MODERN METHODS OF AFTER-LAYING TESTING OF POWER CABLES

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ABSTRACT

In this contribution definition and practical application of testing procedures of damped AC voltage testing combined with sensitive PD detection for monitored on-site testing of newly installed long length HV power cables will be discussed and presented.

INTRODUCTION

Power cables are distributed insulation systems up to multiple kilometers. It is known, that small damages and/or bad installation operations on power cables may deteriorate and lead to failures which can occur in the cable insulation and/or accessories as a result of the normally applied operational stresses or during transient voltage stresses, such as lightning or switching over-voltages [1-12]. Therefore additional to factory routine tests the reliability of power cables may further be improved by on-site testing and diagnosis. In general the on-site testing can be applied for two main reasons, figure 1:

1) as part of commissioning on-site: to demonstrate that the transport from manufacture to site and the final assembling has not caused any new and dangerous defects in the insulation.
2) after on-site repair: to spot bad workmanship during complete installation of the cable (including joints and terminations). To demonstrate that the equipment has been successfully repaired and that all dangerous defects in the insulation have been eliminated.

In general as on-site acceptance test for newly installed or repaired circuits one of the two approaches is in use: destructive withstand tests by over-voltage stresses applied e.g. for 1 hrs to the test object, or alternatively a voltage test of 1x*Uo as* applied for 24 hrs. Both approaches are based on the assumption that a healthy (defect-free and/or non-aged) insulation can withstand high level of voltage stresses and all insulation which is aged and/or consists of insulation defects should have lower level of withstand voltage and should produce a breakdown during the designated test time. It is known that the above described, so called *non-monitored* voltage withstand testing only, is not always sufficient to identify all manufacturing and installation problems. It has been observed that after

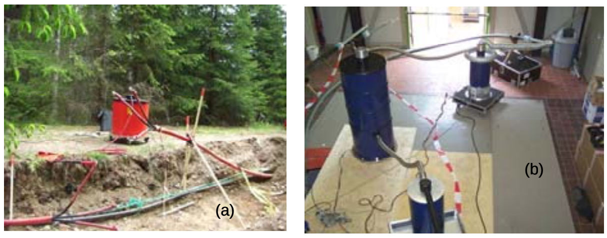

Figure 1*: Example of modern monitored on-site testing and PD measurement using sinusoidal damped AC voltages, (a) after-laying testing by DAC system 28kV of a 13 km long 10kV XLPE insulated cable (b) diagnostic testing by a DAC system 150kV of a 12 km long 50kV XLPE insulated cable.*

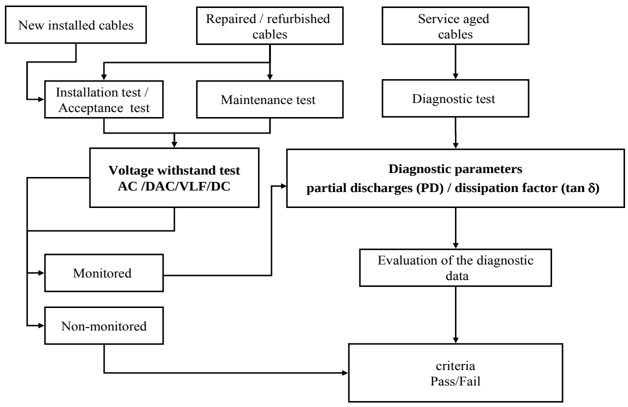

Figure 2*: Types of on-site electrical tests which can be performed on-site on power cables.*

successful *non-monitored* voltage withstand tests as described above, during initial operation failures may occur [13, 14]. It has been found that insulation defects in the cable insulation and cable accessories are responsible for these failures.

Therefore to detect during after-installation testing all weak spots in the cable insulation and cable accessories *monitored* testing is becoming now a days more and more the common practice, figure 2. It is known that *monitored* testing consists of a voltage withstand test combined with a diagnostic test e.g. partial discharge measurement. Practical realization of such tests becomes more attractive if modern on-site testing methods are characterized by

a. lightweight and high level of mobility of the test system,

b. test system compactness versus output voltage,
c. easy system assembling and low voltage erecting effort,
d. low necessary power demand for testing long cable lengths,
e. possibility of sensitive standardized PD detection and dissipation factor measurement

In this paper based on general consideration and practical examples the use of damped sinusoidal AC voltages (DAC) for *monitored* testing of power cables will be discussed.

