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Antenna selection and frequency response study for UHF detection of partial discharges

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Abstract—**Partial Discharge (PD) detection is a widely extended technique for electrical insulation diagnosis. Classical PD detection by means of phase resolved patterns require electrical connections to the power equipment and is sensitive to many noise sources. Ultra High Frequency (UHF) detection techniques are being recently proposed to overcome these problems, and to detect partial discharges on-line. In this paper, four antennas will be tested in order to compare their response to this physical phenomenon.**

Keywords- partial discharges; UHF detection; antennas response.

I. INTRODUCTION

Partial Discharge (PD) is a clear ageing agent in electrical insulation of power systems. Power cables, transformers and generators withstand PD even at rated voltages due to mixed ageing agents arising from thermal, mechanical, electrical and environmental stresses [1]. On the other hand, these microscopic ionizations lead to small signal current pulses that can be detected in electrical equipment. Thus, PD is also a symptom of high voltage electrical apparatus ageing.

Normalized PDs measurements are made using resistive-capacitive dividers [2]. These classical methods use Phase-Resolved PD (PRPD) patterns to identify certain PD sources (corona, internal and surface PD). However, the measurement procedure is always done in industrial environments, where low Signal-to-Noise Ratio (SNR) signals are obtained or several microscopic sites are usually discharging simultaneously. This is the reason to add new measurement techniques where PD pulse waveform analysis is a fruitful methodology for noise rejection and PD source separation [3]. In this case, Very High Frequency (VHF) detectors, such as High Frequency Current Transformers (HFCT), are usually selected.

However, these methods have drawbacks: power equipment disconnection is sometimes necessary to adjust the measurement and detection of discharges and PD geometric location is not possible with these systems. In order to solve this, acoustic and UHF PD detection techniques are recently being applied to these systems, since these are non-contact measurements that can help in on-line PD monitoring and location [4]-[7]. Unfortunately, acoustic detection is restricted to oil-paper insulation systems and inner PD sites can be hardly detected because acoustic waves only propagate through oil.

Despite the fact that UHF detection seems to have clear advantages over other techniques, it is not fully understood the relationship between conventional HF or VHF signals and UHF signals [8]. Moreover, UHF signals depend on the selected antenna bandwidth and gain. Hence, the selection of the proper antenna for PD detection and location in high voltage assets is currently a clear technical challenge.

In this paper, a study about UHF signals from controlled insulating test objects withstanding PD is proposed. Four different antennas: zig-zag, monopoles with two lengths and log-periodic, will be used to measure PD pulses and their responses will be compared in the frequency domain. Discussion will be made taking into account technical and economic characteristics for each device.

II. MEASURING SETUP

The measuring setup consists of two different parts: partial discharge generation and sensor deployment around the test object.

A. Partial Discharge generation

A constant and predictable partial discharges activity is necessary to ensure the repeatability of results. To achieve this, a controlled experiment is carried out in the laboratory with a test object consisting of a vessel filled with transformer oil and two electrodes separated by 5 sheets of transformer insulating paper, see Fig. 1.

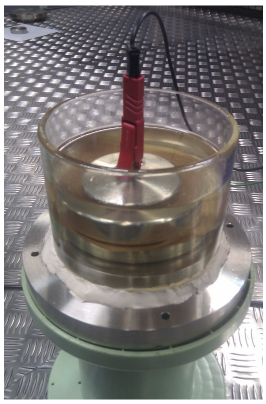

Figure 1. Test object

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Figure 2. Measuring setup with four antennas. The test object and the coupling capacitor are also visible

An electrode is connected to a high voltage source and the other to ground. According to Standard IEC 60270, a coupling capacitor is connected in parallel to the test object to provide a path to ground for high frequency current pulses created by partial discharges in the test object, see Fig. 2. Pulses are measured in VHF with a HFCT with a bandwidth up to 40 MHz connected to a commercial PDs detector (*PD-Check* from *TechImp Systems S.r.l.*) capable to identify PRPD patterns. This test setup in VHF is used to confirm that the detected UHF pulses are a consequence of PDs activity.

