LIGHTNING LOCATING SYSTEM USING TWISTED PAIR OVERHEAD LINES

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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

JANUARY 2010

To my beloved mother (almarhumah) and father,

my wife Yessi Anggraini

my sons Jundullah Ilhaq Aulia,

Mujahid Salafi Aulia

and my daughter Widad Elqudsi Aulia

ACKNOWLEDGEMENTS

Firstly, I like to say Alhamdulillah and thank Allah swt. for His *rahmah*, mercy and guidance in my life. With His blessing I could finish my thesis on time.

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners, especially in Insitut Voltan dan Arus Tinggi (IVAT). They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my thesis supervisor, Associate Prof. Dr. Zulkurnain Abdul Malek, for encouragement, guidance, critics and friendship. Without his continued support and interest, this thesis would not have been the same as presented here.

The authors would like to thank Ministry of Science, Technology and Innovation (MOSTI) Malaysia and Research Management Centre (RMC), Universiti Teknologi Malaysia, for the financial and management support to carry out this research and publications.

My fellow postgraduate students should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance in various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

ABSTRACT

Lightning mapping or lightning locating systems are based on several working principles such as the Time of Arrival and the Directional Finder. The country wide lightning locating system (LLS) operated by Tenaga Nasional Berhad Malaysia is able to determine the coordinate of the cloud-to-ground lightning strike with an uncertainty of about 500 m. The LLS is made of high performance sensors positioned throughout the country together with a central processing unit. An alternative method known as the localised lightning locating system (LLLS) is proposed to determine the coordinate of any cloud-to-ground lightning strike within a certain local region. The LLLS is based on the measurement of induced voltages due to lightning strikes in the vicinity of an existing overhead twisted telephone lines. The system consists of twisted pair overhead lines, induced voltage signal transducers, signal transmission cables, and a user friendly processing unit. The overhead lines have been constructed and laid in such a way to form a cartesian system suitable for lightning strike coordinate calculation with a total coverage area of 210 m x 270 m. The processing software which has been programmed in LabView is able to detect and plot the strike locations. Calibration results on the LLLS performance for one axis (y-axis) show less than 1% error of coordinate position. The field measurements in the month of August 2008 showed a significant result of lightning strike activities. Comparing the lightning density detected by the National Lightning Detection Network (NLDN) and the LLLS for the same day, the LLLS has detected more lightning strikes than NLDN. This may be due to the inability of the LLLS to differentiate between valid cloud-ground discharges and other types of discharges. The developed LLLS can be used as an alternative measuring system to determine a lightning strike location within a small area with a better accuracy due to the small coverage area.

ABSTRAK

Sistem pemetaan atau lokasi panahan kilat adalah berdasarkan beberapa prinsip kerja seperti Masa Ketibaan dan Pencari Sehala. Sistem lokasi kilat kebangsaan yang dikendalikan oleh TNB Malaysia mampu menentukan koordinat panahan kilat awan-ke-bumi dengan ketidakpastian sebesar 500 m. Sistem LLS yang mempunyai penderia berprestasi tinggi diletakkan di seluruh negara dan satu unit pemproses sentral. Satu kaedah alternatif yang dikenali sebagai sistem lokasi kilat tempatan (LLLS) dicadangkan bagi menentukan koordinat panahan kilat awan-ke-bumi dalam satu kawasan yang bersaiz kecil. Sistem LLLS ini adalah berdasarkan pengukuran voltan teraruh di dalam talian telefon atas terpintal kembar disebabkan oleh panahan kilat berdekatan dengannya. Sistem ini mengandungi talian atas terpintal kembar, transduser voltan teraruh, kabel penghantaran isyarat dan satu unit pemprosesan yang mesra pengguna. Talian atas dibina dan direntang supaya membentuk satu sistem Cartesian seluas 210 m x 270 m yang sesuai bagi pengiraan koordinat panahan kilat. Perisian pemproses yang dibina menggunakan LabView mampu untuk mengesan dan melakar lokasi panahan kilat. Keputusan tentu ukur ke atas system LLLS untuk satu paksi (paksi-y) memberikan ralat kurang dari 1%. Pengukuran di lapangan pada bulan Ogos 2008 boleh menunjukkan aktiviti kilat yang tinggi. Perbandingan ketumpatan kilat yang dikesan Rangkaian Pengesan Kilat Kebangsaan (NLDN) dan sistem LLLS pada hari yang sama menunjukkan sistem LLLS mengesan lebih banyak bilangan kilat berbanding sistem NLDN. Ini mungkin disebabkan oleh kelemahan sistem LLLS untuk membezakan antara panahan sebenar awan-ke-bumi dengan panahan atau bentuk nyahcas yang lain. Bagaimanapun, sistem LLLS yang telah dibina boleh digunakan sebagai satu sistem pengukuran lokasi panahan kilat alternatif terutamanya bagi satu kawasan yang kecil dan setempat dengan ketidakpastian yang jauh lebih kecil disebabkan oleh liputan kawasan yang lebih kecil.

