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ADVANCED SOLUTION FOR ON-SITE DIAGNOSIS OF DISTRIBUTION POWER CABELS

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ABSTRACT

Medium voltage cables are of key importance in the power distribution network. The enormous lengths of cable now installed in many countries, together with the socio-economic costs of failure, have identified MV cable networks as a target for further attention. This contribution discusses the use of advanced partial discharge diagnostics at Damped AC voltages in assessing the insulation condition of power cable systems. In particular, based on seven years of field application, integral approach of non-destructive partial discharge diagnosis, field application, data analysis and decision support are discussed for power cable networks up to 60 kV.

KEYWORDS

MV power cables, advanced diagnosis, condition assessment

INTRODUCTION

The detection, location and recognition of partial discharges (PD) at an early stage of possible insulation failure in medium voltage are of great importance for maintenance purposes [1-6]. As a result, maintenance actions can be planned more precisely to prevent unexpected discontinuities in operation of the cable network (figure 1). To obtain a sensitive picture of discharging faults in power cables the PD should be ignited, detected and located at power frequencies which are comparable to operating conditions at 50 or 60 Hz. In particular, using non-destructive e.g. off-line diagnostics realistic data and reproducible patterns of discharges in a power cable can be obtained. Moreover with regard to implementation of to support utility asset management (AM) in decision processes about maintenance and replacement policy integral approach is necessary, where the following steps have to be considered (see figure 2).

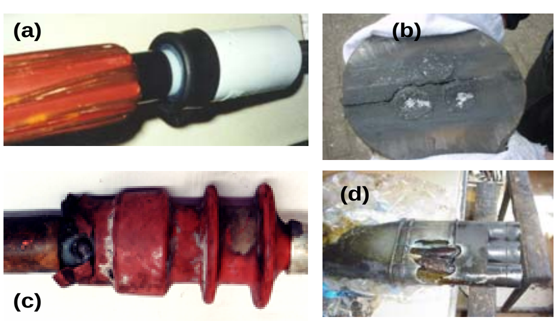

Figure 1: Examples of insulation degradation in MV power cables: (a) bad positioning of field grading, (b) large crack in the centre of a epoxy resin joint, (c) interfacial problems in a termination, (d) connector sharp edges inside mass insulated cable termination.

The above mentioned procedure is based on 7 years field experiences as obtained in world-wide implementation of PD diagnosis for condition assessment of MV power cables. In figure 2 the philosophy behind the above mentioned process is shown. It follows from this flowchart that the major carrier in the execution of condition assessment is the information about the cable system parameters, the diagnostics data and advanced analysis. In this paper based on these steps integral approach will be discussed more in details.

ON-SITE ENERGIZING AT DAMPED AC VOLTAGES

Nowadays a number of diagnostics has found his approval in the field [3, 4]. In this paper, based on worldwide practical experiences the current practices in PD detection and evaluation of distribution power cables using DAC voltages is presented, see figure 3.

To generate damped AC (DAC) voltages with duration of a few tens of cycles of AC voltage at frequencies up to a few hundreds of Hz a system has been developed [2-6] and in practical use for several years, (figures 4-6). This method is used to energize, to measure and to locate on-site partial discharges in power cables in accordance with IEC 60270 recommendations. The system consists of a digitally controlled flexible power supply to charge capacitive load of power cables with lengths up to 10km. With this method, the cable under test is charged during

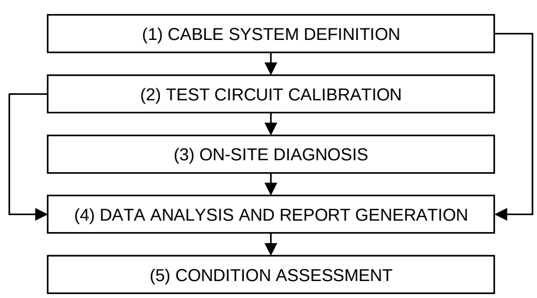

Figure 2: Integral approach for condition assessment of medium voltage power cables by means of on-site diagnosis.

