Innovative Test and Diagnostic System for medium voltage cables – PD monitored withstand testing versus non destructive Partial Discharge (PD) diagnosis

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***Abstract*— For testing and partial discharge (PD) diagnostic purposes many different test voltage wave shapes and frequencies have been established over the past years. Their application is well proven and is guided by IEEE 400 norm. For testing purposes the voltage need to produce enough stress to lead failures to breakdown. The very low frequency (VLF) waveforms turn out to be very effective and economical for that purpose. For PD diagnostic voltages are needed, with waveforms close to power frequency and in its application non destructive for the test object. VLF voltages could cause in case of long testing times during PD diagnosis unwanted breakdowns at weak spots, even if the applied voltage is not that high like it is used for withstand testing. Damped AC voltage (DAC), which is close to power frequency, is well proven to be very effective for partial discharge diagnosis and causes nearly no risk for breakdown due to the short excitation time even for critically aged cables. A new test and diagnostic system combining both, providing an effective test voltage for withstand testing and being non destructive for diagnostic measurements, is introduced recently. This paper describes the application and comparison of the new test and diagnostic system for partial discharge diagnosis by using DAC. Furthermore true VLF cosine rectangular withstand testing with accompanying PD monitoring is discussed. It is demonstrated that cosine rectangular VLF waveform delivers comparable results of PD parameter to judge the severity and to locate PD defects in MV cable systems.**

***Index Terms*—Condition monitoring, High-voltage techniques, Partial discharge, Preventative maintenance, Withstand testing.**

I. Introduction

The reasons and the necessity for cable testing and diagnosis are well known. One of them is the increasing installation complexity for medium voltage accessories which resulted in many cable failures due to bad workmanship in joints and terminations. The visual inspections at www.vde-kabeldatenbank.de give a small impression, which failures appear in aged and new installed cable systems [1]. The IEEE 400.2 norm guides for reasonable testing and combined diagnosis possibilities [2]. Partial discharge (PD) diagnosis has proven to be effective in field for locating weak spots. In the presence of water trees partial discharge diagnosis provides just limited possibilities for proper defect location. So, not only for that reason, very low frequency (VLF) testing is still the essential tool for maintenance and quality control of cable systems. Different VLF testing voltage wave shapes are known and accepted [2], [3]. The VLF cosine rectangular convinces by good test power consumption in comparison to weight and dimension of the equipment, which makes it easy to use at onsite testing [4]. VLF testing is built to be a stress test for cable systems, by applying a multiple of the nominal voltage for quite some time. So, its purpose is to end up with either a breakdown or no breakdown in the cable system. It is named to be a destructive method. For diagnosis a non destructive method is preferred. The damped AC (DAC) voltage wave shape turned out to be a good choice to provide less stress to the cable systems. The application time of the stress will be significant lower at DAC, since the oscillation frequency varies between 30Hz – 400 Hz and the voltage gets attenuated with time.

II. Combined VLF CR & DAC system

In several publications the operating principle of a VLF cosine rectangular (VLF CR) testing system is described [5], [4]. Fig. 1 shows a schematic circuit of the VLF CR system. It is composed out of two DC sources a positive and a negative. A special switch (W) conducts either one of the sources or keeps them isolated of the remaining circuit. The inductance L and the internal supporting capacitance C_S built the basis of the resonance part. The losses of the internal resonance circuit are represented by R.

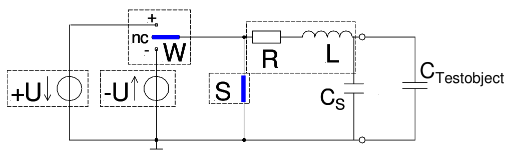

Figure 1. Principle of combined VLF CR & DAC at resonance phase.

The main issue of the system is given by doing the right timing. Fig. 2 shows a schematic timing diagram of the testing mode VLF cosine rectangular at a basic testing frequency of 0.1 Hz. In the plateau phases B and D the voltage keeps constant, which means either the positive or the negative source is conducted by the switch W, switch S is open. In the resonance phases, A and C, the switch W is set to isolate the source from the resonance circuit. Switch S closes and a polarity reversal takes place with a frequency of (1).

$$f_{swing} = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot (C_S + C_{Testobject})}} \tag{1}$$

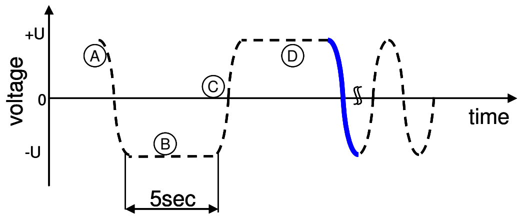

Figure 2. Timing diagram of VLF CR test cyclus.

