

Insulation Diagnosis of High Voltage Power Cables

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Abstract: In this contribution based on field application of advanced diagnostics a systematic approach for condition assessment of HV power cables is discussed. Based on the assumption that there is not one dominant failure process in HV cable networks in addition to partial discharges dielectric diagnosis has also be included to determine the actual condition of service aged e.g. XLPE, oil-filled, gas-pressurized cable insulation systems.

INTRODUCTION

It is known, that the insulation failures in a cable network may be caused by lower dielectric strength due to aging processes and by internal defects in the insulation system. It is known that

- to reduce the failures by the aging of the impregnated insulation diagnostic methods can be used: (a) oil analysis e.g. dissolved gas analysis (DGA) (b) assessment of bulk properties of insulation e.g. $\tan \delta$ measurements [1];
- to reduce the failure by internal defects, on-site cable diagnostics can be applied based on quantities related to insulation degradation, as partial discharges.

Moreover, to assess the condition of a certain cable type testing and diagnostic packages have to be developed. After a survey of all relevant information about the cables in the network, diagnostics are carried out to assess the condition of each cable [2]. Interpretation is done based on criteria for each diagnostic. All results together are used for a classification of the cable into a number of condition categories [3], see table 1.

Table 1: Supported electronic file types.

Condition	Definition
Normal Index 9	No maintenance necessary No problems
Defect initiation Index 6	<i>Short term:</i> No impact on network reliability <i>Long term:</i> without any maintenance possible life time reduction
Defect Index 6	<i>Short term:</i> cable can still be operated but the network reliability is decreased Maintenance is necessary
Failure Index 1	Cable can not be operated and maintenance is necessary Based on economics repair or replacement

Diagnostic	Maintenance frequency [n/yr]				
	A	B	C	D	E
Check oil pressures	12	12	12*	12*	12*
Measure saturation factor (existence of gas)	0,2	1	1*	1*	1*
Oil measurement (dissolved gas, breakdown voltage, $\tan \delta$)	0,2	0,5	1*	1*	1*
Check hydraulic system (leakage)	1	1	1	1	1
Visual inspection cable terminals	1	1	1	1	1
On-site $\tan \delta$ and PD	0,1	0,2	0,2	0,2-1	0,2-1
Inspection lead mantle	-	**	**	**	**
Paper quality	-	**	**	**	**
* special circumstances can lead to higher frequencies.					
** destructive research in case of diversions or disturbances.					

Figure 1: Example of HV power cables diagnosis program.

A maintenance program and/or guideline for further operation of the cable can be than linked to each category. Depending on the category, the condition assessment is repeated once every 3 or 5 years [4], see figure 1.

HV INSULATION DIAGNOSTICS

Nowadays on-site diagnostics are widely accepted and applied in the field of condition assessment of HV assets. It is known that unlike voltage testing, measurements of the dielectric may give an absolute indicator for the quality level of the cable insulation. The results of these measurements have a direct relation to the average qualitative level of the insulation at the moment of measurement and can thus be applied as a trend- or fingerprint measurement.

The partial discharge diagnosis may indicate weak spots in a cable connection. In order to run the measurement partial discharges are ignited in the cable insulation or joints by the application of a test voltage [4-7]. Due to the physical character of discharge occurrence, such as the PD inception voltage the PD pulse magnitudes, PD patterns and PD mappings for a utility interested in applying PD diagnostics for condition assessment of its power cable networks, a number of technical and economical aspects are of importance:

Voltage type: equivalence in PD inception processes among different voltage stresses for solid insulating materials;

Non-destructiveness: non-destructiveness of voltage stress during the diagnosis;

IEC 60270 conformity: in the case of measuring the PD quantity apparent charge of PD pulses in [pC] and [nC] the PD detection methods applied has to fulfill the recommendation of IEC 60270;

Sensitivity: immunity for on-site interferences and the level of system background noise;

Analysis: possibility to generate advanced diagnostic information to support diagnostic knowledge rules;

Efficiency: investment costs, maintenance costs, transportability and operation of the method in different field circumstances

The $\tan \delta$ measurement is applied for the determination of the loss factor of the insulation material. This factor increases during the ageing process of the cable. The $\tan \delta$ measurement should be regarded as a diagnostic and/or supporting measurement. The $\tan \delta$ value of a cable is strongly influenced by the composition of the connection, the trace, and the deviations in joints and the actual cable temperature. The $\tan \delta$ measurement is only applicable as trend measurement if composition circumstances of the trace and thermal conditions of successive measurements are virtually identical. For HV paper insulated cables the $\tan \delta$ can be an important indicator of possible thermal breakdowns [9, 10].

