An Overview of Lightning Air Terminal: Past, Present, and Future

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***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 former performance and its scientific explanation provided by vendor has 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 aims to describe the various types of LATs that being installed on building structures, both concrete and steel type applied to electrical power system, telecommunication and communication system, and others from the time of Benjamin Franklin until now and also describing the current research going on related to the subject concern and possible technologies which can be used for future generation of LAT.**

Index terms* – *lightning protection, lightning air terminal, triggering lightning method.

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 LAT.

Lightning strokes that penetrate to human body can injure any internal organs, stopping heart function, and harm the nerve system. According to storm data recorded by the National Weather Service, in US between 1959 and 1994 there were 3,239 deaths and 9,818 others injured as a result of lightning strokes. Another storm data from National Lightning Safety Institute (NLSI) illustrate that from 1990 to 2003 there were 756 people killed due to lightning strokes. Industrial structures like petrochemical complexes, nuclear power plants, rocket-launching pad, and others may turn out to be extremely hazardous when they were struck by lightning [1].

The Indonesia oil refinery, Pertamina in Cilacap on the southern coast of Java, blown up in October 1995 as a result of lightning stroke. The refinery tank made from 10-cm plate exploded. In just few minutes the burst from the first tank was followed by the six other neighbouring tanks. Even though there was no casualty, evacuation has to be conducted for thousands of Cilacap residents and about 400 Pertamina employees. These tanks have capacity to supply about 34% of Indonesia internal oil consumption for a period of 18 months. As the result of the incidence Indonesian government had to import oil, petrol, kerosene, and diesel that worth approximately USD 430,000.00 daily for the Java island consumption. Pertamina was able to restart its own production only after about 2 (two) years after the incident happened [2].

In 1992, major power system grid in eastern Malaysia was disrupted by lightning stroke that cripple the power system across the nation. The lost of revenue was about RM 220 millions. Meanwhile, in Mexico lightning has caused more than 50% of the total outages in the transmission line 115-kV to 400-kV [3,4].

The most popular major 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 [5,6].

The threat of lightning causes many work stoppages and loss production, plus increase in time, and cost of production. Many solutions have been offered by many lightning protection system (LPS) vendors to anticipate the damage due to lightning. Yet, the problem of protection of terrestrial objects against lightning has not been solved satisfactorily so far. Appolonov, V.V. et al., [1] stated that the existing LPSs being used currently were not always in a position to ensure the desired level of efficiency.

The development and research on technologies to control or even to prevent lightning strokes still continues until the present period. As most people use many electrical devices which are sensitive to electrical system disturbances, in their daily activities. The existence and development of a reliable lighting protection system is therefore, very essential [7].

Generally lightning protection can be categorised into two different types. One is by collecting the lightning strokes, using the conventional LAT (Franklin rod) and several types of Early Steamer Emission (ESE) LAT. The latter is an LAT that generally comprises a special unit attached near the top of the terminal or special shaped LAT. According to the vendors, it is theoretically designed to develop an upward propagating streamer faster than the one generated from a conventional LAT. They claimed that with ESE, the upward streamer launched can reach up to 1×10^6 m/sec whereas the acceptable streamer speed is in the order of 10^5 m/sec.

II. LIGHTNING PROTECTION SYSTEM STANDARDS

Many standards of LPS have been published. Among which are the following standards: BS 6651 (British), NFPA 780 (American), and IEC 61024-1-2. These standards discuss and outline all 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. 1 shows that the lightning struck the building edge instead of the Franklin rod.

Fig. 1: A building structure equipped with standard rod at central and extreme edge of the building still being damaged by lightning stroke.

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 1 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 [8], concern the mechanics and dynamics of lightning leader attachment to the ground and associated structure as in Fig. 2.

