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NEW APPROACH FOR HIGH VOLTAGE CABLE ON-SITE TESTING

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ABSTRACT

The focus of this contribution is the application of sinusoidal VLF test-voltage as it is established for medium voltage cable systems, also on high voltage cable systems. Therefore a HV-test-voltage source and a 110-kV test cable system were realised at the TU Berlin. Typical high voltage components were applied for comparing the results of PD measurements gained at 50 Hz and 0.1 Hz respectively. It could be found out that typical PD characteristics as PD inception voltage, maximum PD levels, average PD levels and even visual diagrams as PRPD pattern are very similar at VLF compared to 50 Hz measurements. A diagnostic assessment of high voltage cable systems can be successfully performed by PD measurements with applied sinusoidal VLF test voltage.

KEYWORDS

Sinusoidal 0.1 Hz VLF test-voltage, On-Site-Testing, PD measuring, HV-Cable-Testing, Artificial defects

INTRODUCTION

Due to higher loads on cable networks caused by liberalisation and deregulation of energy markets it is more important than ever to know the condition of the asset [1]. Therefore diagnostic measuring techniques as tan delta and PD can be very helpful to find weak spots in the cable grid in order to exchange single cable lines with expired lifetime.
Furthermore it is necessary to diagnose even new installed systems because of the ongoing outsourcing process and the resultant loss of know how.
For medium voltage grids the VLF test techniques are well known and accepted [2]. The advantage of these low frequency test voltages is the low demand of reactive power. This leads to smaller and lighter test devices with optimal mobility under on-site conditions.
Nevertheless it has to be ensured that all high voltage components of a cable system, designed for operation frequency, can withstand the VLF voltage as well. Also it should be considered that the results of diagnostic PD measurements can be compared with PD measuring results achieved at operation frequency. In this case all established interpretation methods can be easily adapted.

HIGH VOLTAGE TEST SOURCE AND DUT

At the high voltage test labs of the Technische Universitaet Berlin a high voltage VLF source was developed, constructed and tested in order to perform diagnostic PD measurements on a 110-kV cable system. A voltage test level of 3.5 U_0 can be reached at a very low PD base noise level (typ. <5pC) with this test arrangement.
The components of the test cable system are standard HV components as a XLPE cable, a slip-over joint, a GIS cable adapter, a GIS circuit breaker and an outdoor cable termination. Multiple PD sensors were installed at different components of the cable system to get maximum information about possible PD defects [3-5].

Test voltage source

The VLF test voltage source itself consists of two "Greinacher cascades" which generate a positive and a negative high voltage respectively. These voltages are afterwards superposed and this leads to a sinusoidal voltage with a frequency of 0.1 Hz at the test object.
In figure 1 a photo of the experimental test voltage source is shown. The three poles at the left and the right side of the room are parts of the cascades. In front the output of the voltage source can be seen, connected with two resistors to the cascades.

Figure 1: Photo of the experimental VLF test voltage source at the TU-Berlin

Test cable system (DUT)

One phase of a typical 110-kV test cable system was set up. The components of this test cable system are commercially available HV components:

Cable
As test cable a XLPE-insulated 110-kV cable with laminated sheath (2XS(FL)2Y 1x240/35 64/110-kV) was used. Two short lengths are connecting an air-insulated termination with the joint, and the joint with a SF6-insulated termination (GIS-side).

Outdoor cable termination
A silicon-insulated termination of type ES-S 110-kV (CCC GmbH, Berlin) was connected to one end of the HV cable.

Joint
As a typical accessory a prefabricated slip-on joint (type MAEI 110kV, CCC GmbH, Berlin) was mounted. The interrupted screening wires (cross-bonding type) were re-connected by an external junction (see figure 2).

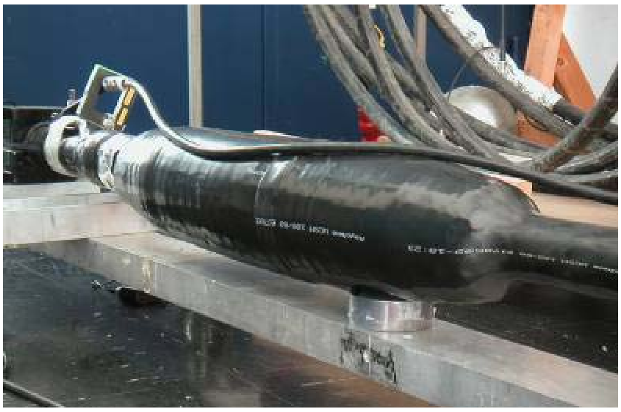

Figure 2: Mounted joint with external screen junction and high frequency current transformers for inductive PD decoupling

SF6-insulated cable termination (GIS-side)
The GIS parts of the test set-up were realized by SF6-housings (type 8DN9-1, 145kV, Siemens AG).
The cable termination (see figure 3, type EGT(K) 110kV, CCC GmbH, Berlin) was realized as a detachable connector to simulate possible contamination of the interfaces due to assembly faults.

