A COMPARISON OF AC AND DC PARTIAL DISCHARGE ACTIVITY IN POLYMERIC CABLE INSULATION*

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Abstract

The majority of PD monitoring is performed on cables operating under AC conditions, however, the increasing use of high voltage DC links, for subsea, or long land-based connections provides motivation for the increased use of PD monitoring on cables operating under HVDC. However, despite the increased intensity of research into PD in HVDC cables, there are significant knowledge gaps, preventing the practical application of PD monitoring techniques to HVDC cables. This paper seeks to partially address these gaps in knowledge, by presenting results obtained from PD measurements on artificial voids created in polymeric cable insulation under both AC and DC conditions. This work was presented at the 21st IEEE International Pulsed Power Conference.

I. INTRODUCTION

PARTIAL DISCHARGE is increasingly becoming a vital part of condition monitoring of electrical assets, as the electricity supply industry moves towards condition-based maintenance regimes. The majority of these schemes, however are used on AC systems. With the ever-increasing use of DC links for subsea and long-distance land interconnectors, there is a strong desire for similar monitoring of DC assets.

Currently, however, there are several barriers to the satisfying implementation of such monitoring, with the most significant being a lack of knowledge concerning DC partial discharge as compared to AC.

This paper aims to address this by comparing measurements on artificial voids in two polymers commonly used in cable insulation.

II. THEORY

A. Cable Insulation

The selection of cable insulation is a fundamental aspect of cable design. For HVDC cables there are a range of insulation options, with modern options utilising polymers. The two most common polymers used are polyethylene and polypropylene.

1) Low Density Polyethylene

Low density polyethylene (LDPE) has a long history of use in power cables, including HVDC cables. More recently, cross-linked polyethylene (XLPE) which shares the ethylene monomer with LDPE has become more popular.[1]

2) Polypropylene

Polypropylene is generally used in HVDC cable insulation in the form of polypropylene paper laminate (PPL).

B. Partial Discharge

IEC60270[2] defines partial discharge as ‘a localised electrical discharge that only partially bridges the insulation between conductors’. This is the definition used for this analysis. Partial discharges occur due to defects in cables, which can be a result of manufacturing, installation or maintenance errors.

C. DC Partial Discharge

Research undertaken at the Technical University of Delft laid much of the initial ground-work for DC PD research. This work, summarised in [3] found several differences between PD under AC and DC conditions, including that DC PD events had significantly lower magnitudes, and recurred far less frequently. One consequence of this, is that PD under DC conditions is not a cause of failures, but merely indicates the existence of a defect, which itself may cause a failure.

III. METHOD

The method used for the creation and testing of the samples was informed by the method used in [4] and has been successfully utilised for testing of LDPE only in [5].

A. Test Rig

The experimental test-rig consisted of two brass electrodes of 7.5mm radius. The bottom electrode is connected to earth and is fixed. The top electrode is connected to the HV source, and can be adjusted up or down with precision.

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B. Test Samples

The test samples were created by layering samples of LDPE and PP measuring 15mm x 15mm. Seven layers were used, giving a total thickness of 0.35 mm. A circular section of diameter 1 mm is removed from the central layer. The layers are then placed between the electrodes and the electrodes adjusted until the gap is the same as the size of the sample (0.35 mm).

C. Experimental Method

1) AC

A IEC 60270 standard-complaint PD measurement system with a bandwidth of 100-400 kHz was used to perform AC testing.

A voltage is applied, starting at the minimum allowed by the equipment, 2.9 kV, this is steadily increased in steps of 100 V every ten minutes until PD inception (defined as at least one PD event per minute) occurs. Once the PD inception is found the voltage is increased to 10 % higher than this, and held for two hours. PD is measured for the entirety of this two-hour test period.

2) DC

The same measurement system was used to perform DC testing, with a high frequency current transformer (bandwidth 100 kHz to 20 MHz) used as the PD sensor.

IV. RESULTS

A. AC Results

The aim of the AC testing was to determine, with reference to the available literature, if the artificial void creation and testing method described above produced the expected results.

1) Low Density Polyethylene

The partial discharge inception voltage under AC for the LDPE was found to be 3.2 kV, therefore the test was performed at 3.5 kV.