Fig. 2 shows a lightning stroke initiated in 1999 from the underground launcher at the centre of 70 x 70 m^2 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. 2: Rocket Triggered Lightning (Rakov 2006)

III. THE EPILOGUE OF LAT

Franklin rod, the oldest LAT proposed by Dr. Benjamin Franklin who first thought that a terminal could silently discharged the electric charge in a thunder-cloud and thereby prevented lightning. However, in 1755 he inferred that point rods erected on buildings would conduct lightning strokes so that the building should suffer no damage. Since the charge flowing between a LAT and a thunder cloud is much too small to discharge the thundercloud. However not all scientists agreed with Franklin at that time. Some of Franklin's contemporaries believed that having a point atop the rod was either futile or sure to cause problem. One of the most eloquent critics of Franklin was Benjamin Wilson. In his opinion such rod less safe than not pointed rods. Every point solicits lightning stroke and as a result not only contributes to increase in the quantity of every actual discharge, but also frequently occasioning a discharge. Wilson believed using points would cause possibility of lightning attacks than that experienced. Alternately, he proposed the blunt rod system and referred to one installed on the new Eddystone Lighthouse. This new building was not been struck by lightning for about 12 (twelve) years, although, in the past, a difference building in the same location had been set on fire due to a lightning stroke [9].

Wilson is supported by Edward H. De Laval on the issue of the futility of trying to drain a cloud of its charge. De Laval revealed that the quantity of lightning, which could be drawn from large thunderclouds by mean of conductor, was so very small a part of the whole contained in them, that any attempts to exhaust them had to be looked upon as altogether vain [9].

However, after that period new innovations or inventions in conjunction with the LAT shapes and concepts are not found in any published literatures until the early of nineteenth century.

It is Szillard, J.B, who presented his paper to the Academy of Science in Paris, on March 9, 1914, came with new idea concerning of LAT. His idea became a foundation for the use of ionisation method for lightning protection innovation. Later on in 1931, Gustav P. Carpart patented the first ionising LAT. Gustav's son, Alphonse Capart, in 1953, started to improve the device and commercialised his development [10]. The LAT is equipped with ionisation generator supposedly ionise the air molecules in the immediate vicinity of the LAT continuously, with or without the presence of a storm cell. The ionisation generator is radioactive material. This kind of LAT also referred then as ionising or radioactive LAT.

However, in 1965 the British Standard Committee as described in BS CP 326:1965 rejected the use of radioactive LAT. Afterwards the use of them was banned in many countries due to the possible human exposure to harmful radiation.

Starting in the 1980s, the LATs encompassed with electrical triggering device were introduced. In principle, their purpose is the same as a radioactive source. However, unlike a rod equipped with a radioactive source that causes continuous ionisation in the surrounding air, they give more control over ion production at the tip of the terminal at which the electrically triggered device produces ionisation only during a brief period prior to the lightning stroke. They also avoid the health and environment issues that are associated with radioactive device but the information about the duration and extent of this ionisation could not be found. The manufactures of this terminal claimed that the device can improve the probability of initiating an upward streamer to connect with downward propagating leader of a lightning stroke. It means that the first streamer reaches the thermal stage before others; therefore this terminal is namely as ESE LAT.

It is found that at present there are three methods in producing the electrical triggering for lightning terminal. They are base on geometrical configuration, by using an auxiliary power apparatus, and by means of a piezoelectric device.

Basically the principle of the geometrical configuration based LAT is to absorb the ambient electrical energy. The energy which is acquired from the electrical field intensity during the approach of a lightning stroke is used to charge a capacitor which is subsequently used to generate sparks discharge to the nearby grounded rod. From published literature, it is found that the energy absorber can be a set of sensor in a sharp form, or a floating semi-spherical dome.

The auxiliary power apparatus based LAT uses batteries and photo cells to produce voltage pulse, and a detector that sense the approach of a downward propagating leader. The detector produces an electrical signal proportional either to electric field or rate-of-change of electric field produced by approaching leader.

