Influence of Air-Gap Length and Position on the Flashover Performance of Ice-Covered Insulators under Switching Overvoltage

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Abstract — **This paper presents experimental investigation results on the influence of ice air gaps on the flashover performance of post type insulators covered with ice under switching impulse voltage. All tests were performed in a climate chamber at the CIGELE laboratories. The critical flashover voltage (V_{50}) of an ice-covered post insulator with various air-gap lengths at different positions was experimentally determined under both positive and negative switching impulse voltages using the "Up and Down" method. The results obtained show that both the length and position of the air gap affect the applied voltage distribution along the ice-covered insulator, and thus, its flashover performance.**

I. INTRODUCTION

In many cold-climate regions of the world, overhead power transmission lines and their related substations are subject to atmospheric ice accretion. Such ice accretion may result in a number of problems to power systems, like flashover on insulators, which will affect the normal operation of power networks. Power outages related to iced-covered insulator flashover have been reported in several countries, particularly in Canada and China [1, 2]. According to these reports, it was observed that the occurrences of lightning or switching impulse voltages (LI and SI) and of ice-covered insulator flashovers seemed to coincide. Although a large number of investigations have been carried out on the flashover process of ice-covered insulators under AC and DC voltages, very little research has been dedicated to electrical performance of ice-covered insulators under lightning (LI) and switching (SI) voltages [4-8].

In the studies on flashover phenomena on ice-covered insulators, it was found that air gaps are often formed on the ice deposits because the heat from partial arcs on the surface of the insulators causes ice to melt [3, 4]. The quantity, geometry, and position of air gaps occur randomly and depend on different factors. Thus, variation on the geometry of ice has been shown to have effects on flashover performance of ice-covered insulators under AC or DC voltages. The effects of air gaps on the flashover performance of ice-covered insulators under impulse voltages need to be studied further.

The main objective of this paper is to experimentally study the effects of air gap length and position on the electrical performance of ice-covered insulators under switching impulse voltage. The results obtained will be particularly useful to get a better understanding of the parameters involved in the phenomena preceding the flashover mechanism of ice-covered insulators.

II. TEST FACILITIES AND PROCEDURE

A. Test insulator and facilities

All tests were carried out in a climate chamber of 6.1 x 4.9 x 3.5 m, located at CIGELE laboratories, which are especially designed for testing the flashover performance of ice-covered insulators (Fig. 1).

Under natural ice conditions, post insulators are more susceptible to flashover than line insulators, especially during melting periods [3, 5]. It is important to determine if this difference in performance under icing conditions could be caused by transient voltage conditions. To this end, a porcelain post insulator was used as a test sample in this study (Fig. 1). Due to limitations of the impulse generator output voltage level, only a portion of the insulator with a dry arcing distance of 80 cm was tested.

An ice layer was artificially formed on the insulator surface, according to the following setup and procedure [9]: Supercooled water droplets were produced by feeding water with pre-established conductivity into an oscillating nozzle system, to be then sprayed into a relatively uniform air flow produced by a set of eight fans placed in a tapering box with a diffusing honeycomb panel. The quantity of ice was checked on a monitoring cylinder rotating at 1 rpm. Additional parameters for ice accumulation are listed in Table 1.

