Development of a programmable partial discharge generator for the evaluation of partial discharge measuring devices

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***Abstract*—Partial discharges (PD) measurement provide valuable information for assessing the condition of the insulation elements in high voltage (HV) electrical grids. During the last three decades, several instruments integrated with specific technical functionalities have been developed in order to perform accurate diagnostics when temporary or monitoring measurements are carried out on-site and on-line. Some electrical utilities, maintenance companies and large electricity consumers have defined technical specifications trying to select the most appropriate PD measuring systems, but in general, no tests are performed to check their capability to perform appropriate and accurate diagnostics. Furthermore, no standard exists to define what type of evaluation should be required to assess the efficacy of this type of instrumentation. In this paper, a reference PD generator developed for the evaluation of the functional features of PD measuring and diagnostic instruments is presented. This PD generator enables the characterization of the technical functionalities of commercial PD instruments in a controlled and homogenous way and without the requirement of apply HV in a test facility. Reference analogue PD time series with superimposed electrical noise time sequences are generated simulating real acquisitions of on-line PD measurements.**

Keywords—partial discharges; insulation testing; performance evaluation

I. INTRODUCTION

The main difficulties that technical analysts face in obtaining appropriate PD diagnostics when measurements are performed on-line are as follows: detection of PD signals with adequate sensitivity, separation of the PD generated simultaneously in different sources, location of these sources and identification of the type of insulation defects. PD measuring and diagnosis instruments used in on-line measurements are integrated with analysis functionalities to assist technical analysts in achieving accurate assessments [1-3]. Thus an adequate knowledge of the functionalities implemented in this type of instruments is essential. Furthermore, the evaluation of these functionalities is advisable as it enables the determination of their degree of effectiveness for the realization of precise diagnosis.

In several studies conducted to develop or improve a certain technical functionality, which can be used in a PD instrument, different experimental setups and case studies were presented to check their performance and to prove the benefits of their application [4-8]. In most of these practical experiences the application of a certain level of HV is required. Although the presented experimental setups were appropriate for the characterization of the proposed developments, none of them were conducted with the intention to evaluate one or more technical functionalities of different PD measuring and diagnosis instruments.

In this research a PD generator has been developed to characterize the technical functionalities of PD measuring and diagnosis instruments, by generating reference analogue PD time series together with noise time sequences. The use of this compact device permits the evaluation of the technical features of these instruments in a controlled and homogenous way and without the need to apply HV in a specific laboratory setup.

In Section II, the programmable PD and noise time series generator is described. In Section III, the functional characteristics of this generator are presented. Finally, the conclusions are outlined in Section IV.

II. PROGRAMMABLE PD GENERATOR

The main characteristic of the device developed is the capability to generate analogue reference PD time series together with background noise time sequences, in order to simulate real PD measurements performed on-site and on-line. The generation of the resulted PD and noise time series enables the characterization of the technical features of PD instruments.

For the realization of the synthetic time series the following procedure split in several stages was applied. Fig. 1 shows a flow diagram that summarizes this procedure.

1. The first step consists in the generation of PD time series in a HV scale modular setup, see Fig. 2. The PD pulses are generated in real insulation defects produced in individual reference test cells, which are plugged in the generation submodule of the setup.

2. The PD time series generated are measured in a shielded laboratory with the acquisition card of the

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compact generator and an initial digitalization is carried out. The measurements can be performed with a high frequency current transformer (HFCT) sensor or in compliance with the reference standard IEC 60270 using a measuring impedance (quadrupole); both sensing units are placed in the measuring submodule of the HV scale modular setup, see Fig. 2.

3. The digitised PD time series are stored in a database.

4. A subsequent post-processing is carried out for a memory optimization in the data storage of the PD time series. This optimization is performed searching the beginning of the individual PD pulses and selecting only the digital samples corresponding to the PD pulses and not to the low background noise signal. Each detected pulse is registered with a sampling period of 5 ns and a vertical resolution of 16 bits. The individual pulses and the information of their respective start time are recorded in a depurated database.

