Frequency dependence of partial discharge initiation voltages with embedded electrodes

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Abstract: Partial discharge initiation voltages of a dielectric insulation material exposed to ac voltages show little dependence on frequency in the power frequency range. This results after significant voltage conditioning at the measured frequencies with samples configured for embedded electrodes. Comparison to previously published results is made.

Introduction

Historically, an important purpose of partial discharge measurements in apparatus has been to promote life extension by identifying key trends in changes in partial discharge activity. The purpose of this work is to extend the success of those efforts to initial testing of new insulation systems for novel machines. This paper presents the trend in partial discharge initiation voltage (PDIV or "onset voltage") with frequency, where epoxy samples have been subjected to stages of voltage conditioning.

Ideally, long-life machines operate in an over-voltage protected environment without the occurrence of partial discharge. This reduces parasitic power losses and dielectric aging. The extent to which the PDIV for various dielectric materials can be improved is important engineering data. Voltage conditioning was previously reported for this type of sample [1]. The exposure of the sample to ac voltage with essentially negligible current at levels near the PDIV was related to an increase in the PDIV.

We chose flat electrodes presenting a reasonable area of electrode to epoxy interface. Electrodes were embedded to reduce effects of humidity, other complications of surface discharges, and complications due to air gaps. The interfacial discharges in such configurations are expected to be representative of some embedded machine coils and magnet wire where multiple turns are encased or potted.

In this study, PD inception and extinction levels are given as rms voltages at the applied ac voltage frequency. Charge populations were counted for 120 seconds. The average energy of a PD event is calculated as defined in [2]. The PD inception and extinction levels, however, are noted as the rms voltage at which PD is first observable within 120 seconds on voltage rise and at the rms voltage at which PD is no longer observed on voltage decrease, respectively. Some researchers prefer to define these characteristics in terms of the presence of one PD event per cycle.

Experimental Conditions

Partial Discharge Instrumentation

The digital detection system used in this work has been previously described [3]. The system has been shown to be extremely sensitive. Partial discharge events are timed using a zero-crossing detector. This is combined with a summing amplifier and digitizer. Pulses with amplitudes lower than 10 pC were not recorded. To produce the applied voltage, a sinusoidal signal from an SRS345 waveform digitizer is fed into a two-to-one Calex noninverting linear amplifier in line with a Trek 30/20 amplifier. The system is currently limited to $\leq$30 kV peak-to-peak voltages or 21.2 kV rms. At frequencies higher than 500 Hz bandwidth limitations due to the system capacitance further limit the maximum voltage available. PDIV in samples having electrode gaps of less than 2.6 mm was observed. However, upon voltage conditioning the PDIV level was higher than this system could achieve at 50 Hz.

Sample Design

Samples are a simple parallel plate capacitor consisting of two brass electrodes potted in epoxy within a PVC ring of 3.9 cm inner diameter and 3.5 cm in height. The epoxy is an unfilled, two-part potting system meeting class H operating requirements [4]. The hardener is an anhydride amine blend. Samples were soaked, gelled, and then cured at 125ºC for four hours following the manufacturer's recommendations. No post-cure heat-treatment was carried out.

Both electrodes are 0.635 cm diameter flat discs mounted on central threaded posts of 0.32 cm diameter. All electrode discs were given a smooth surface finish using a final polish of suspended colloidal (<1 micron) alumina on a felt lap. The electrode posts extend linearly outside of the PVC ring at mid-height. The edge of the disc was rounded, although not by a Rogowski radius, so for these samples the field is only approximately uniform from electrode center to electrode edge.

Results

Key trends in partial discharge behavior and conditioning were observed in spite of amplifier limitations.

Charge per PD Event

A charge distribution for a multitude of PD events at a fixed rms voltage (above the PDIV) is shown in Figure 1. The mean effective charge calculated from the voltage change generated by single PD events remained constant for a given gap spacing, regardless of applied voltage or the extent of voltage conditioning.

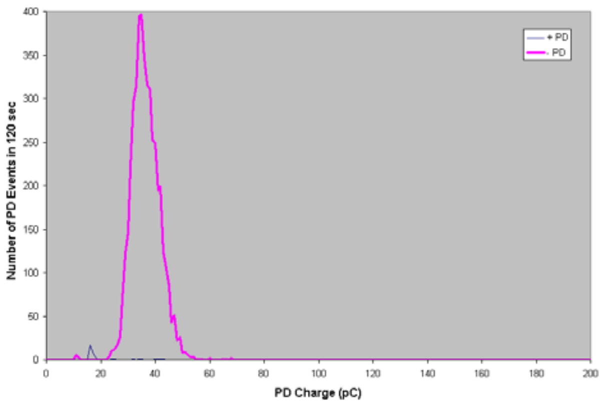

Figure 1. An example of the PD Charge Distribution at a given voltage above PDIV.