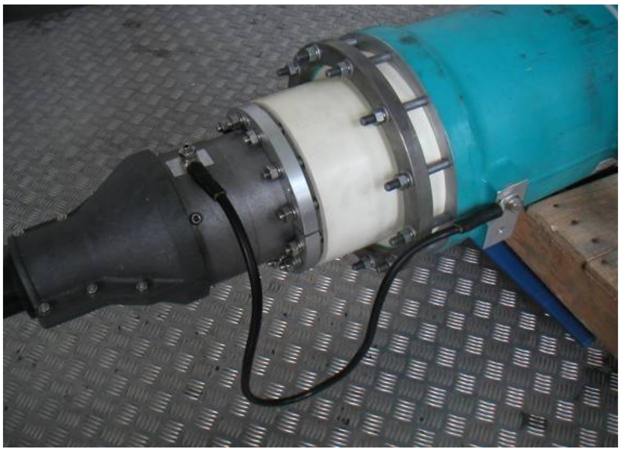

Figure 3: GIS cable termination, detachable

PD MEASUREMENT SETUP

Multiple PD sensors were installed at different components of the cable system to get maximum information about possible PD defects.
Directional coupling sensors (DCS, [8]) were mounted left and right close to the joint to have a high precise PD measurement option. Due to their UHF-properties PD fault localisation therefore is possible within the range of cm. Also directional coupling sensors for GIS-systems [9] were implemented to monitor the cable termination and to distinguish between PD from the cable termination and from inside of the GIS, respectively.
The external screen junction at the joint was used for sensitive inductive PD decoupling with high-frequency current transformers (HFCT), which could also indicate the direction of the current [8].

PD measuring device

The PD measurements have been performed with the MPD 540 (mtronix, [7]) as a modern type of digital PD measuring system. This measurement system consists of one or more acquisition units (figure 4), an optical interface (fibre optic bus-controller) and a PC including measuring software.

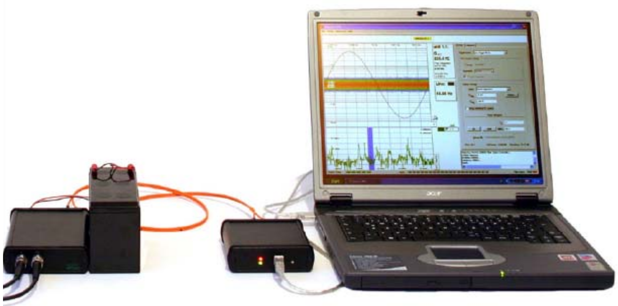

Figure 4: MPD 540 PD measuring system (PD acquisition unit, power cell, Optic-USB converter, Notebook)

The PD signals are filtered, amplified and digitized. Having an amplitude quantization of 14 bit and a sampling rate of 64 MS/s, the time accuracy of detection of a PD signal is at about 2 ns. The quasi-integration is realized by a digital band-pass filter. The centre frequency for the digital filter can be chosen in a frequency range from DC up to 20 MHz, the bandwidth between 9 kHz and 3 MHz, respectively. Hence an optimal frequency band can be chosen to avoid disturbances and to reach a high SNR even under noisy conditions on site. Furthermore, the test voltage signal is digitized in the acquisition unit to document the test voltage during the PD measurement (see figure 5).