ON-SITE DIAGNOSIS OF HV POWER CABLES

For a complete on-site diagnosis of a power cables, it is necessary to energize the disconnected cable circuit using external voltage sources [1, 2]. In particular, the detection equipment e.g. partial discharge or dielectric losses can be directly connected to the cable conductors (or through the switchgear). In this way, the different phases of the cable circuit can be energized and the test can be performed. The capacitive power P needed to stress on-site the cable insulation is determined by the test frequency f , the cable capacitance C_{cable} and the test voltage U_{test} . In order to decrease the capacitive power demands for energizing cables as compared to 50Hz test voltages, different energizing methods using specific voltage shaped and frequencies have been introduced for PD diagnostics nowadays [1].

For this purpose, to perform on-site in non-destructive way advanced diagnosis of power cable circuits up to 250kV new method has been introduced [11, 12]. One of the methods using damped AC voltages for detection and localization of PD in cables is known as Oscillating Wave Test System (OWTS), [6, 7], see figure 2. For the generation of damped AC (DAC) voltages, the power demand is low due to the charging the cable capacitance with an continuously increasing DC voltage, after which the cable capacitance is switched in series with large inductance, resulting in an oscillating voltage wave with a frequency comparable to power frequencies. Due to application to the cable section of a continuously increasing DC voltage supply, directly followed by a switching and oscillation period no “steady state” DC

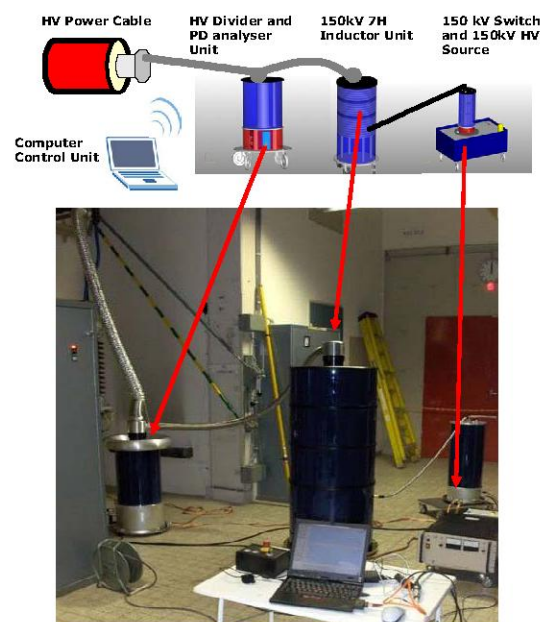


Figure 2: OWTS HV 150 System for on-site diagnosis of HV power cable circuits.

- Weight: 300kg
- Supply voltage: 220V
- Max. load at 150kV: 8 μ F
- Output: DAC voltage 150kV (20 Hz - 500 Hz)
- Test object: power cables: 100m -20km

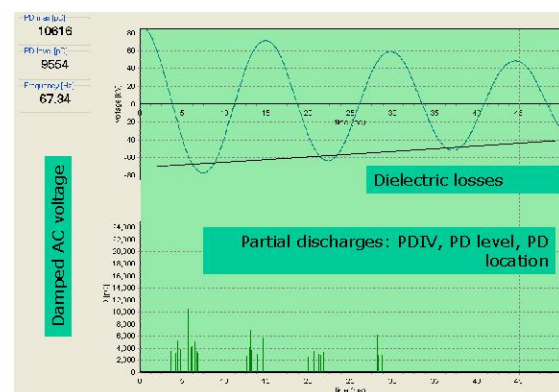


Figure 3: Basic diagnostic parameters of on-site diagnosis using Damped AC Voltage (DAC)

conditions occur [13]. The test frequency of the oscillating voltage wave is approximately the resonant frequency of the circuit. Using damped AC voltages on-site PD diagnosis (detection, localization) and the measurement of dielectric losses at voltage AC frequencies between 20Hz and 500Hz have become possible. During seven years of worldwide application of this method wide range of experiences has been developed for MV power cables. Moreover, since 2004 this method is also applicable for HV power cables up to 250kV.