5. In a first step for data preparation: the pulses to be generated are adjusted to an adequate amplitude or charge level, according to the specified requirements for the evaluation of a particular technical feature of a PD instrument.

6. In a second step for data preparation: a selectable digitised noise signal, previously adjusted in amplitude, is superimposed to the individual PD pulses to be generated. The digitized noise signals were stored in the database of the PD generator.

7. Finally, an analogue synthetic PD time series simulating a real measurement performed on-line is generated. The analogue time series are obtained combining sequentially one or more types of PD pulses and the selected noise signal. The generation of different PD time series will permit the evaluation of the technical functionalities of PD instruments.

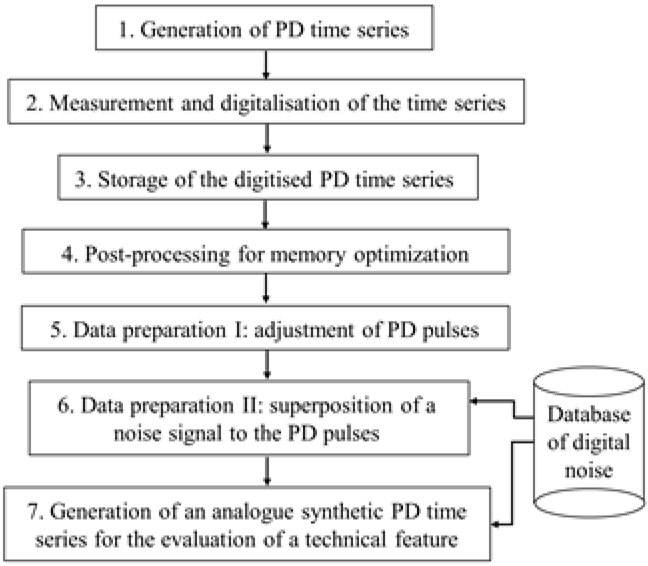

Fig. 1. Flow diagram of the procedure applied for the realization of the reference PD time series.

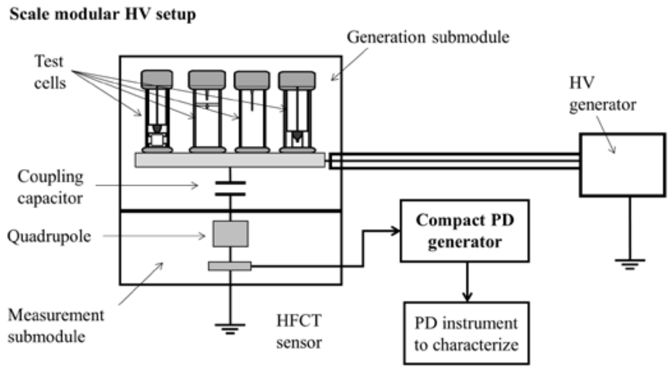

Fig. 2. Layout of the scale modular HV setup developed for the generation and recording of the reference PD time series.

The representative defects generated in the test cells for the acquisition of the reference PD time series were: cavity in an internal solid dielectric, surface defect in air and various types of corona effects. Besides, the electrical noise signals to be superimposed to the reference PD time series can be: white noise, pink noise, power line communications (PLC) noise or modulated noise of varying frequencies.

For the design of the test cells where the reference time series were generated rod electrodes with a semi-spherical end were used to generate corona PD in air, internal PD in polyethylene and surface PD in glass (see Fig. 3).

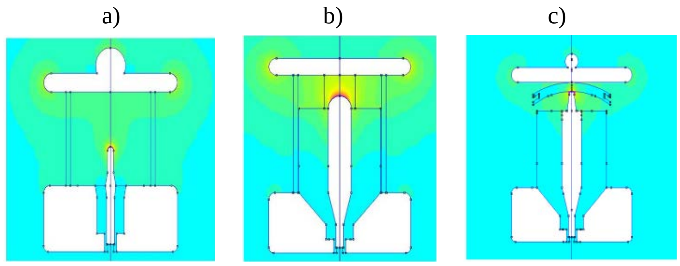

Fig. 3. Layout of the test cells and electrical field distribution calculated by means of FEMM. a) Corona effect in air, b) internal defect in polyethylene and c) surface defect in glass.

