

## On the Study of Modernized Lightning Air Terminal

M. A. B. Sidik<sup>1</sup>, H. Ahmad<sup>2</sup>

**Abstract** – In a direct strike lightning protection system, three components are considered to be of great significance; that is lightning air terminal (LAT), down-conductor (DC), and earth terminal (ET). Since the time of Benjamin Franklin, the founder of lightning rod, until today there are many types of LAT that have been installed on building structures around the world to provide protection to the human being and equipment from the effect of lightning strokes. In general LAT could be classified as in compliance with standard and non-standard method. However, generally people at large are unable to differentiate between standard and non-standard method of protection involving the use of LAT. The latter performance and its scientific explanation provided by vendors have created controversies among lightning scientists and practicing engineers. The development and research on technologies to control or even to prevent lightning strokes continues till today. This paper describes a current research going on related to the subject concern and possible technologies which can be used for future generation of LAT. **Copyright © 2008 Praise Worthy Prize S.r.l. - All rights reserved.**

**Keywords:** *Lightning, Lightning Protection System, Lightning Air Terminal*

### I. Background

Lightning, considered as a spectacular meteorological phenomenon, is one of the most fascinating events in the world. The preliminary scientific and systematic understanding of lightning phenomenon was first constituted by Benjamin Franklin in 1752 that used a kite in order to verify that lightning is really a stream of electrified air. Interestingly when Benjamin Franklin experimented with the electric kite, there were no very tall structures and high rise buildings like we observed today. However till today over more than 200 years the Benjamin's lightning rod is still the most internationally accepted Lightning Air Terminal (LAT). However despite of presence of lightning protections available which are designed based on world standard still lightning related damages that cost millions and also sacrificed of human life. Take for an example a calamity involved with lightning hazards is a proof for immediate improvement on methods of lightning protections.

The Indonesian Pertamina oil refinery in Cilacap, on the southern coast of Java, exploded in October 1995. The culprit was lightning thunderbolt. The refinery tank of concern made from 10-cm steel plate but still exploded. In just few minutes the fire spread from the first tank and subsequently followed by six-tank inferno. [1].

Almost similar with Pertamina incident, on April 28, 2006, at around 06.00 pm, the Malaysia government's petroleum company, Petronas, oil tanks blown up as result of lightning stroke in Pasir Gudang, Johor.

The in that incident not less then 8 (eight) tanks were caught fire. The fire reached up about 20 (twenty) metres height and produced very thick smoke which was able to be seen in radii of 6 (six) kilometres from incident location. Fig. 1 illustrates the situation of aftermath of a lightning strike.



Fig. 1. The situation in Pasir Gudang, Johor, Malaysia

The historical incident due to lightning in aerospace activities occurred during the launching of Apollo 12 mission. The lightning had caused temporary malfunction of vital electronic instruments in the spacecraft. This became the reason for NASA to pursue lightning research. Lightning strikes at the vicinity of aircraft often originate from the body of craft itself. The flash started with the inception of a leader, propagating in both directions away from the craft. These are called triggered lightning flashes [2,3].

From a survey [4] it was found out that from 1995 to

2000 almost 50% of the telecommunication utilities suffered damages to equipment due to lightning related causes. These threats cause system downtime, loss of production and revenue plus increase in customer frustration and loss in market competitiveness. It can be consolidated from the study conducted by Norfifah and Zafirah [4] that even conventional air terminals is not free from the problem of inefficiency in capturing lightning downwards leader and consequently being translated into structures frontal and corners damages as shown in Fig. 2.

The inefficiency, as triggered research and development on different methods to capture more efficiently lightning downwards leaders as to prevent lightning strokes related damages continues till today. For instance Jean-Claude Diels researched on the use of laser in the development of a lighting protection system [5].

## II. Lightning Protection System Standards

Many standards relating to LPS have been published by many institutions of standards. Among which are the BS 6651 (British), NFPA 780 (American), and IEC 61024-1-2. These standards discuss and outline the important aspect of LPSs including design and methods for installing LAT, bonding, and zone of protection calculation. However, these standards utilize Franklin rod concept for their LAT. Even though these standards give some guidance and recommendations for installation of lightning protection, they can not assure the systems can provide 100% protection because there are evidences showing these systems can experience malfunctioning. Fig. 2 shows that the lightning struck the building edge, though of the Franklin rod is installed.

