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Review of Triggered-Lightning Experiments at the ICLRT at Camp Blanding, Florida

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***Abstract*--Triggered-lightning experiments at Camp Blanding, Florida, with emphasis on the lightning interaction with power distribution systems, are reviewed. Both overhead lines and underground cables are considered. The principal results are discussed.**

***Index Terms*--Grounding electrodes, Lightning, MOV arresters, Power distribution lines, Underground cables.**

I. Introduction

Most of the published studies concerned with the responses of power distribution lines to direct and nearby triggered-lightning strikes have been conducted in Japan and in Florida.

From 1977 to 1985, a test power distribution line at the Kahokugata site in Japan was used for studying the induced effects of close triggered-lightning strikes to ground (Horii 1982 [1]). Both negative and positive polarity flashes were triggered. The wire simulating the phase conductor was 9 m above ground, and the minimum distance between the test line and the rocket launcher was 77 m. The peak value of induced voltage was found to be linearly related to the peak value of lightning current, with 25-30 kV corresponding to a 10-kA stroke. Installation of a grounded wire 1 m above the phase conductor resulted in a reduction of the induced voltage peak by about 40 %. Horii and Nakano (1995) [2] show a photograph (their Fig. 6.4.2) of the test distribution line being struck directly during the induced-effect experiments. All triggered-lightning experiments in Japan were performed in winter.

In 1986, the University of Florida lightning research group studied the interaction of triggered lightning with an unenergized, three-phase 448-m overhead test line at the NASA Kennedy Space Center. Lightning was triggered 20 m from one end of the line, and acquired data included induced voltages on the top phase (10 m above ground) and fields at a distance of 500 m from the lightning channel (Rubinstein et al. 1994) [3]. Two types of induced-voltage waveforms were recorded: oscillatory and impulsive. The former exhibit peak values that range from tens of kilovolts to about 100 kV, while the latter show peak voltages nearly an order of magnitude larger. The oscillatory nature of the waveforms is due to multiple reflections at the ends of the line. Both types of voltage waveforms were observed to occur for different strokes within a single flash. The time domain technique of Agrawal et al. (1980) [4] as adopted by Master and Uman (1984) [5], Rubinstein et al. (1989) [6], and Georgiadis et al. (1992) [7] was used to model the observed voltages. Some success was achieved in the modeling of the oscillatory voltage waveforms, whereas all attempts to model the impulsive waveforms failed, probably because these measurements had been affected by a flashover in the measuring system. Rubinstein et al. (1994) [3] used only the return-stroke electric field as the source in their modeling, assuming that the contribution from the leader was negligible. In a later analysis of the same data, Rachidi et al. (1997) [8] found that the overall agreement between calculated and measured voltages of the oscillatory type was appreciably improved by taking into account the electric field of the dart leader.

Since 1993, studies of the interaction of triggered lightning with power distribution systems have been conducted at the research facility at Camp Blanding, Florida. An overview of the facility in 1997 is given in Fig. 1. Two still photographs of rocket-triggered lightning flashes at Camp Blanding are shown in Fig. 2.

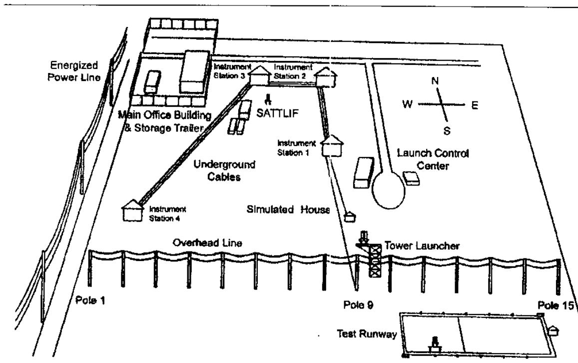

Figure 1. Overview of the ICLRT at Camp Blanding, Florida, 1997.

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The lightning-triggering facility at Camp Blanding, Florida was established by the Electric Power Research Institute (EPRI) and Power Technologies, Inc. (PTI). Since September 1994, the facility has been operated by the University of Florida (UF). During the last seven years (1995-2002) over 40 researchers (excluding UF faculty, students, and staff) from 13 countries representing 4 continents have performed experiments at Camp Blanding concerned with various aspects of atmospheric electricity, lightning, and lightning protection. Since, 1995, the Camp Blanding facility has been referred to as the International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, Florida.

We will present a summary of the selected results obtained at the ICLRT with emphasis on the lightning interaction with power distribution systems, including

(1) effects of lightning on underground power cables;

(2) responses of a two-conductor overhead power line to direct and nearby lightning strikes;

(3) responses of three-phase plus neutral overhead power lines to direct lightning strikes.