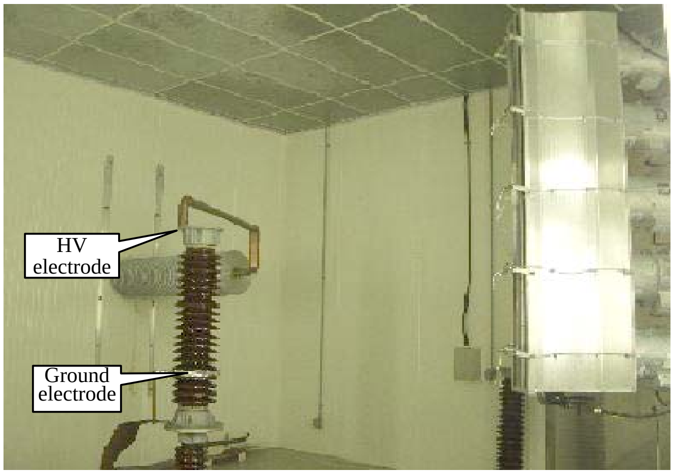

Fig. 1 Test insulator in the climate chamber

TABLE 1
ICE ACCRETION PARAMETERS

Parameters (during icing)	Magnitude
Type of ice	Glaze
Air temperature	-12ºC
Mean droplet diameter	80 µm
Ice thickness	15 mm (on monitoring cylinder)
Wind velocity	3.3 m/s
Water conductivity	80 µS/cm

B. Test procedure

As shown in Fig. 2, the test procedure began with an ice accumulation process which was similar to the one performed at CIGELE laboratories for investigating ice-covered insulator performance under AC voltage [3, 9]. The sequence of evaluation and impulse applications is based upon IEC standards directives about high voltage test techniques [10] and some statistics tools for analysis. The test procedure comprised a combination of the following sequences:

Icing sequence: Wet-grown ice was accreted on the insulator. In real situation, presence of service voltage is important because, air gaps will be formed under this condition [12]. In this study, in order to control the air-gap formation, no voltage was applied during the ice accretion period. To obtain different air-gap lengths and positions on the test ice deposits, a shield with a given width was placed at the desired position of the insulator surface, before the icing process, to prevent ice formation on the covered areas.

Ice severity is characterized by the thickness of ice on the rotating monitoring cylinder. When the desired ice thickness was reached, 1.5 cm in this study, the spraying system and the fans were turned off before the next sequence was started.

Melting sequence: As it is known, the presence of a water film plays an important role in the flashover process on an ice surface [12]. The door of the climate room was opened, after ice accretion, to allow the temperature to rise to about the melting point of ice (~0°C) thus causing the formation of a water film on the ice surface. In this study, this sequence is important because of the absence of voltage service during the ice accreting period. The rate of increase of air temperature was considered to correspond to a slow melting process, believed to be most severe for porcelain insulators (see Fig. 2).

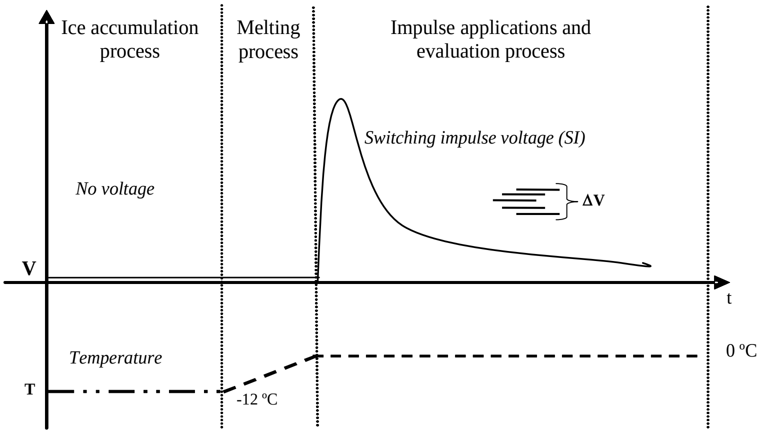

Fig. 2 Test sequences to evaluate the effects of air-gap length and position on ice-covered insulators

Evaluation sequence: During the melting process, the test insulator was connected to a Marx generator, as shown in Fig. 3. When the water film was formed, the temperature was kept at 0°C and the impulse voltage was applied. Then, the 50% flashover voltage (V_{50}) was determined using the "up-and-down" method [10], with steps of about 3 % of the test voltage. At each voltage level, the insulator was stressed by one impulse, and there were at least 22 voltage steps for each V_{50} value.

The standard switching impulse voltage (250/2500µs) was generated with the Marx generator.

