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Comparison of Contact Measurement and Free-Space Radiation Measurement of Partial Discharge Signals

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Abstract—**Two partial discharge (PD) measurement techniques, a contact measurement technique (similar to the IEC 60270 standard measurement) and a free-space radiation (FSR) measurement technique, are compared for the case of a floating electrode PD source. The discharge pulse shapes and PD characteristics under high voltage DC conditions are obtained. A comparison shows greater similarity between the two measurements than was expected. It is inferred that the dominant mechanism in shaping the spectrum is the band-limiting effect of the radiating structure rather than band limiting by the receiving antenna. The cumulative energies of PD pulses in both frequency and time domains are also considered.**

Keywords- Electromagnetic wave radiated; IEC 60270 measurement; Partial discharge; Radio frequency; Ultra high frequency.

I. INTRODUCTION

Many electricity supply organizations around the world are facing growing energy demands and an ageing transmission and distribution infrastructure. The financial cost of replacing infrastructure is high which motivates cost-effective asset management of to maximize its useful lifetime whilst minimizing the risk of failure with consequent (large) costs. To facilitate efficient and reliable operation, continuous condition monitoring of the electrical equipment within substations is required.

PD measurement is an effective method to diagnose imminent failures due to insulation degradation with consequent substation outages [1].

IEC60270 is a standard for measuring the apparent charge of a PD pulse. It is a contact method requiring electrical connection to the test object. Apparent charge is the unipolar charge which, if injected into the terminals of the test object, results in the same reading on a measurement instrument as that due to the measured PD pulse. The IEC measurement therefore quantifies the time integral of PD current.

Free-space radiometric (FSR) measurement of PD uses a broadband antenna to receive the RF energy radiated by the accelerating charge comprising the PD current transient. In FSR measurements the received RF signal is typically proportional to a time derivative of PD current [2].

Since both the principles and practical implementations of contact and FSR methods are quite different they may be expected to have different responses to the same PD event. The severity of PD is normally characterized by its intensity measured in picocoulombs (pC) of apparent charge. The nature of FSR measurements makes their use for the measurement of absolute PD intensity difficult, if not impossible. This is because the received signal amplitude depends on several factors which are unknown to greater or lesser extent and in at least one case is practically unknowable. In order of increasing difficulty to establish, these unknown factors include: (i) the path loss between radiating structure and receiving antenna, (ii) the polarization of the radiated field in the direction of the receiving antenna, (iii) the gain of the radiating structure in the direction of the receiving antenna and (iv) the radiated power. One of the main intentions of the work reported in this paper was to explore the possibility of using a contact PD measurement to empirically calibrate an FSR PD measurement.

As reported below, the utility of the contact method to calibrate an FSR measurement appears to be limited. The value of the measurements presented is therefore restricted to an observation of the degree to which the contact and FSR measurements are similar, at least in the context of a particular type of PD event, i.e. that arising from a floating-electrode discharge. The contact measurement reported here does not comply rigorously with the IEC60270 standard but the configuration of the measurement is very similar.

II. REPORTED RELATIONSHIP BETWEEN APPARENT CHARGE AND FSR MEASUREMENTS

Although both the contact and FSR methods can be used to identify insulation defects, FSR measurements have some practical advantages over contact measurements. Both, however, have limitations. For example, FSR techniques can provide information on the location of PD. However, this technique cannot easily quantify PD intensity. Contact measurements give an indication of the apparent charge (and therefore PD intensity) and may also provide information about the nature of an insulation fault based on PD bandwidth and phase resolved discharge patterns, [3].

