CHARACTERISTICS OF NARROW BIPOLAR PULSES AND NEGATIVE RETURN STROKES OF VERTICAL ELECTRIC FIELDS GENERATED BY LIGHTNING RECORDED IN MALAYSIA

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

AUGUST 2016

Specially dedicated with deepest love to:

“My beloved parents, my late father, Allahyarham Zakaria bin Awang,
my mother, Zauwiyah binti Hasyim,
Dear Husband Muhammad Al Ghazali Khuzairi Bin Khalid
My dear daughter Naurah Insyirah.
Thank you for your support, advice and love.
May Allah blesses and gives Barakah upon you all.

ACKNOWLEDGEMENT

First and above all, I praise Allah, the Almighty for providing me this opportunity and granting me the capability to stay strong and finally finish my Master study. I would like to express my greatest gratitude to my project supervisor, Dr. Noor Azlinda Binti Ahmad, for giving me the opportunity to complete my thesis under her supervision. Her willingness to teach, plus with relentless guidance and unfailing patience has been a great motivation for me to excel in my work.

Also, I would like to express the highest appreciation to Dr Ridzuan and Dr Mona for giving me ideas and suggestions thoroughly on my study. I would like to extend the gratitude to lightning research team in IVAT headed by Professor Dr Zulkarnain and his students Behnam, Kamyar, Ooi and Novizon,whom have helping me during conducting the experiment or while analysing the data.

I would like to thank all technical staffs of the Institute Voltan dan Arus Tinggi (IVAT), Universiti Teknologi Melaka (UTeM), and TNB Research Sdn. Bhd. (TNBR), for their assistance and the use of equipment and data to carry out this work.

Next, I would like to take this opportunity to thank all my friends and office mates, who had helped in many ways by discussing and exchanging ideas and information besides giving me moral support, especially to Kak Lin, Bella, Kak Ain, Miza, Kak Rubi and Solehah.

Last but not least, I would like to dedicate my thanks to all my family members and people who involved in the completion of this project study through hardship and happiness that I have share together with them directly or indirectly. Thank you and May Allah blessed all of you.

ABSTRACT

Lightning that generates electric fields is known to have negative consequences. Therefore, the electric field radiated in microwave and characteristics of different types of lightning activities are studied and analysed to better understand lightning based problems. In this study, two types of lightning electric fields which are Negative Return Strokes (NRS) and Narrow Bipolar Pulses (NBP) are thoroughly analysed. A total of 89 NRS data and 115 NBP data were selected from a set of data recorded during the northeast monsoon period from November to December 2012 in the vicinity of Universiti Teknologi Malaysia (UTM), Johor. For that purpose, flat plate antenna with electronic buffer circuit and a 2.4 GHz monopole antenna were used to measure vertical electric field and microwave radiation. Apart from the electric field characteristics analysis, the measurements of microwave radiation at 2.4 GHz associated with NRS and NBP were also performed and the results are depicted in this study. Nonetheless, the wavelet and the frequency spectrum of both NRS and NBP were examined and the results are discussed inclusively. Furthermore, the number of microwave radiations associated with NBP were notably higher than that of NRS, which indicated that the mechanism of NBP was more distinguished compared to that of NRS. On top of that, the duration of 2.4 GHz emission associated with NBP was discovered to be a factor of a few tens shorter than that of High Frequency (HF) radiation from return strokes. Meanwhile, analysis on the wavelet and frequency spectrum reveals that the energy spectrum for NBP concentrates at high frequency (200 kHz to 500 kHz) with average power spectrum peak of the initial part for NNBP and NPBP to be 76,650 $(V/m)^2$ and 76,309 $(V/m)^2$, respectively. However, the initial part power spectrum peak corresponding to NRS is about 118,931$(V/m)^2$ with lower frequency spectrum (60 kHz). The results suggest that NBP radiates energy at high frequency region compared to NRS. Hence, it can be concluded that electric field pulse for NBP experiences more extensive and rapid ionization process compared to NRS.

