IMPROVEMENT ON SYSTEM AND COMPONENTS OF A ROTATING ELECTRIC FIELD MILL FOR ATMOSPHERIC ELECTRIC FIELD MEASUREMENT

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بسم الله الرحمن الرحيم

Alhamdulillah, all praises to Allah

Dedicated, in thankful appreciation for doa, support, encouragement and understanding
to my beloved father, Shahroom Omar, mother Nor'Aini Haron
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ABSTRACT

Lightning, which is also known as the separation of electrical charges in atmosphere, performs energetic discharge. Monitoring of the atmospheric electric field (AEF) helps to provide precaution against the risks of lightning. The rotating electric field mill (REFM) is a sensor used in measuring AEF. For long-term research, REFM should be modified based on several criteria to improve its effectiveness, cost efficiency and functionality. Studies on the applications of several sensor materials on the performance of REFM are limited. The current research's purpose is to improve REFM as AEF sensor. Furthermore, this research aims to identify the ability of REFM to capture lightning impulses and to track thundercloud development processes and movements. REFM comprises of signal processing circuit (consisting of amplification unit, filtering, conversion and signal conditioning unit) for establishing connection to data acquisition equipment in order to display, collect and analyse data. The calibration and HV impulse experiment have been conducted to this REFM. Moreover, the materials used to develop REFM sensor were mainly made from aluminium or stainless steel. Therefore, an investigation on different materials of REFM rotor and stator was performed to examine their sensitivity and stability towards the high voltage atmosphere. In addition, in order to investigate the characteristics of the signal obtained from a thunderstorm cloud prior to cloud ground lightning discharges, the REFM was installed in an open area. The calibration results showed that the aluminium sensor is more suitable for AEF measurement compared to the stainless steel sensor. The data collected on-site revealed the characteristics of the signals of AEF in the atmosphere as well as the characteristics of the signal from a thunderstorm cloud prior to cloud ground lightning discharges. This research introduced a new design of REFM which offers a reduction of up to one-third of the regular cost of the commercial REFM.

ABSTRAK

Kilat, yang juga dikenali sebagai pemisahan cas elektrik di atmosfera, membebaskan aliran tenaga. Pemantauan medan elektrik atmosfera (AEF) membantu dalam menyediakan langkah berjaga-jaga terhadap risiko kilat. REFM merupakan sejenis sensor yang digunakan dalam pengukuran AEF. Bagi penyelidikan jangka panjang, REFM perlu diubahsuai berdasarkan beberapa kriteria untuk meningkatkan keberkesanan, kecekapan kos dan fungsinya. Kajian yang telah dilakukan melibatkan kepelbagaian dalam penggunaan bahan sensor yang berkaitan dengan prestasi REFM adalah terhad. Tujuan penyelidikan ini adalah untuk menambahbaikkan REFM sebagai sensor AEF. Di samping itu, kajian ini juga mengenal pasti keupayaan REFM untuk mengesan impuls kilat dan menjejaki proses perkembangan dan pergerakan petir. REFM terdiri daripada litar pemprosesan isyarat (yang terdiri daripada unit amplifikasi, penapisan, penukaran dan unit pelaziman isyarat) bagi mewujudkan pautan kepada peralatan pemerolehan data untuk memapar, mengumpul dan menganalisis data. Penentukuran dan eksperimen impuls HV telah dijalankan untuk REFM ini. Selain itu, bahan yang digunakan untuk membina sensor REFM kebanyakannya diperbuat daripada aluminium atau keluli tahan karat. Oleh itu, siasatan ke atas bahan-bahan yang berbeza pada pemutar dan pemegun REFM telah dilakukan untuk mengkaji kepekaan dan kestabilannya terhadap persekitaran bervoltan tinggi. Di samping itu, bagi mengkaji ciri-ciri isyarat yang diperolehi dari awan ribut petir sebelum pelepasan kilat awan ke bumi, REFM telah dipasang di kawasan terbuka. Hasil kajian menunjukkan bahawa penentukuran sensor aluminium adalah lebih sesuai untuk pengukuran AEF berbanding sensor keluli tahan karat. Data yang diperolehi daripada lokasi mendedahkan ciri-ciri isyarat AEF di atmosfera dan juga ciri-ciri isyarat dari awan ribut petir sebelum pelepasan kilat awan ke bumi. Kajian ini memperkenalkan reka bentuk baru REFM yang menawarkan pengurangan sehingga satu pertiga daripada kos tetap REFM komersial.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
AEF	-	Atmospheric Electric Field
AI	-	Artificial intelligence
C	-	Capacitance
CCD	-	Charge-coupled device
CCN	-	Cloud condensation nuclei
CG	-	Cloud-Ground
DC	-	Direct Current
DIR	-	Direction
DSO	-	Digital signal oscilloscope
EF	-	Electric field
EFM	-	Electric Field Mill
EFS	-	Electrostatic field sensor
EMF	-	Electromagnetic field
FTP	-	File transfer protocol
GND	-	Ground
GPRS	-	General Packet Radio Service
GPS	-	Global System for Mobile
GSM	-	Global System Mobile Communication
GUI	-	Graphical user interface
HPS	-	High pass filter
HTML	-	HyperText Markup Language
HVDC	-	High Voltage Direct Current
I/O	-	Input/Output
IDE	-	Integrated Development Environment
IKL	-	Iso-keraunic-level