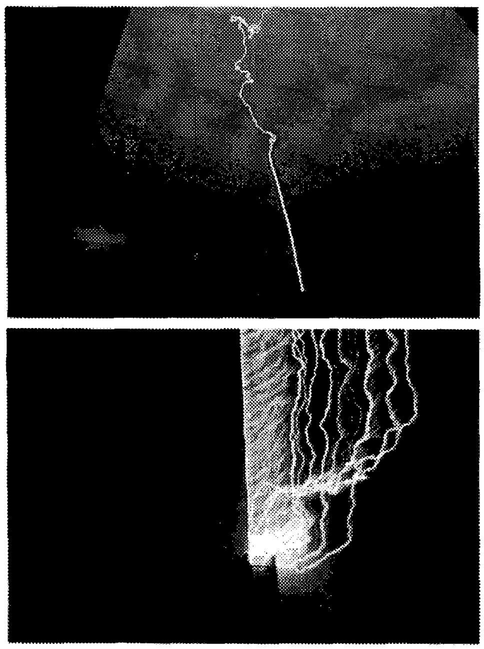


Figure 2. Photographs of lightning flashes triggered in 1997 at the ICLRT at Camp Blanding, Florida. Top, a distant view of a strike to the test runway; bottom, a close-up view of a strike to the test power system.

II. Effects of Lighting on Underground Power Cables

In 1993, an experiment was conducted at Camp Blanding to study the effects of lightning on underground power distribution systems. All three cables shown in Fig. 1 were used in this experiment. The cables are 15-kV coaxial cables with polyethylene insulation between the center conductor and the outer concentric shield (neutral). One of the cables (Cable A) had an insulting jacket and was placed in PVC conduit, another one (Cable B) had an insulating jacket and was directly buried, and the third one (Cable C) had no jacket and was directly buried. The three cables were buried 5 m apart at a depth of 1 m. Thirty lightning flashes were triggered, and lightning current was injected into the ground directly above the cables, with the current injection point being approximately equidistant from instrument stations 1 and 2 (see Fig. 1) but at different positions with respect to the cables. The cables were unenergized. Transformers at instrument stations 1, 2, 3, and 4 were connected to Cable A. More details on this test system configuration are found in Fernandez et al. (1998c) [9].

Barker and Short (1996a,b,c) [11-13] reported the following results from the underground power distribution system project. After lightning attachment to ground, a substantial fraction of the lightning current flowed into the neutral conductor of the cable with approximately 15 to 25 % of the total lightning current (measured at the rocket launcher) being detected 70 m in either direction from the strike point at instrument stations 1 and 2. The largest voltage measured between the center conductor and the concentric neutral of the cable was 17 kV, which is below the cable's basic insulation level (BIL) rating. Voltages measured at the transformer secondary were up to 4 kV. These could pose a threat to residential appliances. The underground power cables were excavated by the University of Florida research team in 1994. Lightning damage to each of these three cables is illustrated in Fig. 3.

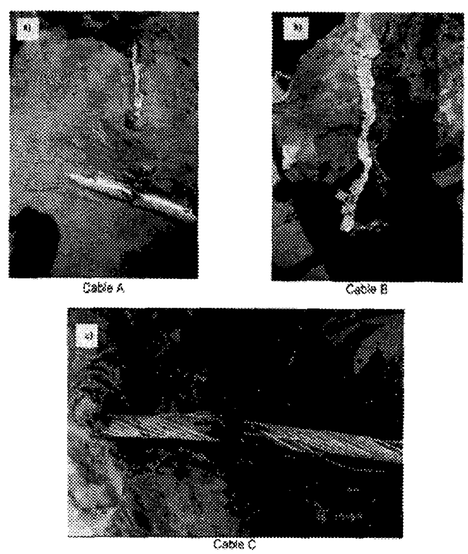


Figure 3. Lightning damage to underground power cables. (a) Coaxial cable in an insulating jacket inside a PVC conduit; note the section of vertical fulgurite in the upper part of the picture (the lower portion of this fulgurite was destroyed during excavation) and the hole melted through the PVC conduit. (b) Coaxial cable in an insulating jacket, directly buried; note the fulgurite attached to the cable. (c) Coaxial cable whose neutral was in contact with earth; note that many strands of the neutral are melted through. The photographs (a) and (b) were taken by V.A. Rakov, and photograph (c) was provided by P.P. Barker.

III. Responses of a Two-Conductor Overhead Power Line to Direct and Nearby Lightning Strikes

During the 1993 experiment at Camp Blanding, the voltages induced on the overhead distribution line shown in Fig. 1 were measured at Poles 1, 9, and 15. The line had a length of about 730 m and was not connected to the underground distribution system (Cable A). The distance between the line and the triggered lightning strikes over the cables was 145 meters. The line was terminated at both ends with a resistance of 500 Ω, and its neutral (the bottom conductor; see Fig. 1) was grounded at Poles 1, 9, and 15. The results of this experiment have been reported by Barker et al. (1996) and are briefly reviewed next. Waveforms for the induced voltages and for the total lightning current were obtained for 63 return strokes from the 30 triggered flashes. A strong correlation was observed between the peak values of the return-stroke current, ranging from 4 to 44 kA, and the voltage, ranging from 8 to 100 kV, induced at Pole 9, with a correlation coefficient of 0.97. Voltages induced at the terminal poles were typically half the value of the voltage induced at Pole 9.

