Study on Corona Discharge of Conventional Lightning Air Terminals

Muhammad Abu Bakar Sidik, *StMIEEE* and Hussein Ahmad, *MIEEE*
Institut Voltan dan Arus Tinggi (IVAT)
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
81310 Skudai
Johor Darul Takzim
Malaysia

***Abstract*— A lightning air terminal (LAT) tip can be damaged under prolonged period of service due to harsh environmental conditions among those is the impact of acid rain. The altered LAT tip profile will ultimately produce different corona discharge pattern which can influence the performance of the LAT itself. This paper presents a new closed loop mathematical modelling which can simulate the magnitude of corona discharge currents of various LAT tip configurations ranging from the typical standard electrode practice in Malaysia, concave-shaped, conical-shaped and flat-shaped as well the blunt-shaped tip under the excitation of high voltage DC. The finding strengthened the fact that the blunt-shape LAT attracts more lightning leaders attachment than the sharp-tip LAT.**

I. Introduction

THE corona discharge mechanism under a static electric field is one of the parameters to assess lightning air terminals (LATs) performance. The static electric field strength build-up between the thunder cloud base and the ground passes the minimum value of the dielectric field strength of air causes the propagation of downwards streamers from the cloud base towards the ground after the occurrence of in-cloud corona activities. Interestingly Moore et al., [1] have conducted experiments to study the comparative competitiveness of a sharp and blunt Franklin air terminal. They found that the blunt rod attracts more lightning leaders attachment than its counterpart. The reason for this to happen is due to the amount of pre-stroke space charge accumulation around the LAT to enhance its ability to initiate and sustain an upward leader [2]. Similar study conducted by Alessandro [3] concerning corona discharge from LATs by using two types of lightning air terminal, e.g. Franklin rod and ellipsoidal LAT to qualitatively study corona discharge phenomenon on the rods' tip. The most recent studies on the comparative competitiveness of various shape LATs was conducted by Ong et al. [4]. They found that the blunt tip LAT has the lowest Critical Flashover Voltage comparing with the standard rod and non-standard tip configuration such as the concave-shaped, conical-shaped and flat-shaped electrode. This paper describes in details the development of a closed loop mathematical model based on the study of corona discharges on the various electrodes which were used in the experiments conducted by Ong et al., in the afford to improve the analysis of the performance of those electrodes under the high voltage DC stresses.

II. Experimental Setup

This study was conducted in two parts. The first part of the works was to carry out experiments to study on the corona discharges on the tips of LATs which involves the measurement corona current and capturing the pre-breakdown streamers of corona phenomenon. The second part was developing a mathematical modelling which leads towards the success of obtaining a closed loop mathematical equation.

The high voltage facilities of the Institute of High Voltage and High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia were used for the corona studies. Basically the system consisting of 230V/100-kV, 5-kVA transformer and a rectifier circuit for high voltage DC generation by means of two 140-kV, 8-kW rectifier diodes and a 25000-pF smoothing capacitor. A rod-and-plane electrode configuration was used to analyze the corona activities. To affect the plane the HV source was connected to steel hollow disc plate of 17-cm in diameter via a high voltage lead. The atmospheric conditions were monitored throughout the execution of the corona studies by means of a weather station Oregon Scientific BAA913HG device. The corona discharges signatures were captured using LeCroy oscilloscope LT344L 500-Mhz DSO. The scope has 4 channels for detection and measurement purposes, and a GPIB port for external connection with a computer for data transfer. Figure 1 shows the various types of LATs used in the experiments. Each electrode in turn was placed beneath the HV side plane electrode with gap clearance of 3.0, 3.5, 4.0, 4.5, and 5.0 cm in length respectively.

