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Information

PD-Diagnostics with OWTS

Oscillating Wave Test System

Mess- und Ortungstechnik
Measuring and Locating Techniques

Elektrizitätsnetze
Power networks

Kommunikationsnetze
Communication networks

Rohrleitungsnetze
Water networks

Leitungsortung
Line Location

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PD Diagnosis on Medium Voltage Cables With Oscillating Voltage (OWTS)

Introduction

Even in times of deregulation, the underground cable networks of the power supplier is one of the most important assets. This fact is often not considered the way it should be in the planning of investment budgets, i.e., the presently practised incident-oriented maintenance leads step-by-step to the exhaustion of the still available safety reserves.
Since the beginning of the eighties, a large number of XLPE first generation cables have shown the known "water treeing" and have meanwhile been exchanged or renovated for the most part. It is possible to determine the condition of these cables with the known dielectric diagnosis methods [1-6], which will certainly be necessary for the next 10 years as well.
The much older paper-oil-cables on the contrary are rather inconspicuous regarding their operating performance, even though their predicted lifetime of 40 years has long since been surpassed. As these cables, as every technical insulation, are subject to complex operating stress, ageing and partly forced local damage accumulation have to be reckoned with.
The recording, location and evaluation of partial discharges (PD) inside the insulation and the accessories of medium voltage cables offer the possibility of an early diagnosis of cable network failures, however, with the need of a clear differentiation between the insulation systems and the accessories.
In order to be able to carry out an evaluation of the risk factor of PD defects as exactly as possible, the applied voltage for a PD diagnosis should be within the range of the operating frequency, because the typical PD parameters, such as inception and extinction voltage, PD level and PD pattern then correspond to the relevant values under operating conditions.
On the other hand, the electricla stress during the diagnosis measurement should be limited to the extent that no irreversible damage and hence deterioration of the condition of the test objects takes place.

PD Faults in Cable Systems

In general, partial discharge is understood to be the partial electrical breakdown of an insulation system, i.e., only a limited section of the total insulation section is bypassed.
Inside cables, PD defects are generally ionisable, gas-filled voids, which either developed already during the production of the insulation, were caused by mechanical damage or are present inside the joints or terminations due to faulty mounting processes.
In addition, thermal degradation processes inside joints with improperly performed workmanship can also lead to PD inception.

Figure 1: PD surface traces on the improperly removed insulation shielding

However, partial discharges can also occur when the electrical strength of the respective insulation material is locally surpassed by the stressing field strength - e.g. by large water trees or uneven semi-conducting layers on the inner conductor of a PE/XLPE cable. Then the irreversible material tearing up, the so-called „electrical treeing" takes place. Inside the homogenous insulation material PE/XLPE, electrical trees grow towards the opposite conductor with approx. 0.2 mm/h even in the case of operating field strengths so that a complete breakdown takes place inside the cable within a few days [6;7].

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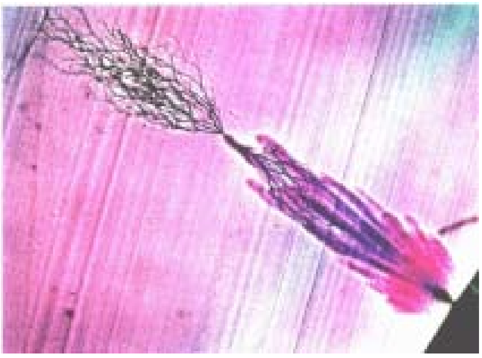

Figure 2: Electrical tree initiated via voltage test on a vented tree

Water trees themselves do not show any partial discharge so that the PD diagnosis is not adequate for the evaluation of the condition of WT-affected PE/XLPE insulations. For this problem, the network operators have adequate dielectric diagnosis methods available [1-6].

Inside paper insulated cables (PILC) and their accessories, however, a completely different PD behaviour is to observe.
In the laminated and impregnated paper insulation, PD occur locally in dry areas, but they may disappear again due to the mass migration in the case of thermal load changes. In the same way, carbonisations have the effect of conductive bridges due to the reacting PD so that the potential differences are "short-circuited" and the PD discontinued.
Due to the barrier effect of the laminated paper insulation, the propagation of PD channels is largely impeded so that PILC cables with PD in the insulation may be safe for operation even for many years.
A similar behaviour can be found in oil-filled joints. The operation of drained terminations, however, is directly threatened, because self-healing by a continuous flow of mass or cable oil cannot take place.

