DIAGNOSIS TOOLS USING DAMPED AND RESONANT AC ENERGIZING VOLTAGES WITH RESPECT TO PREVENTIVE ON-SITE PD DIAGNOSIS TESTS OF MEDIUM VOLTAGE POWER CABLES

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ABSTRACT

In recent years destructive withstand tests of distribution power cables are increasingly substituted by non-destructive methods. For preventive PD diagnostics the application of damped AC (DAC) test voltages as well as resonant frequency AC voltages (RFAC) have well been proven in practice as a cost-benefit alternative to continuous power frequency AC voltages. The presented paper deals with practical experience in preventive PD diagnostics of MV cables under on-site condition using both types of the here mentioned exciting voltages.

INTRODUCTION

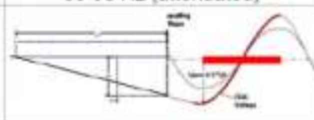
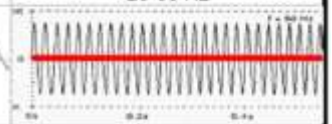
The knowledge of power cable condition is of increasing importance to assure a reliable network operation. Due to the excellent experience in quality assurance PD tests of power cables after manufacturing nowadays also preventive on-site PD diagnosis tools are more and more in demand. These can provide the necessary information, if the installed cables are still in acceptable condition or, in contrary case, whether the cables should be repaired or even if they must be replaced.

Such information is not only of great importance for the asset management but may optimize the operation costs of the cable network, because unexpected outages can be prevented. From an economical point of view, however, on-site PD diagnostics of power cables is a technical challenge due to both the high electromagnetic noises in the measuring surroundings and the high current demand for charging the cable capacitance. More details in this respect will be reported in the following.

ASPECTS OF PREVENTIVE ON-SITE PD DIAGNOSIS OF MV POWER CABLES

Practical experience in PD diagnosis tests of MV cables showed that the detection sensitivity in the range of few tens of pC seems sufficient for most PILC and XLPE insulated MV cables. Under this condition the standardized PD measuring circuit can well be applied not only for PD detection but also for locating the PD sites. From a physical point of view the PD diagnostics of MV cables should be performed under power frequency (50 / 60 Hz) voltages. Due to the high capacitive power demand, however, such test facilities are very costly and hence not an economical solution. To overcome this disadvantage, alternative exciting voltages have been introduced in the past, such as resonance AC test voltages of variable frequency (FRAC), very low frequency (VLF) voltages and damped AC (DAC) voltages. In the following some aspects of on-site PD diagnosis tests of MV power cables subjected to DAC and FRAC exciting voltages will be considered.

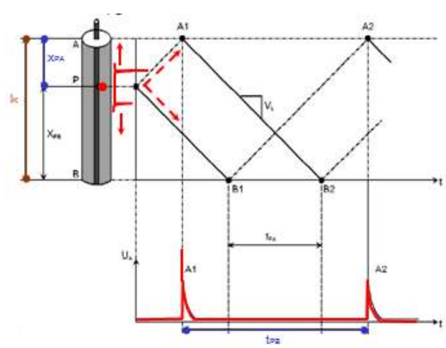
In this context it should be noted that not only the values of the PD quantities like apparent charge level, repetition rate and phase correlation, seems of interest but also the position of the PD defects. Mainly, in spatial extended objects like power cables the localization of PD-faults seems of highest interest. For this purpose the so-called time domain reflectometry (TDR) is commonly used as will be reported in the following.

	DAC Voltages ***(CDA)***	**ACFR Voltages** ***(LDPS-RESO)***
voltage source	D.C. voltage generator	oscillatory circuit over ser. reactor
diagnostic voltage	30-90 Hz (attenuated)	25-80 Hz
voltage type		
Recording capacity of system	¼ period (5 ms)	all AC periods (x min)
no. of measuring cycles per test voltage level	plastic-ins.: 5 x PILC cable: 15 x	arbitrary (continuous recording)
analysis of ambient noise freque.	online and offline	online and offline
PD analysis	automatic / manual	automatic / manual
sensitivity	≤ 10 pC	≤ 10 pC
galvanic decoupling	yes	yes
max. test voltage	Û~85 kV	U_{eff}~50 kV
weight of measuring system	approx.: 1000 kg	approx.: 2400 kg
max. load capacity	2000 nF	2500 nF
connection	16 A	32 A

