Added CFO Voltage by the Fiberglass Distribution Line Pole

S. Grzybowski, *Fellow, IEEE*, and X. Li, *Student Member, IEEE*

***Abstract*—This paper presents the study results conducted on the critical flashover (CFO) voltages of the fiberglass distribution line pole and its combination with polymer and porcelain insulators. Special attention was made to evaluate the Added CFO voltages by the fiberglass pole to the insulators when pole served as a second component in the distribution line structure. A discussion of the results follows the data obtained.**

***Index Terms*—Flashover, Insulation, Insulators, Lightning, Pole, Stress, Voltage.**

I. Introduction

It has been proved that lightning, either induced lightning surge or direct lightning stroke, has much more severe impact on the power distribution systems than the power transmission systems. The critical flashover voltage (CFO), defined as the crest value of a standard impulse for which the insulation exhibits 50% probability of withstand, is always used to describe the lightning impulse strength of an insulation structure. Therefore, it is very important for a design engineer to know the CFO voltage of the available insulation structures when designing the distribution line structure.

The CFO voltages of wood distribution line pole and Added CFO voltage by wood pole have been investigated for many years. Laboratory results and theoretic analysis were presented in the previously published paper [1]. Recently, the fiberglass pole has been used in power distribution systems by some utilities. No study has been made on lightning impulse strengths of fiberglass pole as an insulation structure alone or its combination with insulators. Research on CFO voltages of fiberglass pole and Added CFO voltages by fiberglass to basic insulation components is significant since it can provide some basic information about the lightning impulse strength of the overhead distribution line structure with fiberglass pole.

In power distribution systems, if the insulation structure consists of fiberglass pole and insulators. The pole is considered to serve as an additional insulation component to the basic insulation. Fig. 1 shows the typical configuration of distribution line structure when the pole serves as a second insulation component.

This work was supported by Alabama Power Company, Birmingham, AL.

S. Grzybowski is with the Department of Electrical and Computer Engineering, Mississippi State University, Mississippi State, MS 39762 USA (email: stangrzy@ece.msstate.edu).

X. Li is with the Department of Electrical and Computer Engineering, Mississippi State University, Mississippi State, MS 39762 USA (e-mail: xl2@ece.msstate.edu).

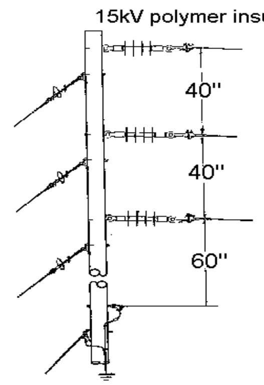

Fig. 1. Typical configuration of distribution line pole structure, the pole serves as a second insulation component.

II. Testing Equipment and Procedure

The lightning impulse used in the laboratory investigation was a 1.2/50 μs standard lightning impulse as described in IEEE Standard Techniques for High Voltage Testing, IEEE Standard # 4 - 1995. The magnitude and waveform of generated standard lightning impulse were measured and displayed on a Tektronix TDS 540 digital oscilloscope. The oscilloscope and other data output equipment was placed in a double-shielded copper screen room to eliminate the intensive electromagnetic interference caused by the flashover of the tested insulation structures.

The fiberglass pole assembly was mounted on a metal base equipped with casters, for ease of mobility. The appropriate insulator assemblies were attached to the top of the fiberglass poles depending upon the tested configuration. The evaluated insulation strength of fiberglass pole was from 1 foot to 8 feet. Two metallic bands, upper and bottom bands, were employed as electrodes and tightly wrapped around the pole. The lightning impulse was applied to the upper band. The bottom band was grounded. If the combined insulation structures were tested, the lightning impulse was applied to the insulator. To simulate wet condition, a water supply system and a set of adjustable nozzles surrounding the insulation structure were set up in the HV laboratory. The water conductivity range was from 180 Ω•m to 200 Ω•m, and the water was sprayed at an angle of 45^o onto the insulation structure at a rate of 3 mm/minute, as specified in IEEE Std # 4- 1995.