There the main difference in voltage generation of VLF CR and DAC takes place. At VLF CR mode the resonance is stopped by opening switch S at the right time. The sources recharge to the nominal voltage given by the control of the system. In DAC mode the switch S kept close, so a resonance circuit with a certain frequency (1) is built. The attenuation of the oscillation is given by the losses of the internal components of the generator in addition to the losses of the test object. Fig. 3 shows a DAC distribution.

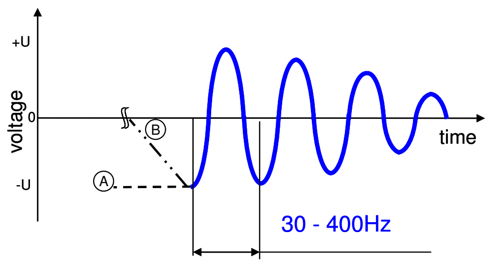

Figure 3. Timing diagram of a DAC test.

The combined system allows both voltage wave forms in one system. Even a combination of the voltages would be possible. Fig. 3 furthermore demonstrates that two charging methods for DAC voltage generation are possible. Charging by following B, could be understood as a usual application for doing PD diagnosis. But by combining the waveforms depicted in Fig. 2 and Fig. 3 a DAC voltage could also be released out of a VLF CR before.

III. Important Parameter for PD Diagnosis

As PD diagnosis is used in field to screen a cable, the most important parameter is that one which identifies if there are or aren't partial discharges occurring at nominal operation of the cable. The partial discharge inception voltage answers this question. So for any test voltage used for partial discharge diagnosis it is important to initiate PD defects at comparable PD inception voltages (PDIV) to operating voltage. Beside the PDIV, at the first instance the amount of charge of partial discharge gives indication of the risk of a partial defect. In order to compare PD level the IEC 60270 provides information how to measure the amount correctly [6]. Nevertheless the absolute value of a partial discharge at surface discharges are lower than those of discharges at voids in a joint, however the surface discharge in a joint will lead quicker to a breakdown. The comparability of PDIV at DAC to 50 / 60 Hz has been proved by several publications [7], [8]. Since the VLF cosine rectangular makes use of the same kind of resonance phase in the polarity reversal it is rather logical to suppose that it will be also comparable in PDIV to operating frequency. The following case studies and publications [5], [9] demonstrate that the assumption is valid.

IV. VLF CR vs DAC at Corona Defect

An easy possibility to check comparability between voltage shapes and PD inception voltages is to use a corona defect. In this test the defect was done by a wire on high potential discharging to an earthed metal plate. Fig. 4 shows the PD measurement with VLF CR wave shape. It can be seen once the inception voltage of the corona defect is exceeded the corona keeps discharging. In the upper part of Fig. 4 a wider area of the plateau phase of the cosine rectangular shape is depicted, there the discharging is more visual.

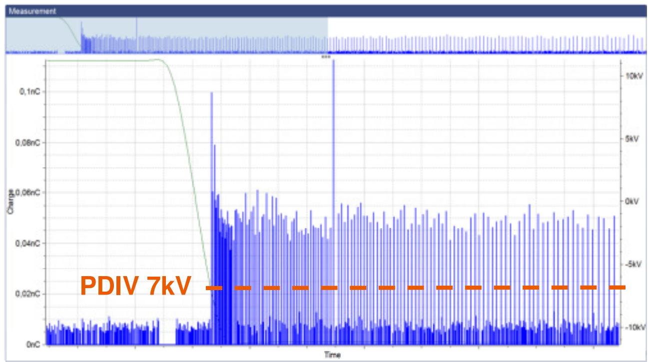

Figure 4. Corona defect at VLF cosine rectangluar wave shape.

Since damped AC voltage gets attenuated by time, the "N-th period" will become lower than the PD extinction voltage of the corona defect and the PD defect will vanish. This could be perfectly seen in Fig. 5 upper part of the graph and is doubtless a big advantage of this kind of wave shape.

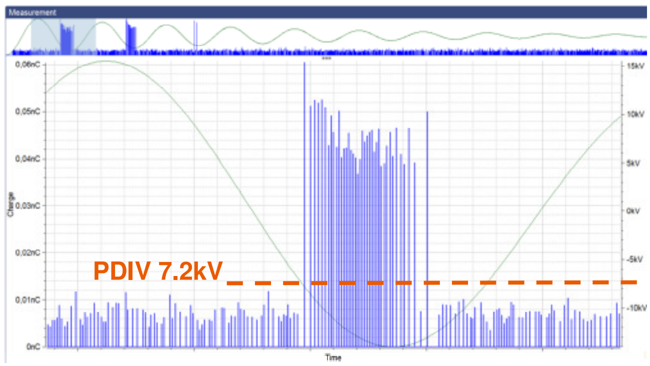

Figure 5. Corona defect at damped AC voltage.

