Advanced test methods for full-scale ice tests of DC insulators strings intended for ±350 kV

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***Abstract*: A new ±350 kV HVDC transmission line is planned from Muskrat Falls to Soldiers Pond in Canada. Along the route, two areas were considered as potential challenges for dimensioning with respect to pollution and ice; one characterized as coastal area and another one characterized as mountainous area. Three basic possible service cases were identified to be simulated by representative laboratory testing: polluted insulator covered by rime ice; polluted insulator covered by glazed ice; polluted insulator covered by glazed ice accreted under full-scale voltage. The insulator string consisted of standard DC glass cap-and-pin insulators and the performance was verified by withstand test during melting phase of ice. For each test case, four insulator strings were first subjected to the specified ice/pollution conditions, and thereafter subjected to a voltage withstand test. This required development of a sophisticated set-up providing automatic application of ice without voltage and later with voltage on the relatively long insulator strings. The paper presents details on testing philosophies and practical principles for all three possible service cases, listed above.**

Keywords: ice, insulator testing, pollution, test facilities

Legend and Abbreviations

SDD	*Salt Deposit Density (IEC 60507)*
NSDD	*Non-Soluble Deposit Density (IEC 60507)*

Introduction

A new ±350 kV HVDC transmission line is planned in Canada from Muskrat Falls to Soldiers Pond. Along the route, two areas were considered as potential challenges for dimensioning with respect to pollution and ice; one characterized as coastal area and another one as mountainous area. Based on the previous work and investigations it was decided to use DC glass cap-and-pin insulators for the new design. To verify DC pollution/icing performance of full-scale 350 kV HVDC overhead line glass insulator strings a number of withstand tests were decided and performed simulating typical service cases. Three basic possible service cases were identified to be simulated by representative laboratory testing:

- Polluted insulator covered by rime ice
- Polluted insulator covered by glazed ice
- Polluted insulator covered by glazed ice accreted under full-scale voltage

These cases required development of a sophisticated set-up providing a combination of pollution and ice accretion on insulators. This in turn required creation of advanced automatic system for the application of ice without voltage and later with voltage on the relatively long insulator strings.

I. Test set-up

For each test case, four insulator strings were first subjected to the specified ice/pollution conditions, and thereafter subjected to a voltage withstand test. In order to be able to meet the test requirements for simultaneous pollution and ice testing sophisticated set-up providing automatic application of ice without voltage and later with voltage on the relatively long insulator strings was developed. The schematic view of the set-up for ice accretion in de-energized state is shown in Figure 1 for three insulators and its final arrangement is shown in Figure 2.

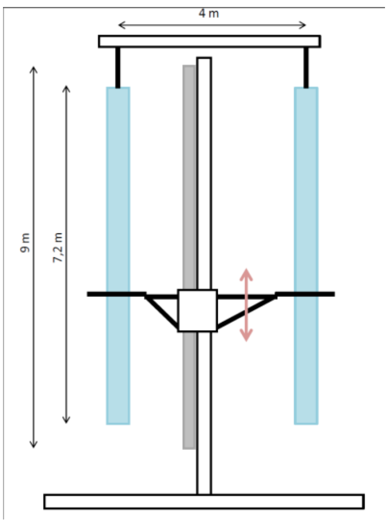

Figure 1: Schematically shown test set-up for insulators in parallel (ice accretion without voltage).

Figure 2: Final set-up for four insulators in parallel during ice accretion without voltage (rime ice).

II. Creation of pollution

In all test cases the insulators were contaminated at room temperature prior to subsequent ice accretion in cold conditions. Pollution was applied by the standard IEC procedure (IEC 61245), i.e. dipping the insulators into a standard suspension prepared from water, salt (NaCl) and kaolin. The required pollution levels, characterized by standard pollution parameter

Salt Deposit Density (SDD) were obtained in the range from about 0,05 mg/cm^2 to about 0,15 mg/cm^2 and were achieved by varying the amount of salt. Another standard pollution parameter, the Non-Soluble Deposit Density (NSDD) was targeted to be approximately 0,1 mg/cm^2. Pollution levels were checked by measurements on sample insulators not included in the following ice accretion and voltage test. Example of contamination procedure by dipping is presented in Figure 3.

