AN EXPERIMENTAL STUDY OF IONIZING AIR TERMINAL PERFORMANCE

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Abstract

An experimental study of the performance of ionizing air terminals versus non-ionizing air terminals is reported. Radioactive sources were used to obtain ionization of the air surrounding the tip of the air terminals.

The tests were conducted at the John Lapp High Voltage Laboratory at LeRoy, New York under conditions approximating the natural setting. The tests were performed in an outdoor area of the laboratory. Tests were made during both rain/fog and clear weather with the natural bias produced by the clouds above the testing area, and also under artificial bias. This arrangement permitted the study of the high relative humidity effects conducive to the successful functioning of the ionizing air terminals.

Some tests were conducted at low humidity in sunny weather for the sake of comparison. All the tests were performed on a comparison basis in which a radioactive air terminal was compared directly with a non-radioactive air terminal. Both air terminals had exactly the same geometrical configuration in each test conducted. The standard (non-radioactive) air terminal chosen was the Franklin Rod. The tests results indicate a substantial superiority for the ionizing terminal when tested under realistic conditions. These results are in agreement with those obtained in field installations.

Introduction

Some previous publications (3,5,10,11) have implied that there is no actual difference in performance between ionizing and non-ionizing air terminals. These tests were, however, made in an outdoor environment using a sharp pointed metal rod as the high voltage electrode. Other publications (6,7,8,9) which refer to results at actual installations indicate a large superiority of the ionizing air terminal over the non-ionizing air terminal. These conclusions are enhanced by test data from an installation of various air terminals in Western New York, where since October, 1987, a period of 4 months; only the ionizing terminal has been struck by natural lightning a total of 4 times. Communication towers in the area of the test site are not being hit as they previously were by lightning and the ionizing air terminal is located on a pole lower than the communication tower that had been struck prior to this time.

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The objective of this experimental study was to determine the influence of ionization at the tip of the air terminals on the probability of flashover with a specific focus upon comparison of the ionizing air terminal to an identical air terminal without a radioactive ionizing source, under realistic conditions. The test consisted of a comparison of the number of electrical high voltage discharges from the "cloud terminal": to each of the pair of terminals being tested: one radioactive terminal and one standard terminal (non-radioactive) of exactly the same geometry.

The conditions under which such a test is conducted should be close as possible to natural conditions during and just prior to rain. Therefore the test should be performed at high relative humidity approaching 100% and electric bias should be applied similar to that present during thunderstorms. [2]

The natural conditions sought were those of rain, high relative humidity and biasing by the cloud above the testing area.

These are the required conditions for proper testing of air terminals. In this study, a natural lightning discharge was not practical therefore flashover voltage was provided by the use of a high voltage impulse generator whose rating is 4.3 megavolts, 115 kilojoules.

In the natural thunderstorm, a charged cloud, which is the source of discharge, is an extended terminal not a point. Therefore, in these tests, an extended terminal in the form of a rectangular flat platform with stretched metallic wire mesh served as the high voltage terminal. This source of discharge was termed the "cloud" or "cloud terminal". (Figure 1)

This experimental arrangement provided stability against the influence of outdoor winds and provided a uniform electrical field in the central part of the cloud terminal where the air terminals which were the subject of testing were positioned.

Experimental Part

The experimental setting is shown in Figure 1, and in the photograph, Figure 2.

Using the experimental setting depicted in Figure 1, the tests were made using a standard switching impulse wave shape (250 x 2500 microseconds.) In some tests, a standard lightning impulse (1.2 x 50) microseconds) was used. No significant difference between the two wave shapes were observed, except that, as would be expected, the faster wave front of the lightning impulse required a higher voltage for flashover. The polarity was set negative with respect to the ground as it is in most instances in thunderstorms: cloud to ground [2]. In this study the two terminals to be compared were placed in an identical symmetrical position with respect to the cloud terminal. The test terminals were sufficiently separated to avoid any coupling effect.

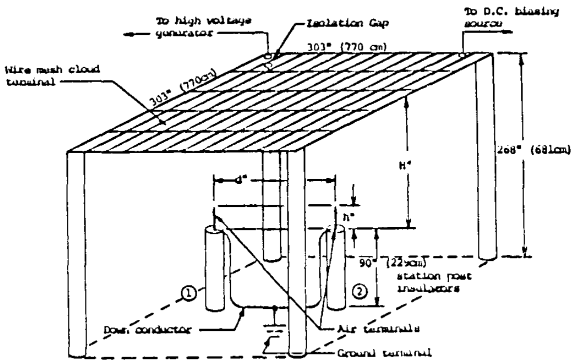

Figure 1: SKETCH OF TEST ARRANGEMENT

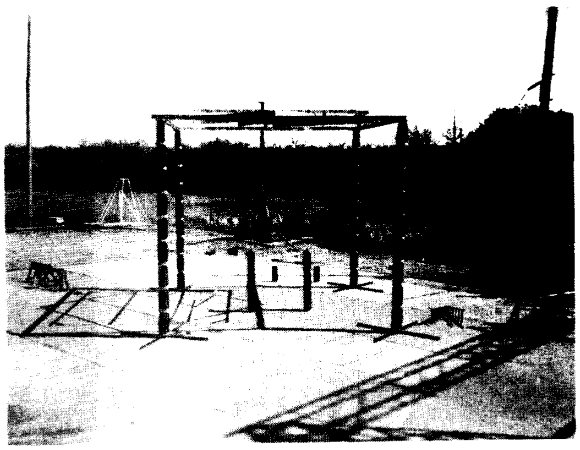

Figure 2: PHOTOGRAPH OF TEST ARRANGEMENT

The parallelism of the fixed cloud terminal and the ground was established by using post insulators of identical length. This parallelism is essential to ensure the equal distances of air terminal tips to the cloud terminal.