In 1994-1997, the test distribution system at Camp Blanding shown in Fig. 1 was subjected to both direct and nearby triggered-lightning strikes. A large number of system configurations were tested, and several important results were obtained. It was observed, for example, that when lightning strikes earth at tens of meters from the system's grounds, an appreciable fraction of the total lightning current enters the system from earth (Fernandez 1997 [14]; Fernandez et al. 1998a, b [15, 16]). The observed peak values of current entering the system from earth, in percent of the total lightning current peak, were (for three different events) 10 % at 60 m (see Fig. 4), 5 % at 40 m,

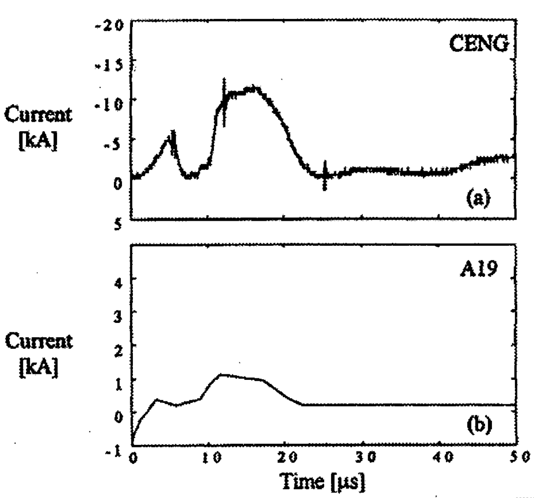


Figure 4. Current versus time waveforms for Flash 9516, displayed on a 50-:s scale. a) Total lightning current [CENG]; b) Ground-rod current [A19] measured 60 m from the lightning strike point.

and 18 % at 19 m from the ground strike point. These observations may have important implications for modeling of lightning-induced effects on power lines. Further, vertical ground rods in sandy soil subjected to lightning currents appeared to exhibit a capacitive behavior rather than the often expected resistive behavior (Rakov et al. 2002) [17]. More details on findings from the 1994-1997 experiments at Camp Blanding are found in Uman et al. (1997) [18], Fernandez (1997) [14], Fernandez et al. (1998c, 1999) [9, 19], and Mata et al. (2000) [20].

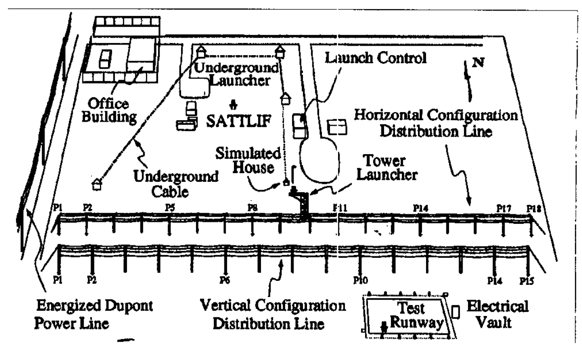
IV. Responses of Three-Phase Plus Neutral Overhead Power Lines to Direct Lightning Strikes

Results of triggered-lightning experiments conducted in 2000, 2001, and 2002 at the ICLRT at Camp Blanding, Florida, to study the responses of four-conductor overhead distribution lines to direct lightning strikes are presented in this section.

An overview of the ICLRT during 2000-2002 is shown in Fig. 5. The facility included two unenergized four-conductor (three horizontally or vertically configured phase conductors plus a neutral conductor underneath) power distribution lines. We first present results for the line with horizontally-configured phase conductors obtained in 2000 and then for the line with vertically-configured phase conductors obtained in 2001 and 2002.

A. Horizontal Configuration Distribution Line

The horizontal configuration, 856-m line was subjected to eight lightning flashes containing return strokes between July 11 and August 6, 2000 (Mata et al., 2003) [21]. The line was additionally subjected to two flashes without return strokes that are not considered here. The lightning current was



injected

Figure 5. Overview of the ICLRT at Camp Blanding, Florida, 2000-2002.

into the phase C conductor in the middle of the line. Six of the eight flashes with return strokes produced damage to the phase C arrester at pole 8. Of the two that did not, one had a rocket-trailing wire over the line and the other produced a flashover at the current injection point. The eight triggered flashes contained 34 recorded return strokes. These return strokes were characterized by submicrosecond-current risetimes and by peak currents having geometric and arithmetic means between 15 and 20 kA with a maximum peak current of 57 kA. Each triggered flash also contained an initial continuous current of the order of hundreds of amperes, which flowed for a time of the order of hundreds of milliseconds, and some flashes contained a similar continuing current after subsequent strokes. The placement of conductors and arresters on the test distribution line is illustrated in Fig. 6. A total of six three-phase arrester stations were installed on the line, at poles 2, 5, 8, 11, 14, and 17, the arresters being connected between the phase conductors and the neutral conductor. The neutral of the line was grounded at these poles and at the two line-terminating poles, 1 and 18. The 856-m three-phase line was terminated at each end in an impedance of about 500 Ω. The distance between poles on the line varied from 47 to 73 m.

