A STUDY ON THE EARLY STREAMER EMISSION (ESE) LIGHTNING PROTECTION SYSTEM

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To my beloved father, mother and brothers

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ABSTRACT

Early Streamer Emission (ESE) Lightning Protection (LP) system is a relatively new approach in solving the perennial problem of lightning damage, which has been associated with the use of Franklin Rod (FR). Based on theoretical consideration and some previous work by several researchers, the ESE is believed to be providing more effective protection against lightning than would a FR system. However, the scientific and technical basis to support the belief of this improved system is still not concrete enough and this then inevitably leads to the efficacy of these technologies still remain opened for further study and improvement. The new system is equipped with a special device that is used to extend the effective range of protection over that of the FR. In this work, results have been obtained from the simulated testing carried out in the laboratory and also from field monitoring of real FR and ESE system installed in the university campus. Visits to several sites, which employ these systems, have enabled physical observation of the after effects of lightning be recorded for analyses. The results show that slightly rounded air terminal, which is typical of ESE system offer better interception ability than that of sharp terminals, which is the typical FR design. It is also shown that ionizing the air around the tip of the terminals can enhance its effectiveness. This conclusion is substantiated by field observation obtained from the installed systems where the ESE system has been found to intercept more lightning strikes than that by the FR.

ABSTRAK

Sistem penangkap kilat *Early Streamer Emission (ESE)* adalah merupakan teknik agak baru yang digunakan dalam menyelesaikan masalah kerosakan akibat sambaran kilat yang berlaku dalam penggunaan sistem penangkap kilat *Franklin Rod (FR)*. Berdasarkan kepada kajian teoritikal dan juga hasil kerja beberapa penylidik adalah dipercayai bahawa *ESE* berkemampuan memberi perlindungan kilat yang lebih efektif daripada *FR*. Sistem ESE ini dilengkapi dengan satu peranti khusus yang berfungsi untuk melebarkan jangkauan berkesan perlindungan berbanding dengan yang diberikan oleh sistem FR. Dalam kajian ini, keputusan telah diperolehi daripada kerja-kerja simulasi di makmal dan daripada pemantauan luar terhadap sistem ESE dan FR yang dipasang pada bangunan dalam kampus. Lawatan ke beberapa tempat dan bangunan di luar kampus yang menggunakan sistem-sistem perlindungan kilat ini membolehkan cerapan fizikal kesan daripada masalah sembaran kilat direkod untuk analisis. Daripada kajian-kajian ini, didapati bahawa pangkal atau bahagian hujung penagkap kilat yang lebih berbentuk bulat (iaitu bentuk yang digunakan dalam ESE) memberikan kemampuan memintas sambaran kilat yang lebih baik berbanding dengan pangkal yang tajam. Juga didapati bahawa kesan proses pengionan di sekitar pangkal penangkap kilat boleh meningkatkan lagi keberkesanan system perlindungan kilat itu. Kesimpulan ini disokong oleh dapatan daripada pemantuan luar yang mana menunjukkan bahawa system perlindungan ESE memintas lebih banyak sambaran kilat daripada system FR di tempat kajian.

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LIST OF ABBREVIATION

AC	-	Alternating current
Ave	-	Average
BSI	-	British Standard Institute
CA	-	Cloud-to-Air
CC	-	Cloud to cloud
CEC	-	Corona emission current
CG	-	Cloud-to-Ground
CLR	-	Conventional lightning rod
CPG	-	Continuous Pulsing generator
CTS	-	Charge transfer system
DAS	-	Dissipation array system
DC	-	Direct Current
DIAS 733	-	Digital Impulse Analyzing System
DMI 555	-	Digital Measuring Instrument
e.g	-	For example
ESE	-	Early streamer emission
etc	-	Etcetera
Fig	-	Figure
FR	-	Franklin rod
HV	-	High voltage
IC	-	Intra cloud discharge
IEC	-	International Electrotechnical Commission
IREQ	-	Institute de Recherche d'Hydro-Quebec
KERI	-	Korea Electrotechnology Research Institute
KMJ	-	Johor Matriculation College
LCD	-	Liquid Crystal Display
LED	-	Light-emitting Diode