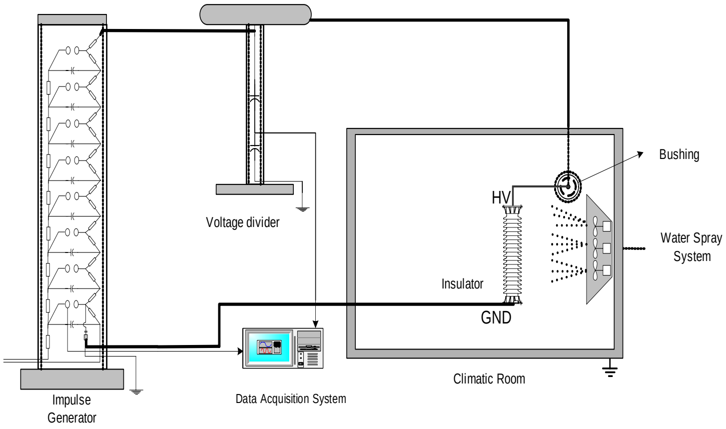

Figure 3: Experimental setup for impulse voltage applications and evaluation process.

III. Test Results and Discussions

A. Critical flashover voltage of a clean post insulator

50% flashover voltage (V_{50}) of a clean insulator was also obtained experimentally, to compare with those obtained with ice-covered insulators. For this purpose, the insulator was placed in a climate room at 0º C and submitted to 25 impulses of standard switching impulse 250/2500 µs, applied according to the “up-and-down” method [10]. The results, displayed in Table 2, show that for post type insulators, the value of V_{50} under positive impulse voltage is lower than that under negative one.

TABLE 2

CRITICAL FLASHOVER VOLTAGE V_{50} (kV/m) FOR A CLEAN POST INSULATOR

polarity	V_{50} (kV/m)
Positive	562.50
Negative	711.41

B. *Effects of air-gap length on V_{50} of ice-covered insulator*

For this tests series, the air-gaps were formed close to the high voltage electrode. Five air-gap lengths were chosen for this study, whose value was expressed as percentage of the total arcing distance, as shown in Fig. 4. After gap formation, negative and positive standard switching impulses (250/2500 µs) were applied at the time interval between two successive impulses of 40s, according to the procedure described above.

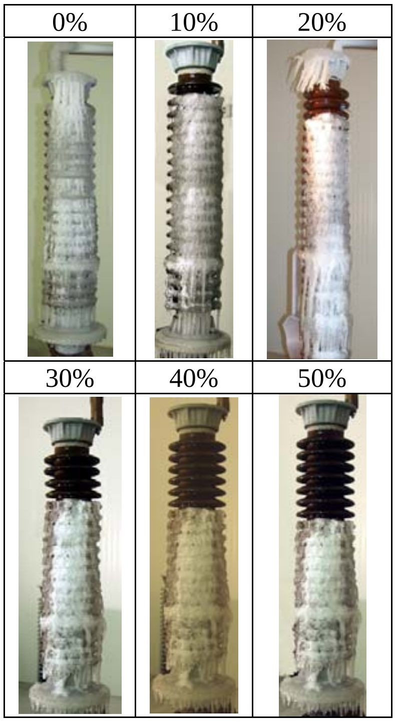

Fig. 4 Air-gap lengths on ice-covered insulators in percentage of total arcing distance.