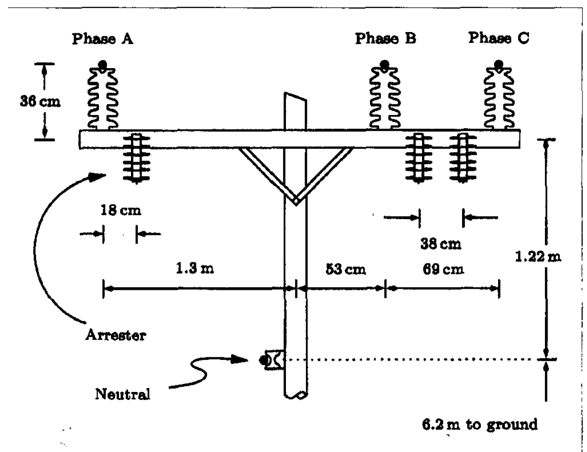


Figure 6. Placement of conductors and arresters on the test distribution line.

The grounding of the neutral at each arrester station pole and at each of the two terminating poles was accomplished by means of 24-m vertically driven ground rods. The low-frequency, low-current grounding resistance of each pole ground was measured on several occasions using the fall-of-potential method. The measured grounding resistances in September 2000 were 41, 47, 28, 52, 55, 37, and 22 Ω for the ground rods at poles 1, 2, 5, 8, 11, 14, 17, and 18, respectively. Although the long-term variation of grounding resistance should be small, short-term variation can be significant due to sporadic rainfall in Florida, particularly during the summer months. Two different brands of 18-kV MOV arresters were used in the experiment: arresters installed at poles 2, 5, 14, 17 were from manufacturer A and those installed at poles 8 and 11 were from manufacturer B. Polymer insulators were used at the terminating poles and ceramic insulators on all other poles, all 35-kV rated.

Arrester currents, line currents, and neutral currents were measured with current transformers (CTs), and currents through the terminating resistors at pole 1 and at each pole ground location with 1-mΩ current viewing resistors (shunts). The current signals were recorded on Lecroy digitizing oscilloscopes at a sampling rate of 20 MHz. The total triggered-lightning current was measured at the rocket launching unit with a 1-mΩ shunt and recorded with a Lecroy digitizing oscilloscope having a sampling rate of 25 MHz.

We focus here on the paths of return stroke current and charge transfer from the current injection point on one phase, C, between poles 9 and 10, to the eight grounds. We study this division only for the case, flash 0036, in which arrester failure did not occur or had not yet occurred in the flash, except for Fig. 10 where all strokes recorded in 2000 without severe saturation are included. We examine the peak return stroke currents and the charge transferred from the start of the return stroke to a time of 1 ms. In flash 0036, an initial continuous current and 5 return strokes were injected into phase C between poles 9 and 10 prior to the arrester failure at pole 8. The arrester on pole 8 failed following the fifth stroke, perhaps from the accumulation of energy from the initial continuous current and the five strokes or from those currents and any following unrecorded continuing current and additional strokes. As an example, Fig. 7 shows a drawing depicting the division of the incident current for the first stroke of flash 0036. This stroke had a peak current of about 26 kA. Note that the arrester current at pole 8 was lost due to instrumentation (fiber optic link) malfunction, but it likely was similar to the arrester current at pole 11, given the symmetry of the other currents on the line. Also, current through the terminating resistor at pole 18 was not measured.

Figure 8 shows the arrester and terminating-resistor peak currents recorded for all five strokes of flash 0036, while Fig. 9 gives the peak currents entering all eight pole grounds for the five return strokes.

It is evident from Figs. 7-9 that the bulk of the peak current injected into phase C passed through the arrester at pole 11, and by inference at pole 8, and also went to ground mostly at poles 8 and 11.