III. CFO VOLTAGE OF FIBERGLASS POLE

The CFO voltages of the fiberglass pole under positive and negative lightning impulses, and wet and dry conditions were evaluated. Based on the test results, the CFO voltages of the fiberglass poles have a linear relationship with the pole length. If the tested pole length was the same, the CFO voltage at negative polarity and dry conditions is the highest; the CFO voltage at positive polarity and wet conditions has the lowest value.

Fig. 2 presents the CFO voltages of the fiberglass and wood poles under wet conditions and positive polarity. It can be found the CFO voltage of the fiberglass pole is higher than the wood pole if the pole length, impulse polarity and test conditions were the same for both tests.

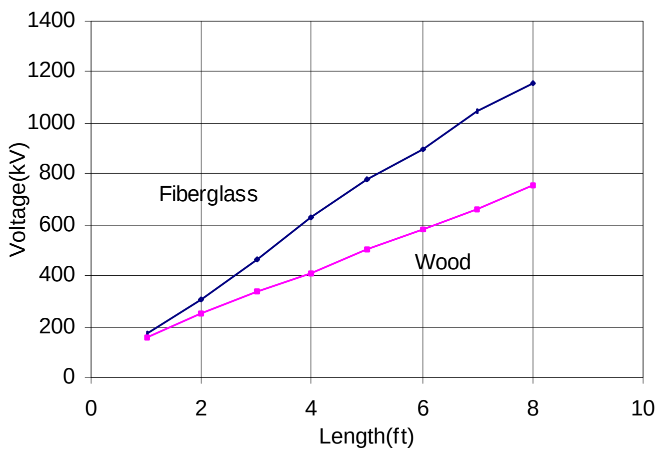

Fig. 2. The CFO voltages of the fiberglass and wood poles under wet conditions and positive polarity.

Under wet condition and positive lightning impulse, the CFO voltage strength of the fiberglass pole, the strength of CFO voltage per foot, decreased from 170 kV/ft, at 1 foot, to 120 kV/ft at 8 feet. For the same condition and impulse polarity, the CFO voltage strength of the wood pole decreased from 150 kV/ft, at 1 foot, to 100 kV/ft, at 8 feet [3]. The CFO voltage strength of the fiberglass pole is approximately 20 kV/ft higher than the wood pole.

IV. CFO VOLTAGES OF INSULATORS PLUS FIBERGLASS POLE

The total CFO voltage of the insulator plus pole is lower than the sum of the CFO voltages of individual insulation components in the combined insulation structure. The CFO voltages of the insulation configurations consisting of two components, is defined as the CFO voltage of the basic components (insulators) plus the Added CFO voltage by the second component (pole or cross-arm).

The 15 kV, 25 kV, and 35 kV polymer suspension insulators and porcelain pin insulators were used in the laboratory investigation. The CFO voltages of 35 kV polymer suspension insulators plus fiberglass pole, the CFO voltages of the fiberglass pole under dry and wet conditions, at positive lightning impulse are presented in Fig. 3. The CFO voltages of polymer suspension insulator plus fiberglass pole exhibit a linear relationship with the evaluated pole length. If the tested pole length is the same, the CFO voltage of polymer suspension insulators plus fiberglass poles is the highest at negative lightning impulse and dry conditions; and it is the lowest at positive lightning impulse and wet conditions.

The CFO voltages of 15 kV, 25 kV and 35 kV porcelain pin insulators plus fiberglass pole were also evaluated and the similar conclusions can be drawn from the test results. The different discharge paths were observed in the tests and presented in Fig. 4 to Fig. 7.

