Diagnostic Potential of Free-Space Radiometric Partial Discharge Measurements

A Jaber* (1), P Lazaridis(1), B Saeed(1), P Mather(1), M F Q Vieira(2), R Atkinson(3), C Tachtatzis(3), E Iorkyase (3), M Judd(4), and I A Glover(1)
(1) Department of Engineering & Technology, University of Huddersfield, Huddersfield HD1 3DH, UK
(2) Department of Electrical Engineering, Universidade Federal de Campina, Campina Grande, Brazil
(3) Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow G1 1XW, UK
(4) High Frequency Diagnostics & Engineering Ltd, Glasgow G2 6HJ, UK

Abstract

The work reported in this paper addresses the calibration of four types of partial discharge (PD) emulator required for the development of a PD Wireless Sensor Network (WSN). Three partial discharge (PD) emulators have been constructed: a floating-electrode emulator, and two internal PD emulators. Both DC and AC HV power supplies are used to initiate PD which is measured using concurrent free-space radiometry (FSR) and a galvanic contact method based on the IEC 60270 standard. A new method of estimating absolute PD activity level from a radiometric measurement is proposed.

1. Introduction

A major problem in high voltage (HV) power systems is degradation and breakdown of insulation. Statistics indicate that most HV equipment failures occur due to insulation breakdown [1]. Measurement of partial discharge (PD) is a useful tool in the identification of incipient insulation faults. It allows the progress of insulation degradation to be monitored resulting in informed decisions about the intervention time.

Galvanic contact measurement, performed in accordance with the IEC 60270 standard, is generally accepted to provide the most accurate method of PD measurement and is often, therefore, used as a reference.

The (more recent) free-space radiometric (FSR) method of PD measurement uses an antenna to receive signals radiated by the transient PD pulses. The precise relationship between the FSR signal at the receive antenna terminals and the PD current pulse may be complicated [2, 3]. If the antenna employed is a broadband variation on an electric dipole, for example, the received RF signal might be expected to be proportional to the time derivative of the incident PD field [4]. The radiation process may also differentiate the PD signal, double differentiate the PD signal or process the signal in some intermediate way, depending on the balance of magnetic and electric coupling between guided and free-space waves. There is, in addition, the possibility of further spectral distortion due to the frequency response of the radio propagation channel.

The objective of this paper is to compare the frequency spectrum of radiated PD signals from different PD emulator types with that of pulses measured using the electrical galvanic contact method. The authors regard the latter as the measurement method most likely to preserve diagnostic information.

2. PD measurement apparatus

The measurement apparatus used for concurrently obtaining galvanic contact and FSR measurements for the same PD event is shown in Figure 1. The experimental setup has used four different PD emulators.

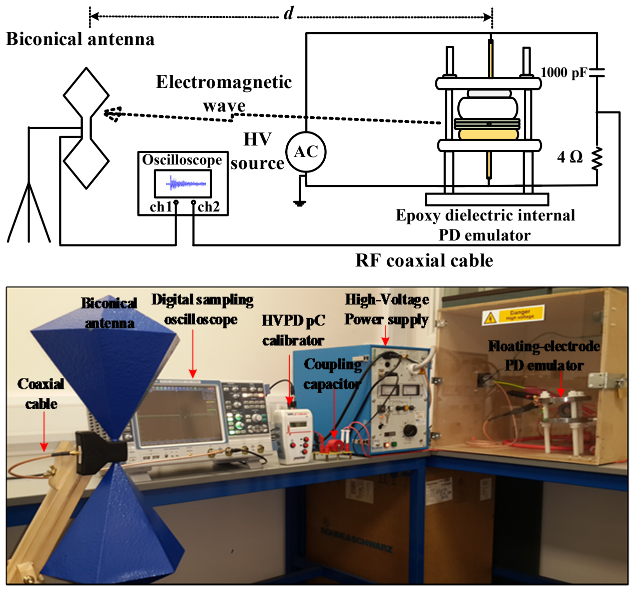


Figure 1. PD measurement apparatus.