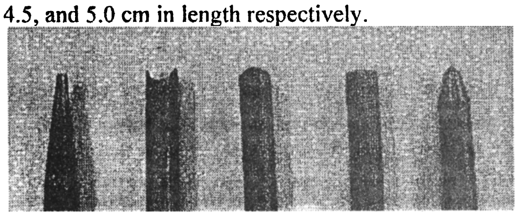


Figure 1. Various types of LAT

III. Experimental Procedures

Corona discharges are best investigated using rod to plane electrode configuration where the rod radius is chosen according to the field non-uniformity desired. For the negative DC voltage three modes of corona discharges are involved that is onset streamer, negative glow, and pre-breakdown streamer. In this case the pre-breakdown streamer mechanism was studied. The general characteristic of the discharge current is in the order of tens of nanoseconds for the front time, whereas the tail time is in the order of 100 nanoseconds, and pulse repetition rate is in the order of kHz.

By gradually increasing the power frequency main voltage, affect the output high voltage DC and when continuous discharge of pre-breakdown streamer commenced after the emergence of negative glow and onset streamer, the voltage increment was stopped. At this point of time, the output voltage of the resistive divider and the peak corona discharge current was observed and recorded.

The observations of the corona discharge current were conducted with the attachment of LATs under test to the experimental rig grounding system via a 1.2-kΩ resistor. Therefore for 1-V measured across the resistor corresponds to 0.833-mA of corona discharge current. For surge protection in case there shall occur unexpected breakdown of air insulation, a metal oxide varistor was connected shunting the resistor. To reduce the noise interference level the measuring shunt resistance was enclosed in metallic box with effective shielding properties against electromagnetic interference. The experimental set-up can be seen in Figure 2.

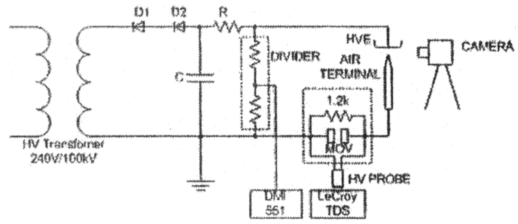
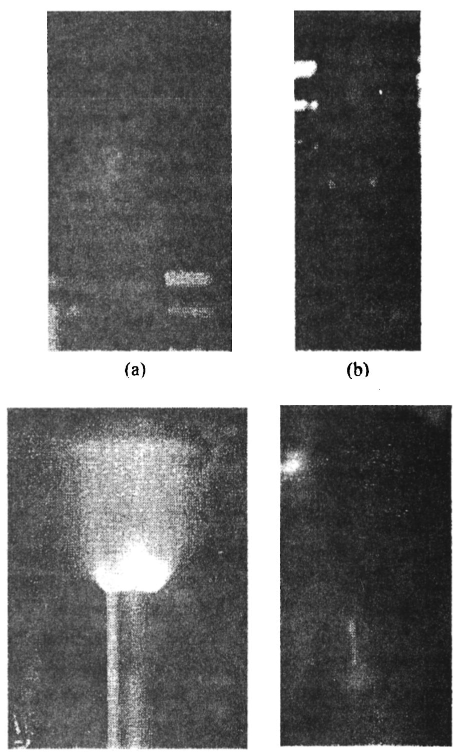


Figure 2. The experimental set-up

IV. Results and Discussions

The photographic details of the corona discharges patterns can be seen in Figure 3.



(a) (b)

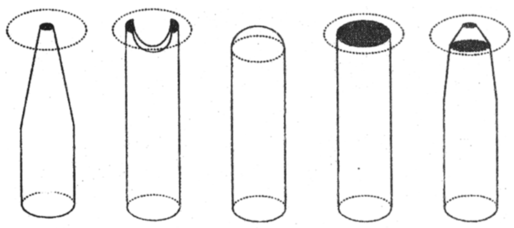
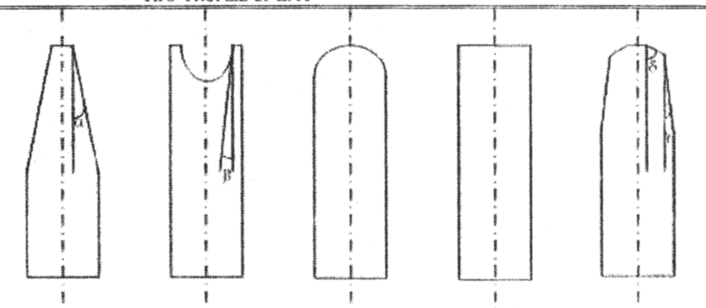


Figure 4. The area of LAT that produce corona discharge current.