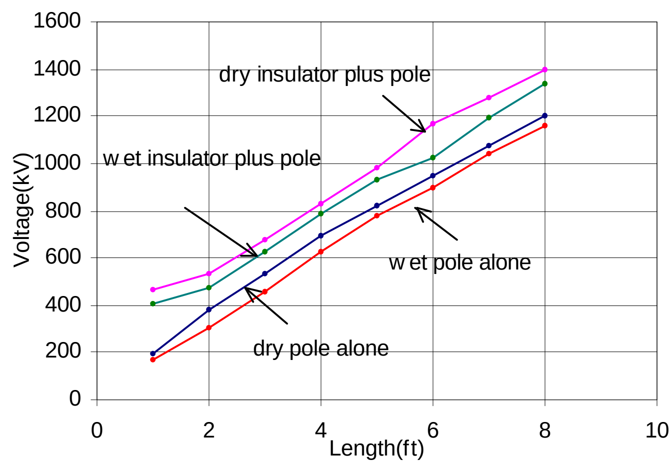

Fig. 3. The CFO voltages of 35 kV polymer suspension insulators plus the fiberglass pole and the CFO voltage of fiberglass pole, under dry and wet conditions, positive lightning impulse.

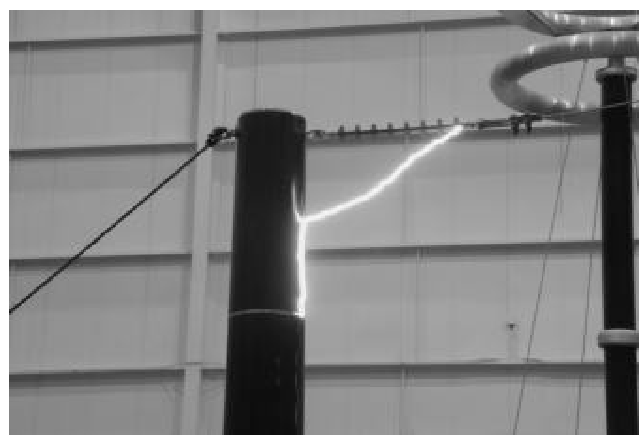

Fig. 4. The 35 kV polymer suspension insulator plus fiberglass pole, the tested pole length is 2 feet. The discharge took place in the air and on the surface of the pole.

The flashover would occur on those paths where the insulation structure exhibits the weakest impulse strength. Therefore, different flashover paths are expected to occur in the tests if combined insulation structure was evaluated. When the pole length is 1 foot, the discharge happened in the air gap,

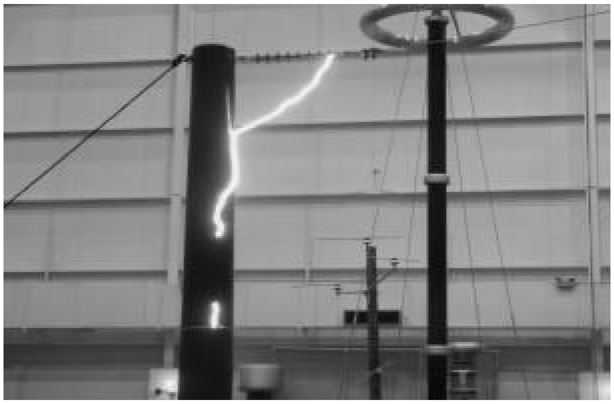

Fig. 5. The 35 kV polymer suspension insulator plus fiberglass pole, the tested pole length is 6 feet. The discharge didn't develop on the surface of insulator, but appeared in the air and on both sides of the pole's surfaces.

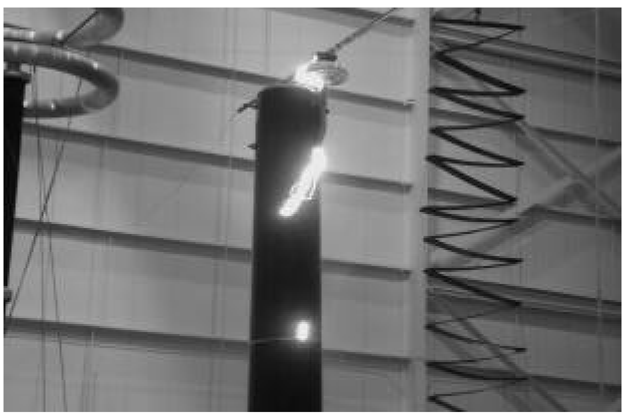

Fig. 6. The 35 kV porcelain pin insulator plus fiberglass pole, the tested pole length is 3 feet. The discharge developed on the surface of insulator and both sides of the pole's surfaces.