LFC	-	Lightning flash counter
LP	-	Lightning protection
LV	-	Low voltage
M&E	-	Maintenance and Engineering
MOV	-	Metal oxide variastor
NCF	-	National Fire Code
NCLR	-	Non-conventional lightning rod
NFPA	-	National Fire Protection Association
No.	-	Number
NPL	-	National Lightning Protection Corporation
OT 270	-	Operating terminal
TV	-	Television
USA	-	United State America
UTM	-	Universiti Teknologi Malaysia
WCC	-	Wireless Communication Center

LIST OF SYMBOL

%	-	Percentage
/	-	Per
<	-	Less than
=	-	Equal
>	-	Greater than
≥	-	Greater or equal to
°	-	Degree
°K	-	Kelvin
A	-	Ampere
A’	-	Area
C	-	Coulomb
cm	-	Centimeters
D	-	Distance
D’	-	Charge density
ds	-	Normal striking distance
E	-	Electric field
E_{FC}	-	Field that needed to start a corona discharge (streamer) at the surface of a lightning rod
E_i	-	The leader onset field
E_{ion}	-	The ionization electric field
E_L	-	The leader propagation field
E_s	-	Corona onset field
f	-	Discharge frequency
h	-	Height of the terminal tip above the element(s) to be protected
Hz	-	Hertz
I	-	One

II	-	Two
III	-	Three
k	-	Kilo
k, K_1, K_2, K_3, *n*, *b*	-	Constants
M	-	Mega
m	-	Meters
m/s	-	Meters per second
mins	-	Minutes
mm	-	Millimeters
ms	-	Millisecond
nd	-	Second
N_g	-	Frequency of earth flash
Q	-	Charge
R	-	Ground resistance
r	-	Radius
R’	-	Tip radius of curvature for a conductor rod
Rp	-	Radius of protection in a horizontal plane located at a vertical distance h from the tip of the non-conventional lightning rod
t	-	Duration of energization time
$T_{b/d}$	-	Time-delay-to-breakdown
V	-	Volts
$V_{b/d}$	-	Breakdown voltage
α	-	Ionization coefficient
β	-	Field intensification factor
ΔL	-	The distance advantage or gain in lead distance
ΔT	-	Initiation advance or gain in spark over time of the upward leader measured in laboratory conditions
ε	-	Permittivity
η	-	Attachment coefficient
θ	-	Angle
μs	-	Microsecond

ν	-	Average speed of the downward tracer
ν^{-}	-	Propagation speed of the downward leader
ν^{+}	-	Propagation speed of the upward streamer
Ω	-	Ohm

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Overview on the Principle of Early Streamer Initiation Mechanism

ESE LP system is a relatively new approach in solving the perennial problem of lightning damage installation, which has been equipped with FR system. The new system is believed to be providing more effective protection against lightning than would a FR. However, the scientific and technical basic for this improved system has yet to be justified by field result. This therefore inevitably lead to the situation, which the efficacy of these technologies still remains, opened to questions.

And thus, the effectiveness of these systems has been hotly debated since early 1980, where the ESE air terminals are claimed to be able to initiate the connecting upward streamer earlier in time than would a simple air terminal in the same position, and are therefore claimed to be able to attract the lightning discharge from a larger distance than would a simple air terminal [1]. Therefore, theoretically ESE LP system supposedly requires fewer air terminals and can be placed at a farther distance apart than the traditional FR, yet still providing superior performance.

Since there have plausible theories supporting ESE technology, the number of users of this system is continuously increasing. But a better understanding is needed in order to make meaningful quantitative comparisons between both systems. It is needed to do so as LP system has played a very important role in giving protection to users to prevent any damages either loss of lives or properties.

