A NEW INTEGRATED DIAGNOSTIC PARTIAL DISCHARGE MONITORING STRATEGY FOR HV PLANT ITEMS: COMBINING UHF COUPLERS AND THE IEC60270 STANDARD

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SUMMARY

This paper presents the initial project developments of a new integrated approach to partial discharge (PD) monitoring of HV plant through the combined simultaneous application of UHF and IEC60270 technology. The benefits and limitations of both techniques are briefly described, and consideration of the power and capabilities of combining both techniques into a new investigative tool for PD research and PD monitoring is presented. Initial results of the combined approach show that it may be possible to discriminate different sources of PD through characterisation plots of the IEC60270 apparent charge and the UHF energy. Future plans, developments and assessments of the combined research tool and monitoring strategy are also discussed.

1. INTRODUCTION

Condition monitoring of insulation systems within items of high voltage (HV) plant is important for power utilities on a number of different levels. Firstly, to evaluate the integrity of the insulation within plant item itself; secondly to anticipate and identify the nature and severity of potential insulation breakdown problems and thus the effective life-time of the plant item, and thirdly, to allow the maintenance, shut-down and replacement of ageing plant to be managed in a controlled and cost effective manner with little effect on the consumer and minimal expense to the power utility.

One of the main indicators of insulation breakdown in HV plant is the presence of partial discharge (PD) activity. PDs are small "sparks" or movements of electrical charge which arise within an insulation material under HV stress when an irregularity exists in the material or when the material exhibits signs of deterioration. When a larger magnitude of PD occurs, a more severe insulation defect is said to exist. A number of techniques are presently applied in an attempt to monitor the level, regularity and sometimes the location of PD activity occurring in plant. These techniques comprise numerous electrical measurement methods, acoustic sensor measurements, dissolved gas analysis measurements and radiated/airborne radio frequency (RF) measurements.

Unfortunately, one of the main problems in PD monitoring is that no one technique can be universally acknowledged as being the “best”. To this end the search for new and improved PD monitoring methods is to be welcomed.

Each of the present monitoring methods measures different aspects of the same PD event. For example, electrical measurements attempt to measure the electrical charge or current flow arising from PD events; acoustic measurements monitor the acoustic shock waves generated by PDs; dissolved gas analysis techniques monitor the presence of particular chemical constituents within insulation oil which arise as a consequence of PD, whilst radiated RF techniques monitor the electromagnetic radiation arising from PD events. Clearly each technique covers a unique aspect of the physical processes associated with the measurement of PD. However, there are limitations of each technique. For example, electrical measurement methods often respond to the "apparent" charge or current pulse generated by a PD, which in itself does not provide detailed insight into the physical processes occurring at the PD source. A major problem with acoustic methods, dissolved gas analysis and electromagnetic radiation measurements is that detailed information of the actual charge involved on the PD event is not directly known.

This paper describes a new strategy for combining the IEC60270 standard and UHF couplers to monitor PD. This is not only an attempt to provide a more powerful tool for understanding the nature of PD mechanisms but is also a strategy to evaluate their combined effectiveness in producing a new and innovative PD monitoring tool for HV plant.

The structure of this paper is as follows. Section 2 describes the principles of UHF diagnostics and the IEC60270 standard. Their inherent limitations and the potential benefits of combining them to provide an improved PD monitoring tool are also discussed. Section 3 provides some preliminary experimental results using the combined techniques, showing that it may be possible to discriminate different PD events based on IEC60270/UHF characteristic plots. Section 4 summarises the initial results from this paper and outlines future work and developments for the combined monitoring strategy.

2. UHF METHOD AND THE IEC60270 STANDARD

UHF monitoring has been successfully pioneered and employed for PD diagnostics by the University of Strathclyde for a number of years and the range of applications has included power transformers and GIS systems [1,2]. UHF couplers do not require connection to HV conductors and they can detect the high frequency radiated signals from PD events well into the GHz region. A further advantage is that employing a number of UHF couplers allows location of PDs to be established using differential time-of-flight calculations. This latter application is
being pioneered for transformer monitoring by the University of Strathclyde [3]. Received UHF signals are normally integrated to produce a measure of the signal energy. PD activity can be monitored based on the signal energy and frequency composition of the radiated signals. Different PD types can also be distinguished in the normal fashion using techniques such as pulse amplitude-phase angle pattern analysis.

