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Fiberglass distribution line pole

Streszczenie. (Słup z włókna szklanego dla linii rozdzielczej). *Artykuł przedstawia wyniki badań krytycznego napięcia przeskoku (CFO) słupa z włókna szklanego dla linii rozdzielczej oraz jego połączeń z izolatorami polimerowymi i porcelanowymi. Szczególną uwagę zwrócono na określenie dodatkowych napięć krytycznych słupa (Added CFO), gdy słup służy jako drugi, poza izolatorem, element izolacyjny struktury linii rozdzielczej. Przedstawiono dane uzyskane podczas badań na słupach poddanych przyspieszonemu starzeniu i przeprowadzono dyskusję wyników.*

Abstract*. This paper presents the study results conducted on 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. Then, the data obtained from the study performed on accelerated aging of fiberglass distribution line poles is presented, followed by the discussion of the results.*

Słowa kluczowe: słup z włókna szklanego, przeskok, piorun, starzenie.
Keywords: fiberglass pole, flashover, lightning, aging.

Introduction

The wood pole is the most widely used insulation material in power distribution systems. In recent years, some utilities have started to install fiberglass poles in their distribution systems. 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.

The fiberglass pole is subjected to continuous electrical stress during its period of service. Besides the continuous electrical stress, additional stresses, such as overvoltage, thermal stress, irradiation, contamination, and mechanical stress, cause electrical degradation of the fiberglass distribution line pole. If these electrical and non-electrical stresses were combined together, they would degrade the insulation strength of the fiberglass pole at a much faster rate than any other single stress. During a multi-stress aging process, the electrical stress always plays a dominant role in insulation degradation process.

When the distribution pole is considered as an insulation component in a distribution line structure, the insulator serves as the primary insulation component. The distribution pole is used as a secondary insulation component. This type of combined insulation structure could greatly improve the lightning impulse strength of the distribution line structure. Compared to the amount of laboratory work done with a wood pole, little work has been done on the lightning impulse strength of the combined insulation structure when a fiberglass pole is used as the secondary insulation component.

Experimental setup for new tests

Experiments were conducted in the High Voltage Laboratory at Mississippi State University. The lightning impulse used in the laboratory investigation was 1.2/50 μs as described in IEEE Std 4-1995. The appropriate insulator assemblies were attached to the top of the fiberglass poles depending upon the tested configuration. The insulation strength of fiberglass pole was evaluated from 1 foot to 8 feet length of the pole. When the fiberglass pole was tested alone, 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, while the bottom band was grounded. When the combined insulation structures were tested, the lightning impulse was applied to the insulator. To simulate wet conditions, a water supply system and a set of adjustable nozzles surrounding insulation structure was set up. The water conductivity ranged from 85 Ωm to 115 Ωm, and the water was sprayed at an angle of 45° onto the insulation structure at a rate of 3 mm/minute, as specified in the IEEE Std 4-1995.

Critical flashover voltage of fiberglass pole

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.

Figure 1 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.

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. The CFO voltage strength of the fiberglass pole is approximately 20 kV/ft higher than the wood pole.

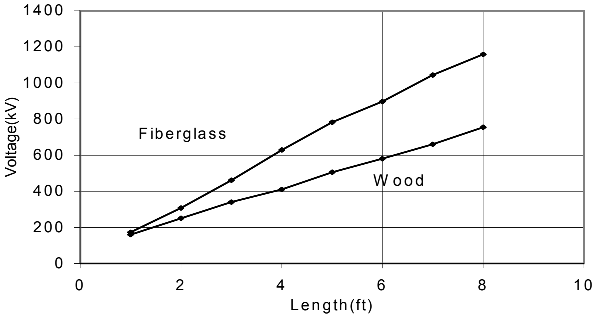

Fig. 1. The CFO voltages of the fiberglass and wood poles under wet conditions and positive polarity

CFO voltage 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. 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 Figure 2.