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LIST OF ABBREVIATION

AC - Alternating Current

ALDIS - Australian Lightning Detection System and Information System

ANSI - American National Standards Institute

ATD - Arrival Time Difference

CA - Cloud to Air Discharge

CC - Cloud to Cloud Discharge

CG - Cloud to Ground Discharge

DAQ - Data Acquisition

DC - Direct Current

DF - Directional Finder

DToA - Different Time of Arrival

DoD - Different of Distance

ELF - Extremely Low Frequency

HEM - Hybrid Electromagnetic Model

IC - Intra Cloud Discharge

IEC - International Electrotechnical Commission

IEEE - Institute of Electrical and Electronics Engineers

IVAT	-	Institut Voltan dan Arus Tinggi
GPIB	-	General Purpose Interface Bus
MDF	-	Magnetic Direction Finding
LDFC	-	Lightning Direction Finder Controller
LDN	-	Lightning Detection Network
LEDs	-	Lighting Emitting Diodes
LF	-	Low Frequency
LLS	-	Lighting Locating System
LLLS	-	Localized Lightning Locating System
LLMS	-	Local Lightning Mapping System
LLPS	-	Lightning Location & Protection System
LLS	-	Lightning Location System
LRD	-	Radio Emission Detector
MTL	-	The Mock Transmission Line
NLDN	-	National Lightning Detection Network
OSR	-	Out of the Oscilloscope Range
PC	-	Personal Computer
RMS	-	Root Mean Square
TL	-	Transmission Line
TCS	-	Traveling Current Source
TDoA)	-	Time Different of Arrival

TNB - Tenaga Nasional Berhad

TNBR - TNB Research

TOA - Time of Arrival

TPoL - Twisted Pair Overhead Line

TSL - Telecommunication Subscriber Lines

TOGA - Time of Group Arrival

UHF - Ultra High Frequency

VLF - Very Low Frequency

VHF - Very High Frequency

VI - Virtual Instrument

VIs - Virtual Instruments

LIST OF SYMBOLS

A - the vector potential

A^2s - joules per ohm.

C - shunt capacitance per unit length

C_L - capacitance per length

^oC - Degree in Celsius

dz - A small section of transmission-line with length

di/dt, - the rate of change of lightning current

E_i - total electric field

E_m - the electric field

G - shunt conductance per unit length,

i - current

kV - Kilo volt

kA - Kilo Amperes

L - total length cable line

L - series inductance per unit length,

MA - Mega amperes

mm - Mili meter

MW - Mea Watt

MHz - Mega hetz

m - Meter

mV - milivolt

ns - nano second

-

N_g - Number of lightning flashes per km2 and year

R - series resistance per unit length,

(td_1) - transient time between the first and the second spikes at the first side (sending end)

(td_2) - transient time between the initial arrivals of the traveling wave at both sides of the cable (sending and receiving ends);

T_1 - the time for the wave to travel distance

Td - an area with a distance of 10 km to the corresponding station

T_d - Thunderstorm days

V - traveling-wave velocity

V - Volt

v - velocity

Z_0 - characteristic impedance

Z_L - the load impedance

$\overline{RNSS}$ - the range normalized signal strengths of individual sensors

Δ - delta

μs - micro second

ϕ - the electrostatic potential

Γ - Reflection coefficient

βl - the electrical length of transmission line

γ - the complex propagation constant

$\beta = \frac{2\pi}{\lambda}$ - the wave number.

CHAPTER 1

INTRODUCTION

1.1 General

One of the most fascinating events in the world considered as a spectacular meteorological phenomenon is lightning. This event is actually a companion (friend) to the earth. It was created to make fear and give hope for human being (Al-Qur'an, Ar-Rum 12). To make fear means that every strike could damage or burn structures or trees, or even people could be killed. Millions of dollars could be lost, but in contrary, lightning can also give hope and benefit to mankind. Usually the rain will come down after lightning strikes and based on a rough calculation, lightning produce about 10 million tons of nitrogen that are needed by plants to grow (Uman, 1987).

The preliminary scientific and systematic understanding of lightning phenomenon was first constituted by Benjamin Franklin who, in 1752, used a kite in order to verify that lightning is really a stream of electrified air. Interestingly, when Benjamin Franklin experimented with the 'electric' kite, there were no very tall structures and high rise buildings like the ones today.

The scientific community has long pondered the cause of lightning strikes. Even today, it is the subject of a good deal of scientific research and theory. The details of how a cloud becomes statically charged are not completely understood.

