Validation of Partial Discharge Emulator Simulations using Free-Space Radiometric Measurements

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***Abstract*—A useful technique to estimate the degradation of insulation in high voltage (HV) installations is the measurement of partial discharge (PD). Free-space radiometric (FSR) detection of PD is a relatively new technique. Several types of PD emulator sources have been constructed: two internal PD emulators and a floating electrode emulator. The emulators have been simulated using the CST Microwave Studio software package. The intention is to use the simulated emulators to establish a relationship between radiated PD signals and PD intensity as defined by apparent charge transfer. To this end the radiated fields predicted in the simulations are compared with measurements. There is sufficient agreement between simulations and measurements to suggest the simulations could be used to investigate the relationship between PD intensity and the field strength of radiated signals.**

***Keywords*— CST Microwave Studio; Electromagnetic waves; FDTD; Free space radiometric measurement; Partial discharge**

I. INTRODUCTION

Partial discharge (PD) is often a precursor event of high voltage (HV) equipment failure. PD diagnosis is an established means of verifying insulation condition. Any method to locate PD sources and assess their intensity would be a significant tool for the early detection of faulty HV equipment. Electromagnetic (EM) waves radiated from the PD source can be detected by sensors positioned near the HV equipment. The majority of energy in radiated PD signals lies in the very-high frequency (VHF) and ultra-high frequency (UHF) bands. The radiation of EM waves created by PD in HV apparatus therefore facilitates compromised insulation diagnosis and location [1, 2]. The use of radiated PD signals is referred to as a free-space radiometric (FSR) method of PD detection and source location [3-6].

The design, validation and calibration of a FSR PD sensor network requires emulated PD sources, i.e. devices that radiate PD-like signals at stable, known, levels of intensity. Furthermore, if FSR measurements are to be used to infer the absolute intensity (in pC) of PD processes then simulations in which both absolute PD intensity and radiated signal field strength can be simultaneously calculated will be enormously helpful. This paper models three PD sources and shows that they can be simulated successfully thus allowing future investigation of the radiated field strength versus absolute PD intensity relationship.

Validation of the simulations requires measurement of FSR PD signals from real PD sources (referred to here as PD emulators). The general measurement setup for a FSR measurement is shown in Figure 1.

Three PD emulators have been constructed. An emulator of the floating-electrode type and two internal PD emulators are depicted in Figure 2. The CST Microwave Studio software package, which can simulate transient electromagnetic fields using the FDTD (Finite Difference Time Domain) technique, has been used to model these emulators [7, 8].

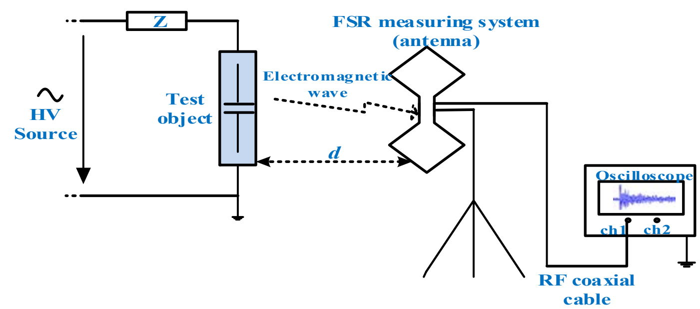
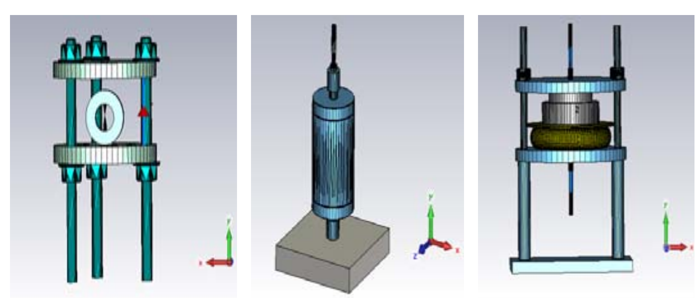


Fig. 1. Free-space radiometric PD measurement.