PD Power Loss with Increasing Voltage

Charge distributions were collected when a sample was exposed to voltages in excess of PDIV at 50 Hz, 500 Hz, and 1000 Hz. Prior to this time, the sample had been examined for PDIV at 50 Hz and 500 Hz. The results of these measurements are given in Figure 2, depicted as power dissipation at a given applied voltage. As anticipated, there is a dramatic increase in the number of PD events as voltage increases that drives the power loss.

Frequency Dependence Prior to Conditioning

The PDIV (V onset - no conditioning) and PD extinction voltage (V extinc - no conditioning) are given in Figure 3 for a sample that had not been previously exposed to high voltage. The measurement sequence commenced from 50 Hz, 200Hz, 500 Hz, to 1000 Hz. Measurements were then made at 500 Hz, 200 Hz, and 50 Hz to determine reproducibility. It can be observed that, at these latter three measurement frequencies, the PDIV and PD extinction voltage had both increased significantly. There is a measured decrease of ~10% between the PDIV at 50 Hz and the PDIV at 500Hz.

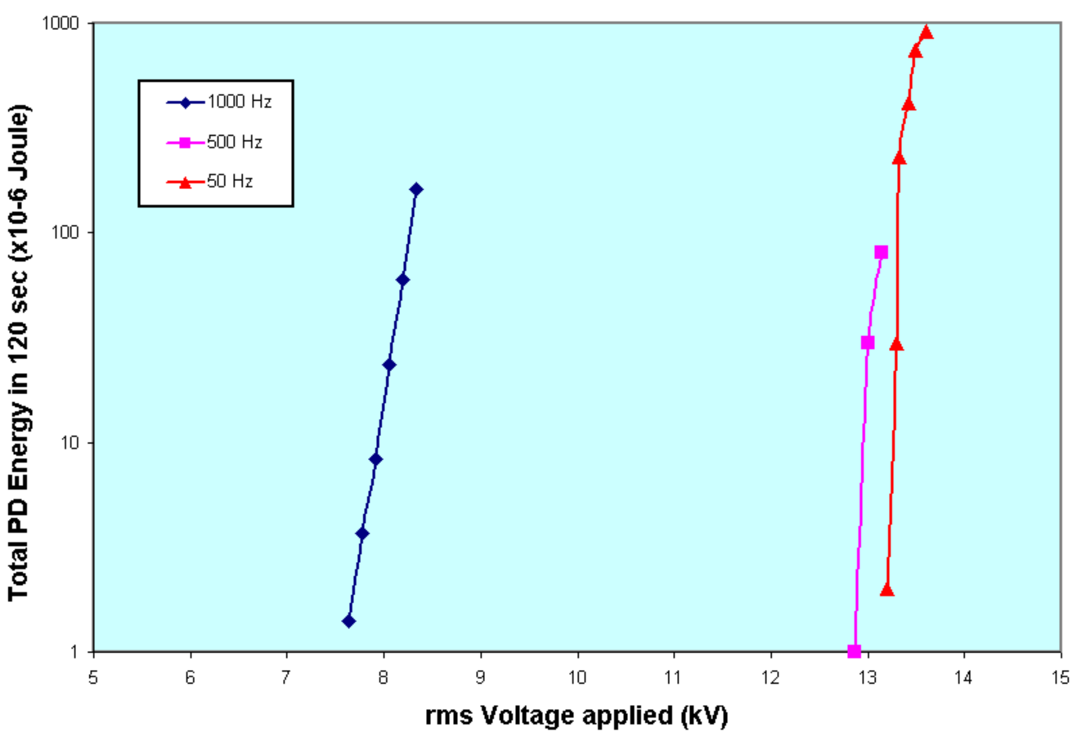

Figure 2. PD Power Dissipation on a sample with some voltage conditioning.