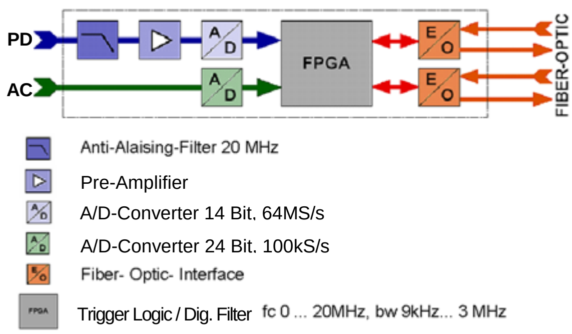

Figure 5: Block diagram of an acquisition unit of the PD measurement device, MPD 540

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WITHSTAND VOLTAGE TEST

The first task was to find out, if the installed test voltage source and the DUT with all their components could accomplish a standard withstand voltage test at 50 Hz and 0.1 Hz. After implementing all PD sensors the test cable system was tested with 2 U_0 (128kV, 60 minutes) and 2.5 U_0 (160kV, 30 minutes) with 50 Hz as well as sinusoidal 0.1 Hz VLF voltage.
No breakdown and no PD activity could be detected from the DUT during this test and thus the withstand voltage test was passed.

PD DIAGNOSTICS OF ARTIFICIAL DEFECTS

Because of the satisfyingly accomplished withstand voltage test with no PD inception of the cable system artificial PD defects were implemented into the cable system to compare the diagnostic results archived with 50 Hz and 0.1 Hz respectively. In several measuring series different typical assembly faults were replicated.

Polluted Outdoor Termination

To simulate pollution of the surface of the outdoor termination, which usually results in a conducting film, one (or two, respectively) metallic stripes were wrapped around the silicon sheds.

Comparison of PDIV
As shown in figure 6 the PD inception voltages (PDIV) of this type of artificial PD defect are very similar for operating frequency (50 Hz) and sinusoidal VLF (0.1 Hz).

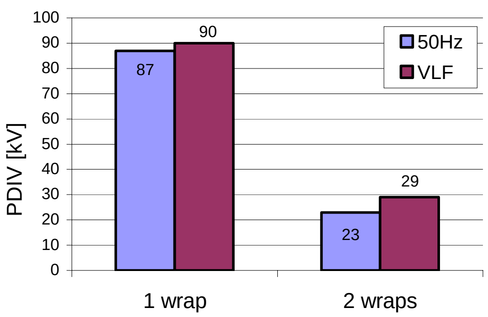

Figure 6: PDIV, artificial pollution of silicon shield

Comparison of PRPD patterns
The visual evaluation of the PD pulses is performed in colour-coded PD pattern (phase resolved PD, PRPD, fingerprints).
For 50 Hz and sinusoidal 0.1 Hz test voltage similar PD pattern could be observed (see figure 7). Nevertheless, for VLF testing there is more time needed to accumulate a complete and expressive PD pattern, as it is recorded at operating voltage in only a few seconds.

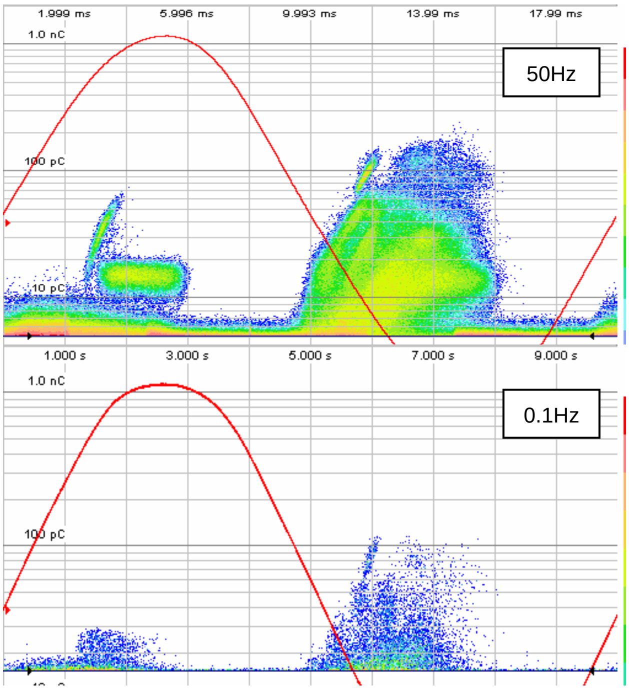

Figure 7: PRPD of polluted outdoor termination

Defect at outer semicon layer

At a single spot the outer semicon layer of the body of the joint was removed to initiate surface PD activity (see figure 8). Therefore outer protection layers, metallic shield layers and wrapped tapes were removed to access the active parts of the joint.