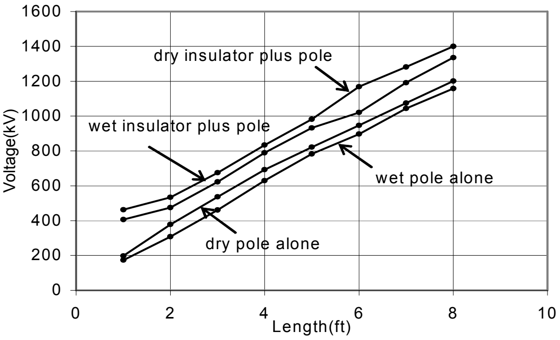

Fig. 2. The CFO voltages of 35 kV polymer suspension insulators plus the fiberglass pole and the CFO voltage of fiberglass pole, under dry and wet conditions, positive lightning impulse

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 Figure 3 and Figure 4.

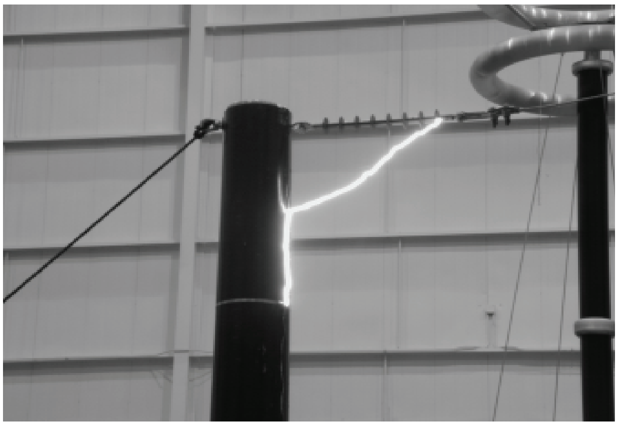

Fig. 3. The 35 kV polymer suspension insulator plus fiberglass pole, the tested pole length is 2 feet. The discharge took place in the air and on the surface of the pole

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.

Fig. 4. 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

When the pole length is 1 foot, the discharge happened in the air gap, 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 discharge 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 least 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 less than under dry condition. Therefore, the flashover always appeared on the outside surface of pole in the wet tests.

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.

Figure 5 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 Figure 5, 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.

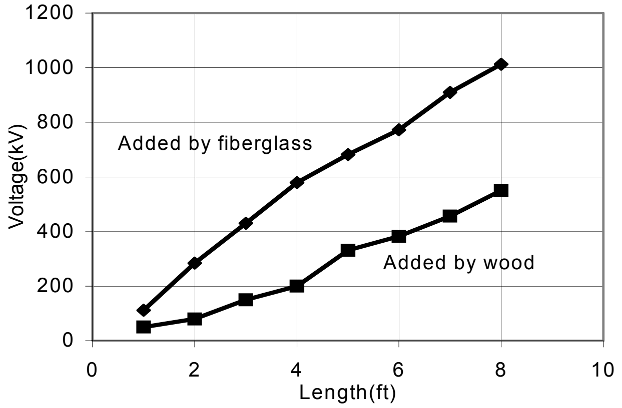

Fig. 5. The Added CFO voltages by fiberglass and wood poles to 15 kV polymer suspension insulators, wet condition and positive polarity lightning impulse

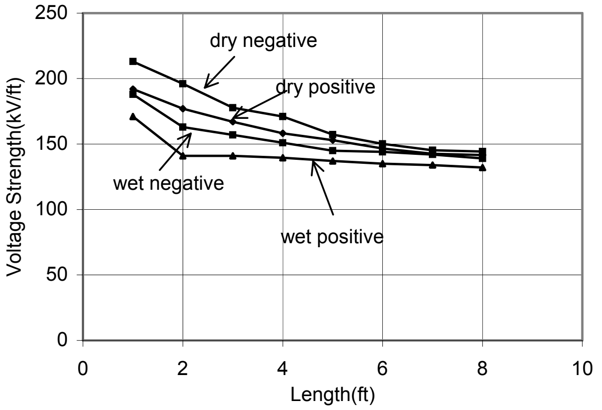

Fig. 6. The Added CFO voltage strengths by fiberglass pole to 35 kV porcelain pin insulators

Figure 6 illustrates the Added CFO voltage strengths by fiberglass pole to 35 kV porcelain pin insulators. 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 lightning impulse strength of the distribution line structure to a higher level than the wood pole.

