DC FLASHOVER PERFORMANCE OF INSULATORS UNDER ICING CONDITIONS

S. Taheri*[1], M. Farzaneh[1,3], C. Potvin[2] and I. Fofana[3]
[1]NSERC / Hydro-Quebec / UQAC Industrial Chair on Atmospheric Icing of Power Network Equipment (CIGELE) and Canada Research Chair on Atmospheric Icing Engineering of Power Networks (INGIVRE), www.cigele.ca
Université du Québec à Chicoutimi (UQAC), Chicoutimi, Qc, Canada
[2]Institut de recherche d'Hydro-Québec (IREQ), Varennes, Qc, Canada
[3]International Research Centre on Atmospheric Icing and Power Network Engineering (CENGIVRE), UQAC, Chicoutimi, Qc, Canada
*Email:shamsodin.taheri@gmail.com

Abstract: This paper presents the effects of voltage type and polarity on the maximum withstand voltage of a string of 5 IEEE insulator units under icing condition. The relationship between flashover voltage level and dripping water conductivity is analyzed. Moreover the variation of leakage current on ice surface under DC+, DC- and AC are measured and the relationship between flashover voltage and leakage current at the instant of flashover is studied.

1. INTRODUCTION

The power outages caused by flashover on ice- or snow-covered insulators have been reported in many cold climate countries including Canada, China, Great Britain, Norway, Finland and Japan [1,2]. Under such conditions, in addition to the mechanical damage due to the excessive static and dynamic loads created by the combination of atmospheric ice and wind, the electrical performance of insulators is adversely affected by these accretions. Under certain conditions, a drastic decrease in electrical insulation strength can lead to insulator flashover and consequent power outages [3,4]. The present investigation concerns DC voltage, which is the most dangerous type of voltage associated to insulator flashover [4].

This paper presents a series of tests carried out under DC+, DC- and also AC voltages which aim to examine the influence of the type and polarity of the applied voltage on the flashover voltage and leakage current. Moreover, under similar conditions, dripping water conductivity is measured under DC- , DC+ and AC. Finally, the relationship between dripping water conductivity and flashover voltage level is studied.

2. RESULTS AND DISCUSSION

Artificial ice was deposited at -12°C on a string of 5 IEEE insulators under the conditions described in Table 1. The flashover test results were obtained from three different series of experiments under DC+, DC- and AC voltages.

Table1: Parameters for ice accretion.

Ambient air temperature (°C)	-12
Wind velocity (m/s)	7
water conductivity at 20°C (µS/cm)	80
Ice thickness on monitoring conductor (cm)	2

According to the evaluation method [6], each series was constituted of at least 5 tests, including 2 flashover and 3 withstand voltage tests. The experimental results related to flashover and maximum withstand voltages under DC+, DC- and AC conditions show that the effect of polarity on the insulator strings is around 20%, which is an acceptable value and that flashover voltage is lower under DC- and AC than DC+.

3. CONCLUSION

In this study, the flashover performance of three types of 5 IEEE insulator units covered with artificial ice at high wind velocity was carried out. These results show that the lowest value of minimum flashover and maximum withstand voltages are obtained under DC- and the highest under DC+ for a given air pressure, and that the effect of polarity under this condition is around 20%. Moreover, it was found that the icicles formed at a high wind velocity (7 m/s) were nearly tilted away by the wind and the maximum withstand voltage is higher at greater than higher wind velocities.

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[1]NSERC / Hydro-Quebec / UQAC Industrial Chair on Atmospheric Icing of Power Network Equipment (CIGELE) and Canada Research Chair on Atmospheric Icing Engineering of Power Networks (INGIVRE), www.cigele.ca
Université du Québec à Chicoutimi (UQAC), Chicoutimi, Qc, Canada
[2]Institut de recherche d'Hydro-Québec (IREQ), Varennes, Qc, Canada
[3]International Research Centre on Atmospheric Icing and Power Network Engineering (CENGIVRE), UQAC, Chicoutimi, Qc, Canada
*Email:shamsodin.taheri@gmail.com

