STUDIES ON PERFORMANCE OF STANDARD AND NON-STANDARD CONFIGURATIONS OF FRANKLIN AIR TERMINALS

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To

The LORD Jesus, whose grace and mercy is unfailing.

My late mother, who loved me as who I am.

My father, who taught me discipline.

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## ABSTRACT

Buildings installed with 200-year-old Franklin rods were reportedly damaged when struck by lightning. When intercepted by lightning, air terminals may also be damaged or physically changed in its tip configurations. In such cases, it is crucial to determine whether the damaged lightning air terminal can still perform as an effective lightning protection system. This research aims to investigate the performance of different tip configuration of air terminals after being struck by lightning. Six different rod tip configurations-sharp, blunt, standard, concave, flat and conical shape rod tip were tested in the laboratory. Two stages of tests were carried out. The first stage of tests was carried out under the application of impulse voltages only and without the pre-ionization condition to simulate the approach of a downward leader. The second stage involved the application of DC and UV radiations to ionize the tip prior to applying impulse voltages. In both conditions, two sets of individual tests and competitive tests were carried out for all air terminals. The individual test is for obtaining the breakdown voltage and the time-to-breakdown. The number of strikes per air terminal were recorded when pairs of air terminals were subjected to competitive tests. During competitive tests in pre-ionization condition, corona was observed at the tips. The flat and concave rods were found to have high formation of corona which results in higher breakdown voltage. The result also shows that the blunt rod is the best performance rod over the others, having the most consistent breakdown voltage and time-to-breakdown in both non-ionized and pre-ionized tips. It is learnt that pre-ionization condition should be adopted when testing air terminals in laboratory to obtain more reliable results as it is able to simulate the condition almost similar to the real lightning condition.

# ABSTRAK

Bangunan yang dipasang Franklin rod yang mempunyai sejarah 200 tahun dilaporkan mengalami kerosakan selepas dipanah kilat. Apabila rod pelindung kilat menyambut kilat, rod berkenaan mungkin mengalami kerosakan dan berubah dari segi rupa bentuk. Maka, adalah mustahak untuk menentukan jika rod tersebut masih dapat berfungsi sebagai sistem perlindungan kilat yang efektif. Penyelidikan ini adalah untuk menyiasat prestasi rod pelindung kilat yang mempunyai konfigurasi bucu yang berbeza selepas dipanah kilat. Enam konfigurasi berbeza iaitu tajam, bulat, piawai, pelbagai bucu, rata dan kon diuji di makmal voltan tinggi. Ujian peringkat pertama dijalankan dengan menggunakan hanya voltan impuls tanpa ionisasi untuk mengimitasi keadaan apabila kilat semakin hampir. Ujian peringkat kedua menggunakan aplikasi voltan DC dan radiasi UV untuk mengionisasi bucu rod pelindung kilat sebelum voltan impuls diaplikasikan. Untuk kedua peringkat tersebut, dua set ujian individu dan ujian persaingan dilaksanakan untuk semua rod. Ujian individu adalah untuk memperoleh voltan pecahtebat dan masa untuk pecahtebat. Ujian persaingan adalah untuk merekod jumlah panahan yang disambar oleh setiap rod dengan mengubah posisi setiap pasangan rod. Semasa ujian persaingan dalam keadaan pre-ionisasi, aktiviti korona diperhatikan di sekitar bucu rod. Rod rata dan rod pelbagai bucu mengalami paling banyak aktiviti korona mengakibatkan voltan pecahtebat yang lebih tinggi. Keputusan juga menunjukkan bahawa rod bulat mempunyai prestasi yang terbaik di antara semua rod dengan voltan pecahtebat dan masa untuk pecahtebat yang konsisten untuk kedua-dua keadaan ujian. Adalah difahamkan bahawa keadaan pre-ionisasi patut diaplikasikan semasa menguji rod di makmal untuk memperoleh keputusan yang lebih kukuh kerana dapat mengimitasi keadaan kejadian kilat yang sebenar. Kesimpulannya, ujian makmal ini telah membuktikan bahawa prestasi rod pelindung kilat sememangnya dipengaruhi oleh geometri bucunya dari segi ciri-ciri pecahtebat dan formasi korona.

# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# LIST OF SYMBOLS

| | | |
|---|---|---|
| CG | - | cloud-to-ground lightning |
| CTS | - | Charge Transfer System |
| DAS | - | Dissipation Array System |
| DIA. | - | diameter |
| DIAS | - | Digital Impulse Analyzing System |
| ESE | - | Early Streamer Emission |
| kV/m | - | electric field strength on ground |
| LAT | - | Lightning air terminal |
| LPS | - | Lightning protection system |
| mb | - | milibar (pressure) |
| MMS | - | Malaysian Meteorological Service |
| MV/m | - | electric field strength at extremities |
| n | - | total impulse application |
| $n_b$ | - | total number of breakdowns |
| $n_w$ | - | total number of withstands |
| pH | - | measurement of acidity |
| U.V | - | ultra-violet |
| $V_{50}$ | - | 50% flashover voltage |
| $V_{actualbreakdown}$ | - | actual voltage breakdown |
| $V_{DIAS}$ | - | voltage recorded in DIAS |
| Vj | - | starting voltage of Up and Down Method |
| $\Delta L$ | - | length of triggered discharge from ESE |
| $L+\Delta L$ | - | protected zone of ESE |
| $\Delta t / \Delta T$ | - | time difference (also known as time advantage) of ESE |
| $v$ | - | speed of upward connecting leader of ESE ($10^6\, ms^{-1}$) |
| $\sigma_{pu}$ | - | per unit standard deviation |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of study

Malaysia is located near the equator line ($1^0 - 7^0$ N) latitude and ($100^0 - 119^0$ E) longitude. It has high isokeraunic level of approximately 200 thunderstorm days a year. The lightning ground flash density is about 15 to 20 strikes per $km^2$ per year. This implies high lightning flash to ground, i.e., approximately there are 15 to 20 lightning strikes to each square km of land in a year [1].

For the last 10 years, Malaysia has experienced more lightning activities than before, from 200 thunderstorm days a year to about 300 thunderstorm days a year. The number of average annual lightning flashes per square km in Malaysia now is about 25 compared to 15-20 ten years ago.

Due to the increasing lightning activities in Malaysia, more building structures are struck and damaged by lightning leaders particularly high-rise buildings in highly industrialized areas like Klang Valley and Johor (refer to Appendix A for some pictures of damaged structures caused by lightning).

Not only are lightning activities a threat to buildings, acid rain is another environmental issue in this rapid developing country. A Malaysian Meteorological Service (MMS) study shows that Malaysia is beginning to experience effects of acid rain similar to those in such industrialized countries as the United Kingdom, Japan and the United States [2]. Acid rain is caused when coal or oil is burned, which in turn generate vast amounts of polluting gases. Airborne by-products of certain industrial processes add to the pollution. Acid rain is corrosive of metals such as iron and zinc roof, marble and limestone. Low pH values have been attributed to increased industrial activity and large numbers of motor vehicles emitting considerable amounts of sulphur and nitrogen compounds into the atmosphere, causing the increase in rainwater acidity. Rainwater of pH less than 5.6 is considered acidic.

Rain acidity in Peninsular Malaysia is on the rise and the number of areas affected by acid rain is growing. Areas most seriously affected by acid rain are Kuala Lumpur, Johor, Kedah and Selangor, while rain acidity in Petaling Jaya and Senai has gone up four times from 1985 to 1988. The average pH of rainwater in the Klang Valley Region and South Johor in 2003 is below 4.4, indicating that it’s very acidic [3]. Rainfall acidity is shown in Figure 1.1.