PD is generated by applying a high voltage (AC or DC) to the artificial PD sources; a floating electrode emulator, an acrylic tube emulator, an acrylic tube emulator immersed in transformer oil, and an epoxy dielectric emulator. The radiometric measurements were made using a vertically polarized biconical antenna connected to a 4 GHz, 20 GSa/s, digital sampling oscilloscope (DSO) [5]. Figure 2 shows the biconical antenna. The antenna's calibrated frequency range is 20 MHz to 1 GHz.

Figure 2. Biconical antenna.

The floating electrode emulator, acrylic tube emulator, and epoxy dielectric emulator are shown in Figure 3. Further detail about the PD emulators can be found in [6].

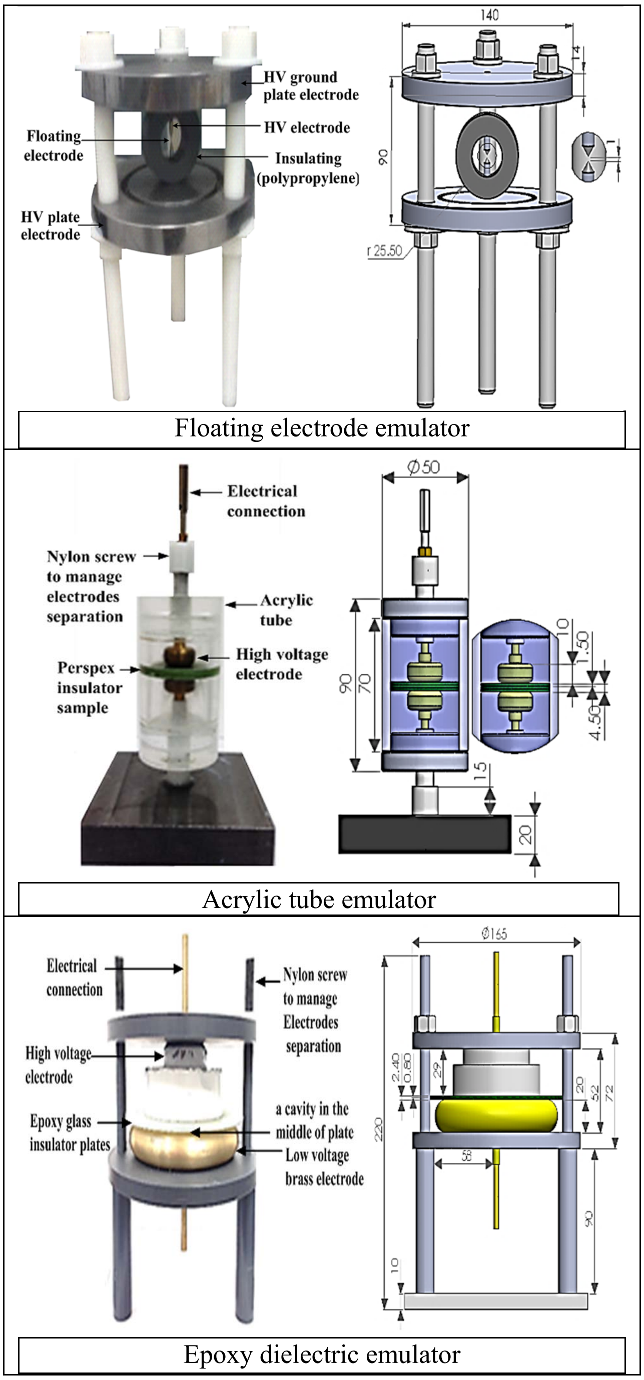


Figure 3. PD emulators.

3. Experimental results

The signals captured (concurrently) by the FSR and galvanic contact measurements using the floating electrode emulator are shown in Figure 4. This observation is one of many and is representative. The radiated signal is captured using the biconical antenna and the frequency spectra are obtained by FFT processing of the time-domain signals.