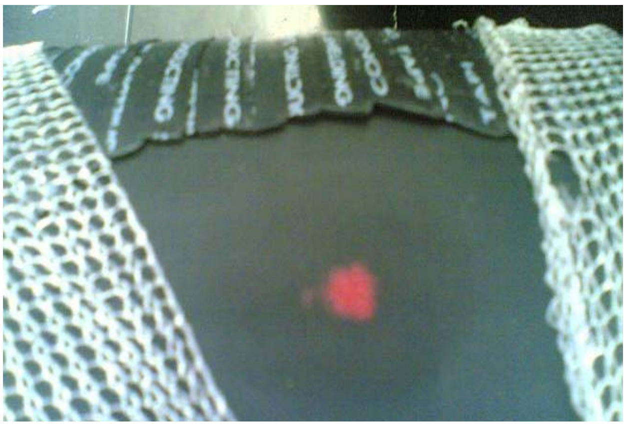

Figure 8: Defect at body of joint

After the defined damage of the joint all important surrounding layers were reconstructed so that the joint was finally electrical shielded again.

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Comparison of PRPD pattern

For 50 Hz and sinusoidal 0.1 Hz test voltage similar PD pattern could be observed (see figure 9). But again, for VLF testing it takes a significant longer time to get an expressive PRPD pattern, comparable to the one at 50 Hz test voltage.

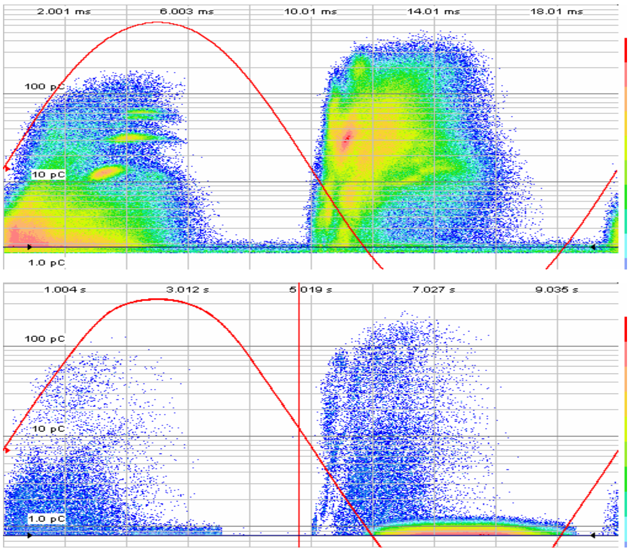

Figure 9: PD pattern, defect of semicon layer

Comparison of Number of PD-Pulses per Period

As the PD impulses seem to be less at 0.1 Hz test compared to 50 Hz operating frequency, it is obvious to compare not the absolute number of pulses per time, but the number of pulses per period of test voltage.

Figure shows the recorded number of pulses per period with increasing test voltage level.

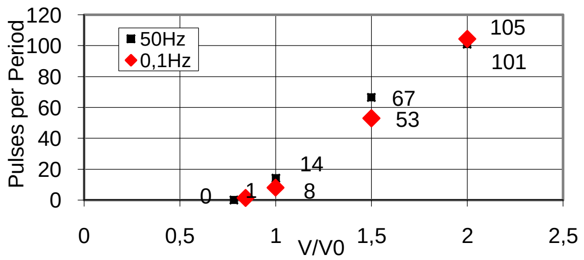

Figure 10: Pulses per period of test voltage

The numbers of pulses per period at VLF (0.1 Hz) and operating frequency (50 Hz) are nearly the same.

Defect at joint deflector

Another typical PD fault is a void located under the deflector of a joint, as it might occur by incorrect or unclean assembly of the joint. To create a reproducible artificial PD fault, a plastic pin was placed under the edge of the silicon body of the joint. The tip of the pin reached up to the semicon inlay of the joint to securely initiate PD activity.

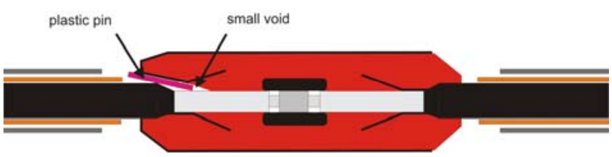

Figure 11: Plastic pin under silicon body

Comparison of PRPD pattern

Figure 11 shows the colour-coded PRPD pattern. For both test voltage frequencies the PD discharges start after the zero crossing of the test voltage occurring over a wide area in phase. Higher levels of the test voltage lead to increasing PD activity and higher PD levels.