Figure 3: Example of application of pollution by dipping of the insulators (IEC 61245).

III. Creation of Ice (without voltage)

After application of pollution, four complete insulator strings were assembled in parallel in the climate test hall. In this part of the investigation ice was accreted onto the de-energized insulator strings through spraying of fog by sophisticated automatic system of nozzles, see Figure 4.

Figure 4: Example of application of ice without voltage application by sophisticated automatic system of nozzles.

For all test cases the ice was formed either from water similar to standard IEC rain from the tap water. During all ice applications the air temperature in the test hall was kept between -7°C and -8°C. Water was sprayed towards the four insulators without additional air flux (no wind simulation).

To avoid removal of the firstly applied pollution layer, small amounts of water were first sprayed onto the insulators in a cyclic manner (using nozzles moving up and down along insulator with adjustable pause length after each sweep). According to the test program both rime ice and glaze ice were simulated. The required type of ice was achieved by use of different nozzles and different distances from the nozzles to the test objects.

The nozzles were moving with a velocity of about 0,1 m/s. By smart combination of the water flow, distances and number of nozzles the water froze more or less instantly when hitting the insulators and no icicles were accreted and no free water could dissolve the pollution layer.

Ice thickness and ice distribution were specified to be measured by rotating rod in some parts of the agreed test program, see examples in Figure 5 and Figure 6. However, the visual criterion for bridging was the dominant criterion to make a decision when the target ice accretion is accomplished. Typically, ice accretion was continued until the “complete bridging” was achieved (according to the agreement additional criterion was that about 50% of the diameter of the insulator should be covered by ice); this was defined by visual observation and recorded by photography. The rotating rod was installed at the bottom of one of the strings in case of ice accretion without voltage application; while it was installed at the top of the arrangement in case of ice accretion with voltage application.

Example of complete ice accretion for the rime ice is presented in xxx and for the glazed ice in xxx.

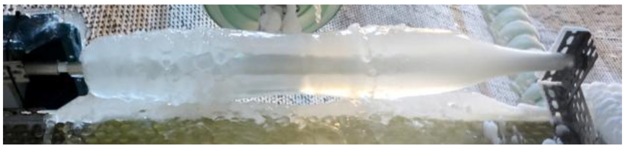

Figure 5: Example of ice accretion at the rotating rod when the rod was installed under the insulators.

Figure 6: Example of ice accretion at the rotating rod, when the rod was installed on top of the insulators.

Figure 7: View of the insulator string covered by rime ice.

Figure 8: View of the insulator string covered by glazed ice.

IV. Creation of ice (with applied voltage)

Insulators were contaminated and after pollution and drying the ice was accreted at the insulators during about 24 hours. The main specifics in this test in comparison to previous ones were that the ice accretion was performed under full DC voltage of 361 kV. For the ice accretion under voltage a certain distance was needed to prevent flashover. Thus in this case nozzles spraying larger droplets (which reach longer) were used. The nozzles were moving up and down with a velocity of about 0,15 m/s. One nozzle was spraying on each string. The water was pre-cooled to a temperature just above 0 degrees C. After the ice accretion time of 24 hours there was bridging of a large part of the insulator strings and the amount of ice was agreed to be sufficient, see Figure 9 and Figure 10.

Figure 9: View of the insulator strings covered by glazed ice accreted under full DC voltage 361 kV.

Figure 10: Close view of the insulator covered by glazed ice accreted under full DC voltage 361 kV. Note long icicles developed along the E-field lines.

