Condition Assessment of Power Cable Accessories using Advanced VHF/UHF PD detection

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***Abstract*- This paper introduces a new advanced partial discharge detection system for detecting partial discharge activity in the accessories of power cables during the acceptance test. The system consists of three autonomous PD measuring systems which communicate via a wireless communication network with one main computer. As a result, the measured data of each measuring unit can be displayed and analyzed at one single point near e.g. the voltage source which makes easy communication between the measuring technician and test engineer possible.**

Based on several field measurements performed in Europe on different 380kV and 150kV cables systems aspects of measurement and data processing are discussed.

I. INTRODUCTION

To achieve high quality of cable accessory installation in transmission power cables, partial discharge detection is becoming an important issue during the on-site acceptance test. In this way, the presence of discharging insulation defects in the cable accessories can be investigated. To be able during this voltage test to detect simultaneously in all cable accessories partial discharge activity, the joints and terminations are equipped with VHF/UHF PD detectors.

II. VHF/UHF PD DETECTION

Partial discharges (PD) may occur in power cables as a result of insulation defects. The origin of discharging defects can be related to poor workmanship (new or repaired cables) or to service related insulation degradation effects. In all these cases, due to local field enhancement till breakdown, discharge pulses are produced at the defect site. It is known that each of these PD pulses consists of energy frequencies up to hundreds of MHz.

Therefore, a spectrum analyser has been used to capture these high-frequency signals, as is commonly used in e.g GIS [1]. The first step in making a measurement is capturing the frequency spectrum. Based on this spectrum, a certain centre frequency which represents PD activity with the highest signal-to-noise ratio is selected. Secondly, a spectrum analyser can also analyse the coupler's signals in the time domain, resulting in similar phase-resolved PD patterns that are obtained with a standardized measuring circuit. Such phase-resolved PD patterns offer the possibility to recognize a certain type of defects and to discriminate between insulation defect and noise.

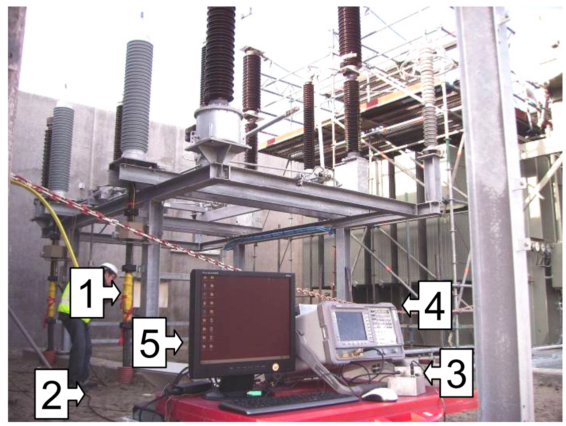

Fig. 1. VHF/UHF PD detection system as installed in the field consisting of (1) internal inductive sensor, (2) a coaxial cable, (3) a VHF/UHF pre-amplifier, (4) spectrum analyser and (5) PC.

The basic parts of the VHF/UHF measuring setup are shown in Fig. 1. It contains:

1) A sensor
2) A 30 dB VHF/UHF pre-amplifier
3) A coaxial cable
4) A spectrum analyser (SA)
5) A computer

Different types of sensors can be used. In practice, capacitive and inductive sensors are used, which can be either internal or external sensors. Fig. 1 shows an internal inductive sensor, installed in the cable. To have better sensitivity, the signals are amplified by a 30 dB pre-amplifier. Using a spectrum analyser, the frequency spectrum is measured, which can contain background noise signals and PD signals. Finally, the data is stored on a PC, which contains software to analyse and further interpret the measured data.

III. WIRELESS PD DETECTION SYSTEM

Fig. 1 shows one VHF/UHF measuring unit. However, most cable systems consists of at least two cable terminations and often one or more joints are present as well. Therefore it is of interest to be able to monitor all terminations and joints at the same time. This is of course possible if more VHF/UHF measuring units are available, but requires additional measuring technicians as well.