Comparison of normalised measurements of the PD event using all the emulators are shown in Figure 5.

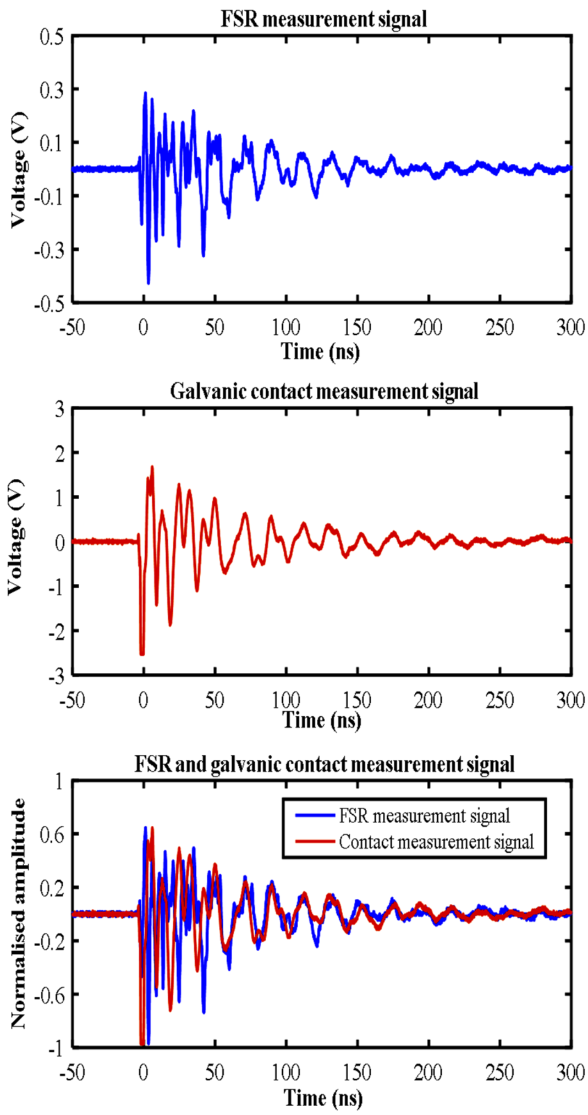


Figure 4. PD event for floating electrode emulator.

The temporal decay of the signals in the two measurements is similar. Band-limiting of the measurement due to electromagnetic radiation and reception processes was expected in the case of the FSR measurement. The expectation was for less severe band-limiting in the case of the galvanic contact measurement resulting a less pronounced ringing. The conclusion is that band-limiting is dominated by the reactive characteristics of the PD source and the connecting cables, rather than the frequency response of the FSR receiving antenna [7].