Fig. 7. The 35 kV porcelain pin insulator plus fiberglass pole, the tested pole length is 8 feet. The discharge developed on the surface of insulator and the pole.

which indicates that the lightning impulse strength of the suspension polymer insulator plus fiberglass pole is higher than the air gap between the energized insulator and the grounded electrode. When the pole length was 2 feet or above, the discharge paths always initiated from energized insulator and terminated on the pole surface about 1 foot below the top of the pole though the air, then developed on the surface of the pole until the grounded electrode was reached. Some times the discharges appeared around the suspension insulator surfaces and the pole surfaces. Therefore, the lightning impulse strength of the air gap between the energized insulator and grounded electrode became higher than the surfaces of insulator and pole in this case.

When the distribution line pole structure of porcelain pin insulator and fiberglass pole was tested, the discharge paths are different from those of polymer suspension insulator. In this insulation structure, the discharges initiated from the energized insulator, and is developing around the surfaces of the insulator and the pole, because the surfaces of the insulator and pole have the lest lightning impulse strength.

When the discharge developed on the surface of the pole, it might take place on either side of the pole surface depending on which side of the pole surface exhibits less lightning impulse strength. The discharge can also be observed on both sides of the pole in case of breakdown of the pole. It is known that the lightning impulse strength of an insulation structure under wet condition is much less than under dry condition. Therefore, the discharge always appeared on the outside surface of pole in the wet tests. Different discharge paths determine that the CFO voltage of an insulation structure would not a constant value.

IV. ADDED CFO VOLTAGES BY FIBERGLASS POLE

The Added CFO voltage by fiberglass pole is calculated by subtracting the CFO voltage of insulator from the total CFO voltage of insulator plus fiberglass pole [1, 2, 3]. The Added CFO voltage to 15 kV, 25 kV, and 35 kV polymer suspension insulators by the fiberglass pole is higher at dry condition than at wet condition. Fig. 8 presents the Added CFO voltages by the fiberglass pole to 15 kV, 25 V, and 35 kV polymer suspension insulators at dry condition and positive polarity. Fig. 9 shows the CFO voltages of fiberglass pole and Added CFO voltages to 35 kV porcelain pin insulator. Fig. 10 presents the CFO voltages of fiberglass pole and Added CFO voltages to 35 kV polymer suspension insulators. Fig. 11 illustrates the Added CFO voltages by the fiberglass and wood pole to 15 kV polymer suspension insulators at wet conditions and positive lightning impulse

From the Fig. 11, it can be found that the Added CFO voltage by the fiberglass pole is much higher than the wood pole. This indicates that the lightning impulse strength of the distribution line structure with fiberglass pole can be greatly improved if fiberglass pole is used as a second insulation component.

.

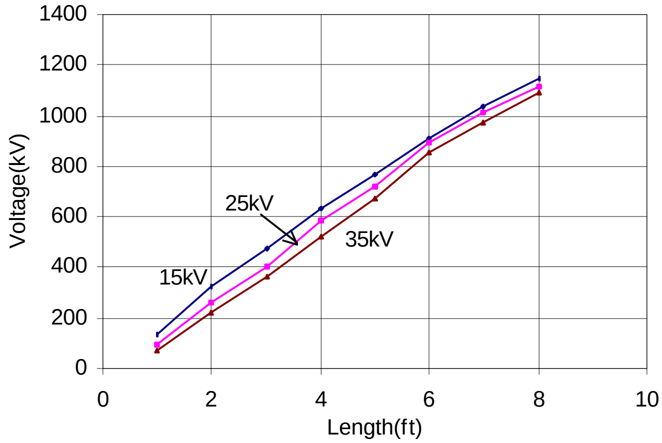

Fig. 8. The Added CFO voltages to 15 kV, 25 kV, and 35 kV polymer suspension insulators, dry condition and positive impulse.

