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Investigation on the Breakdown Characteristics of Different Types of Lightning Rods

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Abstract: This paper investigates the voltage breakdown characteristics of three types of lightning rods - blunt, sharp and flat. The objectives of this study are to determine the voltage breakdown characteristics of various types of lightning rods and to obtain the striking distance of each rod. A series of experiments were conducted in the high voltage laboratory consisting of individual testing rod, competitive testing rod and also horizontal distance changing. All three types of rods have been tested in each experiment in order to obtain a comprehensive result. The blunt rod has been proven as the best strike receptor in comparison to sharp and flat rod. This is because breakdown voltage for blunt rod is much lower (199 kV) than that of flat and sharp rod. Therefore, replacement of widely used sharp rod with the blunt one should be considered in order to provide better protection for buildings from lightning activities

Keywords: air terminal, lightning, lightning protection, lightning rod, striking distance

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1. INTRODUCTION

Lightning strike is the most powerful and dangerous electrostatic discharge in nature. With the conductive air, charges in the cloud can be transferred to the ground and hence lightning strike occurs. Lightning strike is a major cause of destruction of power electric system and many other electrical equipment as well as fatalities of human beings. Because of that reason, controlling and directing the energy of lightning to protect humans, buildings and equipment is very critical and is of a main concern of electrical engineers [1].

Basically, there are three different parts of external lightning protection systems for buildings, which consists of lightning air terminal (lightning rod, which is typically installed on top of buildings or structures), down conductor and earthing systems. All three parts are crucial and extra precaution is needed during the installation to ensure the efficiency of protection system and safety of buildings to be protected. A network of lightning rods will intercept the lightning event and direct it to the conductor wire. Then the conductors confine and direct the lightning event towards eventual dissipation into earth. Finally, the grounding system of the lightning protection system is designed to transfer the lightning current from the conductor into earth.

This study will focus on the external protection component that is lightning rod. There are two types of lightning rod design; conventional and non-conventional (ESE or Early Streamer Emission). Majority of lightning rod in use today are of the traditional Franklin design. The fundamental principle used in Franklin-type lightning protection systems is to provide a sufficiently low impedance path for the lightning to travel through to reach ground without damaging the building [2]. Lightning rod requires a connection to earth to perform its protective function. The main attribute of all lightning rods is that they are highly conductive. Typically, copper and its alloys are the most common materials used as lightning rod [3]. In recent study, a metal layer was set to surround lightning rod for shielding [4] in order to reduce electromagnetic field radiation from lightning. It is shown that the metal layer affects the distribution laws of vertical electric field above the ground fiercely.

There are sev eral types of lightning rods such as sharp-pointed tip, blunt tip, standard tip and many more in use nowadays. Sharp tipped rods are widely used all over the world, however research done previously found that moderately blunt tipped is the most effective lightning strike receptor in comparison to the sharp one [5, 6]. A group of researchers did an experiment with several sharp and blunt rods with different diameter of tip [7]. Each lightning rods were set up with the same height. The lightning rods were mounted on the 6 meter tall poles and separated 6 meter with each other. Their result showed that none of the sharp rods were struck by lightning. Also, there was no lightning strikes on the smallest and biggest diameter of blunt tipped. Most of the time, lightning strike the blunt tipped with the moderate diameter which is about 19 mm. Most recently, an investigation of attachment process of downward lightning flashes to residential building had been carried out by [8] using a high-speed video camera. Based on their study, parameters like striking distance and connecting leaders speed, largely used in lightning attachment models and in lightning protection standards, are revealed.

On the other hand, a non-conventional lightning protection system known as ESE (Early Streamer

Emission) had been claimed by their manufacturer to be more effective than sharp pointed lightning rods. Nevertheless, these system do not fucntion as it was claimed. The same goes with the Charge Transfer System (CTS) too. They claimed that the CTS can eliminate the lightning strike but the facts is the CTS can only reduce damage from lightning strike [7]. Another non-conventional air terminal which uses the teory of corona discharge phenomenon is Bipolar Conventional Air Terminal (BCAT) developed by OMNI LPS [9]. It was reported that BCAT has proved its efficacy at a number of sites where it is installed, as well as through related papers published in IEEE [10-12]. Also, it is further verified that BCAT is effective at discharge than existing air terminals for lightning prevention [13]. Since many of these claims were made by the manufacturer, therefore further investigation is However, thourough investigation is needed before one can jump into conclusion on the effectiveness of BCAT.

