Identifying Prognostic Indicator for Electrical Treeing in Solid Insulation through Pulse Sequence Analysis

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INTRODUCTION

This research aims to predict the lifetime of solid insulation by experimentally inducing electrical treeing in samples of Silicone Rubber. Indicators of ageing are features of the partial discharge (PD) plot that correspond to electrical tree growth, and can therefore be used to identify the stage of growth and predict remaining life. In this paper, the pulse sequence analysis (PSA) technique has been applied and shows distinctive features which change with the tree evolution. A prognostic indicator has been identified as the error term when applying linear regression to the PSA plots.

ELECTRICAL TREEING EXPERIMENT

This study employed needle-plane test arrangement on commercially available pre-formed silicone samples as shown in Fig. 1.

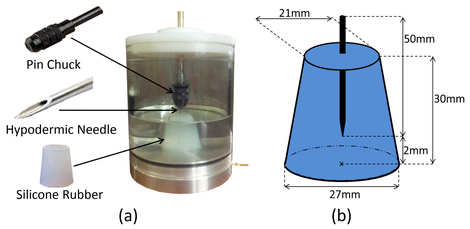

Fig. 1: Test arrangement (a) Test cell (b) Test sample

PULSE SEQUENCE ANALYSIS (PSA)

The basis of pulse sequence analysis is that strong correlations exist between consecutive discharge pulses due to the influence of local space charge on the ignition of the following discharge pulse [1]. Thus, the characteristic parameters for the discharges are the local electric fields and their changes, which can be represented using only the change in voltage due to the excitation waveform. Fig. 2 shows the basic principle of PSA approach, where the solid circles represent PD pulses within the reference cycle.

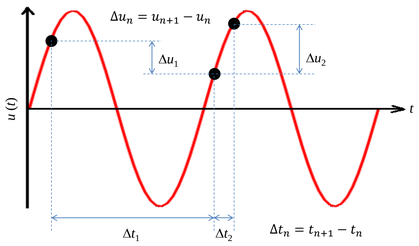

Fig. 2: Basic principle of PSA

DATA ANALYSIS

The data analysis is based on one particular electrical treeing sample that was aged for 9 hours at 9kV. The tree touched the ground plate after 3.5 hours and was still growing after 9 hours of ageing. In order to identify the prognostic indicators, the recorded phase-resolved PD (PRPD) data is transformed into the PSA plot, e.g, u_n vs u_{n-1}, Δu_n vs Δu_{n-1} and $\Delta u_n/\Delta t_n$ vs $\Delta u_{n-1}/\Delta t_{n-1}$. In this paper, only the u_n vs u_{n-1} plot is discussed in detail. Figures below show a comparison of the data plots at 1.5 hours and 6 hours of tree growth.