Figure 10 shows the measured distribution of peak current to ground for all strokes triggered to the horizontal-configuration line in 2000. In many of these events there were line flashovers. It is evident that all strokes show a behavior similar to that in the example above for flash 0036.
Figure 7 shows current waveforms only to 100 :s, although the total duration of current records is 10 ms. Figure 11 shows percentages of charge transfer through arresters and terminating resistor at pole 1, and Fig. 12, percentages of charge transfer through ground rods, at 100 :s, 500 :s, and 1 ms.
It is interesting to note from Fig. 7, an observation also illustrated in Fig. 12, that after 25 :s or so the current to ground no longer from the neutral primarily through the grounds closest to the strike point but is more uniformly distributed among the eight grounds. In fact, the currents after 25 :s are distributed roughly inversely to the measured low frequency, low current ground resistance. Figure 12 shows that the percentage of charge transferred to a given ground in the first 100 :s is not much different from that transferred in the first millisecond.

As seen in Fig. 7, there are considerable differences among the waveshapes of currents measured in different parts of the test system. As a result, the division of peak current to ground (Fig. 9) is very different from the division of associated charge transfer (Fig. 12). It appears that the higher-frequency current

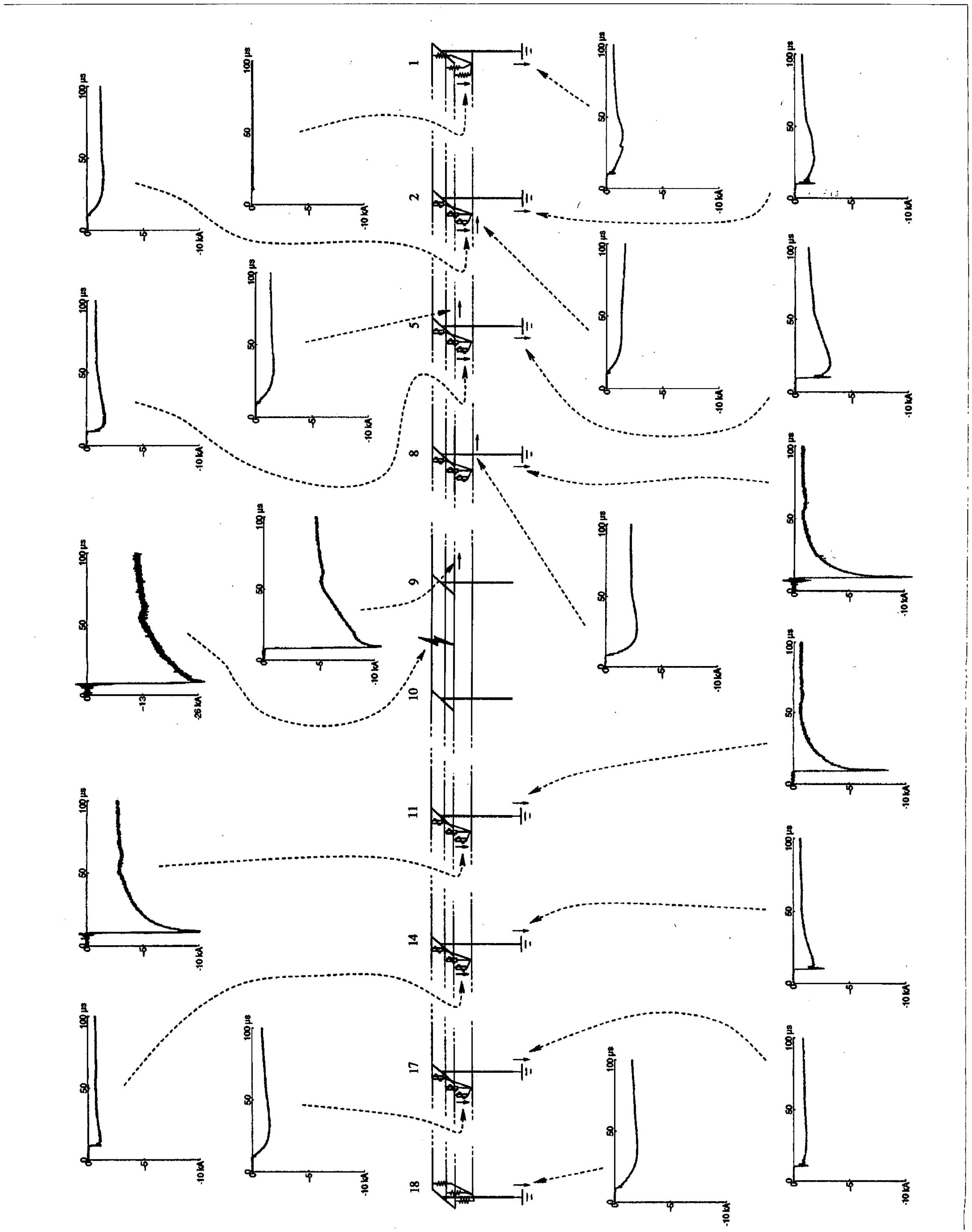


Figure 7. Current distribution for flash 0036, stroke 1.

