An Account of A Modified Lightning Protection System For Power Stations.

H. Ahmad, *Senior Member, IEEE*, and L. M. Ong

Abstract- **Power stations may face huge losses and damage when struck by lightning. Much effort has been carried out to find an alternative to the conventional lightning air terminal for direct protection to power stations. One of the alternative is to modify the tip configuration of conventional air terminals to enable it to be better inceptor. This paper looks into such possibility by designing and testing different tip configuration air terminals, i.e. sharp, blunt, flat, conical and concave. Tests in high voltage laboratory revealed that blunt air terminal has lower breakdown voltage and longer time to breakdown compared to other air terminals. This suggests that the performance of blunt rod is better than other rods. Based on the laboratory experimental studies, the modification of air terminal geometrical tip could be an alternative for future application specifically for the lightning protection of power stations against direct strokes.**

Index Terms**—Lightning protection system, modified Franklin rod, breakdown voltage, time to breakdown, number of strikes.**

I. Introduction

EACH year, lightning causes massive blackout everywhere around the world when power stations are struck by powerful lightning. When this happens, many sectors especially the manufacturing industry is affected and suffers huge losses due to power outage. Needless to say, fingers are pointed to the local electricity utility company. Thus, this is a problem worth solving to save millions of dollars in the long run.

In Malaysia, lightning return stroke carries with it high magnitude current in range of 4kA to 300kA. In the case of lightning strike to the power stations, the current is directed to ground by means of lightning protection which is installed on them. Along its path to the ground, there will be a possibility of ground potential arising due to the existence of high impedance discontinuities in the path taken by the lightning current discharges to the ground. When there is potential difference between the points, side flash may occur and it may create sparking which in the worst condition will set the power stations on fire and eventually causes explosions, endangering the lives of many. Most of the current lightning protection system installed in power stations in Malaysia is still the conventional lightning rod. Interestingly, most of the country's power stations are on the coastal areas of the Peninsular. In the state of Terengganu Darul Iman, YTL Thermal and Paka Thermal Power Station are found. While in the state of Johor Darul Takzim, Pasir Gudang Power Station is one of the major landmarks of the state [1]. By virtue **of** their locations, which are close to the sea, the lightning rods installed are prone to corrosion due to high density of salt. In the long term, the effectiveness of the air terminal will deteriorate or will be damaged when struck by direct powerful lightning. The rod which intercepts the leader can be forced out of its base and sometimes broken into two parts.

The question to be asked here is whether the damaged air terminal can still perform as a LPS or otherwise, assuming replacement of LPS is not done on time which allows sufficient time for subsequent lightning strike to happen on the same point of the concerned power station.

H. Ahmad is with the Institute of High Voltage and High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor. (e-mail: hussein@fke.utm.my).

L. M. Ong is with the Institute of High Voltage and High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor. (e-mail: laimunong@yahoo.com).

II. Design Of Air Terminals

Due to the fact that the 200-year-old "technology" of Franklin rod, when intercepted by lightning, may be damaged or physically changed in its tip configurations, a few non-standard configurations like concave, flat and conical tip were designed on top of the standard, sharp and blunt air terminals. The six air terminal designs are shown in Fig. 1.

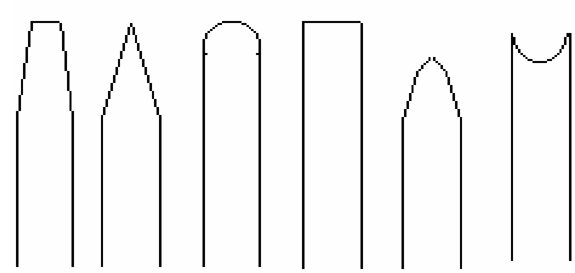


Fig. 1. Different configuration of air terminals. From left to right: Standard, sharp, blunt, flat, conical and concave.

Another justification for changing the configuration of the air terminal tip is to discover possible better improved lightning protection devices.

III. Laboratory Testing

The designated air terminals were tested in two stages to determine the performance of each air terminal in conditions without ionization. The first stage involved the testing of air terminals individually to obtain voltage flashover and time to breakdown. The second stage of test involved competitive testing of air terminals to obtain the number of strikes per air terminal.

