Insulation Design of Prefab Insulating Covers in Overhead Distribution Lines Concerning the Protection from Animal Contacts and Surges

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In order to prevent the accidents due to the contact of animals, trees and etc., prefab insulating covers are installed in overhead distribution lines. However, sufficient effect is not realized. To make their protection performance at high level, they should be designed taking the combination with the lightning protection equipments into consideration. With arrestors, they are required to withstand the lightning and switching surges smaller than the operation voltage of the lightning arrestors. With high-speed circuit breakers, as the breakage by the lightning surge is permitted and the following current is intercepted, the covers should withstand the switching surge when the lines are re-closed. In this study, the impulse withstand voltage of a gap between the conductor and the contact object was examined assuming that the conductor cover and the prefab insulating cover were damaged. And the authors proposed a design method of the prefab insulating cover by comparing the withstand voltage of the air gap with the operation voltage of the arrestor and the magnitude of the switching surge.

Keywords: overhead distribution line, insulating design, prefab insulating cover, animal contact, lightning surge, switching surge, bird nest

1. Introduction

In the overhead distribution lines, the number of lightning accidents decreased remarkably with substantial lightning protection equipments. In connection with this, the rate of accidents caused by the contact of animals, bird nests, trees, and etc. increases. Then, the extermination of such accidents has been an important subject. Although the prefab insulating covers are employed to prevent such accidents, it cannot be said that sufficient effect is realized.

The prefab insulating covers are installed to the energized part of the overhead distribution lines to prevent the contact of animals, trees and etc. In the insulation design, the service voltage is taken into account. However, in the overhead distribution lines, lightning and switching surges sometimes appear. Therefore, in order to make their protection performance at higher level, it is necessary to take the lightning and switching surges and the combination with the lightning protection equipments into consideration.

There are the following views about the combination of the prefab insulating covers and the lightning protection equipments(3). (1) Lightning surge is absorbed with an arrestor and the accident by the contact of animals, trees and etc. is prevented with the prefab insulating cover. (2) The breakdown by lightning is permitted but the following current is intercepted by the high-speed breaking with a circuit breaker.

In case (1), the prefab insulating cover should withstand the lightning surge lower than the operation voltage of the arrestor. On the other hand, the prefab insulating cover is necessary to withstand the switching surge when the line is re-closed, in case (2).

The withstand voltage characteristics for the lightning surge lower than the operation voltage of the arrestor have been already reported(2x0). Then, the withstand voltage characteristics for the switching surge were examined in this study. From the results of this study and the previous study(2), the authors proposed a design method of the prefab insulating covers.

2. Experimental Set-up and Procedure

Fig1 shows an illustration of a bird nest of magpie on a pole in the overhead distribution line. Magpie is a family of crow. Accidents due to the bird nest sometimes occur especially in northern Kyushu, Japan. The bird nest is mainly made on the arm near the insulator. The diameter of the nest is about 1m. The main materials are tree branches and soil. However, metal wires are sometimes included. The prefab insulating covers are installed on the conductors in the region where the nest may contact.

The covered conductors have quite high insulation performance when it is new. However, they get damages such as pinholes and
the performance becomes lower in service. The insulation performance of the prefab insulating cover is not so high itself. It plays a role to make the objects apart from the energized conductors.

In order to make the protection performance of the prefab insulating covers at higher level, it is necessary to know the withstand voltage of the gap between the conductor and the objects in contact with the insulating cover under the lightning and the switching surges. Then, comparing the withstand voltage with the operation voltage of the lightning arresters and the magnitude of the switching surges, the required gap length can be obtained. The characteristics of the lightning-impulse withstand voltage against the gap length have already been reported\(^2\). In this study, the characteristics of the switching impulse withstand voltage were examined.

A schematic diagram of experimental set-up is shown in Fig. 2. A covered conductor was set between two LP (line post) insulators and a rod electrode was arranged in the middle. Al-OC (aluminum conductor with polyethylene cover for outdoor use) of 400mm\(^2\) and 200mm\(^2\) in conductor cross sections were employed. They are mostly used as the high voltage conductors in the overhead distribution lines. The conductor outer diameters are 29.8mm for Al-OC 400mm\(^2\) and 23.0mm for Al-OC 200mm\(^2\), respectively. The thickness of conductor cover is about 3mm. In the conductor cover, there are electrical weak points such as pinholes by lightning stroke or the erosion especially in heavy contamination. Then, in consideration of these weak points, knife-trace damage that reaches the core conductor is put in the conductor cover with a pipe cutter. The width of the damage was about 5mm.