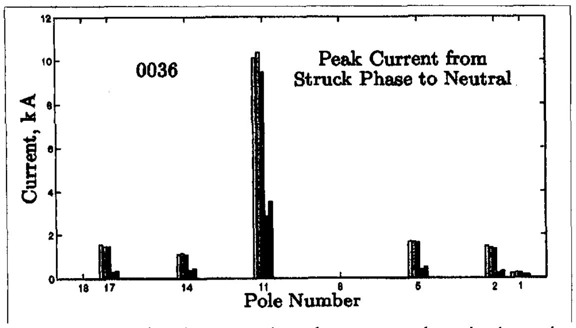


Figure 8. Measured peak currents through arresters and terminating resistor at pole 1 for strokes 1 through 5 (in ascending order from left to right) of flash 0036. Arrester currents at pole 8 were lost due to instrumentation malfunction. Currents through the terminating resistor at pole 18 were not measured.

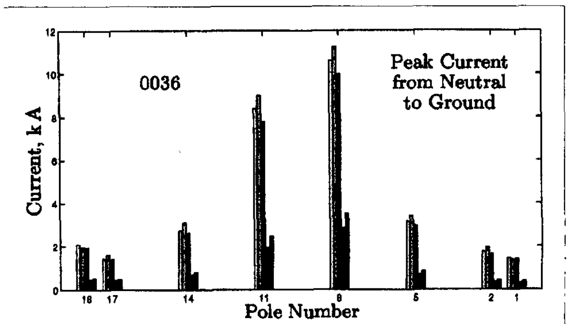


Figure 9. Measured peak currents to ground for strokes 1 through 5 (in ascending order from left to right) of flash 0036.

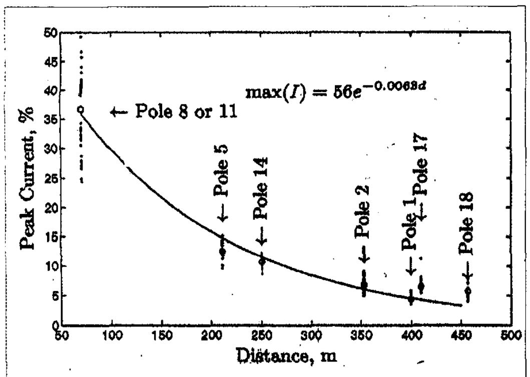


Figure 10. Measured peak current to ground in percent of the total lightning peak current as a function of distance from the strike point. Dots represent measured peak current to ground for all strokes triggered in 2000 with no severe saturation, circles indicate mean values, and the solid line is the exponential function that fits the mean values.

components that are associated with the initial current peak tend to flow from the struck phase to ground through the arresters and ground rods at the two poles closest to the current injection point (see also Fig. 10). The low-frequency, low-current grounding resistances of the ground rods apparently have little or no effect on determining the paths for these current components. The lower-frequency current components that are associated with the tail of current waveforms are distributed more evenly

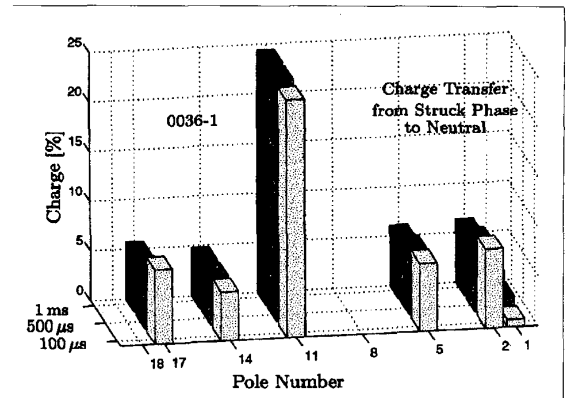


Figure 11. Percentage of total charge transferred through phase C arresters at different poles and terminating resistor at pole 1, calculated at three different instants of time (100 :s, 500 :s, and 1 ms from the beginning of the return stroke) for stroke 1 of flash 0036. No measurements are available at pole 8 and pole 18.

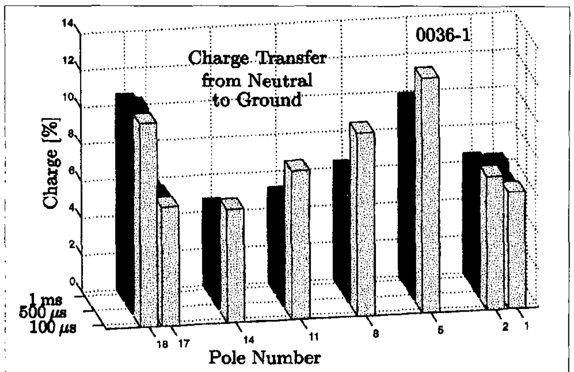


Figure 12. Percentage of total charge transferred to ground at different poles, calculated at three different instants of time (100 :s, 500 :s, and 1 ms from the beginning of the return stroke) for stroke 1 of flash 0036.

among the multiple ground rods of the test system and appear to be significantly influenced by the low-frequency, low-current grounding resistances of the ground rods. In fact, the distribution of charge transfer in Fig. 12 is very similar to the distribution of the inverse of the low-frequency, low-current grounding resistances of the ground rods, with poles 5 and 18 having the largest charge transfer and the lowest grounding resistances. Since the current waveshapes may differ considerably throughout the system, charge transfer is apparently a better quantity than the peak current for studying the division of lightning current among the various paths in the system.