(a) (b) (c)

Fig. 2. PD emulator types: (a) floating-electrode (b) internal and (c) internal with epoxy dielectric.

To measure PD from the different emulators, the setup shown in Figure 3 is used. More information about PD measurement can be found in [9-11].

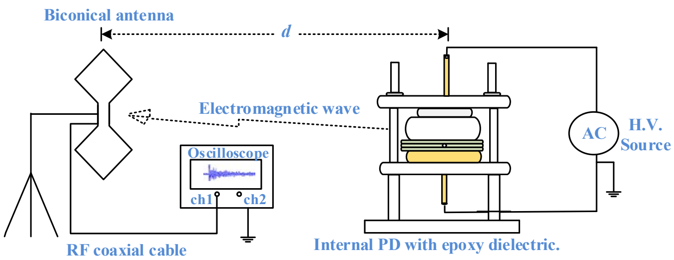


Fig. 3. PD measurement circuit with internal PD source.

PD is created by applying a HV 50 Hz AC signal to three PD emulators. Measurements were performed using voltages of 15 kV RMS for a floating-electrode PD emulator, 20 kV RMS for an acrylic tube internal PD emulator and 18 kV RMS for an internal epoxy dielectric PD emulator. The FSR measurements were made using a biconical antenna connected to a 20 GSa/s digital sampling oscilloscope (DSO) with an analog-bandwidth of 4 GHz. The biconical antenna, Figure 4, was located at a distance of 3 m from the PD source and was vertically polarised.

Fig. 4. Biconical antenna.

The frequency range of the antenna is 20 MHz to 1 GHz and its nominal impedance is 50 ohms. The antenna gain at 100 MHz is around -9 dBi and its dimensions are 540 mm×225 mm × 225 mm.

The floating-electrode PD emulator is shown in Figure 5. The output of the HV power supply is connected to the lower electrode, and the upper electrode is connected to earth. When the electric field is sufficiently large a discharge is initiated from the floating electrode [12, 13].

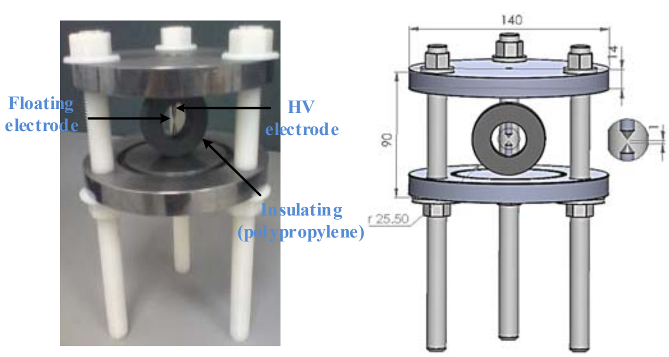


Fig. 5. Floating electrode PD emulator (dimensions in mm).

An internal PD source is shown in Figure 6. The electrodes are smaller than those in the floating electrode emulator. The insulation is perspex. The edges of the electrodes are rounded to avoid the enhanced electrical field strength, and the resulting corona, that would otherwise occur close to the sharp edge [14]. The insulator was constructed by compressing three circular plates between the two electrodes to form a composite disc. The thickness of each plate is 1.5 mm. The insulation defect necessary for the occurrence of partial discharge is realised by drilling a hole (diameter 1 mm) in the middle plate [14]. The electrodes and insulating disc are enclosed in an acrylic cylinder filled with transformer oil to avoid discharge from the disc edges.

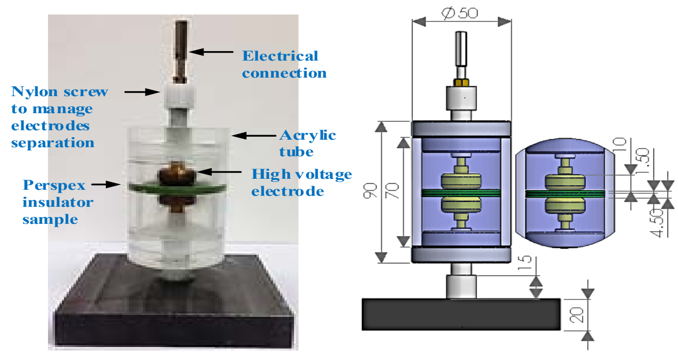


Fig. 6. Acrylic tube internal PD emulator (dimensions in mm).