***Abstract*—The main objective of this paper is to study the effects of voltage type and polarity on the maximum withstand voltage of a string of 5 IEEE insulator units under icing conditions. The relationship between flashover voltage level and dripping water conductivity is analyzed. Moreover the variations of leakage current on ice surface under DC+, DC- and AC are measured and the relationship between flashover voltage and leakage current, at the instant of flashover, is studied. A coefficient that has been used as flashover index, icing stress product (ISP), is determined and discussed under different voltage types and polarities. The results obtained will be helpful in the design of HVDC insulators in regions subjected to atmospheric icing.**

Keywords-Insulator, Icing phenomenon, flashover, DC voltage, water conductivity, leakage current, maximum withstand voltage

I. INTRODUCTION

As power networks are expanding and the voltage level of transmission lines is being increased, the performance of outdoor insulators plays an increasingly important role in assuring the secure operation of power systems. Atmospheric icing of power transmission systems is a serious problem in many cold climate regions of the world. The power outages caused by flashover on ice- or snow-covered insulators have been reported in many cold climate countries including Canada, China, Great Britain, Norway, Finland and Japan [1-6]. Under such conditions, in addition to the mechanical damage due to the excessive static and dynamic loads created by the combination of atmospheric ice and wind, the electrical performance of insulators is adversely affected by these accretions. Under certain conditions, a drastic decrease in electrical insulation strength can lead to insulator flashover and consequent power outages [7].

The mechanisms of flashover on ice-covered insulators are not yet fully understood but from field observation as well as from laboratory investigations, it has been found that the flashover of insulators covered with a very thick layer is not an instantaneous phenomenon, but results from a process involving ice and discharges. Hence, the flashover process can generally be summarized as follows [8]. Following ice accretion, due to sunshine or the heating effect of partial discharges, several sections of the insulators, especially in areas near the electrodes, may become free of ice. These ice-free zones are referred to as air gaps. The presence of a water film on the ice surface is necessary for the flashover process to occur. This water film can be produced by many factors, such as wet ice accretion, condensation, heating effect of leakage current and partial arcs or, in many cases, by a rise in air temperature or the effect of sunshine. The presence of a highly conductive water film increases the voltage across the air gaps. Now, if the applied voltage (electric field) across the air gaps is high enough, corona discharges are initiated, which can lead to flashover.

Several investigations have been carried out in order to assess the flashover phenomenon on ice-covered insulators under AC voltage [8-11]. The present investigation concerns under DC voltage, insulator flashover is more likely to occur. This is due to the fact that DC insulators collect more contaminants and flashover more readily than AC ones under identical conditions. Hence, the study of ice-covered insulator performance under DC voltage is essential [12]. Under DC voltage, leakage current does not pass through zero and it is not possible for the arc to extinguish by itself. Therefore the design of DC insulators for cold climate regions is a challenging task. So far, several studies have been carried out under DC resulting in the proposal of several static and dynamic models to predict flashover parameters under icing condition [12-14]. Despite these efforts, many aspects of the flashover phenomena of ice-covered insulators, particularly for HVDC insulators, are still not well understood.

In order to improve our understanding of the ice-covered insulator flashover process, fundamental investigations under DC voltage must still be undertaken. This paper presents a series of tests carried out under DC+, DC- and AC voltages. It aims to examine the influence of the type and polarity of the applied voltage on the flashover voltage and leakage current of 5 IEEE insulator units positioned vertically in the center of a climate room under high wind velocity. Dripping water conductivity is measured under these conditions in order to study the relationship between dripping water conductivity and flashover voltage level.

II. TEST FACILITIES AND PROCEDURE

Artificial ice was deposited at -12°C on a string of 5 IEEE insulator units positioned vertically in the center of a 5.8 m×6.3 m×3.9 m climate room. In order to achieve the test conditions, super-cooled droplets having a mean diameter of 80 μm were produced by five pneumatic nozzles at a wind velocity of 7 m/s. For each test, a wet-grown ice layer, known as the most dangerous type for flashover, was accreted on the insulator strings under the conditions described in Table 1.

TABLE 1: EXPERIMENTAL CONDITIONS OF THE TESTS.