1.2 Research Background

Lightning is a phenomenon on the earth that already exists for a long time, accompanying the human life more than three billion years ago, (Rakov *et al.*, 2003). Lightning can threaten and cause fear to people. In the USA, lightning kills about 150 people every year (Nicos, 1990). The fatality increases tenfold for the case of Malaysia (Hartono *et al.,* 2003). Many researchers engage in research activities in order to understand the lightning phenomenon from the Franklin Era until now. Numerous papers and dissertations have already been published, but the phenomenon and its parameters could not be fully understood (Rajeev, 2005). Partly, the reason is the large natural variability of the lightning flash, and the other is the lack of availability of better technology to observe lightning. The research activities are not only focused on the calculation and simulation, but also using specially designed equipment that could detect and determine the lightning parameters from a remote area.

A cloud to ground (CG) lightning discharge is the most dangerous type of lightning strike for human life. National Lightning Detection Network (NLDN) own by Tenaga Nasional Bhd. (TNB) has been engaged more than 15 years detecting CG lightning strike with the accuracy in an area of 1000 m in diameter. With this accuracy, the exact location of lightning strikes cannot be performed correctly in a remote area. Finding this weakness, it is possible to develop a localised lightning locating system (LLLS) for a small area that not cot covered by TNB system to get a more accurate lightning strike locations. This data is highly required by electric power utilities to determine the fault location of power line caused by lightning. This data also need by insurance company to investigate the claim verification (Cummin *et al.*, 2006).

The CG lightning current produces a strong electromagnetic field in the surrounding area. If a nearby telephone line (TL) is present, this electromagnetic field can cause transient voltage and current within the line. The induced transient voltage and current then propagate in an opposite directions from the point of induction toward the ground. In the case of lightning strike directly the line, the same propagation process will be taken place in the line. The speed of propagation is dependent only on the cable characteristics. Previous researches have shown that the propagated transient or surge in turn can be captured and measured at the cables ends (Sorwar, 1999).

1.3 Problem Statement

A lightning detection system which can monitor lightning activities is very useful especially for protection purposes. The lightning data could be requested from the National Lightning Detection Network (NLDN) such as the TNBR Research for the case of Malaysia. However, due to the methods used, which are the time of arrival (TOA) and the angle of incidence, a far away location in reference to the nationwide sensors result in poor accuracy of lightning data, especially for the strike locations around the perimeters. This is due to the fact that the larger the distance between the sensor and the strike location, the larger is the error in measurements (Cummin *et al.*, 2006). Therefore, an accurate figure of lightning density in that remote area is not possible. Hence it is very desirable to come up with a system that can accurately determine the coordinates of lightning strikes within a small localised area. This work attempts to develop a new method of determining the lightning strike location using measurement of induced voltages on overhead twisted pair lines.

1.4 Objectives of the Study

The research aims to develop a new localised lightning locating system based on induced voltages on cable ends of overhead telephone lines. Specifically, the following objectives are desired to be achieved:

(i) to study the lightning surge propagation and the corresponding induced voltages on twisted pair overhead line (TPoL) within a laboratory set up;
(ii) to develop the necessary infrastructure (hardware) and software for a localised lightning locating system (LLLS);
(iii) to perform verification test (calibration) and field test of the LLLS;
(iv) to determine the location of lighting strike within a 210 m x 270 m area.

1.5 Research Scope

This research focuses on the lightning induced voltage measurements on TPOL. The dimension of the strike area concerned is 270 m x 210 m, and specially laid overhead line telephone wires are used. The lightning parameters are limited to the striking coordinate only and other parameters such as the ground flash density, peak currents, and lightning waveforms are not covered.

1.6 Contributions

The contributions of this research are listed below:

(i) a small scale model to demonstrate and validate the working concept of measuring the lightning induced voltages on TPoL;
(ii) a localised lightning locating system (LLLS) utilizing TPoL as the ‘sensor’ to determine lightning strike locations;
(iii) a user friendly LabView based program to capture, analyse, calculate and display the location, and store the lightning strike data;
(iv) an alternative measurement system so that the data from existing NLDN system can be compared with and verified.

1.7 Thesis Outline

Chapter 2 explains the basic concepts of the lightning phenomena and related works. Chapter 3 reviews the lightning interaction with transmission line and lightning detection concept. Chapter 4 describes the lightning locating system based on the induced voltage. The major issues are about the mock telephone lines (MTL), voltage transducers, data transceivers, data acquisition system and equipment used in the experiment. Chapter 5 presents result and discussion of LLLS, the experimental results obtained from calibration works, as well as in field performance data of LLLS. Finally, in Chapter 6 the conclusions and proposed future work are presented.