The Influence of the Stress Time Duration on the Partial Discharge Behavior in Cast Resin Insulation

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Abstract- It is well known that thermal and electrical stresses have a strong influence on the degradation of insulation, but the effect of the stress duration is not yet well analysed. On this account thermal, electrical, and a combination of thermo-electrical stresses were applied to a number of cast-resin samples, and their effects were evaluated via partial discharge measurements. Stress duration as well as time without stress was varied. This information will be used in a statistical method to recognise the influence of the duration of the applied stress on the partial discharge activity of every sample.

The statistical method is the Analysis of Variance (ANOVA), which is useful when the frequency distribution of the measurements is a so-called Normal Distribution. All measurements were carried out following this distribution and thus the reliability of such tests is only dependent on the linear behaviour of the following variables: partial discharge inception and extinction voltage, number of discharge impulses, sum of the charges of all impulses, and average charge per impulse. The other variables are the stress duration and the time without stress.

In order to recognise variations which only correspond to the same effect, tests must be ordered in groups with the same characteristics. Tests must also be performed in continuous and repetitive cycles under stress in order to avoid undesirable effects. The results of these experiments may form the basis for the identification of a relationship between one or more partial discharge parameters and the stress duration.

I. INTRODUCTION

The discussion about the interdependence between partial discharges (PD) and remaining life is centered on the identification of changes in PD behavior after the application of stresses to the insulation samples and a subsequent grouping according to the insulation’s age [1]. However, the implementation of this analysis does not completely account for the nature of the erosion effects and their measurable quantities. Therefore, a series of 40 samples of epoxy insulators with needle and Rogowski electrode profiles was produced and the samples were stressed electrically, thermally, and electro-thermally, carefully controlling the time which the stress was applied and the time after the stress was removed (i.e., time without stress). The monitoring of PD characteristics was done through the comparison of variables such as the partial discharge inception and extinction voltages versus the duration of the stress and the duration without stress. This comparison was made with the help of the ANOVA (Analysis of Variance) statistical method [2].

II. EXPERIMENTS

The electrical ageing of the samples was carried out by applying a voltage of 10 kV at 50 Hz for the needle samples and 20 kV at 50 Hz for the Rogowski profiles. Thermal ageing was made at a temperature of 80°C, which is appropriate for this epoxy system because it is still below the glass transition temperature but above the operating temperature and permits accelerated ageing effects. The combined electro-thermal ageing had the same parameters as the single-stress tests.

For the measurement of the PD variables, a voltage of 6 kV at 50 Hz was selected. The time periods for measuring the PD behavior were chosen following a gauss-curve, or normal distribution. Thus, the measurements were carried out after 1, 3, 5, 10, 15 and 20 hours with stress and 1, 7, 10, 14, 24 hours without stress. The number of measurements made at the center of the time period is greater than at the other time instants in order to get the normal distribution. Fig. 1 shows the number of measurements as a function of the stress duration. This measurement distribution is required by the ANOVA calculation, which is only appropriate for comparing groups with normal distribution and linearity. The linear behavior of the samples is not influenced by the number of measurements, but can be used as an evidence of the group’s linearity.

![Fig. 1. Number of measurements vs. stress duration](image-url)
To prevent undesirable surface discharges, every specimen was placed into a receptacle filled with an ester-insulation fluid that also acts as a heat transfer medium during the electro-thermal ageing.

The total duration of the electrical and electro-thermal ageing processes are still until the specimens go to breakdown. But the duration of the thermal ageing was not determined for the breakdown of the samples, because it does not occur after 1600 hours. Therefore, at this time the ageing was stopped.

III. RESULTS

Analysis of the PD measurements using the ANOVA statistical method was performed in order to find similarities in the behavior of samples subjected to the same stress. Some particular characteristics of every stress and type of electrode were found.

The thermally stressed specimens with a needle-plate configuration present a clear decline in partial discharge inception and extinction voltages (PDIV and PDEV) as the time without stress is increased. This result is illustrated in Fig. 2, where PDIV versus time without stress is shown.

