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Assessment of toughened glass insulators removed from HVDC lines after more than 40 years in service

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SUMMARY

This paper presents a method for, and the results of, condition assessment of toughened glass insulators removed from service on HVDC transmission lines. Manitoba Hydro's HVDC lines Bipole 1 and 2 are energized at 450 kV and 500kV and have been in service since 1972. During the 40 years following installation, no condition assessment of the insulators has been made beyond visual examination. In 2014, it was decided that tests would be carried out in order to determine the remaining life of the insulators. Tests were conducted at the Sediver research and testing facility in St. Yorre, France, and were witnessed by a member of the transmission line design group from Manitoba Hydro. The insulators to be tested have experienced various levels of stress dependant on placement on the lines. In the southern portion near Winnipeg, Manitoba, Canada, the terrain is open and flat with cultivated fields and little protection from wind. Near the center of the line and to its northern end the terrain transitions to boreal forest. Over 40 plus years in service the Bipole insulators have faced high levels of vibration, icing and ambient temperatures of -45 to 40 °C. Contamination levels range over the course of the line from very light to light. Because of the diversity of conditions existing over the 895 km length of the bipoles, the insulators to be tested needed to be selected to provide a representative sample. Insulators were removed from both bipoles and both polarities. Sites for removal of insulators were chosen near both ends of the bipoles near Winnipeg and Gillam, Manitoba, and the approximate center of the lines at Grand Rapids, Manitoba. For each of the three locations, two strings were removed from the energized lines, one deadend string of 29, 220 kN standard profile insulators and one suspension string of 21, 180 kN fog type insulators. At the time of removal, samples of surface contamination were taken and later tested for Equivalent Salt Deposit Density (ESDD) and Non Soluble Deposit Density (NSDD). In total, 150 insulators were removed and shipped to St. Yorre for testing. Tests conducted at the Sediver research and testing facility were conducted in accordance with the latest CSA standard C411.1-10 [1]. Several tests were performed including galvanizing tests, electromechanical failing load tests, residual strength tests and thermal-mechanical performance tests. The results are included in this paper and indicate that the samples show little to no sign of aging or degradation with all insulators performing at levels expected from their rating. The investigation into the remaining life of the insulators provided clear evidence and information which has proved useful to the Manitoba Hydro asset management group. The results show that the insulators will almost certainly perform for another 40 years or more. Further, in the current context where utilities and designers consider life cycle costs in selecting suitable components for new transmission line development, these tests also confirm the expected long term durability and reliability of toughened glass insulator technology.

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KEYWORDS

HVDC - Toughened - Glass - Insulator - Assessment - Aging - Life - Cycle - Cost

1. INTRODUCTION

The purpose of this paper is to outline a general methodology for the effective assessment of toughened glass insulators in operation for many years, and to present the results of Manitoba Hydro's testing of toughened glass insulators removed from HVDC lines after more than 40 years in service. The assessment of these insulators was intended to gauge their remaining life.

2. METHOD

a) Removal of samples

The insulators to be removed for testing were manufactured in 1968 and 1969 and have been in service on Manitoba Hydro's 450 kV DC Bipole 1 since 1970 and 500 kV DC Bipole 2 since 1978. All units were made prior to the existence of any specific DC technical standard calling for high resistivity dielectrics and, therefore, it was decided to test them under CSA C411.1-10 procedures.

The insulators to be tested have experienced various levels of stress dependent on placement on the lines. In the southern portion near Winnipeg, Manitoba, Canada, the terrain is open and flat with cultivated fields and little protection from wind. Near the center of the line and to its northern end the terrain transitions to boreal forest. Over 40 plus years in service, the Bipole insulators have faced high levels of vibration due to the nature of the twin bundled conductor and failed spacer dampers. The insulators have also contended with icing and ambient temperatures of -45 to 40 °C. Contamination levels range over the course of the line from very light to light. Because of the diversity of conditions existing over the 895 km length of the bipoles, the insulators to be tested needed to be selected to provide a representative sample. Sites for removal of insulators were chosen near both ends of the bipoles near Winnipeg and Gillam, Manitoba, and the approximate center of the lines at Grand Rapids, Manitoba. Insulators were removed from both bipoles and both polarities. For each of the three locations, two insulator strings were removed from the energized lines by Manitoba Hydro's Live Line Maintenance group, one deadend string of 29, 220 kN standard profile insulators (model N21/171DC), and one suspension string of 21, 180 kN fog-type profile insulators (model N18P/171DC). Insulators were removed during May 5-11, 2014