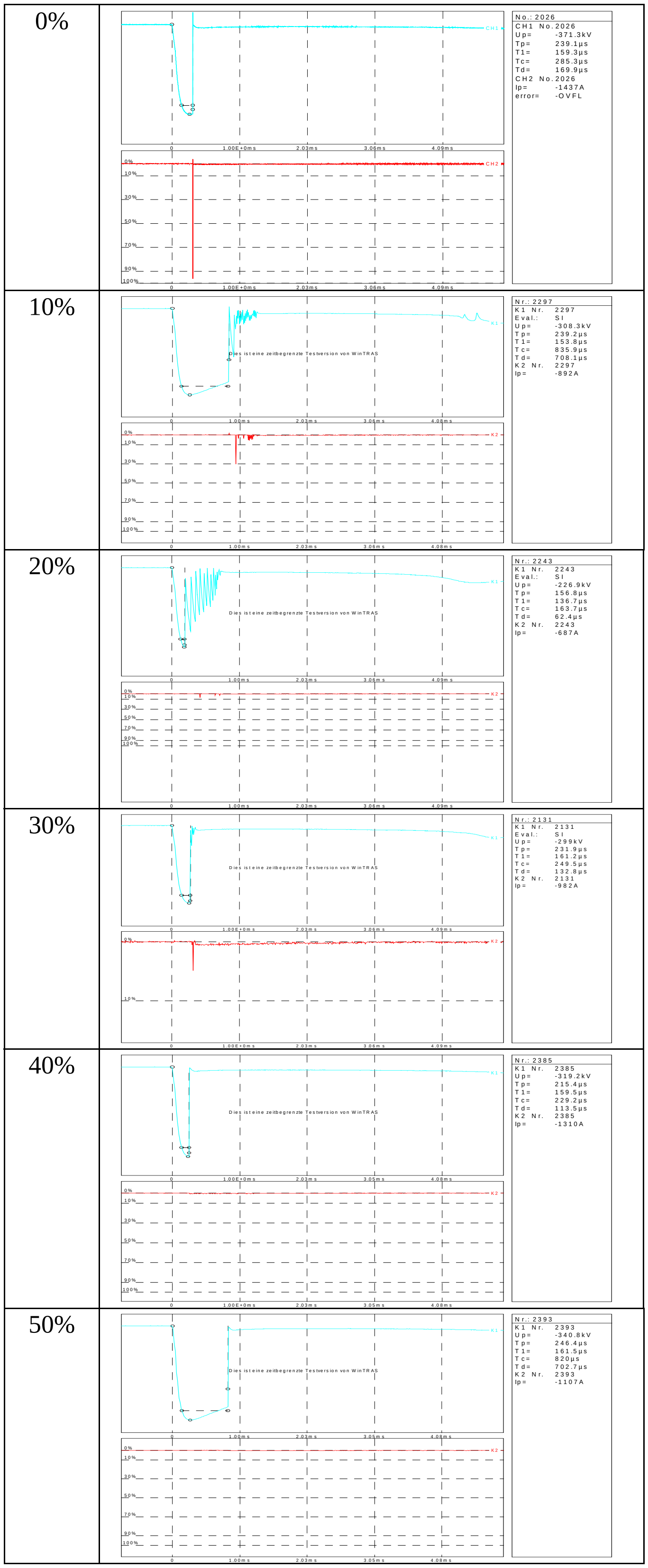

Fig. 5 Voltage and current waveforms during flashover under negative SI voltage

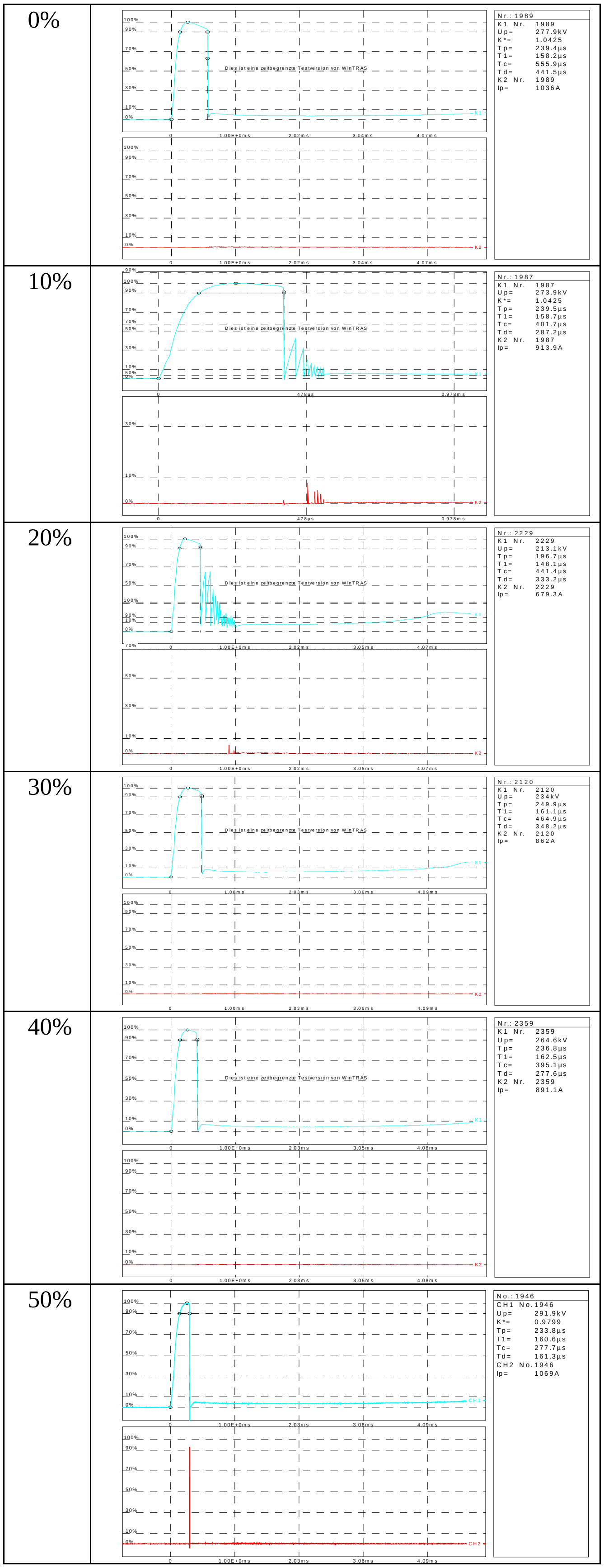

Fig. 6 Voltage and current waveforms during flashover under positive SI voltage

Some voltage and current waveforms, observed during flashover process, are shown in Figs. 5 and 6, for negative and positive polarities, respectively. It is possible to observe some transient appearances on the waveform when an air gap takes values between 10% and 20% of the dry arcing distance tested. These transients are present for both negative and positive polarities.

The results of this series are shown in Fig. 7. The critical flashover voltage (V_{50}) in kV/m for standard switching impulse (250/2500 µs) is represented as a function of the air-gap length, with the V_{50} tendency showing a so-called "U-shape" characteristic. V_{50} is lowest when the air gap on ice deposit is around 20% of the total arcing distance for both positive and negative polarities. The value of V_{50} at 20% air-gap length is only about 42% and 46% of V_{50} with a clean insulator for negative and positive polarities, respectively. The same trend was also found by other researchers for insulators covered with snow [4-8].