The size of the nest materials including tree branches, metal wires etc. is mostly a few millimeters in diameter. Then, brass rod electrode with a diameter of 3mm was employed in this study. The tip of the electrode was finished in the shape of a hemisphere. The main reason to use the electrode with a hemispherical tip is to make discharges easily to occur at the shortest path between the electrodes. Moreover, if a sharpened electrode was employed, the effect of consumption of the electrode must be considerable. The rod electrode was attached on the micrometer head so that the adjustment of the gap length \(d\) [mm] between the surface of the covered conductor and the tip of the electrode was enabled, as shown in Fig. 2.

Switching impulse voltage of 180/2550\(\mu\)s was applied to the conductor and the rod electrode was grounded. The waveform of the applied voltage was observed with an oscilloscope (IWATSU DS 8617). The breakdown of the gap was checked from the observation of the generation of light and sound accompanied with the discharge and the collapse of applied voltage waveform.

The gap length \(d\) was changed, and the switching impulse withstand voltage (SIWV) was measured. 50 times of voltage application were performed on each voltage level from the lower level where the breakdown does not occur. The step of increase of applied voltage is about 1kV. The maximum voltage under which the breakdown does not occur among 50 times voltage application, was decided as the withstand voltage of the gap.

In order to discuss the protection of the distribution line, it is necessary to know the operation voltage of the lightning arrester. The operation voltage for the lightning impulse has been already measured\(^3\). Then, the operation voltage for the switching impulse was measured in this study.

The arrester used in this study is ZnO lightning arrester that is used in the 6.6kV distribution lines and standardized JEC-203. 50 times of voltage application were performed on each voltage level, and the discharge probability of the arrester was obtained. The minimum voltage, under which the arrester works all of the 50 times voltage application, was decided as the 100% discharge voltage of the arrester.

3. Experimental Results

3.1 Operation Voltage of Arrester

The 100% discharge voltages of the arrester for the switching impulse were 27.5kV under positive voltage application and 28.4kV under negative voltage application. From the previous paper\(^1\), the 100% discharge voltages for the lightning impulse were 24.6kV under positive voltage application and 27.2kV under negative voltage application.

3.2 SIWV for Al-OC 400mm\(^2\)

Fig. 3 and Fig. 4 show the results of the switching impulse withstand voltage (SIWV) for Al-OC 400mm\(^2\). They are the results of positive and negative impulse voltage application, respectively. In these figures, the 100% discharge voltage of the arrester and the voltage levels for surge factors 3 and 5 are also shown. In the overhead distribution lines, surge factor 3 is usually considered and the surge factor 5 is a rare case.

From the results, the formula of the relation between the withstand voltage and the gap length was decided due to the following approximation.
(1) The relation between the withstand voltage and the gap length was assumed to be in a straight line.

(2) The gradient of the line was obtained from the measured values by using least square method.

(3) The formula of the relation between the withstand voltage and the gap length was decided from (1) and (2) so that any measured value did not exceed the value from the formula.

The formulas for positive and negative impulse voltage application were as follows:

**SIWV for Al-OC 400mm²**

- Under positive impulse voltage application:
  \[ SIWV_{400p} = 1.8d - 1.3 \text{ (kV)} \]  

- Under negative impulse voltage application:
  \[ SIWV_{400n} = 1.2d - 2.0 \text{ (kV)} \]

**3.3 SIWV for Al-OC 200mm²**

Fig. 5 and Fig. 6 show the results of the switching-impulse withstand voltage (SIWV) for Al-OC 200mm². They show the results of positive and negative impulse voltage application, respectively. In these figures, the 100% discharge voltage of an arrester and the voltage levels for surge factors 3 and 5 are also shown.

The formulas for positive and negative impulse voltage application were also decided by the same way as mentioned above.

**SIWV for Al-OC 200mm²**

- Under positive impulse voltage application:
  \[ SIWV_{200p} = 1.6d - 4.3 \text{ (kV)} \]  

- Under negative impulse voltage application:
  \[ SIWV_{200n} = 1.2d - 0.7 \text{ (kV)} \]

The withstand voltage for Al-OC 200mm² is slightly lower than that for Al-OC 400mm². The diameter of Al-OC 200mm² is slightly smaller than that of Al-OC 400mm². Therefore, the tendency is considered to be reasonable.