The LAT which incorporated with piezoelectric device was patented by Robert Andre, et al [11]. This lightning conductor pole put on a support fixed by using a ball. Under the action of the wind, the pole moved out of the vertical position until a shoulder abuts against a flange of the support. With the wind continuing to act on the pole, the latter applied a considerable force on the support. The reaction force or torque was transmitted to the piezoelectric device by using the ball. Even though this type of terminal is now available commercially [12], there are very little published information about performance of the lightning terminal with the piezoelectric device.

However, a complete and universally accepted understanding of how ESE LATs work has not yet been achieved. Proponents of the ESE LATs claimed that the lack of credible statistical data on failure of these LATs prove their effectiveness, while opponents of these LATs argue that a lack of evidence about the improved performance of these terminals over conventional terminals prove their ineffectiveness.

Hartono and Robiah [13] published a study upon some buildings in Kuala Lumpur and Shah Alam, Malaysia provided with ESE LATs. By using lightning interception prediction method they acquired the pre-strike and post-strike photographs of the affected building. Based on this study they proved the failure of ESE LATs to provide the enhanced protection as claimed by the proprietors.

In United State the issue of ESE brought the proponents and the opponents of ESE to court. In 1998, the NFPA agreed to re-open the study to determine whether any new information behind the claims made by ESE vendors and continued by the NFPA upheld their 1995 rejection of the proposed NFPA 781 standard, in 2000. The ESE vendors then sued those who claimed that the vendors are making false advertising by claiming that the ESE lightning rods have large protection radii.

On October 7, 2005, the United States District Court of Arizona issued an injunction which prohibits the vendors of ESE can provide range of their gadgets exceeds that of a Franklin rod. The order also dismissed all claims of the vendors of ESE gadgets and granted the counterclaims of all dependents.

Another type of LAT categorised as preventive method of lightning protection is known as Charge Transfer System (CTS) LAT. The history of CTS concept started in 1754 when Czech scientist, Prokop Divish, proposed the idea of using multi point discharge to neutralise cloud charge in other to prevent lightning strokes. Since that period the concept of CTS has become an issue among scientist until today. Though, J.M. Cage, a southern California resident who was an oil-field worker, patented a multipoint discharge system to prevent lightning stroke in 1930. The systematic commercialization of the CTS, however, started in 1971. A prototype was designed and the application of CTS began to be marketed by Roy Carpenter, Jr. The explanation of working principle and theory behind the CTSs can be found in some published papers [10,14,15,16,17,18]. Although the manufacturers of CTS proclaimed that the CTS are developed on the basis of physical theories; however, the laboratory tests and some field observations have proved that CTS cannot prevent a lightning strokes at all [19].

When in the earliest Franklin proposed the application of a sharp rod for LAT some scientists like Wilson and De Laval proposed the use of a blunt rod, instead a sharp rod, for prevention of building from lightning strikes. In contrast, a report from Moore, C.B., et al [20] suggesting that is moderately blunt rods in certain ratio of tip height to tip radius of curvature is better lightning receptors than sharper rods or very blunt ones. That was inline with the results obtained by Ong L. M., et al [21] that had proved the effectiveness of blunt rod compared to the other 5 (five) difference tip LATs.

IV. LASER-TRIGGERED DISCHARGES

Einstein, in 1917, introduced the concept of stimulated emission. After forty years later, Schawlow and Townes gave the idea about light amplification of stimulated emission radiation (laser). In 1960, Maiman succeeded to demonstrate the first laser produced from ruby rod in laboratory of Hughes Aircraft Company, California. It was a pulse laser, 694.3-nm, namely ruby laser. Koopman and Wilkerson [22] conducted an experiment in which a long electrical spark discharges was directed through air along predetermined paths defined by a concentrated laser beam. He founded that the average E field required to obtain a discharge between electrodes was reduced from 7.3- kV/cm to 5.5-kV/cm with the laser powers employed.