When the lightning approaches the ground, a luminous ascending brush discharge is initiated at the lightning conductor. In the case of the conventional lightning rod or so-called FR, this ascending brush discharge propagates in the direction of the descending leader after a long transition phase. The ESE type of Non-Conventional Lightning Rod (NCLR) will act to reduce the required time for the formation and continuous propagating of the ascending discharge and enabling a higher efficiency for the lightning capture than a FR terminal. This is as illustrated in Figure 1.1.

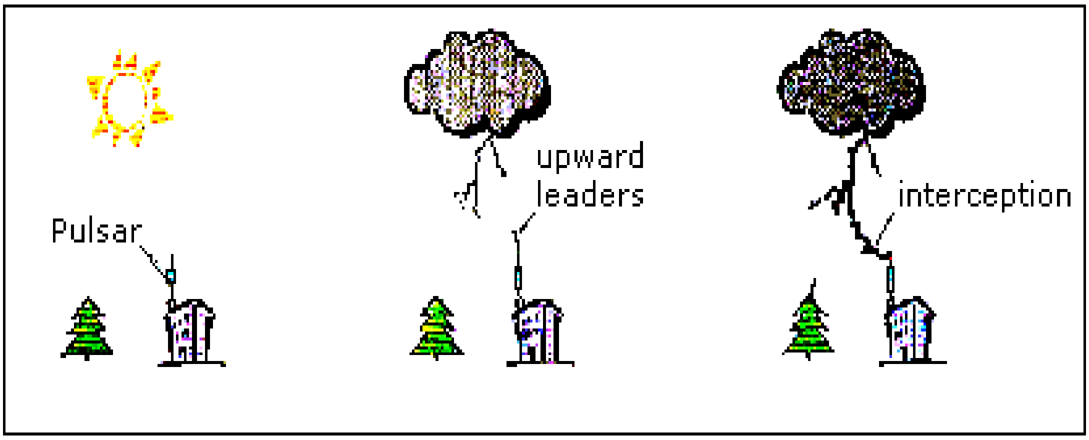

Figure 1.1 The advantage of initiation advance of the ESE as claimed by its manufacturer. The unique efficiency of the Pulsar lightning conductor is based on a specific initiation advance, well before the natural formation of an upward leader [2].

Nowadays, the usage of the ESE LP system is very wide especially in Asia. Several types of ESE devices have been introduced in the market to date where each type is claimed to have different protection radius as stated by the manufacturers. The earliest and most frequently used of ESE device is the radioactive non-conventional air terminal [3]. But most countries have banned it, as it is believed that its radioactive source positioned near the top of the terminal is harmful to the health. The most common use of non-radioactive ESE devices in Malaysia is the Pulsar (developed by Hélita, France) and Dynasphere (developed by Erico, Australia).

The radius of protection, Rp of an ESE device as shown in Figure 1.2 is given by French standard NF C 17-102 (July 1995) [2, 4]. It depends on the initiation advance, ΔT of the ESE device.