It was determined experimentally that the difference in height above the ground plane of air terminal tips tested was critical. A difference in excess of 0.25 inches (6.4 mm) could not be tolerated because the outcome of the flashover distribution was affected. The flashover comes randomly from all parts of the cloud terminal as observed by means of both video tape and visual observations. A streamer usually formed on the unstruck terminal when flashover occurred to the other terminal.

Consequently, the measurements of the height of the air terminals had to be precise, since a difference in heights would have the effect of superimposing on random flashover events a tendency toward higher frequency of discharges to the air terminal tip which is closer to the cloud terminal. This unwanted effect was avoided by carefully and precisely measuring the height of the terminals in all instances to ensure that there was equal distance between each air terminal tip and the cloud terminal.

Some examples of the length and intensity of the streamers emanating from the air terminals are shown in the photographs, Figures 3-5. In general terms, the streamers from the radioactive sources are longer and brighter than are those from a non-radioactive terminal.

The majority of the tests were performed under the condition of minimum voltage required for the flashover thereby avoiding overvoltage. This condition simulated the natural setting with a necessary and sufficient condition of minimum voltage.[2] The randomness of the path of flashover is indicative of the fluctuations which occur in time with respect to electric stress and the conductivity of the air. This was documented on videotape for further study.

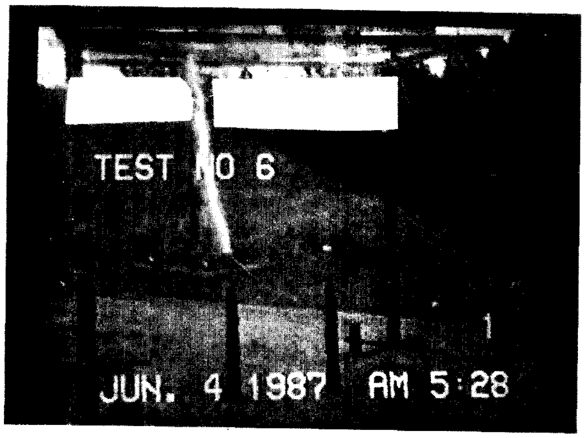

Figure 3: STREAMERS FROM TEST TERMINALS

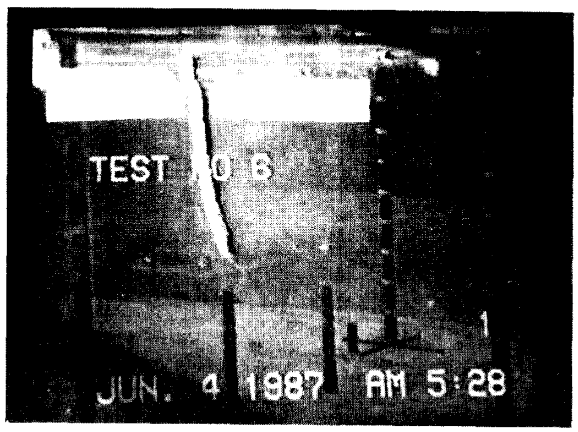

Figure 4: STREAMERS FROM TEST TERMINALS

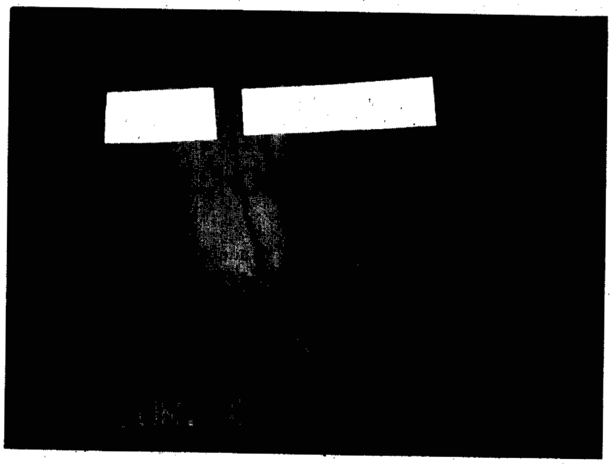

Figure 5: STREAMERS FROM TEST TERMINALS

In addition, specific tests were made to determine experimentally the existence of space charge and its influence on flashover events. These particular tests, used only one Franklin rod air terminal. The arrangement permitted the determination of the minimum voltage necessary for flashover. Thereafter, a measured bias of 40kv negative D.C. was applied between the cloud terminal and the tip of the Franklin rod which were separated by 145.25 inches (369 cm). Again, the minimum flashover voltages were determined. The voltage necessary for flashover (1800kv) was the same in both cases, thereby demonstrating that there was no effective space charge influence present.

The voltage for flashover was always kept at the minimum necessary and electric stress was adjusted to approximately 12kv/inch (5kv/cm) which is the value that is considered to be general level at which actual lightning strikes occur.[2].