In 1974, Ball, L.M. [23] suggested a possibility of the application of a laser lightning rod. Schubert, Jr., and Lippert [24] presented an experimental model of the laser lightning rod with pulse laser.

Laser guided discharge is very different from those of unguided discharges. Laser could reduce the flashover voltage of a gap. This phenomenon is associated to the trigger effect of laser. When a high power laser beam was focused in air, a high degree of ionisation was produced in brilliant bead at the focus [25]. This is a well-known phenomenon called optical breakdown. If the power of the laser is high enough a chain of air breakdown plasmas are produced along the laser beam. The stepped progression of the negative leader along laser produced plasmas required only a small electric field. [25]. Bruno, et al [26] described that further simplification were brought about by using as little laser energy as possible while maintaining a triggering ability, so that the plasma heating was kept to a minimum.

The experimental results indicated that negative electrical discharges were appropriate to be guided by the laser-produced by the laser produced-plasmas. Floating particles had an ability to guide electrical discharges, especially in the case of a negative polarity [27]. Comtois, D., et al [28] reported that laser pulse could initiate a corona at the tip of the positive rod and instantaneously trigger leader propagation, at voltage that could be 30% lower than the normal minimum inception voltage of the first corona. This technique was potentially very interesting because the natural breakdown voltage could be significantly reduced, the discharge could be precisely located in space and time, and it could be initiated from a distance [26].

The mechanism of the guiding ability of the laser could be explained by the behaviour of the plasma as a conductor [29]. 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 [10].

The laser beam can guide a lightning leader while it developed toward the earth. The laser beam will function as a conductor from cloud the ground and will be terminated through a down conductor and a grounding system. Triggered lightning strokes by using laser were successfully achieved during the field experiment on the Sea of Japan. It was found that timing was critical to successfully drawing the lightning strokes in that system [30]

By using laser, instead of the lightning strokes travel in a zigzag motion it will travel alongside the laser beam path and hit ground at a define spot. One of good achievement in conjunction the laser trigger experiment was made by Ahmad, H. B., et al [31], when they carried out a set of test to compete the laser triggered LAT and non-triggered LAT by using 2.0-MV Marx impulse generator. It was reported that the performance of laser triggered LAT was better in intercept the discharge then non-triggered LAT. It was assumed that 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 [1].

V. DISCUSSION

It is realised that lightning is complex and chaotic phenomenon. Lightning exhibits a broad range of behaviours and characteristics that are some times unpredictable.

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 system utilizing intense laser beams to guide a leader discharge is possible become a promising and appropriate technology of LPS in the future.

According to the previous works that accomplished by Ahmad, H.B., et al [31], found that even by using a small laser system, the conventional LAT equipped with laser system is more prone to strike then non equipped LAT. By using the laser aided system the striking distance of LAT can be increased. This is analogues to what has been reported by Hartono and Robiah [32] that practically in Japan, Franklin rod of great length being installed on their building structure. 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.

VI. CONCLUSION

This paper has presented an overview of LATs that in any form of LATs there bound to have merits and demerits. However certain LAT is definitely cannot be accepted just because of mere concern of controversies (standard or non-standard) but rather the actual scientific explanation of some of them unacceptable in term of fundamental of physics like in the case of ESE LAT. There is promising future for LAT with the use of laser-triggered system to capture lightning.

VII. REFERENCES

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Site survey done in 2003 by a group of researchers from Universiti Teknologi Malaysia (UTM) on buildings installed with CVM in Klang Valley showed that they have being hit by lightning stroke. The readings registered by the lightning strike counters concern provide a positive indicator of its performance. One of the data set obtained from the survey was of LPS AM Finance Building,No. 8, Yap Kwan Seng, Kuala Lumpur dated 15 April 2003 endorsed by Mr Ramesh Kumar, Building Manager, the register of the lightning strike counter was 15. Similar incidents happened when the lightning strike counter of Public Bank, No 146, Ampang Road recorded 12 strokes to the building which was endorsed by the personnel of Property Division.