Ambient air temperature (°C)	-12
Wind velocity (m/s)	7
water conductivity at 20°C (μS/cm)	80
Ice thickness on monitoring conductor (cm)	2

The water used was de-ionized water, stored in tanks before starting the accretion process. The proper water conductivity level was set by adding sodium chloride (NaCl) to the de-ionized water, and it was verified before and after each test. Another major parameter was the accumulated ice thickness on the insulator string, which was checked by the accretion on a 3.8 cm diameter monitoring cylinder, rotating at one round per minute (rpm). For all the experiments carried out, the monitored thickness was kept constant at 2 cm. For the AC tests, the voltage was supplied to the insulator string by a 240 kVA, 120 kV transformer with a 240 kV regulator (Figure 1). The overall short-circuit current of the HV system was about 28 A at the maximum operating voltage of 120 kV rms. The insulator leakage current and the voltage were measured using a LabVIEW® data acquisition system. For the DC positive or negative tests, the AC output voltage was rectified by a series of electronic components, diode and thyristor (SCR). The "icing regime" test procedure was used for these experiments. Testing under "icing regime" corresponds to the case where the flashover performance test is carried out shortly after the ice accretion is completed and a water film is still present on the ice surface. In such a case, the preparation period is short, typically about 2 to 3 min [15], which gives enough time for taking pictures, adjusting the test setup, installing/removing the collector receiving dripping water from test insulators, and measuring ice thickness. Immediately after this period, the flashover test voltage should be applied. This procedure can be observed in Figure 2. The evaluation of the electrical flashover performance of the ice samples was based on that described in the IEC standard 60507 which is normally used for flashover tests on polluted insulators and on an IEEE Position Paper by Farzaneh [15,16]. Using this method, after the first useful flashover result, the voltage was decreased by less than 5% of the nominal voltage, and then after any maximum withstand or flashover result, the voltage was increased or decreased once more by the same value, or else it was maintained. Based on this method, the maximum withstand voltage is the maximum level of applied voltage at which flashover does not occur for a minimum of 3 tests out of 4, under similar experimental conditions.

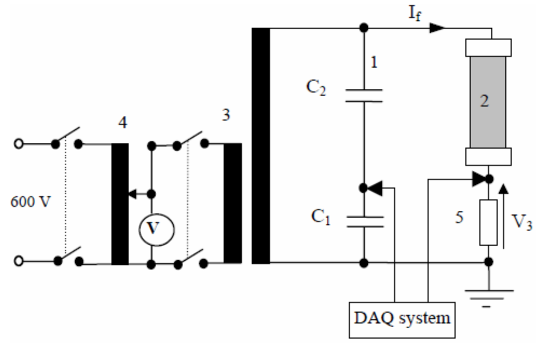

Figure 1. Measuring circuit for AC breakdown test. 1. Capacitive divider (C1=0,47 μF and C2=50 pF), 2. Iced-insulator, 3. high voltage transformer, 4. voltage regulator, 5. Shunt Resistance (Rm=10Ω), V2 = V1.(C1 + C2)/C2 and If = V3/Rm.

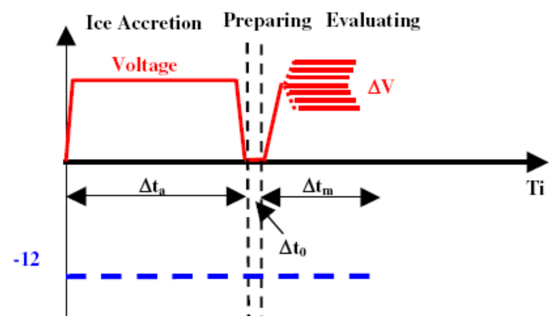

Figure 2. Sequences of the icing regime test procedure.