Figure 1. Different types of lightning rod, from left: flat, sharp and blunt surface

2. EXPERIMENT

In order to investigate the breakdown characteristics of different types of lightning rods, three different experimental set up had been designed which include:-

- Breakdown voltage of Individual lightning rod
- Competitive rod test of lightning strike
- Striking distance test

Experiment was held at Institute of High Voltage & High Current (IVAT) Laboratory in Universiti Teknologi Malaysia with the temperature and pressure in the range of 28 - 29.5℃ and 1015 - 1016 Mbar, respectively.

2.1 Breakdown voltage of individual lightning rod

The experimental setup to determine breakdown voltage for individual lightning rod is illustrated in Figure 2. The objective of this test is to dete rmine the breakdown voltage of each lightning rod. The lightning rod was set up at 1.0 m height above ground. A gap of 0.2 m between lightning rod and impulse conductor was set. A 250 kV impulse was injected ten times to the impulse conductor via High Voltage Impulse Generator and breakdown voltage was recorded using High Resolution Impulse Analyzing System (HiAS 743). Similar procedures were repeated with other types of lightning rod.

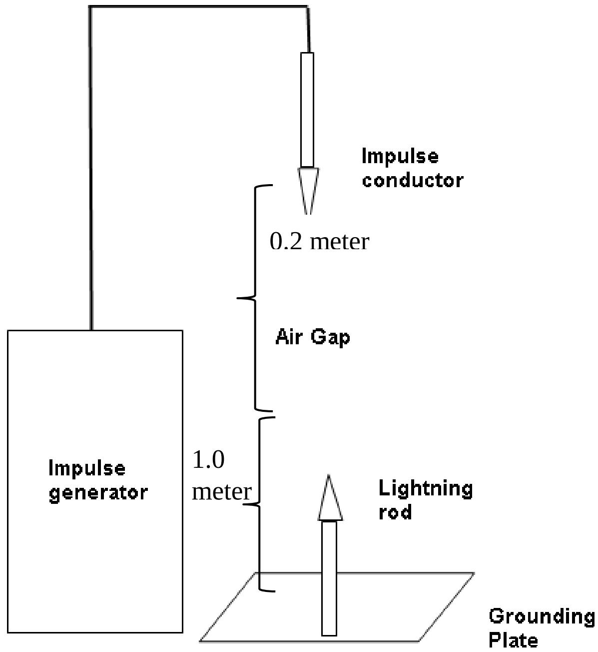

Figure 2. Experimental set up of individual lightning rod breakdown voltage

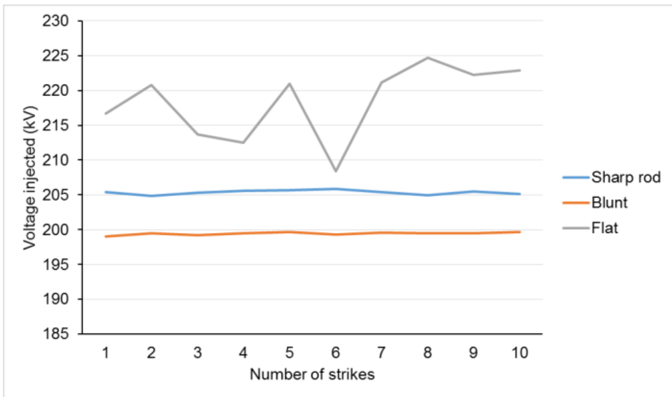

Figure 3. A graph showing various breakdown voltage for different types of lightning rod.

2.2 Competitive rod test of lightning strike

In this test, lightning rods were arranged 0.2 m apart from each other. Three different pairs of lightning rods were selected that are blunt – flat, sharp – flat and blunt – sharp. The distance between lightning rod and impulse conductor is also set to 0.2 m. A voltage of 220 kV was applied to every pair of lightning rod. Ten sets of data were recorded. Similar procedures were repeated with other pair of rods.