GENERAL ASPECTS OF ON-SITE TESTING

According to [1-12] several voltages and test procedures have been defined for on-site testing. Based on field experiences a number of test voltage types are in use for testing and diagnosis. It follows from [1-7] that depending on particular voltage type different application effectiveness's can be given. In particular applying sinusoidal ac voltages has long history in laboratory testing of all types of cable insulation and more than 10 years long history in on-site testing of all types of cable systems. Experiences have confirmed that applying on-site AC electrical stresses is applicable for the recognition of all types of failures related to insulation and it can also be combined with diagnostics e.g. PD, dielectric measurements [14].

According to [1] the sinusoidal damped AC voltages have been proposed 20 years ago as a complementary and/or alternative method to sinusoidal continuous AC voltages and in the last years DAC has become accepted for on-site testing and PD measurements of all types and length of power cables [4]. Moreover as compared to conventional continuous AC testing DAC systems fulfill the above mentioned a)-e) characteristics of modern on-site testing methods. [1-12], figure 1.

As a result of expectations of modern *monitored* testing for on-site the use of DAC testing includes several parameters which can be measured in function of the applied test voltage, table 1. Extending the voltage testing by PD measurements provides information about changes in the test voltage and or test duration and the presence of discharging insulation defects. Moreover the increase of PD activity up to e.g. $1.3xU_0$ (generally accepted test voltage level for PDIV to set the PD-free status of a component) is an important indicator about the PD activity at voltages higher than the operational stress which may occur during the service life [10], figure 3. The estimation of the

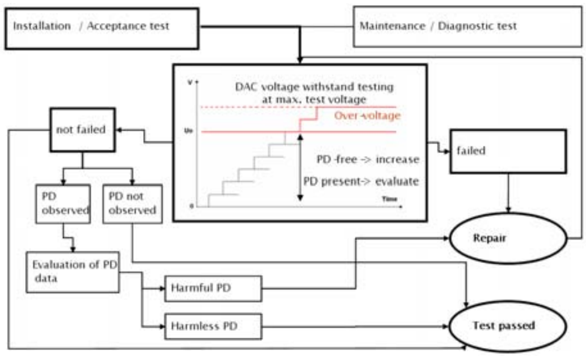

***Figure 3**: Procedures of monitored on-site electrical tests on power cables using sinusoidal AC and DAC voltages.*

dissipation factor at operational stresses e.g. up to 2.0Uo and at one of the equivalent power frequencies e.g. 20Hz - 300Hz is an important parameter of oil-impregnated cable.

ON-SITE ENERGIZING AT DAMPED AC VOLTAGES

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 [1-12]. This method is used to energize and to test on-site power cables with sinusoidal AC frequencies in the frequency range of 20Hz up to 500H. In addition this method can easily be used to measure and to locate on-site partial discharges in power cables in accordance with IEC 60270 recommendations, Figure 4. The system consists of a digitally controlled flexible power supply to charge capacitive load of power cables with large capacitive load e.g. 10 µF. With this method, the cable under test is charged during $t_{charge}=U_{max}\,C_{cable}/I_{load}$ with increasing voltage over a period of a number of seconds to the selected maximum test voltage level. Then a specially designed solid-state switch connects an air-core inductor to the cable sample in a closing time of <1µ. Now series of AC voltage cycles starts with the resonant frequency of the circuit $f_{DAC} = 1/2\pi\sqrt{(L \bullet C_{cable})}$ where L represents the fixed inductance of the air core and C_{cable} represents the capacitance of the cable sample. The test frequency of the damped AC voltage is the resonant frequency of the circuit. The air core inductor has a low loss factor and design, so a slowly decaying AC waveform of test voltage is applied to energize the cable

