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ON-SITE VHF PARTIAL DISCHARGE DETECTION ON POWER CABLE ACCESSORIES

Sander MEIJER, TU Delft, (Netherlands), s.meijer@tudelft.nl
Rogier A. JONGEN, TU Delft, (Netherlands), r.a.jongen@tudelft.nl
Johan J. SMIT, TU Delft, (Netherlands), j.j.smit@tudelft.nl
Paul P. Seitz, Seitz Instruments A.G., (Switzerland), pps@seitz-instruments.ch
Theo J.W.H. HERMANS, Prysmian B.V., (Netherlands), Theo.Hermans@prysmian.com
Lawrence LAMBALLAIS, Prysmian B.V., (Netherlands), Lawrence.Lamballais@prysmian.com

ABSTRACT

During the on-site installation of power cables, mistakes in installing cable accessories can occur. If this results in insulation defects, partial discharges (PD) can occur. These PD will erode the insulation, can bridge the distance between both conductors which will result in a complete breakdown and failure of the cable system. It is known that PD pulses consists of energy frequencies up to hundreds of MHz. Therefore a VHF/UHF PD detection system is applied to detect partial discharges in a non-conventional way. Aspects that need to be considered during the development of such a system such as detection method, sensor type and location, calibration etc. are presented and discussed in this contribution.

KEYWORDS

Partial Discharges, VHF/UHF PD detection, Non-conventional PD detection.

INTRODUCTION

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

Partial discharges in a power cable system can occur due to different insulation defects: such as at a gas-filled cavity, a protrusion in a semi conductive layer, or conversion of a water tree by a lightning or switching over-voltage etc. [1]. If allowed to continue, partial discharges will erode the insulation, usually forming a tree-shaped pattern of deterioration (electrical tree) which will grow through the dielectric and eventually bridge the conductors resulting in a complete breakdown and failure of the cable or accessory.

In this paper the results of after-laying testing of transmission power cable accessories using a non-conventional technique are being presented. The non-conventional system is based on the detection of high frequency signals being emitted by the discharge. Therefore, each power cable accessory is equipped with either an internal or external sensor to decouple the partial discharge signals. The partial discharge detection system uses narrow-band detector, in this case a spectrum analyzer. Laboratory experiments are presented on artificial defects to show its applicability.

PARTIAL DISCHARGE DETECTION

PD pulses as occurring in the cable insulation can contain frequencies of up to several hundreds of MHz. However, especially the higher frequencies tend to attenuate rapidly with the distance, see figure 1. As is shown in this figure, below 10 MHz, the attenuation is negligible, however, above this frequency the attenuation increases rapidly with the frequency at which the PD signals propagate. As a result, picking up the higher frequency components is only likely when the sensor is close to the discharging site. Therefore, to be selective during the after-laying test in which the accessories are of main interest, selecting higher measuring frequencies will ensure that only PD activity present in the accessories will be detected. In this way, discrimination between PD in the cable itself and the accessory is effectively achieved.

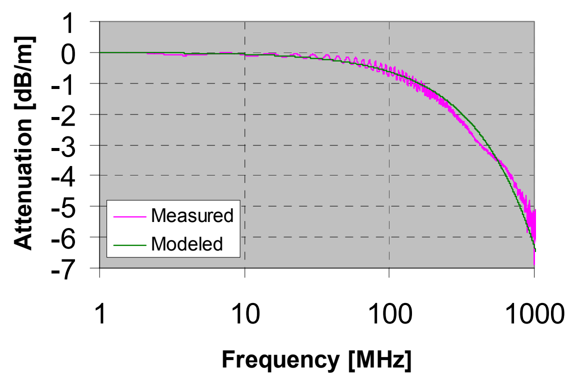

Figure 1: Measured (pink line) and modeled (green line) attenuation of high-frequency signals propagating inside a 380 kV XLPE power cable.