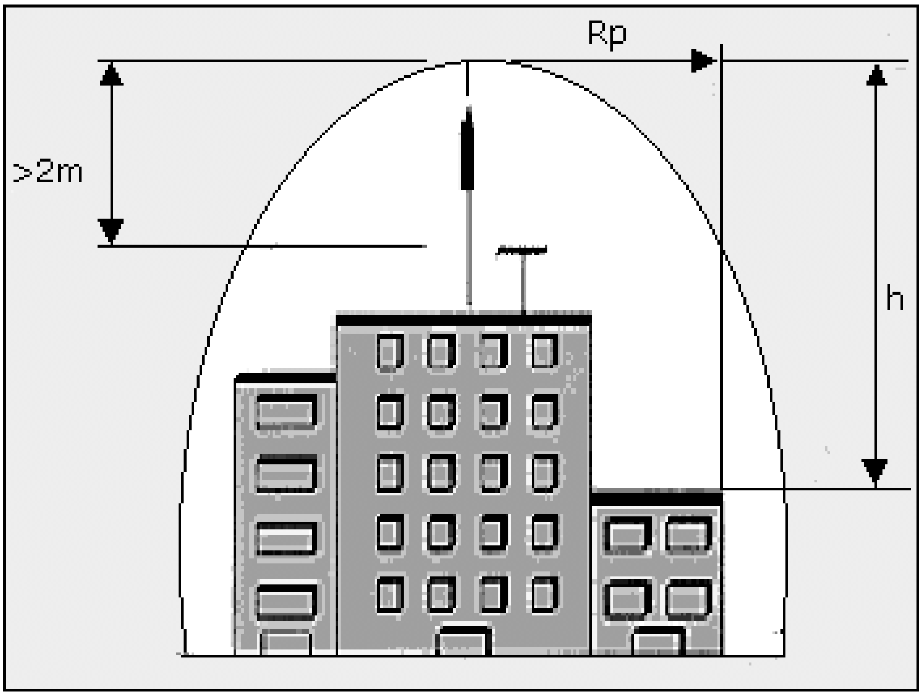

Figure 1.2 : Protected area of the ESE system [2].

From [2, 4], the radius of protection, Rp is given by

$$Rp = \sqrt{h(2D - h) + \Delta L(2D + \Delta L)} \;; \quad (\text{For h} \geq 5\text{m}) \qquad (1)$$

where

Rp	:	Radius of protection in a horizontal plane located at a vertical distance h from the tip of the ESE type of NCLR.
h	:	Height of the terminal tip above the element(s) to be protected
D	:	20m for level of protection I
		45m for level of protection II
		60m for level of protection III
ΔL (m)	:	the distance advantage or gain in lead distance.

The distance advantage, ΔL is given by

$$\Delta L = \nu \Delta T \tag{2}$$

where

ν (m/µs): average speed of the downward tracer ($2\text{x}10^4$ m/s).

ΔT (µs) : initiation advance or gain in spark over time of the upward leader measured in laboratory conditions

$$\Delta T = T_{FR} - T_{ESE} \tag{3}$$

For terminal height lower than 5m, the respective values of Rp can be obtained from the table provided by the French Standard NF C.

So the excellent performance in LP comes from the ability to cause earlier initiation of the upward continuous streamer than a FR under the same condition of lightning stroke. It can be seen from the equation (2) that radically ΔT decides the capability and effectiveness of the NCLR, so it is the parameter where most parties are interested in. To have better understanding on the function of the ESE LP system, the operating principle of two types non-conventional devices are chosen to be discussed in the next chapter.

1.2 Review of Previous Works

According to Zipse [5], the ESE enhanced ionizing (non-conventional) air terminal can be considered to be consisted of a FR with a radioactive radium and or thorium source for the generation of ions and connected to a special down conductor attached to an earthing system. The use of the radioactive type of ESE air terminal has been banned by most of the countries in the world, as it is believed that the spreading of radioactive sources over the building and cities can be harmful to human. Therefore, the performance of this kind of air terminal will not be investigated in this work.

But, radioactive sources which were used in comparative performances between the ionizing and non-ionizing air terminals in the laboratory is acceptable as it is one of the alternatives that has been used to obtain ionization of the air surrounding the tip of the air terminals.

All researches and the outcomes of past works that have been done by other researchers elsewhere are as follows. Some of these outcomes indicate that the significant superiority of the ESE LP system. However, there are some outcomes that do not show any advantages as compared to the FR system.

1.2.1 Outcomes that Indicate the Relative Superiority of the ESE Lightning Protection System

(i) Several outdoor tests have been carried out in the USA and Australia. According to Zipse [5] the performance of the ionized air terminals are more effective in attractive lightning strike than the non-ionized FR. Such field-testing are continuously been carried out as the field tests are more indicative of the actual condition than the controlled short distance between the terminals and the overhead mesh used for the laboratory testing.

