

AC Breakdown Voltage of 50-Year-Old Service Aged Hydro Power Generator Stator Bars

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Abstract

Randomly selected generator bars from a 50-year-old Norwegian hydro power generator were examined in this work. Typical non-destructive tests, as partial discharge and dissipation factor measurements were initially performed at both 50 Hz and 0.1 Hz. Then, the AC breakdown strength of the epoxy/mica/glass fibre reinforced bar insulation was measured by gradually increasing the voltage in steps of 5 kV with duration of 1 min until breakdown occurred. The field graded terminations were soaked in transformer oil during breakdown testing to prevent external surface flashovers. The AC breakdown voltage ranged between 60 kV and 75 kV, which corresponds to 8-10-fold the service voltage of 7.4 kV. No significant difference in breakdown voltage was observed between bars being located close to the high voltage or neutral terminal during service. This indicates minor degradation caused by the AC service stress, even after 50 years in service. No correlations were found between the measured breakdown voltage and the diagnostic partial discharge activity and dissipation factor measurements.

1. Introduction

Condition assessment of hydropower generators is important for prolonged safe operation and thus plan optimal refurbishment and replacement. It is therefore important to know correlations between non-destructive condition assessment techniques and breakdown voltage.

In the case of condition assessment of important hydropower generators, partial discharge measurements are commonly performed to indicate large delaminations within the insulation or lack of field grading at the HV terminations. Aging of the insulation is not solely dominated by AC electrical service stress but rather by a combination of several stresses, of which thermal and mechanical wear are the most important [1].

The main aim of the investigation presented here has been to examine the AC breakdown strength of service aged generator bars, using samples removed from a 95 MVA Hydro Generator, which was to be replaced after 50 years in service. Prior to breakdown testing, diagnostic measurements of partial discharge (PD) and dielectric loss were performed to possibly correlated condition assessment indicators to values of AC breakdown strengths.

2. Methodology

The Roebel conductor type bars were insulated by 3.6 mm thick mica/epoxy/glass fibre reinforced insulation with a maximum service voltage of 7.4 kV to ground. Six bars were randomly chosen as follows: Three bars were taken from close to the high voltage termination and three bars were taken from close to the neutral termination. That is, all six bars have experienced the same 50 years of thermal stresses, but only half of the bars have experienced high voltage during service.

The terminations of the generator bars were first removed and then remade enhanced to reach breakdown voltage without surface flashover. The terminations were painted with field grading varnish in 9 layers, resulting in a thickness of total 0.5 mm. The length of the termination was 20 cm.

This paper has investigated generator bars from a replaced 50-year-old hydropower generator, in which some results from testing of the bars have been reported earlier [2] [3]. A fast screening of all the collected bars without mechanical damage caused by the dismantling from stator showed no correlation between location in stator and PD reading [3]. As many as 50 % of the bars had low PD reading, that is a maximum apparent charge of less than 1.2 nC.

2.1. Partial discharge tests

A standardized PD test scheme was used, including a coupling capacitance and Omicron MPD600 system. The PDIV, apparent charge, and repetition rate were used as measures on the PD activity. The PDIV was found by increasing the voltage stepwise at both 0.1 Hz and 50 Hz at room temperature.

2.2. Dissipation factor tip-up

The dissipation factor was measured by an insulation diagnostic analyser IDA 200 and high voltage amplifier. The voltage magnitude was increased stepwise by a step height of $0.2 U_0$ with both 0.1 Hz and 50 Hz. The tip-up value was found by using the difference $(\tan(\delta)(U_0) - \tan(\delta)(0.2U_0))$ as described in [4]. In these measurements, 3 bars had guarded terminations, whereas 3 bars had measure area on the complete bar without guard.

2.3. Breakdown tests

The setup for breakdown voltage testing is sketched in Fig. 1. A high voltage transformer is feeding high voltage to the test object. The terminations were submerged in transformer oil to prevent surface flashover, as seen in Fig. 2. The terminations were challenged to their limits as a starting surface flashover was often observed when inspecting the bars after a breakdown had occurred. The test procedure was following IEEE std 1310 [5] with the option ASTM D149 Method B: The voltage was increased in steps of 5 kV every minute until breakdown occurred.

