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SENSITIVITY VERIFICATION PROCEDURE OF VHF PD DETECTION SYSTEMS

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ABSTRACT

Partial Discharges (PD) in a power cable system can occur due to different insulation defects. If allowed to continue, PD will erode the insulation, eventually bridge the conductors resulting 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 using a VHF/UHF sensor detecting partial discharges is possible. However, the high-frequency behaviour of the sensor, the measurement cables, etc. have a strong influence on the response of VHF/UHF PD detection systems. Therefore, calibration is difficult and several related issues are presented analytically and discussed.

KEYWORDS

Partial Discharges, VHF/UHF detection, Calibration, Sensitivity Check.

INTRODUCTION

Partial Discharges (PD) 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 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.

The purpose for testing new installed power cables is mainly checking the assembly or workmanship performed in the cable accessories. As a result of poor workmanship, defects can be introduced. Moreover, since the power cable itself has been tested in the factory it may be assumed that the cable itself is defect-free. Therefore, for new installed power cables, the accessories are the main interest of the investigation. Due to local field enhancement till breakdown, discharge pulses are produced at the defect site, which consists of energy frequencies up to hundreds of MHz.

In this respect, partial discharge (PD) detection during the on-site after-laying test is getting more and more important to ensure high quality of the power cable installation. The presence of partial discharge activity can be used to assess the condition of the cable accessory during e.g. the rise of the test voltage and the test can be put on hold in order to take the proper actions. To enable PD detection, non-conventional detection techniques based on very- or ultra-high frequencies are more and more applied. Although these techniques are very sensitive and detection of small insulation defects is possible, the calibration of these systems in a similar way as a conventional detection system is not possible yet. This paper will give an overview of the influencing parameters and discuss a procedure that can be used to check the sensitivity of the detection system on-site.

VHF/UHF PARTIAL DISCHARGE DETECTION

The 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. As a result, picking up the higher frequency components is only likely when the sensor is close to the discharging site. In the case described here, the focus is on cable accessory testing and the sensor will therefore be always close to possible discharging defects.

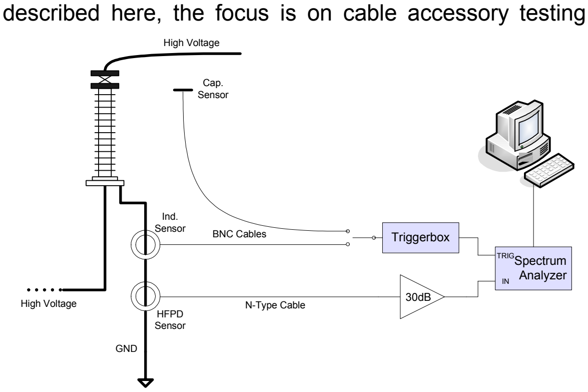

Figure 1: Sketch of the high frequency partial discharge detection system for testing of cable accessories.

As known from high-frequency PD measurements on GIS, a spectrum analyzer (SA) is a suitable and convenient instrument of capturing and analyzing the PD pulses [2]. Figure 1 shows the measuring setup at a cable termination. The system can be divided into a signal part and triggering part. The signal part consists of an internal or external high frequency PD sensor, a signal amplifier and the spectrum analyzer connected to a PC. The triggering part consists of an inductive sensor for picking up the applied test voltage, a trigger box to generate the trigger signal which is connected to the spectrum analyzer.

Based on the measuring set-up as shown in figure 1, it can be concluded that the PD detection part contains several components, which all have their specific influence on the sensitivity and response. In this paper the influence of 1) the PD sensor, 2) the pre-amplifiers and measuring cables and 3) the cable accessory will be investigated and used to set up a procedure to verify the detection sensitivity of the PD detection system.

SENSORS FOR PD DETECTION

In order to capture the PD presence in cable accessories, the PD pulses have to be decoupled from the cable accessory using a high-frequency sensor as stated before. Figure 2 shows examples of possible ways to extract the PD signals from the cable. In practice, ways to extract the PD signals from the cable accessories is based on capacitive or inductive coupling. However, mainly inductive coupling is used, either by internal sensors or external sensors. Although internal sensors are sometimes available on new cables (if specified during the development process), most new cables and of course older cable systems are not equipped with internal sensors. For that purpose, external inductive sensors (high-frequency current probes) can be applied, mounted around the ground wire to pick up the PD signals.