Applying this method provides in addition to PD diagnostic information also the dielectric losses, see figure 3. Due to the fact that by using this method:

- the frequency of damped AC voltages is in the range of

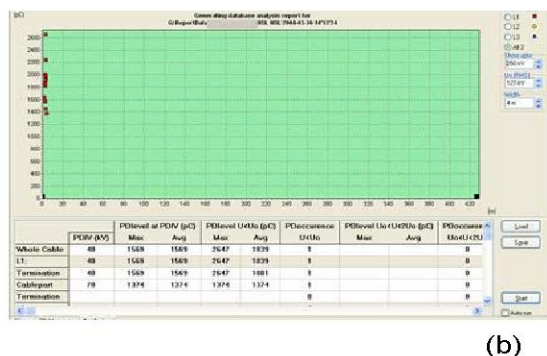
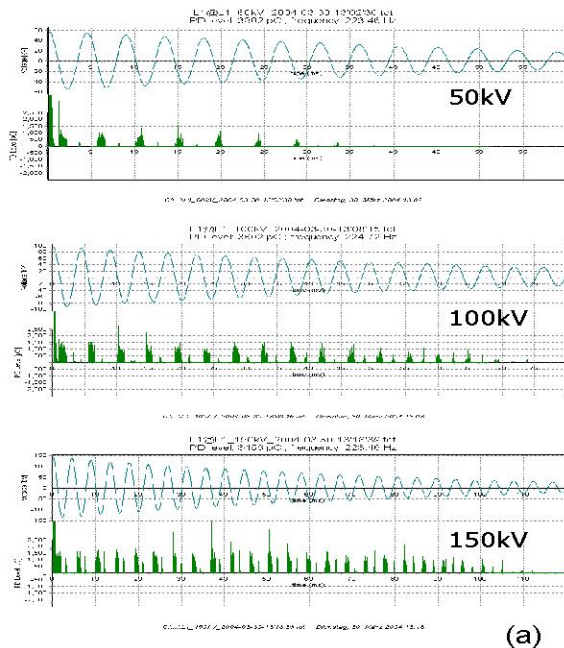


Figure 4: Examples of DAC voltages as applied to a 220kV power cable showing PD activity in a termination: (a) PD patterns at different voltage levels, (b) Mapping of PD location in the cable up to 250kV.

power frequency of acceptable HV test systems,

- a number of power cycles is applied to the cable sample provide ignition of PD sources in similar ways as compared to operating conditions,

the PD activity can be on-site measured with multiple undisturbed sinusoidal voltage cycles, see figure 4. The PD activity signals, ignited during one or more oscillating voltage waves, are detected by the system, which can process the signals for several purposes:

- A phase-resolved PD pattern can be resolved from multiple DAC sequences. In this way, patterns can be obtained which are similar to those recognized under 50(60) Hz conditions [12].
- Single PD pulses can be analyzed for original location by using traveling wave analysis. Statistical evaluation of PD signals obtained after several oscillating waves can be used to evaluate the location of discharge sites in the power cable. A PD mapping is created, which shows the distribution of the detected PD in a cable circuit, as a function of the

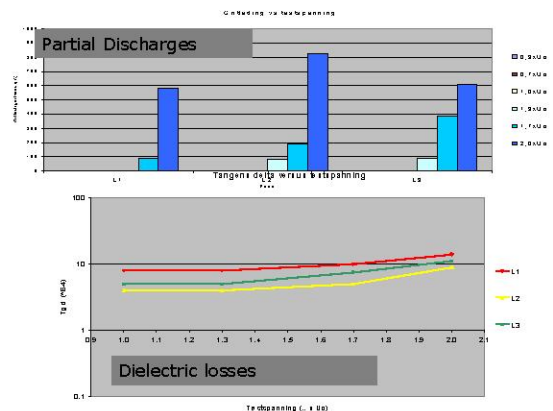


Figure 5: Example of PD diagnosis ($PDIV > 1 \times U_0$) and dielectric losses measurements from $0.3 \times U_0$ to $2.0 \times U_0$ on a service aged 150kV oil filled power cable: 2km.

magnitude or the intensity.