***Table 1:** Important diagnostic parameters*

Condition assessment	Type of diagnosis	Important parameters
Insulation voltage withstand	Over-voltage application	Max. test voltage Criteria: Pass / Fail
Insulation weak-spots detection	Detection of partial discharges	PDIV / PDEV PD magnitudes in [pC] in function of the test voltage e.g. up to $2.0xU_0$ PD site location, PD phase-resolved patterns Criteria: PD level
Insulation integral condition	Estimation of dielectric losses	Dissipation factor in [%] in function of the test voltage e.g. up to $2.0\ xU_0$ Criteria: tan δ, Δtanδ

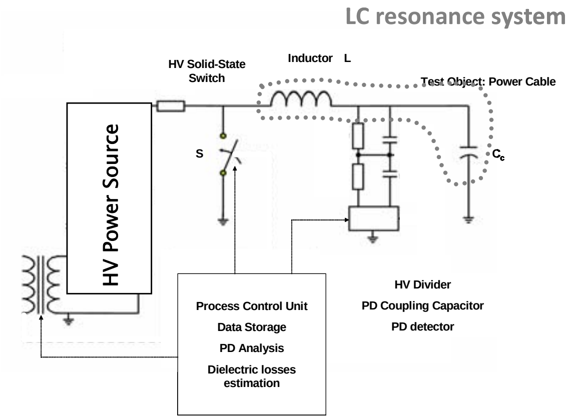

***Figure 4**: Schematic diagrams of damped AC systems for on-site testing and PD detection of distribution and transmission power cables.*

sample. During a number of AC voltage cycles the PD signals are initiated in a way similar to 50(60) Hz inception conditions [1-12]. As a result the use of damped AC voltages for testing power cables is in compliance to the following international standards:

[1] IEC 60060-3: High Voltage test techniques –Part 3: Definitions and requirements for on-site testing;
[2] IEEE 400: Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems;
[3] IEC 60840: Power cables with extruded insulation and the accessories for rated voltages above 30kV up to 150kV Test methods and requirements;
[4] IEEE 400.3: Guide for PD Testing of Shielded Power Cable Systems in a Field Environment;
[5] IEC 60270: Partial discharges measurements;
[6] IEC 885-3: Test methods for partial discharges measurements on lengths of extruded power cable;
[7] IEC 60141: Tests on oil-filled and gas-pressure cables and their accessories;

In particular the IEC 60840 recommends that the test voltage must have a sinusoidal shape, and it should have the frequency in the range 20-300Hz. As a result damped sinusoidal AC fulfills both recommendations and it can be used for on-site testing. It has to be remarked that comparing to continuous AC test voltages in case of strong inhomogeneous defects (PD presence) the destructiveness of DAC testing can be lower. Therefore it is recommended to perform DAC testing as *monitored* testing where PD measurement is used to demonstrate the up-coming defects [4-6]. Referring to IEEE 400 and 400.3 the DAC testing is fully recommended for testing and PD detection.

PRACTICAL EXAMPLES

A newly installed 12 km long, 50kV XLPE insulated underground cable circuit has been tested in accordance to the Dutch NEN 3630 recommendation. This norm recommends voltage withstand testing using AC resonance system 25Hz-200Hz applied at 2.5xUo. It has been decided to perform *monitored* withstand testing by using damped sinusoidal AC voltages (25Hz-200Hz) for 1 hour testing at 2.5Uo. During the whole time of withstand test standardized PD detection has been applied. As a result of 1 hour DAC over-voltage no breakdown has been observed, figure 5. Also no internal PD activity has been registered (except external corona). It has been concluded that up to 1.7Uo the complete cable system was PD –free (background noise level < 10pC) and the test has been considered as successful.

