OBSERVATION OF DIELECTRIC PARAMETERS AT GENERATOR STATOR WINDINGS UNDER CHANGING ENVIRONMENTAL CONDITIONS

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Abstract: In this paper the focus is laid on the observation of different dielectric parameters of the electric insulation system of generator stator windings. Spar bars of a generator were tested under laboratory conditions, the dielectric dissipation factor (DDF) as well as the partial discharge (PD) behavior was recorded under changing environmental conditions. In a test chamber the temperature and air humidity could be controlled and the DDF and PD were measured. In the same way the dielectric response function in frequency domain (FDS) was measured over a large scope of different climates.

To verify the results of the laboratory tests two onsite measurements were done at generators in hydro power stations. The tests were applied during the maintenance period at an asphalt insulated and one resin insulated generator. For the dielectric tests the FDS method as well as a PDC measurement were recorded. The results of the onsite measurements were evaluated under different aspects, the aim was to find out the expressiveness of FDS and PDC parameters to determine the winding condition. At least the test methods were compared and advantages/disadvantages were worked out.

1. INTRODUCTION

During maintenance and for the condition evaluation of generators various diagnostic measurements were done. Normally a mixture of condition and risk based maintenance strategy is applied. The standard program for the technical diagnostic measurements is the insulation resistance, the dielectric dissipation factor, the partial discharge behavior and a withstand voltage test. The focus on this paper is the dielectric response measurement in time and frequency domain [1, 2]. In laboratory different climatic situations were simulated and the several FDS plots were taken as well as PD measurements. The test results were verified on two generators at onsite tests.

2. LABORATORY TESTS AT SPARE BARS

2.1. Dielectric Response Investigations

The spare bars were of resin rich technology with a rated voltage of 10.5kV. In a first trial the thermal behavior of the tan δ was observed in a dry test chamber. In earlier investigations the temperature performance of the tan δ was already described as exponential function by classical measurements with Schering Bridge [3]. Now the dielectric spectrum in frequency domain was recorded from room temperature up to 70°C. The tests were passed through with a conventional FDS analyzer [4]. The results were shown in Figure 1. The DDF has the lowest value at about 1kHz and raises slowly at low frequencies (1mHz). The whole curves were shifted parallel with raising temperature. The absolute value was more than the doubled at 72°C, shown in Figure 1.

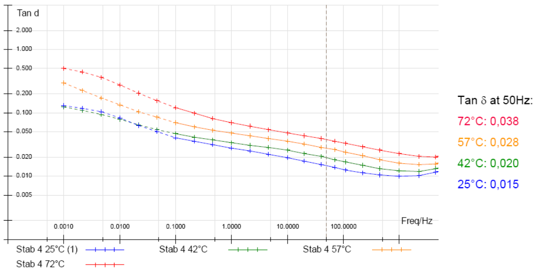


Figure 1: tan δ as function of temperature

In the second trial the same spare bars were used for the test in the climatic chamber. Additionally to the thermal test setup the air humidity could be controlled. The variation of the climate was done between dry (25%RH), normal (50%RH) and wet (90%RH) conditions.

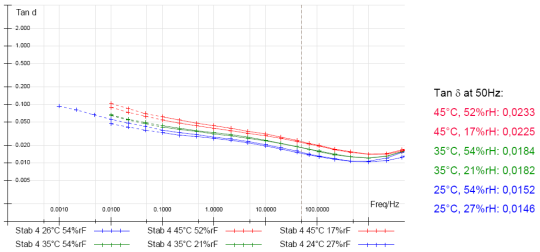


Figure 2: tan δ as function of temperature and air humidity

The results in Figure 2 showed the same results for all test objects and test conditions. Lowest value of DDF was observed for the dry climate and for higher humidity the DDF shows a stronger raise at lower frequencies. At higher frequencies (>50Hz) there were almost no differences. At very high humidity the DDF raised significant at low and very low frequencies - see Figure 3. In earlier investigations it was shown that the reason can be found in the dominance of surface effects at high humidity (>60%RH).