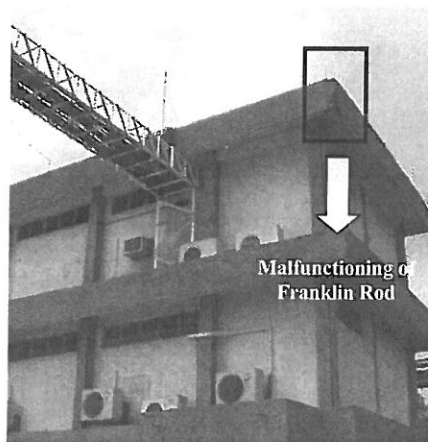


Fig. 2. Building structure equipped with a monopole at the roof top at the central and extreme edge of the building still being damaged by lightning stroke in spite of LAT installed

The standard advocate the use of standard LAT is due to the principle of operation of LAT is based on sacrificial point of stroke. However Fig. 2 shows the failure of LAT to perform as a point most likely to be struck by lightning leaders. The interesting part that has been shown in [6], concern the mechanics and dynamics of lightning leader attachment to the ground and associated structure as in Fig. 3.

Fig. 3 shows a lightning stroke initiated in 1999 from the underground launcher at the centre of 70 x 70 m<sup>2</sup> buried metallic grid at Camp Blanding Florida. From here what can be said is that a rocket which has a ground wire attached to it is launched upwards after the magnitude of electric field surpassed a threshold value indicative of lightning stroke. If the target is right, and lightning downwards leader is formed and strike the rocket head and flows downward through the wire which is connected to the metallic grid. The attachment points on the ground surface are numerous not a single concentrated point but multiple. Only a fraction is attached to the LAT as indicated with the arrow. However this model is not the perfect model to explain the malfunctioning of LAT. The best method is to capture the actual scenario of lightning leaders' attachment to buildings.

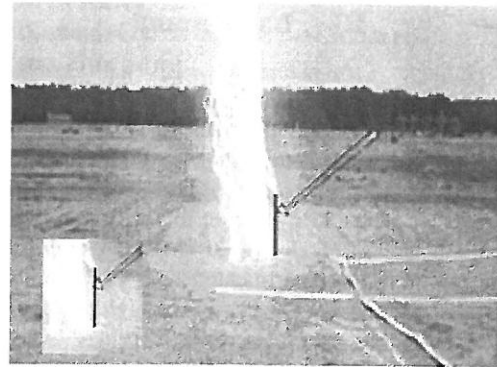


Fig. 3. Rocket Triggered Lightning [6]

## III. The Need for improvement of LAT

The concept of lightning protection afforded by a Franklin Rod is basically serving as the sacrificial point of strike. Upon attachment of lightning leaders to the rod, the down-conductor will drain the lightning energy to the ground via the earth terminal. However Tetsuya et al found that not all of the lightning direct strike current goes to ground through the down-conductor whereas the remaining lightning energy disperses into the building structures [7]. This scenario of "energy leakage" is intolerable when the building structures have contents which are inflammable, sensitive capital equipment like in the telecommunication transmitting and receiving station and other relevant structures. Such leakage can rise to dangerous step and ground potential rise. Now there is a need to capture the lightning

downward leaders away from the facilities intended for lightning protection and quickly discharge the energy to ground without providing time for the rise of dangerous ground potential and step-potential which could adversely effect the facilities, equipment and systems in its vicinity. Thus the cost for secondary protective devices can be minimized since the lightning strike is not a direct strike to the building structure but at a sacrificial point normally a LAT positioned some distance away from the building (not install on structures roof top). So this paper presents a current research going on concerning a new LAT that has features a) It is a better lightning leader captor, much better than the Franklin Rod, b) It can provide the pre-ionization process to enhance the capturing ability of the terminal by ionizing the LAT tip, c) It will launch a laser beam prior to the emergence of downward lightning leaders in awaiting mode to allow lightning to pass through the ionized air channel created prior by the laser beam. The new invention can be configured to suit the need of on-the-roof installation and off-the-roof installation depending on the severity of such consequential of mishap and the cost of such facility to be protected and its impact to the national economy (if such calamity to befall). The incorporation of laser-triggered discharge system to the new LAT can make the system useable for off-the-roof application.