From a multitude of PD measurements on PE/XLPE cables and PILC cables, there is knowledge and experience for the evaluation of the threat to the respective insulation systems by PD.

Requirements for the On-Site PD Diagnosis

Basically, three parameters are important for the judgement of the PD behaviour of a cable system.
PD Inception Voltage Ui : The PD inception voltage is determined by a stepwise or continuous increase of the voltage applied to the test object. Ui is the voltage, where measurable PD start, i.e., the sensitivity of the measuring system and the existing ground noise during the measurement influence the recording of the inception voltage.

PD Extinction Voltage Ue : Since PD sources often show a hysteresis response regarding the inception and extinction voltage, i.e., the PD in ignited locations are often only extinguished below the PD inception voltage, the value of the extinction voltage is important for the judgment of the risk factor.

PD Level : Normally, the maximum impulse charge at Uo is used as a assessment criterion. There are already relatively good experiences in order to evaluate the risk factor for the reliability of operation depending on the location of the PD (cable, joint, terminations), the type of insulation of the cable and the design of the accessories. The occurrence of PD impulses also characterizes the risk coming from a PD source.

The phase-resolved display of the PD offers for typical types of PD sources the possibility of comparison with so-called "fingerprints". For GIS systems, there are already relatively exact characterizations. For cable systems, however, fingerprints depend on a number of influencing factors so that presently significant correlations are not possible, but useful additional information can nevertheless be derived.

For the network operator, the following requirements are important for the assessment of cable systems.

- The cable systems should be free from PD at the rated voltage Uo.
- In networks with resonance earthed starpoint , there should not be any PD up to 1.7 Uo. Should this nevertheless be the case, the PD must be extinguished again above Uo.

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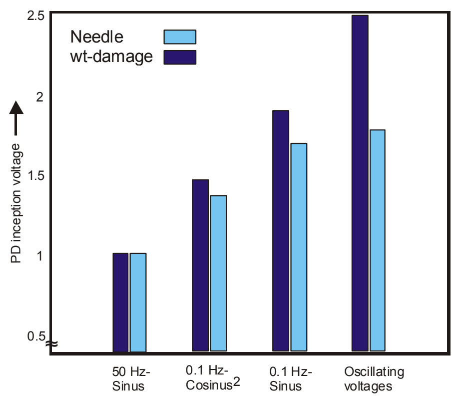
- For the PD diagnosis, a voltage shape should be used, which creates comparable PD parameters (inception and extinction voltage and PD level), such as the 50 Hz service voltage.
- The voltage stress during the PD diagnosis must incite the existing PD faults in order to detect them, determine the intensity and locate the position of the PD.
- The PD diagnosis must to take place non-destructively, i.e., no additional fault locations in the form of electrical trees should be initiated.
- When using power-frequency or similar voltage shapes, the gradual increase in voltage may be limited to levels up to max. 1.7 Uo during the diagnosis. This way, the risk of damage to the insulation is minimized.
- When using distinct different voltage shapes (e.g. 0.1 Hz Sine), there should be knowledge for interpretation as to how and whether the obtained test readings can be transferred to 50 Hz



service conditions.

Figure 3: Influence of the voltage shape to the electrical tree inception voltage (tree ignition) [9]

The studies of Kalkner and others [9] in figure 3 show that in case of oscillating voltages the ignition of electrical trees and thus the irreversible destruction of the dielectric at non-homogeneities or water trees only develops at distinct higher voltages. Hence this voltage shape stands out as a particularly „gentle“ voltage stress for a non-destructive PD diagnosis.

Oscillating Wave Test System (OWTS)

The Oscillating Wave Test System described hereinafter unites all advantages of a non-destructive PD diagnosis system.
The principle of high voltage generation and the measuring circuit are shown in figure 4.

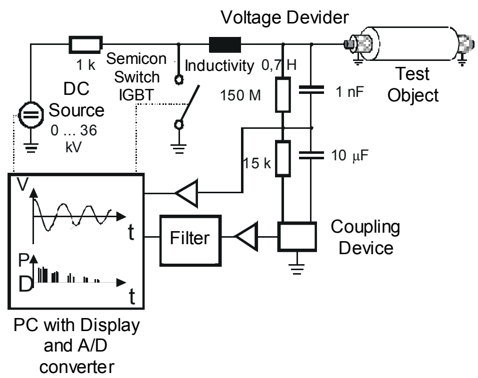


Figure 4: Principle circuit diagram of the OWTS – PD – diagnosis system

The test object is charged within a few seconds to the desired voltage and then discharged via the electronic high-voltage switch and the specially designed air-core coil. This creates an oscillating decay voltage, the oscillation frequency of which is determined by the inductance of the air-core coil and the capacity of the test object according to equation 1.