Accelerated Aging Tests

The accelerated aging tests in this study were conducted based on specified standards [7-9]. Five sets of fiberglass samples were used in the accelerated aging tests, each set included nine fiberglass samples. The tested insulation length of these samples was chosen as 12 inches [9]. Two metallic bands, upper and bottom, were used as electrodes and tightly wrapped around the samples. The upper electrode was energized and the bottom electrode was grounded. To investigate the effect of the surface conditions on the electrical degradation of the materials, each set of the samples was divided into three groups. In group 1, the outside surfaces of three samples were kept intact; some scratches were made to the outside surfaces of the three samples in group 2; and five holes with a 1 inch diameter were made to each of three samples in group 3.

Four different accelerated aging tests were conducted:

- aging in clean fog, 1000 hrs
- aging in salt fog, 1000 hrs
- aging in clean fog with electrical stress of 25 kV, 1000 hrs
- aging in salt fog with electrical stress of 25 kV, 1000 hrs.

The fog chamber is the most widely used tool in conducting accelerated aging tests in laboratory research, and has been used to test other organic insulation materials. The fog chamber dimensions in this experiment were 3 m × 3 m × 3.2 m. Two sets of nozzles were mounted on the interior walls of the fog chamber to generate the fog. Some of the nozzles were for distilled or salt water, and the others were for compressed air. The fog was produced by a stream of compressed air flowing at a right angle to the water nozzle. The water flow rate was 0.4±0.1 liter/min [9]. In salt fog tests, the NaCl was added to the clean water to produce the salt fog. The NaCl content in the water was 10 ± 0.5 kg/m^3 [10]. The external electrical stress was applied to the tested samples through a porcelain bushing mounted through the chamber wall. According to the standard [10], the accelerated aging test duration should be 1000 hours.

Electrical Evaluation Tests

According to IEEE and other relevant standards [7,8,9], the electrical tests used to evaluate the insulation strength of fiberglass pole material include the ac dry and wet flashover tests, the ac leakage current tests under dry conditions, and lightning impulse CFO voltage tests. The CFO voltages were determined for positive polarity of the lightning impulse under dry and wet conditions. The electrical tests were conducted before the accelerated aging process and 24 hrs after the sample was removed from fog chamber. Results presented are average of three measurements performed on each sample.

Aging in clean fog

The CFO voltages and ac flashover voltages under dry conditions were higher than under wet conditions for all of the tested samples. The wet ac flashover voltages were approximately half the value of dry ac flashover voltages. Among the samples with different outside surface conditions, the CFO voltages and ac flashover voltages did not show any obvious differences.

After 1000-hours aging in clean fog, there was no apparent decrease in CFO voltages, especially in the dry tests. The ac flashover voltages after the aging tests were slightly lower than before the aging tests. The ac leakage currents of the samples increased after the aging tests. The leakage currents of a few samples were much higher than before the aging tests, but the magnitudes of the leakage currents were still less than several milliamperes.

Based on the lightning impulse CFO voltage, the ac flashover voltage, and the leakage current tests, the electrical insulation strength of the tested fiberglass samples did not show significant decrease after the clean fog test.

Aging in salt fog

Figure 7 presents the CFO voltages for samples tested before and after 1000 hours aging in salt fog. Figure 8 presents the ac flashover voltages for samples tested before and after 1000 hours aging in salt fog. Figure 9 presents the corresponding ac leakage currents for samples tested before and after 1000 hours aging in salt fog.

The CFO voltages and the ac dry and wet flashover voltages were lower than before the aging tests, especially in the wet tests. The leakage currents were two or three times higher than before the aging test. The electrical strengths of the samples decreased significantly after exposure to salt fog for 1000 hrs.