#### IV. Laser-Triggered Discharges

The mechanism of the guiding ability of the laser could be explained by the behaviour of the plasma as a conductor [8]. The laser ability to trigger and guide discharge is due to the laser-produced plasma distort the ambient electric field. Laser could produce multi-photon ionisation [9].

By using laser, the lightning strokes instead of travelling in a zigzag motion it can travel along the laser beam path and hit the ground at a desired spot. One experiment in conjunction with the laser trigger experiment was conducted by Ahmad et al [10]. They carried out a set of lightning flashover test in a competitive mode between the laser triggered LAT and non-triggered LAT which involved the use of a 2.0-MV Marx impulse generator. It was reported that the laser triggered LAT has better performance in intercepting the discharges than the non-triggered LAT. The lightning discharge channel developed guided towards the LAT along with the plasma channel formed as a result of the laser-induced breakdown of the atmosphere [11].

Several studies, in the laboratory and field, had shown that the laser triggered lightning technique can be effective in initiating and controlling the path of an electrical discharge in long air gaps. A LPS utilizing intense laser beams to guide a leader discharge has great potentiality to become a promising appropriate technology of LPS in the future.

Ahmad et al [10] found that even by using a small laser system, the conventional LAT equipped with laser system is more prone to lightning strike than non-equipped LAT. Thus by using a laser aided system the striking distance of LAT can be increased. This is analogous to having a long monopole for lightning protection. The effective application of this version of Franklin LAT is one of the reasons for the reported low incidence of damages due to direct lightning strokes to buildings in Japan [12].

#### V. A New Direct Strike LAT

A new direct strike (DS) LAT has been developed in the Institute of High Voltage and High Current (IVAT), Universiti Teknologi Malaysia. The improvement was made based on the original design of a blunt-rod LAT. It is then incorporated with a system that has connection with electrostatic generator and triggering of laser beam.

##### V.1. Conceptual Design

The newly developed DS LAT has several novelties noted as a result of literature survey conducted as described above which ultimately could improve the performance of LAT. The invention novelties are the blunt-tip rod, generation of free electrostatic charges, and triggering of laser. All the novelties as described above being incorporated in the new DS LAT, categorically it is of three main units; static unit, a laser triggering unit, and a rotating unit.

Basically the static unit consists of a blunt-rod tip, a two-field-plate as capacitor, and a pair conductive-brush. The diameter of the blunt rod is about 19-mm which is based on Moore's study [13] where the blunt rod of similar shape but of particular size could intercept more lightning downward leaders than other type of tip configuration.

Free electrostatic charges are produced by using a particular type of electrostatic generator known as the Varley machine concept. The model of the Varley machine is shown in Fig. 4.

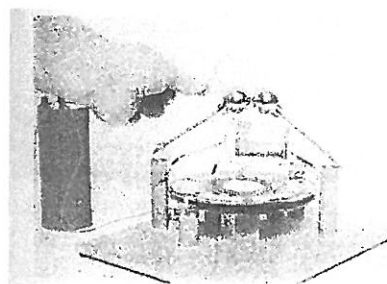


Fig. 4. Varley machine [14]

Based on the Varley machine concept, an innovative electrostatic generator has been realized for its

application in the new DS LAT. The generator model of concern developed consists of 2 (two) concentric cylindrical tubes. The schematic diagram of the model is given in Fig. 5 and Fig. 6 presents the electrostatic generator prototype.