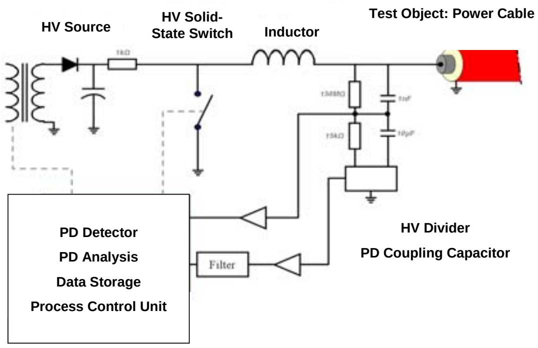

Figure 3: Schematic diagram of damped AC voltage generation and PD diagnosis of power cables.

$$t_{charge}=U_{max}\,C_{cable}/I_{load}$$

with increasing voltage over a period of just a few seconds to the usual service voltage. Then a specially designed solid-state switch connects an air-core inductor to the cable sample in a closure time of <1µ. Now series of AC voltage cycles starts with the resonant frequency of the circuit

$$f_{DAC} = 1/\sqrt{(L \bullet C_{cable})}$$

where **L** represents the fixed inductance of the air core (0.8H) and $\mathbf{C_{cable}}$ represents the capacitance of the cable sample. During charging period, due to stressing the cable section at continuously increasing DC voltage, directly

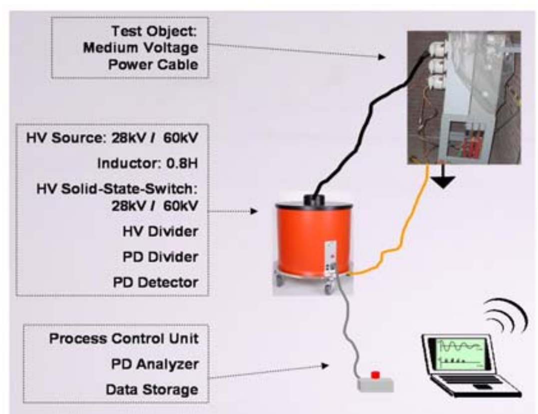

Figure 4: OWTS M-Series method (up to 60kV$_{peak}$) for on-site testing and PD diagnosis of power cables.

followed by a switching process and period of several AC cycles no ‘‘steady state’’ DC conditions occur in the cable insulation [7]. The test frequency of the oscillating voltage wave is approximately the resonant frequency of the circuit. The air core inductor has a low loss factor and design, so that the resonant frequency is close to the operating frequency of the service voltage: from 50 Hz to several hundred of Hz. As a result, a slowly decaying AC waveform of test voltage is applied to energize the cable sample. During tens of cycles the PD signals are initiated in a way similar to 50(60) Hz inception conditions [2], see figure 5. Due to the fact that the decay of the DAC voltage depends on the dielectric losses of the cables section under test

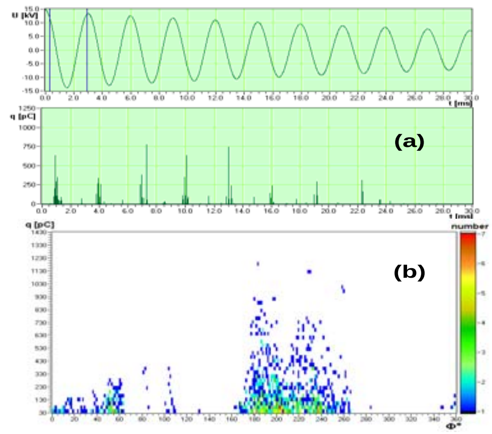

Figure 5: Partial PD patterns at DAC test voltages: (a) 2-dimensional pattern with the PD occurrence *q* versus the test voltage *U* on identical time base;
(b) 3-dimensional pattern with the PD occurrence represented in discharge magnitude, phase angle and number of PDs (by color).

different time constants may be observed. This effect can also be used to evaluate the dielectric losses e.g. by calculating the tan δ parameter.

To generate on-site damped AC voltages up to 60 kV$_{peak}$ and to perform advanced diagnosis by meaningful PD parameters modular hardware/software solution has been developed (figure 4). In particular, by use of

- modern solid-state technology and laser-control techniques (HV Solid-State Switch),
- power electronics, digital signal processing (HV Solid-State Switch, HV source),
- digital signal processing and filtering (PD detector),
- wireless communication and embedded computer system (PD detector, Control unit, PD analyzer)

novel system OWTS M-series has been developed for on-site PD diagnosis of power cables (figure 6).