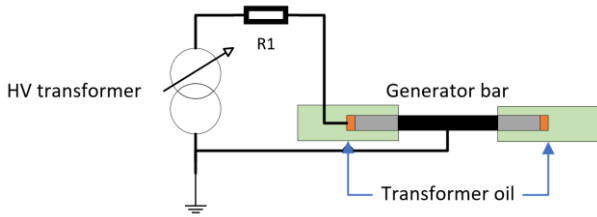


Fig. 1. Principal drawing of the breakdown test setup.

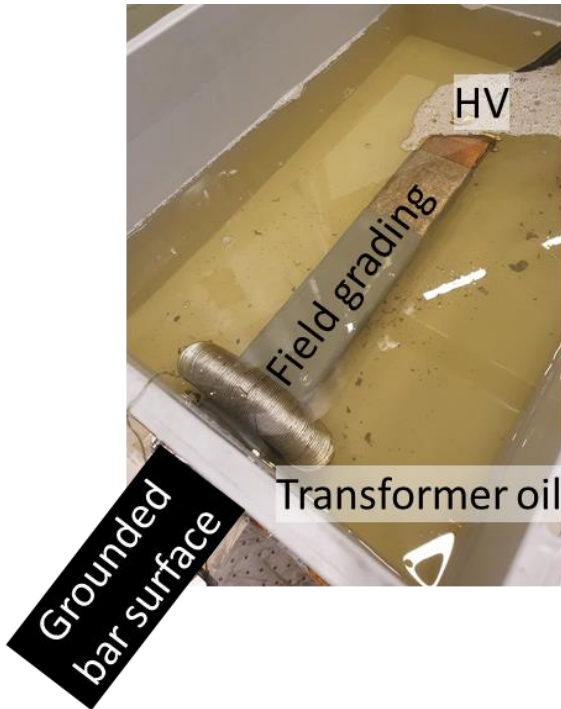


Fig. 2. Picture of the generator bar termination submerged in transformer oil.

4. Results

4.1. Partial discharge tests

A typical phase resolved PD (PRPD) pattern at service stress of $U_0 = 7.4$ kV at 50 Hz and 0.1 Hz at room temperature for one of the bars is shown in Fig. 3 and Fig. 4, respectively. Both patterns are comparable in shape and are typical for void discharges. The PRPD patterns varied with PD number and PD magnitude for the different bars, but the overall shape was similar. The PDIV was found to vary between 4.5 kV and 6.5 kV.

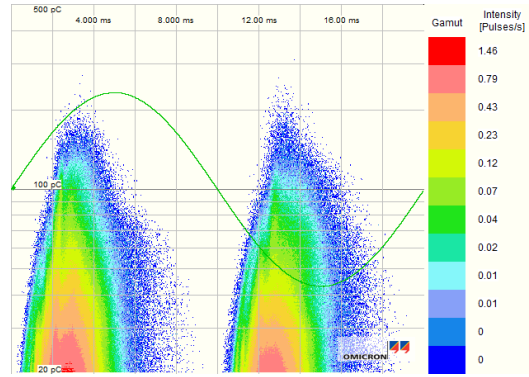


Fig. 3. PRPD for 10 minutes at $U_0 = 7.4$ kV at 50 Hz. 4.8 million PDs above 20 pC were recorded, which gives an average of 100 PDs per period.

