Simulation of PD Phenomenon in Epoxy-resin Insulation at Very Low and High Stressing Frequency

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***Abstract*— In this paper, the phenomenon of partial discharge (PD) within an air-filled void in epoxy-resin insulation test sample was investigated under the influence of very low frequency (VLF), 0.1 Hz, as well as power frequency (PF), 50 Hz, of the applied AC voltage stress. A 3D model of the test sample was developed in COMSOL Multiphysics and simulated alongside MATLAB. The model was found to produce electric field magnitudes adequate enough to initiate PD within the void. The distribution of field in the test sample after PD event indicates a much a significant drop in cavity field as compared to the bulk sample. It is seen from the PD results that the voltage frequency influences the phase-resolved PD distribution in the sample, with more PD repetition rate recorded under 50 Hz, PF as compared to the 0.1, VLF case.**

***Keywords*— Cavity, COMSOL, Epoxy-Resin, Frequency, PD**

I. Introduction

Insulation quality is critical to reliable and efficient operation of high voltage (HV) equipment. Solid dielectric materials are used to provide insulation in a variety of HV equipment such as power transformers, cables and generators [1]. Under normal operation conditions and applied voltage, the electric field lines within a defect-free solid dielectric material are expected to be uniform. However, the presence of defects in the insulation can cause the field lines to be distorted at the site of the defect, making the area vulnerable to electrical discharges [2]. When the equipment is operated under sustained stress, partial discharge (PD) may occur. The presence of air-filled cavities within the insulation material occur mostly due to imperfections from manufacturing process or as by-product of streamer propagation [3]. PD is a localized discharge that occur within a small portion of a dielectric material without actually bridging the high voltage and low voltage electrodes [4].

Finite element analysis (FEA) models are widely used to study the distribution of electric field as well as the activity of PD in cavities that may be present in the dielectric materials due to changes factors such as; temperature, pressure, over excitation, as well as the cavity dimension [5].

In this work, the field distributions in a 3D solid dielectric model as well as the impact of stressing frequency on PD occurrence in a cavity of spherical geometry is investigated..

II. Materials and Methods

The test sample depicted in Fig. 1 is used in this work. It represents an existing model employed for field studies in [6]. The sample was excited with an 18 kV peak AC voltage. The frequency was varied, and PD activity was recorded at 0.1Hz and 50Hz. While the model dimension and material properties in this research are presented on Tables I and II respectively, the PD simulation parameters were adopted from [4].

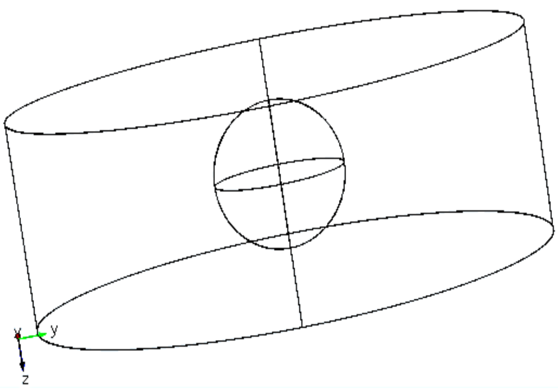

Fig. 1: 3D Geometry of the Model

TABLE I: GEOMETRICAL DIMENSION OF THEORETICAL SAMPLE MODEL [6]

Description	**Value (mm)**
Insulation thickness	3.5
Insulation radius	5
Cavity diameter	1.25
Cavity wall thickness	0.05

TABLE II: MATERIALS PROPERTIES OF THEORETICAL SAMPLE MODEL [6]

Components	**Item**	**Electrical conductivity, σ (S/m)**	**Relative permittivity, ε_r**
Electrodes	Copper	5.998×10^{7}	1
Insulation	Epoxy-resin	1×10^{-18}	4
Cavity	Air	1×10^{-100}	1

A. Field Model Equations

Several techniques have been used in literature to model the activity of PD. Among these approaches are; the three capacitance model, analytical methods as well as numerical techniques [7]. However, FEA, which is a variant of the numerical technique is used in this work. The FEA model is capable of solving the Poisson's equation defined in equation (1) for potential distribution, V, within the dielectric with permittivity, ε, and electrical conductivity, σ. The instantaneous value of the applied voltage is computed using equation (2) [4].

$$\vec{\nabla}.\left(\sigma\vec{\nabla}V-\varepsilon\vec{\nabla}\frac{\partial V}{\partial t}\right)=0 \tag{1}$$

$$V = V_P \, Sin\, 2\pi f \tag{2}$$

where V_P and f are the peak value and the frequency of the supply voltage respectively.

Although this work is centred around PD simulation, the corresponding PD model equations adopted from [8] are not considered part of this report.

III. Results and Discussion

Electric field distribution within the test sample was simulated and analysed before and after the occurrence of PD.

While the field results prior to PD has been reported [6], the distribution of electric field after PD event is shown in Fig. 2. It can be observed that the field intensity within the cavity has dropped to almost zero value. This variation in field magnitude across the model can be attributed to differences in material properties.