Both stages were accomplished in the High Voltage laboratory of Universiti Teknologi Malaysia (UTM) by applying negative standard lightning impulse voltage (1.2/50 μs) from a 2MV, 20 stage Marx Generator. Negative voltages were applied in all experiments to simulate a possible near to real actual lightning discharge due to the descent of the downward leader. This is due to the fact that most thunderstorms accumulate an excess of negative charges in their lower regions Thus, the polarity of the induced charges on lightning rods, air terminals and other objects exposed to the resulting electric fields at the Earth's surface is usually positive [2].

All testing were carried out under almost similar atmospheric condition to avoid inaccuracy in results. The influence of humidity is neglected as its influence (an increase in breakdown voltage with increasing humidity) is unlikely to exceed 2 or 3% over the range of humidity normally encountered in laboratories [3].

A. Stage 1: Individual Testing Of Air Terminals To Obtain Voltage Breakdown And Time To Breakdown

The objective of this stage is to determine the voltage breakdown and time to breakdown of the various types of conventional air terminals.

1) Experimental setup and procedures

The air terminals were set at 1m height above ground. A gap of 2m was chosen from tip of air terminal to impulse electrode because according to [4], the practical air gaps for which a stable corona discharge is self-sustained is in the range 2–4 m to give the best scaling to natural conditions. The experimental setup is shown in Fig. 2.

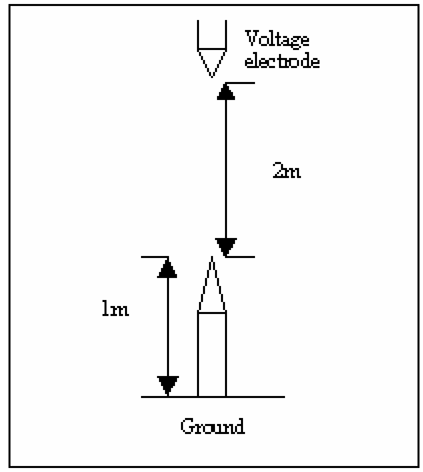


Fig. 2. Experimental arrangement of individual testing of air terminals.

1 air terminal was tested per experiment and 10 data was taken per air terminal. 2 sets of tests were carried out to obtain more accurate results. TABLE I shows the ambient temperature and pressure for two sets of tests.

TABLE I
AMBIENT TEMPERATIRE AND PRESSURE FOR TWO SETS OF TESTS

Type	Set 1		Set 2	
	Ambient Temperature (^{0}C)	Pressure (mb)	Ambient Temperature (^{0}C)	Pressure (mb)
Blunt	26.9	1006	29.4	1004
Sharp	28	1003	26.4	1009
Flat	27.3	1005	26.8	1009
Conical	27.8	1006	26.8	1009
Standard	26.1	1004	26.8	1009
Concave	26.8	1004	26.8	1009

The voltage breakdown and time to breakdown for each air terminal were recorded using Digital Impulse Analyzing System (DIAS). The up and down method in [5] was used to determine the voltage flashover (V_{50}) of each air terminal. For this method, a starting voltage (V_j) close to the anticipated flashover value is selected. Then, equally spaced voltage levels (V) above and below the starting voltage are chosen. The first shot is applied at the voltage V_j. If breakdown occurs, the next shot is applied at V_j - V. If the insulation withstands, the next voltage is applied at V_j+V. The V_{50} value is calculated using either the withstand or the breakdown events in which the smaller of the two should be used.

By calibrating the impulse system to obtain accurate values, the V_{50} obtained is converted to the DIAS reading (V_{DIAS}) and then converted to the actual voltage breakdown value ($V_{actualbreakdown}$). The equations for conversion are as below:

$$V_{DIAS} = 0.9304V_{50} + 36.598 \quad (1)$$

$$V_{actualbreakdown} = 1.0797V_{DIAS} - 61.298 \quad (2)$$

B. Stage 2: Competitive testing of air terminals to obtain to obtain number of strikes.

The objective of this second stage is to investigate the competitive performance of air terminals by taking into account the number of strikes per air terminal.

1) Experimental setup and procedures

The air terminals were arranged 2m apart from each other with an average distance of 2.24m. The test arrangement of air terminals is shown in Fig. 3.