Description of Air Terminals

1. The ionizing air terminal is a Franklin rod -9.5" (24.13cm) in height, modified by the addition of a metallic saucerlike form 9" (23cm) diameter, placed 4" (10cm) below the tip and containing radioactive sources -Figure #6

2. The Ellipsoid air terminal is a Franklin rod, which goes through the metallic hollow Ellipsoid and protrudes 4.5" (11 cm) above it. The Ellipsoid is electrically insulated from the rod, and therefore is in a "floating condition." Radioactive sources can be placed in an indentation below the tip which is 0.25"(1cm) deep and 4.5"(11cm) wide. Dimensions of the prolate Ellipsoid are: 2a=20"(51cm), 2b-14"(36cm). Figure #7

3. Radioactive sources rating:

   I. Radium - 72 Microcuries
   II. Thorium - 0.72 Microcuries

The data in Table 1, is a sample of the extended data base obtained using the arrangement described in Figure 1 under a wide range of atmospheric conditions of bias. In general, there are four (4) important conditions:

Test No.	Reference Figure	Distance H Height in inches	Height of Air Term. h in inches: Air Term #1	Height of Air Term. h in inches: Air Term #2	Separation D of Air Term. in Inches	Description of Air Terminals: Air Term #1	Description of Air Terminals: Air Term #2	No. of Flash-overs: Air Term #1	No. of Flash-overs: Air Term #2	Avg. Flashover voltage in kV	Avg. Voltage Wave rise time in Microseconds	Applied bias in kV	Avg. relative humidity in per cent	Fahrenheit Temperature degrees	Pressure in inches	Description of Atmospheric Conditions
1	1	178	38 1/2	38 1/2	84	Ionizing Radium	Franklin Rod	15	5	1320	120	Natural	83	58	29.21	Cloudy
2	1	178	38 1/2	41 1/2	84	Ionizing Radium	Franklin Rod	5	15	1290	110	Natural	83	58	29.21	Cloudy
3	1	178	38 1/2	38 1/2	84	Ionizing Thorium	Franklin Rod	12	8	1310	130	Natural	78	58	29.21	Cloudy
4	1	178	38 1/2	38 1/2	84	Ionizing Blank 4" Sphere	Franklin Rod	11	9	1290	110	Natural	81	53	29.27	Cloudy
5	1	178	38 1/2	38 1/2	84	Ionizing Blank	Franklin Rod	10	10	1300	115	Natural	66	54	29.27	Cloudy
6	1	178	38 3/4	38 3/4	84	Ionizing Radium	Preventor Blank	10	10	1260	120	Natural	70	37	29.28	Sunny
7	1	178	34 3/4	34 3/4	84	Ionizing Thorium	Preventor Blank	11	9	1480	90	Natural	95	66	29.25	Clouds overcast after rain
8	1	178	34 3/4	34 3/4	84	Ionizing Thorium	Preventor Blank	12	8	1520	100	20	90	66	29.25	Clouds Overcast
9	1	178	34 3/4	34 3/4	84	Ionizing Thorium	Preventor Blank	14	6	1480	95	40	90	66	29.25	Clouds Overcast
10	1	178	34 3/4	34 3/4	84	Ionizing Radium	Preventor Blank	12	8	1540	90	20	90	66	29.25	Clouds

TABLE 1

1.) High relative humidity - no bias
2.) High relative humidity with bias
3.) Low relative humidity - no bias
4.) Low relative humidity with bias

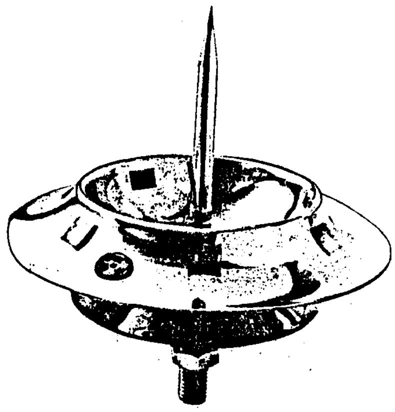

FIGURE 6: RADIOACTIVE IONIZING AIR TERMINAL

The standard practice in high voltage experiments is to take about 20 flashover events as indicative of statistical trend. In the present experiments, each point in Figure 8 & 9 collectively are composed of close to 1000 events, a significantly large enough statistical base to support the conclusion regarding the experimental trend.

Another effect which is important to account for, is the influence of the difference of electric-stress at the tip of air terminal on the flashover probability. Therefore two air terminals were placed under the "cloud", one of the spheroidal shape with diameter of 35 cm. and with the blunt tip, and the other was chosen to be the standard Franklin Rod with the sharp tip. The heights of both terminals were the same (98 cm), separation of test terminals (213 cm) was sufficient to avoid coupling effect and the distance of both terminals to the "cloud" was 369 cm. When the voltage for discharge was applied, all 20 flashover events went to the Franklin Rod. The spheroid terminal had to be raised closer to the cloud terminal by 19.7 cm. to become equivalent to the Franklin Rod, that is 10 flashover events to each terminal. This experiment demonstrates geometrical sensitivity for the attractiveness of flashover and is related to the electric stress at the tip of the test terminals.

Such a "bluntness" effect can be produced likewise by closely packed multiple sharp points at the tip of the terminal or strong corona discharge.

In general, strong ionization is not necessarily better, but indicates that there is an optimum condition for the attractiveness of flashover to the terminal if additional conditions are also fulfilled. Figure 8.

The term "bias" is intended to refer to the more or less steady state condition of elevated electrostatic field stress which exists prior to a lightning strike. It is to be expected that the stream of ions emanating from the various designs of terminals would be affected by the presence of this electrostatic stress. To study the behavior of the various terminals under such stress, the testing circuit was modified.