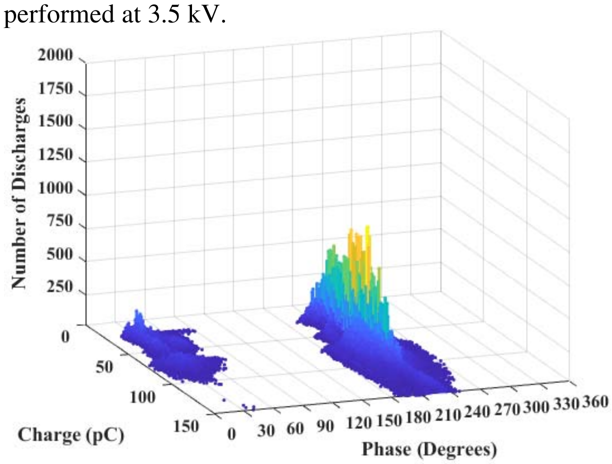

Figure 1. PRPD Plot for first 2-hour test period on LDPE at 3.5 kV.

The phase-resolved partial discharge (PRPD) plot (Figure 1) for the first two-hour test period for the LDPE sample shows two clusters of discharge events around the 30° and the 210° phases. This pattern, often called the 'rabbit ear' pattern, is indicative of void discharge [6]–[10].

The PRPD plot for the second two-hour test period (Figure 2) also displays the 'rabbit-ear' pattern, although overall the average magnitude of the PD events has decreased. This is consistent with void type discharges in LDPE [6]–[10].

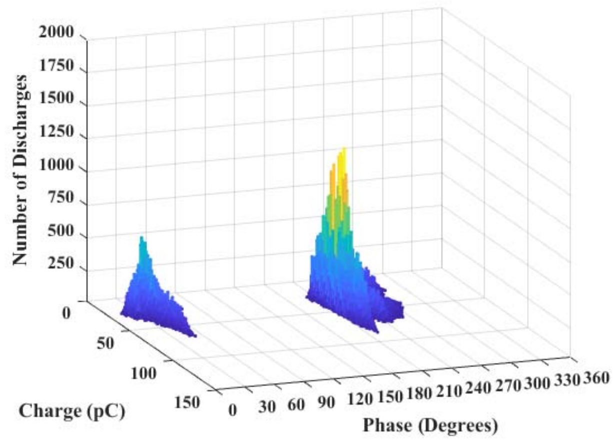

Figure 2. PRPD Plot for second 2-hour test period on LDPE at 3.5 kV.

2) Polypropylene

The inception voltage under AC for the polypropylene samples was also found to be 3.2 kV, so as previously the test voltage was 3.5 kV.

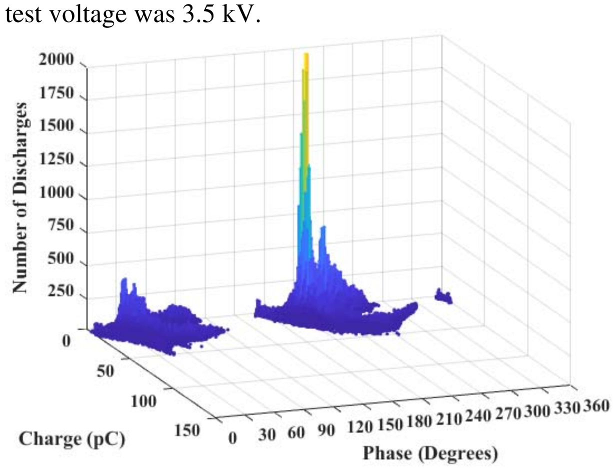

Figure 3. PRPD Plot for first 2-hour test period on PP at 3.5 kV.

The PRPD plot for the first two-hour test period (Figure 3) again shows the 'rabbit-ear' pattern clustered around the 30° and the 210° phases. This again confirms the dominant form of PD detected is a void discharge.

Figure 4, the PRPD plot for the second two-hour test period for the polypropylene, once again displays the 'rabbit-ear' pattern, confirming the void discharge remains dominant for the duration of the test.

The AC results for each of the polymers for the entire test period are consistent with what would be expected from a void-type discharge.