Oscillation frequency of the testing voltage

$$f_o = \frac{1}{2\pi\sqrt{LC}} \qquad \text{(eq.1)}$$

The attenuation of the decaying voltage amplitude corresponds to the dielectric losses within the test object, because the ohmic line losses in the test circuit can be neglected. This

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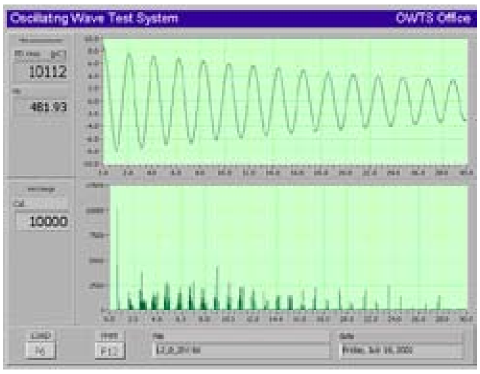
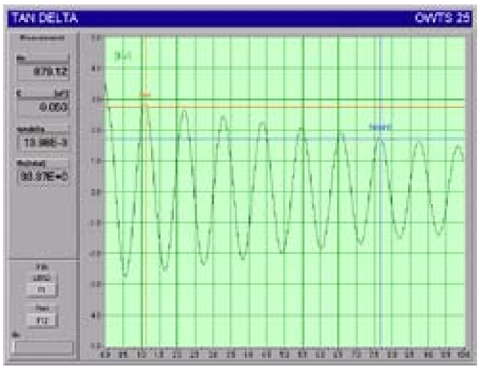
way, the dielectric characteristics (tan δ) of the test object can be characterized (figure 5).



Voltage shape and PD signals



Determination of tan δ; resolution 1*E-3

Figure 5: Oscillating testing voltage with PD pattern and tan δ determination

Depending on the length of the cable to be tested and its kilometric capacity, an oscillating switching voltage with a frequency of 100 Hz up to 1 kHz is generated. For typical cable lengths of 1000 m, the oscillation frequency is about 250 to 300 Hz, i.e., factor 5 to 6 to the operating frequency. In order to measure in the low frequency range below 300 Hz even on short cables, an additional PD-free load capacitor with a blocking inductance can optionally be connected.

The PD test circuit is calibrated according to IEC 60270 [10]. By a stepwise increase of the testing voltage, the PD inception voltage Ui is determined. The PD extinction voltage can also be clearly determined by the attenuated voltage curve. An indication for the type of PD source (void or inclined contact surface) is often given by the PD pattern, i.e. the occurrence and phase angle of the PD pulses. A comfortable software for locating the PD sources is available with which the reflection patterns of the recorded and stored PD signals are evaluated in a semi- or fully automatic process (figure 6). By digital filtering, an excellent interference suppression is achieved, and the attenuation of PD signals on long cables is taken into consideration for the evaluation of the reflection patterns.

Original form of the PD signals


Location of PD fault positions
with TDR software

Figure 6: PD signals with a bandwidth up to 3 MHz and automated location of PD sources

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This enables a successful location of PD sources also on PILC cables up to a length of 3 - 4 km.
As a result of this evaluation, the so-called mapping of the PD sources can be displayed (figure 7). In our case, the PD sources are represented over the cable length for all three phases of the system. It can clearly be seen that in the set of joints at 200 m in conductor 1 and at 360 m in conductors 2 and 3, PD with high intensity very often occur. This test object is a 20 kV XLPE cable system with poorly mounted heat-shrink joints. Remarkably these extremely high PD levels did not lead to a failure of the joints until 5 to 6 years of operation.
Because of the stochastic of PD processes, a statistical evaluation of the PD signals is absolutely necessary for a significant statement about the type and location of PD sources! Interpretations based on just a few assumed PD signals can lead to wrong decisions with very high subsequent costs. After all, the network operator must make a sound decision about the replacement or not of the affected accessories or cable sections based on the PD diagnosis.