A direct current source was connected to the "cloud" so that steady state direct voltages could be applied for whatever period of time was chosen. This "bias" voltage was maintained up to and during the firing of the impulse generator. To prevent damage to the D.C. source, a special protective circuit was used.

The bias voltage was varied over a wide range to obtain 1 kv/meter (.025 kv/inch) to 20 kv/meter (0.5 kv/inch) average stress. The average stress was calculated using the 3.55 meter (140") spacing from the tips of the terminals being tested to the bottom of the cloud.

In this investigation, the bias at high relative humidity was provided by either natural sources, i.e., the raining cloud, or by a separate biasing circuit. Testing of air terminals must be carried out under the conditions existing in thunderstorms, i.e., high relative humidity and bias. These conditions must also be maintained even for testing the geometrical form effectiveness of air terminals to attract the flashover (lightning) when comparing to the standard Franklin Rod.

In a planned subsequent paper a study of the geometrical effects of air terminals which is too extensive for inclusion here will be presented.

In general, the flashover path is determined by the highest electric conductivity channel in the air at the moment of discharge and also the highest electric stress present.

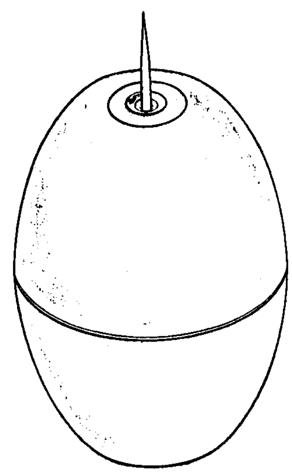

FIGURE 7: ELLIPSOID AIR TERMINAL

These two conditions are responsible for the uneven path appearance of the flashover spark. The formation of the streamer at the tip of the air terminal which propagates towards the "cloud terminal" is controlled by the Townsend avalanche process [1], which depends on the ion concentration at the tip and electric field present.

The strong formation of the streamer at the tip required intitial high ion concentration and high electric stress [1]. The streamer is formed on each air terminal and the one which is stronger results in the successful flashover.

In Figure 8, percent flashover of ionizing to non-ionizing air terminal is plotted as a function of applied electric biasing voltage, at two levels of relative humidity and radioactive activity. Radioactive activity determines the level of ion concentration at the tip of air terminal. The ion cloud at the tip is composed of positive and negative ions generated by collisions of high speed Alpha and Beta particles streaming from the radioactive sources. These particles also are responsible at high relative humidity for the formation of ionized fog as in a Wilson cloud chamber. Therefore one expects some dependence of flashover probability on relative humidity. The result presented in Figure 8, shows that at low relative humidity and low electric bias the frequency of flashover to non-ionizing air terminal dominates; indicative of the depressive effect of ionized air at the tip of air terminal. Conductive air space at the tip decreases electric stress not conducive for the generation of a strong streamer and the ionizing air terminal appears blunt rather than sharp with respect to the "cloud".

At the biasing level in the range from 1 to 20 kv/m associated with the actual thunderstorm activity, however, the ionizing terminal forms a long, strong streamer which causes the ionizing terminal to appear much "sharper" than the non-ionizing and results in a shifting of flashover activity to that terminal.

The percentage of flashover is strongly dependent on relative humidity suggesting that ionized fog is the dominant factor in enhancement of flashovers at ionizing air terminals. Finally, at very strong biasing, the percentage of flashover drops again due to the fact that corona discharges are produced on both air terminals making them identical, and modified to some degree by the presence of ionized air produced by radioactive sources.

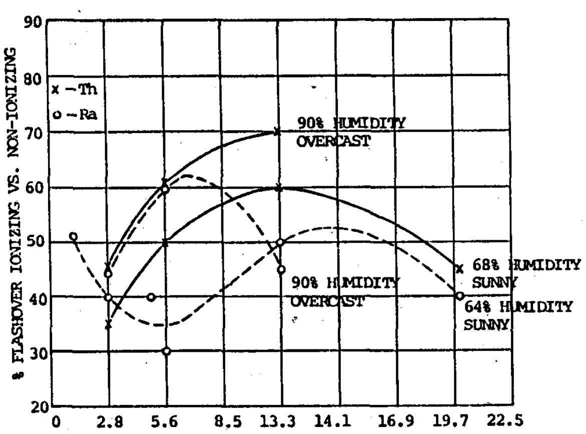

Fig. 8

In Figure 9, percentage of flashover of ionizing to non-ionizing air terminal is depicted versus percentage of relative humidity at different levels of electric bias. Over all, the points at high relative humidity are above 50%, indicating that flashovers at this range are more frequent to an ionizing air terminal. This range corresponds to the actual atmospheric conditions just prior to a lightning stroke. Lower levels of probability apply to less likely strike conditions. Furthermore, the vertical points scatter of flashover percentage at a fixed relative humidity level is due to the different natural and imposed electric bias levels as can be seen for comparison in Figure 8. In general, the tendency for the flashover to the radioactive ionizing air terminal at relative humidity above 70% is significant and indicates that ionizing air terminals are attracting flashover more efficiently than non-ionizing air terminals.