It has been found, that using new and dry transformer paper sheets, the partial discharges activity (internal PDs in microscopic air voids between papers) starts around 2 kV and is stable during at least three hours which is enough to acquire proper signals in VHF with the HFCT and in UHF with the antennas. Hence, the high voltage source is slowly set slightly above the inception voltage and the measuring campaign starts. Pulses were acquired at 3600 V.

B. Antennas deployment

Four antennas are used in the experiments with different frequency ranges: UHALP 91088A log-periodic from 250 to 2400 MHz, two monopoles, 5 and 10 cm long, which ensures a wide frequency range [7], and a zig-zag antenna, see Fig. 2 and Fig. 3. The antennas are deployed around the test object and their outputs connected to an oscilloscope. The distances between the test object and the antennas are not critical parameters at this stage because the experiment is focused on studying the frequency response of the signals and not the pulses in the time domain; nevertheless, distances were of a similar range, as can be seen in Fig. 2. Since PD source location is not the focus of this paper, the lengths of the coaxial cables are random too.

UHF acquisitions were made in a Tektronix DPO7254 8-bit, 40 GS/s, 4 channel oscilloscope, where the response of each antenna to PD pulses was registered. PDs activity is a stochastic phenomenon that depends on several factors such as applied voltage level, insulation ageing status, environmental conditions, etc. Despite the fact that, during the experiments in laboratory, most factors were controlled to assure uniformity in

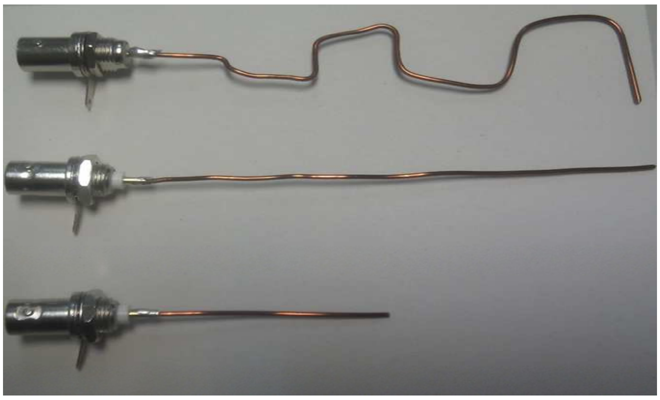

Figure 3. Zig-zag, 10 cm monopole and 5 cm antennas

the measurements, series of 500 pulses were recorded and processed to guarantee that the results were statistically reliable.

III. SIGNAL ACQUISITION AND PROCESSING

Prior to starting the acquisition of partial discharge pulses, the background noise is characterized to be compared with the FFT in the presence of pulses. This is done by measuring the