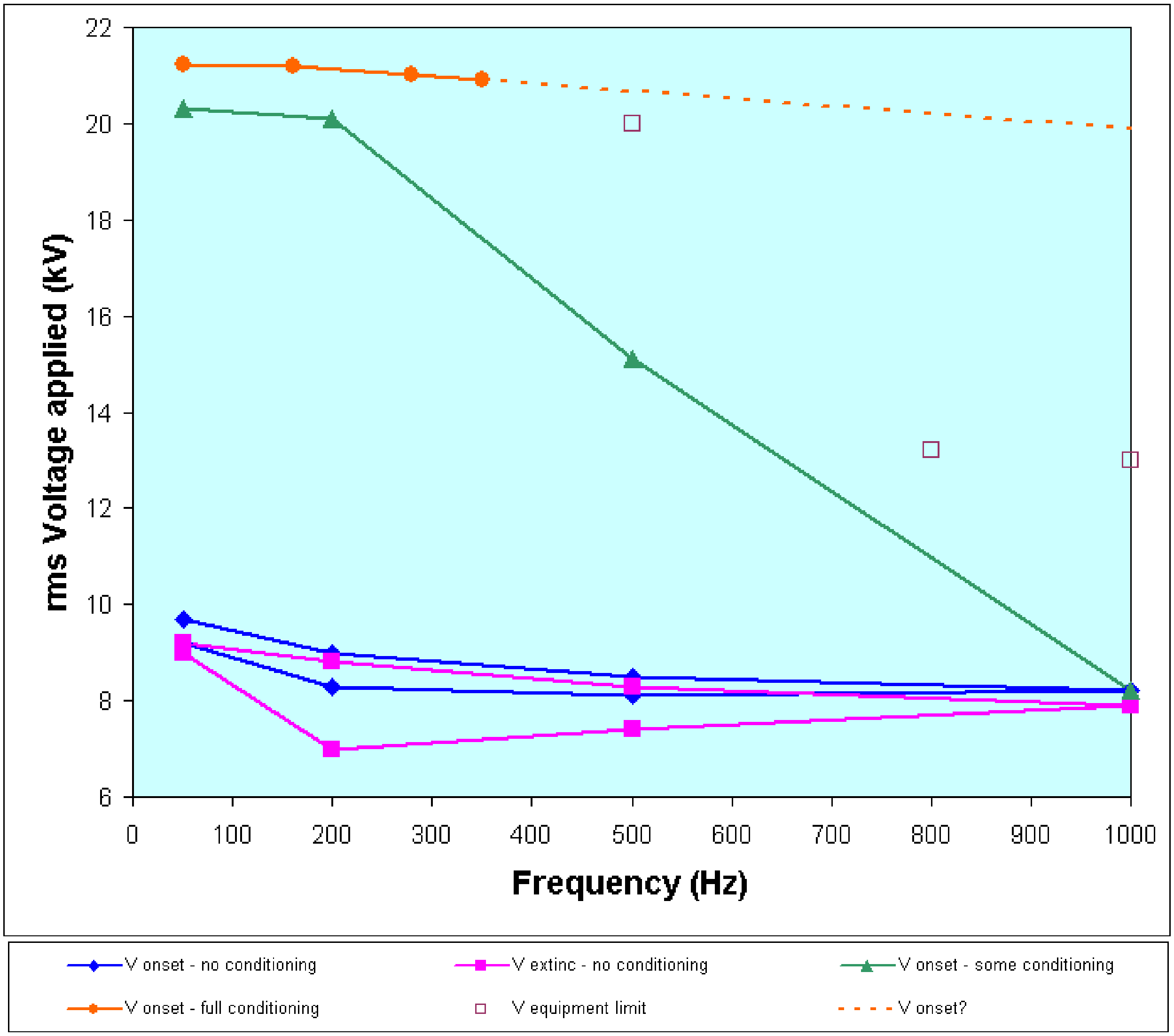

Figure 3. Partial Discharge Initiation Voltages with frequency and conditioning for samples with a 2.6 mm gap.

Frequency Dependence of PDIV with Conditioning

PDIV as a function of frequency is given for a fully conditioned sample in Figure 3. Fully conditioned PDIV at frequencies of 500 Hz and higher could not be determined for a gap size of 2.6 mm due to amplifier voltage limits. The PDIV levels were above these limits, shown in Figure 3 as unfilled squares.

The extrapolated (dashed) line gives a PDIV change of ~3% from 50 Hz to 500 Hz. Fully conditioned samples exhibited identical PDIV levels for consecutive tests. Another indication of full conditioning is a dramatic increase in the number of events over a small voltage increment (i.e., the slope of the power loss to voltage relationships shown in Figure 2 increased). Also shown in Figure 3 are the PDIV levels for a sample that had received some voltage conditioning. It appears that voltage conditioning of this dielectric is frequency specific.

Discussion

The frequency dependence of PDIV at power frequencies for conditioned samples is small. This is in agreement with the results of Mason [5], for breakdown strength, who showed no dependence on frequency until the MHz range was reached. The slight decrease in

PDIV with frequency observed in this study may be connected with low levels of dielectric heating.

While examining the frequency dependence of PDIV levels, an opportunity to increase the initial ac PDIV value by over 100% has been demonstrated by voltage conditioning. The frequency dependence of PDIV levels of the sample prior to voltage conditioning is much greater. The trend observed in this study is identical to that reported by Krachen and Laghari [6], who observed a >10% decrease in PDIV between 60 Hz and 400 Hz. It is our opinion that the trend of voltage conditioned samples is more representative of long-term dielectric behavior.

The PD behavior with ac frequency is significantly different when voids are present, as described by Bodega et al. [7] They found that frequency in the power regime does influence the PD activity when "air filled cavities" are present in the dielectric; and particularly that the PD event magnitude decreases at frequencies above 50 Hz. Unfortunately, no PDIV levels were given. They state that without such cavities no frequency dependence is predicted.

We found partial discharge behavior of this voltage conditioned epoxy with embedded electrodes to be reproducible. Voltage conditioning should be considered during other types of partial discharge testing. It would also be interesting to examine voltage endurance behavior for samples that had previously been voltage conditioned. We plan to pursue an understanding of the mechanism of voltage conditioning to guide the engineering of solid dielectrics in avoidance of early-use partial discharge aging in machine applications.

References

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