For fixed gap distances *s* and well-known dielectric media, electrode configurations and operating conditions (temperature, pressure and humidity), the inception voltage can be selected by choosing an appropriate curvature radius of the rod electrode. The inception voltage U_i of PD activity for an electrical configuration is given by the following equation:

$$U_i = E_{dh} \cdot s \cdot \eta \qquad (1)$$

where

U_i is the inception voltage
s the gap distance
η the inhomogeneity coefficient, and
E_{dh} the breakdown electrical field for quasi-homogenous field in air, that is given by the empirical formula:

$$E_{dh} = 23 \cdot \left(1 + \frac{1}{\sqrt[3]{R}} \right) \qquad (2)$$

being *R*, the curvature radius of the electrode expressed in cm to get the electrical field in kV/cm. The maximum electrical field in each test cell was calculated using the finite element software FEMM. It is important to note that these cells have a revolution geometry.

The PD pulses generated in the dielectrics were measured with the quadrupole or with the HFCT sensor placed in the measuring submodule of the developed scale modular HV setup, see Fig. 2. The bandwidth of the HFCT sensor used in the measurements is from 100 kHz to 20 MHz. Several PD time series were recorded applying different voltage levels in a range between 6 and 10 kV AC.

In the memory optimization performed in the stage 4 of the applied procedure for the generation of the PD time series (see Fig. 1), only the pulses previously detected in the initial digital time series are finally stored. For the detection of the pulses and for the determination of their origin, the following steps were carried out:

- Scanning from left to right of the first 20 samples acquired, to check that no PD pulses were registered in this interval.
- Calculation of the offset and the standard deviation of the signal in the first 20 samples.
- Definition of the noise threshold as offset ± 3σ.
- Comparison of the consecutive samples amplitude with the noise threshold and updating of the offset, the standard deviation and the noise threshold.
- If the amplitude of more than 5 consecutive samples is outside the noise threshold, it is considered that a PD pulse has started.
- Realisation of a linear regression using the first point of the detected pulse and its point of maximum amplitude (see Fig. 4).
- The origin of the pulse is in the intersection of the linear regression and the offset level.

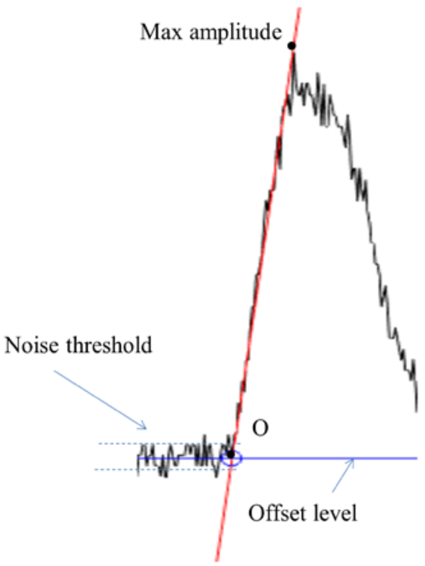

Fig. 4. Detection of the PD pulses and determination of their origin for the final digitalisation.

III. PD AND NOISE TIME SERIES GENERATION

The functional characteristics of the developed compact PD and noise generator were designed in order facilitate the evaluation, in a controlled a homogenous way, of the technical features of PD measuring and diagnosis instruments. The main functional characteristics can be summarised as follows:

Capability to generate representative PD time series of one or more insulation defects (see Fig. 5) and to superimpose a noise signal on them (see Fig. 6).