Experimental set up of competitive test is as shown in Figure 4**.**

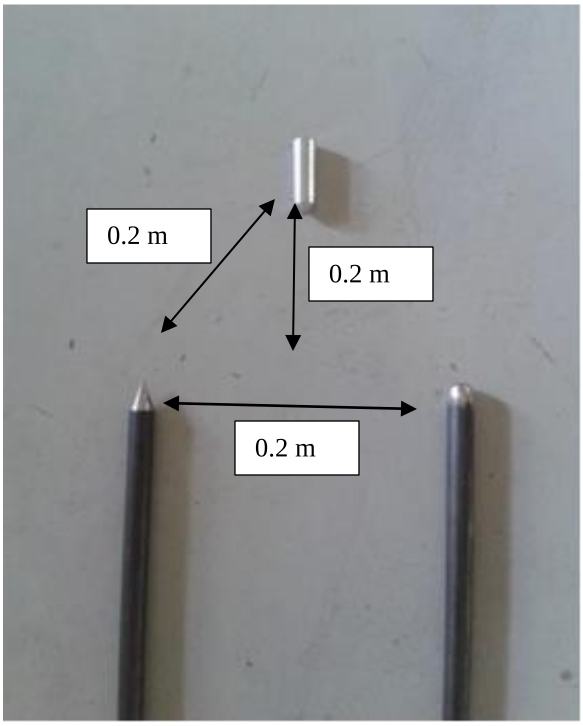

Figure 4. Experimental set up of competitive rod test

2.3 Striking distance test

The striking distance is determined based on the average potential gradient between the upward leader tip and the downward leader tip and is equal to or larger than the critical electric field of the streamer channels [14]. The main factor that determines the striking distance is the electric field distribution between the downward leader tip and the lightning rod. The electric field was found to be strongly dependent on the structure of the lightning rod [15]. For similar dimensions of lightning rod and conditions of air, the obtained striking distance may vary between different models due to the different conditions for the inception of upward leaders.

The objective of this test is to obtain the maximum striking distance of each type of lightning rod. A pair of similar types of lightning rod was arranged horizontally and 220 kV was applied to every pair of lightning rod being tested with various distances (refer to Figure 5 where Y distance is varied until it reaches the maximum distance).

3. RESULTS AND DISCUSSION

3.1 Breakdown voltage of individual lightning rod

Data from the experiment is depicted in Figure 6 below. It can be seen that the blunt rod has the lowest breakdown voltage in comparison to sharp and flat lightning rod. Breakdown voltage for blunt rod varies between 199.1 kV to 199.5 kV with the average of 199.5 kV. For sharp rod, the breakdown voltage ranging between 204.8 kV to 205.8 kV with the average value of 205.4 kV. Finally, flat rod breakdown voltage fluctuates from 202 kV to 222.8 kV and average at 218 kV.

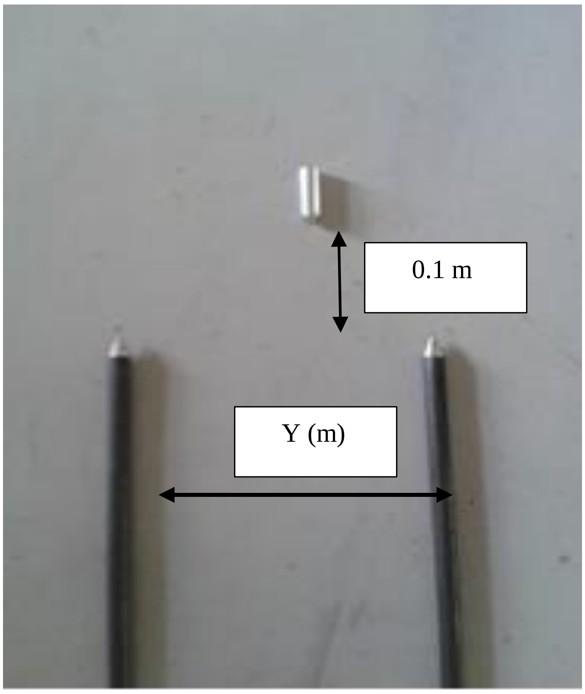

Figure 5. Experimental set up for striking distance test. Distance between two lightning rods, Y is varied until maximum distance is achieved.