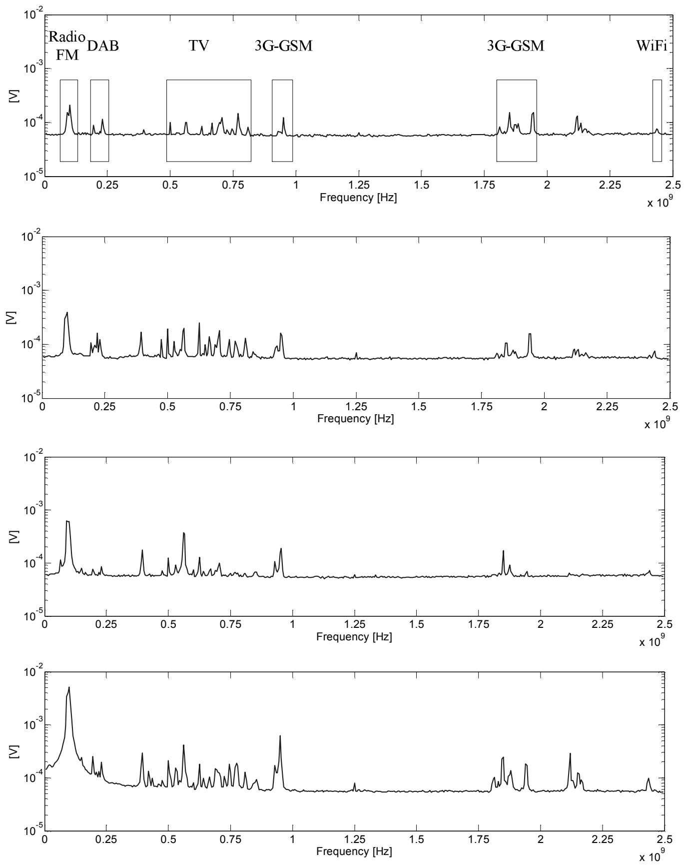

Figure 4. FFT voltage amplitude. Top: 5 cm monopole antenna; Second one: 10 cm monopole antenna. Third one: zig-zag antenna.; Bottom: log-periodic antenna

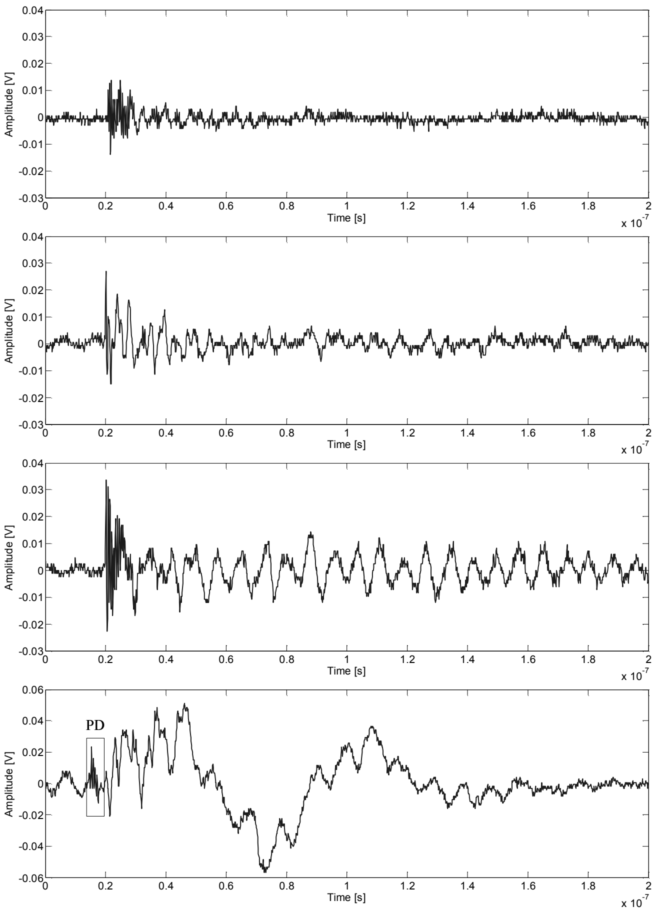

Figure 5. Voltage amplitud versus time for PD at 3600 V. Top: 5 cm monopole antenna; Second one: 10 cm monopole antenna. Third one: zig-zag antenna.; Bottom: log-periodic antenna

amplitude in absence of applied high voltages and shown in Fig. 4, where the FM radio, Digital Audio Broadcasting (DAB), TV broadcast, GSM and WiFi signals are clearly visible. The vertical axis for the four antennas is set to a logarithmic scale in volts. The noise floor is around $6{\cdot}10^{-5}$ V, $5.8{\cdot}10^{-5}$ V, $6{\cdot}10^{-5}$ V and $7{\cdot}10^{-5}$ V for the 5 cm monopole, 10 cm monopole, zig-zag and log-periodic antennas, respectively. Using the FM band to compare the response of the antennas to external radiation, it can be observed that the peaks are located in $2{\cdot}10^{-4}$ V, $4{\cdot}10^{-4}$ V, $6{\cdot}10^{-4}$ V and $5{\cdot}10^{-3}$ V for the 5 cm monopole, 10 cm monopole, zig-zag and log-periodic antennas, respectively. This means that, considering wide band behaviour, the log-periodic antenna has better sensitivity than the others. The horizontal axis is the frequency in Hz with a scale of 250 MHz/div, from 0 to 2.5 GHz. This plot is done by averaging the FFT of 500 time signals acquired with the oscilloscope.