Characteristics of the DAC and ACFR Test Facility
Commercially available by Doble Lemke GmbH
Figure 1

LOCATION OF THE PD SITE

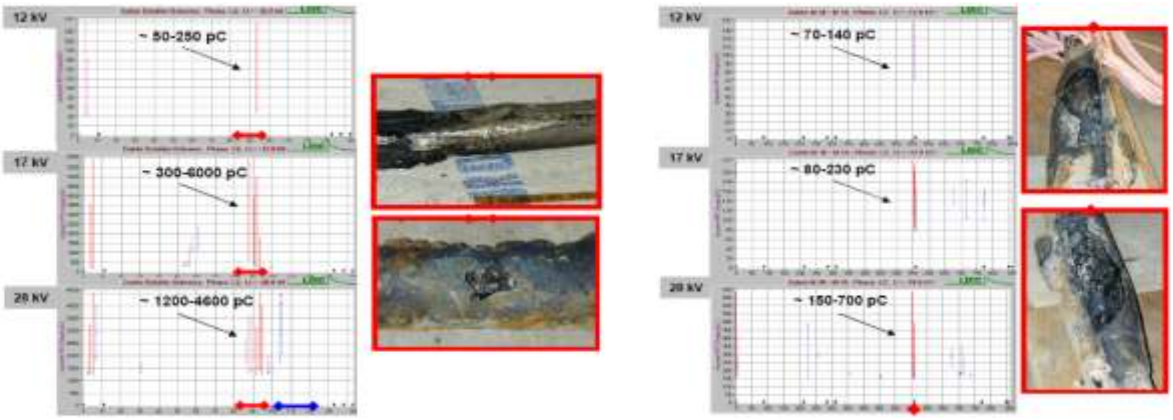
For the PD-pulses to be located the cable appears like an electromagnetic waveguide. Therefore, at the point of origin each PD-pulse is separated into two partial pulses of opposite direction. Consequently, at each cable end a direct and a reflected pulse can be captured, see Figure 2.



$$x_{PA} = l_k - t_{PB} * v_K / 2$$

Principle of the Reflectometer Method
Figure 2

The occurring double pulses are wide-band amplified up to about 10MHz using a separate fault location amplifier. In the following high-speed digitizer the signal is digitized with a sampling rate of 100 Ms/s and a dynamic range of 12 Bit. Finally the time delay between the direct and the first reflected pulse is evaluated by means of a fault location unit. This unit is able to run the impulse-echo for each evaluation captured reflectogram. Hence, not only the individual PD-fault with the highest magnitude but also multiple faults can be located. All extracted PD-faults are mapped automatically, i.e. the PD-pulse magnitudes correlated to its particular position vs. the number of the localized PD-pulses is displayed. Typical PD-position maps are shown in Figure 3.



**PD Defects in the Insulation of a Service Aged PILC Cable (left)
and in Accessories of a PILC Cable due to Earth Line Transients (right)
Figure 3**

For an easier analysis the counted pulse pairs are displayed in a histogram. Considering the PD frequency, the localized PD sources are indicated by vertical lines ranging between the minimum and maximum PD magnitudes. Using the cursors with the mouse in a snap-to-point mode the PD fault position can easily be determined in the created maps.

ENHANCEMENT OF THE LOCATION SENSITIVITY

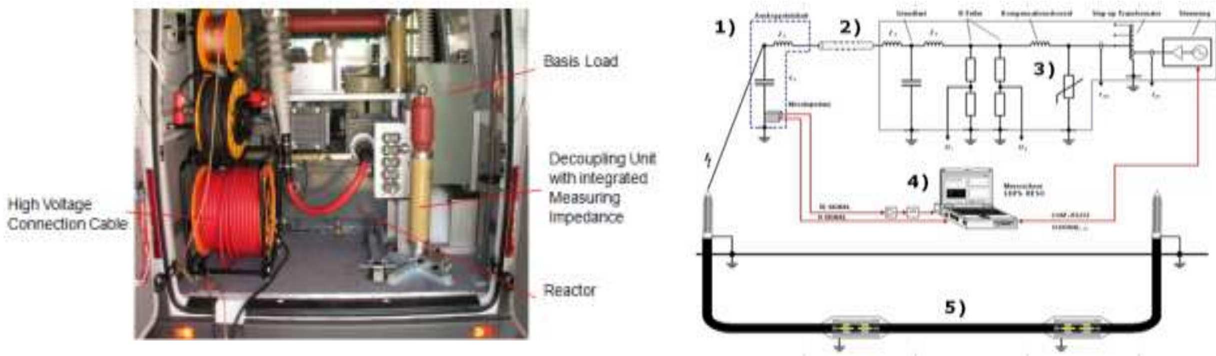
To improve the location sensitivity as well as the detection sensitivity various high sophisticated features have been introduced, such as:

- A pulse averaging tool and an adjustable threshold level in order to reduce the impact of continuous occurring interferences, such as radio background noise and pulse-shaped oscillations.
- A FFT feature which assists the user finding harmonic radio interference's. Supported by this harmonic analysis, a selection of digital filters can be adjusted optimally.
- A rise time discrimination of the pulses to distinguish between near-end and far-end PD-sources.
- A transmission-loss-adjustment which is automatically executed for all located PD-pulses for an exact position independent determination of the real PD-impulse magnitudes.

RESONANCE TEST SYSTEM RESO-50

To achieve the resonance condition the frequency of the test facility RESO-50 is tuned accordingly. This type of HV equipment is generally called frequency-tuned resonance AC (FRAC) test system. The RESO-50 shown in Figure 4 is equipped with a high voltage reactor acting as a high voltage source, a control and voltage measuring unit, as well as computer-based PD and dielectric loss factor (DF) measuring systems.

The operation principle of the RESO-50 is based on the series resonance. As mentioned previously, to achieve the resonance condition of the test circuit only the frequency is tuned, whereas the inductance of the HV reactor is left constant. The input of the HV reactor is connected to the output of the step-up transformer. The output of the HV divider is connected to the control circuit which contains a microprocessor to assure the stability of the test frequency, i.e. to provide an automatic resonance tuning. Due to a special high voltage PI-filter as well as the analogue operating power electronic, electromagnetic disturbances at the HV output are rejected which ensures high sensitive PD measurements. A base load capacitor can be connected to the HV output or disconnected from this output depending on the resonance frequency requirements.

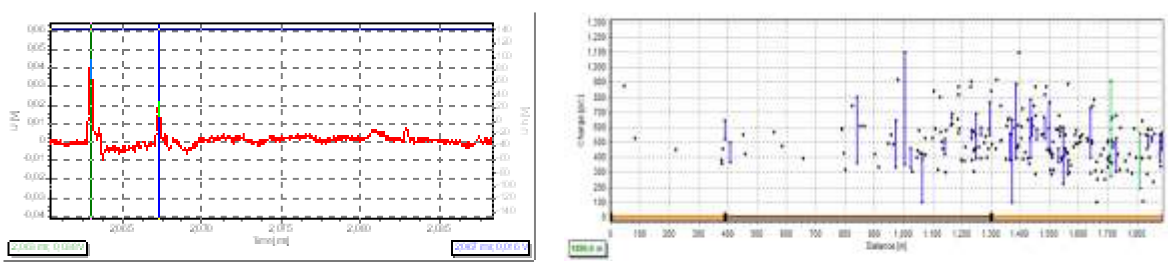


Test Van RESO-30 (left) and Schematic Diagram of the HV Resonance Test System (right)
1) PD Decoupling Unit, 2) HV Connection Cable, 3) Reactor, 4) PD Measuring Instrument, 5) DUT
Figure 4

PD MEASUREMENT AND LOCATION UNIT

The HV test equipment can simply be connected to the power cable under test via a PD-free HV connection cable having a length of 50 m. The PD signal is decoupled by means of a 2 nF coupling capacitor whose output is connected to an active measuring impedance. The PD signal is digitized by means of a 14 bit A/D converter as part of the PD detector. The captured PD data can be displayed in either the real-time mode or the replay-mode on the PC screen. Moreover they can be stored for further signal processing.