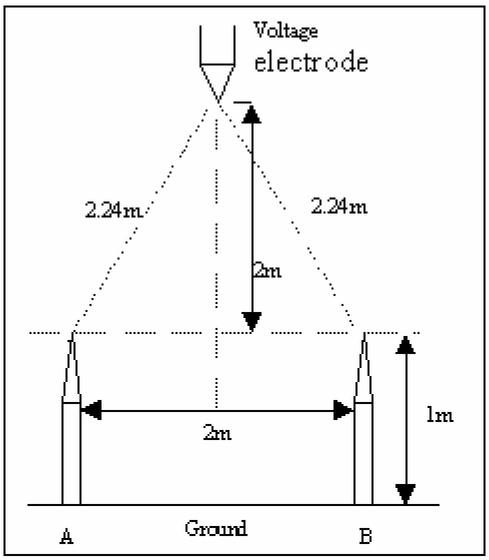


Fig. 3. Competitive method of testing via interchanging air terminals to obtain number of strikes per air terminal

A steady and similar voltage breakdown of 1653kV was applied to every pair of air terminal being tested under the ambient temperature of 25.4^0C and pressure of 1006 mb. After 10 sets of data, the position of the air terminal was interchanged (Rod A at position B and Rod B at position A) and another 10 sets of data were recorded. The number of strikes per air terminal over a total of 20 sets of data were recorded

IV. RESULTS

A. Stage 1: Voltage Breakdown And Time To Breakdown Of Individual Testing

The results obtained in stage 1 are presented in TABLE II

TABLE II
VOLTAGE BREAKDOWN OF INDIVIDUAL TESTING

Type	Set 1 (-kV)	Set 2 (-kV)	$\Delta V = \lvert V_1 - V_2 \rvert kV$
Blunt	1472.31	1453.04	19.27
Standard	1473.07	1462.58	10.49
Sharp	1481.85	1471.93	9.92
Conical	1491.40	1472.31	19.09
Concave	1501.32	1478.04	23.28
Flat	1510.49	1481.85	28.64

Analysis of results in TABLE II is represented by Fig. 4.

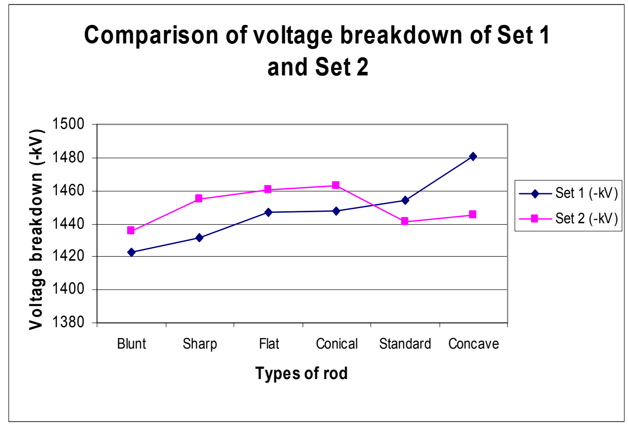


Fig. 4. Graph for voltage breakdown analysis

In set 1, the order of rods from lowest to highest breakdown is blunt, sharp, flat, conical, standard and concave but in set 2, the order of rods from lowest to highest breakdown is blunt, standard, concave, sharp, flat and conical. The lowest breakdown voltage for both sets is blunt rod. Blunt rod also has the lowest differential in voltage breakdown for both sets of tests that further substantiate the consistency of blunt rod's performance.

It is shown that for both sets of tests under condition without ionization, the voltage breakdown for all the rods are not consistent. However, both sets show that blunt rod has the lowest voltage breakdown and lowest differential in its voltage breakdown.

TABLE III
TIME TO BREAKDOWN OF INDIVIDUAL TESTING

Type	Set 1 (us)	Set 2 (us)	$\Delta T = \lvert T_1 - T_2 \rvert$
Blunt	12.65	12.24	0.41
Sharp	10.75	12.15	1.40
Flat	11.71	10.31	1.40
Conical	11.23	10.26	0.97
Standard	12.64	11.53	1.11
Concave	8.37	11.87	3.50

Analysis of results in TABLE III is represented by Fig. 5.

