On the Concern of Aged Lightning Air Terminal's Capturing Capability and Improvement by Mean of Chemical Treatment

H. Ahmad [#1], Z A Malek [#2], N. Azlinda Ahmad [#], Z. Adzis [#], N. A. Samad [#], M. A. B. Sidik [#*2]

[#]*Institute of High Voltage and High Current, Universiti Teknologi Malaysia*
81310 Skudai Johor, Malaysia
[1]hussein@fke.utm.my
[2]abubakar@fke.utm.my
[*]*Department Electrical Engineering*
Faculty of Engineering, Sriwijaya University, Indonesia

Abstract— **Lightning Air Terminal (LAT) is normally a sharp-tipped rod that is used to intercept direct lightning strike to ground structures. However it was found that LAT sometimes does not function as it should be due to aging and prolonged exposure to the acidic rain. This paper presents on the studies to determine chemical compounds; Polyvinyl Acetate and Polyvinyl Alcohol that can be use to enhance LATs' capturing capability. The chemicals act as a 'make-up' that helps the LAT to resist the effect of acid rain while increasing its conductivity and lightning leaders capturing capability. These findings were based on laboratory experiments. Further research has to be done on actual site testing using rocket-triggered lightning or on-situ monitoring of LATs performance. However it was found that in an environment where acidity is at pH 4, Polyvinyl Acetate is best for the LATs' performance improvement.**

I. INTRODUCTION

For more than 200 years Franklin Rods have been the reference for conventional method of lightning protection system standard. Any studies to improve on their performance are beneficial to the public especially when they are used as Lightning Air terminal (LAT) for direct strike protection of buildings, structures and other facilities. LAT that have been affected by corrosive effect of acid rain are unable to protect a building efficiently from lightning strike. An example of LAT inefficiency to capture lightning leaders is shown in Fig. 1.

The problem can be addressed generally by two ways. Firstly, it can be replaced with new LATs and secondly by refurbishing technique using chemical coating to improve on the LATs' performance. The paper described the latter method to determine new chemicals for LATs improvement. In order to accomplish the task, certain types of chemical that can cover the corroded LAT besides enhancing its capturing capability have been identified. The chemicals used for this study are polymer-based compounds that help in reducing the effect of space charges surrounding the LATs' tip. To study and determine the effectiveness of these chemicals, a series of testing have been conducted at the Institute of High Voltage and High Current (IVAT) Laboratory by using 4-stage, Marx Generator. At the end of this study, the performance and comparison between the coated LAT with the standard LAT had been determined.

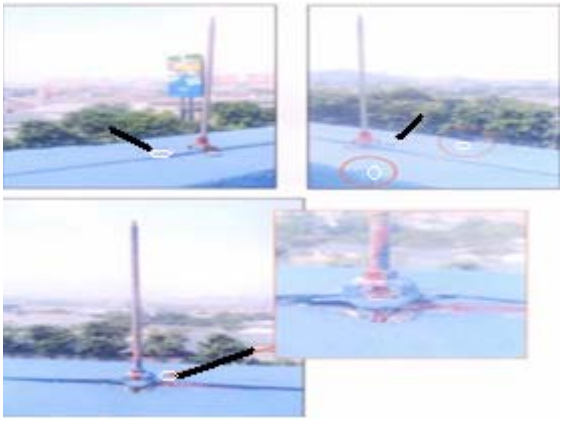

Fig. 1 Arrows pointing to marks of missed capturing on building parapet wall.

Acid rain has become another environmental issue in this rapid developing country. The size of areas suffering from acid rain continues from year to year as well as the increase in rain acidity also increased [1]. Due to rapid development of power generation, industrial, transportation and human daily activities, large amount of sulphur (SO_x) and Nitrogen Oxides (NO_x) are released to the atmosphere. SO_x and NO_x have been identified as the most important component of acid rain [2]. However, the type of acid rain actually depends on nearby location itself [2]. Acid rain has multiple effects on almost every life support system, but "corrosion" is one of the most common effects. Since the LAT is placed on tops of buildings, it is frequently exposed to the effect of acid rain.