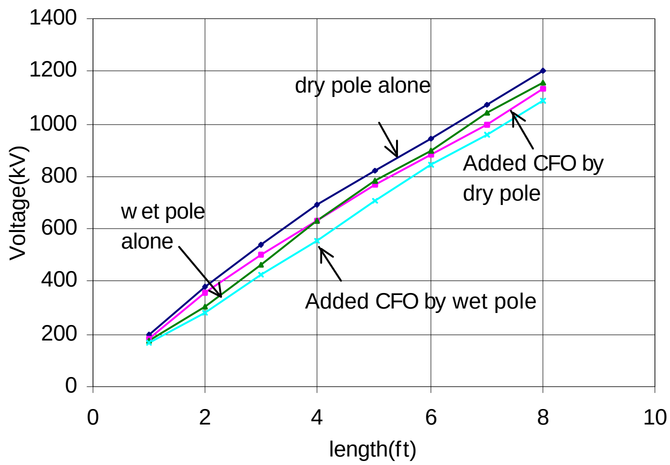

Fig. 9. The CFO voltages of fiberglass pole and the Added CFO voltages to 35 kV porcelain pin insulator, wet condition and positive impulse.

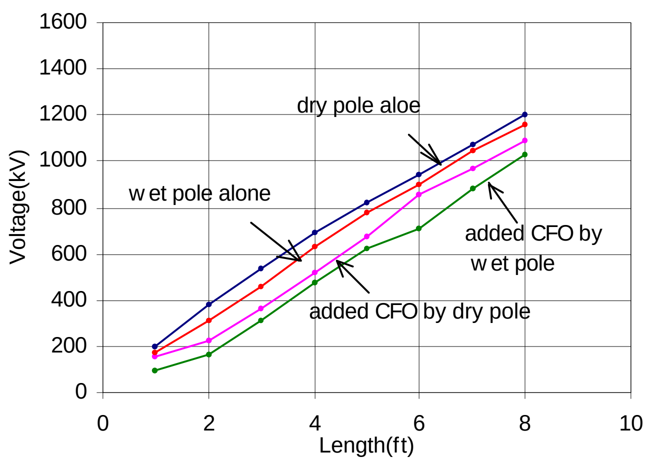

Fig. 10. The CFO voltages of fiberglass pole and the Added CFO voltages to 35 kV polymer suspension insulator, wet condition and positive impulse.

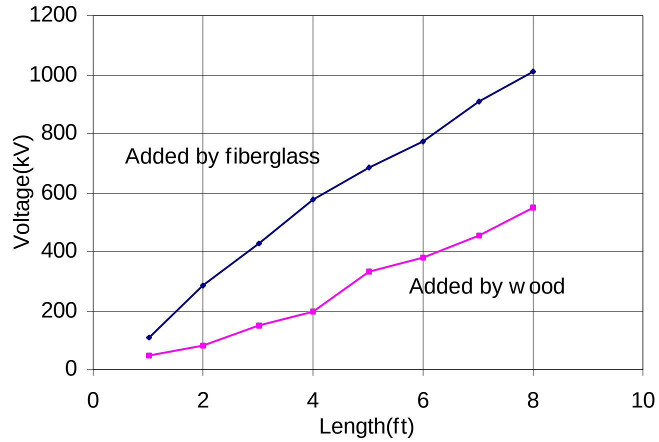

Fig. 11. The Added CFO voltages by fiberglass and wood poles to 15 kV polymer suspension insulators, wet condition and positive impulse.

