance of Transmission Lines, 1991
[40] Weidman, C. D., Krider, E. P., The Radiation Field Waveforms Produced by Intracloud Lightning Discharge Processes, *J. Geophys. Res*., *84* (1979), June, pp. 3159-3164
[41] Le Vine, D. M., *et al.*, Comparison of Fast Electric Field Changes from Subsequent Return Strokes of Natural and Triggered Lightning, *J. Geophys. Res*., *94* (1989), 13, pp. 259-265
[42] Cooray, V., Lundquist, S., On the Characteristics of Some Radiation Fields from Lightning and Their Possible Origin in Ground Flashes, *J. Geophys. Res*., *87* (1982), 11, pp. 203-214
[43] Villanueva Y., *et al.*, Microsecond-Scale Electric Field Pulses in Cloud Lightning Discharges, *J. Geophys. Res.*, *99* (1994), 14, pp. 353-367
[44] Sharma, S. R, *et al.*, Signatures of Electric Field Pulses Generated by Cloud Flashes, *Journal of Atmospheric and Solar-Terresterial Physics*, *67* (2005), 4, pp. 413-422
[45] Bodhika, J. P., *et al.*, Characteristics of Cloud Flashes Inferred from Measurements of Electric Fields over Sri Lanka a Tropical Country, *Proceedings,* 28th Int. Conf. on Lightning Protection, Kanazawa, Japan, 2006
[46] Ahmad, N. A, *et al.*, The First Electric Field Pulse of Cloud and Cloud-To-Ground Lightning Discharges, *Journal of Atmospheric and Solar-Terresterial Physics*, *72* (2010), 2-3, pp. 143-150
[47] Hamzah, M. N., *et al.*, Unique Stroke-Multiplicity of Positive Lightning in Malaysia, *Applied Mechanics and Materials*, *793* (2015), 1, Sept., pp. 39-43

[48] Qie, X., *et al.*, Characteristics of Positive Cloud To-ground Lightning in Da Hinggan Ling Forest Region at Relatively High Latitude, Northeastern China, *J. Geophys. Res. Atmos.*, *118* (2013), 13, pp. 393-404
[49] Nag, A., Rakov, V. A., Positive Lightning: An Overview, New Observations, and Inferences, *J. Geophys. Res.*, *117* (2012), D8
[50] Saba, M. M. F., *et al.*, High-Speed Video Observations of Positive Lightning Flashes to Ground, *J. Geophys. Res.*, *115* (2010), D24, pp. 201-225
[51] Fleenor, S., *et al.*, Characteristics of Cloud-To-Ground Lightning in Warm-Season Thunderstorms in the Central Great Plains, *Atmospheric Research*, *91* (2009), 2-4, pp. 333-352
[52] Heidler, F., Hopf, C., Measurement Results of the Electric Fields in Cloud-to-Ground Lightning in Nearby Munich, Germany, *IEEE Transactions On Electromagnetic Compatibility*, *40* (1998), 4, pp. 436-443
[53] ***, CIGRE Task Force 33.01.03, TB 118. Lightning Exposure of Structures and Interception Efficiency of Air Terminals, 1997
[54] ***, CIGRE Task Force 33.01.02, Characterization of Lightning for Applications in Electric Power Systems, 2000
[55] ***, CIGRE WG C4.302. Insulation Co-Ordination Related to Internal Insulation of Gas Insulated Systems with SF6 and N2/SF6 Gas Mixtures under AC Condition, 2008
[56] ***, CIGRE WG C4.408. Protection of MV and LV Networks Against Lightning – Part 1: Common topics, 2006
[57] ***, CIGRE WG C4.402. Protection of Medium Voltage and Low Voltage Networks against Lightning, 2010

Paper submitted: October 26, 2015
Paper revised: December 7, 2015
Paper accepted: January 17, 2016