Fig 1- Deadend structure

Fig 2- Insulator removal May 5, 2014

Fig 3- Suspension structure

Fig 4 – Removal locations, Manitoba, Canada *Fig 5 – Model N21/171DC (1969 production)*

b) Contamination measurements

Immediately after the removal of each set of insulators, three insulators were selected from the string and washed with demineralized water for ESDD (equivalent salt deposit density) and NSDD (non-soluble deposit density) measurements, according to IEC 60815 [2]. Washing and measurement was performed separately for the top and bottom sides of the insulator. Samples for pollution measurement were taken at the locations near Winnipeg and Grand Rapids by the Sediver staff. No on site samples were obtained from the Gillam insulators. In order to obtain a pollution sample from Gillam, instructions were left to enclose the insulators in a sealable plastic wrap. They were then shipped to St-Yorre, where pollutions measurements were made. From these measurements, we can observe the pollution level pattern of the bipoles, which is summarized in the below figure. Most of the lines run through very light pollution levels, where the Winnipeg area may on occasion have seen pollution levels as high as medium.

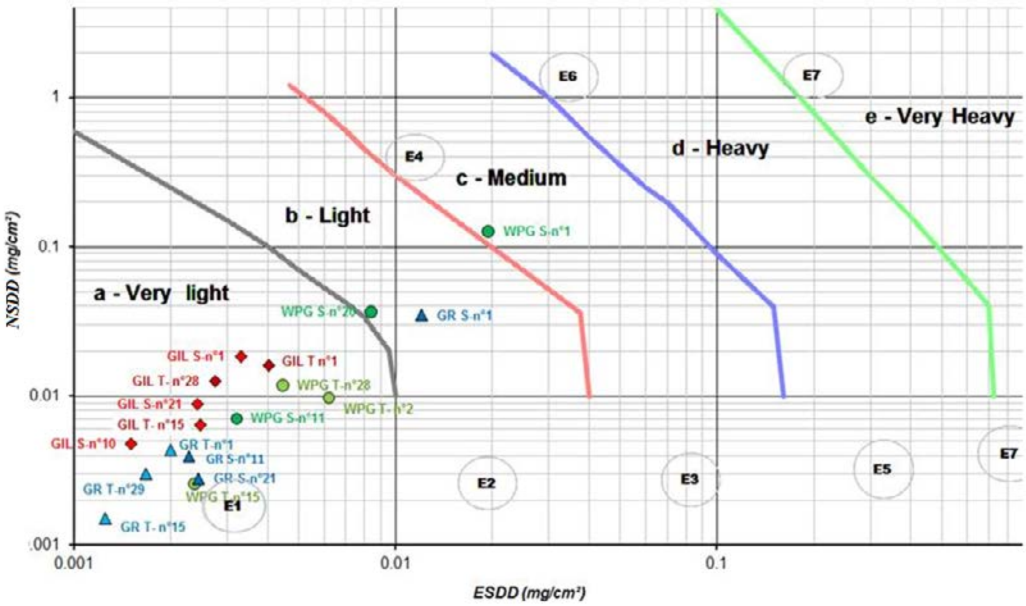

Fig 6 – Pollution level in terms of ESDD and NSDD (Winnipeg, Grand Rapids and Gillam regions)

c) Visual inspection

Visual inspection was performed on site as insulators were removed as well as at the testing facility in St. Yorre. Insulators were in excellent condition with no sign of corrosion or degradation except for a small amount of corrosion on one 180 kN insulator removed from tower #2006 near Winnipeg. The corrosion was visible on the inner circumference of the cap, and was likely caused by mild electrical activity between the cap and shell. Note these insulators have no zinc collar at the base of the cap, which is common practice today to avoid such corrosion. The zinc sleeve on all pins showed no signs of corrosion or damage.

d) Galvanization thickness measurement

Galvanization measurements were made on the metal caps and pins of four insulators of each type. The acceptance criteria were taken from the CSA C411.1-10, which requires a thickness greater than 85 µm. All values for thickness of galvanization were well above the acceptable limit.

e) Electromechanical failing load testing

The purpose of this test is to verify the failing load of the insulator against the electromechanical rating (M&E). The test evaluates the failure modes and their statistical distribution (average value and standard deviation) in order to ensure that a sufficient safety margin exists between the specified working load and the minimum failing load of the insulator. Forty (40) units of the 220 kN model and sixteen (16) units of the 180 kN model where tested, according to CSA C411.1-10 (clause 6.13). Although it can be argued that it is not necessary to test toughened glass insulators with an applied voltage, since shattering of the glass shell can be visually observed, the test was performed with a voltage of greater than 75% of the dry power frequency flashover voltage as required by the CSA standard. The results of the test are translated into a quality index (Q), which is determined using the M&E rating (R), the mean value (X) and standard deviation (σ) of the individual insulator failing loads. The quality index is defined as $Q = (X-R)/\sigma$, and must be equal to or greater than 4. The results of the test are summarized in the following table:

Model	N21/171DC	N18P/171DC
M&E rating (R)	222 kN	178 kN
Mean value of failing loads (X)	252.9 kN	235.1 kN
Standard deviation (σ)	4.1	11
Quality index (Q)	7.5	5.2

The test results are fully satisfactory, with a quality index higher than 4 and no failing load below the M&E rating. The resulting quality index for the N18P/171DC model is lower than the N21/171DC model due to a higher standard deviation. The reason for the lower deviation in the N21/171DC is that the samples failed exclusively in the forged steel pin, which has a more consistent breaking strength as compared to the metal cap and glass shell.

f) Residual strength testing

The purpose of this test is to verify that the mechanical failing load of the insulator, after its dielectric shell has been broken, is sufficient to ensure the mechanical integrity of the line. The test evaluates the failure modes and their statistical distribution (average value and standard deviation) in order to ensure that a sufficient safety margin exists between the specified working load and the minimum failing load of the insulator. Twenty-five (25) units of each type of insulator where tested according to CSA C411.1-10 (clause 6.9). The test consists of a temperature cycle test, after which the glass shell is broken off by blows from a hammer. The remaining stub is submitted to a tensile test and the results of this test are translated into an acceptance constant (k), which is determined using the M&E rating (R), the mean value (X) and standard deviation (σ) of the individual stub failing loads. The acceptance constant is defined as $k = (X-1.645\sigma)/R$ and must be equal to or greater than 0.65. The results of the test are summarized in the following table.

Model	N21/171DC	N18P/171DC
M&E rating (R)	222 kN	178 kN
Mean value of failing loads (X)	254.8 kN	217.2 kN
Standard deviation (σ)	5.8	11.8
Acceptance constant (k)	1.10	1.11

The test results are fully satisfactory, with an acceptance constant higher than 0.65. In fact, all failing loads were higher than the M&E rating of an unbroken (intact) insulator. Similarly to the electromechanical failing load test, the N21/171DC samples all failed by a broken pin, which results in a lower standard deviation.

Fig 7–Temperature cycle test

Fig 8–Stub in traction machine

Fig 9 – Failed stubs

g) **Thermal mechanical performance testing**

The purpose of this test is to verify the ability of the insulator to withstand combined thermal and mechanical stresses. Twenty (20) units of each insulator type were tested according to CSA C411.1-10 (clause 6.10). The first stage of the test subjects the insulators to four 24 hour cycles of cooling and heating while under a tensile load equal to 70% of the specified electromechanical failing load. The insulators are then subjected to an electromechanical failing load test per CSA C411.1-10 (clause 6.13). The results of the test are summarized in the following table:

Model	N21/171DC	N18P/171DC
M&E rating (R)	222 kN	178 kN
Mean value of failing loads (X)	256.2 kN	230.2 kN
Standard deviation (σ)	3.6	16
Quality index (Q)	9.5	3.2

The test results are fully satisfactory for the N21/171DC model, with a quality index higher than 4 and no failing load below the M&E rating. As with the previous tests, all N21/171DC samples failed exclusively by a broken pin while N18P/171DC samples failed by a mix of glass shell shattering, pin pull out, broken pin and broken cap. For the N18P/171DC model, one sample’s glass shell shattered at 172.4 kN (97% of the M&E strength) and as such does not comply with the current standard’s requirements, while all the other units failed above the rating. The unit with the shattered shell at 172.4 kN reached a mechanical load of 228.5 kN before mechanical separation, which demonstrates the strength and reliability of a stub (insulator with broken glass shell).

Fig 10 – Thermal mechanical machine

Fig11 - Insulator in traction machine

Fig 12 - Failed insulators

3. CONCLUSION

After over forty years in service, the tested insulators did not show any significant aging or degradation. All results of testing comply with the current CSA standard (C411.1-10) with the exception of one glass shell of insulator model N18P/171 DC which broke at 97% of the rating, with the remaining stub separating at 128% of the rating. As explained above, this result is not of particular concern because of the high mechanical failing load, which is in line with the remaining values. Based on the satisfactory information found in this assessment, the current population of insulators are deemed to be in condition to remain in service, with no replacement required. It is expected that the population could almost certainly perform for another 40 years in service. Therefore, in the current context where utilities and designers consider life cycle costs (inspections, replacements, disposals, etc) in selecting suitable components for existing and new transmission line developments, these tests, in line with previous work [3][4], confirm the expected long term durability and reliability of toughened glass insulator technology.

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