MONITORING OF PARTIAL DISCHARGES IN OIL-PAPER INSULATION IN A LABORATORY ENVIRONMENT FOR DIAGNOSTICS

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Abstract: In the diagnosis of transformers the partial discharge measurement is one of the several test methods in high voltage engineering. At first only single measurements were common. Recently monitoring of the partial discharges on single devices during operation is possible and increasingly in use. Because of the continuous acquired data new additional possibilities to gain information about the equipment arise besides the current evaluation methods. Therefore systematic measurements about the behaviour of partial discharges over the time to examine the potential use in a monitoring system seem to be reasonable. For the application of oil-paper-insulation measurements with test samples in a laboratory environment were done. The preparation of suitable specimen, from segments of paper insulated conductor for the production of transformer coils, for simulation partial discharges in voids is described. With equal boundary conditions the specimen of a collective show in certain limits a reproducible behaviour. Now the curves have to be evaluated together with the measurement data of further collectives with different boundary conditions.

1 INTRODUCTION

Partial discharges are electrical discharges in a limited area of the insulation caused by defects in the material and induce a damaging aging process in the insulation of electric power system components. Continuous discharges can lead to an expansion of the fault area and cause electrical breakdown and failure of the equipment.

Partial discharge measurement is a non-destructive and well established test method in high voltage engineering to detect faults early, for example in regular maintenance or acceptance tests.

With the growing technical possibilities and at the same time reducing costs in the area of electrical measurement as well as in data acquisition and processing, it has become increasingly possible to implement monitoring systems for continuous measuring of partial discharge activity on single devices during operation. For evaluation of these test results, generally the current methods of partial discharge measurement, for example the analysis of the phase resolved partial discharge pattern, can be used with monitoring systems as well. Because of the continuous acquired data new additional possibilities to gain information about the equipment arise.

For the application with oil-paper insulated transformers little research has been done on the suitability of time-dependent measurement values for fault evaluation. There is less knowledge which information's about the fault and the insulation system are possible to achieve from the continuous monitored values. The best known criterion is still the amount of the apparent charge, but because of the time-dependency of the measured values over a longer time instead of the snap-shot of the faults behaviour, it is to assume that further characteristic values can give further information.

With this background, it seems reasonable to make systematically measurements of the partial discharge activity over the time with test samples in a laboratory environment to examine the collected data and parameters calculated from them, on their time-dependent behaviour and their potential use in a monitoring system. Possible information could be also about the type of fault or the degree of damage in the insulation material.

In the first step, it is necessary to analyse, with which limitations and conditions it is possible to simulate different typical faults in the laboratory. Furthermore it is possible to investigate the time dependent behaviour of the partial discharges.

In comparison with monitoring of partial discharge in the field, an investigation of partial discharges in a laboratory environment has some advantages:
- the type of fault can be selected and is known,
- it is perfectly possible to monitor the fault until a breakdown occurs,
- a collective of the same specimen can be examined,
- influencing parameters can be chosen and kept constant,
- an accelerated aging can be tested.

Therefore two different types of faults were tested and some measurement curves were collected.

2 METHODS

For the investigation test samples were prepared from segments of paper-insulated conductor for the production of transformer coils. In the test setup two ca. 25 cm long segments are curved and arrayed like it is illustrated in Figure 1a. In a small area the segments are faced to each other with a small gap. The selected distance is 1 mm. One segment is grounded by a metallic connection to the bottom. To the other segment the high voltage is lead from the top. In the area with the small gap is the highest exposure of the electric field and the simulated, partial discharge causing fault should be located. The assembly is adjusted on an isolating, temperature- and oil-resistant carrier made with Teflon. The complete configuration is placed in a test vessel filled with oil (cp. Figure 1b).

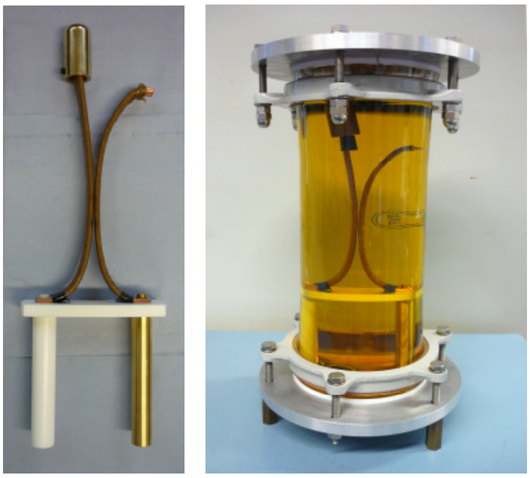

Figure 1: Arrangement of test samples on a carrier (a) and with mineral oil in the test vessel (b)

The preparation of the test samples begins with a drying. Therefore the specimen were put in a vacuum oven by a temperature of 105 °C and a pressure of ca. 1-3 mbar for 24 h. The required 6 l mineral oil has also to be prepared: it was dried and degassed.