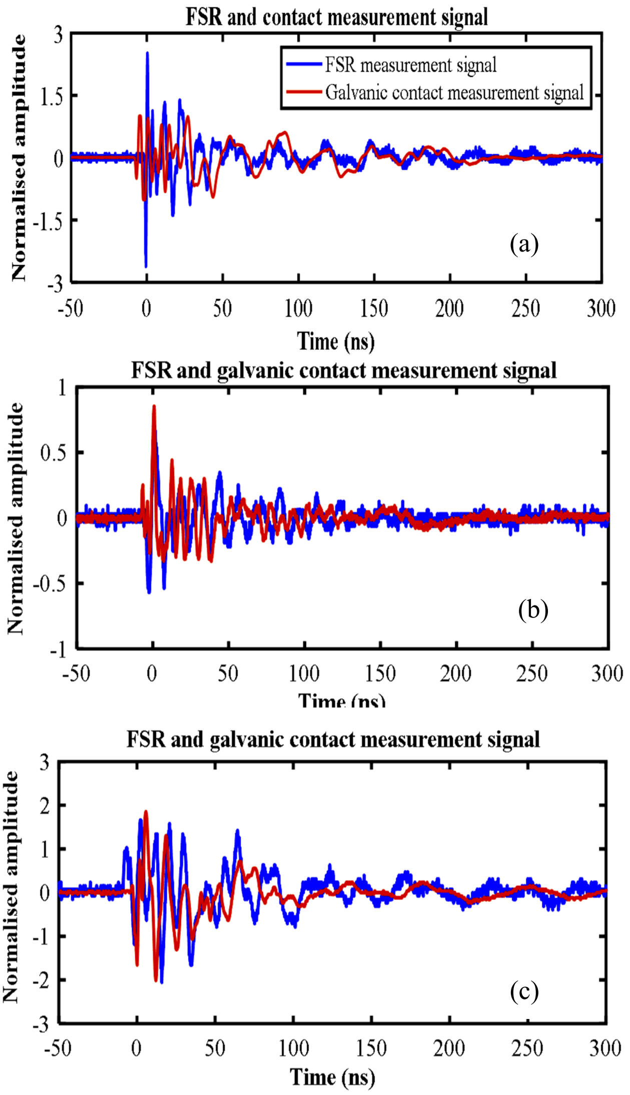


Figure 5. Comparison of normalised measurements of PD (a) acrylic tube emulator (b) acrylic tube emulator immersed in transformer oil and (c) epoxy dielectric emulator.

The frequency spectra of the galvanic contact and FSR signals is compared in Figure 6 for the floating electrode emulator. Figure 7(a), (b), and (c) compares normalised spectra for the acrylic tube emulator, the acrylic tube emulator filled with transformer oil, and the epoxy dielectric emulator. The energy in the PD radiation is contained in the band 50 MHz to 800 MHz [2] with most of the radiation energy below a frequency of 290 MHz. The frequency spectra of FSR and galvanic contact measurements are not identical but sufficiently similar to suggest any diagnostic information residing in the galvanic contact signal is, at least partly, preserved in the FSR signal.

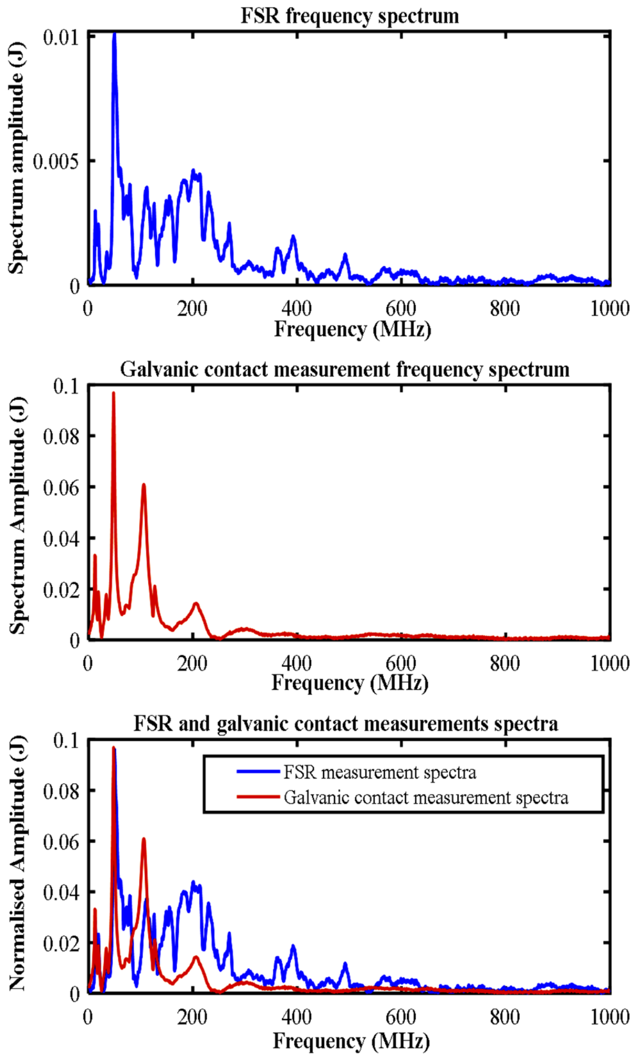
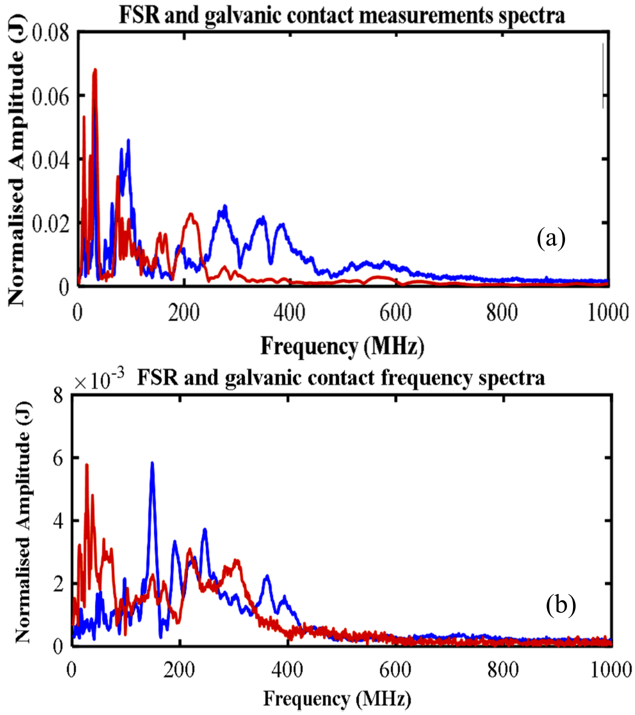