IMPACT	-	Improved Accuracy Using Combine Technology
LCD	-	Liquid Crystal Display
$LiNbO_3$	-	Lithium niobate
MDF	-	Magnetic Direction Finder
MIMO	-	Multiple-input multiple-output
NC	-	Not Connected
PC	-	Personal Computer
PCB	-	Printed Circuit Board
PDE	-	Partial differential equation
PDU	-	Protocol Data Unit
PHP	-	Hypertext pre-processor
PLDS	-	Pekan Lightning Detection System
PMT	-	Photomultiplier tubes
PVC	-	Polyvinyl Chloride
PWM	-	Pulse Width Modulation
QoS	-	Lower quality of service
R	-	Resistance
RC	-	Resistance-Capacitance
REFM	-	Rotating electric field mill
RMS	-	Root Mean Square
SAFIR	-	System de Surveillance et d'Alerte Foudre Par Interferometrie Radioelectrique
SD	-	Storage Device
SMS	-	Short message service
SOI	-	Silicon-on-insulator
TLE	-	Transient luminous events
TOA	-	Time of Arrival
USB	-	Universal Serial Bus
UTM	-	Universiti Teknologi Malaysia
VHF	-	Very high frequency
WLAN	-	Wireless Local Area Networking

LIST OF SYMBOLS

\$	-	US Dollar
%	-	Percent
°C	-	Degree Celcius
A	-	Area
A	-	Ampere
Ac	-	Altocumulus
As	-	Altrostratus
C	-	Coloumb
C_{AV}	-	External connected capacitor
Cb	-	Cumulonimbus
C_c	-	Capacitance of the coaxial cable
Cc	-	Cirrocumulus
C_g	-	Antenna capacitance with respect to the ground
Ci	-	Cirrus
Cs	-	Cirrostartus
Cu	-	Cumulus
D	-	Electric flux density
d	-	Height/Gap distance
d_{eff}	-	Effective height
E	-	Electric Field
E_n	-	Normal electric field
$\mathcal{E}_o$	-	Permittivity of free space
$\mathcal{E}_r$	-	Relative permittivity
f/s	-	Flash per second
GB	-	Giga byte
Gbps	-	Giga bit per second

I_{max}	-	Maximum Current
kA	-	kilo Ampere
kHz	-	kilo Hertz
km	-	kilo meter
km/h	-	kilometer per hour
kV	-	kilo volt
kWh	-	kilowatt hour
kΩ	-	kilo ohm
m	-	Meter
Mbps	-	Mega bit per second
MHz	-	Mega Hertz
ms	-	mili second
nm	-	nano meter
ns	-	nano second
Ns	-	Nimbostratus
P_i	-	Input Power
P_o	-	Output Power
q	-	Charges
Q	-	Quality factor
r	-	Correlation coefficient
R^2	-	Multiple correlation coefficients
R_f	-	Feedback resistor
R_i	-	Input resistor
RM	-	Ringgit Malaysia
rpm	-	Revolution per minute
S	-	Standard error regression analysis
S/m	-	Siemens per meter
Sc	-	Stratocumulus
St	-	Stratus
V	-	Volt
V/m	-	Volt per meter
V_{cc}	-	IC power-supply pin
V_g	-	Ground voltage

V_{in}	-	Input Voltage
V_m	-	Measured Voltage
V_o	-	Output Voltage
W	-	Watt
Λ	-	Wavelength
Ms	-	micro second
Φ	-	Phase shift
Ω	-	Ohm
$\Omega.m$	-	Ohm meter