For each withstand test, the insulator was kept at the test voltage for a period of at least 15 min to ensure that no flashover occurred during this period. Another parameter to measure was the minimum flashover voltage, which corresponds to the voltage one step higher than the maximum withstand voltage, at which flashover occurs twice out of a maximum of three tests.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The AC and DC minimum flashover and maximum withstand voltages of the insulator were determined under the above conditions. Concerning the flashover propagation mechanism, it was observed that the local arc consistently started from the grounded top electrode and propagated towards the HV bottom electrode regardless of the voltage polarity. Consequently, a positive arc was defined in the case when DC- is applied to the bottom electrode and a negative arc when DC+ was applied. The physical aspects

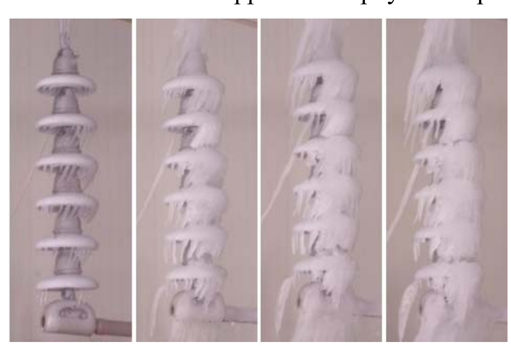

Figure 3. Physical aspects of an insulator during ice accretion.

of the ice-covered insulator strings under DC+ at different time sequences during ice accumulation are shown in Figure 3 .The flashover test results were obtained from 3 different series of experiments, under DC+, DC- and AC voltages. According to the evaluation method, each series comprised at least 5 tests, including 2 flashover and 3 withstand voltage tests. The experimental results related to flashover and maximum withstand voltages under DC+, DC- and AC conditions are presented in Figure 4, Figure 5 and Figure 6, respectively, and then in a summary form in Table 2. These results show that the effect of polarity on the insulator string is around 20%, which is in accordance with the results presented in [46]. So, accordingly with the results obtained, it can be concluded that flashover voltage is lower under DC- and AC than under DC+. It was found that the icicles formed at a relatively high wind velocity (7 m/s) were nearly tilted away by the wind, but were nearly vertical for the lower wind velocity (3.3 m/s). Compared to previous studies, mostly at low wind velocities, the maximum withstand voltage is higher at a high wind velocity [13].

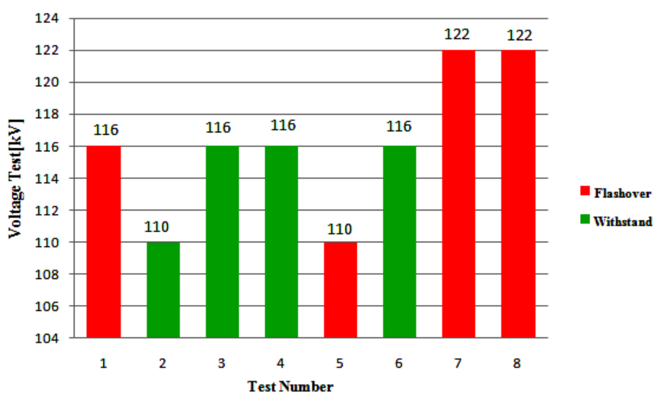

Figure 4. Withstand voltage test results under DC +.

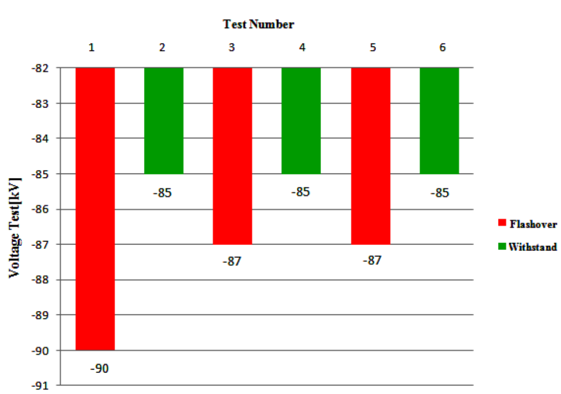

Figure 5. Withstand voltage test results under DC -.

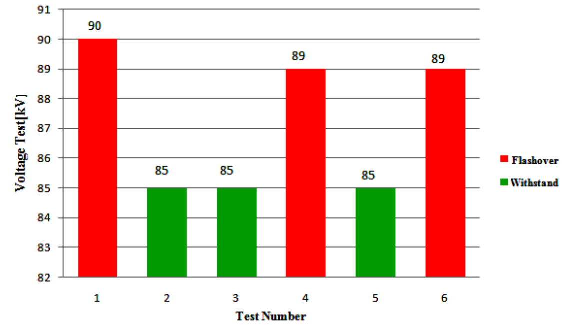

Figure 6. Withstand voltage test results under AC.