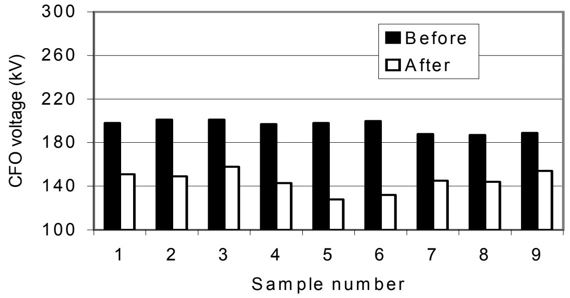

Fig. 7. CFO voltages of fiberglass samples tested before and after 1000 hours aging in salt fog, under wet condition, positive polarity

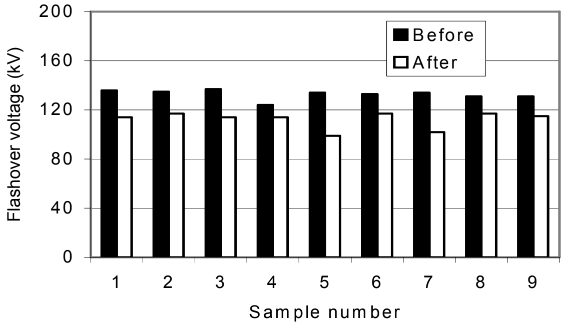

Fig. 8. AC flashover voltages of fiberglass samples tested before and after 1000 hours aging in salt fog, under dry condition

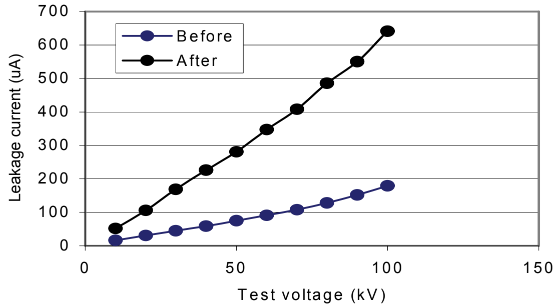

Fig. 9. The ac leakage current of fiberglass samples tested before and after 1000 hours aging in salt fog, under dry condition

It was also found that the outside surface condition of the sample had insignificant impact on its electrical degradation due to salt fog. By comparing the test results obtained in the clean fog test with those obtained in the salt fog test, it was found a decrease in the insulation strength for the sample aged in salt fog, due to the aging process. The salt fog tests had a greater impact on the insulation strength of the sample than the clean fog test. The fog (clean or salt) was the only aging stress in these two types of accelerated aging tests.

After the salt fog aging process, the tiny salt granules deposited on the surfaces together with the water absorbed by the fiberglass samples decreased the insulation strength of the samples. The tiny salt granules from the salt fog contaminated the surfaces of the samples in the salt fog aging process.

Under dry condition tests, these tiny salt granules had little effect on the electrical strengths; the water absorbed by the fiberglass material was the main reason for its electrical degradation. This explains why the test results for the CFO voltages and ac flashover voltages, under dry conditions after the salt fog aging process were almost the same as those obtained after the clean fog aging process. In wet tests, the tiny salt granules dissolved in the water droplets on the sample's surface. The conductivity of water became very high, which caused a significant decrease in the insulation strength of the fiberglass sample. As a result, the CFO voltages and the ac flashover voltages under wet conditions were lower than before the salt fog aging process. The measured ac leakage currents increased two or three times due to high surface conductivity.

Conclusions

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

1. The CFO voltage of the insulator plus the fiberglass pole is higher than that for the wood pole under the same test condition, impulse polarity, and pole length.
2. The Added CFO voltage strength by the fiberglass pole is higher than the Added CFO voltage strength by the wood pole. The Added CFO voltage by fiberglass pole is highest in dry conditions for negative polarity lightning impulse. It is the lowest in wet conditions for positive polarity lightning impulses.
3. The clean fog test has a negative impact on the electrical strength of fiberglass pole samples, but the rate of degradation is very low, especially for clean fog aging test without electrical stress.
4. After the salt fog test, the electrical strength degradation of the fiberglass pole samples is more severe under wet conditions.

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