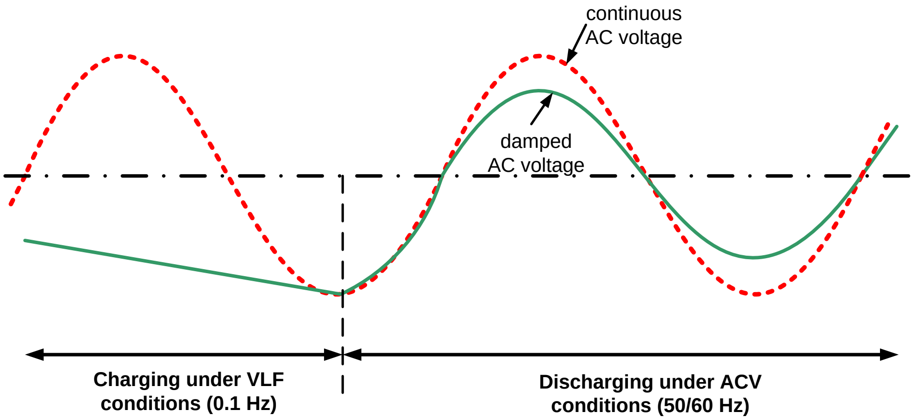
During the high voltage test the control and measuring software of the RESO-50 displays besides the phase-resolved PD pattern simultaneously the time-dependent test voltage. This signal is created by individual shots of single cycles of the applied AC test voltage. The time-dependent PD and voltage signals can also be zoomed over a wide range to identify possible PD defects in the cable insulation. The zoomed PD signal shows additional to the direct pulse and the pulses reflected from the far cable end, see Figure 5. Based on the actual wave propagation velocity, which was determined by the calibration procedure, the time scale of the record is converted into an equivalent length scale. This dimension ensures the information on the actual PD fault position, see Figure 5.



A Zoomed PD Signal for PD Fault Location Identification and the
PD-Position Map as Result of the Signal Evaluation
Figure 5

DAMPED AC VOLTAGE TEST SYSTEM CDA-30

The basic principle of damped AC voltage test systems has already been presented, for instance, in the references [3 - 6]. However, it shall be recalled here again briefly. Generally the voltage generation can be divided in the following two essential steps, see Figure 6:



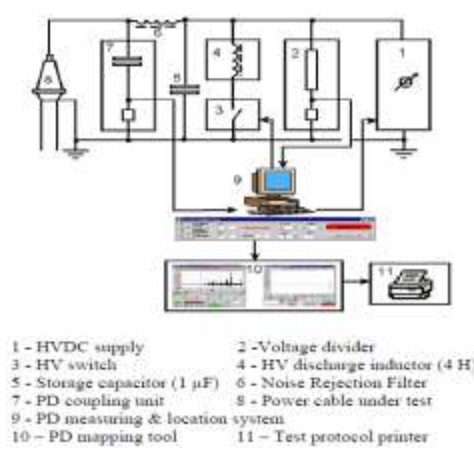
Characteristic Shapes of Continuous AC Voltage (ACV) and Damped AC Voltage (DAC)

Figure 6

1. Charging the cable up to the specified test voltage level during a pre-stressing time of few seconds, which is similar to VLF conditions.
2. Discharging the cable via an inductance, which causes decaying oscillations where the frequency is close to the power frequency (50/60 Hz) AC voltage.

In particular, the application of DAC test voltages offers the following benefits:

- The long charging period of few seconds requires only a low power demand for energizing the cable capacitance, in general below 500 Watt. This ensures a compact and light-weight design of the HV test equipment, which can easily be transported in the field.
- The oscillating discharging period causes a voltage stress close to the conventional power frequency AC voltage. Hence the PD quantities, measured during this time, are well comparable to those, which appear under service condition.
- The damped AC exciting voltage avoids an overstressing of the insulation due to the short stressing time below one second and the comparatively low voltage level, generally below 2 x U_0. Under this condition the inducing of new PD defects is excluded which seems important for PD diagnostics of heavy aged cables.
- Combined with advanced tools for digital signal processing (DSP) and computer-aided data acquisition, the analysis and mapping of PD defects can be performed very cost-effectively.