ABSTRAK

Kilat yang menjana medan elektrik adalah diketahui mempunyai kesan-kesan negatif. Oleh itu, medan elektrik yang dipancarkan dalam gelombang mikro dan ciri-ciri pelbagai jenis kilat dikaji dan dianalisis untuk memahami dengan lebih baik masalah berkaitan kilat. Dalam kajian ini, dua jenis medan elektrik kilat iaitu Strok Pulangan Negatif (NRS) dan Denyutan Sempit Dwi-Polar (NBP) telah dianalisis. Sebanyak 89 NRS data dan 115 data NBP telah dipilih daripada satu set data yang direkodkan dalam monsun timur laut dari bulan November hingga Disember 2012 berhampiran Universiti Teknologi Malaysia (UTM), Johor. Untuk tujuan itu, antena plat rata dengan litar penampan elektronik dan antena ekakutub 2.4 GHz akan digunakan untuk merekod medan elektrik menegak dan radiasi gelombang mikro. Selain daripada analisis ciri-ciri elektrik, pengukuran radiasi gelombang mikro pada 2.4 GHz yang berkaitan dengan NRS dan NBP juga telah dilakukan dan hasilnya boleh dilihat dalam kajian ini. Namun begitu, gelombang dan spektrum frekuensi kedua-dua NRS dan NBP telah diperiksa dan keputusan dibincangkan secara inklusif. Tambahan pula, jumlah radiasi gelombang mikro yang berkaitan dengan NBP lebih tinggi daripada NRS, menunjukkan bahawa mekanisme NBP adalah lebih terkenal berbanding dengan NRS. Selain itu, tempoh pelepasan 2.4 GHz yang berkaitan dengan NBP telah ditemui sebagai satu faktor berpuluh kali lebih pendek berbanding dengan frekuensi tinggi (HF) dari strok balikan. Sementara itu, analisis mengenai gelombang dan frekuensi spektrum menunjukkan bahawa spektrum tenaga untuk NBP tertumpu pada frekuensi tinggi (200 kHz hingga 500 kHz) dengan purata puncak kuasa spektrum awal untuk NNBP dan NPBP adalah 76,650 $(V/m)^2$ dan 76,309 $(V/m)^2$. Namun, puncak kuasa spektrum awal yang sepadan dengan NRS adalah 118,931 $(V/m)^2$ dengan spektrum frekuensi yang lebih rendah (60 kHz). Keputusan menunjukkan bahawa NBP memancarkan tenaga pada frekuensi tinggi berbanding NRS. Oleh itu, denyutan medan elektrik untuk NBP mengalami proses ionisasi yang lebih luas dan pesat berbanding NRS.

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LIST OF ABBREVIATION

CGs	-	Cloud to ground flashes
FWHM	-	Full Width at Half Maximum
HF	-	High frequency
ICs	-	Cloud flashes
kHz	-	Kilo Hertz
LF	-	Low Frequency
MHz	-	Mega Hertz
NBPs	-	Narrow Bipolar Pulses
NLSI	-	National Lightning Safety Institute
NNBPs	-	Narrow Negative Bipolar Pulses
NPBPs	-	Narrow Positive Bipolar Pulses
NRS	-	Negative Return Stroke
RF	-	Radio Frequency
RS	-	Return strokes
RT	-	Rise time
UHF	-	Ultra High Frequency
VLF	-	Very low frequency
US	-	United States

UTM	-	Universiti Teknologi Malaysia
VHF	-	Very High Frequency
LF	-	Low frequency
ZCT	-	Zero crossing time
FWHM	-	Full width and half maximum
PBP	-	Preliminary breakdown process
SLs	-	Stepped leaders
MMD	-	Malaysia meteorological department
DOG	-	Derivative of Gaussian
PD	-	Pulse Duration

LIST OF SYMBOLS

%	-	Percentage
D	-	Electric flux density
E	-	Electric field intensity
Q	-	Charge on Plate
S	-	Area of plate
ε_o	-	absolute permittivity's
ε_r	-	Relative permittivity's
r	-	distance
Q	-	Charge
d	-	Height
Vg	-	Voltage measure between plate
E_n	-	Normal electric field
C_c	-	Capacitance for RG58
C_g	-	Capacitance between plate
C	-	Capacitance of the electronic circuit
Ω	-	Unit for resistor value(ohm)
d_{eff}	-	Effective height of the antenna
V_m	-	Measure voltage

R	-	Resistor
R_{OT}	-	Total output resistor
R_m	-	Matching resistor
T_d	-	Decay time constant
P_a	-	Peak Amplitude
O_s	-	Overshoot Amplitude

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Thunderstorm or lightning is a natural phenomenon which usually occurs in rainy season, indicated by the appearance of a flash of blinding light in the sky for a moment (lightning), and followed by a thunderous noise (thunder). Lightning and thunderstorm phenomena can cause damages, injuries, and loss of life every year. Due to this, numerous studies on the characteristics of lightning have been carried out many researchers, namely on lightning related to ground flash since it is one of the most fascinating natural phenomena on earth[9-10]. However, many aspects of lightning are yet to be well understood due to the complexity in the characteristics of lightning. Hence further research is imperative in grasping the knowledge pertaining the characteristics of lightning's electric field.