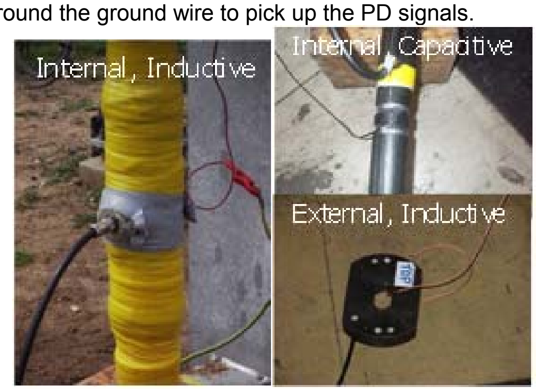

Figure 2: Examples of different sensors to extract the partial discharge pulses from the cable accessories.

To compare the sensitivity of PD sensors, the transfer functions of internal and external sensors were compared. The tests were performed on a 30 meter long, 275 kV XLPE cable setup, containing two terminations, a cable joint and a cable transition joint. Each joint and termination was equipped with an internal PD sensor. Moreover, at both terminations, an external PD sensor was fitted as well. The results of the measurements are shown in figure 3. As we can see, the internal PD sensors have a much higher TF than the external current probes, and thus can reach a much higher sensitivity.

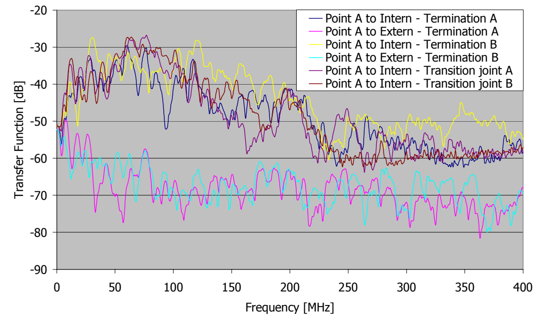

Figure 3: Transfer functions to compare internal PD sensors (yellow, blue, purple and brown lines) with external PD sensors (blue and pink lines).

Besides the influence of the location of the sensor (so either internal or external) also the type of (external) sensor has an influence. Figure 4 shows a comparison between two external sensors: one VHF probe and one UHF probe. As could be expected from the specifications of both sensors, the UHF probe shows a flatter transfer function over the full frequency range up to 500 MHz, whereas the VHF probe shows a more irregular behaviour. However, the average transfer impedance over the frequency range of interest (up to 500 MHz) is the same for both sensors. Therefore it can be concluded that both sensors can be used, however, the high frequency behaviour of the VHF probe in the UHF range should be known in order to ensure sensitive PD measurements. For that purpose, a sensitivity check has to be performed, as will be discussed later in this contribution.

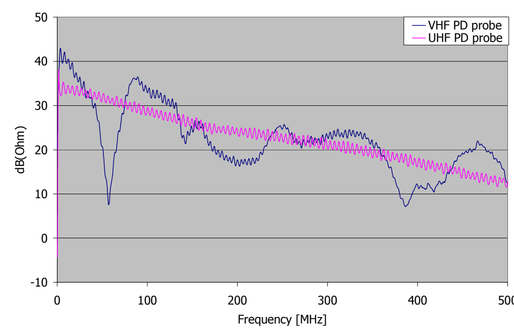

Figure 4: Transfer functions to compare external PD sensors: blue line is a VHF PD probe, pink line is a UHF PD probe.

Besides the transfer functions of the sensors, also the response of the detection system to partial discharge pulses is of importance. For that, a fast calibrator is being used and the response of the detection system to different PD magnitudes is measured at different frequencies. An example is shown in figure 5.

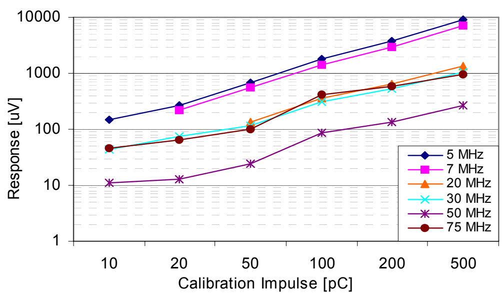

Figure 5: Response of the VHF/UHF detection system to calibration impulses at different measuring frequencies.