Fig. 3 exhibits an increase in the number of impulses as the stress duration increases. With the help of ANOVA, the probability of dependence of the results shown in Figs. 2 and 3 can be calculated, yielding 0.23 for Fig. 2 and 0.01 for Fig. 3. These values indicate the reproducibility of the measurements is better for the data in Fig. 3 than in Fig. 2.

For samples subjected to both thermal and electrical stress, the measurements indicate an important dependence of the Average Charge per Impulse (ACpI) versus time with and without stress, as shown in Figs. 4 and 5. ACpI is the result of the division of the total apparent charge on every measurement by the total number of impulses on the same measurement, and is given in pC/Impulse according to [3]. It can be evaluated from Figs. 4 and 5 that ACpI increases with stress time and also decreases with time without stress.

ACpI is not the only variable with a dependence on the stress duration; the total apparent charge is also affected, as shown in Fig. 6.
and 24 hours under stress in Fig. 4, which shows unexpected values for a linear curve fitting.

The measured PD variables of the specimens under electrical stress appear more complicated, making it difficult to identify an obvious common behavior for all samples with the needle-plate arrangement.

The evaluation of the measured PD variables for the Rogowski samples was started with the same PD variables as for the needle-plate specimens. For the thermally stressed samples, a non-linear decay of the total apparent charge can be seen in Fig. 7.

The measurements of the total number of impulses as a function of the stress times are shown in Fig. 8. The dependence probabilities for measurements in Figs. 7 and 8 were also evaluated, and give 0.30 for both results due to their extremely non-linear behavior.

The thermo-electrical stressed Rogowski samples exhibit a different tendency in ACpI, shown in the Fig. 9, than the needle-plate specimens (Fig. 4) when subjected to the same stress conditions. The tendency of ACpI for the Rogowski samples is opposite to that of the needle-plate samples for the same variable. It is not clear if the decrease of the ACpI with increasing stress times is caused by a change in the local cavity behaviour in the insulating system, which is the source of the partial discharges. But it should be taken into account that the average charge per impulse is much lower for the Rogowski configuration compared to the needle-plate configuration, and that the stress times for the Rogowski configuration are much longer than for the needle-plate configuration.

The dependence probability of Fig. 9, estimated by ANOVA, is 0.28 and this is a clear signal that the values of every measurement will be influenced by former measurements, as can be seen for the first four measurements.

In Fig. 10 another parameter, the partial discharge extinction voltage (PDEV), is shown as a function of the time without stress. The results show a consistent decrease of the PDEV as function of the time without stress, except for the measurements at 48 h. Measurements at this particular point were repeated several times. The results are strange and need further investigation.
The results of the evaluation for the electrically stressed Rogowski samples display a decrease in the total number of impulses with increasing stress time, as shown in Fig. 11.

The ACpI exhibits an increase as a function of the stress time, as shown in Fig. 12. The calculation of the dependence probability using ANOVA gives a value of 0.26 for the results of Fig. 11, mainly caused by the large deviation of the measurements at the beginning, and a value of 0.04 for the results of Fig. 12, which means that there is almost no relationship between the measurements.

Opposite profiles were not only observed for Figs. 4 and 9. A reversed progression of values was also exhibited in Figs. 3 and 8, and with a similar change of scale because the total number of apparent impulses in Fig. 3 is only 9000, whereas the number in Fig. 8 is about 650,000. The reason for these opposite tendencies may be the formation of multiple conducting channels on the Rogowski configurations, which cause an increase in the number of impulses but with less intensity compared to the needle-plate configuration.

The linear behavior of Fig. 6 and the relatively high value of the dependence probability is caused by the small number of tests available for the statistical evaluation due to the fact that a number of test samples failed during the test time. However, the dependence probability gave the lowest value for all tests with a small number of test results.

The absence of common patterns for the electrically stressed needle-plate configurations prevents the possibility of a comparison with the results of the Rogowski profiles.

IV. CONCLUSIONS

The main conclusion of the results is that the PD variables measured at a certain time and used for a pattern of the age of an insulation material could lead to incorrect results concerning the real condition of the insulating system. It is therefore necessary to analyze the tendency of the PD variables in order to get sufficient reliability in the interpretation of the measurements and its effects.

REFERENCES