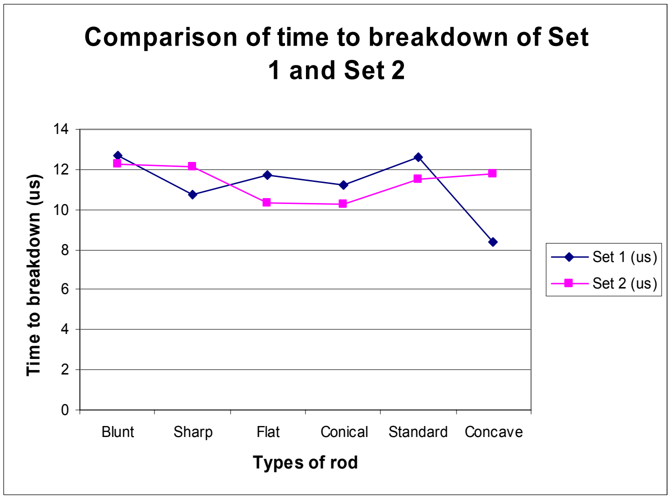


Fig. 5. Graph for time to breakdown analysis

Blunt has the least deviation of average time to breakdown. This shows that the time to breakdown of blunt rod is more consistent with no significant difference between the two sets of tests.

B. Stage 2: Number Of Strikes Per Air Terminal For Competitive Testing

To further enhance the result of this research to ascertain that the blunt rod is the best performance rod, competitive studies were conducted between blunt and sharp and between blunt and standard. Only sharp and standard rods were chosen for this competitive study because according to the results obtained, sharp rod is second best to blunt. The standard rod is chosen as it is commonly used as a lightning air terminal in the market today.

The results for competitive testing between blunt and sharp and blunt and standard are shown in TABLE IV.

TABLE IV
NUMBER OF STRIKES AND PERCENTAGE OF STRIKES

Types of comparison		Number of strikes	% of strikes
Sharp and blunt	Sharp	8	40
	Blunt	12	60
Standard and blunt	Standard	6	30
	Blunt	14	70

Analysis of results in TABLE IV is represented by Fig. 6.

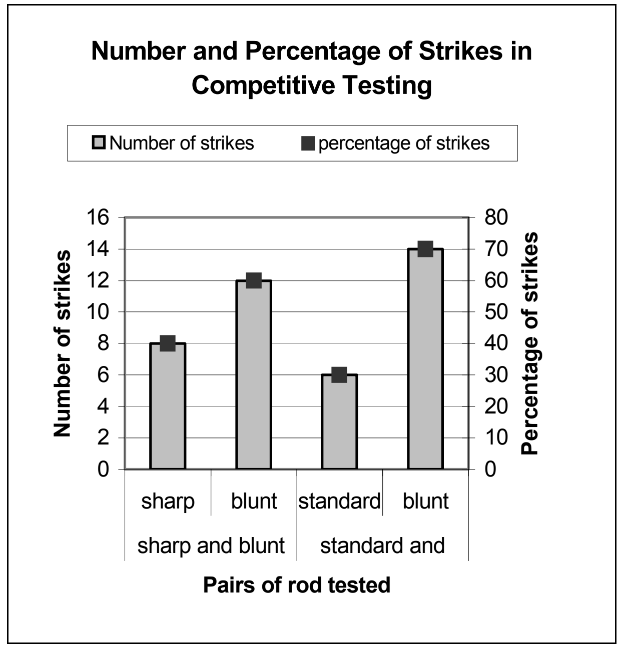


Fig. 6. Graph for competitive testing analysis

From TABLE IV and Fig. 6, the blunt rod has higher number and percentage of strikes compared to sharp and standard. The number of strikes for blunt is 20% and 40% higher than the sharp and the standard rod respectively. These results further substantiate that the blunt rod is a better performance rod over the sharp and standard rod as discovered in Stage 1, thus is also the best performance rod among other rod geometries.

V. DISCUSSION

The results obtained showed that the blunt rod is better than other rods and even better than the widely used sharp and standard rod. These laboratory results are compatible and in line with the results obtained in field tests [6], where rods with rounded tips have been found to be better strike receptors than were nearby sharp-tipped rods.

It is found that blunt rod has lower voltage breakdown. As the leader approaches, the electric field around the tip of the blunt rod increases. The energy associated with the electric field over the blunt rod will be very much greater than that over the other rods. The absence of point discharges around the blunt tip due to increase of electric field energy thus encourages the interception of lightning to blunt rods at lower voltage breakdown.

The time to breakdown for the blunt rod is slightly longer than the sharp one as shown in this study. This is because under intensifying fields, the field strength above the blunt rod can reach the same limit as earlier developed over the sharp rod and it may increase above the streamer-propagation threshold for an appreciable distance into the air with the corona onset potential at 8 kV [7]. When the field strength at the tip exceeds the threshold for point discharge, the possible interception of an approaching lightning streamer is significant. However, it takes time to intensify the local electric field around the blunt rod to initiate streamer for further breakdown to occur. Thus, the time to breakdown for the blunt rod is longer compared to the sharp one.