Moreover, for negative polarity, values of V_{50} at 0% and 50% air-gap lengths are comparable, representing about 61% of V_{50} with a clean insulator. In the case of positive polarity, V_{50} at 50% air-gap length represents around 62% of V_{50} with a clean insulator. A possible explanation is that, without air gaps, ice makes the insulator surface more uniform. This, in turn, makes the electric field distribution uniform since the relative permittivity (from the ice surface) is uniform all along the insulator.

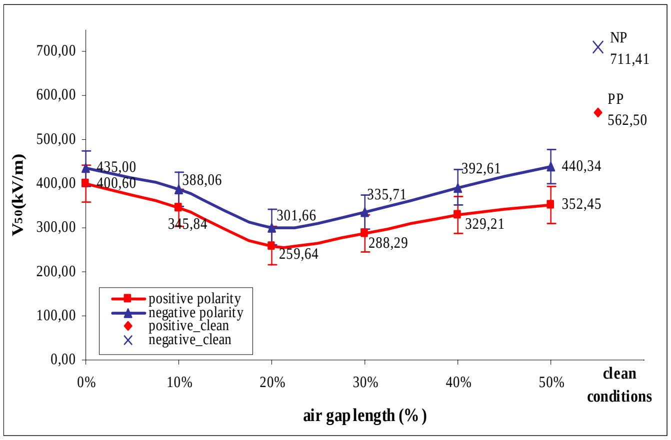

Fig. 7 Effect of air-gap length on the switching flashover voltage (V_{50}) of ice-covered insulators

When an air-gap length is between 10 and 30% of the total dry arcing distance, V_{50} presents a minimum. This can be explained by the presence of a strong potential concentration along such air gaps, which results in the occurrence of partial discharges at a lower voltage level.