Another problem encountered by LAT is the formation of space charge layer above the tip of the LAT [1]. As the downward leader travel to the ground, the field intensity around the sharp tipped LAT increased. The enhancement of the field intensity causes ionization of the surrounding air with electrons falling into the tip, leaving immobile ions in the air above the tip of air terminal. These immobile ions weaken the electric field until there is no further ionization occurs. The

ionization will only occur if the immobile ions migrate or blown by the air. These immobile ions form a layer called space charge. The formation of the space charge inhibits the ability of the air terminal to emit the naturally occurring upward streamer consequently restricting the capturing capability of LAT.

The chemical compounds that were used to improve the capturing capability of LAT were Polyvinyl Alcohol (PVA) and Polyvinyl Acetate (PVAc). It is a type of polymer-based compound. Polymers were chosen in the study due to their dielectric property that can attract charges and store it within itself. Since there are positive ions on top of the air terminal tip, the polymer will induced negatively charged ions [3]. Due to the opposite polarity, the positive charges will be attracted to the polymer and trapped within it. However, since the polymer is coated on high conductivity surface, the trapped charges will be drained through a proper conductor network. Other reasons that enable the usage of Polyvinyl Acetate for the study was it has strong yet excellent mechanical property, high electrical conductivity and capability to resist corrosion once it is in film form. In terms of cost, Polyvinyl Acetate is considered as inexpensive material [4] since it can easily be found in latex paint and white glue. It is important to use chemicals that have strong mechanical property and able to resist corrosion since the air terminal is placed on the top of a building.

II. Experimental Section

In order to observe the performance of LAT that is affected by acid rain, the LATs for this project have been soaked in an artificial acid rain solution for three months. The artificial acid rain was prepared by adding the sulphuric acid (95-97%) into the distilled water. Three different pH of artificial acid rain were prepared which are pH 2, pH 3 and pH 4. The pH value was determined by using the pH indicator. In order to maintain the pH level, daily check on the pH by using the pH indicator was conducted.

The tests were conducted in High Voltage Laboratory of Universiti Teknologi Malaysia. The Marx Generator (4 stage-max voltage is 400kV) were used to simulate the negative standard impulse voltage (1.2/50 µs). The voltage breakdown and time to breakdown during the tests were recorded using Digital Impulse Analyzing System (DIAS). There are two types of test conducted for this study which are individual test and competitive test. To confirm the accuracy of each test, 5 sets of data for each testing were taken.

A. Individual Test

For the individual test, the prototypes were tested separately. Each prototype was set at 5cm from the impulse electrode. Air terminals that have been soaked into artificial acid rain of, pH2-LAT, pH3-LAT and pH4-LAT, respectively and one air terminal in a good condition (control-LAT) were tested separately. The experiment setup is shown in Figure 2.

B. Competitive Test

The tests were carried out by testing two prototypes of different condition together to compare the performance of each prototype. Each prototype was set at 30cm apart from each other and the gap between the air terminals and the impulse electrode is 5cm. The setup was maintained during each test. To ensure the readings were unbiased and unaltered by the positions of the prototype, the position of the prototypes were switched to the other side after a set of data were obtained. For the test, Polyvinyl Acetate was compared with Polyvinyl Alcohol to determine the difference of performance of both chemical. The experiment setup is also shown in Figure 2.

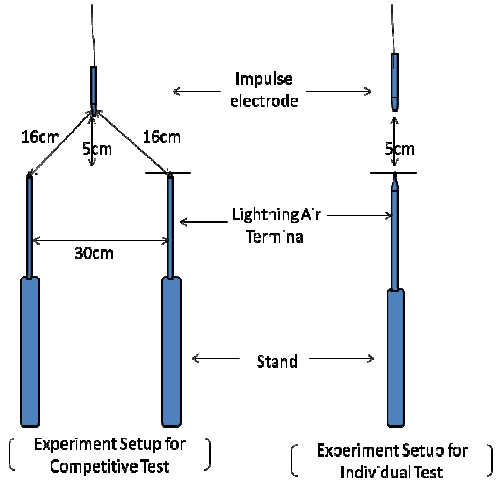

Fig. 2 Experiment setup for competitive test and individual test

III. Result and Discussion

Several tests had been conducted to observe the performance of the prototypes. All data from those tests were obtained. From those data, analysis was made to clearly state the comparison between the prototype and the reference LAT, thus confirming the performance of the prototype.