Typical causes of partial discharges in oil-paper-insulated transformers are metal particles, voids in the oil-paper insulation as well as contamination in the oil. In this investigation the examined type of fault were voids in the insulation. To generate this fault, the specimen was not vacuum-impregnated. After the drying process, it stayed for another day in the vacuum-oven without heating for cooling down. Afterwards the test sample, together with the dried and degassed mineral oil, was inserted into the test vessel. The oil diffuses and saturates the paper-insulation gradually.

In a preliminary investigation the behaviour from the test samples and the degree of impregnation in dependency of the waiting time was estimated. In intervals of several hours the partial discharge inception voltage was measured. The first two days the inception voltage was comparatively low and nearly constant. After the second day the inception voltage increased till the third day up to the fivefold.

On account of this, in this investigation a waiting time of 24 h follows after the specimen was inserted into the test vessel with the oil. An impregnation of the paper with the oil happened, but still a lot of voids stayed in the insulating material.

After the waiting time the test vessel with the specimen was connected to the high voltage with power frequency and the partial discharge measurement was started. Orientated on the partial discharge inception voltage in the area of 8-12 kV and the breakdown voltage between 55 kV and 70 kV of this arrangement, the voltage was selected to a level of 35 kV.

The complete test setup with the partial discharge measurement was installed in a shielded cabin to avoid disturbing signals. For the measurement acquisition in intervals of two minutes the partial discharges of ten cycles were recorded and analysed. According to the standard IEC 60270:2000 [1] the analysis of the measurement signal effected broadband in a frequency range from f_1 = 100 kHz to f_2 = 500 kHz.

Three test samples prepared by the described way were measured. The test samples of this collective are denoted by group A. After three weeks the measurement was interrupt to investigate further specimen with different characteristics.

The second three test samples, denoted by group B, were prepared in the same way. Additionally the paper insulation was damaged by highly thermal stress. The drying was done by a temperature of 200 °C for one week.

3 RESULTS

With the described preparation of the test samples, made from segments of paper-insulated conductor for the production of transformer coils, it is possible to generate typical faults in form of voids in the oil-paper insulation, which are causing partial discharges. The generated faults are low enough so that the partial discharges don't cause a breakdown within a short time and are high enough so that the partial discharge activity occur stable over a time of several days and weeks. Therefore the development of the partial discharge activity can be measured and observed.

Due to the laboratory environment the boundary conditions can be determined and be equal for a collective of specimen. Two different prepared kinds of specimen are investigated and it is to note, that the three specimen of each group within certain limits have a similar behaviour in the measured partial discharge values.

But both collectives show a different development of the partial discharge activity and behaviour, which possibly could be characteristic for the fault, dependent on the boundary conditions. The measurement results of one specimen of each collective are presented below. The selected values were the characteristic partial discharge parameter apparent charge q_s and the number n of pulses per period.

The number of pulses per period from the test sample of group A is depicted in Figure 2. The measured curve could be classified in two parts: within the first five days, there was a transient behaviour. After this the number of pulses per period increases more or less constantly till the measurement is interrupt after three weeks.

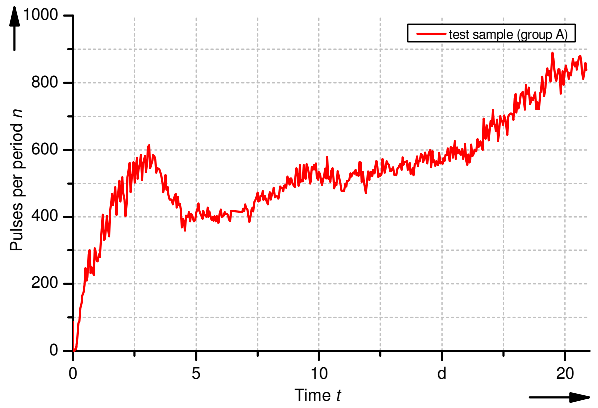

Figure 2: Time-dependent behaviour of number n (pulses per period) of the partial discharge activity from a test sample of group A

This different development is also visible in the measured curve with the average apparent charge q_s per pulse shown in Figure 3.

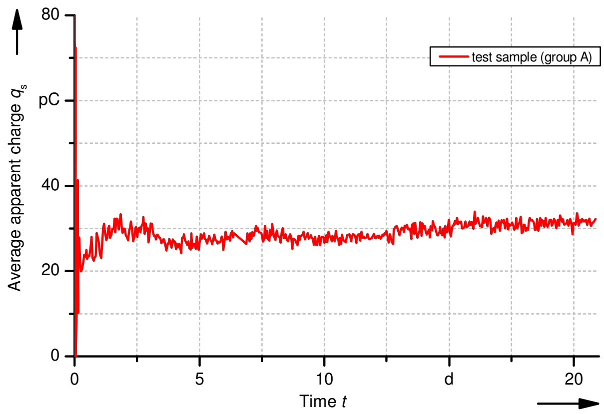

Figure 3: Average apparent charge q_s of the partial discharge activity from a specimen of group A as function of the test time

Additionally there is a transient behaviour within the first hours of the first day of the voltage exposure and the measurement. Here the apparent charge, compared with the remaining time, shows remarkable, bigger oscillations. Subsequent to this part, the average apparent charge is nearly constant, however with a slight upward trend.

