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Experiments for the Life Assessment of Generator Bars

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Abstract: **In order to estimate the remaining life of a hydro power plant generator bars in Iran, one new and four old stator bars of the generator are tested under combined electrical, thermal and mechanical aging stresses. Partial discharge quantity (total integrated charge of the bars in cooling-down period) before and during the aging is used for the life assessment.**

INTRODUCTION

Insulation aging of an electrical machine is influenced by electrical, thermal, mechanical and environmental stresses during its operation. The mechanical, thermal and resulting thermo-mechanical processes have an excessive influence on the service life of the insulation. Partial Discharge (PD) can cause erosion of insulation materials and accelerate aging processes. On the other hand, they give information about the insulation condition and degradation mechanism of the insulation. PD analysis is an effective tool to study the aging process. The aim of PD monitoring is to assess the aging phases and fault developments of the insulation. Data processing of the recorded PD signals can show a correlation between the PD activities and aging levels of the insulation [1].

During warming up of generator bars, flat voids inside the main insulation or between conductors and insulation are decreased, because thermal expansion factor of the insulation and copper are different. Therefore, PD activities of the bars are minimized. When generator bars are cooling down, conductor of the bars cool faster than the insulation in a contraction manner. Therefore, the voids become larger and the PD activities of the bars rise up. This process makes a closed hysterical form curve (Figure 1). By the insulation aging, the inside surface of this closed loop becomes larger and partial discharge of the bar is more intensive during the cooling down period [1, 2]. Two factors, K1 and K2 are illustrated in Figure 1. K1 is the warming-up PD-factor (Min. ΣNQ of the bar in warming up period /ΣNQ of the bar in 20°C temperature), and K2 is cooling-down PD-factor (Max. ΣNQ of the bar in cooling down period / ΣNQ of the bar in 20°C temperature) [2].

This project is to assess the remaining life of a power plant generator winding (Shahid Abbasspour power plant on Karoon River in Iran). The generators of this power plant have approximately one insulation failure per year. The records show that, all breakdowns of the bars happened at the slot end portion of the bars. The generators are approximately 6 hours per day at full load and 10 hours at no load. The nominal and constructional characteristics of the power plant generators are given in Table 1.

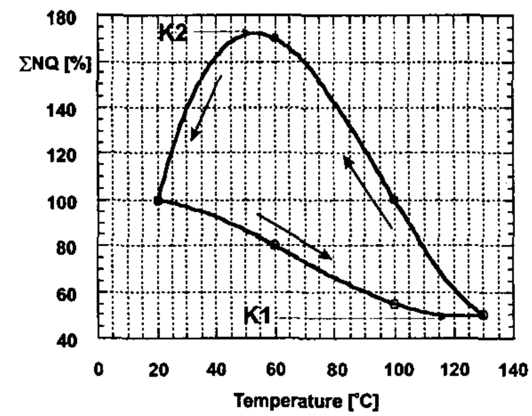

Figure 1. Variation of the total integrated charge (ΣNQ) of a new bar during warming-up and cooling-down periods

Table 1. Nominal and constructional characteristics of the tested generator

Power	250MVA
Voltage	18kV
Speed	166.7 RPM
Number of Slots	378
Permissible overload	15%
Insulation class	B
Slot length	240 cm
Type of insulation	Mica paper, epoxy resin
Main insulation thickness	4 mm
Permissible temperature rise	60 °
Permissible Temp. rise in maximum load	80 °
Installation year	1977

TEST SAMPLES AND TEST PROCEDURES

Five stator bars of the generators are tested during this project [3]. The bar No. 1 is new (not used) and the rest are old. The old bars were taken out of the generators during maintenance in different years. The semi conducting and anti corona layers of the bars were renewed before the tests.

Experiments on the bars include insulation resistance, polarization index, tanδ, partial discharge and aging by combined electrical, thermal and mechanical (vibration) stresses. In order to simulate the operational condition of the bars during the aging, an aging machine is constructed (Figure 2). The vibrated length and the vibrating amplitude of the bars are adjustable. The bars No. 1, 2, 3 and 4 are aged with combined electrical (200% of nominal voltage), thermal (cyclic by nominal current between 40°-80° C) and mechanical (vibration) stresses. A warming up and cooling down period has a duration of 90 minutes. The bar No. 5 has a breakdown during the electrical test before the aging process. The PD measuring system [4] has a 50-800 kHz bandwidth with a 1200 PF coupling capacitor. Measuring quantities of detected partial discharges are apparent charge, polarity and phase position of each PD event related to the alternative test voltage. Because of the test arrangement (two bars in series), while the PD measurement is down on the first bar, the partial discharge pulses of the second bar is filtered through an inductance (see Figure 2). The system can detect 250000 PD events per second.