V. Important parameters to be checked during the test

The following important parameters were measured during the tests (see summary in Figure 11):

- Temperature in the climate hall
- Humidity in the climate hall
- Ice density
- Melted ice water conductivity via collection of melt water during voltage test
- Melted ice water volume via collection of melt water after voltage test
- DC test voltage
- Leakage current
- Ice temperature by non-contact IR measurements (see example of measurements in Figure 12).

Parameter	Target value if applicable
Temperature in the climate hall during ice accretion	Stable, about -7÷-8°C
Temperature in the climate hall during the voltage test	Increased to about +1°C
Humidity	NA
Ice density	Rime ice or glaze ice according to IEEE
Melted ice water conductivity	NA
Melted ice water volume	NA
DC test voltage	-361 kV DC
Leakage current	NA
Ice temperature	NA
Dew point*	NA

Figure 11: Parameters measured during the test and their target values.

The following procedure was used for the measurements of ice weight per unit of insulator length and further calculations. The total amount of ice and dripping water were collected from the insulators of the full length during and after the voltage test. The weight of the collected samples was measured by a scale and the melted ice water conductivity was measured in specially cleaned boxes.

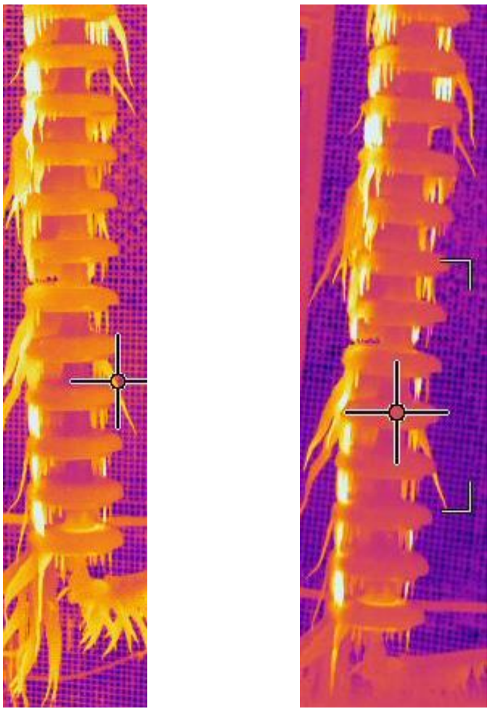

Figure 12: Examples of IR camera measurements of ice temperature (surface temperature is influenced by partial discharge activity).

VI. SUMMARY

To verify DC pollution and icing performance of 350 kV HVDC full-scale glass insulator strings chosen by Nalcor, withstand tests defined by Nalcor according to the principles of IEC 61245, IEEE 1783 [1] and IEEE position paper [2] were performed at STRI. Three basic service cases included pollution and rime ice; pollution and glazed ice and pollution and glazed ice accreted under full voltage. Special sophisticated and automated arrangements of nozzles made this possible and also different levels of pollution and ice were feasible to achieve, see examples in Figure 13.

Figure 13: Examples of different levels of ice created during the test: left – low level; right – high level.

According to the test program, after the pollution and ice accretion was finished, the voltage withstand tests were performed in "melting regime" mode according to the principles of IEEE 1783 [1]. This was achieved by increase of temperature in the climate test hall after finalized ice accretion for each case. The door of the chamber was opened and additional flow of warm air was created by the fans evacuating air through the roof of the chamber.

Due to the size of the test objects, and due to the amount of ice, the test objects could not be moved after ice accretion. Thus, the insulators could not be tested one by one. Therefore, for all cases insulators were tested in the same position as during ice accretion phase; i.e. four insulators in parallel. This arrangement simulated IEC standard withstand procedure, where it is allowed to treat as withstand test either no flashovers after three tests or one flashover after four tests. If flashover occurs on two parallel test objects of four, then the test in this project was treated as failed to confirm the withstand level.

The results of voltage tests will be reported in the separate contribution from Nalcor at the 2015 World Congress & Exhibition on Insulators, Arresters & Bushings to be held in Germany in October 2015.

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