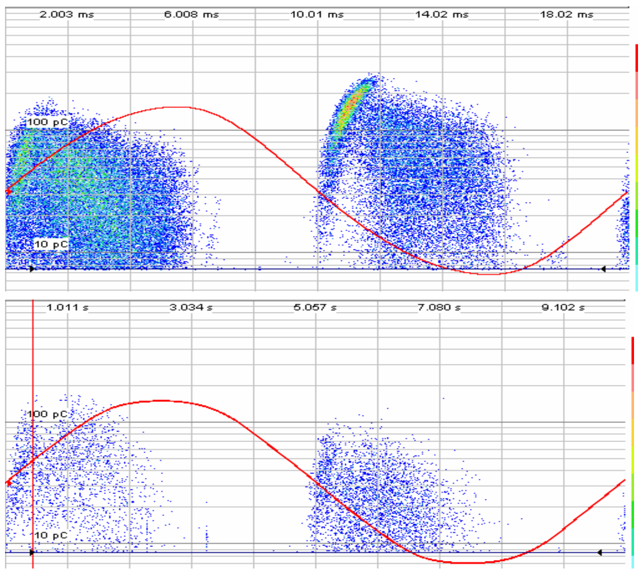

Figure 12: PD pattern at 64kV

Comparison of maximum PD level

Figure 13 shows the maximum values of detected PD pulses at 50 Hz and 0.1 Hz test voltage for nominal voltage and PD inception voltage, respectively.

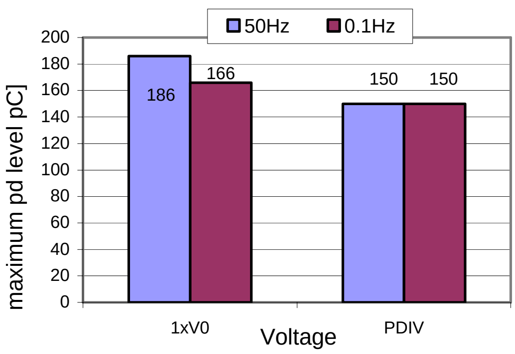

Figure 13: Comparison of maximum PD level

The occurring maximum PD levels are almost identical, as well as the calculated average PD levels for 50Hz and 0.1Hz.

Results

For the analysed artificial PD defects all measuring results as PD inception voltage, average PD level and number of PD pulses per period are in good accordance. Also the statistical analyses in fingerprint diagrams lead to similar visual patterns.

CONCLUSIONS

At the high voltage laboratory of the Technische Universitaet of Berlin extensive studies concerning PD behaviour of high voltage cable systems had been performed [6]. Therefore a 110-kV test cable system consisting of one air insulated cable termination, a XLPE cable, one insulating joint (suitable for cross bonding), one SF6-cable termination and one GIS casing including an opened contact breaker was constructed and tested with operating frequency of 50 Hz and sinusoidal VLF voltage of 0.1 Hz. An experimental 0.1 Hz voltage source was developed to apply test voltages of up to 3.5 times of nominal phase voltage.

By the use of an innovative synchronous multi-site PD measuring system different PD sensors could be observed at the same time to achieve maximum PD in-formation. Due to the fact that no PD occurred at a voltage test level of 2.5 U_0 neither for operating frequency nor VLF (withstand voltage test passed), artificial PD defects were implemented to simulate assembly faults as they are typical for on site mounting.

It can be stated that sinusoidal 0.1 Hz VLF test voltage is suitable for testing high voltage cable systems. All typical insulating components withstand the required voltage test levels without indication of partial discharges.

Also it can be stated that PD measurements performed with sinusoidal 0.1 Hz VLF voltage lead to similar results as they can be achieved with operating frequency voltage applied to the DUT. The test series concerning the PD inception voltage showed in most cases a slightly higher level for VLF test voltage, but still well comparable.

After exceeding PD inception voltage the recorded values of maximum PD level and average PD level are well comparable, too. In most cases the levels related to the VLF test voltage are slightly lower than the levels achieved at operating frequency voltage.

The visual analyses by colour-coded PRPD pattern (fingerprints) show similar results for 50 Hz and sinusoidal VLF test voltage. VLF test systems of sinusoidal 0.1 Hz test voltage therefore prove to be an alternative for high voltage cable testing on site.

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