Return stroke is types of ground flash lightning that has been frequently and extensively discussed in previous studies compared to another type of lightning, which is cloud flash. Return stroke also holds one of the most powerful energy content in the whole part of a lightning strike. This has resulted to an increasing number of accidents caused by the electric field of the ground flash lightning leading to the growing needs and awareness to carry out further research on the characteristics of lightning flash. For example, negative return stroke (NRS), type of lightning cloud to ground flash has caused highly hazardous conditions and injuries each year.

Studies on cloud flashes have begun since the year of 1930 in order to enhance the understanding of the mechanism of this type of lightning. The result of the studies shows that about 90% of lightning phenomenon occurred inside the cloud structure. Hence, this type of lightning does not cause any harm to living things or structures on the ground itself. However, the danger is more on flying objects specifically those linked to the aviation industries which has been rapidly growing in the past century.

Previous studies on cloud flashes such as the Narrow Bipolar Pulses were focused on high frequency (HF) and very high frequency (VHF) which are the strongest source of frequency radiation. Due to the emission of very strong HF - VHF radiation, NBPs have become a major concern in lightning protection systems especially for aviation industries whose fundamental resonances lie at 3 – 30 MHz [11] and communication data line that uses electronics and solid state devices greatly. Ahmad [12] has analysed lightning radiation associated at HF radiation at 3MHz and 30MHz. According to [13], the mean duration of HF emission (3 – 30 MHz) associated with NPBPs were 2.8 μs with amplitudes 10 times larger than emissions from ordinary cloud flashes or return strokes. Le Vine et al.[14] who observed NBP associated at strongest frequency, reported observations of narrow positive bipolar pulses (NPBPs) at 3MHz, 139MHz, and 295MHz using vertically polarized antennas. Rison, et al.[15] on the other hand reported observations of narrow negative bipolar pulses (NNBPs) at 63MHz. Previous research shows that most of the NBP are radiated at HF and VHF. Ahmad et al. [16] analyzed the temporal characteristics of microwave radiation bursts for both NNBP and NPBP which was reported for the first time in Malaysia. Observations by all these studies show that NBP is the strongest lightning electric field that can radiate at HF, VHF and also microwave region.

Consequent studies on the electric field of lightning in microwave region in the range of kHz to GHz were done to understand the temporary HF radiation from lightning. A study conducted by Ahmad et al. [17] examine the interactive lightning flash in wireless communication networks (2.4 GHz).The first research work investigated the effect of lightning-induced radiation on wireless communication link at UHF band. Based on previous research, the electric radiations field produced by

lightning may cause error or loss of rates hence reducing the overall performance of the wireless networks. A related work in [18] also showed that the effect of lightning-induced transient in RF and microwave region was observed marked at 2.4GHz. Nevertheless, the lightning signature at 2.4GHz is less studied compared to other frequency ranges. Since issues related to wireless communication systems are being vigorously researched, the study on electric field in microwave region is conducted to study the effect on microwave electric field in a communication system.

1.2 Problem Statement

The world needs to know, the impact of lightning electric field that radiates in microwave frequency region to communication signal transfer. The effect of lightning radiation at microwave frequencies is more critical for countries located in tropical region such as Malaysia which experiences a high rainfall rate throughout the year [19]. Studying lightning in microwave frequencies is essential since people do not know the impact of electric field that radiates in microwave region, especially in wireless communication network frequencies. Recognizing the importance of addressing these weaknesses, investigationson lightning-generated radiation at microwave frequencies have begun.

Since then, the characteristics of lightning electric field from other regions such as Sweden, Florida (USA) and China have been greatly studied. However, such studies in the tropical region, specifically in Malaysia, are very limited. Even though similar studies have been performed in Sri Lanka, the outcome was not as comprehensive as those that had been done in Sweden and Florida. Furthermore, Sri Lanka is an island located in the Indian Ocean and the weather, temperature as well as moisture levels may greatly affect the formation of lightning and hence distinct characteristics of lightning electric field may be observed.