To solve this problem, the concept of a wireless VHF/UHF PD detection system was introduced [2]. In this concept, the

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PC which is already part of each VHF/UHF measuring unit is equipped with a network interface card to set up a wireless communication network. Using a remote control software, a main computer can access and control the PC of each measuring unit from a distance via this wireless network. As a result, there is a high reliability in the measuring results, because the measuring system is still fully controlled by its own PC and all data is stored on this PC as well. However, the measuring technician controlling the main computer to analyze the measuring results of each measuring unit, is still able to change settings if required. If the measuring technician is close to the test engineer, good communication between both is guaranteed and proper actions can be taken if the measuring results require that. Fig. 2 shows the basic layout of the developed wireless VHF/UHF PD detection system. In this example, three measuring units were used.

Fig. 3 shows an example of an actual field measurement in which the wireless VHF/UHF PD detection system was used. It shows one side of a 380 kV cable system consisting of three single phase XLPE cables, with two terminations and one joint. During this experiment, internal inductive PD sensors where used.

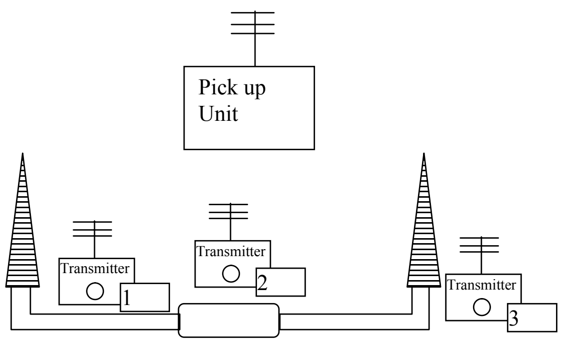


Fig. 2. Basic setup of the wireless VHF/UHF PD detection system.

Fig. 3. Overview of one side of a 380 kV cable system. The top inset shows the antenna which is used to make the wireless communication with the main computer and other measuring units possible. The lower inset shows a detail of the internal inductive PD sensor.

IV. DATA PROCESSING

To control the spectrum analyzer settings, and to analyse the obtained data, a special designed software package is being used. With this software it is possible to measure the coupler's signal in frequency and phase domain. The data obtained in frequency domain is particularly used to determine the frequency bands in which continuous disturbance signals are present, e.g. coming from radio, television and radar. During the setting of the narrowband filter for the PD measurement in phase domain, these frequency bands should be omitted.

An example of such a frequency analysis is shown in Fig. 4. This Fig. 4 shows both the background noise frequency spectrum as well as the frequency spectrum at the test voltage level. Although both spectra seem to be slightly different, further analysis is required to specify this difference.

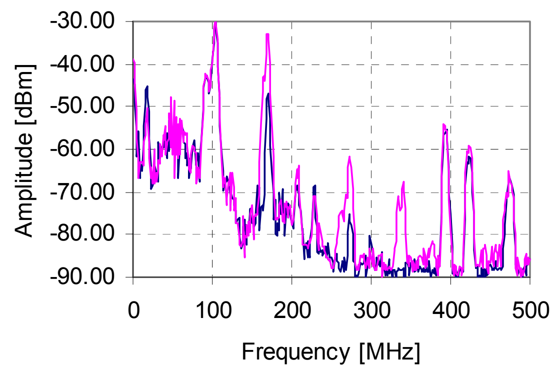


Fig. 4. Frequency spectra as obtained during testing: blue: background noise level; pink: at test voltage.

One possibility is to process the signal-to-noise ratio of both captured frequency spectra [3]. Due to the fact that both spectra are measured as logarithmic values, this means a simple subtraction of both spectra. The result is shown in Fig. 5.

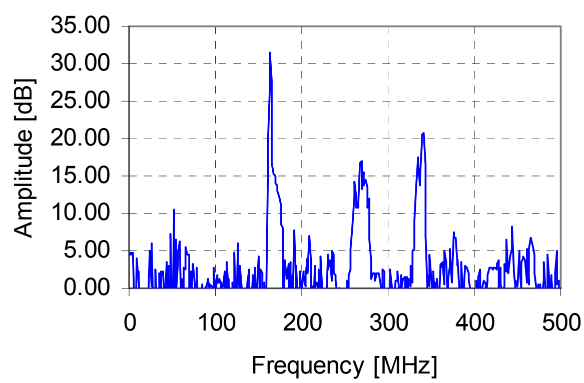


Fig. 5. Signal-to-noise ratio of the frequency spectra shown in Fig. 4.

Once with high signal-to-noise ratio and disturbance free frequency bands are selected, the operation mode of the spectrum analyzer is changed into a tunable filter mode. The bandwidth ranges from 3-5 MHz and the center frequency is selected inside the defined proper frequency bands. During the measurement, the PD pulses are stored in relation to the phase-angle of the test voltage. Moreover, during the test time, the PD level is shown as function of the time, see Fig. 6.