A second internal PD emulator is shown in Figure 7. The insulation comprises three epoxy glass plates. A cavity with a diameter of 1 mm was drilled in the middle plate. The thickness of the three-plate composite is 2.4 mm. The HV electrode is made from stainless steel with a well-rounded edge to avoid surface discharge from regions of elevated field strength [15].

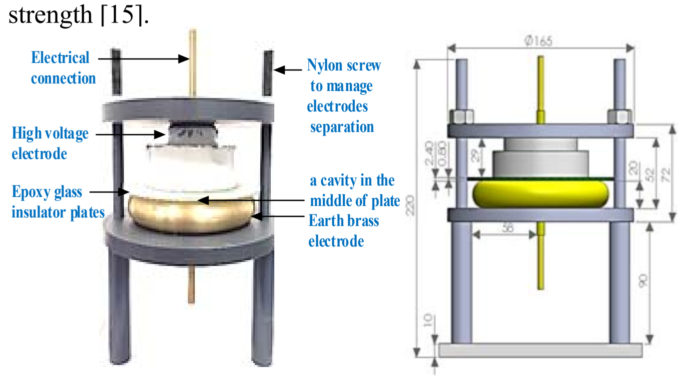


Fig. 7. Epoxy dielectric internal PD emulator (dimensions in mm).

II. FSR PD MEASUREMENTS AND SIMULATIONS

Measurements were made of the radiated PD signals from all three emulators. In each case the sensing antenna was located 3 m from the emulator. The received signals are shown in Figure 8.

A Gaussian current signal with a frequency spectrum in the VHF-UHF band has been used to excite in the simulated PD sources. The Gaussian signal is [7, 16]:

$$i(t) = I_0 e^{\left(\frac{-(t-t_0)^2}{2\sigma^2}\right)} \qquad (1)$$

where I_0 is the peak current, σ characterizes the pulse width and t_0 is the time the pulse peaks. The charge contained within the pulse (at least approximately equal to the apparent charge of the PD intensity) is:

$$q = I_0 \sigma \sqrt{2\pi} \qquad (2)$$

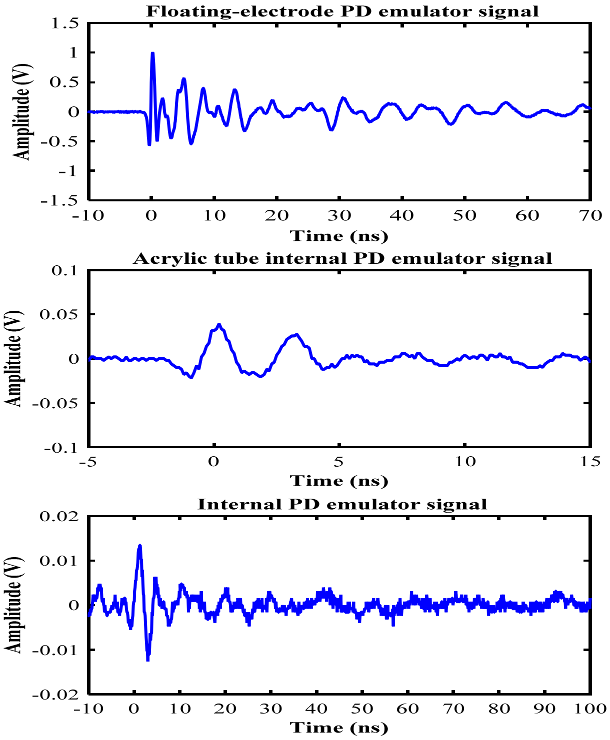


Fig. 8. PD FSR measurement signals.