In parts a comparable behaviour has also the measurement curves of the chosen test sample from group B, depicted in Figure 4 and Figure 5. The first part, until day three respectively four, looks like a transient effect, too. After this the measurement value is oscillating around a nearly constant value. This kind of steady state last for the next five days till a breakdown occurs.

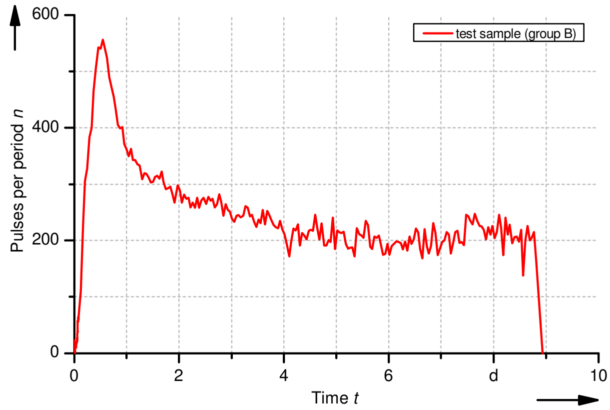

Figure 4: Time-dependent behaviour of number n (pulses per period) of the partial discharge activity from a test sample of group B

The corresponding curve with the average apparent charge of the specimen from group B is shown in Figure 5.

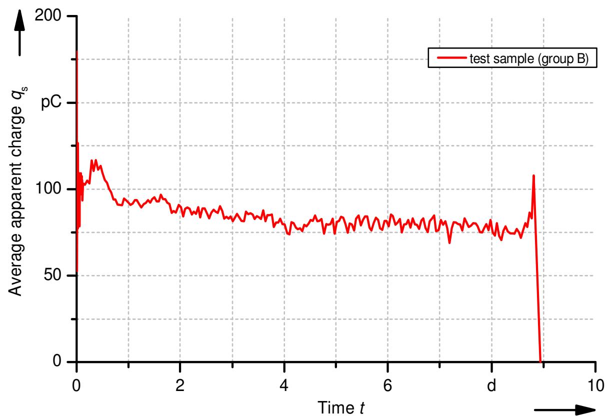

Figure 5: Average apparent charge q_s of the partial discharge activity from a specimen of group B as function of the test time

Again the transient effect is visible within the first days and also a remarkable, bigger oscillation in the first hours of the first measured day can be observed. In the area of the steady state the average apparent charge is nearly constant, in this case with a slight downward trend. Noticeable in this curve progression are raising values a short time before the breakdown occurs.

The location of the breakdown by specimen of group B with the highly thermal stressed und damaged paper-insulation is shown in Figure 6. It is located in the small gap between the two electrodes as expected. The puncture is in both electrodes, but is not straight vertically to the electrode surface. In an area up to 5 mm, around the visible void in the surface, the puncture is wandering through and partially along the paper layers. The diameter of this channel is variable between 0,5 mm up to 3 mm.

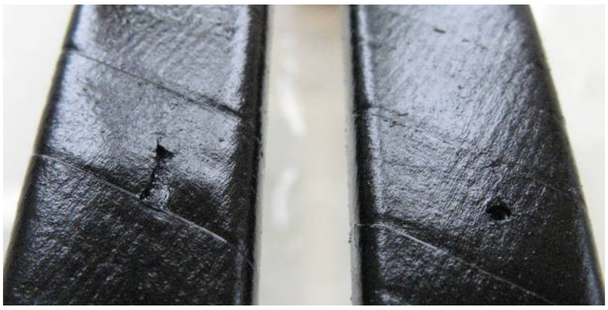

Figure 6: Surface of a specimen from group B with the puncture after the breakdown

4 DISCUSSION AND CONCLUSION

The behaviour of the partial discharge activities of the investigated collectives can be reproduced within certain limits and can be measured for a longer period of time even until the insulation fails.

The first results of the adopted procedure to generate adequate faults in a laboratory environment for investigations about monitoring of partial discharge development are promising.

Now an examination and evaluation which information the measurement curves contain has to be done. Therefore further measurement values for example the maximal apparent charge or the converted energy per pulse can be considered.

Thereby it has to be investigated in which way the behaviour changes with different boundary conditions for example with a lower or higher voltage exposure and dependent from this how far the information from the measured curves are transferable to other arrangements and configurations. For comparison further kinds of faults or different configurations can be analysed as well.

5 ACKNOWLEDGEMENT

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6 REFERENCES

[1] Standard IEC 60270: “High-Voltage Test Techniques - Partial Discharge Measurements”, 2000