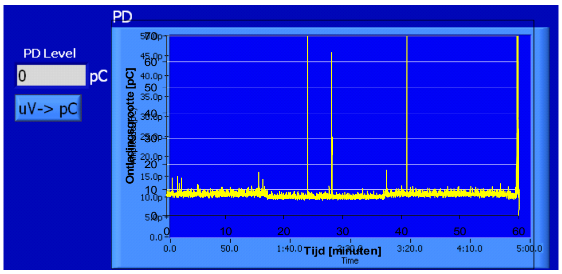


Fig. 6. Screen dump of the software during testing: PD magnitude vs time.

During the testing time, the screens of the three different measuring units are sequentially displayed on the main computer. As soon the PD level trend over time changes, the phase-resolved pattern belonging to this change are viewed. In case of the large peaks shown in Fig. 5, the patterns showed no correlation with the test voltage. Moreover, only some large disturbance signals were present and no actions were needed.

V. Measuring Results

The first example is the 'after laying test' of two 2-phase cable systems of 150 kV. Fig. 7 shows the terminations of both circuits at the side of the voltage source. In this example, integrated inductive sensors were applied. The test specifications were 10 minutes of 2.5U0 (220 kV) voltage application. During these 10 minutes, no PD activity should be visible.

Fig. 7. On-site testing of two 2-phase 150 kV cable systems with integrated inductive PD sensors.

Fig. 8 shows examples of phase-resolved PD patterns as were obtained during these 10 minutes test and during the rise

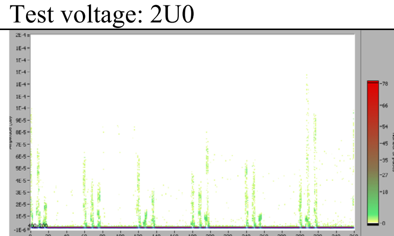
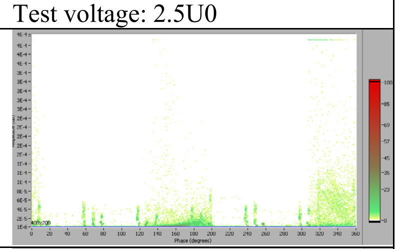
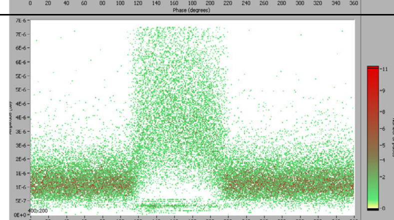
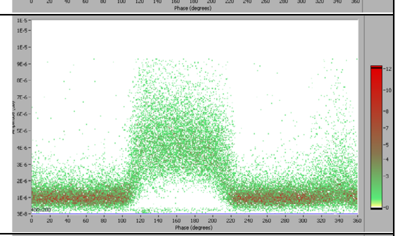
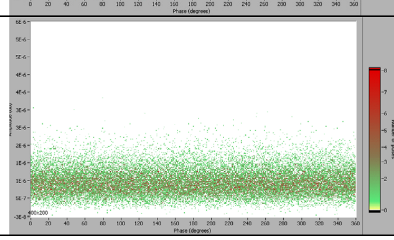
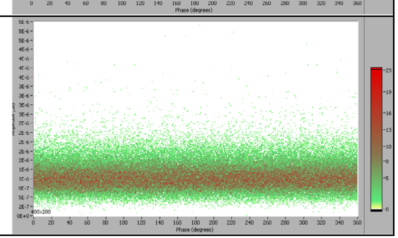
Center frequency	Signal type	Test voltage: 2U0	Test voltage: 2.5U0
3 MHz	Thyristor pulses originating from the voltage source		
123 MHz	Corona in air		
320 MHz	Noise and PD free		

Fig. 8. Examples of measured phase-resolved PD patterns at different measuring frequencies during on-site testing of two 2-phase 150 kV cable systems with integrated inductive PD sensors.