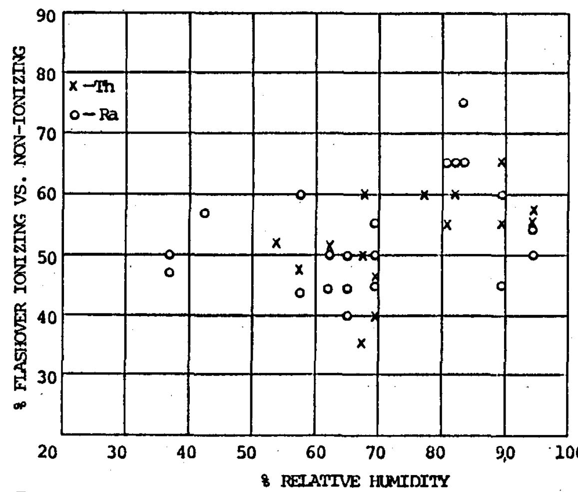

Fig. 9

Conclusions

1. From Figure 8 & 9, it can be concluded that under the conditions of high relative humidity and electric bias the radioactive ionizing air terminal is more likely to attract flashover than is the non-ionizing air terminal and these are the conditions present during the thunderstorm activity.
2. Conclusion 1 suggests that the area protected by the ionizing air terminal is appreciably larger than that of the non-ionizing termials.
3. More effective protection for natural lightning strikes is provided by the ionizing terminal.
4. Tests made indoors do not produce the results obtained in outdoor conditions because there is no natural bias since the building is effectively screening the outside electric field, and likewise relative humidity is modified inside building enclosure.
5. Radium sources are more effective than other sources because of higher specific activity.
6. Since the results using ionizing air terminals in the field, both in Western New York and in Australia [7] show the same relative results, i.e., the ionizing air terminals struck more often than

the non-ionizing types, it is reasonable to believe that the laboratory tests set up and procedure described here is a valid means of comparing various air terminals. This is true despite the fact that the length of the first step in natural lightning is much larger than that used in the laboratory study.

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Frank Richens (M-'69) was born April 4, 1941 in Rochester, New York. He received his B.S.E.E. degree at Clarkson College of Technology, Potsdam, New York in June 1964.

Mr. Richens started his carreer with Niagara Mohawk Power Corp. and spent four years with the Engineering Department, in substation work. He joined Lapp Insulator Company as an engineer in the Product Engineering Group in 1969 and in 1973 was placed in charge of the High Voltage Laboratory. His duties were expanded over the years and now includes the Mechanical Testing Lab. and the Pavilion Transmission Line Lab. Operation and test procedures.

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He is a member of NFPA MacAdvisory Committee, IEEE, Buffalo Engineering Society, ANSI and the Flying Engineers International. He has attended schools in Europe, Canada and the U.S.A.

Mr. Heary has over 35 years experience specializing in the field of lightning protection systems design and engineering. Mr. Heary is involved with research projects in the study of lightning and lightning protection systems being conducted by his corporations, research and products development worldwide.

Aleksander Z. Chaberski, was born in Lodz, Poland on January 1, 1928. He received the B.S. degree in Chemistry from Alliance College in 1952.

He studied mathematics in Kent State University in 1953 towards M.A. degree and received Ph.D. degree from SUNY at Buffalo for solid state physics in 1965. He was teaching physics and electrical technology for seven years in three Buffalo based colleges. He published a number of papers, and holds two patents. His industrial experience extends over nine years, in the fields of semiconductors and radioactivity.

He held positions of research scientist, senior engineer and Chief Chemist at various Buffalo based companies.

Dr. Aleksander Z. Chaberski presently is engaged in the research of lightning protection air terminals and systems and is a consultant to the local based industry.

Dr. Stephen J. Gumley is currently the Engineering Director of Component Resources Pty. Ltd. of Hobart, Australia, a company involved with the design and manufacture of surge, transient, and lightning protection equipment. Dr. Gumley holds a first class Honours degree in Engineering from the University of Tasmania and is a Member of the Institution of Engineers Australia. In 1979, Dr. Gumley was awarded a Rhodes Scholarship to attend Oxford University, England from where he received a Doctor of Philosophy degree in engineering in 1981. Dr. Gumley is currently involved with research projects in lightning, lightning terminals, and lightning down conductors in the U.S.A. and Australia.

Mr. J.R. Gumley is Managing Director of Lightning Protection International Pty. Ltd. of Hobart, Australia. He is a Fellow of the Institution of Engineers (Australia) and is past-chairman of the National Committee for Electronics and Telecommunications.

Mr. Gumley has had thirty years experience as a professional engineer specializing in communications and lightning protection. Since 1971, Mr. Gumley has been actively involved with research into lightning and the design of cost-effective lightning protection systems for structures and equipment. Mr. Gumley is currently supervising several lightning protection research projects in the U.S.A., Asia, and Australia. Mr. Gumley is a member of the Standards Association of Australia Lightning Protection Committee EL24 and was one of two Australian representatives at the IEC TC80 meeting at Orlando, Florida in June 1986.

John H. Moran, Jr. (M '47,SM-'55,F-'80) was born Philadelphia, Pa. on September 22, 1923. He received the BSEE degree from Case School of Applied Science (Now Case-Western Reserve University) in 1947. He is a Registered Professional Engineer in New York and Ohio.

Mr. Moran was employed by Allis-Chalmers Mfg. Co. West Allis, Wisconsin in the Transformer Dept. as an electrical engineer in charge of the High Voltage Laboratory from 1947 to 1955. In 1955, he joined the Lapp Insulator Co., LeRoy, New York where he remained until retiring a Chief Electrical Engineer and Manager of Bushing Engineering in 1986. He is now engaged in private consulting work.