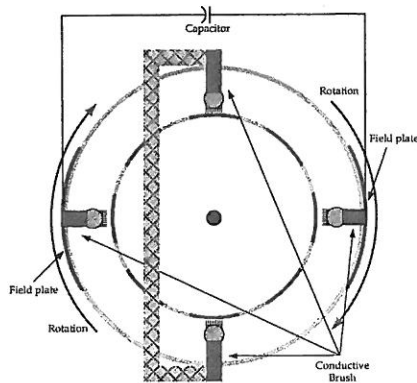


Fig. 5. Schematic diagram of electrostatic generator model

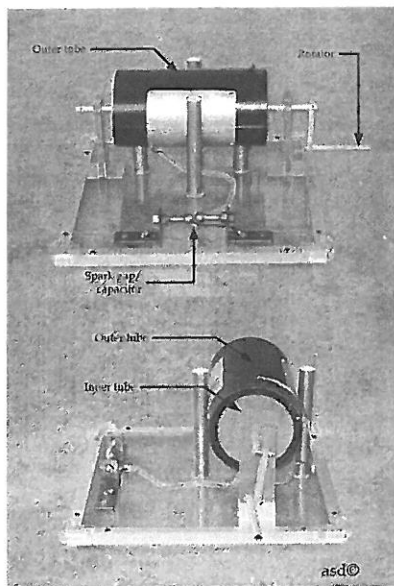


Fig. 6. Electrostatic generator model

It is assumed that initial charge on the field plates are zero. By rotating the handle and cranking it manually, the inner tubular rotor is set to motion. The movement of air through the field plates initiates flow of electrical charge to a pair of plate. In this situation each plate will possess dissimilar polarity of electrical charge; one plate is positive and the other plate is negative. Since the rotation of aluminium segment (similar pattern to rotor bar of an induction motor rotor) passes through the field plate, by induction process electrical charges will induce on these segments. For every period of rotation, two-metal-segment is connected by a pair of fixed brushes, connected to one another between them resulted in a flow of electrons. As result of that there will be different polarity charges occurring between two

aluminium segments, one is charged positively and the other is charged negatively. This process repeats itself for other adjacent metal segments for every rotation, thus increasing the electrical charge on the field plates. As the electrical charges increase on the field plates, the induced electrical charges of the rotating foil segments will also increase. Therefore, in a short time, build-up of the electrical charges occurs. The capacitor is connected across the field plates. The rotation of the disc then repeats the whole process of induction; charging the field plates and subsequently the capacitor until electrical energy accumulation enough to cause breakdown of spark gaps. The spacing of the pair of metal electrode determines the rate at which the charging and discharging take place [14].

In actual field application, wind energy is utilised to drive the rotating unit of the new DS LAT. When the wind blows at a certain magnitude of velocity, the rotating unit of the DS LAT will move.

## V.2. Computer Aided Modelling

The computer aided modelling was initiated with a series of model design sketches. These models drawings were implemented by mean of Solidworks 3D Mechanical Design and 3D computer-aided design (CAD) software. Solidworks is a new generation 3D solid modelling software. It is user friendly software easy to use for design works related to many engineering fields.

Solidworks involves each component being drawn separately and subsequently they will be grouped together to form a solid structure drawing. There are twenty four components that make up the new DS-LAT. Fig. 7 shows the new DS- LAT computer aided model. The dimension of the LAT is roughly 250-cm (diameter) and 240-cm in height.

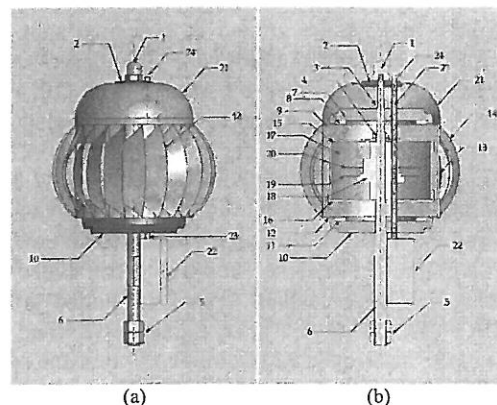


Fig. 7. Computer aided model of DS LAT, (a) Full 3-D model and (b) Sectional view. The components call-out description: 1) Blunt tips, 2) jointer, 3) nut, 4) nut, 5) nut, 6) shaft, 7) top bearing holder, 8) top bearing, 9) outer tube top cover, 10) bottom bearing holder, 11) bottom bearing, 12) outer tube bottom cover, 13) outer tube, 14) leafs, 15) inner tube top cover, 16) inner tube bottom cover, 17) inner tube, 18) disk support, 19) bottom disk, 20) top disk, 21) dome, 22) laser beam box, 23) laser-gun channel, 24) laser channel cover