Based on the result obtained from these field studies, there has been a work made by NFPA to adapt the performance of non-conventional LP as a reference when determining LP for any installation. The reference procedure has been developed into standard No 781 entitled “LP System Using ESE Air Terminal.”

(ii) Allen et al in [6] carried out a study on the performances passive FR (grounded rod) and active FR (subsidiary 1/50μs under simulated lightning storm conditions. They found that the active FR reduces the time to spark over by between 40µs and 70µs, compared with that for the passive FR.

(iii) Allen et al in [7] have adopted a methodical approach for examining, under laboratory conditions, the discharge emanating from an air terminal can be influenced by voltage application to the tip of the air terminal; since such voltage application is one technique employed by ESE air terminals to expedite upward leader inception relative to a FR. They observed that a reduction of 10µs for energized lightning rod was achieved in the authors' experiments when compared to the case for the rod where no lightning impulse was applied. According to the authors, result obtained in this work is only the preliminary observations. More experiments need to be carried out before any conclusive results can be made.

(iv) Heary et al in [8] and [9] compared the performance of the ionizing and non-ionizing air terminals under outdoor test condition. The test condition was prepared so as to resemble the natural operating condition of the LP when used. Radioactive sources were used to ionize the air surrounding the tip of the air terminal. Tests were made during both rain or frog and fine weather with the natural bias produced by the clouds above the testing is also under artificial bias.

Both air terminals had exactly same geometrical configuration in each test conducted. The standard or non-radioactive air terminals chosen was the FR. The objective of this experimental study was to study the influence of ionization at the tip of the air terminals on the probability of flashover with a specific focus upon comparison of the ionizing air terminal to an identical air terminal without a radioactive source, under realistic condition.

Results obtained indicate a substantial superiority of the ionizing air terminal when tested under realistic conditions. These results are in agreement with those obtained in the field installation of various air terminals obtained by Allen et al [9], where in a study period of 4 months, only the ionizing terminals has been struck by natural lightning with total number of 4. These authors also discovered that sharp air terminal is more effective in attracting flashover than blunt lightning rod. This observation is however in contrast to the experimental result obtained by Moore et al [10, 11, 12] in their finding over past 7 years, where more blunted rod has been founded to be a better lightning receptor.

(v) The study by British Standard Institute (BSI) [13] on the triggering advance of the ESE lightning conductor from one manufacturer gives a figure of 54μs compared with the simple rod lightning conductor (Refer to Appendix D). BSI has witnessed testing of this item and the result of the test is as shown in the Report of Test Witnessing. The full details of BSI's finding are given in the Report No 227/005069 dated 2nd November 1999.

(vi) Allen et al [14] investigated the performance of simulated ESE, which is one of the non-conventional terminal developed and widely used. A positive auxiliary voltage impulse, of profile 1/30μs of sufficient amplitude to produce corona has been applied independently at the rod at controlled, variable times during the rise of the slow-front field. The effects of this pulse on the corona produced at the rod by the negative impulse at the plane, on the breakdown voltage of the gap, and on the times to breakdown have been recorded. Assessment of the impulse corona behavior shows that the auxiliary pulse had little measurable effect unless it aided the immediate formation of a leader, or unless the slow-front impulse field had already formed a leader.

(vii) Grzybowski et al [15] had conducted tests at Mississippi State University HV Laboratory, USA to compare the performance of the ionizing and non-ionizing air terminals in 1997. Two types of air terminals with different operation principle were tested for their ionization capability under conditions simulating the quasi-static electric fields expected below a thunderstorm. Type 1 terminal used a number of outrigger electrodes to capture ions at their extremity, and transfer charge to produce repetitive arcing near the central grounded electrode. Type 2 terminal were spherical in nature and designed to inhibit discharge under high levels of electric field above the sphere.