The phase-resolved PD distributions generated under VLF as well as PF are depicted in Figs. 3 and 4 respectively. In Fig. 3, the PD pulses exhibit a linear pattern in both the positive and negative half-cycles of the reference AC voltage. The distribution is more likely to increase and decrease respectively within the voltage cycle during transitions from one half-cycle to the other. This can be attributed to the reduced availability of seed charges and relatively large decay in surface charges immediately after every PD occurrence before the next one. The extended delay due to excitation under VLF gives rise to a handful of trapped electrons inside the cavity, thus, the little impact on the local cavity field.

In comparison with the VLF pattern, the PD phase distribution under power frequency, PF, in Fig. 4 is more scattered across both cycles of the applied voltage. It can be observed that the phase-resolved PD pattern under this condition appears to close to experimental results in literature. A possibility of such scenario could be attributed to adjustments in the PD simulation parameters.

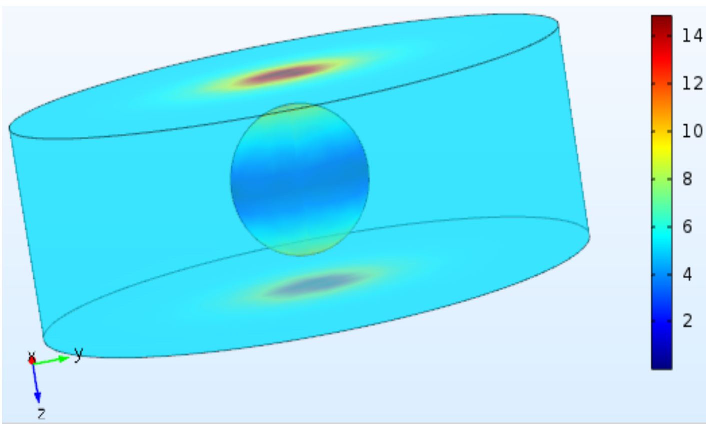

Fig. 2: Electric Field Distribution within the Test Sample after PD

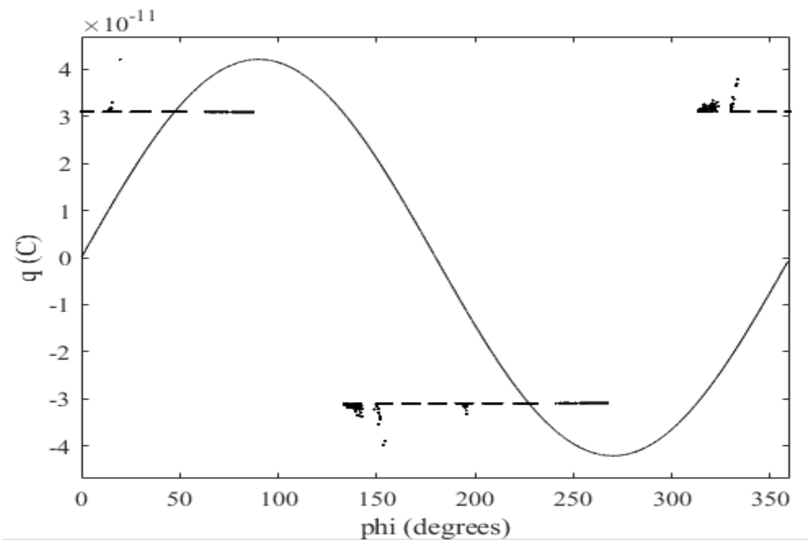

Fig. 3: PRPD pattern simulated under 0.1 Hz very low frequency

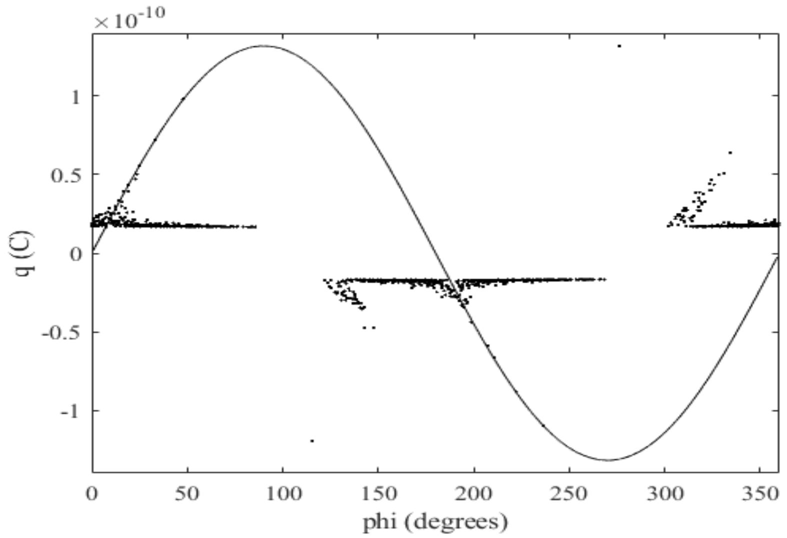

Fig. 4: PRPD pattern simulated under 50 Hz power frequency

IV. CONCLUSION

An adequate simulation study on the impact of stressing frequency on PD occurrence in a solid HV insulation sample characterized by a spherical cavity has been presented. The PD patterns were observed to be greatly influenced by changes in the frequency of the supply voltage. At power frequency (PF), the PD patterns were seen to be closer to experimental finds. As such, at this frequency, the activity of PD is expected to be more damaging to the insulation material of the HV equipment. Subsequently, the impact of variable voltage magnitude on the activity of PD will be investigated.

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