In contrary from the previously mentioned electrostatic generator as shown in Fig. 6 where the moving part is the inner cylindrical tube, the new DS LAT's moving part is the exterior cylindrical tube. Fig. 8 shows the schematic diagram of the electrostatic generator being use in the new DS LAT.

A pair of field plates indicated by number 19 and 20 is embedded inside the inner cylindrical tube (number 17). Each plate is connected to a conductive brush. This particular arrangement behaves like an air-filled capacitor.

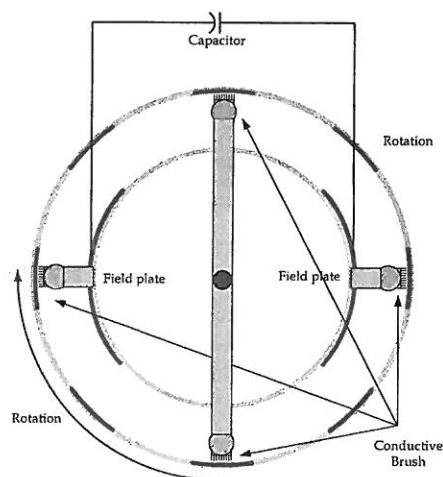


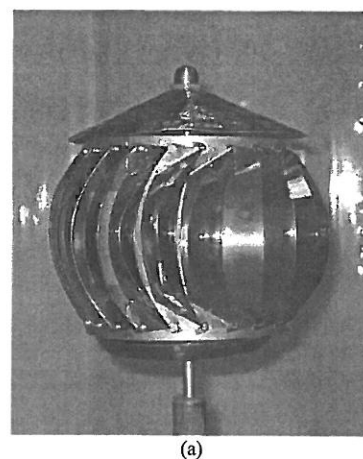
Fig. 8. Diagram of electrostatic generator applied to DS LAT

### V.3. Development of the Prototype

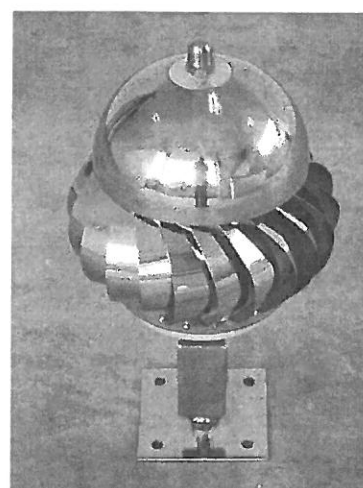
By means of computer-aided modelling, the design of two prototypes have been completed (refer to Fig. 9). Generally the new DS LAT basically consists of 3 (three) parts. The central shaft is actually the grounded lightning rod. Secondly a wind-powered rotating turbine (WPRT) encircled the rod. Thirdly a capacitor, charges as WPRT rotates. The capacitor in turn energizes the floating hemispherical metal cap. This mean that between '1' and '21' there is some form of electrical stress is taking place. Under this circumstance, free electrons will be attracted to the grounded lightning rod ('1'). The accumulation of free electrons assists in making the surrounding air more conductive to lightning strike. Combining the dimensional size, rotating blade and ionisation of air, makes the product more efficient lightning captor. Fig. 9 shows the two prototypes.

### V.4. Experimental Setup

To observe the performance of the new DS LAT numerous tests have been conducted in Institute of High Voltage and High Current (IVAT), Faculty of Electrical Engineering, Universiti Teknologi Malaysia by utilising a 2.0-MV impulse voltage (1.2/50- $\mu$ s) of 20-stage Marx generator.