It is obvious that the corona discharge current will not occurred on the blunt LAT because A is zero.

Closer analysis of tips' profile show the included angle of the tip could be a parameter for classifying the severity of pre-breakdown streamer activities as shown in Table 1.

TABLE 1
TIPS' PROFILE OF LAT

The LATs					
Included angle (°)	90+α	90+β	0	90	90+δ+γ
Area (mm^2)	12.57	0.85	0	37.70	21.99

V. DIMENSIONAL ANALYSIS

This section describes the development of a mathematical model by using dimension analysis to obtain the closed loop equation. The corona discharge current (I_{cd}) depends on a number of parameters that have significant contribution. The important amongst them are permittivity (ε), time (T), area of tip that produce corona (A), distances (d), and input voltage (V). A mathematically relationship between the I_{cd} and the parameters can be presented in the form,

$$I_{cd} = I_{cd}(\varepsilon, T, A, d, V) \tag{1}$$

When the parameters in equation (1) are written in terms of four fundamental dimensions; length (L), mass (M), time (T), and electric charge (Q), the corresponding dimensional matrix is

	I_{cd}	ε	T	A	d	V
M	0	-1	0	0	0	1
L	0	-3	0	2	1	2
T	-1	2	1	0	0	-2
Q	1	2	0	0	0	-1

(2)

The rank (r) of dimensional matrix is 4, and the number of parameters (n) is 6. According to Buckingham-π theorem a solution can be presented as (n-r) = 6 - 4 = 2 independent dimensionless product (π_x). Then the dimensional matrix can be written in the form:

	ξ_1	ξ_2	ξ_3	ξ_4		
	I_{cd}	ε	T	A	d	V
M	0	-1	0	0	0	1
L	0	-3	0	2	1	2
T	-1	2	1	0	0	-2
Q	1	2	0	0	0	-1

(3)

where ξ_1, ξ_2, ξ_3, and ξ_4 are the indices of the variables in equation (1) as repeating variables.

The dimensional expression for π_1, and π_2;

$$\pi_1 = I_{cd}^{\xi_1}\varepsilon^{\xi_2}T^{\xi_3}A^{\xi_4}d \tag{4}$$

$$\pi_2 = I_{cd}^{\xi_1}\varepsilon^{\xi_2}T^{\xi_3}A^{\xi_4}V \tag{5}$$

As the π groups are all dimensionless $M^0L^0T^0Q^0$ the principle of dimensional homogeneity to equate the dimensions for each π can be used. Then a set of dimensionless products are introduced.

$$\pi_1 = A^{-0.5}d \tag{6}$$

$$\pi_2 = I_{cd}^{-1}\varepsilon T^{-1}A^{0.5}V \tag{7}$$

According to Buckimham's Theorem, the dimensionless parameters are related by function

$$\phi(\pi_1, \pi_2) = 0 \tag{8}$$

Finally, the model of corona discharge current can be presented as:

$$I_{cd} = D_c\left(\frac{\varepsilon AV}{Td}\right) \qquad (9)$$

where D_c is a dimensionless constant that will be determined from the experiments.

The peak to peak of corona discharge current average against the HV input per centimetre of distance and the corona discharge current model for standard, concave, flat, and conical LATs are shown in Figure 5 to Figure 8. The uncertainty ranges are within ±0.5-mA. Corona discharge current developed on the blunt LAT, however, was so small which can be neglected. The model and the experimental results are in agreement.