Fig. 12 presents the Added CFO voltage strengths by fiberglass pole to 35 kV polymer suspension insulators. Fig.13 illustrates the Added CFO voltage strengths by fiberglass pole to 35 kV porcelain pin insulators. The Added CFO voltage strengths by the fiberglass and wood poles to 15 kV polymer suspension insulators at wet condition and positive impulse are presented in Fig. 14.

The Added CFO voltage strength to polymer suspension insulator has a smaller value for shorter pole length (1or 2 ft) than for longer length. The Added CFO voltage strength to porcelain pin insulator almost decreases with the increase of the pole length.

The Added CFO voltage strengths by fiberglass pole are higher than those by wood pole under different test conditions and lightning impulse polarities. The higher Added CFO voltage strength also suggests that the fiberglass pole, if used as a second insulation component, can increase the lighting impulse strength of the distribution line structure to a higher level than the wood pole.

V. ACCELERATED AGING OF FIBERGLASS POLE

The fiberglass pole is subjected to all kinds of aging stresses during its service cycle. The electrical, thermal and environmental stresses will degrade the insulation performance of fiberglass pole. The degraded insulation strength of insulation material is considered as one of the most important reasons to cause fault in electric power systems. Therefore, it is necessary to conduct a study on electrical degradation of fiberglass pole for preventing the fault caused by insulation failure from occurring in power distribution systems. The accelerated aging tests were conducted based on the specified standards [4, 5, 6], and the electrical evaluation tests were used to evaluate the insulation strengths of fiberglass pole before and after the accelerated aging tests were performed.

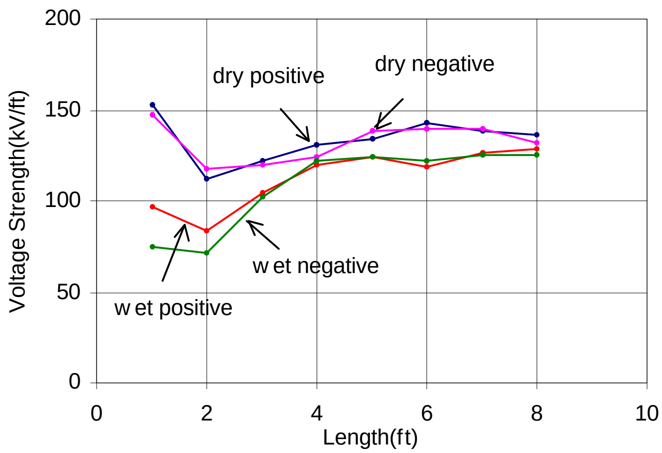

Fig. 12. The Added CFO voltage strengths by fiberglass pole to 35 kV polymer suspension insulators.

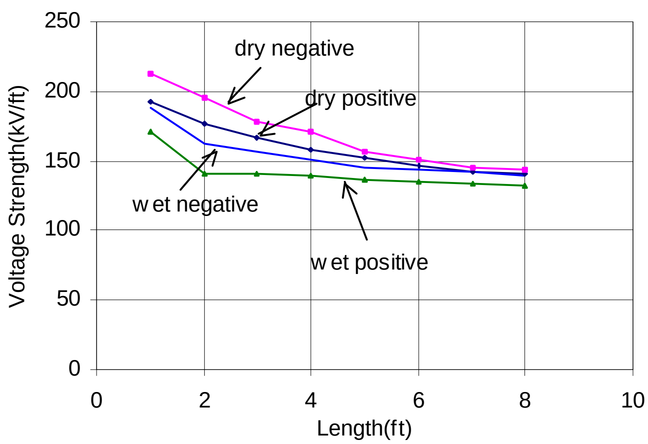

Fig. 13. The Added CFO voltage strengths by fiberglass pole to 35kV porcelain pin insulators.