MEASURING CABLES

The second influencing parameter is coming from the measuring cables, which connect the PD sensor via a high-pass filter and a pre-amplifier to the spectrum analyser.

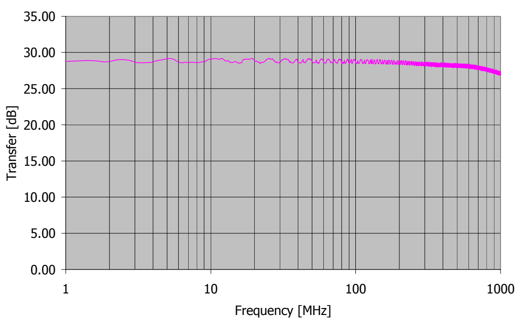

Figure 6: Transfer function of a pre-amplifier.

Figure 6 shows an example of the transfer function of one of the pre-amplifiers. It can be seen that the amplifier has an almost flat response of 28 dB up to 1000 MHz. As a result, the amplifier has no significant influence in the signal response other than increasing the signal in a same way for all frequencies. A similar statement can be made for the high-pass filter, which is used to protect the high-frequency amplifier against high-energetic low frequencies picked up by the PD sensors. The transfer function is shown in figure 7.

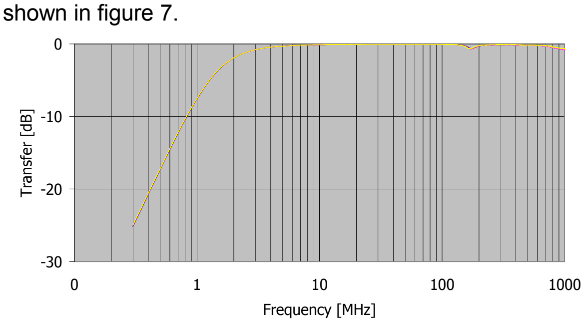

Figure 7: Transfer function of a high-pass filter.

The transfer of the used measuring cables is shown in figure 8. It shows measured and calculated values for 10m, 15m and 45m long measuring cables. The transfer was calculated using the method as described in [3]. It can be concluded that the measurements and calculations agree well within 0.2 dB. Moreover, the cable attenuation increases with increasing frequency. As a result, the sensitivity of the measuring system decreases slightly with increasing frequency. Moreover, longer measuring cables exhibit higher attenuation as well.
As a result, it can be concluded that the pre-amplifier and high-pass filter have no influence on the frequency behavior of the detection system. The measuring cables have an influence but this influence can be estimated accurately.

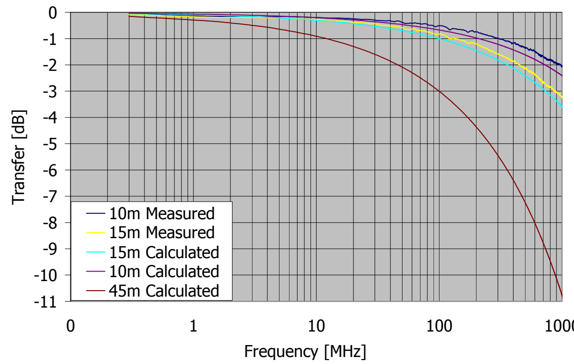

Figure 8: Calculated and measured transfer function of different lengths of measuring cables.

CABLE ACCESSORY

If a partial discharge source is present in a cable accessory, its location is also influencing the detectability. To investigate this influence, a 380 kV termination of 4 meters high was modelled. Five PD sites where simulated inside a termination. PD site C1 is located on top of the termination, PD site C5 at the bottom of the termination. In between, three other locations were selected. The transfer from these artificial PD sites inside the termination (C1-C5) to the sensor (D) was then calculated. C1 is furthest away from the sensor, C5 is closest to the sensor. Figure 9 shows the used model to estimate the transfer function. Figure 10 shows the simulation results.