The primary difference between these terminals is that the type 1 is reactive to static fields in the pre discharge phase, which will produce copious ions in the vicinity of, and above the central electrode. On the other hand, the type 2 terminal is passive under steady fields and only reacts to the approach of a down leader.

In the strokes to air terminals test, the screen charged with both positive and negative polarities standard lightning impulse of 1.2/50μs was placed at 5m above the ground. 2m long rod was used to simulate the downward leader. The tips of the terminals were 1m above the ground and the separation between the terminals was 2m.

In the case of negative polarity at screen result shows that the long tip type 2 receives the strokes in the ratio of 22/40 and 18/40 in favor of type 1 but this advantage was neutralized in the case of positive polarity at screen with each terminal receiving an equal number of strokes.

In the short series of impulse Critical Flashover (CFO) test, the result showed an expected lower strike voltage with the type 1 terminal. Lastly, the type 1 emissions started at low levels of electric field stress in the corona emission current (CEC) measurement. The authors conclude their finding by proposing a plan to progress their work to a series of tests in which various levels of permanent Direct Current (DC) bias voltage are applied before and during the superimposition of impulses.

1.2.2 Observations which Do Not Indicate Significant Advantage of the ESE Lightning Protection System

(i) Mackerras et al [1] made a conclusion that non-conventional (including ESE) air terminals are not significantly different from the collection distances of simple air terminals. They cannot have collection distances up to 50m greater than the collection distances of simple air terminals.

(ii) Moore et al [10, 11 and 12] have carried out the outdoor field test under real lightning condition in New Mexico for past seven summer thunderstorm seasons. In an effort to compare the strike reception effectiveness of lightning rod with various tip configurations, pairs of various sharp-tipped and blunt rods have been exposed beneath thunderclouds to determine the better strike receptor. Result obtained after seven years of tests shows that none of the sharp FR or ESE has collected any strike, but 12 blunt rods with tip diameters ranging from 12.7mm to 25.4mm have taken strike.

(iii) Lee et al [16] performed lightning impulse voltage test, flashover direction test and CEC test on a comparative test of a particular type of ESE air terminals and DAS with a simple rod had been carried out in the Korea Electrotechnology Research Institute (KERI). The results obtained from this experiment in this paper show that the characteristics of special air terminals are not superior to a simple rod for lightning and switching impulse voltages. In the discharge time, the ESE is averagely 2μs earlier to discharge than that of the simple rod.

Apart from this, there was no manifest evidence to verify the effects of ESE air terminals through the comparative assessment test under the same electro-geometrical condition where discharge number to the ESE air terminal was 61 and to the simple rod was 55, and the rest did not has any discharge throughout experiments of 120 times. They have concluded that if simple rod was installed on the building, it is not a practical idea to replace it with ESE terminals as study shows that there is no outstanding improvement for the ESE lightning rod.

(iv) According to Uman et al [17], various tests in the field and the laboratory have shown that radioactive rod does not have or only has little significant different from a similarly installed conventional rod of the same height (e.g. Muller-Hillebrand 1962b; Baatz 1972). One of such observations is the failure of radioactive LP systems in Singapore, where at the time of their study, over 100 such systems were installed. Another observation is the failure of a radioactive lightning rod to give the protection to the papal crest off Bernini Colonnade at the Vaticanin in 1976.

Based on these surveys, NFPA conclude that there was no basis for issuing a standard for ESE systems.

(v) Hartono and Robiah in [18] have done long-term studies on the performance of ESE air terminal in Malaysia. Two cities, Kuala Lumpur and Shah Alam where the average annual thunderstorm day of about 250 has make it a very ideal location for the field testing of lightning air terminals.

Their studies show that the ESE terminals do not provide the enhanced protection as claimed by their proprietors as some of the buildings equipped with one or more of the devices had been struck by lightning repeatedly over a period of time. Besides, the lightning damaged locations had been found to be very near to and, in many instances, at a lower height than the position of the ESE air terminal.