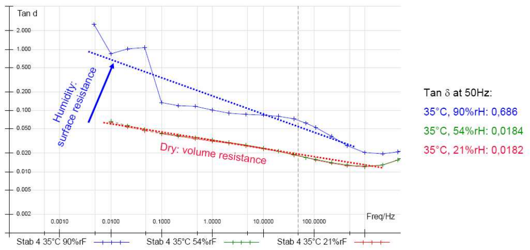


Figure 3: tan δ under extreme high air humidity

The relevance of the capacitance ratio (CR) was described in [5]. A low ratio of the winding capacitance between low and net frequencies is an indicator for a good quality of the electric insulation system. In following Table 1 the CR is calculated for different climatic conditions.

Table 1: capacitance ratio CR between 10mHz and 50Hz at different climatic conditions

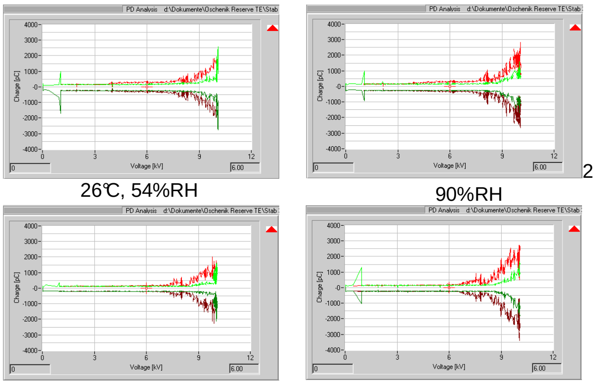
climatic condition	bar 1	bar 2	bar 3	bar 4
25℃ 27%RH	1.13	1.21	1.18	1.16
25℃ 54%RH	1.17	1.21	1.16	1.17
25℃ 90%RH	1.33	1.66	1.44	1.35
35℃ 21%RH	1.21	1.28	1.23	1.20
35℃ 54%RH	1.22	1.29	1.24	1.20
35℃ 90%RH	1.75	1.75	1.44	1.45
45℃ 17%RH	1.28	1.38	1.30	1.26
45℃ 52%RH	1.31	1.44	1.32	1.28

The CR showed a low dependence to temperature. In this case a CR below 1.2 indicates a dry insulation at 25°C, below 1.3 for 35°C and below 1.4 for 45°C.

2.2. Partial Discharge Tests

The partial discharge behavior was measured and recorded for several climatic points. The absolute value of the PDs (apparent load Q_{IEC}) and the fingerprints as well as the inception voltage was evaluated. The measurements were done with a broadband unit according to the IEC 60270 and a coupling capacitor of 2nF. The calibration for all measurements was done identically with 5nC.

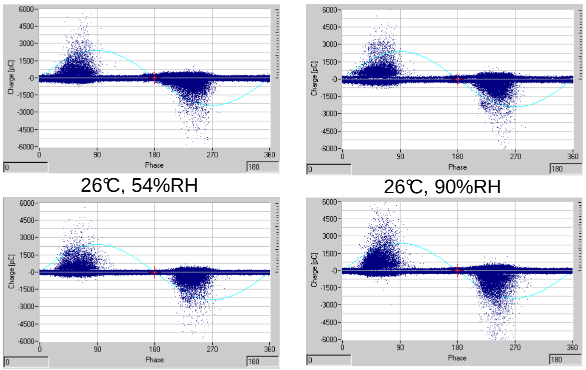
In opposite to the tan δ the PD behavior is almost not influenced with temperature or degree of air humidity. The PD over voltage functions (inception voltage - red line and extinction voltage - green lines) of one bar can be seen in following Figure 4. The PDIV is in all cases higher than the PDEV. Classically this can be interpreted as internal discharges in the groundwall insulation caused by voids and gaps.



26℃, 54%RH
26℃,
90%RH
35℃ 90%RH
45℃ 50%RH

Figure 4: PD inception and extinction voltages at different climatic points

The surface discharges in the area of the voltage grading tape and winding head do not influence the result noticeable. Some bars showed a better PD behaviour at higher temperature or higher humidity. This can be explained with thermal strains due to manufacturing process.



26℃, 54%RH
26℃, 90%RH
35℃ 90%RH
45℃ 50%RH

Figure 5: PD finger prints at different climatic points

The PD finger prints at different climatic conditions showed a quite similar behaviour. In Figure 5 the results at rated voltage (10.5kV) is shown.