In a newly installed 7.8km long, 132kV XLPE insulated underground circuit two cable faults occurred after the circuit has been energized after a successful after-laying test by 1xUo as applied for 24 hours. Both faults have been localized in two joints. After inspection of the failed joint evidence of installation faults (insulation cuts) have been found. To inspect other 13 joints for the presence of similar insulation defects DAC *monitored* voltage test was performed. The cable section was tested up to 1.3U_0 using sinusoidal DAC voltages (43Hz) including standardized

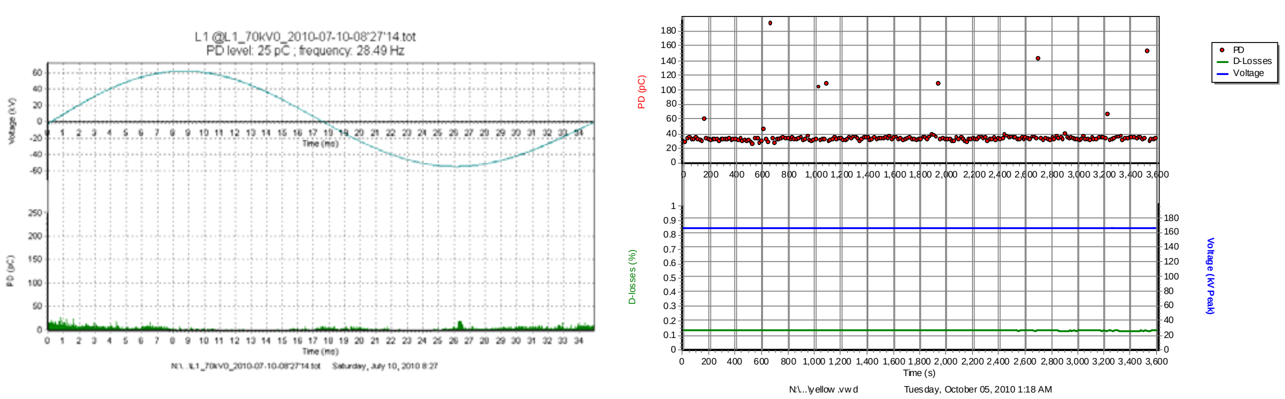

***Figure 5:** Monitored voltages withstand testing of a 50kV XLPE cable underground circuit (12km): a) example of PD pattern at 1.7Uo, b) DAC voltage withstand test 1hrs 2.5Uo.*

partial discharge measurement. Due to the long length of the cable circuit the test has been done from both cable ends. For on-site PD detection the noise level was below 25 pC. Figure 6 shows results of the PD measurements and analysis. Based on this test the cable circuit was PD-free up to 1.2 U_0. Starting at 1.3 U_0 PD activities up to 1000pC have been observed in a number of joints. This observation that at test voltage higher than U_0 PD activity in other joints has been localized, confirm that in addition to two joints failed at U_0 (during energizing) also other joints might have been not properly installed.

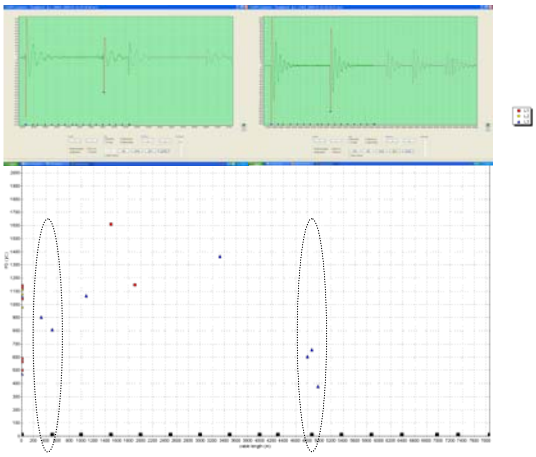

Figure 6: *On-site testing of a 132kV kV XLPE cable underground circuit (7,8km): example of TDR analysis of PD pulses and PD mapping of PD pulses as observed up to 1.3Uo in two joints.*

CONCLUSIONS

Based on the results above the following can be concluded:

1. According to newest developments the *monitored* voltage withstand testing is becoming more and more a common practice. The use of the PD measurement helps to detect and to localize discharging defects in the insulation and in accessories.
2. For testing power cables damped AC voltages can be applied as an alternative to continuous AC test voltages.
3. Regarding breakdown and as compared to *non-monitored* continuous AC voltage testing in case of inhomogeneous defects (PD occurrence) *monitored* testing using damped AC voltages can be less destructive and more sensitive (in case there is no breakdown observed) to detect and to localize discharging defects in accessories.

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