Mr. Moran is a member of the Power Engineering Society of the IEEE, the PSIM and T&D committees and is the immediate Past Chairman of the High Voltage Testing Techniques Subcommittee of PSIM. He was presented the PSIM Committee Distinguished Service Award in 1986. He served as the U.S. Delegate to IEC T.C. 42, High Voltage Testing 1979-1986. Mr. Moran has been involved in a large number of working groups and other IEEE activities, has authored or co-authored a number of technical papers, and holds four patents.

DISCUSSION

Gianguido Carrara (CESI, Milano, Italy, EC) The Authors must be commended for the well conducted and exhaustive tests performed and for the detailed publication of the test results. It would be difficult, however, to find a better test to reach a conclusion exactly the opposite to that of the paper: <u>Ionizing material does not affect the protection given by a lightning rod</u>. The indication of a preference for strokes to the ionized terminal is shown in Fig. 9, for humidities higher than 70%. This "preference", however, consists in an average value of 60% of strokes to the ionized terminal, against 50% in case of no effect. Is this a "protection"?! This effect is made even more problematic by the large scatter affecting the results (from 45% to 75%). The Authors say the scatter is "furthermore" attributed to the difference in bias level "as seen in Fig. 8". This figure and the relevant explanations do not clarify the problem, even less the word "furthermore". Against the claimed influence, finally, stays the warning contained in page 2 (first column, last paragraph) where it is emphasized the high precision necessary in equalizing the heights of the terminals, since it was determined experimentally that a difference of a quarter of an inch (!!!) cannot be tolerated as affects the flashover distribution. This effect can, actually, be observed in TABLE I comparing Test n. 2 with Test n. 1: increasing the length of the Franklin Rod of 3 inches reverses the flashover distribution. In other words, increasing the height of a rod of inches is equivalent to installing radioactive material! All this is more than enough to justify the aforementioned opposite conclusion.

Who could not follow the work of CIGRE should examine all references given by Golde [1]: they deny any practical effect of ionizing material. Furthermore, extensive studies on discharge formation in long air gaps confirm this statement. In the majority of the cases the downward flashes are negative and strike where the upward positive leader starts. The leader formation depends on the electric field produced around the tip of the rod by the charge in the cloud and in the descending channel. The rise of the field strength around the rod is, therefore, very slow, hundreds of microseconds, so that the natural ionization of the air is enough to have a free electrons in the position required to start the phenomenon [2]. This is why the increase of production of free electrons has a negligible effect.

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Manuscript received August 9, 1988.

Discussion

Ian S. Grant, (Power Technologies, Inc., Schenectady, New York): The concept of enhancing the performance of lightning protection rods through use of radioactive materials is a very old one. Previous studies of the subject did not provide a convincing demonstration that this technique is effective, although, of course, the nature of lightning makes it difficult to provide such a demonstration in a limited scale experiment. An excellent review of the subject may be obtained from Golde (reference 2 of the authors).

The authors have described a study in which improved performance is claimed by a preferential flashover to ionizing terminals. However, this would seem to be an inappropriate basis of comparison. The sensitivity of flashover location described and the results presented in Figures 8 and 9 by the authors show that any improvements are at best minimal, and that the converse to conclusion 2 of the paper would be a better assessment of the performance found. Similarly, the results of the field installation fail to demonstrate any improvement in protection, even if results over such a short period as four months could be considered as reliable.

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A. C. Liew, (Department of Electrical Engineering, National University of Singapore, Singapore 0511): The authors have done interesting work on the performance of some ionizing air terminals but I find some of the conclusions drawn rather misleading and disturbing.

The experimental study was done using an extended terminal and not a point and it was emphatically stated that it is representative of the source of the discharge—the charged cloud. Yes, the cloud is indeed an extended terminal but this cloud base is typically 3 to 5 km above ground. For a downward stroke, it is well known that the lightning leader discharge proceeds earthward as a point (the leader tip), guided only by the local field distribution ahead of it and not by features in the ground until striking distance is reached. Hence, at the moment of stroke target determination, the lightning leader should be simulated by a point (the leader tip) and not an extended terminal system (the whole cloud base). The presence of the d.c. electrostatic field bias afforded by the extended terminal system is, however, important.

The authors themselves have stated that the difference in height above the ground plane of the air terminal tips tested was critical citing that 0.25″ (6.4 mm) was sufficient to upset the flashover distribution pattern. This can also mean that any terminal device which can effect a flashover distance advantage of as little as 0.25″ (6.4 mm) will, in this experimental set-up, cause all flashovers to be directed to it.

Because of the above two limitations, I dispute conclusion 6 that the set-up is a valid means of comparing the performance of various air terminals under lightning conditions. Not withstanding the above, I find the paper informative and the authors are encouraged to continue the tests.

Conclusion 2, which states that the results suggest that the area protected by the ionizing air terminal is *"appreciably larger"* than that of the non-ionizing terminals, is disturbing. No where in the paper has there been any attempt to determine the area of attraction of any kind of terminal. The use of the phrase "appreciably larger" is misleading as it has not been quantified.

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C. Menemenlis, (University of Patras-Greece.): The authors made a serious experimental effort to detect possible effects of radioactivity on the attracion of lightning by a lightning rod. Their results, however, do not show that such an effect is present and it is difficult to justify the conclusions drawn in the paper by the presented experimental results. The small differences in breakdown probability between radioactive and non radioactive aerials reported in table 1 and Fig. 8 and 9 obviously lays within the confidence limits of the measurements.