The peak current through the arrester at pole 11 in percent of the total lightning peak current for the five strokes of flash 0036 ranges from 48 to 40% (see Fig. 8), similar to the average percentage, 37%, for all strokes (Fig. 10). If we assume similar percentages for pole 8, then the sum of arrester peak currents at the two poles nearest to the current injection point for each of the five strokes of flash 0036 ranges from 76 to 80%. The percentage of total charge transferred through the arrester at pole 11 by stroke 1 in 1 ms is about 24%, not much different for time intervals ranging from 100 :s to 1 ms.

Percentages of peak current to ground for stroke 1 at poles 8 and 11 (Fig. 9) are 40 and 31%, while the percentages of charge transfer to ground (at 100 :s) are 10 and 8%. Note that the sum of charges transferred to ground at all eight poles (Fig. 12) is only about 70% of the total lightning charge determined from the current waveform measured at the rocket launcher. The reason for this discrepancy is unknown, one possible explanation being flashovers at the launch tower. If indeed about 30% of the charge was lost at the launch tower, that is, was not injected into the line, then the percentages in Figures 11 and 12 should be multiplied by roughly 1.4, so that, for example, the percentage of total charge transferred through the phase C arrester at pole 11 by stroke 1 is about 34%.

In summary, for a 856-m, four-conductor, unenergized test power distribution line equipped with six MOV arrester stations and each phase terminated at each end in a 500-Ω resistor, we found that:

- There are considerable differences among the waveshapes of currents flowing from the struck phase to neutral and from the neutral to ground at different poles of the line.
- The higher-frequency current components that are associated with the initial current peak tend to flow from the struck phase to neutral and then to ground at the two poles adjacent to the lightning current injection point.
- The division of lightning charge among the multiple paths between the struck phase and neutral is different from the division of charge among the multiple ground rods. The charge transfer from the struck phase to neutral tends to occur at the two poles adjacent to the lightning current injection point, while the charge transfer from the neutral to ground is apparently determined by the low-frequency low-current grounding resistances of the ground rods.

B. Vertical Configuration Distribution Line

The vertical configuration, 812-m line was subjected to four lightning flashes containing return strokes (also to four flashes without return strokes) between July 26 and September 5, 2001 and to ten flashes with return strokes between June 27 and September 13, 2002 (Mata et al. 2001, 2002) [22, 23]. In 2001, return-stroke peak currents ranged from 6 to 28 kA and in 2002 from 6 to 34 kA. Arresters were installed at poles 2, 6, 10, and 14. Lightning current was injected into the top conductor near the center of the line.

In 2001, for one of the flashes having return strokes, an arrester failed early in the flash, probably during the initial stage. The three other flashes with return strokes were triggered with failed arresters already on the line, those being caused by previous flashes without return strokes and by the one flash that likely caused an arrester failure during its initial stage. Two flashes without return strokes did not damage arresters. One flash with return strokes was triggered when the line contained two damaged arresters, resulting in the failure of a third arrester. Note that the charge transfer associated with the initial-stage current is of the order of tens of coulombs, more than an order of magnitude larger than the charge transfer associated with triggered-lightning return strokes.

In 2002, in order to reduce arrester damage during the initial stage of rocket-triggered lightning, a different configuration of the tower launching system was used. This new configuration allowed the diversion of most of the initial-stage current to ground at the tower base. Additionally, two arresters were installed in parallel on the struck (top) phase conductor. In 2002, arresters failed on three storm days out of a total of five (60%), compared with two out of three storm days (67%) in 2001. Flashovers on the line were very frequent during the direct strike tests. Significant currents were detected in phase B, which was not directly struck by lightning, with the waveshape of phase B currents being similar to that of the corresponding current in phase A that was directly struck. For all flashes occurring during July 2002, it was assumed that this current in phase B was due to a short circuit through instrumentation at pole 7. On the other hand, even after this problem had been fixed at the end of July, out of 15 return strokes only three showed no evidence of current in phase B, the remaining 12 probably being associated with flashovers between phases A and B.