Figure 6. Measurement spectra for floating electrode PD emulator.



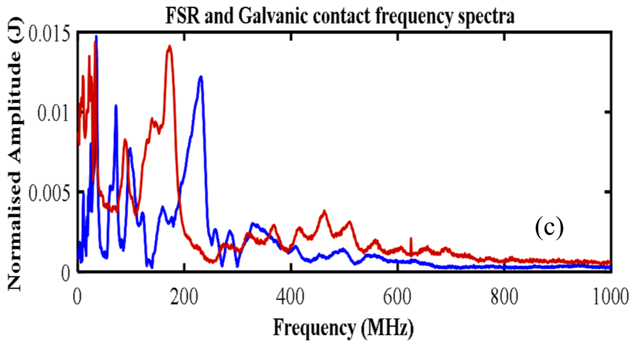


Figure 7. Comparison of normalised frequency spectra (a) acrylic tube emulator (b) acrylic tube emulator with transformer oil and (c) epoxy dielectric emulator.

In addition to diagnostic information residing in the FSR spectrum it also resides in the PD absolute intensity. An absolute measurement of PD intensity has, until now, been thought difficult if not impossible due to the uncertainties associated with FSR propagation, polarization and other losses. If an estimate of the range from an FSR sensor to the PD source is available, however, then an estimate of effective radiated power (ERP) calculated from received radiometric power can be related to PD apparent charge calculated from the galvanic contact measurement [3]. Figure 8 is estimated ERP versus apparent charge for the four emulated PD sources described above. It suggests that an estimate of absolute PD intensity can be made from aradiometric measurements of PD alone.