Resuming the results of PD measurements it can be said that neither temperature nor air humidity has a significant influence to PD behaviour. The occurrence of PD was not influenced noticeable in the phase resolved finger prints as well as the PD inception or extinction voltage [6, 7].

3. ONSITE TESTS AT GENERATORS

For the verification of the laboratory tests two different types of hydro generators were chosen to apply the dielectric response measurements onsite. The first test was carried out at a resin insulated generator and the second at an asphalt insulated. Within the revision period a dielectric spectroscopy could be recorded. At the first generator the measurements could be done at each phase separately and at the second the whole winding was tested at neutral point and line side.

3.1. FDS Measurements

At first the results of the FDS measurements should be discussed. The plot of the dielectric spectroscopy is shown in Figure 6.

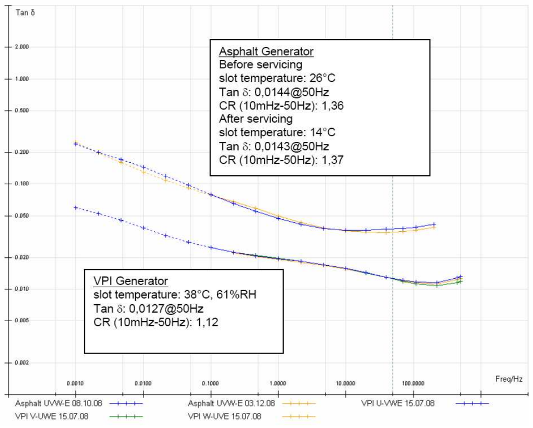


Figure 6: FDS plot of asphalt and resin insulated generators

The frequency dependant tan δ showed a small gradient at low frequencies, the CR between 10mHz and 50Hz is 1.12 at the VPI generator and 1.37 at the asphalt insulated. Interpreting the results of the laboratory tests it can be resumed that this CR is an indicator for dry insulation conditions and a good quality of the insulation.

Due to the high capacitance of the generators (especially testing the whole winding) the applied test voltage was limited with 20V. Comparing the dielectric measurements carried out at low voltage with the results at high voltage (up to rated voltage at 10.5kV) the tan δ at 50Hz gives similar results at both methods. It has to be pointed out that the ionization losses caused by PDs can not be detected with dielectric measurements of course.

3.2. PDC Measurements

At the asphalt insulated generator additionally PDC measurements were carried out. To get comparable results the same tests voltage level were chosen. The polarization and depolarization time was set to 700s. In [8, 9] some results of PDC measurements at generators onsite were discussed.

The results of the PDC measurement were plotted in time domain. In Figure 7 the polarization and depolarization currents before and after servicing were shown. The standstill period during the maintenance period took 8 weeks. During this time the machine was opened and overhauled.

The PDC currents before servicing were almost identically and after the servicing period there is only a small drift noticeable. Additionally the insulation resistance IR was measured conventional at 1kV DC. The polarization index PI (insulation resistance after 600s to 60s) was determined as 4.79 (before) and 4.25 (after) servicing. The insulation time constant τ (IR x C) was calculated to 1433 (before) and 1470 (after).

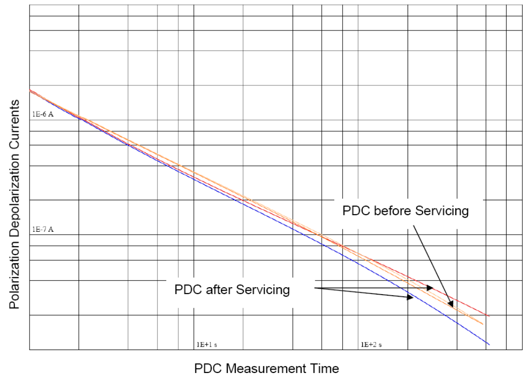


Figure 7: PDC plot of asphalt insulated generators before and after servicing

Transforming the PDC currents from time to frequency domain the complex capacitance can be determined mathematically. The results were shown in Figure 8. The real part of the complex capacitance c´ is almost linear over the whole frequency band. After the servicing interval the c´ is rising slightly from frequencies under 10mHz. Possible reasons can be absorption of humidity from cooling air during service period. In [10, 11] some theoretical considerations about humidity absorption in generator insulation systems can be found.