The curves of Fig. 8 do not show a systematic increase of breakdown probability of the radioactive rod. It is also difficult to understand the authors' insistence to relate breakdown probability with *relative* humidity while it is well known that *absolute* humidity is the governing factor.

The authors do not make any statistical analysis of their results neither do they give sufficient details of the test procedure in order to enable a rigorous statistical analysis by a reader of the paper. Reference to the physical background that could justify such an effect is not made, neither conclusive theoretical consideration by Muller-Hillebrand, H. Baatz and numerous other workers which show that such an effect could not exist, is reported. A vague reference is only made at the initial report of Muller-Hillebrand without even elaborating at the negative conclusions of this report.

The references 6, 7, 8, and 9 which, according to the report, "indicate a large superiority of the ionizing air terminal", are either by the authors themselves or by manufacturers of such devices. Furthermore, some of the references, given at the end of the paper are not formal publications and for some of them is not given sufficient information enabling the reader to find them.

The idea of improving the attracting capability of the Franklin rod by using radioactivity was initially presented, at the beginning of the century, by a collaborator of Marie Curie. This idea was never supported by conclusive experimental results. Theoretical and experimental considerations by Muller-Hillerbrand of the Upsala H.V. laboratory have shown that such an effect could not exist. The extensive studies on the physics of the discharge of long gaps performed during the last two decades in large part by the Renardiere group, form a solid physical background by which it can be theoretically understood why such an effect could not exist.

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DISCUSSION

ABDUL M. MOUSA (British Columbia Hydro, Vancouver, BC, Canada): Examining available literature on the subject of radio-active lightning rods suggests that only the documents produced by the manufacturers and distributors of such devices, including this paper, claim them to be effective. On the other hand, all studies done by independent investigators found them to be ineffective. In addition to references 3, 5, 10 and 11 of the paper, there are 3 other references which find radio-active rods to be ineffective, see [1-3] below. The authors' response to the following comments and questions would be appreciated:

1. The results of tests 1 and 2 in Table 1 indicate that a 3" difference in height reverses the distribution of discharges between the radio-active rod and the Franklin rod. This being the case, would it not be more economical to increase the height of the Franklin rod(s) by 3 inches instead of incurring the cost of radio-active devices?
2. Effective shielding can be easily provided, even for very tall structures, using conventional lightning rods and wires [5]. Also, item 1 above indicates that the contribution of radio- active devices, if any, is rather insignificant. This being the case, what justification do the authors have for promoting the spreading of nuclear pollution sources over our buildings and cities?
3. Natural lightning discharges are known to originate from the clouds, then progress downward until they terminate on ground objects. In the tests reported in this paper, the opposite was happening: the discharge starts from a lightning rod, then progresses upwards until it terminates on the so-called "cloud electrode". Does this not indicate that the adopted test set-up is not representative of actual conditions? As discussed below, the cause of the problem seems to be the gap configuration used in the study.
4. When Golde [4] first calculated the striking distance in 1945, the source of the discharge consisted of only a vertical leader with exponential charge density distribution (no cloud charges). This is because it was found that the effect of the charge remaining in the cloud on the striking distance was rather negligible. Since then, it has been widely accepted to take the upper electrode in the lightning discharge process as a rod. What justification do the authors have for employing a plane instead? The approach adopted in this paper implies that lightning strikes to flat ground should be represented by a plane-to-plane gap. The discusser notes that such a proposition has never been made by any other researcher.
5. Proving the effectiveness of a shielding system requires many years of field observations. The discusser feels that a record based on a 4 month period is rather insignificant. Further, no description of the installation and the surrounding structures and terrain is given in the paper. Considering that commercial radio- active rods have been in use for over 25 years, why did the authors not give a more substantial service record? Golde [3] describes a case in which radio-active rods failed in preventing lightning from striking a Vatican installation in Rome in 1976. What is the authors' explanation of that failure incident?
6. When attempting to prove that radio-active rods are superior, the discusser suggests that the following be noted:
   (a) Showing that radio-active rods can provide effective shielding to a given installation does not mean much by itself because Franklin

rods have been proven to be able to do the same when properly designed.

(b) Showing that a radio-active rod would collect more discharges when placed side-by- side with a Franklin rod does not mean much either because such a set-up has no practical application.

(c) The proper approach is to prove that radio-active rods have a larger "protective radius". Referring to Fig. 1, the following test plan is hereby proposed: Use a model of a Franklin rod installation which gives only partial shielding, apply 100 switching type surges using a fixed rod electrode, and determine the corresponding number of shielding failures n. Let the distance between the rod and the protected object in this case be D_1. Next, replace the Franklin rod by a radio-active rod having the same height and increase its separation to the protected object (distance D_2) until the same performance (n shielding failures per 100 applied surges) is obtained. The radio-active rod would be superior only if distance D_2 was significantly larger than distance D_1.

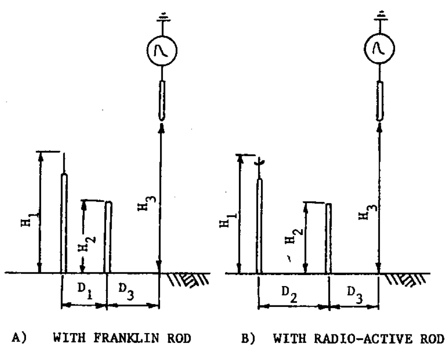

Fig. 1. Test set-up proposed for determining whether radio-active rods are worthwhile.