The dielectric losses can be derived from the decay characteristics of the oscillating voltage wave. In particular comparing the values at U_0 and $2U_0$ can and used to evaluate the over-all insulation degradation, see figure 5.

PRACTICAL EXAMPLES

Performing on-site testing/diagnosis of installed HV power cable circuit may have different purposes. In particular the following goals could be of interest:

- verify that a new circuit installation or repaired circuit does not contain gross workmanship problems or was not subject to severe mechanical damage;
- to assess the actual condition of a cable system as a

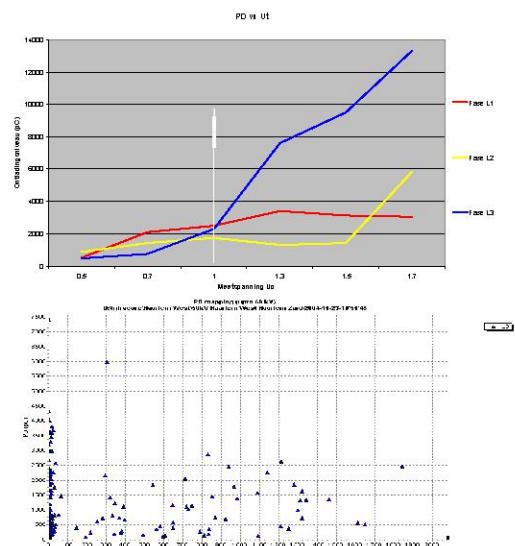


Figure 6: PD evaluation of 50kV, 6km long service aged power cable. From the PD analysis phase blue shows high PD activity as compared to other phases and the reference norms. Using PD mapping analysis of the phase blue the PD source has been located in the near cable termination.

part of asset management program e.g.

- to support maintenance and replacement management or
- as a means to support the operational decisions e.g. about the load profile as acceptable for a particular cable connection

In figure 6 and 7 examples of measuring results as obtained from such diagnostic tests are shown.

CONCLUSIONS

Based on the research results as discussed in this contribution the following can be concluded:

- New and service aged HV power cables are important assets and have to be tested on-site;
- PD and dielectric losses diagnosis at Damped AC voltages can be used for non-destructive on-site testing of new and service aged power cables;
- Based on field experiences and using diagnostic data (PD, dielectric losses) for different types of insulation and accessories experience norms can be estimated;
- Such experience norms for PD and dielectric losses can be used to support the Asset Management decision processes of HV power cable networks;

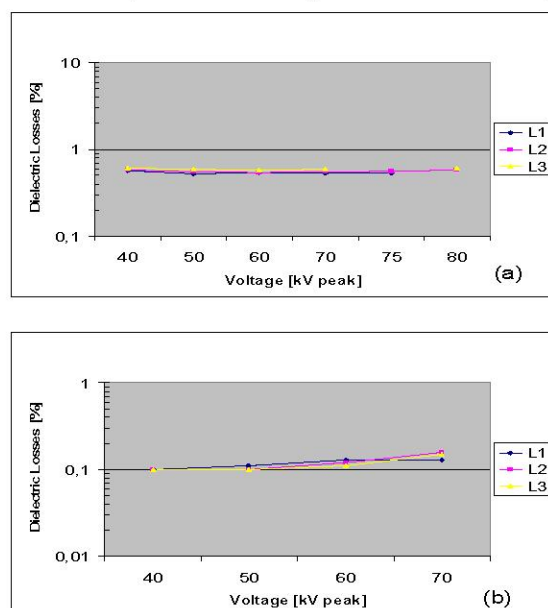


Figure 7: Examples of dielectric losses diagnosis of two service aged power cables:

- dielectric losses ($\tan \delta$) as measured on a 40years old oil filled power cable length 12.4 km using damped AC voltages (23 Hz) in function of the test voltage up to $1.5 U_0$; the measured values vary between 0.35% and 0.62% (35×10^{-4} and 62×10^{-4})
- dielectric losses ($\tan \delta$) as measured on a 29 years old XLPE power cable length 14.9 km using damped AC voltages (30 Hz) in function of the test voltage up to $1.3 U_0$; the measured values are lower than 0.15% (15×10^{-4})

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