Judd et al., [3], proposed a new integrated approach to PD monitoring using the combined and simultaneous application of UHF and IEC60270 measurements. Initial results of the combined approach show that it may be possible to discriminate between different sources of PD using apparent charge and UHF signal energy. Zhang, et al., [4], investigated the correlation between RF measurements and the apparent charge of partial discharge. The results show a linear association between the amplitude of the RF signal and apparent charge in a positive half cycle. Ohtsuka et al., [5], investigated the association between apparent charge and FSR signals using measurements and an FDTD simulation. It is suggested that the PD charge quantity can be corrected by using the FSR method. Reid et al., [6], calculated the energy spectrum of the RF signal and showed that apparent charge together with the frequency distribution of the RF signal can prove useful as an identifier of PD and a means of defect characterization. Reid et al., [7], present phase resolved patterns of RF signals. The results show defect detection is possible if the system is trained by using both RF and contact measurement data. Reid et al., [8], recorded PD using contact and RF methods. Results indicate that the relationship between the methods creates characteristic patterns specific to defect types. Xiao, et al., [9], used RF and IEC time domain analysis measurements to investigate the assessment of insulation integrity for six types of defects. Results were inconclusive in respect of distinguishing differing defects using time domain analysis, but frequency domain analysis revealed information relating to the resonances of the radiating structure which might provide useful defect discrimination. Sarathi et al., [10], analyzed UHF FSR signals caused by the movement of conducting particles subject to a high voltage in transformer oil. (The magnitude of the UHF signal generated by a DC voltage was higher than that generated by an AC voltage.) It was concluded that it was possible to classify an incipient discharge from either an AC or a DC routine substation pressure test. Sarathi et al., [11], made conventional FSR measurements of PD in gas insulated switchgear and concluded that signal bandwidth is independent of applied voltage and operating pressure. Li et al., [12], described measurement results of PD under DC conditions. The results showed that discharge pulses have different shapes depending on the DC voltage and the main part of the discharge energy is situated below 100 MHz.

III. APPARATUS

Figure 1 is a schematic diagram of the measurement apparatus used to simultaneously obtain contact and FSR measurements for the same PD event.

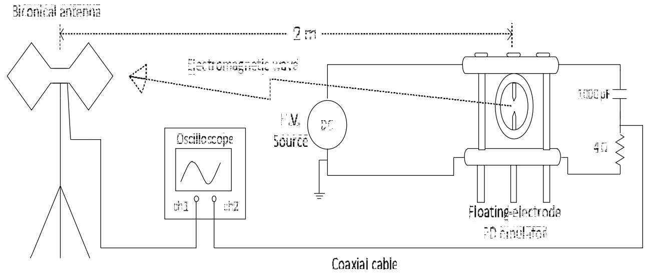

Fig. 1. Experimental apparatus.

PD is generated by applying a large DC voltage to a floating-electrode PD emulator with 1 mm gap between the HV and floating electrode.

The RF signal radiated from the emulator is captured using a wideband biconical antenna connected to one channel of a 4-channel, 4 GHz, digital sampling oscilloscope (DSO). The DSO sampling rate of each channel is 20 GSa/s. The antenna, oriented for horizontal polarization, is located 2 m from the PD source.

Figure 2 shows the floating-electrode PD emulator which is based on that described in [13]. The high voltage output of the power supply is connected to the upper electrode and the lower electrode is connected to earth. A floating metallic needle is located between the electrodes but is not (electrically) connected to either. The long dimension of the needle is parallel to the applied electric field. When the electric field is sufficiently large a corona discharge from the floating electrode is initiated, [14].

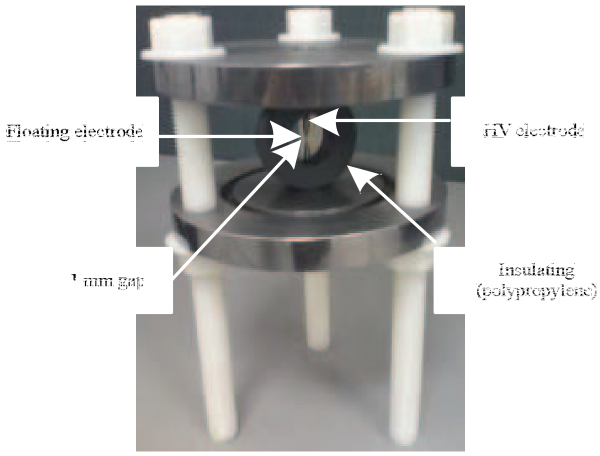

Fig. 2. Floating-electrode PD emulator.

IV. EXAMPLE EVENT

Figures 3 and 4 show a typical PD event captured by the FSR and contact measurements respectively. The voltage at which this PD event occurred was 6.2 kV. Figure 5 compares the two normalized measurements. This event is representative of many such measurements.