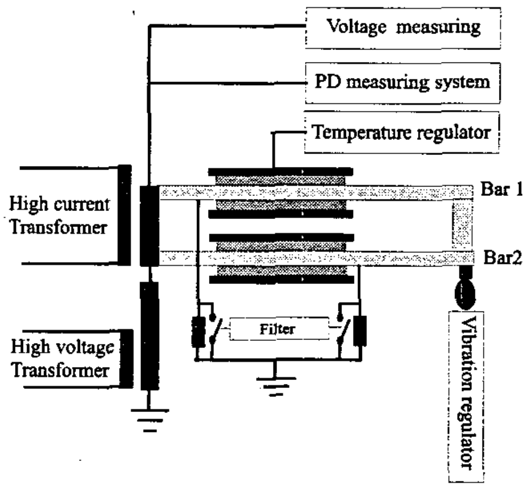

Figure 2. Aging machine

TEST RESULTS

The results of tanδ measurements of the bars at 20°C and 70°C are given in Tables 2-1 and 2-2. Partial discharges of the bars at 20 °C are measured in test voltages U_{ph}, U_n and $1.5U_n$, and a test duration of 500 ms. Total integrated charges (ΣNQ) of the bars related to the test voltage are shown in Figure 3. The warming-up and cooling-down PD-factors of the bars (before starting the aging tests) at nominal voltage is given in Table 3. The bar No. 5 is failed during cooling down period of this test. During the aging, the bars are under electrical, thermal and mechanical stresses. Vibration amplitude of the bars is 1.25 mm with a frequency of 20 Hz, which creates a bending stress at the bending point of the bars equal to 8.4 N/mm^2. Electrical voltage on the bars is 32 kV. Thermal stress in the bars is maintained cyclic between 40-80°C by circulating nominal ac current of the bars. Temperature sensors are installed on the outer surface of the bars. The aging period of the bars (time to electrical breakdown) are mentioned in Table 4. During the aging, partial discharge of the bars are detected and recorded in the cooling down periods (before restarting the circulating current). Figure 4 shows variation of PD activities of the bar No. 1 (the new bar) during the aging [5]. The electrical breakdown is happened after 530 hours aging. Figure 5 shows a two-dimensional diagram of the total integrated charge of the new bar related to the phase angle of the test voltage before the aging and after 450 hours aging.

The bar has mica paper insulation. After mechanical and thermo-mechanical fatigue of the insulation, its PD rises and its discharge-tree grows up till the electrical breakdown is happened [6, 7, 8].

Table 2-1. Tanδ ($*10^{-3}$) of the bars at 20 °C

Bar No.	1	2	3	4	5
$\tan\delta_{(0.2Un)}$	11.2	11.0	11.7	12.1	14.3
$(\Delta\tan\delta_{(0.6Un)-(0.2Un)})/2$	1.8	0.9	1.5	2.2	5.3
$\Delta\tan\delta_{max}$	2.3	1.2	1.5	2.2	5.5

Table 2-2. Tanδ ($*10^{-3}$) of the bars at 70 °C

Bar No.	1	2	3	4	5
$\tan\delta_{(0.2Un)}$	41	35	35	67	278
$(\Delta\tan\delta_{(0.6Un)-(0.2Un)})/2$	2	4	5	3.5	9
$\Delta\tan\delta_{max}$	1.4	4.2	4.6	3.7	49

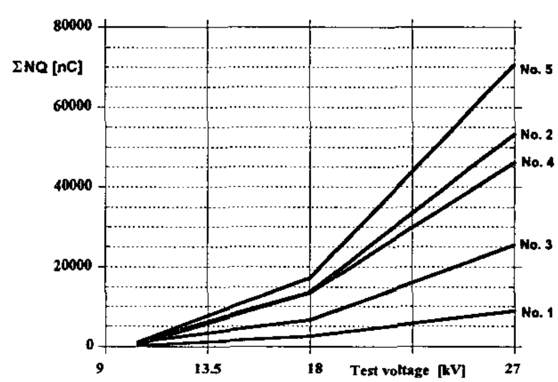

Figure 3. Total integrated charges of the bars related to the test voltage, temperature 20 ° C, test duration 500 ms