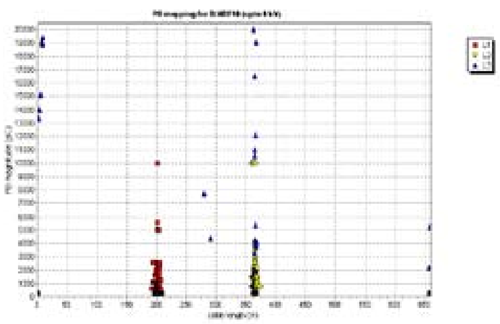

Figure 7: Statistical distribution of the PD locations and PD levels over the cable length of a 20 kV XLPE cable system

Knowledge Base and Limiting Values for the PD Diagnosis

Worldwide, there is a multitude of practical experience of on-site PD measurements. [10-16]. In the direct comparison of different PD measuring systems, OWTS was judged to be the best system for the considered cases of application [16].

Normally, ground noise levels within the range below 100 pC can be observed in the field so that the requirements for a sufficient measuring sensitivity are given in order to detect PD.
The occurrence of PD signals is strongly determined by the frequency of the testing voltage and hence the voltage gradient. In particular regarding PD sources in the area of the field stress control (inclined contact surfaces) in joints and terminations, highly frequency-dependent PD inception voltages, impulse occurrences and PD levels can be observed [13;14;16]. Therefore, resonance testing systems with variable or fixed frequencies and the oscillating switching voltage (OVS) to simulate the operating voltage are recommended. The OSV represent nearly no stress due to their short application time (some 100 ms) on the test object and do not cause significant damage during the diagnosis measurement [13-15].

The PD locations are often to be found in the accessories of the cables. There is comprehensive experience on PILC cables (figure 8).

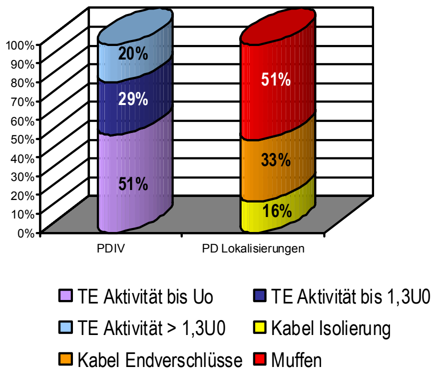

Figure 8: PD inception voltages and PD locations in PILC cables [14]

Due to the different insulation materials and their sensitivity for or resistance against PD, other criteria have to applied to PE/XLPE cables than to PILC cables regarding the risk evaluation of partial discharges (figure 9).
The shown trend or limiting values offer the network operator a good orientation.
Nevertheless, the respective operating experience with the relevant cable systems is of great importance.

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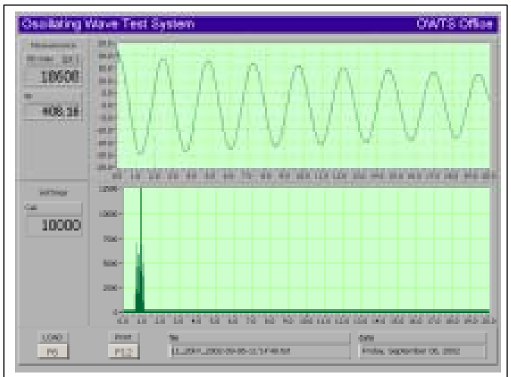
For instance, a joint in PILC cables can be the cause of brief transient earth faults even with relatively low PD levels. If it is found out during the PD diagnosis that only this one joint is PD-affected, it is obvious to replace this joint in order to eliminate the problem.
Typical series faults, e.g. due to wrong mounting, will be assessed according to the outage behaviour and the PD parameters, in particular the inception voltage.

An observation of the tendency at intervals of 3 to 6 months is useful in any case, if the limiting values shown in figure 9 have been reached or exeeded during the PD diagnosis, but before an outage of the cable system has been stated.

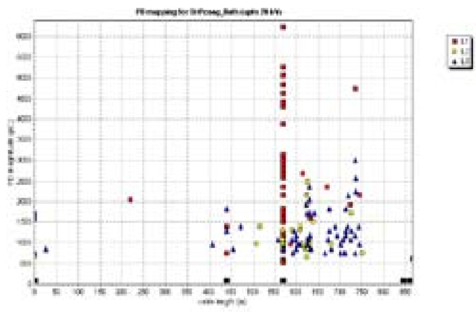
Cable Element	Type	Trend / Limit
Insulation	Paper	up to 10.000 pC
	PE /XLPE	< 20 pC
Joints	Oil Insulation	> 10.000 pC
	Oil /Resin Insulation	5.000 pC
	Silicone / EPR Insulation	500 to 1.000 pC
Terminations	Oil Termination	6.000 pC
	dry Termination	3.500 pC
	Shrink-/Slide-on Terminations	250 pC