So, the HF/VHF/UHF PD detection system is applied locally on the power cable accessories [2, 3]. Figure 2 represents two stand-alone systems diagnosing different cable accessories. The diagnostic HF/VHF/UHF (PD) detection systems consist mainly of four parts:

1. a detection part that acquires information about possible PD in an accessory (red: sensor, amplifier),

2. a triggering part taking care of a proper correlation with the applied high-voltage (blue: sensors, triggerbox),
3. a measuring part that uses the tunable band-pass filter of a SA to reject ambient noise (yellow: SA) and
4. a PC equipped with special designed software for further interpretation of the acquired information (green).

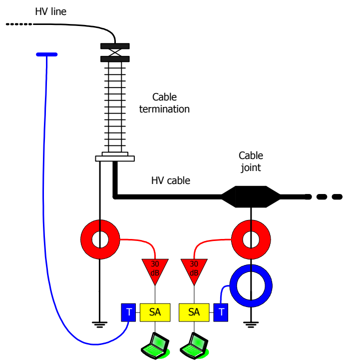

Figure 2: Two stand-alone systems applied to a cable termination (left) and a cable joint (right).

For successful narrow-band PD measurements at HF/VHF/UHF parts of the spectrum, basically three things are necessary:

1. a proper transfer of PD signals through the object under test and the detection system at the selected centre frequency (CF) of the band-pass filter,
2. low ambient noise and disturbances in the frequency spectrum around the selected CF and, most important,
3. in case a PD source is present, it should emit signals with a frequency-content around the CF.

Aspects regarding the first point are described in more detail in [4]. Regarding the third point, these aspects can not be influenced and in general frequencies up to 500 MHz can be expected. The second point will be addressed in this contribution.

Figure 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.

In the Netherlands, during the after laying test of e.g. 380 kV XLPE cable circuits a voltage of 1.7U0 (374 kV) has to be applied during one hour. As described, PD activity has to be monitored for during this one hour at the accessories. To assist the test engineer who is controlling the voltage source during the test, it would be beneficial to have all measuring data available at the voltage source site. Therefore, an advanced PD detection system was developed. It consists of stand-alone VHF/UHF measuring units that communicate with and are controlled by a main computer next to the test engineer using a wireless communication network. In case any change in PD magnitude or PD pattern (if present) is observed, this can be reported immediately in order to take the required actions. Figure 3 shows the hardware of the wireless system.

LABORATORY MEASUREMENTS

The first point is also well-known from measurements taken in the field of GIS and transformers [5]. 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. From the SNR as shown in figure 4, a frequency of 10 MHz, 40 MHz and 175 MHz show peaks that might indicate partial discharge activity.

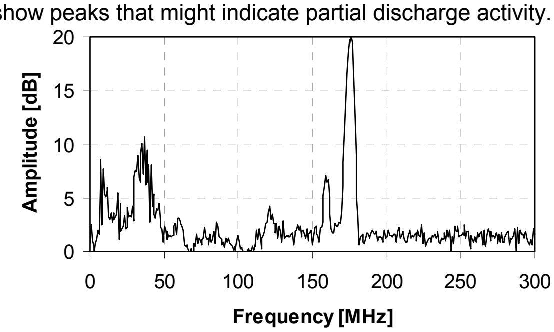

Figure 4: Example of a SNR frequency spectrum obtained during a laboratory experiment in which three frequency ranges show additional activity which could originate from partial discharges.

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 offers the possibility to recognize a certain type of defect and to discriminate between insulation defect and noise. At 10 MHz and 40 MHz, the phase-resolved PD pattern shown in figure 5 was detected. At 175 MHz, no PD activity was observed.

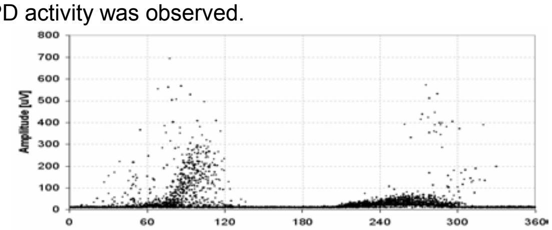

Figure 5: Detected PD pattern in the same laboratory set-up, detected at 40 MHz, originating from a small cavity in the cable.