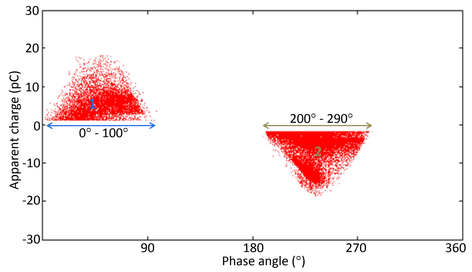

Fig. 3a: PRPD plot after 1.5 hours

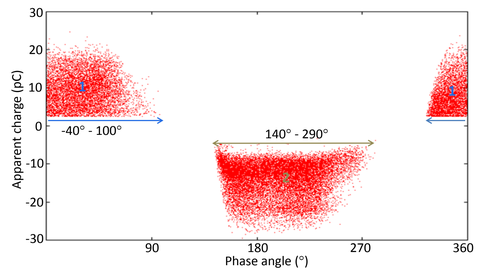

Fig. 3b: PRPD plot after 6 hours

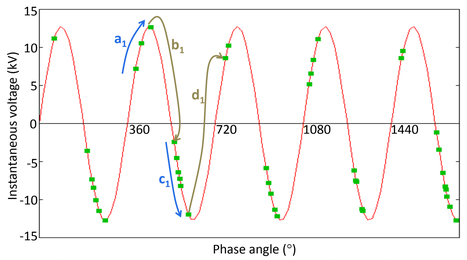

Fig. 4a: Instantaneous voltage plot after 1.5 hours

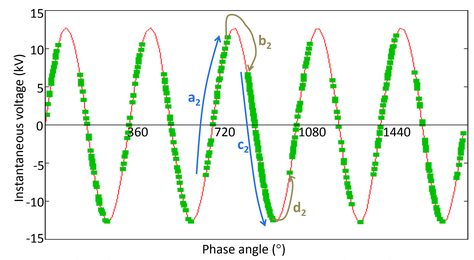

Fig. 4b: Instantaneous voltage plot after 6 hours

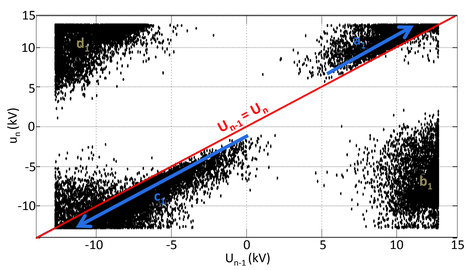

Fig. 5a: PSA plot after 1.5 hours

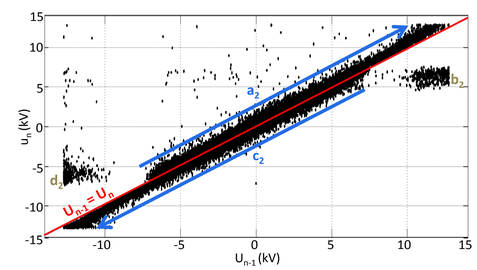

Fig. 5b: PSA plot after 6 hours

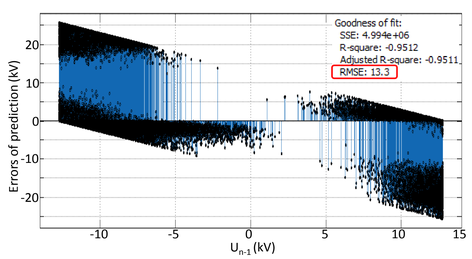

Fig. 6a: Errors of prediction after 1.5 hours

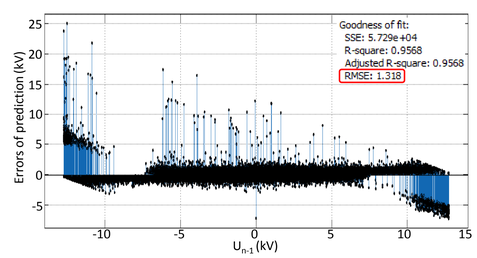

Fig. 6a: : Errors of prediction after 6 hours

PRPD Plot

- In this plot, the most significant change is the expansion of phase distribution throughout the treeing process.
- There are 2 dominant clusters from the plots.
- The 1st cluster expands from 1st quadrant only in Fig. 3a to 1st quadrant and half of 4th quadrant in Fig. 3b.
- As for cluster 2, the pulses expand from 3rd quadrant to the half of 2nd quadrant.
- The phase distribution can also be clearly seen in Fig. 4.

Instantaneous Voltage Plot

- This plot indicates the HV voltage at the point of occurrence of every PD pulse in the first 5 cycles of Fig. 3.
- It can be seen that PD occurs more frequently after 6 hours.
- Pairs of PD pulses in Fig. 4a can be grouped into 4 clusters depending on the phase quadrant.
- All PD pulses in the 1st quadrant forms cluster a_1.
- The last pulse of the 1st quadrant and the first pulse of 3rd quadrant forms the cluster b_1.
- All PD pulses in 3rd quadrant form cluster c_1.
- The last pulse of the 3rd quadrant and the first pulse of the 1st quadrant form cluster d_1.

PSA Plot (u_n vs u_{n-1})

- This is the plot of instantaneous voltage of consecutive pulses (u_{n-1}, u_n).
- For this plot, only number of cycle and phase angle are taken into account.
- Every consecutive pulse in the clusters of Fig. 4 is plotted, and the same clusters emerge in Fig. 5.
- When breakdown occurs, it is expected to have PD pulses all over the phase range, resulting in very small voltage change, i.e, $u_{n-1} \approx u_{n-1}$.
- Thus, the u_n vs u_{n-1} plot for breakdown will form a 45° line as shown in red.
- Throughout the growth, we can see that the four clusters in Fig. 5a merge to form the diagonal line in Fig. 5b.

Errors of Prediction

- Knowing the PD clusters in Fig. 5 will form a diagonal line towards breakdown, the root mean squared error (RMSE) between the actual voltage and the 45° line is calculated.
- The RMSE is expected to decrease throughout the tree growth as shown in Fig. 6, making it an indicator of ageing.
- RMSE will be used for prognostic modelling in further work, allowing the prediction of insulation remaining useful life.

CONCLUSION & FUTURE WORK

1. There is evidence of breakdown indicators in PSA for electrical treeing faults, namely the appearance of heavily clustered data points that lie diagonally in the scatter plots of
   (i) u_n vs u_{n-1} [2]
   (ii) $\frac{\Delta u_n}{\Delta t_n}$ vs $\frac{\Delta u_{n-1}}{\Delta t_{n-1}}$ [2, 3]
2. In this paper, a potential prognostic indicator has been identified that is based on the u_n vs u_{n-1} plot.
3. The other two PSA plots, i.e, Δu_n vs Δu_{n-1} and $\frac{\Delta u_n}{\Delta t_n}$ vs $\frac{\Delta u_{n-1}}{\Delta t_{n-1}}$ also show a clear pattern of electrical tree growth.
4. From the u_n vs u_{n-1} plot, the RMSE between data points and the diagonal can be used for prognostic modelling.
5. The next step is to investigate how the RMSE values change with the tree growth.
6. A number of tree samples will be used to investigate the consistency of the result.

REFERENCES

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2. K. Lai, A. Lohrasby, B. Phung, and T. Blackburn, "Partial discharge characteristics of electrical trees prior to breakdown," *International Symposium on Electrical Insulating Materials, 2008 (ISEIM 2008)*, pp. 649–652, 2008.
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