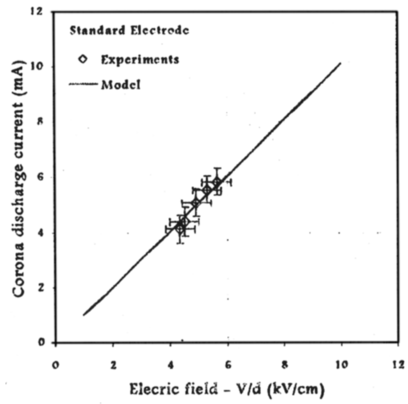


Figure 5. Electric field versus corona discharge current of Standard LAT.

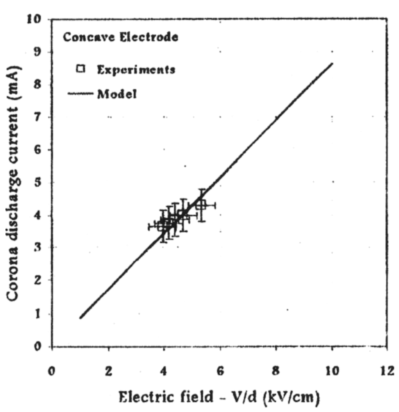


Figure 6. Electric field versus corona discharge current of Concave LAT.

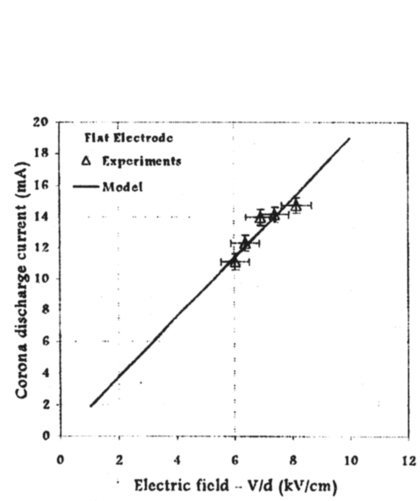


Figure 7. Electric field versus corona discharge current of Flat LAT.

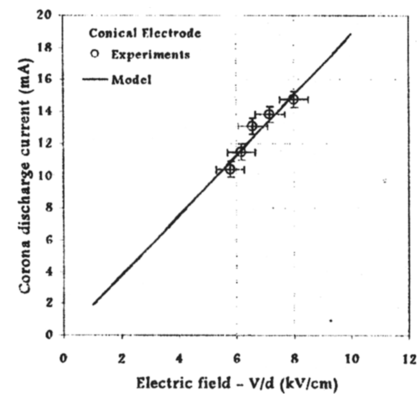


Figure 8. Electric field versus corona discharge current of Conical LAT.

VI. CONCLUSION

From the observation of the corona discharge a new closed loop mathematical modelling has been developed by applying dimensional analysis which can simulate the magnitude of corona discharge currents involved. The standard Franklin rod used in this work is a typical Franklin rod practically installed in Malaysia. Again, the finding strengthened the fact that for better capturing of lightning leaders, blunt tip LAT is preferable.

REFERENCES

[1] C.B. Moore, William Rison, James Maths, and Graydon Aulich, "Lightning rod improvement studies," *Journal of Applied Meteorology*, Volume 3, pp. 593-609, May 2000.

[2] W. Rison, C.B. Moore, and G.D. Aulich, "Lightning air terminal – Is shape important?," in *Proc. International Symposium on EMC*, pp. 300 – 3005, August 2004.

[3] F.D. Alessandro and G. Berger, "Laboratory studies of corona emissions from air terminals," *J. Phys. D: Appl. Phy.* 32 pp. 2785-2790, September 1999.

[4] L.M. Ong, H. Ahmad, and N.A. Idris, "The Performance of damaged franklin rods,", in *Proc. VIII International Symposium on Lightning Protection*, Sao Paulo, Brazil, pp. , November 2005.