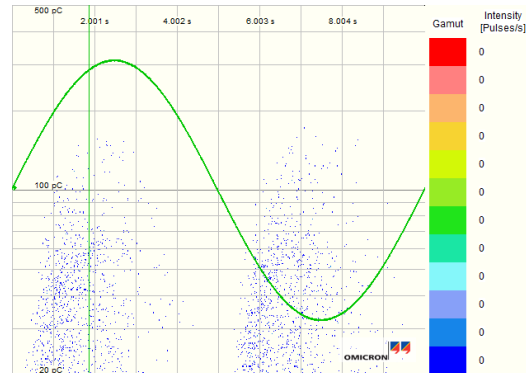


Fig. 4. PRPD for 10 minutes at $U_0 = 7.4$ kV at 0.1 Hz. 2200 PDs above 20 pC were recorded, which gives an average of 25 PDs per period.

4.2. Dissipation factor tip-up

One typical example of the dissipation factor $\tan(\delta)$ as a function of applied voltage is given in Fig. 5 for both 0.1 Hz and 50 Hz for an unguarded bar. The loss at 0.1 Hz is higher than at 50 Hz. The conductivity in the field grading enables a larger area with high voltage when applying 0.1 Hz, that is, higher $\tan(\delta)$. The tip-up values in this case are 0.017 at 50 Hz and 0.029 at 0.1 Hz. The trend of the voltage dependence for the bars with guard was similar, but the absolute values were lower by a factor 4-5, and also lower tip-up values.

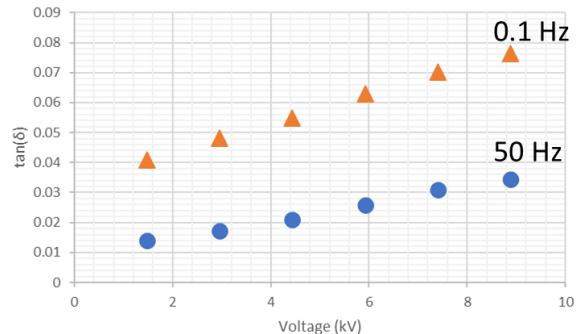


Fig. 5. Measured dissipation factor $\tan(\delta)$ as a function of voltage for 0.1 Hz and 50 Hz.

4.3. Breakdown tests

The measured breakdown voltage values are grouped in two groups in Fig. 6; bars close to HV terminal and close to neutral terminal. Similar to the PD screening in [3], there is no correlation between breakdown voltage and voltage applied during service. The maximum normal service voltage U_0 is indicated by a dotted line. This is the voltage applied during service for the bars close to the high voltage terminal, whereas no voltage was applied to the bars close to neutral terminal during service.

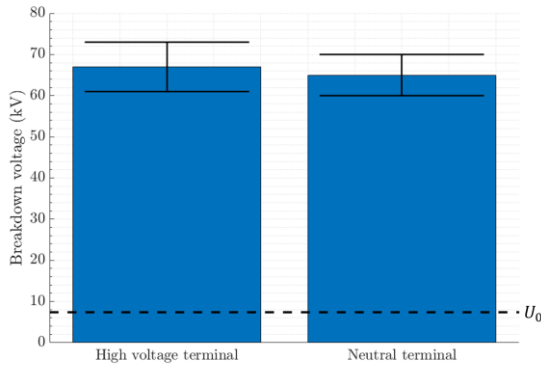


Fig. 6. Measured breakdown voltage as a function of service voltage for the tested bars.

One typical example of the breakdown location is given in Fig. 7. The breakdown voltage was always located at the corners of the bar, thus at the locations with geometrical field enhancement.

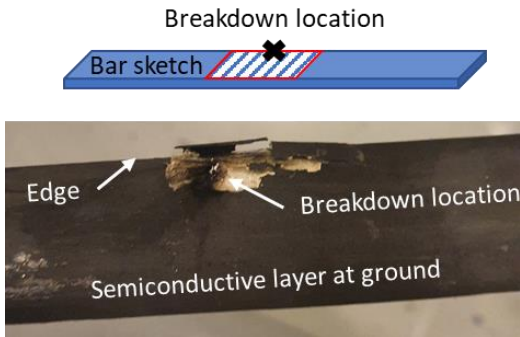


Fig. 7. A typical example of the breakdown location.