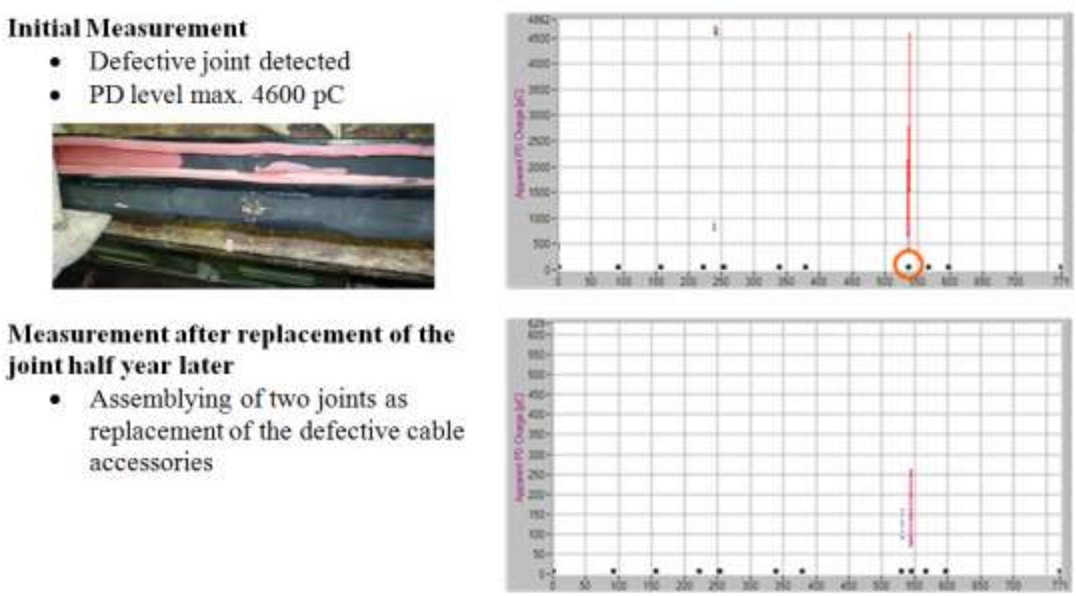
Test Facility CDA-30 (left) and Circuit Diagram (right)

Figure 7

A commercially available test facility generating a damped AC voltage up to 30kV, which is called CDA-30, is shown in Figure 7. This modular DAC test system is equipped with a discharge inductor of 4 H and a storage capacitor of 1 µF, which keep the maximum resonance frequency as low as 80Hz, even if the cable length becomes shorter than 100 m. For the maximum recommended cable length of 4000 m the frequency decreases only to about 50Hz. Due to this comparatively low frequency change the impact of variable oscillating frequencies on the PD occurrence can be neglected.

The facility for PD measurement and location of the PD site is similar to those used in the resonance test system RESO-50, as described above. In the following a typical case study shall be presented, which refers to the detection and location of a PD defect in a MV power cable. The test was performed as part of a routine check. In the here presented example an increased PD activity up to 4,600 pC has been measured, which appeared already at a test voltage level significantly below U_0. The PD site was clearly assigned to a joint.

The recognized PD defect resulted from an insufficient heating of the insulation shrinking hose. A remarkable high amount of liquid escaped at the point where the power cable has been cut. The measuring results are evident from Figure 8. After replacement of the defective cable accessory the PD test has been repeated. Under this condition a PD level in the order of 250 pC was detected, which was about 20 times lower as the previous detected value. Even if this PD magnitude was accepted by the utility it was decided to repeat the PD detection after one year to assess any trending. Generally it was stated that the assembling work was not done perfectly.



Results of s On-Site PD Measurement MV Power Cable Before and After Joint Replacement
Figure 8

CONCLUSIONS

The knowledge of the insulation condition of power cables is of increasing importance to enhance a reliable network operation. A key tool in this respect is the preventive PD diagnostics. Practical experiences in on-site PD diagnostics of MV power cables showed, that in most cases a measuring sensitivity of few tens of pC seems sufficient. Under this condition the well proven PD measuring circuit recommended in IEC 60270 [1] can be applied for both, PD detection and location of the PD sites. For this purposes both damped AC (DAC) test voltages and frequency-tuned resonance AC (FRAC) test voltages can be considered as a cost-effective alternative for conventional power frequency (50/60 Hz) exciting voltages. This is, because the inception voltages as well as the apparent charge magnitudes and the characteristic PD patterns are well comparable for those kinds of test voltages.

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