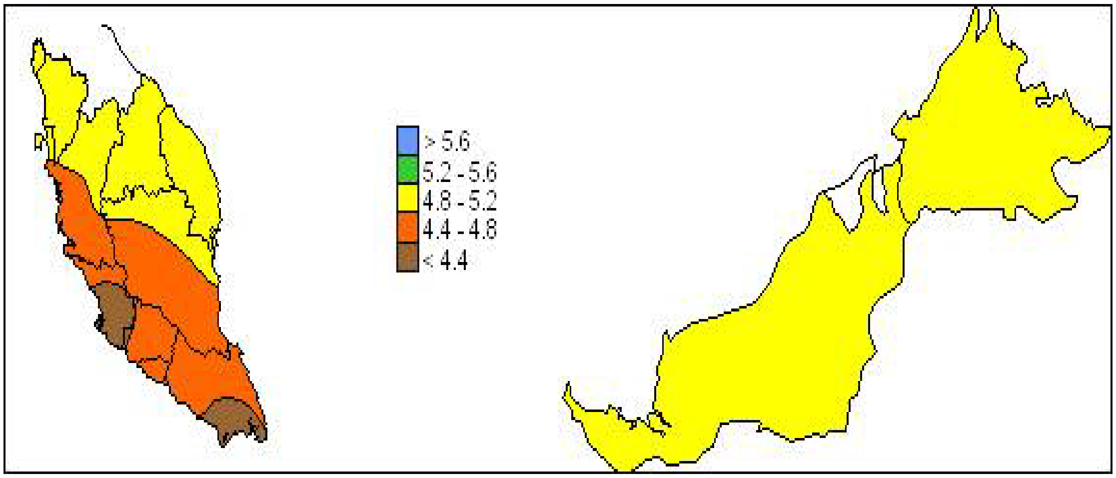


**Figure 1.1** Rainfall acidity in Malaysia for the year 2003

Buildings installed with conventional lightning protection system (LPS) using 200-year-old technology Franklin rod, are exposed to the effect of these acid rains. Not all of the conventional LPS installed can withstand against the corrosive effect of acid rains. This is because some of the materials used for the installation of LPS are non-resistant to corrosion which is brought about by the electrochemical reaction on galvanized steel rods (coated with very thin copper material).

Judging on the lightning air terminal (LAT) physical arrangement placed on top of building structures, inundation of acid rains is likely to occur at the base and tip of Franklin rod. This phenomenon encourages the metallic corrosion of the rod itself. By coincidence when this concerned LAT is struck by a powerful lightning leader, the rod which intercepts the leader can be forced out of its base, sometimes broken into two parts and changed in its physical configuration (refer to Appendix A for pictures of damaged lightning air terminals).

Thus, in this research, a few non-standard configuration LAT were designed due to the possible damage that may change the tip configuration of a standard rod when struck by lightning. The question to be asked here is whether the damaged LAT can still perform as a LPS or otherwise, assuming replacement of LPS is not done on time which allows sufficient time for subsequent lightning strike to happen on the same point of the concerned building. Therefore, it is crucial to determine the performance of the damaged LAT which consist of different shapes.

Many researches have been carried out to discover better improved methods for lightning protection. One such research is by C.B. Moore. He carried out an assessment on Benjamin Franklin's lightning rods and found that Franklin's ideas about the functioning of his sharp-tipped rods neither prevent lightning nor are they the preferred strike receptors when conductors with less curvature in their tips are nearby [4]. Nevertheless, Franklin rod can continue to provide protection against lightning as long as they have no nearby competitors for strike reception.

A few other researches by C.B. Moore [5]- [7] also found that the blunt-tipped lightning rods are better strike receptors than the conventional sharp-tipped ones. In these papers, he carried out field tests in real lightning condition on top of a mountain to examine the competition between sharp and blunt rods. He also carried out laboratory demonstrations with the Van de Graff generator to study the discharges from exposed electrodes by investigating the current emission [8]. The experimental field results and the laboratory demonstrations with the Van de Graff generator are consistent with the preceding analysis; they all indicate that blunt rods are better candidates for strike reception than the sharp ones.

This research is an extension based on C.B. Moore's research but with a different approach and parameters of study. In this research, the rods tested were not limited to sharp and blunt only but it also included other tip configurations like the concave, flat and conical type. The performance of the air terminals were examined through laboratory studies based on the breakdown characteristics, i.e. breakdown voltage and time to breakdown instead of current emission as done by C.B. Moore. Whilst C.B. Moore carried out competitive test in real lightning condition to examine which rod is a better receptor, competitive tests were also carried out in this research but in the laboratory to determine the probability of strikes to air terminals.