1.3 Objectives of the Study

To date, there is still no concrete evidence showing that the ESE type of NCLR does provide better protection although there is many researches finding indicate the superiority of NCLR over the FR of CLR. Thus, the objectives of this research are

- To investigate the relation of the early streamer emission device (pulsing unit) to the ability to launch the upward streamer
- To determine the significance of conditioning the air above the rod tip, and
- To find out the effect of geometrical configuration on the interception ability

1.4 Contributions of the Project

Through the limited publication on the ESE LP system, it is found that work on studying the effect of conditioning the gap above the air terminal can be found nowhere. Most of the overseas researchers conducted their tests by applying an auxiliary pulse of impulse shape to the rod. Small impulse generator is used to generate this impulse at a controlled delay time varied in steps of few tens microsecond after the start of main switching impulse. While for my work, a continuous or repetitive pulse is connected to the rod to create an ionization condition at the tip of the rod. This can help to enhance the electric field strength above the tip and thus increase the ability of sending up the streamer successfully. Results obtained from my work provide very useful information for the manufacturer to improve their current design.

From extensive experimental results and analysis, it is discovered that shape of a rod tip does bring a significance effect on the lightning interception ability by enhance or inhibit the streamer initiation. Furthermore, it is found that very little works have been done on this issue. Although overseas researchers such as Moore et al have conducted lots of tests studying the effect of the geometrical profiles on the performance of a rod, they change the diameter of the rod instead of varying the curvature and angle of the rod. Results obtained from the laboratory tests on the geometrical profiles in this work provide another good idea for manufacturer in designing a better lightning rod.

According to my study from literatures, lots of works have been done on the comparative performance test in the laboratory instead of field tests. Nobody has published detail work on the study that uses the actual ESE and FR with the complete set of Lightning Flash Counter (LFC) unit under the real lightning condition in elsewhere, especially in Malaysia and any countries in Asia. Apart from this, works carried out by local researchers are more on the physical treatments that focus on the damage of buildings. Thus, statistical data on this comparative performance test between these two types of LP system is still lacking. And hence, the lightning detection systems that have been set-up at black P18, UTM provide a life comparison between both systems.

1.5 Scope of Study

The study focuses on the streamer initiation ability of an ESE LP system. A non-conventional air terminal from a manufacturer, which has been installed in the campus, is monitored for its ability to intercept lightning stroke. Factors, which inhibit or enhance this phenomenon, are studied. Observations, which result from these factors such as the time-delay-to-breakdown, are studied. The scope also covers field and laboratory works on set-up to give observation, which allows the intercepting ability of the ESE LP to be analyzed.

The scope excludes detail study on the earthing system of the building, which has been fitted with both the FR and ESE air terminals. Apart from this, bias field due to the cloud, detail study on design of the device, field and current emission, material of the air terminal and ratio of the air terminal height to the curvature are not included in this study due to certain limitations of equipment available at the IVAT laboratory.

1.6 Summary of Thesis Chapters

This thesis consists of six chapters, namely:

I. Chapter 1 describes briefly on the overview of the principles of early streamer initiation mechanism, review of previous works or study on the performance of the ESE LP system compared to the FR, objectives of this project, scope of study and the contribution of the project in the improvement of the LP system

II. Chapter 2 contains the brief introduction related to the lighting activity such as lightning phenomena, lightning discharge mechanism, risks and effects from lightning strike. This chapter also discuss in brief on the types of LP system, their categories and classification of the LP technique. Differences in between the conventional and non-conventional have been discussed too.

III. Chapter 3 thrash out three different approaches that had been adopted in this work namely field testing site survey and experimental works. Set-up for several number of tests conducted has been clarified in this chapter.

IV. Discussion and analysis on the results obtained from the above-mentioned methods have been described in Chapter 4.

V. Conclusions on the works that have been done in this project are made in Chapter 5.

VI. Some suggestions have been proposed in Chapter 6 with hopes that more convincing and realistic results can be obtained in the future before any conclusions are made.