(a)



(b)

Fig. 9. New direct strike lightning air terminal, (a) first prototype, and (b) second prototype

Two competitive tests were conducted to observe the performance of the new DS LAT. The competitive tests were conducted with the use of a system comprised of three main components, the HV generator, a sharp rod electrode (SRE) and a digital camera. The general setup is depicted in Fig. 10.

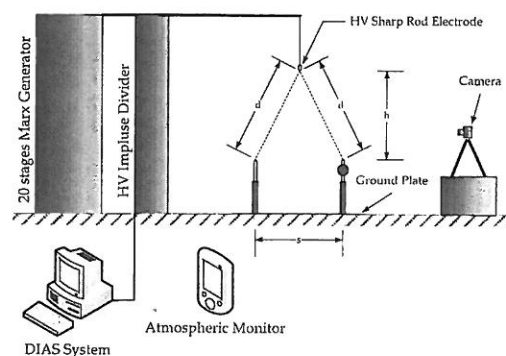


Fig. 10. General setup of the competitive tests

There were two distance settings applied to these

experiments i.e. for the first prototype the distance (d) was set to 0.5-m and for the second prototype the height (h) was set to 1.0-m.

The span interval between two LAT was set to 1.0-m. Fig. 11 shows the general experimental setup for the first prototype test meanwhile for the second prototype is given in Fig. 12.

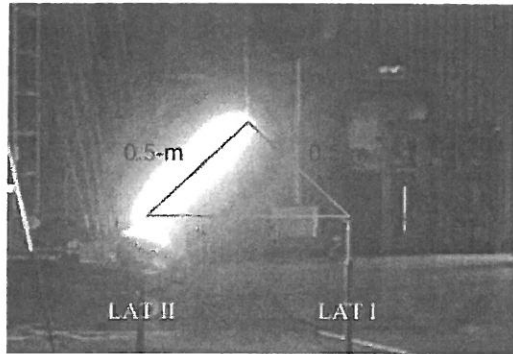


Fig. 11. Testing setup for the First prototype, showing the distance between the source injection point and the LAT connected to the competitive test

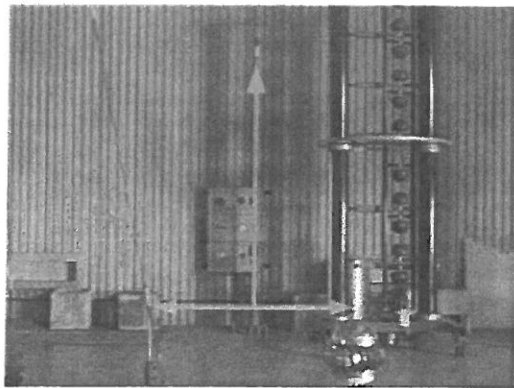


Fig. 12. Testing setup of the Second prototype, showing the distance between the source injection point and the LAT connected to the competitive test

The test samples consisted of two-rod arrangement and consider the rods alignment is at a specific point. To get better results in rod-streamer attachment, the rods alignment-position was rotated at  $45^\circ$  and swapped over to interchange their positions as shown in Fig. 13 to eliminate errors in the test results mainly due to impulse electrostatic field distribution irregularity.

Five injections of negative impulses were applied to each LATs' arrangement during the test. The voltage injected into the SRE which could result in flashover was observed by mean of DIAS system. DIAS is a computerized detection system used for high voltage test and measurement. The numbers of breakdown occurrences were observed when lightning impulse voltages were applied to LATs arrangement simultaneously. The light emitted during the discharge was captured with a 7.1-mp digital camera.

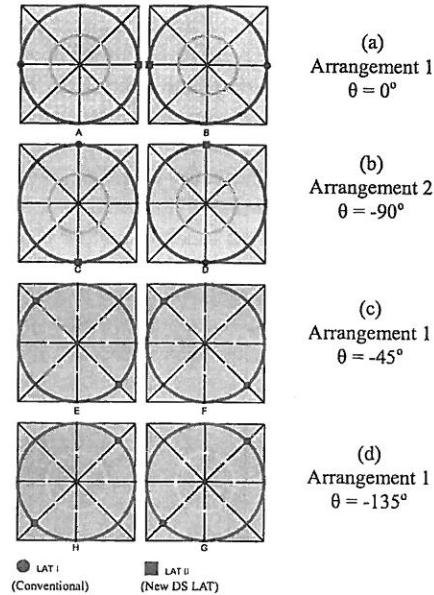


Fig. 13. Tested LAT samples positions (LAT I as reference point) for  $\theta = 0^\circ$ ,  $\theta = -90^\circ$ ,  $\theta = -45^\circ$ , and  $\theta = -135^\circ$  respectively without wind and triggered laser