For his laboratory tests, C.B. Moore used the Van de Graff generator in reference [8] to create strong electric fields to study the responses of various electrodes to strong electric fields. However, due to the unavailability of Van de Graaf generator in Institute of High Voltage and High Current (IVAT), the Marx generator, U.V radiation and D.C ionization method were used in replacement of the Van de Graff generator to observe and study the discharges from the rods (U.V and D.C ionization method will be explained in Chapter 3. Please refer to Appendix B for explanation on the operations of Van de Graff and Marx generator). Therefore, this research attempts to discover the possible alternatives to improve the conventional Franklin rod by investigating the breakdown performance of different tip configuration of air terminals, considering the damage caused on rods after being struck by lightning.

## 1.2 Objective

The objectives of research are:

1) To review and discuss the published studies on performance of conventional lightning air terminals based upon C.B. Moore's past researches and tests on the performance of blunt and sharp rods. The

results obtained in this research is to be compared with C.B. Moore's research results.

2) To obtain a good understanding of the types of testing methods and approaches used in laboratory and real lightning condition to test lightning air terminals.

3) To design, construct and improve the tip configurations of Franklin lightning air terminal for laboratory test.

4) To test different design configurations of Franklin air terminals in laboratory.

5) To study the performance and behaviour of different design configurations of Franklin air terminals through the voltage breakdown, number of strikes and time-to-breakdown under high impulse voltage and high DC tests, with and without ionization activity around the tip of the rod.

6) To study the corona formation around the tip of the air terminals that would affect the breakdown phenomenon.

7) To contribute to a better understanding of the effects of different lightning air terminals tip configurations by providing a substantial/logical explanation to the ionisation and breakdown phenomenon.

## 1.3 Contributions of the Thesis

This research has contributed the followings:

1) An extensive review of published literature on the performance of lightning rods was achieved.

2) A series of lightning rod configurations were creatively designed. Previous researches have focused on Early Streamer Emission (ESE) devices and on limited designs of lightning rod, e.g. sharp, blunt, multi-pointed. For this research however, new designs such as the concave, flat and conical tip configurations were modified from the existing conventional Franklin rod.

3) Different configurations are considered to affect breakdown performance through different discharge mechanisms. The performance of different configurations of lightning rod was determined through experimental methods in laboratory. Past researchers have been using the method of DC superimposed on impulse to test lightning rods in laboratory [9]. In this research though, a different approach was used to test the lightning rod by using DC and impulse separately yet obtaining almost similar results with previous researches.

4) Previous researches carried out in laboratory by C.B. Moore investigated the performance of lightning air terminals through observations of current measurements but this research focused on laboratory measurements of voltage breakdown and time-to-breakdown. Good agreement was obtained between the voltage breakdown experimental results in this research with the current measurement results in C.B. Moore's research.

5) This work has contributed to the frontier of lightning protection studies by comparing the performance of various air terminal tip configurations with and without ionization. A comparison between the two conditions revealed significant differences in the breakdown characteristics, number of strikes and corona formation. Results from condition with ionization in laboratory shows that laboratory condition could also be used to represent condition almost similar to real lightning.

## 1.4 Organization of work

The main purpose of Chapter 2 is to look into the history of Franklin rod and the improvement on lightning rods throughout the decade, with the existence of blunt rod and early streamer emission (ESE). The review provides a better insight into the different designs and configurations of lightning rods that have been used in past researches. This chapter also reviews on the lightning attachment process.

Chapter 3 is the research methodology chapter. It describes in detail the design of air terminals, the experimental setup, the methods of testing and the equipment used in the course of this research. Results obtained in this research are being discussed in Chapter 4. Theories described in Chapter 2 are put into practice to discuss the performance of the designated air terminals. Chapter 5 which is the final chapter, is to conclude on the whole research and to give suggestions for further improvements on the results in future research.

deeper understanding on various mechanisms of blunt rod that has yet to be discovered, i.e. the striking distance and the protection zone of the blunt rod. In the future, the different tip configuration of air terminals used in this laboratory test could also be installed on real buildings in real lightning condition for field tests to reconfirm the results obtained in laboratory condition. If the results are non-contradicting, then the blunt rod could be commercialized to replace the Franklin rod in the market.

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