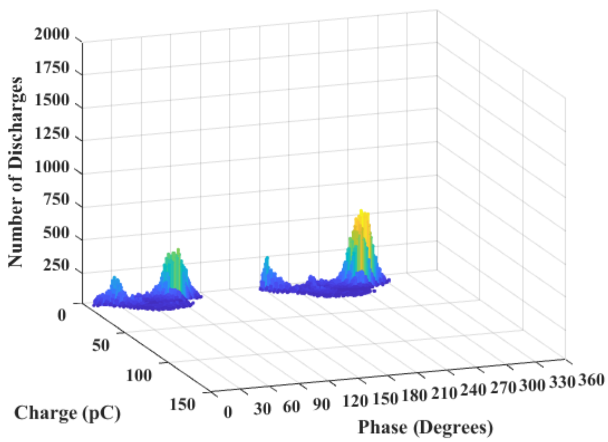

Figure 4. PRPD Plot for second 2-hour test period on PP at 3.5 kV.

B. DC Results

The focus of the DC testing was to determine any differences between the presentation of DC PD in different polymer types.

1) Low Density Polyethylene

The inception voltage for the PD in the LDPE was found as 8.2 kV, so the test voltage was 9.1 kV.

The charge histogram for the LDPE for the first two-hour test period (Figure 5) shows a greater number of PD events occur at lower charge magnitudes.

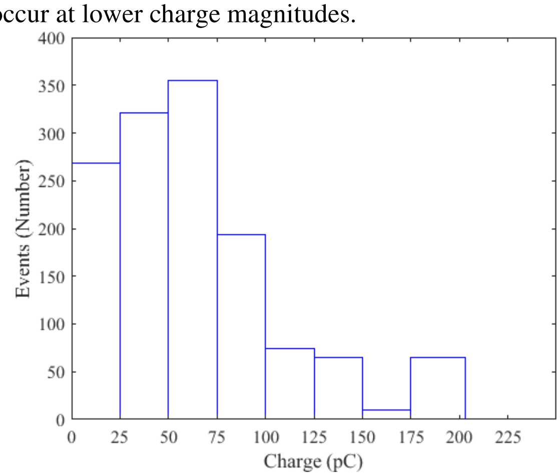

Figure 5. Charge histogram for first 2-hour test period on LDPE at 9.1 kV.

Comparing this to the charge histogram for the second two-hour test period on the LDPE (Figure 6), the high magnitude events have significantly decreased, with a smaller decrease seen in the lower magnitude events. This is similar to the behaviour found in the AC testing, although the number of events in total is much lower under DC conditions.

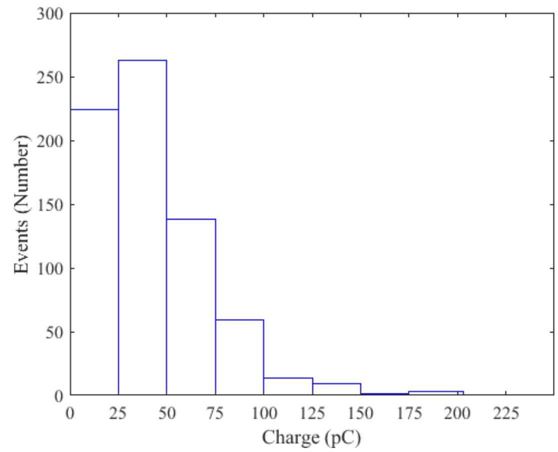

Figure 6. Charge histogram for second 2-hour test period on LDPE at 9.1 kV.

2) Polypropylene

The threshold for the PD inception voltage (one PD event per minute) was not reached in the polypropylene at 18 kV (Figure 7) over a one-hour testing period.

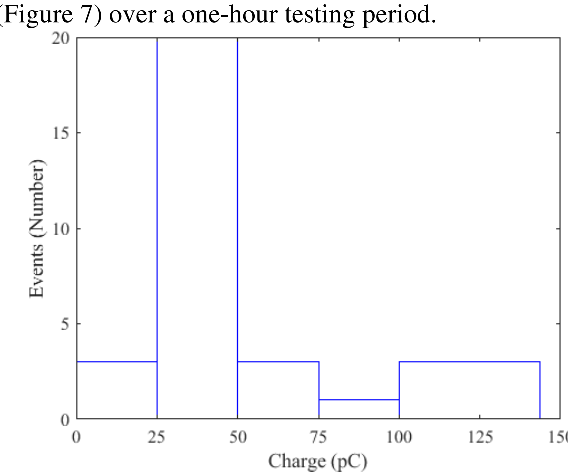

Figure 7. Charge histogram for 1-hour test period on PP at 18 kV.