**4. Discussion**

The relations between the lightning-impulse withstand voltage (LIWV) and the gap length for Al-OC 400mm² have been
measured previously \(^3\). The relations for AI-OC 200mm\(^2\) were measured in this study. Moreover, additional experiments were conducted for AI-OC 400mm\(^2\). The formulas are as follows.

\[ L_{IVW} \text{ for AI-OC 400mm}^2 \text{ under positive impulse voltage application} \]
\[ L_{IVW,400} = 1.2d + 7.0 \text{ (kV)} \] \(5\)

\[ L_{IVW} \text{ for AI-OC 400mm}^2 \text{ under negative impulse voltage application} \]
\[ L_{IVW,400} = 1.1d + 7.5 \text{ (kV)} \] \(6\)

\[ L_{IVW} \text{ for AI-OC 200mm}^2 \text{ under positive impulse voltage application} \]
\[ L_{IVW,200} = 1.8d + 4.4 \text{ (kV)} \] \(7\)

\[ L_{IVW} \text{ for AI-OC 200mm}^2 \text{ under negative impulse voltage application} \]
\[ L_{IVW,200} = 1.2d + 6.3 \text{ (kV)} \] \(8\)

A polarity effect can be seen in the withstand voltage. From Eqs. \(1\) to \(8\), the withstand voltage of negative voltage application is found to be lower than that of positive, except for the region where the gap length is shorter than 10 mm. However, the polarity effect has been found experimentally in that region. On the other hand, a specific relation was not seen clearly between the withstand voltage and the conductor size. The relation may be affected by the complicated configuration of the stranded conductors.

From the formulas of SIWV and LIWW, the 100% discharge voltages of the arrester for switching and lightning impulse voltage and the switching surge level considered, the gap length required for the prefab insulating covers can be discussed.

Fig. 7 shows a design concept of prefab insulating covers at high-level protection performance. The required gap length is decided from the comparison between the withstand voltage and the 100% discharge voltage of arrester or the considered switching surge level.

Table 1 and Table 2 show the required gap length for AI-OC 400mm\(^2\) and AI-OC 200mm\(^2\), respectively. They are obtained according to the design concept as shown in Fig. 7. When the required gap length for the switching surge was obtained, the withstand characteristics of the air gap for the switching impulse voltage was used. On the other hand, when the required gap length for the lightning surge was obtained, the withstand characteristics of the air gap for the lightning impulse voltage was used.

From these tables the size of the prefab insulating covers are found to be decided by the withstand characteristics for negative surges.

The conductor outer diameters are 29.8mm for AI-OC 400mm\(^2\) and 23.0mm for AI-OC 200mm\(^2\), respectively. Then, the required diameters for the prefab insulating covers are decided as shown in Table 3. A schematic diagram of the cross section of an example of a prefab insulating cover and a covered conductor is shown in Fig. 8.

From Table 3, the diameter of the prefab insulating cover can be decided taking the protection method and the surge factor into consideration.

If surge factor 3 is taking into consideration, the diameter of the prefab insulating cover must be larger than 66.0mm for the protection method (1) and 54.0mm for the protection method (2). The protection method (1) and (2) are mentioned in the introduction and as follows. (1) Lightning surge is absorbed with an arrester and the accident by contact of animals, trees and etc. is prevented with the prefab insulating cover. (2) The breakdown by lightning is permitted but following current is intercepted by a high-speed breaking with a circuit breaker.

If surge factor 5 is taking into consideration, that is a rear case in the actual line, the diameter of the prefab insulating cover must be larger than 72.0mm regardless of the protection method.

The relation among the cover size, protection method and the surge factor is summarized in Table 4.

Table 5 shows the comparison of the proposed design of the
prefab insulating covers with the conventional one. The surge factor of 3 was considered in the proposed design because it is usually considered in the overhead distribution lines.

5. Conclusions

In this study, the size of the prefab insulating covers was examined so that they have the protection performance at high level. The impulse-withstand voltage of a gap between the line conductor and the contact object was examined assuming that the conductor cover and the insulating cover were damaged. From the results, the required diameter of the prefab insulating cover for the protection of the overhead distribution line from animal contacts and surges. The results are summarized as follows.

(1) The diameter of the prefab insulating cover should be decided taking the protection method and the surge factor into consideration. However, when the surge factor 5 is considered, the diameter is required to be larger than 72.0mm regardless of the protection method.

(2) When a protection method in which the lightning surge is absorbed with an arrestor and the accident by contact of animals, trees and etc. is prevented with the prefab insulating cover, and the surge factor 3 are considered, the diameter of the prefab insulating cover is required to be larger than 66.0mm.

(3) When a protection method in which the breakdown by lightning is permitted but following current is intercepted by a high-speed breaking with a circuit breaker, and the surge factor 3 are considered, the diameter of the prefab insulating cover is required to be larger than 54.0 mm.

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References


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