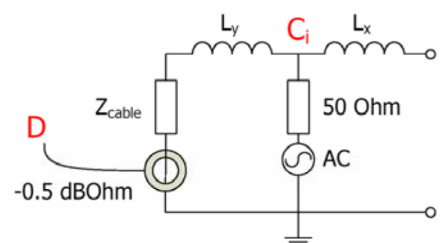

Figure 9: Model used to simulate the influence of the location of PD sources inside a termination.

As expected, the simulation results confirm that PD signals originating from the top of the termination are more attenuated than PD signals originating from e.g. halfway the termination. Moreover, the attenuation is frequency dependent, and again the higher the frequency, the higher the attenuation.

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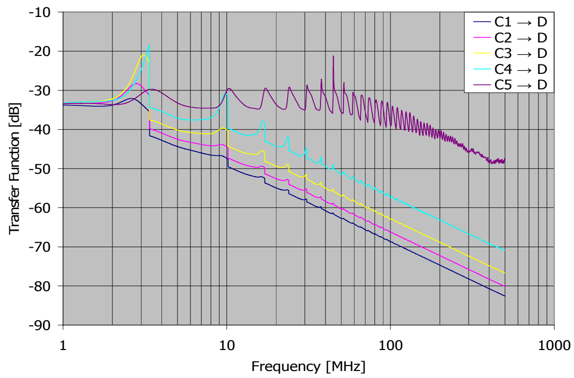

Figure 10: Simulated transfer functions between an artificial PD site inside a termination and PD sensor.

SENSITIVITY CHECK

As shown in the previous sections, the several parts in the detection part influence the sensitivity. In particular the cable accessory itself and the measuring cables attenuate the signals which increases with increasing frequency. However, this influence can be estimated rather well by simulations.

On the contrary, the PD sensors show to have a more complex and completely different influence on the transfer function. Moreover, another important aspect for performing partial discharge measurements is the calibration of the detection system. For PD detection systems according to the IEC 60270 [4], this calibration procedure is well defined and described in the standard. However, for these VHF/UHF PD detection systems, calibration is not possible, due to the high-frequency behaviour of the sensor, the type and routing of the measurement cables as shown before.

To determine the response of the detection circuit on PD pulses, a sensitivity check was performed. The basic circuit of this sensitivity check is shown in figure 11. Using a high-frequency pulse-generator, artificial PD pulses are injected into the cable termination and detected on the VHF/UHF sensor installed at the same termination. In this way, the frequency response of the detection circuit at this termination can be determined in which the influence of the full termination, the PD sensor and measuring cabling is taken into account.

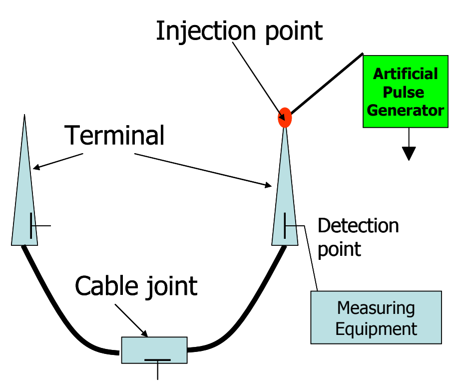

Figure 11: Sensitivity check of the VHF/UHF detection circuit for on-site PD detection on power cables.

As a result, a sensitivity check procedure is proposed which is similar to the sensitivity check as is being applied for UHF PD detection on gas-insulated systems [5]. The procedure consists of the following steps:

1) In a laboratory setup use a PD-source with known magnitude (pC) and measure the frequency spectrum.
2) Use an artificial pulse generator to inject pulses into the termination and change the amplitude until a frequency spectrum is detected which is comparable to the measured frequency spectrum originating from the PD source (see step 1).

From this test, the relation between calibrated PD magnitude and artificial pulse is known for a certain measuring circuit. This can be used to test the sensitivity of the on-site measuring circuit by the step 3.

3) Sensitivity check of the on-site measuring circuit by injecting the pulse shape found under step 2 on each termination. If the injected signal is detected, this means that the sensitivity is high enough to detect partial discharge activity with a certain magnitude in pC as defined under step 1.

This sensitivity check procedure was used in a cable setup inside the laboratory. An artificial corona source was generated at the termination and its amplitude was recorded using an IEC 60270 detection circuit and using the VHF/UHF detection circuit at different measuring frequencies.