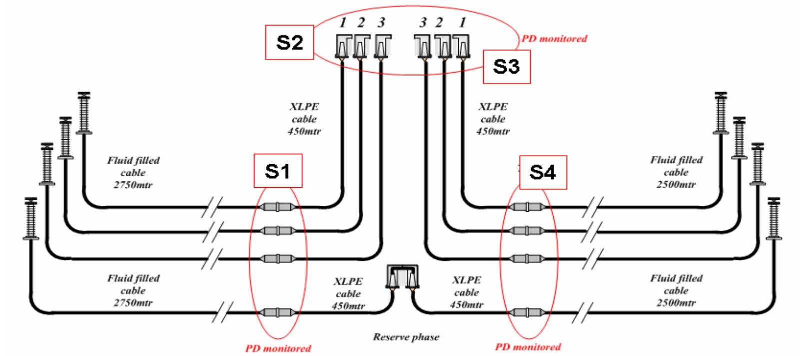

Figure 6: Lay-out of the cable system under test.

Figure 7: Oil-XLPE cable transition joint

FIELD MEASUREMENTS

Above mentioned system was being applied during acceptance tests of new high-voltage power cables. The lay-out of the first example is shown figure 6. In fact, an existing three-phase 110 kV oil-filled cable with one reserve phase has been split to install a GIS substation. The connection between the GIS and the existing cable system is made of new XLPE cables. During the after-laying test, PD activity is monitored at the XLPE-oil transition joints (figure 7) and the GIS terminations.

No PD activity was detected on sensor-locations S1 and S2. However, in phase 3 on sensor S3 and S4, PD activity was detected. Figure 8 shows the detected PD levels in [uV] as obtained at both sensor locations. The PD pattern shows similarities with internal discharges as can be seen in figure 9.

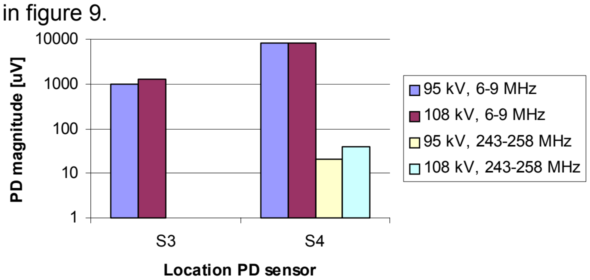

Figure 8: Example of measuring results obtained in phase 3.

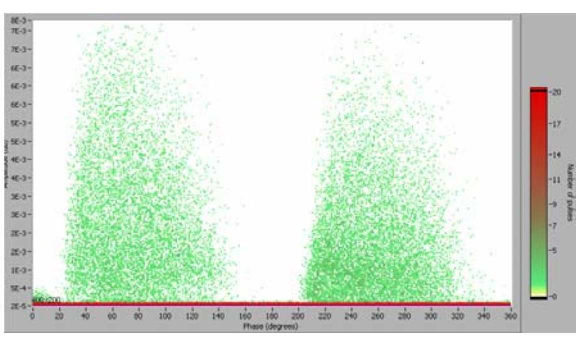

Figure 9: Example of a phase-resolved PD pattern as obtained in phase 3.

Furthermore, the following observations can be made from figure 8. First of all, the PD levels detected in a low frequency range of 6-9 MHz at sensor S4 are slightly higher than at sensor S3. Secondly, in a higher frequency range of 243-258 MHz, PD activity was only detected at sensor S4.

From the determined frequency response during the sensitivity check the PD level was estimated to be 70 pC. This level was stable during the 1 hour test and no breakdown occurred. Based on these results it was concluded that there is PD activity in phase 3. Due to the fact that in higher frequencies these PD's are not detectable at the GIS terminations (S3) it can be stated that the GIS terminations are PD-free. At the joint the PD activity was measured also at the higher frequencies. Therefore, as demonstrated in figure 1, it can be stated that the PD activity has its origin near these joints, in the oil-filled part of the cable system. The utility decided to take the cable system into service, but have regular oil samples at the joints to monitor the development of the PD activity.

A second example is the after-laying test of a 380 kV XLPE cable of 500 meters long. It connects an HVDC converter station to a gas-insulated substation. External sensor where applied around the earth connection, as shown in figure 10.