The PD inception voltage of the corona defect is independent of the voltage wave shape. Even the amount of discharge measured according to IEC 60270 [6] gives a comparable result of approx. 50 pC.

V. CASE STUDIES OF ONSITE PD MEASUREMENTS

In order to prove the successful comparison of the PD parameters at the corona defect, onsite measurements in Germany were carried out. Beside the following two examples many further unpublished measurements were performed, which basically lead to equal results.

A. Test setup at onsite PD measurement in Germany

Fig. 6 shows the test setup at a medium voltage cable station. The setup consists of the combined VLF CR and DAC voltage source and a filtering and PD coupling device, which is connected directly to the object to test. The PD measurement system was built conform the IEC 60270 standard [6]. The source and the measurement device were controlled by software on a notebook.

Figure 6. Test setup combined VLF CR and DAC voltage source and PD measurement device.

B. First case study – paper-mass impregnated cable of 1096m length

The first test object was a cable dominated by insulation of paper mass. It is known that paper mass cable tend to have more PD defects, because of lack of impregnation. This leads to distributed voids in the insulation, which let expect high partial discharge activity. Fig. 7 shows the cable sections and the accessories.

Figure 7. Cable section plan; mixed 10kV cable with 12 splices.

TABLE I. PD INCEPTION VOLTAGES OF CASE STUDY 1

	VLF CR in kV*			DAC in kV peak		
	L1	*L2*	*L3*	*L1*	*L2*	*L3*
PDIV	5	6	6	4.6	6.4	5.8

* kV peak ≈ kV rms at VLF cosine rectangular

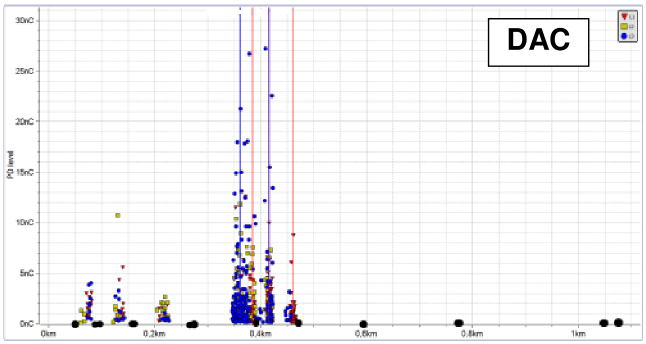

Figure 8. PD mapping of three cable phases done with DAC voltage < = 10kV peak.

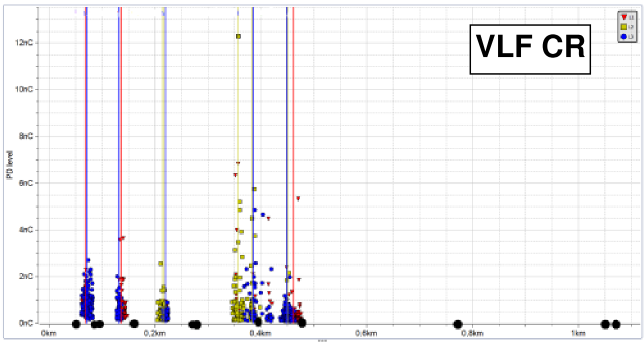

Figure 9. PD mapping of three cable phases done with VLF CR voltage < = 10kV peak.

Fig. 8 and Fig. 9 show the PD location after PD measurement. It could be seen that the same defects were triggered with both wave shapes, while the repetition rate and PD values differs slightly between the defects. The PD inception voltages showed good correlation.

C. Second case study – mixed cable paper-mass impregnated and XLPE of 343m length

As observed at the first case study the second also showed a good correlation in PD locations and PD inception voltages. Fig. 10 shows the cable sections and the two accessories.

Figure 10. Cable section plan; mixed 10kV cable with 2 splices.