Then a pulse generator was used to inject pulses at the cable termination and the response was measured. The pulse was adjusted until a similar result as coming from the corona source was achieved. The results are shown in figure 12 and 13.

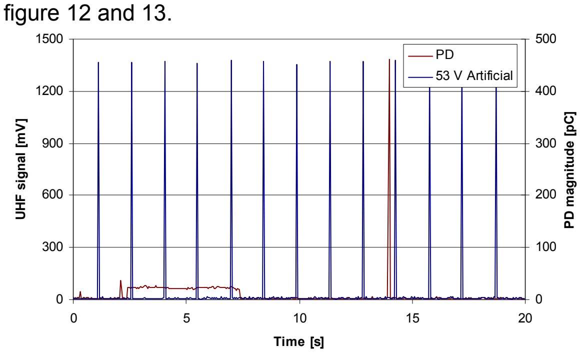

Figure 12: The recorded pulses of 53V from the pulse generator (blue) match in amplitude with the max peak of the corona PD pattern (red) of 500pC

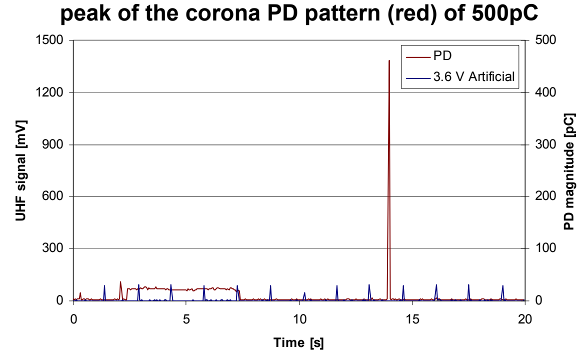

Figure 13: The recorded pulses of 3.6V from the pulse generator (blue) match in amplitude with the PD level of 40pC at the first half cycle (red).

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The recorded pulses of 53V from the pulse generator (blue) match in amplitude with the max peak of the corona PD pattern (red line) of 500pC at the second half cycle. The voltage level of 3.6V matches the PD level of 40pC at the first half cycle. Thus 1V represents 10pC.

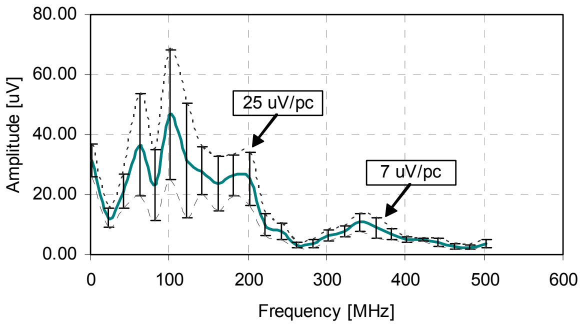

Figure 14: Average transfer function and its spread of 12 cable terminations.

Now the relation between real PD magnitude and artificial pulse is known, it can be applied in the field. Using a fast impulse generator which was calibrated in the laboratory, artificial PD pulses were injected into each cable termination before the actual PD test. The VHF/UHF measuring unit was tuned at different center frequencies and the response (or transfer function) was measured in µV's. As a result, 12 cable terminations were investigated in this way. Based on these results, the average transfer function and the spread in the results were available, see figure 14.

As can be concluded from figure 14 mainly two frequency ranges show to be of interest: ranging from 60-200 MHz and 320-380 MHz. Although the response in the first frequency range is higher compared to the second, also the spread in the amplitude is much higher. As a result, only the frequency range between 160-200 MHz is of importance and in this range, about 25 µV represents 1 pC of PD magnitude. In the second range, a relation of about 7 µV per pC was found. Moreover, the sensitivity to detect PD activity was proven to be in the order of 5-10 pC.

CONCLUSIONS

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

1) Calibration for the VHF/UHF PD detection system for cables is difficult to perform, since it is dependent on factors that change over time and setup:
   1. Test cable and measuring cables length
   2. External noise
   3. Position of measuring cables
   4. PD sensor
   5. Cable accessory
2) The transfer function of each setup (especially at the higher frequencies, which are the most important for this measuring technique) is different at different measuring frequencies. This makes calibration results difficult to repeat for even the same setup.
3) A sensitivity check can be performed to give at least an idea of detectable PD levels.

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