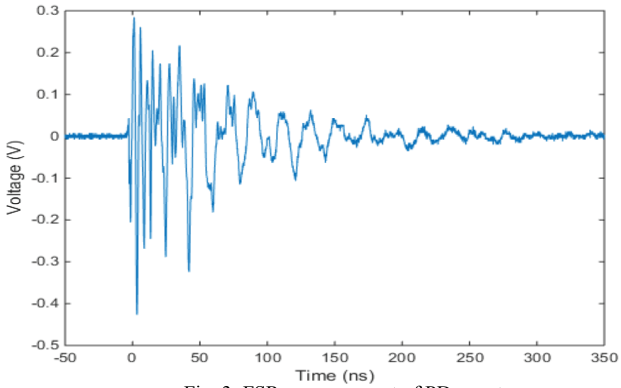

Fig. 3. FSR measurement of PD event.

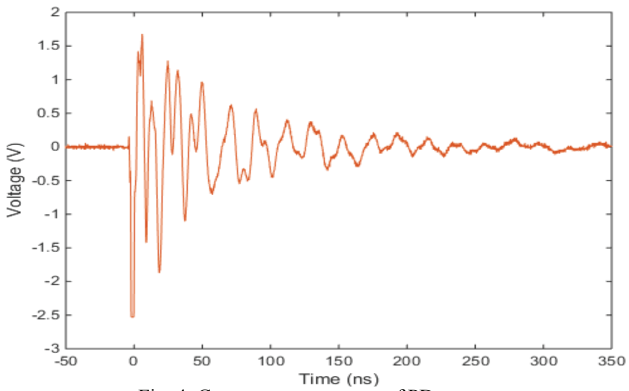

Fig. 4. Contact measurement of PD event.

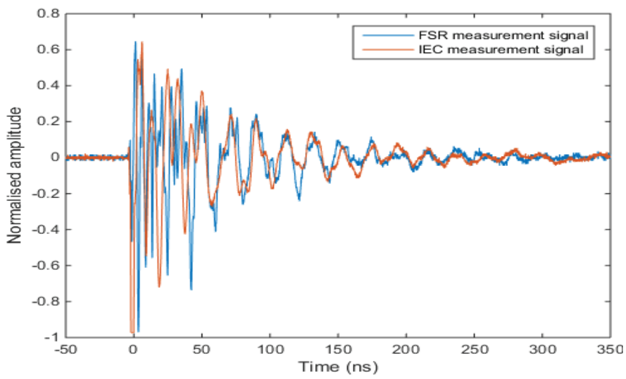

Fig. 5. Comparison of normalised FSR and contact measurements.

The similarity in the temporal decay of the two signals is more similar than was expected. Band limiting of the measurement due to the electromagnetic radiation and reception processes was expected in the case of the FSR measurement. The expectation was for a somewhat less severe band limiting in the case of the contact measurement resulting in shorter ringing. The inference drawn is that band limiting is dominated by the inductive and capacitive characteristics of the PD source rather than the frequency response of the FSR receiving antenna.

The total duration of the pulse is approximately 300 ns and the $1/e$ duration of the pulse envelope is approximately 70 ns. The normalised frequency spectra obtained by FFT analysis using 10^4 time samples are shown in Figures 6 and 7. Figures 8 and 9 show the frequency sub-bands and the fraction of energy that they contain. Most of the energy lies between approximately 10 MHz and 300 MHz, although the exact distribution of energy is not the same in the two sets of figures.

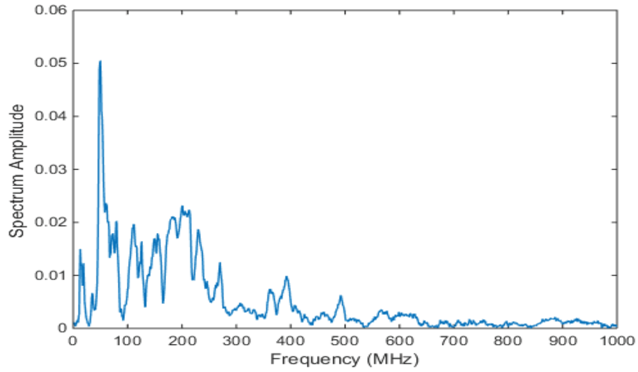

Fig. 6. Frequency spectrum of FSR measurement.

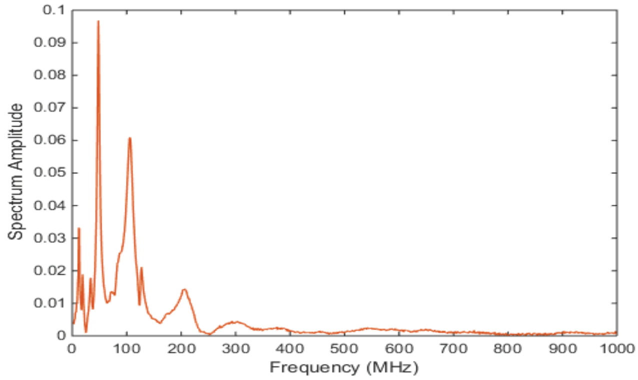

Fig. 7. Frequency spectrum of contact measurement.