Figure 9: Trend or limiting values for PD levels [14]

It is interesting to evaluate the quality of newly installed cable systems, in particular when transition joints (PILC/XLPE) have been mounted. The mounting quality of transition joints is highly influenced by the subjective factor due to the complexity of the processes. The PD diagnosis enables the selective evaluation of the joint as well as of the paper and XLPE cable sections (figure 10). Besides the concentrated PD activity in the transition joint, locally distributed PD can be observed in the paper cable section.
The quality control of cable installations by PD measurements will become increasingly important in the future, because the increasing cost pressure upon the network operators leads to a placing of the order to the cheapest construction company and it is advisable to check the work performance.
For the evaluation of PD occurrences, the PD inception and extinction voltages and the local concentration of PD have to be considered as the most important parameters besides the trend or limiting values of the PD levels.



PD pattern of a transition joint



PD-Mapping of mixed cable XLPE / PILC

Figure 10: PD parameters of a mixed cable section with oil filled transition joint

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The decision path has been summarized once more in figure 11.

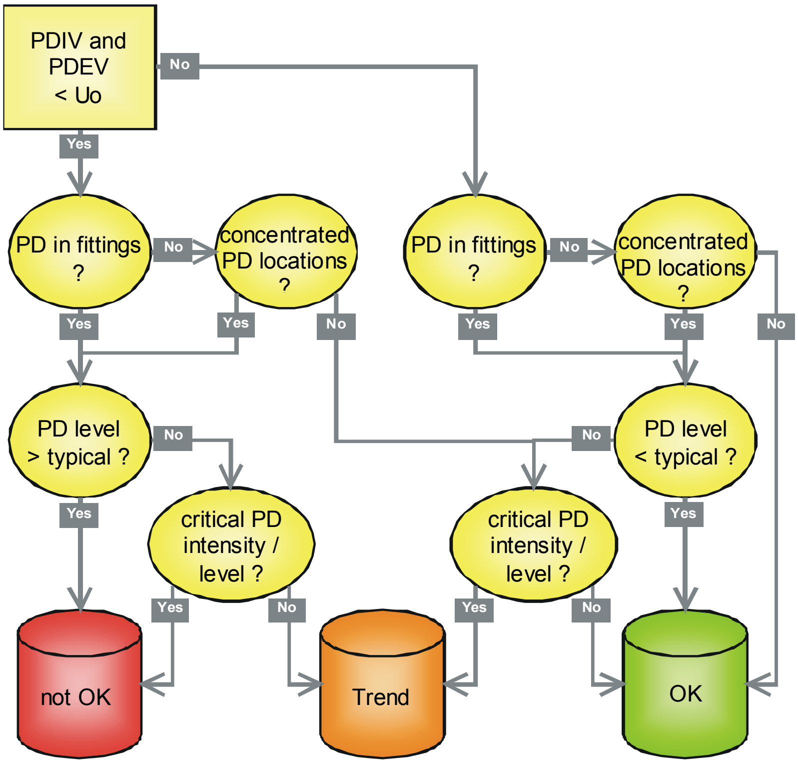

Figure 11 : Decision process for the classification of results of the PD diagnosis [14]

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IPC with integrated PD Measuring System and HV -Source

HV - Inductivity and PD-free connection cable

Figure 12 : OWTS installed in the cable test van

Summary

For the control and maintenance of the reliability of medium voltage cable networks, the PD diagnosis is an important tool for the asset management.

The essential characteristics of the Oscillating Wave Test System with absolutely user-friendly software are :

- Based on the resonance principle, the measuring system produces a sinusoidal oscillating voltage (compact dimensions and low weight)
- The oscillation frequency of the test voltage amounts to 50 Hz up to several 100 Hz depending on the test object capacity
- The test voltage at the test object corresponds largely to the conditions at operating frequency
- The oscillating voltage is applied to the test object only for a few 100 ms and therefore causes no further ageing or damage
- The PD extinction voltage can be determined very easily based on the decaying voltage amplitude
- PD level measurement according to IEC 60270 at a bandwidth of 150 … 650 kHz
- PD source location at a bandwidth up to 3 MHz with semi- or fully automatic software

Statements on the remaining life of cables are generally not possible via the PD diagnosis. However, an evaluation based on practical experience permit an orientation regarding the condition and risk factor of the cable network. This way, the PD diagnosis gives valuable information for necessary maintenance activities, if necessary, and helps to use the available budgets effectively.

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