Figure 10: PD and trigger probe around the earth connection of a 380 kV cable-to-GIS transition joint.

Figure 11 shows examples of obtained measuring results as detected at both ends of the cable. Measurements where obtained at 374 kV, during 1 hour of testing, and the detection circuit was tuned at 294 MHz. At both sides, a noise level of about 3 pC was reached. However, at the cable-to-air termination, the disturbance level was larger, coming from electrical machines present. At the GIS-transition joint, no disturbances where detected.

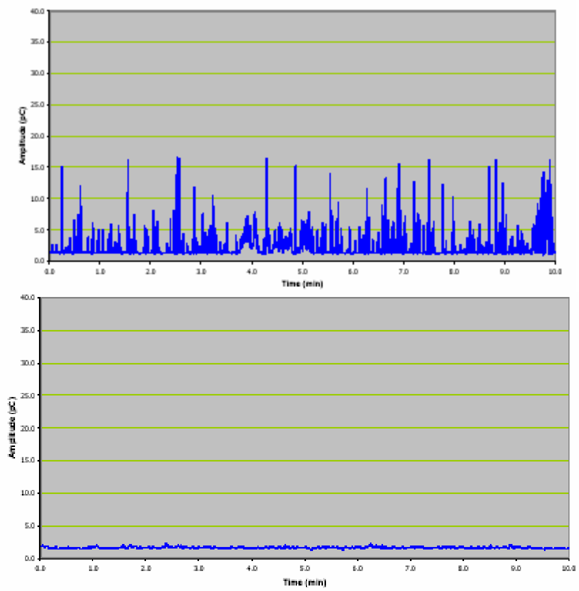

Figure 11: PD magnitude as function of time, detected at a center frequency of 294 MHz, at a voltage level of 374 kV. Top figure is measured at the air-termination, bottom figure at the cable-to-GIS transition joint.

For both sides could be concluded that no partial discharge activity above noise level was present, which is confirmed by the phase-resolved PD patterns as shown in figure 12.

CONCLUSIONS

Based on the investigations described in this contribution, the following conclusions can be drawn concerning the VHF/UHF PD detection technique:

1. It is a flexible and non-intrusive technique suitable for PD detection during after-laying tests of power cables;
2. Sensitive enough to detect PD several pC's by selecting a frequency range with good signal-to-noise ratio in which case a noise-level of around 2-3 pC can be achieved;
3. Rough PD site location can be done by comparing data obtained in low- resp. high-frequency ranges;

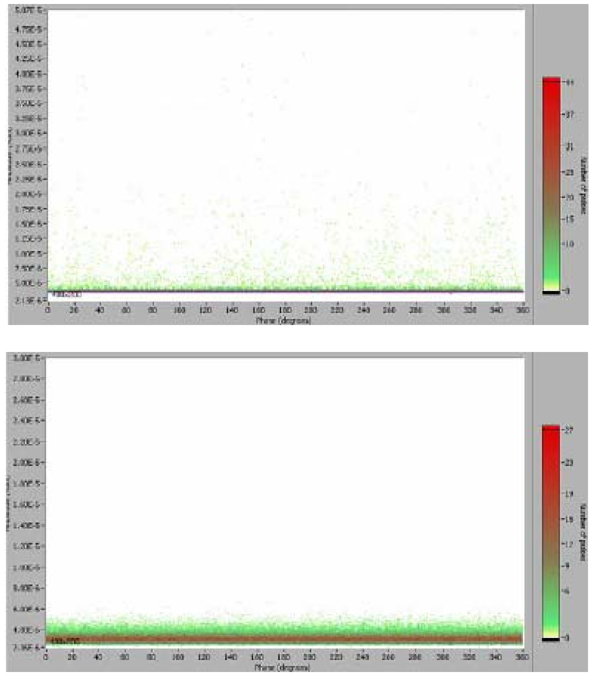

Figure 12: Phase-resolved PD patterns, detected at a center frequency of 294 MHz, at a voltage level of 374 kV. Top figure is measured at the air-termination, bottom figure at the cable-to-GIS transition joint.

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