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CHAPTER 1

INTRODUCTION

1.1 Background

Lightning is a natural phenomenon that causes damages, injuries, and fatalities every year. Lightning is a fascinating and spectacular event that expresses a big impact on human. The lightning may interfere or harm people and the surroundings at the struck area. In 1752, Benjamin Franklin conducted a lightning experiment as an attempt to evidence the scientific and the understanding of lightning phenomena. The idea of Benjamin Franklin has led many innovators to further conduct researches pertaining to the lightning field until present. Benjamin Franklin started his research on lightning by using a flying kite in order to prove that lightning is static electricity. He attached a flying kite with a silk string and tied an iron key at the other end. The key was tied with a thin metal wire and a Leyden jar (a container for storing an electrical charge), which was used to insert this wire. On the other hand, he held the kite with a dry silk ribbon which acted as an insulator to prevent him from being electrocuted. The results from the Franklin's experiment successfully indicated that lightning is static electricity [1].

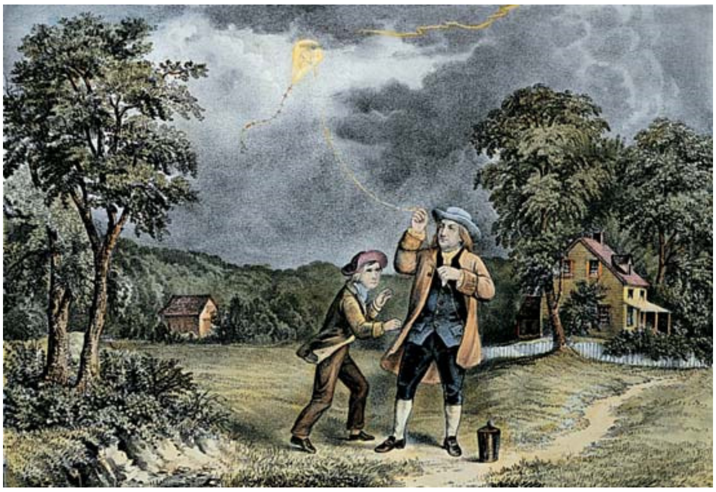

Figure 1.1 Benjamin Franklin's lightning experiment to prove the lightning phenomena [2]

The ordinary cloud changes to a thunderstorm when the accumulated electric charge in the clouds discharges to the cloud between them or to the ground. The electrode separation, such as cloud to cloud or cloud to ground, is very large as it can reach 10 km or more. During a thunderstorm, the charge is separated by positive and negative charges at the upper and the lower sides. The upper side of the clouds consists of heavy air currents with ice crystals, whereas the lower side of the clouds consists of rain. The height of the clouds influences the charge separation, which is usually in the range of 200 to 10,000 m, where the charge centre is usually at a distance of 300 to 2,000 m. In the cloud, the upper region is a positive charge, while the lower region is a negative charge, except on the local region. Local region is a positive charge located near the base and "the head", as shown in Figure 1.2. The charge inside the cloud can achieve 1 to 100 C and the energy of cloud discharge can reach up to 250 kWh. Besides, the charge cloud can acquire up to 300 kV/m of maximum gradient when it reaches the ground, whereas the gradient of fair weather is 100 V/m [3].