In the competitive study, the blunt rod has higher number of strikes. The reason is when both sharp/standard and blunt rods are exposed to an intensifying electric field, both will eventually emit point discharge ions and plasmas will form in the air above them. If the external field continues to intensify, upward going streamers can be launched from each of the points but since the field strength decreases more rapidly with distance over a sharp point than it does over a blunt one, the blunt tip becomes the preferred point of interception. Another reason the sharp tip is not preferred is that the point discharge or corona that built up at the sharp tip limits electric field and causes a shielding effect to the tip. This makes the tip looks as if invisible to the simulated down coming lightning leader and interception does not take place.

VI. CONCLUSION

In this experimental work, it has been proven that the performance of air terminal is affected by its tip geometry. Different geometry tip has different breakdown characteristics. It was found that the blunt lightning rod has a better performance over other geometries of rod in terms of its breakdown voltage, time to breakdown and number of strikes. Therefore, it is recommended that the standard conventional sharp tipped Franklin rods installed on any power stations be replaced by blunt ones. The deterioration of performance of other damaged lightning air terminal (flat, conical, concave) compared to the conventional sharp tip Franklin rod and the blunt rod, as proven in this laboratory study also calls for replacement of any damaged lightning air terminal immediately in order to provide sufficient protection to the structure involved.

VII. REFERENCES

[1] Abdus Salam, M.; Ahmad, H.; Fuad, S.A.; Ahmad, A.S.; Tamsir, T.; Piah, M.A.M.; Buntat, Z.; Saadom, Z.;Budin,R.; "Development of mathematical relation between ESDD and wind velocity for a contaminated insulator in Malaysia," Proceedings of the 6th International Conference on Properties and Applications of Dielectric Materials, vol. 1, pp. 379 – 382, 21-26 June 2000.

[2] C.B Moore, J. Mathis, W. Rison and L. Paterson, "Report On A Competition Between Sharp and Blunt Lightning Rods", IEEE Transactions on Electromagnetic Compatibility, pp. 1-28, March 1997.

[3] E. Kuffel, W.S. Zaengl, and J.Kuffel, "High Voltage Engineering Fundamentals," Butterworth-Heinemann, 2000, pp. 88.

[4] F.D'Alessandro and G.Berger, "Laboratory Studies of Corona Current Emissions From Blunt, Sharp Multipointed Air Terminals", J. Phys. D: Appl. Phys. 32, pp. 2785-2790, 1999.

[5] E. Kuffel, W.S. Zaengl, and J.Kuffel, "High Voltage Engineering Fundamentals," Butterworth-Heinemann, 2000, pp. 480-482, 2000.

[6] C.B Moore, "Improved Configurations of Lightning Rods and Air Terminals", Jour. Franklin Inst., 315, pp. 61-85, 1983.

[7] J.M. Meek and J.D. Craggs, " Electrical Breakdown in Gases," Wiley-Interscience, 1978, pp. 346.

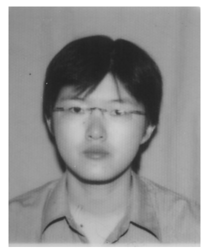
VIII. BIOGRAPHIES

H. Ahmad was born in Johor, Malaysia on July 1, 1953.

He received his B.Sc. in Electrical Engineering from the University of Strathclyde, Scotland in 1977 and M.Sc. in Electrical Power System from the same university in 1981. He received his Ph.D in High Voltage Systems from the University of Manchester Institute of Science and Technology in 1986.

He is now a Professor and Director of the Institute of High Voltage and High Current in Universiti Teknologi Malaysia (UTM). His research interests and expertise are in lightning phenomenon and high voltage contamination studies.

He is a member of IEEE Power Engineering Society and Dielectric Insulation Material since 1986 and a senior IEEE member since 1998.



L. M. Ong was born in Penang, Malaysia on January 3, 1981. She received her B.Sc. in Electrical Engineering from Universiti Teknologi Malaysia (UTM) in 2003. She has worked as a research assistant and currently pursuing her Master in Electrical Engineering at the same university. Her research interests are lightning protection and electrical breakdown.