The most common electrical PD technique is known as the IEC60270 standard, which prescribes the methods used to measure the apparent charge associated with a PD event from a suitable measuring point on a plant item or sample under test [4]. The peak output signal from an IEC60270 detector system (once properly calibrated) is a measure of the apparent charge. IEC60270 measurement methods (and their predecessors) and diagnostic techniques have been successfully employed by Glasgow Caledonian University for more than 15 years. The present Caledonian system employs optical fibre isolation and has been implemented on a variety of power plant items including power transformers [5]. The Caledonian IEC60270 instruments provide a measure of the apparent charge of the PD and also a power phase reference to allow further data analysis and $\Phi-\psi-n$ plots to be generated for interpretation of PD patterns.

Individually, both the UHF and IEC60270 methods have had success in identifying insulation defects. However, as evidenced by many situations, both techniques have limitations. For example, the IEC60270 technique gives only an indication of the PD charge magnitude and the potential nature of the fault based on discharge levels and time/phased resolved discharge patterns. It does not provide any direct information on location or the precise physical processes taking place within the discharge event itself, only the cumulative nature of the apparent charge involved in the discharge. In order to understand physical processes, other techniques require to be introduced such as time/phased resolved pattern interpretations. The UHF technique suffers from the problem of being unable to quantify the magnitude level of discharge activity accurately from the measured signals, as the precise relationship between radiated signal strength and apparent or true charge variations is not known. As such, there is no accurate calibration or reference for PD levels to relate UHF signals from different PD source geometries. These issues are further complicated by UHF propagation effects involving complex reflective and absorptive processes.

An understanding of the scientific basis for combining the techniques is as follows. The UHF energy released from different geometrical sources of PD may be different, even when the actual charge movement or apparent charge involved in the discharges is the same. This is to be expected because the radiated signal energy is related not only to the quantity of charge but also to its rate of movement and the geometrical path taken by the charges as they move in the PD process. For a given PD source, we would expect the UHF energy to change as the apparent charge changes and to this end our study will investigate and quantify these changes for different PD sources. Integrating and evaluating the simultaneous application of both techniques should result in a monitoring tool which is superior and more informative in terms of PD processes than simply using one technique on its own. Combining the techniques therefore has the potential to yield two significant benefits. Firstly, the UHF energy and the apparent charge can be investigated for different PD source geometries so that identification and calibration can be made in relation to the nature of radiated signals. Secondly, the nature and variations of the UHF radiated signals and diagnosis methods can be quantified and investigated against apparent charge variations and accepted IEC60270 diagnosis methods in order to better understand the physical processes of insulation breakdown mechanisms. In this way, it should become possible to correlate apparent charge and UHF energy, allowing correlations of PD activity between both methods to be compared, analysed and interpreted in a new way and thus make an attempt to discriminate between different PD source structures, geometries and severity of discharge activity. As a result, diagnosis of defective insulation conditions should become more effective.

The next section details some initial results from preliminary experimental work on simultaneously monitoring both the UHF signal energy and the IEC60270 apparent charge.

3. INITIAL RESULTS

The first set of experiments for the combined UHF and IEC60270 measurements were taken for single voids in resin. The power cycle voltage, the IEC60270 discharge level in pC and the energy of UHF signals were simultaneously measured for each discharge event using a LeCroy WavePro7300 digital oscilloscope sampling at 2.5 Gsamples per second.

A number of void samples were tested. A simple schematic of a disk (cylinder) void is shown in Figure 1. Examples of typical plots of the IEC60270 apparent charge against UHF energy were obtained for this arrangement.