The radiated electric fields predicted by simulation at a distance of 3 m for each of the emulators in response to excitation by the above current pulse are shown in Figure 9. Simulated and measured fields are compared in Figure 10. The CST simulation of the PD emulators are in good agreement with the measurements. This gives confidence in the simulations which may, therefore, be used to calculate absolute PD intensity (in pC) and relate this to radiated signal field strength at a particular distance from the PD source.

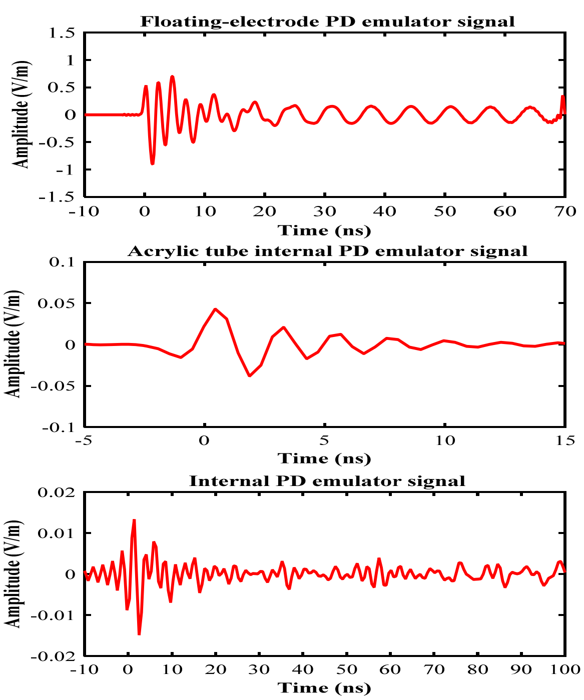


Fig. 9. Simulated PD electrical fields.

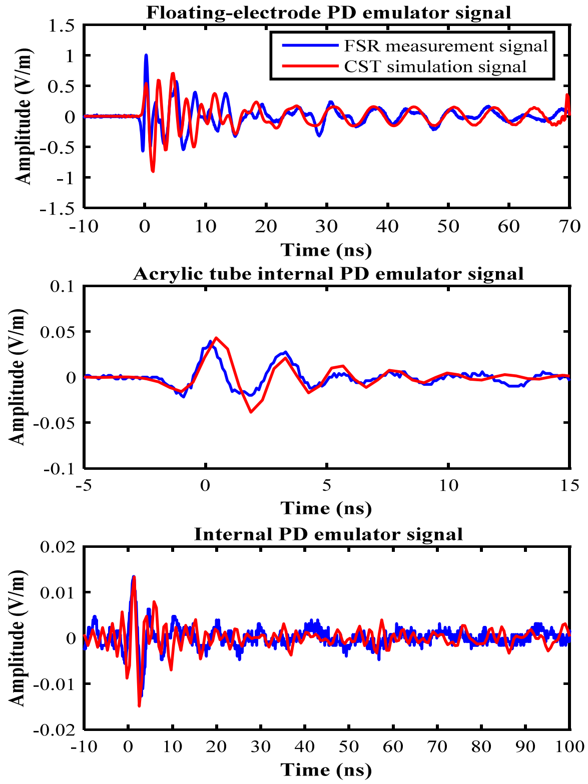


Fig. 10. Comparison of measured and simulated PD electrical field amplitudes.

III. Conclusions

Three different PD emulators have been constructed and the radiated fields from each due to a given excitation derived by simulation. The PD intensity corresponding to the excitation is easily calculated allowing this to be related to radiate PD field strength. The simulations have been validated by measuring the radiated fields, comparing them with the fields predicted from simulation and showing the agreement to be good. The validated simulations will be used to investigate the relationship between FSR PD measurements and absolute PD intensity. If such a relationship can be, even approximately, established then the utility of FSR PD measurement and locations systems for the condition monitoring of insulation integrity in high voltage plant will be greatly enhanced.

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