7. The discusser notes that most of the citations of the paper are incomplete, thus making it difficult/impossible to locate them, Figs. 8 and 9 have no titles, and several of the conclusions do not follow from the material given in the paper.

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K.P.HEARY, A.Z. CHABERSKI, S. GUMLEY, J.R. GUMLEY, F. RICHENS, J.H. MORAN :

The authors are grateful to the discussors for their comments and interest in our experiments. We are pleased to give the following reply to the questions raised by them.

All of the discussors seem to be concerned with the authors' statement that the relative size difference of 1.5 inches in height between ionizing and non-ionizing air terminals is significant. It should be realized that this small difference is referred to the small strike distance used in the experiments. If the ratio of $\frac{1.5}{140.25}$ equal to approximately 1% is referred to a natural strike distance of some 1000 meters, the difference quoted assures proportion of about 10 meters, - a very significant difference in air terminal height and in the size of the corresponding zone of protection. Both of these are confirmed by field experience.

Dr. Carrara

It is always recognized that any form of laboratory test will be but a poor substitute for field recording. The important point from the test methodology is that an effect is shown to exist and this effect has some dependence on humidity. The scaling of the effect is difficult to quantify and further testing on air terminal configuration is in progress.

In respect to the effect of natural ionization, it is suggested that charge-induced conductive space exists around an air terminal which tends to inhibit or mask the electric field increase at the tip. The effect of this conductive air creates a non-linear field and forces a downward leader to approach closer than would be expected in order to initiate an avalanche. It is conceivable but not proven that the effect of radioactivity could modify the field gradient and lead to an earlier avalanche.

Mr. Grant

Mr. Grant has quoted from one of our references of which we are well aware. The purpose of our experiments was to show the need to change direction in the method of testing air terminals, that is, the use of bias, overhead cloud, slow risetime etc. to more accurately simulate nature. We believe our results invalidate previous results conducted indoors and sets the pattern for future testing.

Dr. Liew

One problem of high voltage testing is to ensure that the discharge is upward propagating. This would not necessarily be so if the cloud was a point as suggested by Liew. The purpose of the experiment was to compare the upward discharge process at the air terminal against competing ground connected points.

It is agreed that the term "appreciably larger" may be misleading. The term "larger" is more appropriate until the results of further testing are available.

Professor Menememlis

The work of Baatz and Muller-Hillebrand is well known to the authors. Both are considered of historical interest. The former reached conclusions without simulating the natural conditions attempted

by the authors. The latter conducted static tests of ion emissions under field conditions. These tests concluded no effect existed, but no recording was made of the dynamic situation during the approach of a downward leader. Conversely, Thum was able to repeat the work of Muller-Hillebrand in Malaysia and go on to show an improved performance of a radioactive air terminal during leader approach. That is, a different performance is observed under static and dynamic conditions. With respect to the comments that theoretical and experimental consideration of the work in Muller-Hillebrand Upsala High Voltage laboratory and the studies at Les Renardiere show that the improvements of the attracting capability of the ionizing air terminal could not exist we are reminded of the same type of theoretical studies in the earlier days of aerodynamics which proved conclusively that the bumblebee could not fly! Later work, of course, corrected the errors in the earlier thinking.

Dr. Mousa

Contrary to the suggestion by Dr. Mousa, natural lightning discharges do not propagate downward until they terminate on a grounded object. It is well known that the lightning down leader causes an upward intercepting leader to originate from a grounded object. The aim of the experiment was to trigger upward discharges from positive ground points and thus simulate conditions which occur in nature. The reference and test terminals were placed in a competitive situation to determine the advantage of one over the other. The simple use of rod/rod configuration does not achieve this objective.

In developing a test scenario, the key requirement was to create an upward discharge as occurs in nature. This is best performed by an artificial cloud which simultaneously could be used to generate bias.

The claim that nuclear pollution is being spread over our buildings and cities is totally unfounded. In today's environment regular testing of sources for leakage is mandatory. The level of radioactivity used in the current models of ionizing air terminals is well below any and all governmentally approved standards.

The authors cannot comment in detail on commercial installations as claimed attractive zones and installation methods are widely variable. In the opinion of the authors, claims of some producers of radioactive air terminals are not supportable in either theory or field performance. This does not mean that some effect from radioactivity is not present in other situations. The purpose of the experiment was to try to identify and quantify the effect.

With respect to the Vatican incident, there are several questions still not clear even at this late date. The main question has to do with the installation being properly spaced and installed. There is also some question, occasioned by the lack of ability to check the installation, that the terminals were in fact radioactive.

Regarding Para. 6 (a) we must ask the question "What is a properly designed Franklin Rod?" We have seen rods with single points, multiple points, blunt points and sharp points, even points with roosters on them, but nowhere have we found literature showing what comprises a "properly designed" Franklin Rod and proof of performance of that rod.

In Para. 6 (b) the suggestion is to simply replace the artificial cloud with a rod. This we do not believe is correct procedure. However, we do intend to make a few tests using both the cloud and a rod simultaneously.

Finally, we apologize to all for the lack of sufficient detail in some of the references given. The following additions are made to the noted reference. In any case, copies of references [6] through [11] will be furnished by Mr. Heary to interested parties, upon receipt of a request for same.

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