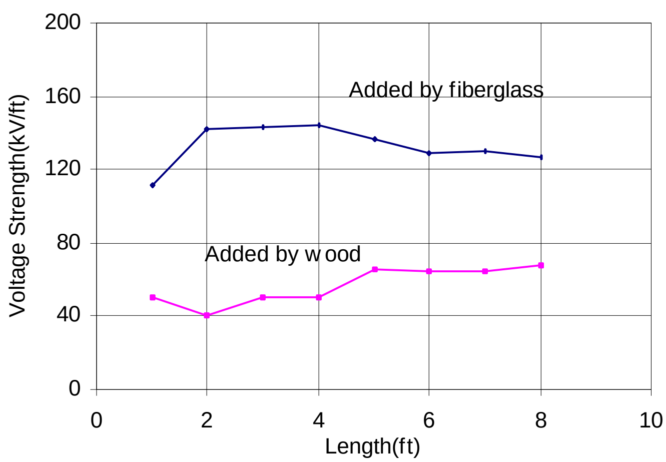

Fig. 14. The Added CFO voltage strengths by fiberglass and wood poles to 15 kV polymer suspension insulators at wet condition and positive polarity.

Five sets of samples, each consisting of nine samples, were selected to age in the accelerated aging tests. To investigate the effect of surface conditions on the electrical degradation of the materials, each set of the samples were divided into three groups in the same accelerated aging test. The three samples were kept intact; some scratches were made to the outside surfaces of other three samples; and five holes with 1 inch in diameter were made to each of the last three samples. Four different accelerated aging tests were conducted, each at 1000 hours of aging. The samples were aged in clean fog, in salt fog, in clean fog with 25 kV/ft electrical stress, and aged in salt fog with 25 kV/ft electrical stress.

The AC leakage current at dry condition, the AC dry and wet flashover voltages, and the CFO voltages at dry and wet conditions, positive polarity lightning impulse were measured for each sample before and after these accelerated aging tests.

The electrical insulation strengths of fiberglass samples decreased after aging based on the results from the clean fog test and clean fog plus electrical stress tests, but the rate of degradation is very slow, especially for clean fog aging tests. It is found that the aging effect of salt fog plus 25 kV/ft electrical stress test on the insulation strengths of fiberglass material is very severe. The flashover occurred to all of the samples aged in the test of salt fog plus electrical stress in less than 10 hours. The tracking and arc trail were observed on both sides of the surfaces of these samples.

The conducted accelerated aging tests suggest that the fiberglass pole could be used in power distribution systems to improve the lightning impulse strength of distribution line structure, but should be not used in the area where salt fog occurs very frequently. The tracking on the surfaces of the samples after salt fog plus electrical stress aging test are presented in Fig. 15 to Fig. 16.

Fig. 15. The tracking appeared on the inside surface after 6.5 hours aging in salt fog with 25 kV/ft electrical stress, recorded leakage current is about 75~85 mA.

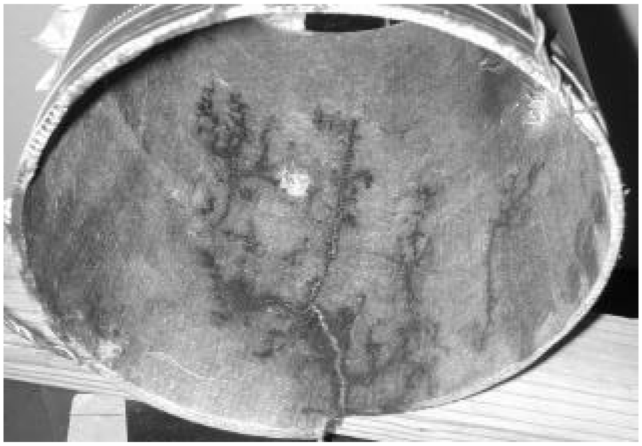

Fig. 16. The tracking appeared on the inside surface after 4 hours aging in salt fog with 25 kV/ft electrical stress, recorded leakage current is about 50~75 mA.

VI. CONCLUSION

The following conclusions on fiberglass distribution pole can be made based on the conducted tests.