The following table is the tabulated data gained from the experiment:

TABLE I
Breakdown Voltage For Each Sample Tested Separately

Negative Breakdown Voltage (kV) [without coating]				
No.	**pH2-LAT**	**pH3-LAT**	**pH4-LAT**	**Control-LAT**
1	-151. 495	-185.882	-195.371	-151.855
2	-152.727	-198.961	-175.976	-153.424
3	-181.447	-198.443	-179.603	-152.081
4	-182.049	-196.907	-179.731	-154.445
5	-182.094	-181.688	-195.372	-153.110
Ave	-169.962	-192.376	-185.211	-152.983

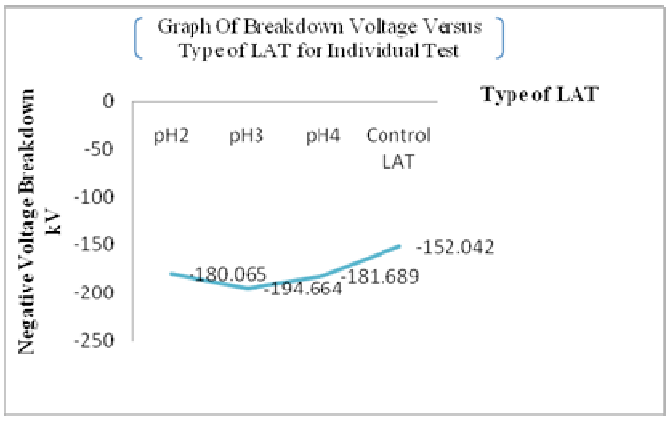

Fig. 3 Graph of breakdown voltage versus type of LAT for individual test (by using average value)

Table I shows the breakdown voltage of each sample tested under negative standard impulse voltage (1.2/50µs) from 4 stages Marx-generator. Basically, the test was conducted to compare the performance of the LAT which is in a good shape (control-LAT) with the corroded ph-LAT, pH3- LAT and pH4 -LAT. From the data, a graph of breakdown voltage versus type of LAT was plotted as shown in Figure 3. As shown in the graph, the breakdown voltage of control LAT is lower than the corroded LAT.

A good LAT will produce upward streamer earlier and will become the preferred striking point. When a certain lightning rod manages to emit upward streamer earlier than the other lightning rod in the lightning protection system, it indicates the breakdown field of the lightning rod is less. As a result, the possibility of the lightning rod becoming the preferred striking point will be high.

Based on the graph of Figure 4, it was proved that corroded LAT is having a degradation of performance and could be dangerous to be use as a lightning protection system. The effect of corrosion is more significant on pH4-LAT. Several studies have been conducted and it was found that the pH value of real acid rain is about pH4.5. Thus, the results of this study are especially useful in real acid rain effect situation.

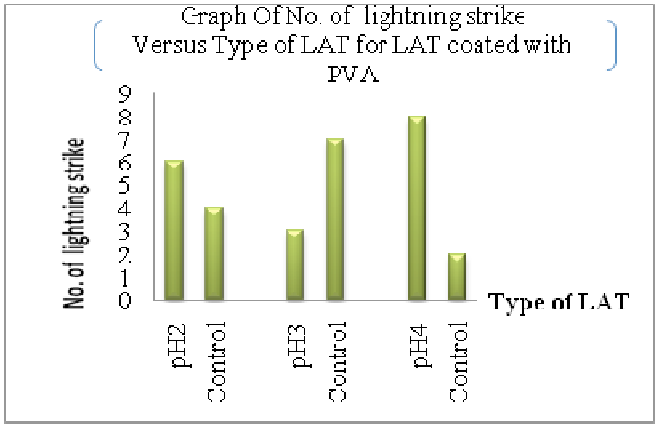

Fig. 4 Graph of no. of lightning strike versus type of LAT for LAT coated with PVA.

The test was conducted to compare the performance of the LAT which is in a good shape (control LAT) with the corroded ph2-LAT, pH3-LAT and pH4-LAT coated with PVA. Each corroded LAT was tested separately with control LAT to observe the preferable point to discharge out of the two tested LAT. As shown in the graph, pH2-LAT was chosen 6 times, pH3 LAT was chosen 3 times and pH4-LAT was chosen 8 times out of ten tests. As the analysis narrowed to pH4-LAT, it seems that PVA is able to improve the capturing capability of the LAT. This indicates that PVA is able to attract the space charge above the sharp tipped of the LAT to allow the formation of the upward streamer.