Table 3. Warming-up (K1) and cooling-down (K2) PD-factors of the bars by nominal voltage

Bar No.	1	2	3	4	5
K1	0.05	0.55	0.32	0.45	1.7
K2	1.8	31	2.0	26	-

Table 4. Aging duration of the bars

Bar No.	1	2	3	4	5
Aging duration till breakdown (hours)	530	32	389	8	0

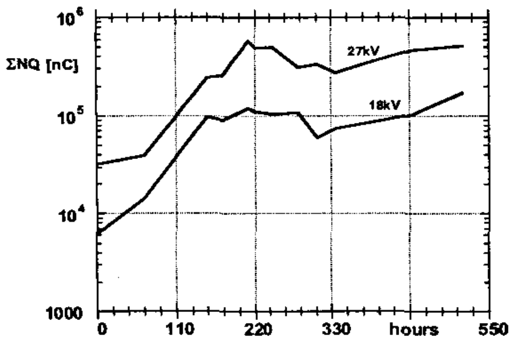

Figure 4. Variation of the total integrated charges of the new bar in cooling-down periods during the aging, PD measuring test voltage 18 and 27 kV, test duration 500 ms

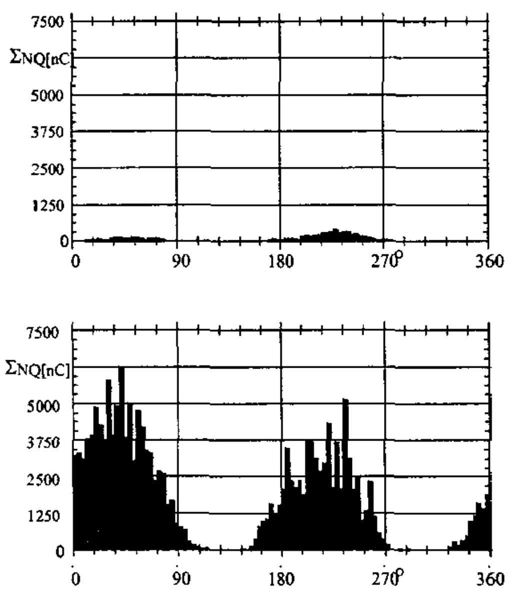

Figure 5. Two-dimensional diagram of the total integrated charges of the new bar related to the phase angle of the test voltage, up) before the aging, down) after 450 hours aging

CALCULATION

If the total integrated charge of each bar (before starting the aging tests) is indicated on the curves in Figure 4, time to breakdown of the bars can be calculated as below:
Time to breakdown of the old bar = Total aging time of the new bar – Time to appear the amount of ΣNQ of the old bar on the curve.

Total integrated charge of the bars 1, 2, 3 and 4 at the beginning of the aging tests in cooling down period and in 18 kV test voltage are 6, 400, 15 and 340 μC respectively (see Figure 3 and Table 3). These amounts of integrated charge are related to 0, >506, 95 and >506 hours respectively in figure 4. Calculated times to breakdown of the bars are calculated as below and given in Table 5.

Time to breakdown of the bar No. 1 = 530-0=530
Time to breakdown of the bar No. 2 = 530-506=24
Time to breakdown of the bar No. 3 = 530-95=435
Time to breakdown of the bar No. 4 = 530-506=24

From the results shown in Tables 4 and 5, it seems that the total integrated charge of the old bars measured at cooling-down period has a good relation to the bars remaining life time. Using accelerated aging stresses on the new bar, similar to the operating stresses on the old bars in the generator, results can be more realistic.

Table 5. Calculated time to breakdown of the bars

Bar No.	1	2	3	4	5
Calculated time to breakdown (hours)	530	<24	<435	<24	-

CONCLUSION

Time to breakdown of the old generator bars could be calculated from accelerated aging test on a new bar of the same generator and indication of the amount of total integrated charges of the old bars, measured at cooling-down period of the bar, on the results of the aging test of the new bar. The accelerated aging stresses on the new bar (cyclic or continuous thermal stress and vibration) must be similar to the operating condition of the generator.

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