1. The Added CFO voltage by fiberglass pole is highest at dry condition and negative polarity lightning impulse, and has the lowest value at wet condition and positive polarity lightning impulse.
2. The Added CFO voltage strength by the fiberglass pole is higher than the Added CFO voltage strength by the wood pole.
3. The Added CFO voltages by fiberglass pole to 15kV, 25kV, and 35kV porcelain pin insulators and polymer suspension insulators are almost the same.
4. The salt fog plus 25kV/ft electrical stress aging test imposes the most severe effect on the insulation performance of the fiberglass distribution pole.

VII. REFERENCES

[1] P. B. Jacob, S. Grzybowski, and E. R. Ross, "An Estimation of Lightning Insulation Level of the Overhead Distribution Lines," *IEEE Trans. Power Delivery*, pp.384 - 390, Jan.1991.

[2] S. Grzybowski, and E. B. Jenkins, "AC and Lightning Performance of Cross-arm Aged in 115kV Transmission Line," *IEEE Trans. Power Delivery*, Vol.8, pp. 1914–1920, Oct. 1993.

[3] S. Grzybowski, X. Li, and E. C. Mullinax, "Critical Flashover Voltage by Fiberglass Distribution Line Pole," *in Proc. of the 6th International Conference on Properties and Applications of Dielectric Materials (ICPADM 2000)*, pp.350- 353.

[4] *IEEE Standard Techniques for High-Voltage Testing*, IEEE Standard #4, Apr. 1995.

[5] *IEEE Recommended Practice for Specifying Distribution Composite Insulator*, IEEE Standard 1024-1988.

[6] *Standard Specification for Fiberglass-Reinforced Plastic Rod and Tube Used in Live Line*, ASTM F711-89, The American Society for Testing and Materials, 1989.

VIII. BIOGRAPHIES

Stanislaw Grzybowski (SM'1970, F'1999) received the M. Sc. and Ph.D. degrees in Electrical Engineering in 1956 and 1964, respectively, from the Technical University of Warsaw. In 1984, he obtained the Dr. Hab. (Dr. Habilitated) degree from the Technical University of Wroclaw, Poland. In 1956, he joined the faculty of Electrical Engineering at the Technical University of Poznan, Poland. From 1958 to 1981, he was the Head of the High Voltage and Electrical Material Division and served as Vice-Dean of Electrical Engineering Faculty in 1969 and from 1975 through 1977. He has been a Visiting Professor at the University of Manitoba, Winnipeg, Canada and at the University of South Carolina, Columbia. In 1987, Dr. S. Grzybowski joined Mississippi State University, where he is now a Professor at the Electrical and Computer Engineering Department. He served also as Director of the High Voltage Laboratory in 1993-2000.

His main research interests are in the area of high voltage engineering: electrical strength of high voltage devices, lightning protection of power systems, and other objects. His research focus on the electrical strength and aging processes in polymer insulation such as high voltage XLPE cables, polymer insulators, fiberglass distribution pole and magnet wires. He developed a new method of Added CFO voltage for evaluation of critical flashover voltage (CFO) of combined insulation system in distribution and transmission lines.

Dr. S. Grzybowski is author/co-author of three books in high voltage engineering, three problems books on HV Engineering for students and four IEEE Standards. He presented his research results in 52 papers published in refereed journals (22 papers in IEEE Transactions) and over 130 research papers published in Proceedings of International and National Conferences.

Xiaoyong Li (S' 1999) was born in Chengdu, the peoples Republic of China, on Nov. 10, 1970. He received his B.Sc. and M.Sc. degree from Xi'an Jiaotong University in 1993 and 1996, respectively. He is now a graduate student in Mississippi State University. His current research interests include lightning protection of power systems, the CFO voltages of electrical devices, and the aging process in fiberglass materials.

His employment experience included the Sichuan Electric Power Company, Chengdu, P.R. China. He is co-author of three papers published in Proceedings of International Conferences.