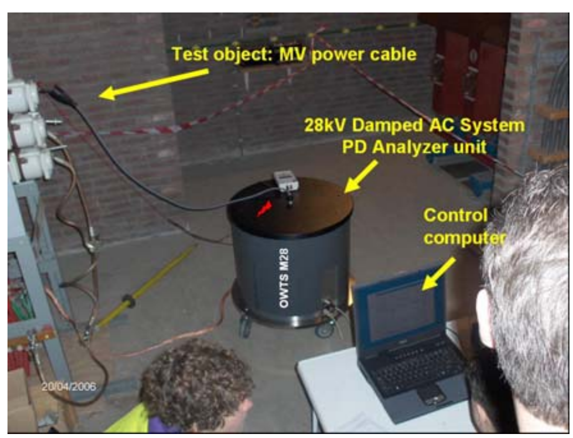

Figure 6: Advanced non-destructive diagnosis of MV power cables using OWTS M28 system. This method provides actual insulation condition by means of PD detection, localization and analysis including dielectric losses assessment of a MV power cable at damped AC voltages up to 60kV$_{peak}$.

DIAGNOSTIC PARAMETERS

To fulfill the utility expectations with regard to condition assessment several aspects should be taken into account by selecting diagnostics for on-site condition assessment. In table 1 an overview is given of most important requirements. It follows from this table that with regard to diagnoses several parameters has to be measured in function of the applied test voltage. Moreover the following has to be taken into account:

- The experiences have shown [1] that the observed changes in the voltage at which the PD activity starts PDIV is a good indicator to monitor the degradation by discharging defects.
- Moreover the increase of PD activity up to 1.7 U_0 is important indicator about the PD activity at voltages higher than the operational stress which may occur during the service life [2, 6].

Table 1: Important diagnostic parameters

Condition assessment	Type of diagnosis	Important parameters
Weak-spots	PD diagnosis	PDIV / PDEV PD magnitudes at voltages up to 1.7xU_0 PD location/ patterns
Integral condition	Dielectric losses	tan δ behavior at voltages up to 1.7xU_0

Due to the fact that diagnostic tests e.g. PD or dielectric losses measurements should have non-destructive character the maximum voltage level as used for the on-site diagnosis should not exceed the 1.7 U_0 (maximum AC voltage stress as expected to a cable section during the service life).
All relevant information from a PD measurement should be collected. Moreover, this diagnostic information as given by PD advanced quantities has to be combined with technical data of the particular cable section. To describe the PD process in the cable section under investigation OWTS M-series diagnostic method generates several PD quantities, which can be divided into two groups:

1. Basic quantities: PD level in [pC or nC], PDIV & PDEV in [kV];
2. Derived quantities: e.g. q-V curve, phase-resolved PD pattern, PD magnitude/intensity mappings.

This PD information which can be determined at different voltage levels e.g. up to 2U_0 is collected in a so-called PD 'fingerprint' of a power cable section. Different examples of PD ´fingerprint's´ are shown in figures 7-9. The characteristic of these quantities measured on different cable sections may vary in dependence on factors like type, age, service history, and location of the elements used. Linked to the different parameters from the PD fingerprint, interpretation rules are of importance as reflected in [3-6].

FIELD EXAMPLES

Many breakdowns in the MV power cables are caused by damages due to digging activities [2]. But still, more than half of the breakdowns in the cable network are caused by internal fault in the insulation systems of the cable network.

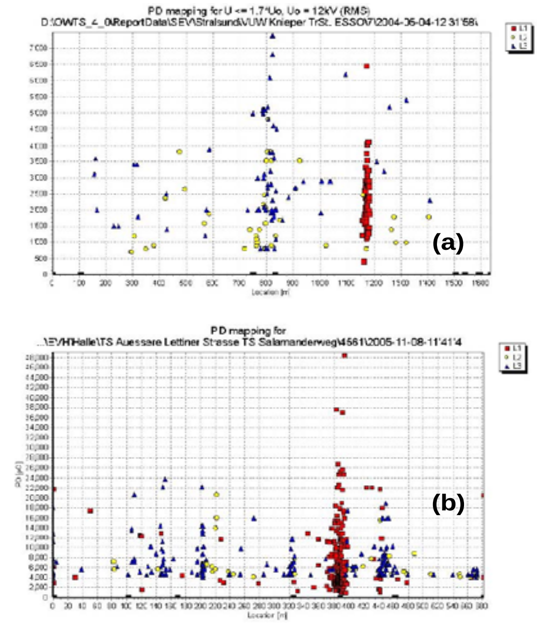

Figure 7: Example of a PD mappings: (a) PD concentration in PILC insulation at 1180m and in a joint at 820m, (b) PD in paper insulation nearby a dry joint due to leaking.