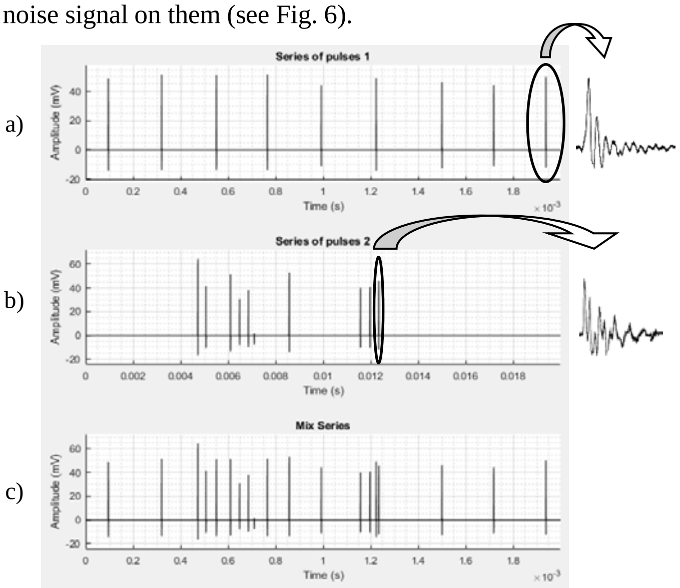

Fig. 5. Synthetic generation of analogue PD time series. a) Corona effect, b) surface defect and c) simultaneous generation of the corona effect and the surface defect.

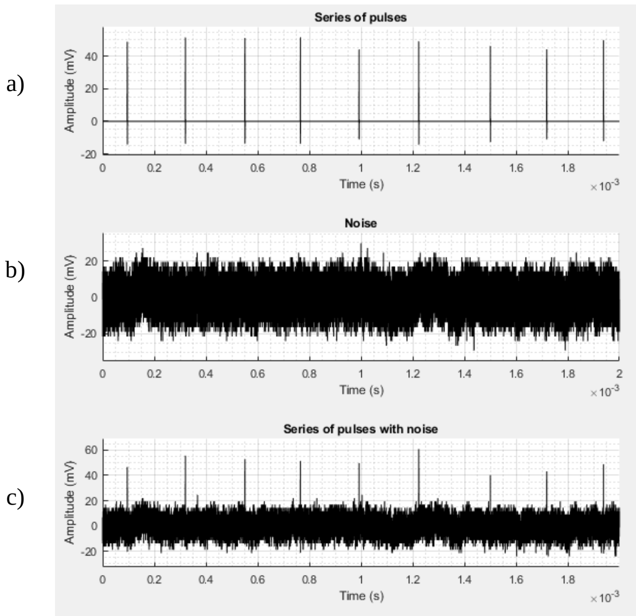

Fig. 6. Synthetic generation of analogue PD time series. a) Corona effect, b) pink noise and c) simultaneous generation of the corona effect and the pink noise.

Capability to duplicate PD time series with a time offset and filtered in frequency to simulate PD measurements performed in different points of a HV installation. In this case two synchronised time series are generated in different channels.

And capability to duplicate PD pulses in the same time series with an offset in time and filtered in frequency, which enables the realisation of reflectometry analysis.

IV. Conclusions

An appropriate knowledge and handling of the technical functionalities integrated in the measuring and analysis PD instruments, used in on-line measurements, avoid misinterpretations of the information acquired in PD tests and thus enable the performance of accurate diagnoses. The evaluation in a controllable and homogenous way of these functionalities efficiency is important for electrical utilities, maintenance companies and large electricity consumers as a proper selection and use of them will permit precise insulation condition assessments of HV grid assets.

The compact generator developed enables the evaluation of the technical functionalities of PD instruments in a controlled and homogenous way. The information processing performed for the generation of the analogue PD time series allows the storage of the reference pulses with low requirements of memory. With this new device, the evaluation of the practical functionalities of PD instruments can be performed everywhere and anytime due to its interesting practical portability. Furthermore, these evaluations are carried out without the requirement to apply HV in a specific laboratory setup.

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