### V.5. Results and Discussion

The results obtained from the tests involved a total number of 40, 800-kVshots applied to the LAT I and LAT II. The former was struck for a total of 13 times. The Fig. 14 presents details of the first prototype competitive test results. While for the second prototype test, it was found that from a total shots of 40 only 15 shots struck the LAT I as illustrated in Fig. 15.

Fig. 16 and Fig. 17 depicts the results obtained from the competitive tests involving both prototypes. Interestingly an upward streamer launched from the conventional lightning rod LAT I was captured during the process of testing as highlighted in circle as shown in Fig. 16. It was observed that lightning impulse discharge (LID) attachment on to the new DS LAT did not always strike LAT tips instead in several occasions, the LID struck the "leaves" of the new DS LAT.

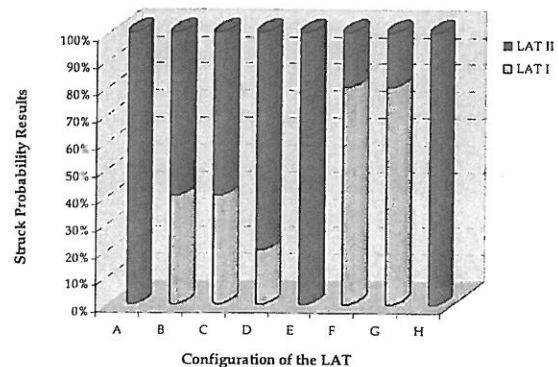


Fig. 14. First prototype testing results

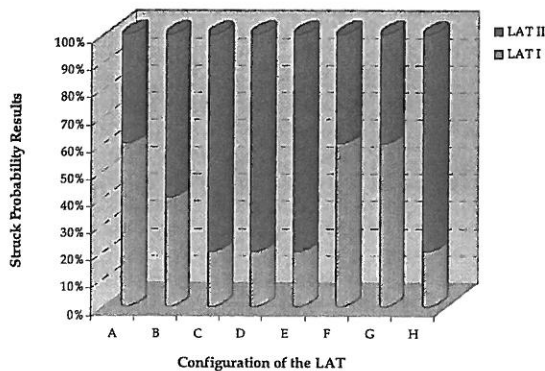


Fig. 15. Second prototype testing results

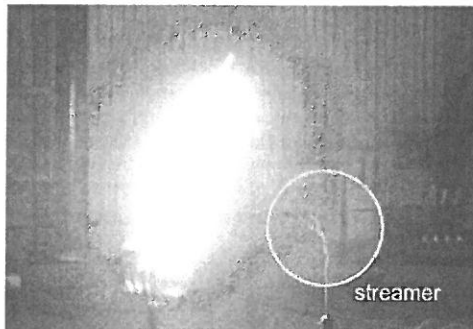


Fig. 16. The competitive test of the first prototype which saw the upward streamer development occurrence on the tip of the conventional LAT being photographed

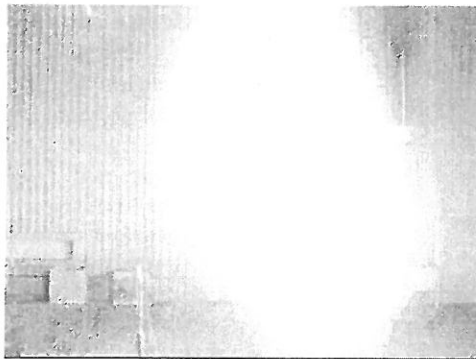


Fig. 17. A lightning impulse discharge of a competitive test for the second prototype

## VI. Conclusion

From the above overview it can be concluded that in any mode of LATs there bound to have merits and demerits. In this respect, concerning the LATs, there are two schools of taught in the methods of LPS. There are proponents and opponents for any school of taught either conventional or unconventional. The proponents of the conventional method of LPS have lost the zeal and enthusiasm to improve on the 200-years old method of LPS because it is protected by the standards. On the other hand, the proponents of unconventional LPS are

pursuing research and development affords to make their LPS technically and scientifically acceptable to the lightning scientists and engineers.