Overall, our results suggest that many direct lightning strikes to power distribution lines are capable of damaging MOV arresters, unless alternative current paths (flashovers, transformers, underground cable connections, etc.) are available to allow the lightning current to bypass the arrester. The 2001 and 2002 results are in support of the trend seen in Fig. 10.

V. Acknowledgment

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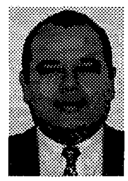
VII. Biographies

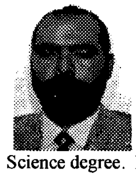
Vladimir A. Rakov is Professor of the University of Florida's (UF) Department of Electrical and Computer Engineering. He is the author or co-author of over 30 patents and about 270 papers and technical reports on various aspects of lightning, with about 100 papers being published in reviewed journals. Dr. Rakov received the Master's and Ph.D. degrees from Tomsk Polytechnical University (Tomsk Polytechnic), Russia in 1977 and 1983, respectively. From 1977 to 1979 he worked as an Assistant Professor of Electrical Engineering at Tomsk Polytechnic. In 1978 he became involved in lightning research at the High Voltage Research Institute, a division of Tomsk Polytechnic, where from 1984 to 1994 he held the position of Director of the Lightning Research Laboratory. In 1991, he joined the faculty of the Department of Electrical and Computer Engineering at UF. He has been named an Inventor of the USSR (1986) and received a Silver Medal from the (USSR) National Exhibition of Technological Achievements (1987). Dr. Rakov is Chairman of the Technical Committee on Lightning of the biennial International Zurich Symposium on Electromagnetic Compatibility and former chairman of the AGU Committee on Atmospheric and Space Electricity. He has been elected IEEE Fellow "for contributions to the understanding of lightning discharge phenomena".



Carlos T. Mata received his Bachelor's degree from the "Universidad Simón Bolívar" (USB), Venezuela in 1993, his Master's and Ph.D. from the University of Florida (UF) in 1997 and 2000, respectively. Dr. Mata is involved in the area of computer modeling of different lightning processes and responses of power distribution systems to direct and nearby lightning strikes. Dr. Mata currently works at the Kennedy Space Center doing embedded system and advanced data acquisition systems design in support to the Shuttle program. He is author or co-author of eight journal publications and eight technical reports. Dr. Mata is a member of the American Geophysical Union (AGU), the Institute of Electrical and Electronics Engineers (IEEE), and the Power Engineering Society (PES). In 1998 Dr. Mata received the GAANN fellowship and in 2001 the IEEE Power Engineering Society SPDC Prize Paper Award and the Kennedy Space Center Innovative Excellence Award.

Martin A. Uman is Professor and Chair of the University of Florida's Department of Electrical and Computer Engineering. Dr. Uman has written 3 books on the subject of lightning, as well as a book on plasma physics, ten book chapters and encyclopedia articles on lightning, and has published over 140 papers in reviewed journals. He holds 5 patents, 4 in the area of lightning detection. Dr. Uman received the Ph.D. degree from Princeton University in 1961. He was an Associate Professor of Electrical Engineering at the University of Arizona in Tucson from 1961 to 1964. Dr. Uman joined the University of Florida faculty in 1971 after working for seven years as a Fellow Physicist at Westinghouse Research Labs in Pittsburgh. Dr. Uman co-founded and served as President of Lightning Location and Protection Inc. (LLP) from 1975 to 1985. Dr. Uman is the recipient of the 1996 IEEE Heinrich Hertz Medal for outstanding contributions to the understanding of lightning electromagnetics and its application to lightning detection and protection" and the 2001 AGU John Adam Fleming Medal for original research and technical leadership in geomagnetism, atmospheric electricity, space science, aeronomy, and related sciences: for outstanding contribution to the description and understanding of electricity and magnetism of the Earth and its atmosphere." Dr. Uman is a Fellow of AGU, AMS, and IEEE.

Keith J. Rambo received the B.S.E.E. degree from the University of Florida (UF) in 1978. As an undergraduate he worked in the UF Lightning Research Laboratory. From 1979 to 1983 he was Senior Process Development Engineer of Intel Corporation in Santa Clara, California. From 1983 through 1986 he was a Product Line Manager for Xicor, responsible for all aspects of wafer fabrication. In 1986, he joined the UF Department of Electrical and Computer Engineering where since 1989 he has been Director of Technical Support Services. Since 1994, Mr. Rambo has been heavily involved in triggered-lightning experiments at Camp Blanding, Florida. He has 10 technical publications.



Angel G. Mata received his Bachelor's degree from the "Universidad Simón Bolívar" (USB), Venezuela in 2000. In Summers of 1999 and 2000, he participated in triggered-lightning experiments at the ICLRT at Camp Blanding, Florida. In 2001 Mr. Mata joined the UF Lightning Research Laboratory, where he holds a graduate research assistantship. He is currently pursuing his Master's of Science degree. Mr. Mata has two technical publications.