Once this noise is characterized, the voltage is raised up to the inception voltage and the pulses are synchronized with the trigger set to channel one in the oscilloscope where the 10 cm monopole is connected. An example of the time domain signals acquired is shown in Fig. 5 for pulses at 3600 V. The sampling frequency is 10 GS/s, the acquisition time is 200 ns and the voltage peaks for the three signals are below 60 mV. Notice

TABLE I. CUMULATIVE POWER BY BANDS

Antenna type	**Cumulative Power by Bands (V^2)**		
	0 V	***3.6 kV***	***Ratio***
5 cm monopole 0 – 600 MHz	$6.53{\cdot}10^{-7}$	$1.98{\cdot}10^{-6}$	3.0
5 cm monopole 1300 – 1900 MHz	$2.51{\cdot}10^{-7}$	$3.661{\cdot}10^{-6}$	14.6
10 cm monopole 0 – 600 MHz	$3.62{\cdot}10^{-7}$	$1.034{\cdot}10^{-5}$	28.6
10 cm Monopole 1300 – 1900 MHz	$3.20{\cdot}10^{-7}$	$1.82{\cdot}10^{-6}$	5.7
Zig-zag 0 – 600 MHz	$1.30{\cdot}10^{-6}$	$2.96{\cdot}10^{-5}$	22.8
Zig-zag 1300 – 1900 MHz	$2.57{\cdot}10^{-7}$	$1.90{\cdot}10^{-6}$	7.4
Log-periodic 0 – 600 MHz	$4.22{\cdot}10^{-5}$	$3.13{\cdot}10^{-4}$	7.4
Log-periodic 1300 – 1900 MHz	$3.86{\cdot}10^{-7}$	$1.87{\cdot}10^{-6}$	4.8

that the signal for the log-periodic antenna is detected before the signals of the monopoles and zig-zag antennas. This is due to the fact that, even when the monopoles and zig-zag are closer to the test object, they have longer coaxial cables, (3 m long for log-periodic antenna and 5 m long for the others), connected to the oscilloscope.

The same FFT analysis is done for signals with pulses from partial discharges and the result is shown in Fig. 6. It is a remarkable fact that the amplitudes of the spectra in the low frequency range of the FFT, up to 600 MHz, are noticeably larger. However, the importance of these results lays on the FFT content that appears in the range from 1300 to 1900 MHz and that is directly related to the UHF emission of the partial discharge pulse, compare Fig. 6 and Fig. 4. These peaks are captured by the four antennas being the 5 cm monopole antenna the best one to visualize them. Moreover, it is also remarkable the performance of the 10 cm monopole considering its simplicity and inexpensive manufacture compared to the log-periodic antenna.

Table I. summarizes the behavior of the antennas showing the cumulative power by bands, in order to make a comparison between the frequency response of the antennas, in two ranges of frequency: from 0 to 600 MHz and from 1300 to 1900 MHz. The column on the right represents the ratio between the power content in squared volts in those ranges with PD and without PD. It can be clearly seen that the spectral power of the PD pulses detected with the antennas is notably larger than in the case of absence of PD, specially, in the lower frequency band of study, from 0 to 600 MHz. The best frequency response in this band is for the 10 cm monopole, and the zig-zag antennas, reaching a ratio of 28.6, and 22.8 respectively. In the higher frequency band, from 1300 to 1900 MHz, the cumulative power increase due to PDs activity is not so high but is more relevant because there is energy only when PD occurs otherwise, this band is flat. In this band, the best behavior is found for the 5 cm monopole with a remarkable ratio of 14.6. The 10 cm monopole and the zig-zag antennas only reach ratios of 5.7 and 7.4, respectively. The differences between 10 cm and 5 cm monopoles arise from their different sensitivity to