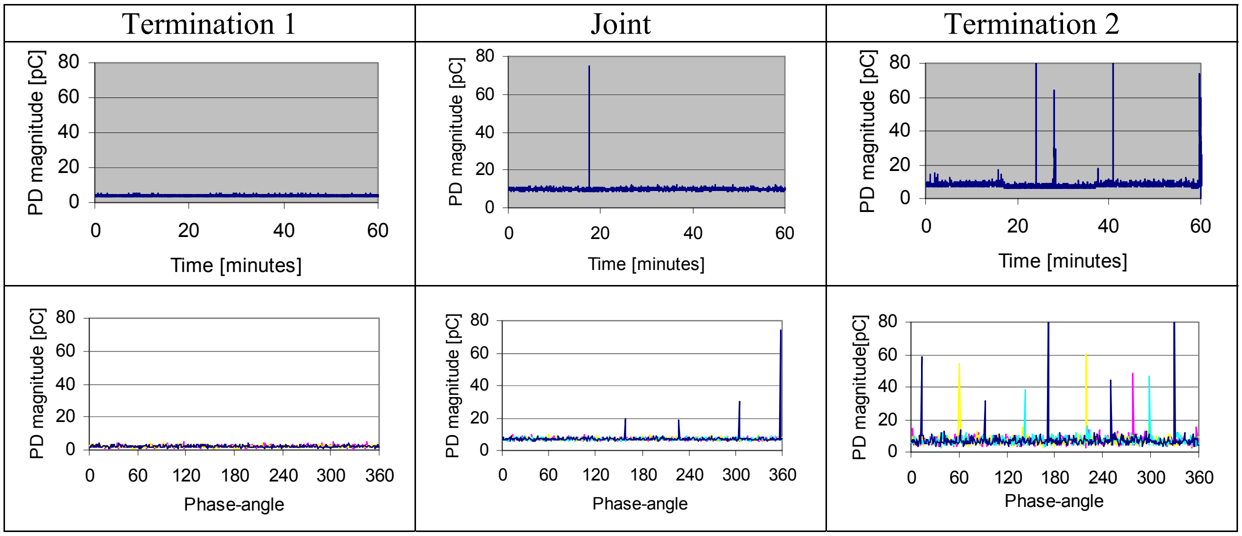


Fig. 9. Measuring results simultaneously obtained at the three cable accessories during the acceptance test of one cable: the PD magnitude versus time for one hour testing and examples of phase-resolved patterns obtained during several cycles of the test.

of the test voltage. During the tests, measurements were performed at three different center frequencies not only to investigate the influence of the centre frequency, but to scan for PD activity over the full frequency range. The results confirm the common knowledge of the effect of tuning the frequency [3]. At frequencies below some tens of MHz, only the inverter of the voltage source influences the measuring results as can be observed in the first row of patterns shown in Fig. 8. Corona discharges in air are usually well below 200 MHz and can therefore clearly be recognized. Furthermore, at higher frequencies, PD pulses are expected to be more dominant. In this case however, no partial discharge activity was observed.

As a second example, the described measuring system was applied during the 'acceptance test' of two new 380 kV XLPE cable connections of about, see Fig. 3. The test voltage was 374 kV for 1 hour and the measuring system was active during the voltage increment and the 1 hour test. At the start of the test, the voltage was increased to about 100 kV to check the triggering and the communication between the systems. After that, the voltage was increased in three steps to the test voltage. At each voltage step, the measuring systems were tuned at different frequencies to investigate the presence of partial discharge activity at one of the accessories. Except for some corona discharges in air at the voltage source side, no partial discharge activity was observed at the accessories and the 1 hour test was started.

During the 1 hour test, the measuring frequencies of each measuring unit was kept constant at the best signal-to-noise ratio. Due to the fact that the terminations act as large antenna's, some external noise activity could be expected and was observed. In order to discriminate between these external disturbances the phase-resolved PD patterns were measured as well. The advantage of using a narrow-band tunable filter is that such phase-resolved PD patterns are measured real-time, in other words, no time-consuming data-processing is required afterwards to determine the presence of insulation defects. Even during voltage rise, the PD patterns are displayed and updated continuously and any inception of PD or change in PD pattern is detected at a very early stage and can be used for the decision-process of continuing the test.

VI. Conclusions

Based on the investigations described in this contribution, the following can be concluded:

1) Using a wireless communication network, data obtained at three different cable accessories could be simultaneously displayed and analyzed.
2) Using a narrow-band VHF/UHF detection system, the disturbances level was below 10 pC.
3) By changing the center frequency of the tunable filter, disturbances coming from thyristor pulses and corona in air can be effectively suppressed.

Acknowledgment

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