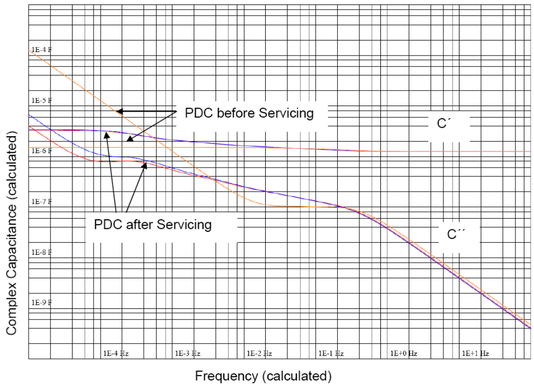


Figure 8: Calculated complex capacitance of asphalt insulated generators before and after servicing

3.3. Comparing FDS and PDC results

The capacitance ratio CR between 100µHz and 50Hz is 2.53 (before) and 2.74 (after) and the calculated capacitance of the winding at 50Hz is 1.26µF (before and after). Compared to the results of the FDS measurement the capacitance at 50 Hz was 1.43µF. Due to the long measuring interval the capacitance could not be measured at 100µHz with FDS method. For this reason the CR can not be compared.

The results of the PDC measurement were transformed from time to frequency domain and imported to the FDS plot. In Figure 9 the results were displayed. The transformed PDC values were in the same range of the FDS test results, only small deviations were present. It is not useful to display the whole dielectric spectrum of the PDC measurement in frequency domain. The transformation can be done mathematically correct but physically there were no practically valid values above 1Hz.

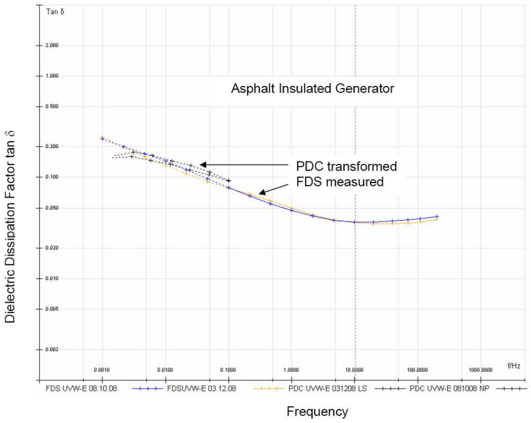


Figure 9: Tan δ of asphalt insulated generators with FDS measurements and transformed from PDC measurements

4. CONCLUSIONS

In laboratory tests the dielectric behaviour of dielectric parameters were carried out and evaluated. The DDF and PD under different climatic conditions were tested. The DDF was determined with different dielectric spectroscopy measurements, the FDS and PDC method were used as well as classical tests with high voltage.

A parameter for the determination of the humidity is perhaps the capacitance ration CR between low (10mHz and lower) and net frequency but additional tests have to be done to determine an absolute value.

The onsite tests at an asphalt and a resin generator (VPI technology) were carried out successful. The FDS and PDC method is applicable and the dielectric parameters can be determined and evaluated.

Comparing the FDS and PDC method it has to be mentioned that both methods give useful results. The evaluation with the FDS device is much easier and comfortable. The PDC results can be imported for data processing to the FDS device but not in opposite.

The dielectric response measurements were supplementary test methods where additional dielectric parameters can be determined in a fast way with low costs. But the classical diagnostic methods carried out with high voltage tests (tan δ and PD up to rated voltage) can not be replaced due to the fact that the ionization mechanism were not activated under the PD inception voltage. Also a high voltage test as pass/fail decision of the insulation system can not be replaced.

5. TEST EQUIPMENT

Following measuring equipment was used:

- FDS Analyser DIRANA, Omicron
- PDC Analyser 1 MOD, ALFF
- Dielectric dissipation factor and capacitance measuring system LDV-6, LDIC
- Digital partial discharge measuring system LDS-6, LDIC
- Insulation Resistance: Megger MIT 520

Nominal values of the tested Generators:

- Asphalt Generator: 20MVA, 6,3kV, 1833A, Class B Insulation, 1962, ELIN
- VPI Generator: 20MVA, 6,3kV, 1833A, Class F Insulation, 1993, ABB

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