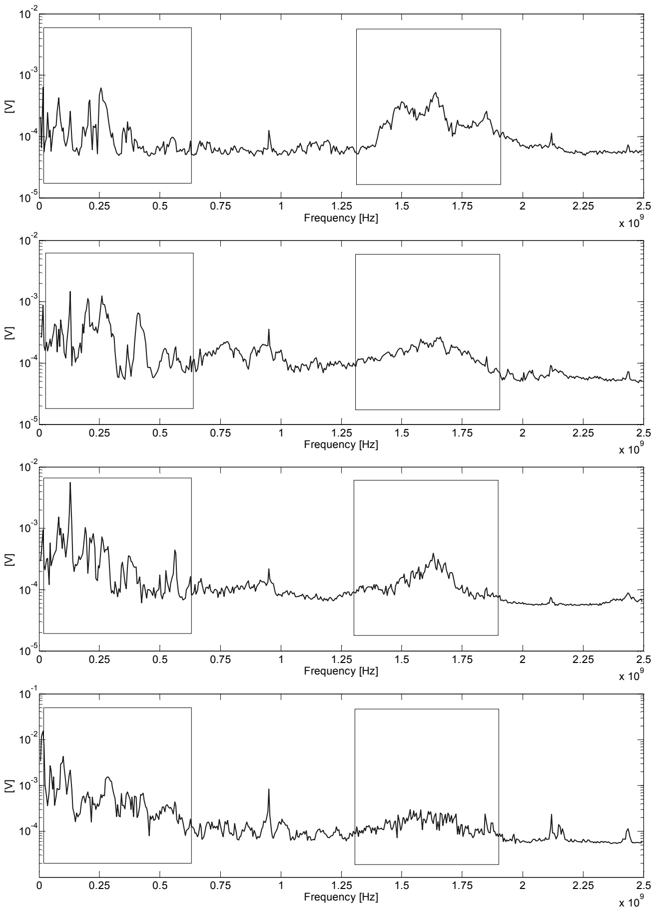

Figure 6. FFT voltage amplitude during the presence of PD at 3600 V. Top: 5 cm monopole antenna; Second one: 10 cm monopole antenna. Third one: zig-zag antenna.; Bottom: log-periodic antenna

electromagnetic radiation for different wavelengths, so the 5 cm monopole must have a better response at higher frequencies.

The poor performance of the log-periodic antenna can be seen in Fig. 5 where the direct electromagnetic wave of the PD had to be highlighted putting it into a box. These types of antennas capture PD and signals without diagnosis interest in a broadband of frequencies, and PD, generally with low emitting powers, are hidden by the rest of signals.

For all these reasons, if measurements are taken in noisy electromagnetic environments with high Radio Frequency (RF) spectral amplitudes, the 5 cm monopole would be the best option because it would detect PDs in the 1300-1900 MHz band with good sensitivity.

This study opens a research trend to characterize the behavior of monopole antennas with different lengths and shapes. The frequency response for these inexpensive monopoles shows a broadband behavior appropriate for UHF emissions from insulation systems. Their significant components above 1.3 GHz are an interesting characteristic for PDs location, where the geometric sensitivity is determined by the bandwidth of the antennas. Thus, several inexpensive monopoles can be used for PDs sites location in power systems.

IV. Conclusion

The 10 cm monopole and zig-zag antennas show an overall better performance in the two frequency bands of study after comparing the behaviour of the four antennas. However, the 5 cm monopole antenna is the best detecting PDs emitting in UHF from 1300 to 1900 MHz band. Monopoles and zig-zag antennas are strong candidates for further studies because these antennas are inexpensive, simpler, smaller, easier to manufacture and can be tuned to a frequency band of interest by changing their lengths. The paper also gives practical indications about PDs detection with different antennas.

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