TABLE 2: MINIMUM FLASHOVER AND MAXIMUM WITHSTAND VOLTAGES FOR 5 IEEE STANDARD INSULATOR STRING.

Voltage type	Maximum withstand voltage(kV)	Minimum flashover voltage(kV)
DC+	116	110
DC-	85	87
AC	85	89

A combination of causes including wet ice accretion, condensation and partial arcs and, in many cases, by a rise in air temperature or the effect of sunshine, is responsible for the presence of a water film on the ice surface. As a result, ice surface resistance will decrease thus causing an increase in leakage current. Flashover can occur at the point where leakage current has its maximum value. Figure 7 and Figure 8 depict the variation in leakage current on the insulator's surface. As dripping water conductivity under DC- is higher than DC+ therefore the level of leakage current under DC- is higher than DC+, so that flashover can be occur under DC- at a lower voltage than DC+.

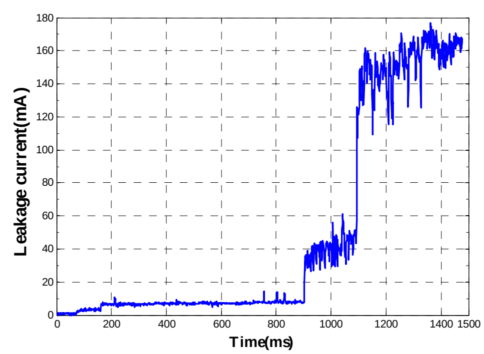

Figure 7. Leakage current under DC+.

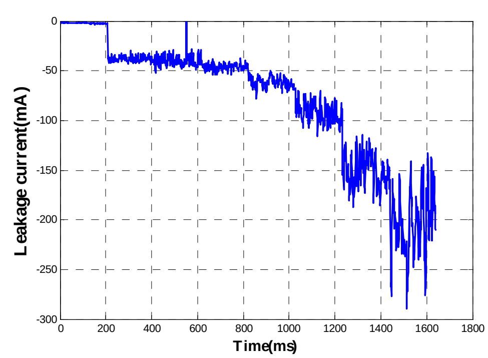

Figure 8. Leakage current under DC-.

Empirical investigations show that many parameters including water conductivity, ambient temperature and wind velocity are the major parameters influencing insulator flashover under icing conditions. Water conductivity is the most significant factor of flashover occurrence. Water conductivity can be classified into three categories, applied water conductivity, dripping water conductivity and melted ice conductivity. This way, dripping water conductivity can be considered as a major parameter to predict insulator behaviour under icing conditions. Another important parameter, so far used as a flashover index, is the Icing Stress Product (ISP), the product of the ice, snow, or rime accretion per centimetre of insulator length, with the dripping water conductivity. Measurements obtained from experiments are presented in Table 3. Experimental results show that dripping water conductivity under DC- is higher than under DC+, which means that the flashover can only occur under DC- with voltages lower than under DC+. Concerning the data in Table 3, it can also be observed that dripping water conductivity is higher than melted ice conductivity. The high conductivity of the water film is caused by the rejection of impurities from the solid portion of the ice towards the liquid portion of drops or droplets during solidification [17].

TABLE 3. RESULTS RELATED TO WATER CONDUCTIVITY.

Voltage polarity	Applied water conductivity	melted ice conductivity	Dripping water conductivity	ISP
DC+	80	31.4	202.5	1256
DC-	80	38.6	256.6	2792.4

IV. CONCLUSION

Laboratory investigations for determining flashover performance of an ice-covered insulator string composed of 5 IEEE insulator units at a relatively high wind velocity (7 m/s) were carried out. The experimental results have shown that the type of applied voltage and its polarity have an obvious effect on the minimum flashover voltage and the leakage current. These results also show that the lowest value of the minimum flashover and maximum withstand voltages is obtained under DC- for which the effect of polarity is around 20%. The leakage current is also influenced by the type and polarity of the applied voltage, and has been found to be higher under DC- than under DC+. Moreover, it was found that the icicles formed at a relatively high wind velocity (7 m/s) were tilted away by the wind and that the maximum withstand voltage was greater at high wind velocities than lower ones.

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