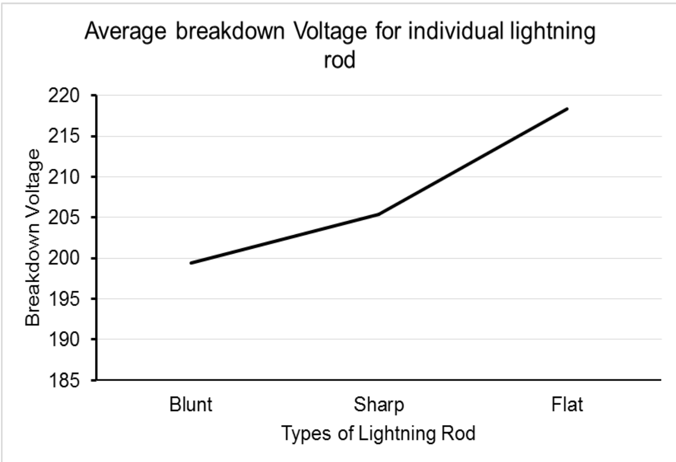

Figure 6. The average breakdown voltage of individual lightning rod.

3.2 Competitive rod test

Meanwhile, result for competitive rod test is tabulated in Table 1 below. Based on the result, it is observed that blunt rod has higher percentage of being strike compared to the sharp and flat rod. This result shows that the blunt rod had 60% of strikes while sharp rod suffers only 40% of strikes. For the sharp and flat rods, 70% of strikes went to sharp compared to flat which is only 30% of strikes. The last trial was between blunt and flat rod. About 70% of strikes went to the blunt rod while flat rod received only 30% of strikes.

3.3 Striking distance test

In Table 2, it can be clearly seen that blunt rod has the highest striking distance which is 25.5 cm to that of sharp and flat rod. The gap was varied from 0.1 m to 0.25 m in 0.05 m steps. The maximum striking distance recorded for sharp and flat rod are 24.6 cm and 23.7 cm, respectively. The average breakdown voltage for the three recorded distances were approximately 213 kV. Referring to all the results of experiment conducted, blunt rod obtained the best result among all rod being tested based on its performance on voltage breakdown and the highest striking distance.

Table 1 Percentage of strike for various type of lightning rod

Types of Comparison	% of Strikes	
Blunt and Flat	Blunt	70
	Flat	30
Sharp and Flat	Sharp	70
	Flat	30
Blunt and Sharp	Blunt	60
	Sharp	40

Table 2 Striking distance result of different type of lightning rod

Types of Rod	Maximum Striking Distance (m)	Voltage Breakdown (kV)
Blunt	0.25	211.5
Sharp	0.24	216.3
Flat	0.23	213.0

From the three results obtained, it is clearly shown that the blunt rod has better performance than flat rod and the widely used sharp rod. These experiment results are compatible with the previous studies [16, 17 and 15], where blunt rod has been found as the best rod with the minimum voltage breakdown compared to flat and sharp rod. Very strong electric fields occurred at the top of the rod and the value increases as the leader approaches [6]. The interception of lightning leader to the blunt rod at the lower voltage breakdown encouraged by the increases of electric fields energy. In their experiment to compare the performance of a sharp and blunt rod, they found that the blunt rod attracts more lightning leader attachment than its competitor [18]. It is happening due to the minimum pre-stroke space charge accumulation around the rod that enhances ability to initiate and sustain an upward leader [18]. In the competitive testing rod, the blunt rod has higher percentage of strikes while the sharp become second and flat has the lowest percentage of strikes. This blunt rod is exposed to intensifying electric field compared to both sharp and flat rod. Therefore blunt rod becomes the preferred point of interception. The limit of point discharge that built up at the sharp rod is the reason sharp rod is less preferred than the blunt rod.

3. CONCLUSION

From this experimental work, it is clearly proven that blunt rod can be the best strike receptor among other conventional lightning rod like sharp and flat rod. The blunt lightning rod has lower voltage breakdown and received more percentage of strikes compared to the sharp and flat rod. Further, it is also confirmed that blunt rod achieved highest distance of lightning strike in comparison to flat and sharp rods. Therefore, to avoid damages cause by lightning strike, it is suggested that the widely used conventional sharp rod to be replaced by the blunt rod.

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