Data from the positive half-cycle discharge pulses is presented in Figure 2 and from the negative half-cycle discharge pulses in Figure 3. All of the graphs in this paper are based on the signals that have been denoised by using wavelet methods. The applied voltage during these tests was 10 kV. These figures display what may be called characteristic plots or correlation plots/curves. Both figures show a general trend of increasing UHF energy with increasing apparent charge. However, note that these characteristic plots do not exhibit a simple linear relationship.
All single voids measured in these initial experiments showed similar forms of characterisation curves at higher voltages. At lower electrical stress levels the points were congregated at levels further down characteristic curves. Though the nature of the changes in the curves for different field stress levels and different void sizes has not yet been established, the general trend in the initial experiments indicates that single curve characterisation plots seem to exist for individual voids under different electrical stresses.

A second set of experiments was performed on a separate small void encased in resin, but which had undergone an external flashover event causing surface damage to its outer plastic housing. Simultaneous measurements of IEC60270 and UHF energy for individual positive and negative half-cycle discharge pulses were made under applied voltages of 15 kV and 20 kV. Correlation plots for positive and negative discharges are shown for 15 kV in Figures 4 and 5 respectively and for 20 kV in Figures 6 and 7.

A number of interesting features can be seen from these graphs. Firstly, in Figures 4 and 5, two different PD correlations appear to be present and these are repeated for both positive and negative half-cycle PD pulses. One characterisation curve is similar to that expected from a void.

The other appears to be a localised cluster of PD pulses that have a higher UHF energy for a given apparent charge. At 20 kV Figures 6 and 7 show that the upper cluster of higher energy points appears to now merge with the lower part of the lower discharge curve, to form two “distinctive” characteristic curves which follow different trajectories on the plot.
Though further analysis is needed to confirm and quantify the nature of these characterisation plots, the initial hypothesis is that these graphs display two separate sources of simultaneous PD activity indicating two different geometrical faults. It is also believed that the reason for the different curves or clusters is related to the different physical mechanisms which produce the UHF energy. The lower characteristic curve may possibly be identified with a well defined void in the sample, as a void type characteristic curve seems to exist. The other characteristic cluster appearing at lower stress levels, and forming a separate characteristic curve at higher stress levels may be a second source of PD activity from either another “void” type source or a possible weakened surface fracture which has occurred as a consequence of the flashover damage. However, the major result is that the characterisation plots from the combined approach have potentially shown evidence of the existence of more than one PD source without using phase angled resolved plot techniques. Where two or more PD sources are present in different regions of the correlation plot, the data could be separated prior to applying phase-resolved analysis, thereby simplifying the subsequent interpretation task.

4. CONCLUSIONS AND FUTURE WORK

This paper has described initial PD experiments undertaken on a project which combines UHF coupler and IEC60270 measurement methods. A number of conclusions can be drawn from this preliminary work. Firstly, it is possible to combine UHF coupler techniques and the IEC60270 standard technique to produce characteristic plots of apparent charge against UHF energy. For a simple void geometry, these plots produced distinctive characteristic correlation curves. When a sample comprising a void that had undergone flashover was measured, the characteristic plots showed two distinctive patterns and correlation curves, the forms of which were dependent on the electrical stress. One of the curves appeared to be consistent with PD associated with the void while the other appeared to indicate a distinctly separate PD source caused either by another void or a different discharge mechanism within the PD test cell. Though this work represents a preliminary study, it is important to indicate that the combined application of both techniques shows potential for PD measurement and insulation diagnostics. To this end, future work will include:

- Investigating the combined techniques using a range of controlled PD source defects including corona geometries, point-plane arrangements (in air, oil and SF₆), free particles, voids, etc.
- Evaluating, quantifying and interpreting IEC60270 and UHF energy characteristic plots as a function of controlled single and multiple PD sources.
- Comparing and contrasting of the information gained from the apparent charge and UHF energy characteristic plots with standard phase resolved pattern techniques to ascertain whether discrimination of different PD sources can indeed be improved using the combined approach.
- Investigation of IEC60270 vs. UHF energy characteristic plots in terms of radiated frequency energy bands to investigate whether PD source discrimination can be determined using frequency selective methods.
- Application to on-line plant items.

5. ACKNOWLEDGEMENTS

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6. REFERENCES