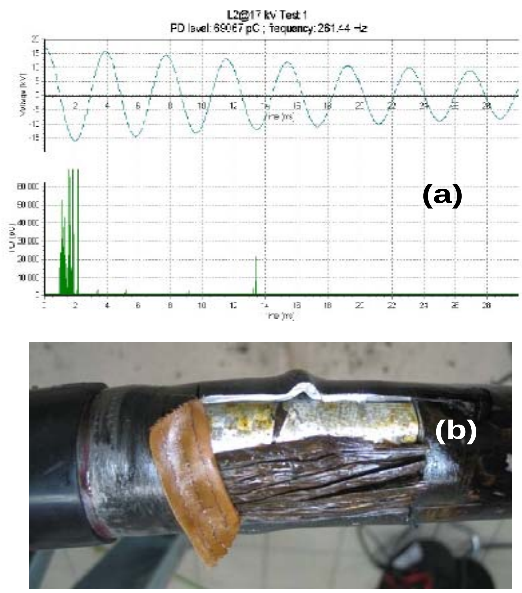

Figure 8: Example of a PD defect in PILC: (a) PD pattern, (b) evidence of mechanical damage due to strong internal bending.

Visual inspection of the disturbed components gives insight in the different types of breakdown related insulation defects. In the following typical examples of insulation defects as found using above described PD diagnosis technique are shown.

Typical pattern from PD in an oil filled system can be clearly distinguished from PD in voids, gaps or for example from PD between paper layers in a dry area of PILC cables. The PD locations are often to be found in the accessories of the

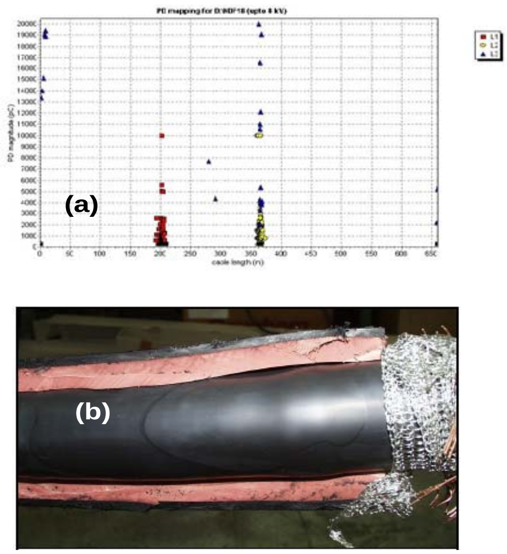

Figure 9: Example of a PD defect in XLPE (a) PD mapping with indication of PD activity in bad mounted heat shrink joints, (b) evidence of gap between stress tube and insulation tube due to incomplete shrinking.

cables. There is comprehensive experience on PILC cables [2-6]. While PD in oil filled joints up to 10 nC are mostly not critical also over a long time, a concentrated PD within the paper insulation Figure 7a could force to a breakdown in a certain time. On the other hand, a joint in PILC cable 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 one joint is PD-affected, it is obvious to replace this joint in order to eliminate the problem, even it has low PD level. Mappings of PILC cables often show a high PD intensity (local concentration) on one position in the power cable (figure 7b). In this case the joint looses its oil filling due to a leakage and the paper insulation nearby the joint is drying out.

Also other typical situation is mechanical damage of PILC lead sheath due to too strong bending. In this example the PD occurrences where located at a place of a transition joint with about 60 nC at U_0 (figure 8a). The inspection of the joint shows no mistake in the joint but an extremely deformed lead sheath close to the joint (figure 8b).

While in PILC scattered PD locations in the paper insulation are quite normal and not dangerous (figure 7) in XLPE cables in the insulation normally no PD is to be observed. In XLPE cables PD faults are mainly caused by bad workmanship at joints and terminations. In figure 9a 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 bad mounted joints with very high PD levels did not lead to a failure of the joints until 5 to 6 years of operation (figure 9b).

CONCLUSIONS

In this paper, novel solution of PD on-site diagnosis for MV power cables is presented. In particular the following has been concluded:

1. Condition assessment means combination of advanced diagnostics and technical information of the cable section.
2. With regard to distribution power cables, PD detection is a good method to get insight into discharging insulation defects.
3. Using PD diagnosis at DAC voltages up to $60kV_{peak}$ discharging defects in XLPE and PILC cable insulation can be detected and localized.
4. Due to application of modern technological solutions in power electronics and signal processing very compact and advanced system has been developed for on-site PD diagnostic of MV power cables.
5. To obtain experience norms for maintenance and replacement of a particular power cable, the diagnostic information as obtained using PD diagnostic at DAC voltages can statistically be analyzed. For more details see [8].

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