5. Discussion

The spread in the breakdown voltages was small, ranging from 60 kV to 75 kV, far above the maximum service voltage of 7.4 kV. This strongly indicates that the insulation of all the bars is in good shape. The measured breakdown voltage as a function of PDIV is shown in Fig. 8 including both values for 0.1 Hz and 50 Hz. The overall impression is that those few data points together with a small spread in results do not provide any clear correlation between PDIV and breakdown voltage: The data points are too close to claim any dependence. The same arguments apply for correlations between tip-up and breakdown voltage in Fig. 9. The samples that were not guarded have a higher tip-up value, especially for 0.1 Hz, whereas the tip-up was frequency independent when guarding the test objects.

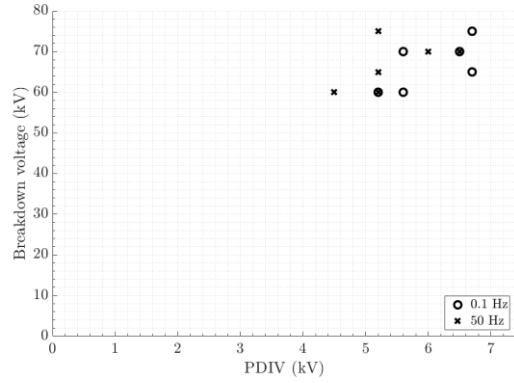


Fig. 8. Measured breakdown voltage as a function of PDIV for the tested bars.

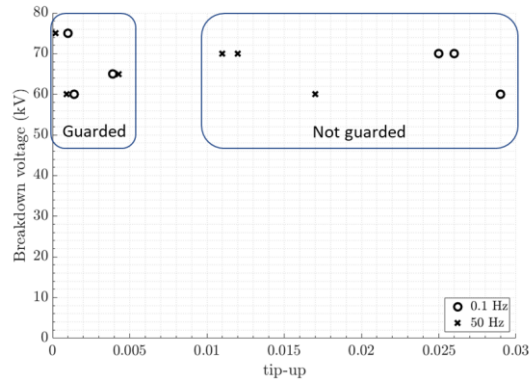


Fig. 9. Measured breakdown voltage as a function of tip-up for the tested bars.

It is, based on the presented results, reasonable to claim that the tested bars after 50 years in normal service are in good shape and that the service voltage has a minor or no effect on ageing, which is in line with results in another study [1]. There was only a small spread in condition assessment values, such that any correlation between condition assessment and breakdown voltage is impossible to find. This is in agreement with a study comparing the highest PD reading location and BD location that found no correlation [6]. They studied 6 similar generator Roebel bars rated 13.8 kV and applied different stress history to trigger different degradation to the samples. Some bars were treated with thermal cycling and voltage endurance tests at 30 kV for 400 h at 110 °C, other were as-is. Thermal cycling and voltage endurance created locations with high PD. They found no correlation between the highest PD reading and the BD location with 1 kV/s voltage rise.

Another study [7] with 122 bars found correlations between breakdown voltage and partial discharge inception voltage (PDIV) and dissipation factor tip-up. Very low PDIV values correlate to a low breakdown voltage, and similarly very high tip-up values correlates to a low breakdown voltage. There was a spread in breakdown voltage for the 'normal' PDIV and tip-up values, thus basically showing that extreme values for PDIV and tip-up correlates to lowered breakdown voltage. This also support the findings in this paper, as the spread of the breakdown voltage in Fig. 6 was low.

6. Conclusions

- After 50 years in service, the AC breakdown strength of the generator stator bars is still 8-10 times higher than the rated voltage to ground.
- There were observed no significant difference between the breakdown voltage for bars that have been in service with approx. 7.4 kV across the insulation and bars with approx. 0 kV across the insulation. This indicates minor degradation caused by the AC service stress.
- The condition assessment techniques showed a small variance between the bars, but without correlation to the breakdown voltage. That is, the bars seem to be in too good shape for any tested condition assessment technique to provide any significant differences between the bars.

Acknowledgement

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