Similar to the previous test, this test was conducted to compare the performance of the LAT which is in a good shape (control-LAT) with the corroded LAT-ph2, pH3-LAT and pH4-LAT) coated with PVAc. Each corroded LAT was tested separately with control LAT to observe the preferable point to discharge out of the two tested LAT. Figure 5 shows the graph of number of lightning strike versus type of lightning rod. Out of ten tests, pH 2-LAT was chosen three times, while pH3-LAT was chosen nine times and pH4 LAT was performed as similar as the control LAT. The improvement made by the PVAc was unobvious. However, it was able to enhance the performance of the corroded LAT at least to perform as well as the control LAT.

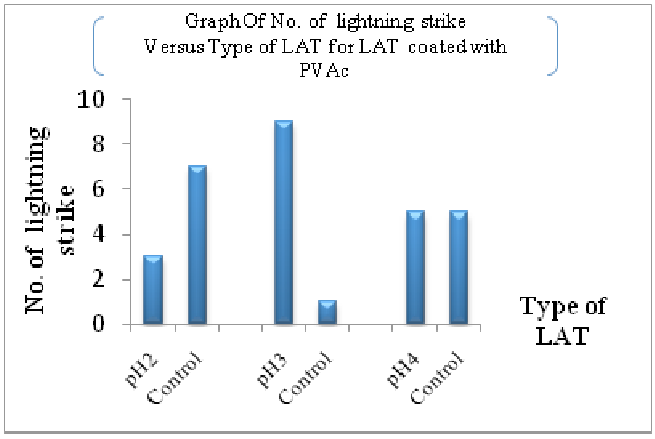

Fig. 5 Graph of no. of lightning strike versus type of LAT for LAT coated with PVAc.

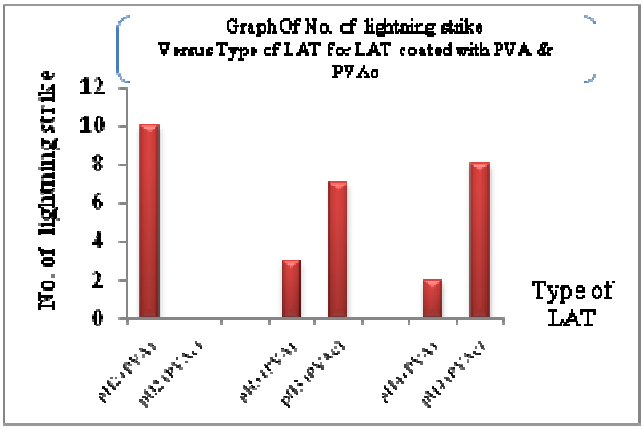

Fig. 6 Graph of no. of lightning strike versus type of LAT for LAT coated with PVAc and PVA

Figure 6 above shows the graph of number of lightning strike versus type of LAT for two samples tested with each of the sample coated with different coating. Two of LAT of same pH value were tested together with one of the LAT coated with PVA and the other coated with PVAc.

Based on the result obtained from the test, it can be concluded that most of the time, the lightning chose to strike on LAT coated with PVAc. The most significant effect of PVAc on LAT is on pH4-LAT. From all the tests conducted for the study, PVAc shows the most significant effect in improving the performance of pH4-LAT. As stated earlier, since several studies have found that the pH for naturally occurring acid rain value is about pH 4.5, thus, the results of this study are useful in real acid rain effect situation and consequently proved that PVAc is suitable to be use in order to enhance the lightning air terminal capturing capability.

IV. CONCLUSIONS

For the first time, studies on the improvement of aged Lightning Air Terminals have been conducted. Two chemicals have been tested which are Polyvinyl Alcohol and Polyvinyl Acetate. Both chemicals are able to enhance the capturing capability of the LAT. However, only PVAc shows the significant effect on improving the corroded LAT which exposed to artificial acid rain with pH value similar to the naturally occurring acid rain value.

Based on the results of the tests, it is proven that PVAc is an effective chemical to improve the performance of lightning air terminal. Due to the performance of LAT that coated with PVAc, it is deduced that PVAc could reduce the effect of space charge by attracting the charge and discharge it through a proper path to ground. This consequently enables the LAT to emit localized corona discharges sooner in order to intercept with the downward leader.

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