According to the National Lightning Safety Institute (NLSI)[20], the number of days of thunderstorm occurrence per year in Malaysia is between 180 to 260, while

the number of flash density recorded in Kuala Lumpur is 48.3 ground strikes/km/sq. Due to the great number of lightning activities in Malaysia, it is tremendously important that the study on the characteristics of lightning electric field carried out. However, despite being among the countries with the highest density of lightning, information related to lightning characteristics in Malaysia for both ground (NRS) and cloud flash (NBP) are still significantly insufficient.

Therefore in this study, the characteristics of lightning electric field in Malaysia is studied, with the aim to lessen the gap of knowledge regarding lightning physics, its formation and mechanism in the tropics as compared to the temperate region. Understanding the following matters has to be enlightened:

a) Some unique and distinctive features of negative return strokes (NRS) and narrow bipolar pulses (NBP).
b) Characteristics of NRS and NBP electric fields.
c) Detailed wavelet analysis for NRS and NBP for energy distribution.
d) Comparison of power spectral density between two types of lightning.

1.3 Research Objectives

The main objectives of this study are to conduct a thorough analysis on the electric field characteristics of two types of electric field namely negative return strokes (NRS) and narrow bipolar pulses (NBPs). Details of the aims are presented as follows:-

a) To measure and record vertical electric fields radiated (fast field) from NRS and NBPs.
b) To analyze the characteristics of NBPs and NRS.
c) To analyze the power spectrum of both types of power spectrum of electric field through wavelet analysis.

d) To measure and analyzed the features of microwave radiation at 2.4 GHz from NRS and NBPs

1.4 Scope of the research

The measurement of this study was conducted in the vicinity of Observatory Building, Malaysia, Skudai, Johor in 2012. Only the fast field or radiation from NRS and NBPs was recorded to be further analysed. Even though there were thousands of lightning electric fields recorded during measurement from November to December 2012, only hundreds of them were selected for detail analysis due to some factors such as distance and conditions of the waveforms. The lightning location was obtained from Tenaga National Berhad Research (TNBR) and also from time to thunder measurement. For microwave radiation measurement of NRS and NBPs, this study only presented the observation of microwave burst at 2.4 GHz associated with both discharges and no detail analysis was conducted due to limited number of data for such detail analysis. Nonetheless, the wavelet analysis of both negative return stroke and NBPs was investigated and the result will be discussed inclusively.

1.5 Organization of Thesis

This research is divided into five main chapters; introduction, literature review, methodology, result and discussion, and conclusion. Generally, some basic principles, theories, equation, previous researches references, experimental results and discussion are included in these five chapters based on the contents requirements of each chapter.

Chapter one describes the background of this study including lightning hazardous phenomenon and general introduction to lightning physics, formation and mechanism. Some backgrounds of electric field of lighting and their importance are

also explained. Scopes and objectives of this study are listed to give a clear overview on the research work conducted.

Chapter Two discusses in details the lightning mechanism in cloud flash and ground flash, respectively. Extensive literature review regarding analysis of electric field characteristics for NRS and NBPs in different temperate region is presented. Furthermore, HF and VHF radiation from lightning discharges are also described so that a clear picture pertain this issue can be dispersed. This includes some explanation on the wavelet analysis in order to understand the behaviour of energy dispersion from lightning.

Measurement set up, location, equipment used and detailed of the measuring and recording process are presented in chapter three. In this chapter, basic introduction to the physics and mathematics of electromagnetic field of lightning is described. Relationship between charges, electric field and voltage based on Gauss and Coulomb's Law is discussed for a better understanding on the fundamental theory of lightning electric field. Detailed description of the parallel plate antenna and electronics buffer used for electric field measurement is included in this chapter. Similarly, the measurement set up for microwave radiation from NRS and NBP is also presented.

Electric field analysis to study the characteristics of NBPs and NRS in both time and frequency domain is presented in chapter four. Result of the analysis is discussed thoroughly in this section.

Finally, Chapter 5 summarizes the research work of this study which has been presented earlier in Chapter 1 to 4. Some limitations and constraints during the implementation of this study are highlighted and discussed. Recommendations for improvement of this study as well as suggestions for future studies are clearly elaborated in this chapter.

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