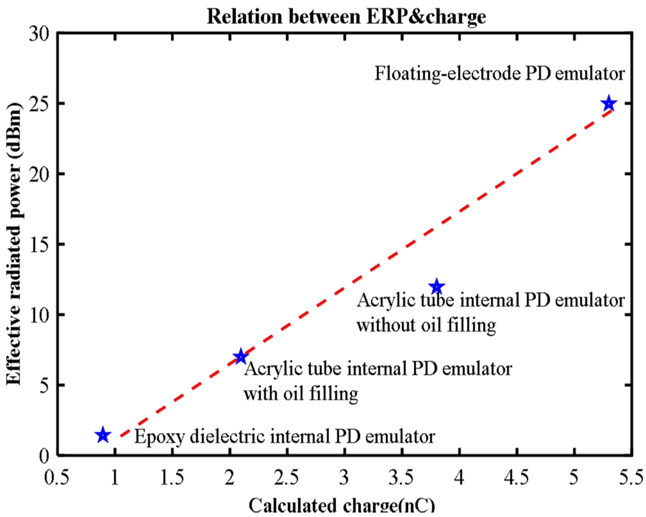


Figure 8. Estimated ERP versus estimated apparent charge for different types of PD sources.

4. Conclusions

Evidence has been presented that diagnostic information in galvanic partial discharge measurements originating from HV insulation defects may still be present in free-space radiometric measurements. Such diagnostic information includes absolute partial discharge intensity if distance from the PD source is known and ERP can be reliably estimated. Since radiometric location of partial discharge sources is possible with multiple radiometric sensors, an absolute measurement of partial discharge intensity for radiometric measurement alone is almost certainly possible.

5. Acknowledgements

The authors acknowledge the Engineering and Physical Sciences Research Council for their support of this work under grant EP/J015873/1.

6. References

1. D. A. Genutis, "Using Partial Discharge Surveys to Increase Electrical Reliability," presented at the Annual Technical Conference Communications and Metering-NETA WORLD, USA, 2002.

2. Y. Zhang, D. Upton, A. Jaber, H. Ahmed, B. Saeed, P. Mather, P. Lazaridis, A. Mopty, C. Tachtatzis, R. Atkinson, M. Judd, M F Q Vieira, and I A Glover, "Radiometric wireless sensor network monitoring of partial discharge sources in electrical substations," Hindawi International Journal of Distributed Sensor Networks, vol. 2015, p. 179, 2015.

3. A. Jaber, P. Lazaridis, Y. Zhang, B. Saeed, U. Khan, D. Upton, et al., "Assessment of absolute partial discharge intensity from a free-space radiometric measurement," in URSI Asia-Pacific Radio Science Conference (URSI AP-RASC), Seoul, South Korea,2016, pp. 1011-1014.

4. A. Reid, M. Judd, B. Stewart, D. Hepburn, and R. Fouracre, "Identification of multiple defects in solid insulation using combined RF and IEC60270 measurement," in Solid Dielectrics, 2007. ICSD'07. IEEE International Conference on, 2007, pp. 585-588.

5. A. Jaber, P. Lazaridis, B. Saeed, Y. Zhang, U. Khan, D. Upton, H. Ahmed, P. Mather, M. F. Q. Vieira, R. Atkinson, M. Judd, and I. A. Glover, "Comparative study of Partial Discharge emulators for the calibration of Free-Space radiometric measurements," in Automation and Computing (ICAC), 2016 22nd International Conference, Colchester, UK, 2016, pp. 313-316.

6. A. Jaber, P. Lazaridis, B. Saeed, Y. Zhang, U. Khan, D. Upton, H. Ahmed, P. Mather, M. F. Q. Vieira, R. Atkinson, M. Judd, and I. A. Glover,"Validation of partial discharge emulator simulations using free-space radiometric measurements," in Students on Applied Engineering (ISCAE), International Conference, Newcastle, UK, 2016, pp. 475-478.

7. A. Jaber, P. Lazaridis, Y. Zhang, U. Khan, D. Upton, H. Ahmed, P. Mather, M. F. Q Vieira, R Atkinson, M. Judd, and I. A. Glover., "Comparison of contact measurement and free-space radiation measurement of partial discharge signals," in Automation and Computing (ICAC), 2015, 21st International Conference on, Glasgow, Scotland, 2015, pp. 1-4.