The laboratory test and experimentation has provided good picture concerning the performance of the new DS LAT. Notwithstanding, further testing yet to be conducted for various vertical distances of impulse injection point. Field observations are also necessary to be carried out to study their performance in the naturally occurring lightning flashes. This type of test is more convincing than in the laboratory exercise.

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## References

- [1] Pater Hasse, *Over voltage protection of low voltage systems, 2nd edition*, The Institution of Electrical Engineers, London, United Kingdom, 2000.
- [2] R.K. Traeger, The Lightning Arrestor Connector, *IEEE Trans. On Parts, Hybrid, and Packaging*, Vol. PHP-12, No. 2, 1976, pp 89-94.
- [3] M. Brook, C.R. Holmes, C.B. Moore, Lightning and rockets: Some implication of the Appollo 12 lightning event, *Naval Research Reviews*, 1970, pp 1-17.
- [4] Norfiza Binti Othman, Zafira Binti Abdullah, *Report On The Investigation Of Lightning Related Damages To Buildings Installed With Multipoint-Franklin-Rod*, Institut Voltan dan Arus Tinggi, Internal Report, IVAT/IR/002/2005
- [5] Jean-Claude Diels, *UNM researchers use lasers to guide lightning*, Campus News, January 2001.
- [6] V.A. Rakov, Lightning Electric and Magnetic Fields, *17th International Zurich Symposium on EMC*, 27 February – 3 March, 2006, Singapore, pp 20 – 28. 2006.
- [7] Tetsuya Tominaga, Nobuo Kuwabara, Jun Kato, Annuar Ramli, A. Halim, Hussein Ahmad, Characteristics of Lightning Surges Induced in Telecommunication Center in Tropical Area, *IEEE Transaction on EMC*, Vol. 45, No. 1, February 2003, pp 82-91.
- [8] Megumu Miki, Takashi Shindo, Yoshinori Aihara, Mechanism of guiding ability of CO<sub>2</sub> laser-produced plasmas on pulsed discharges, *J. Phys. D: Appl. Phys.*, 1996, pp. 1984-1996.
- [9] Donald W. Zipse, Lightning Protection System: Advantages and Disadvantages, *IEEE Transaction on Industry Application*, Vol. 30, No. 5, 1994, pp 1351-1361.
- [10] H.B. Ahmad, Kwang Ghee Sin, Muhammad Abu Bakar Sidik, New method to overcome physical damage of building structure using laser-aided ionization of air, *Jurnal Elektrika Fakulti Kejuruteraan Elektrik, Universiti Teknologi Malaysia*, Vol. 7, No. 2, December 2005. pp 47-56.
- [11] V.V. Appolonov, L.M. Vailyak, I.P. Vereshchagin, V.V. Glazkov, D.N. Gerasimov, I.G. Kononov, A.V. Orlov, D.N. Polyakov, O.A. Sinkevich, M.V. Sokolova, A.G. Temnikov, K.N. Firsov, Experimental Simulation of a Laser Lightning-Protection System on a Device with an Artificial Cloud of Charged Aqueous Aerosol, *Journal of Quantum Electronic*, 2002, pp 523-527.
- [12] Z.A. Hartono and I.Robiah, "Location Factor and Its Impact on Antennae Safety with Reference to Direct Lightning Strikes", in *Proceeding TENCON*, 2000, pp 351-356.
- [13] C.B. Moore, William Rison, James Maths, Graydon Aulich, Lightning Rod Improvement Studies, *Journal of Applied Meteorology*, Vol. 39, 2000, pp 539 – 609.

- [14] Charles Green, *Electrostatics Hand Book*, Hawan Sams Publication, 1973.

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