Figure 8 shows the charge histogram for a one-hour test period of the polypropylene at a test voltage of 24 kV. As before the PD inception threshold of one PD event per minute was not reached.

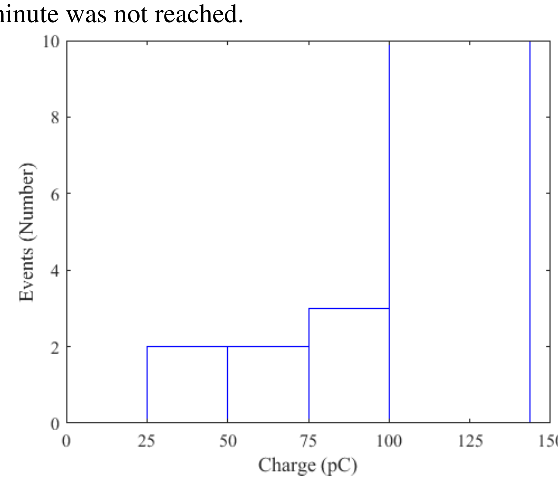

Figure 8. Charge histogram for 1-hour test period on PP at 24 kV.

A test voltage of 33 kV was then applied for one hour, with the charge histogram (Figure 9) showning that as with previous tests the PD inception voltage threshhold was not reached.

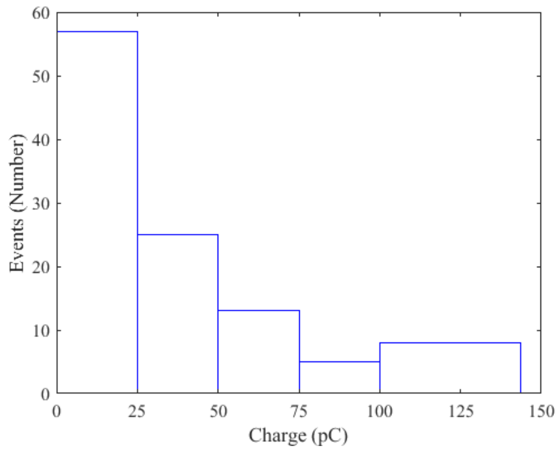

Figure 9. Charge histogram for 1-hour test period on PP at 33 kV.

The final attempt to reach the PD inception voltage threshold also met with limited success, although PD events were recorded at greater than one per minute at 35 kV as can be seen the charge histogram (Figure 10) the sample experienced breakdown 5 minutes into the planned two-hour test.

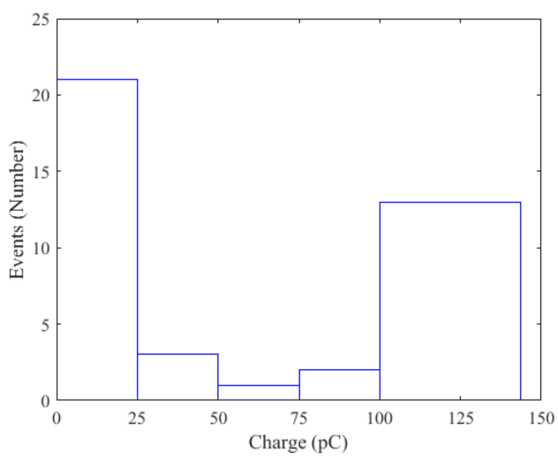

Figure 10. Charge histogram for 5-minute test period on PP at 35 kV.

Overall the DC test produced interesting results which warrant further study. Specifically, the lack of PD found in the polypropylene as compared to the polyethylene.

V. CONCLUSIONS

This paper provided analysis presented at the 21st IEEE International Pulsed Power Conference.

The validity of the artificial void creation and testing method was demonstrated through AC testing, and knowledge was generated regarding DC partial discharge from the DC testing.

The results presented suggest that polyethylene is more conducive to the existence of partial discharges and that polypropylene is more resistant. This behaviour was not exhibited under AC conditions.

VI. FUTURE WORK

Future work for this project will focus on the creation of artificial voids in full HVDC cable samples. The frequency characteristics of PD signals, and therefore their attenuation over longer distance cables will also be a focus.

VII. REFERENCES

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