TABLE II. PD INCEPTION VOLTAGES OF CASE STUDY 2

	VLF CR in kV*			DAC in kV peak		
	L1	*L2*	*L3*	*L1*	*L2*	*L3*
PDIV	4	5	5	3.4	5.1	5.1

* kV peak ≈ kV rms at VLF cosine rectangular

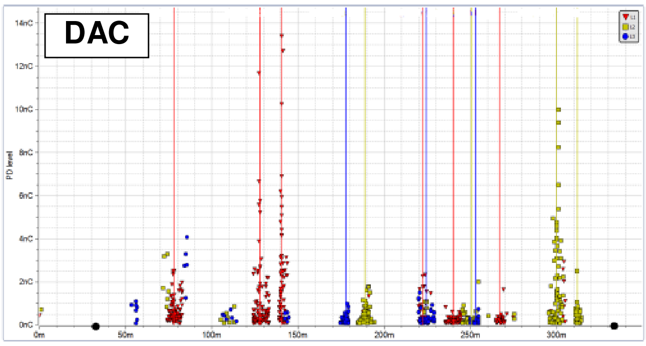

Figure 11. PD mapping of three cable phases done with DAC voltage < = 10kV peak.

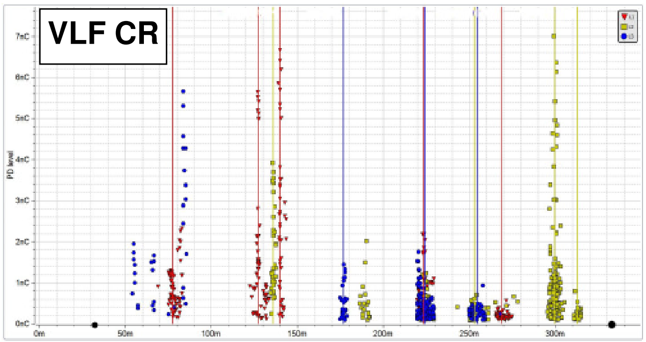

Figure 12. PD mapping of three cable phases done with VLF CR voltage < = 10kV peak.

VI. Combined PD and VLF CR Withstand Test

As already mentioned a VLF withstand test ends up with a pass or fail result. At its first instance it won't give any further information about location of the breakdown or health of the cable. An accompanied partial discharge monitoring support the result of the VLF withstand test with additional information about the test object, like presents of PD, location of PD defect, phase resolved PD pattern (PRPD) and trending of PD during the test. Even the drawback that the PD measurement is just performed at the withstand voltage level is acceptable by the fact that the PD measurement contributes many valuable information. So a passed withstand test ends up with additional results, which could induce a pure partial discharge diagnosis, to prove the critically of the defect.

A monitored PD withstand test using VLF cosine rectangular could follow the distribution like the snapshot of the sequence depicted in Fig. 13. There is a certain window of PD measurement ΔW, in which all partial discharges are captured and evaluated. The window is composed of negative DC, the polarity reversal close to operating frequency and positive DC vice versa respectively. The time in between the measurement windows allow proceeding of the captured PD data to provide directly a PD localization map.

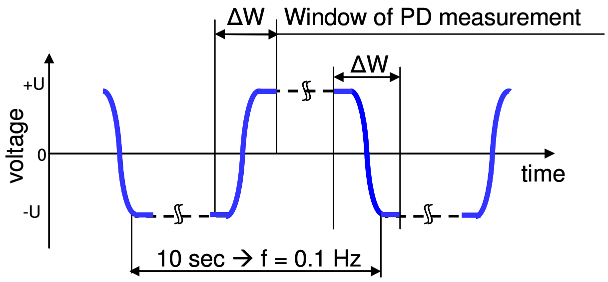

Figure 13. VLF cosine rectangular voltage distribution showing window of PD measurement.

VII. Discussion and Future Work

A new testing and diagnosis system is introduced, which combines the advantages of testing in an effective way and allowing partial discharge diagnosis. The VLF cosine rectangular (CR) wave shape provides frequency ranges in the polarity reversals which are close to operating frequency. It has been shown at two field case studies that partial discharge diagnosis done at VLF CR is comparable to damped AC. PD diagnosis at damped AC voltage is well proven and internationally accepted to be efficient for detection of partial discharge defects. Furthermore the new system could provide damped AC voltage for pure PD diagnosis as well. The measurements in the field show good correlation in PD inception voltage as expected, since the voltage gradient of the polarity reversal is the same. The absolute PD values differ in some range. The introduced measurement do not show higher PD values at VLF cosine rectangular wave shape, as it was measured in [9].

Further investigations on academic and reproducible artificial PD defects need to be carried out to get more knowledge about the influence of the plateau phase of the VLF CR shape on absolute PD values.

Future work will include phase resolved partial discharge pattern (PRPD) analysis at PD monitored withstand test with VLF cosine rectangular. It was demonstrated that different PD defects depend voltage wave shape [10]. The VLF CR is unique by providing a DC plateau phase and a resonance phase in its wave shape. Depending on the type of PD defect it could occur that it will incept at DC plateau and at resonance slope or at just the resonance slope only. This may help for evaluation of criticality and interpretation of the PD defect.

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