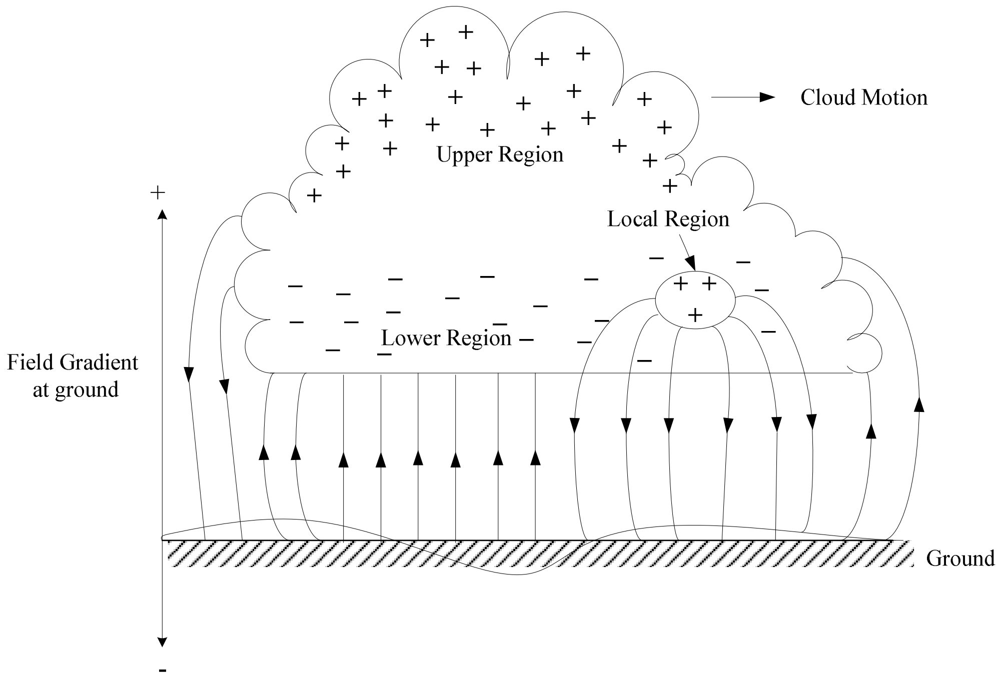

Figure 1.2 Charge distribution in a cloud corresponding to the field gradient near the ground [3]

The measurement of lightning current is wide in range; 5,000 A to 20,000 A. A lightning strike energy approximately has the same energy to turn on 150,000,000 light bulbs or a striking lightning can power a 100 W light bulb for three months [4]. According to Holle [5], the impact of lightning to the worldwide has caused 24,000 fatalities and 240,000 injuries each year. Table 1.1 reveals the statistics recorded in several countries.

Table 1.1 : Statistics of Fatalities and Injuries in several countries

Country	Year	Fatalities	Injuries	Other Cases
Kerala, India [6]	Each year	71	112	118
United States [7]	Each year	62	100	-
Sri Lanka [8]	Each year	50	-	-
Columbia [9]	Each year	100	1,000	-
Brazil [10]	2000-2009	-	-	1,321

Swaziland [11]	2000-2007	123	-	-
Uganda [12]	Jan 2000-Dec 2011	150	584	91
China [13]	1997-2009	5,033	4,670	61,614 damages 9,703 casualties
Northern Malawi [14]	Each year	84	419	-
Austria [15]	2001-2010	11	76	8,662 fire losses

Based on the statistics, lightning contributes to the fatalities and injuries each year. Hence, the high number of lightning accidents have encouraged researchers to invent new technologies to monitor and to alert the presence of lightning strikes in order to reduce fatalities and injuries.

1.2 Problem Statement

Lightning is a natural phenomenon hazard, which is a destructive force of nature. Malaysia is known to experience the highest lightning occurrences in the world compared to other bigger countries. In fact, accidents related to the frequent lightning occurrences are a major concern to the public and the utility companies. Besides, damages due to lightning can cause loss of billions of Ringgit Malaysia, which also affect industries, electricity, and aircraft.

Moreover, a lightning strike can give a big impact when it strikes victims or objects near/held by the victims that can cause injuries or death. When the lightning strikes a victim, it may affect all organ systems, especially the cardiovascular system. This effect is the primary cause of death due to lightning. Another human effect of the lightning strikes is the central and the peripheral nervous systems, such as transient confusion, paralysis, amnesia; dermatologic effect, which gives first and second degree of burns; ophthalmic and otologic effect, such as eye damage, cataracts, retinal bleeding; and musculoskeletal effect, such as confusions and fractures of muscle and ligament tears [16].

Hence, in order to prevent the dangerous effects of lightning, a lot of researches concerning lightning have been done. Besides, it is well known that the occurrence of lightning is unpredictable; thus it is difficult to identify the exact time and location event. The lightning monitoring system and the lightning detection system, such as electric field mill, electrostatic field sensor, and electro optic sensor, had been established to give precaution before lightning occurs. Meanwhile, lightning location systems, such as Magnetic Direction Finder (MDF), Time of Arrival (TOA), Improved Accuracy Using Combined Technology (IMPACT), System de Surveillance et d'Alerte Foudre Par Interferometric Radioelectrique (SAFIR), and interferometry, are the techniques used to locate the real-time and the real-location of a lightning strike.