Finally, when an air gap occupies a significant portion of the space between the HV electrode and the ground (50% overall length of the insulator), this potential concentration is not sufficient to maintain the discharge activity. Thus, a big air-gap length will produce a better dielectric performance than a shorter one.

C. Effects of air-gap position on V_{50}

According to the above results, an air-gap length of 20% of the total arcing distance was chosen for investigating the effects of air-gap position on V_{50}. Three positions were considered for this investigation (figure 8) according to observations during ice accumulation with the presence of AC service voltage. Positive and negative switching impulses were applied.

To HV electrode	Middle	To ground electrode
		

Fig. 8 Air-gap positions on ice-covered insulator.

Figure 9 shows V_{50} values in kV/m for different air-gap positions. The lowest value was found for an air-gap set close to the HV electrode. The V_{50} value increases as the air gap is placed farther away from the electrode. The minimum V_{50} value (air-gap close to the HV electrode) was about 42% and 46% of the V_{50} value of the clean insulator for negative and positive polarities, respectively. When the air-gap moves away from the HV electrode, the V_{50} value is as high as 49% and 59%, for negative and polarities respectively, as compared to the corresponding V_{50} values of the clean insulator.

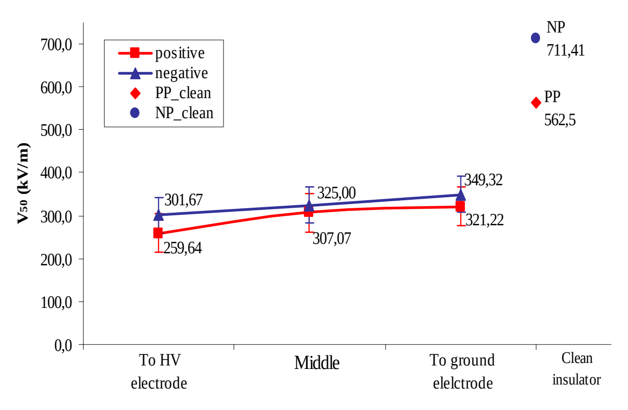

Figure 9: Effects of air-gap position on the flashover voltage (V_{50}) of ice-covered insulators under switching impulse

These results are in agreement with the results obtained by modeling the electric field distribution along post insulators covered with wet ice [13]. In that simulation, it was found that voltage and electric field are more concentrated in air intervals close to the HV electrode when compared to air intervals close to the ground electrode.

Due to the limitation of room conditions and impulse generator output voltage level, the V_{50} of an insulator with a length of 80 cm was determined in this study. More studies are needed for the V50 of ice-covered post insulators longer than 1 m. under impulse voltages.

IV. CONCLUSIONS

The effect of air gaps on the electrical performance of an ice-covered post insulator portion was experimentally studied under switching impulse voltages. From the results obtained, the following conclusions may be drawn:

1. The presence of an ice deposit on the insulator surface has significant effects on the insulator flashover performance under switching impulse voltage.

2. Flashover voltage of ice-covered insulators under switching impulse voltage depends on different factors including air-gap length. When air-gap length increases from 0 (no air-gap) to 50% of dry arcing distance of insulator, V_{50} decreases and then increases. The lowest value appears when the air-gap length is equal to about 20% of dry arcing distance of insulator and this value is as low as 42% of the value found on a clean insulator.

3. Air-gap position affects also the flashover voltage of ice-covered insulators under switching impulse voltage. When the air-gap is close to the high voltage electrode, V_{50} is at its lowest. This may be explained by the fact that the electric potential and field are more concentrated in air intervals close to the HV electrode as compared to a location closer to the ground electrode.

4. More studies are needed to determine the critical flashover voltage V_{50} of ice-covered insulators longer than 1 m under impulse voltages.

V. ACKNOWLEDGMENTS

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