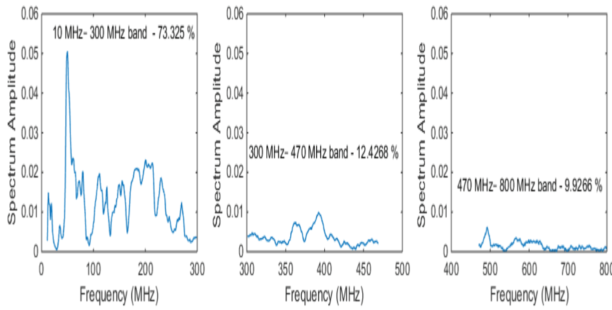

Fig. 8. Sub-band spectra and energy proportions for FSR measurement.

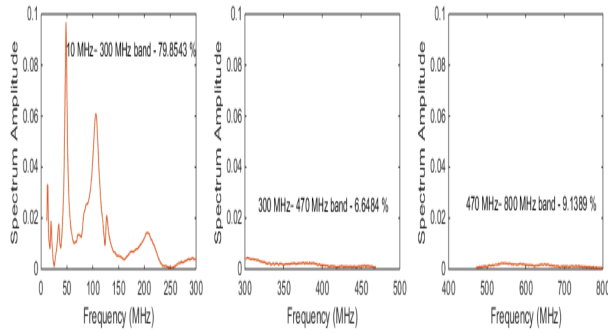

Fig. 9. Sub-band spectra and energy proportions for contact measurement.

The time-cumulative energies of the PD pulse measurements are shown in Figures 10 and 11. The total energy of the FSR pulse is 2.8×10^{-7} J and the total energy of the contact pulse is 1.2×10^{-5} J.

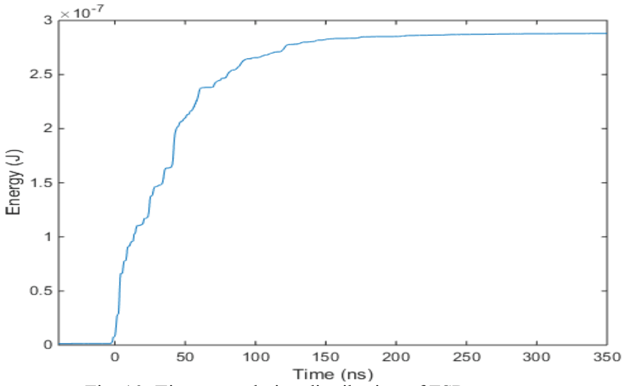

Fig. 10. Time-cumulative distribution of FSR energy.

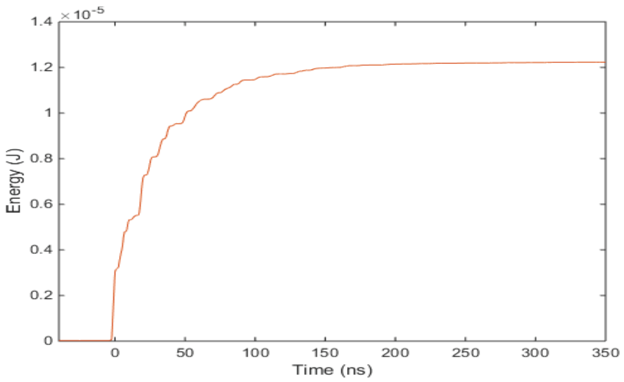

Fig. 11. Time-cumulative distribution of contact energy.

V. CONCLUSIONS

A comparison of PD signals captured using FSR and contact methods has been carried out. Preliminary results show greater similarity than was expected in the time domain signals. It appears that the signal characteristics in both cases are dominated by the lossy equivalent (resonant) circuit of the radiating structure. Normalised frequency spectra obtained by FFT analysis from the time domain pulses indicate that the main frequency content of the PD discharge is situated in the range of 10 –300 MHz, i.e. 73% of the total energy for the FSR measurement and 80% of the total energy for the contact measurement.

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