Rotating electric field mill (REFM) is equipment used to monitor the occurrence of lightning. However, there has been limited enlightened in terms of sensor materials and circuitry of REFM. Therefore, the purpose of this research was to improve REFM as an atmospheric electric field (AEF) sensor. There was also limited study regarding the different application at sensor material related to the performance of REFM. The different materials may influences the performance of the sensor. Furthermore, there was vague information whether the REFM could detect lightning occurrence. In Malaysia, the investigation of the characteristics of the atmospheric electric field activities prior to CG lightning discharge has not been performed. Most of the commercials or established REFM(s) have fixed specification features and very costly. The cost of the commercial REFM is expensive because it is included the profit, transportation cost, and tax since the products is made in overseas. If the REFM is made for research purpose, the cost can be reduced and the lack of efficiency of REFM from previous research can be overcomed especially in terms of materials and its applications. Therefore, as for long-term research, the REFM should be modified in several criteria in order to improve its effectiveness, cost efficiency, and functionality.

1.3 Research Objectives

The objectives of this research work were:

i. To improve weakness possessed by current an REFM sensor.
ii. To investigate the different sensor materials in REFM.
iii. To investigate the ability of new REFM to capture lightning impulse.
iv. To install and verify the effectiveness of new REFM and to observe the AEF changes in UTM Johor Bahru campus.
v. To investigate the characteristics of the signal from a thunderstorm cloud prior to CG lightning discharges.

1.4 Scope of the Research

This research that had been conducted in Universiti Teknologi Malaysia, Johor Bahru focused on:

i. The new REFM sensor which consist of rotor, stator, motor controller system, signal processing circuit and 12 V power supply is improved and developed for measuring atmospheric electric field.
ii. The power consumption of REFM is measured using Kyoritsu Kew Power Quality Analyzer.
iii. Two different materials which are aluminium and stainless steel are tested on REFM stator and rotor using calibration procedure.
iv. The REFM is calibrated using HVDC to identify the correlation factor between the actual electric field strength and the output voltage. Then, the REFM is installed at the open area.
v. The REFM is tested using HV Impulse to detect the lightning impulse.

1.5 Significance of Research

This research provides advantages to the government, research, industrial, residential, and society as REFM offers an accurate measurement of the electric field, which provides information that helps to assess the probability of lightning strikes in the measurement area. The REFM data are of importance and are valuable assets when making safety decision regarding the threat of lightning. Therefore, the suitable way to provide advanced warning of lightning condition is by monitoring and interpreting the local electric field in order to identify if the condition is safe or dangerous.

Furthermore, some important applications that can be applied are military ordinance facilities; near aircraft refuelling for airport safety; near demolition and blasting operations; at aerospace and missile facilities; location of hazardous fuels or materials; at construction sites; at recreational and amusement facilities; near oil storage and refineries; and atmospheric research and weather forecasting.

1.6 Research Contribution

i. This thesis provides a summary of lightning monitoring systems that include information pertaining to the available electric field sensor, lightning sensor, methods of data observation, data analysis, data transmission, and data storage, which had been collected from a variety of works in the literature.

ii. Development of a new design of REFM for AEF monitoring system.

iii. A verification of sensor material that influences the sensitivity and the stability of REFM.

iv. A verification of the ability of REFM to capture lightning impulse.

v. The REFM has one-third cost reduction compared to the commercial REFM.

vi. A verification of the electric field changes relates to the relative humidity changes.

1.7 Outline of Thesis

CHAPTER 1: Introduction

This chapter briefly explains the introduction of the research, including background, problem statement, research objectives, scope of the research, significance of the research, research contribution, and thesis outline.

CHAPTER 2: Theory and Literature review

This chapter elaborates the atmospheric electrification, formation of thunderstorms, lightning discharge, lightning in Malaysia, and reviews of related works. The reviews of lightning monitoring system, AEF and lightning sensor, as well as methods of transmission, storage, observation, and analysis data were collected from a variety of works in the literature.

CHAPTER 3: Research Methodology

This chapter explains the flow chart of research methodology, the development of REFM, the REFM power consumption measurement, the REFM calibration, the REFM sensor testing, the lightning impulse experiment, and the location of installation, which includes the experimental setup on-site and the REFM mounting technique.

CHAPTER 4: Results and Discussion

This chapter reveals and discusses the results of REFM with and without signal processing circuit, power measurement, calibration in stainless steel and aluminium sensors, the interaction of REFM sensors (Aluminium and Stainless Steel sensors) and calibration device, and lightning impulse tests, as well as results retrieved during installation on-site and estimation cost of REFM. The analysis and discussion on every sub-section is also included in this chapter.

CHAPTER 5: Conclusion

This chapter concludes the overall research and provides recommendation for future research.

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