ANWENDUNG VON MODERNER TEILENTLADUNGSDIAGNOSTIK FÜR INSTANDHALTUNG VON MITTELSPANNUNGSKABELSYSTEMEN

Frank J. Wester

NUON Infra Noord-Holland N.V.
Voltastraat 2, Alkmaar
PO Box 9111
1817 DD Alkmaar
The Netherlands
wester.frank@enw.emswitch.nl

Abstract:

Vom Standpunkt eines Energieversorgungsunternehmens ist zur Sicherstellung einer effizienten und zuverlässigen Energieversorgung eine genaue Bestimmung des Isolationszustandes von Mittelspannungskabelsystemen wichtig. Kabelanlagen mit großem Störungsrisiko sollten identifiziert und vor dem Auftreten der Störung präventiv und in einem ökonomisch vertretbaren Rahmen repariert werden können.

Für diesen Zweck sind moderne, leistungsfähige, nicht destruktive Diagnosemethoden erforderlich. Mit Hilfe der Diagnostik kann Condition Based Maintenance (CBM) durchgeführt werden.

In diesem Beitrag wird der systematische Einsatz der TE Diagnostik mit Hilfe oszillierender Spannungen nicht nur für betriebsgealterte Kabel, sondern auch für neue Kabelsysteme präsentiert.

INTRODUCTION

From the point of view of a power utility, insight in the condition of their medium voltage power cable network becomes more and more important to guarantee a reliable and secure power supply. Nowadays, modern measuring techniques give the opportunity to identify faulty sections in power cable systems on-site, so only the defective metres or accessory can be replaced before failure occurs.

For several years, detection and localization of partial discharges (PD) using AC voltages is internationally accepted as a symptomatic, reliable diagnostic method for the determination of the quality of insulation systems. In that respect, different energizing methods have been introduced and employed in recent years [1-4].

Furthermore, also from a point of view of the utilities, the requirements for the used diagnostic tool are as follows:

- symptomatic for cable insulation degradation;
- AC voltage stress conditions;
- according IEC recommendation related quantities;
- providing distinction between different types of insulation problems;
- providing PD location mappings.

OSCILLATING WAVE TEST SYSTEM

Oscillating Wave Test System (OWTS), figure 1, is a lightweight measuring method, using damped oscillating voltage waves for the ignition of partial discharges (PD) in the cable insulation, which are detected and located by the system.

The cable sample is charged over a period of just a few seconds to the adjusted test voltage (up to $37kV_{max}$) using a DC power supply. At this moment, a specially designed

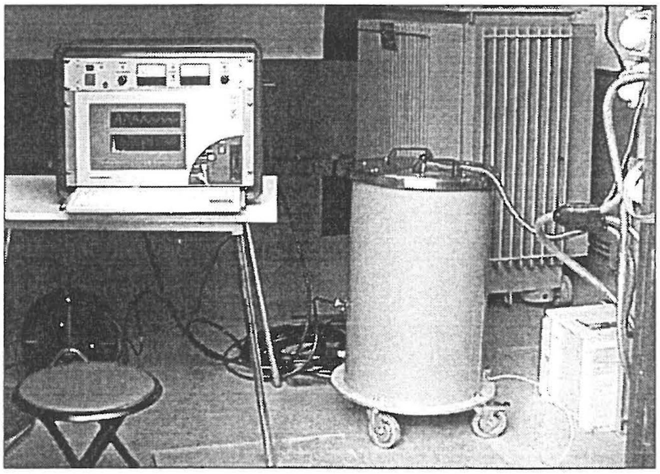

Figure 1: Oscillating Wave Test System during field measurements (on the table the DC supply and the computer, in the blue barrel the air-core and the solid state switch).

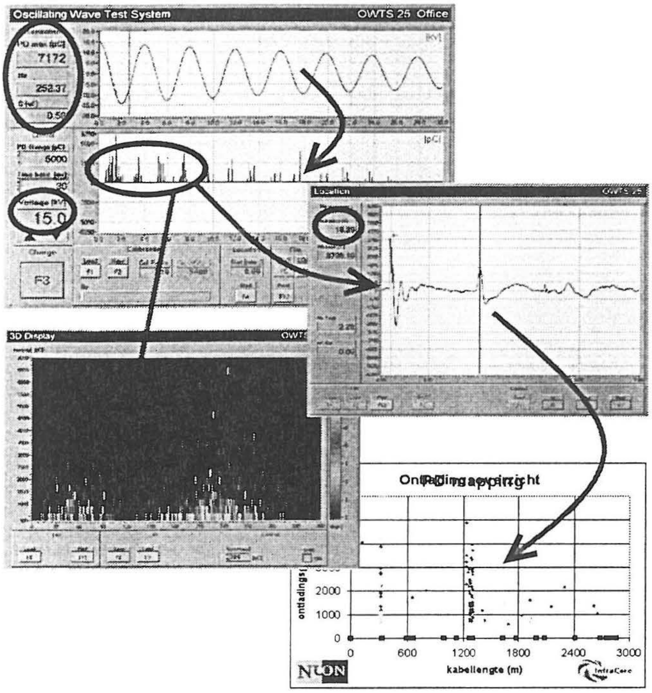

Figure 2: 'Fingerprint' of a cable section measured with OWTS, containing PD inception voltage, PD magnitudes, PD intensity, PD pattern and PD mapping.

The air-core inductor has a low loss factor and design, so that the resonant frequency lies close to the range of the service power frequency (within the range from 50 to 800 Hz). Due to the fact that the insulation of the power cables usually has a relative low dissipation factor, the Q of the resonant circuit remains high depending upon cable (30 to more than 100). The result is a slowly decaying oscillating waveform (decay time 0.3 to 1 second) of the test voltage, which energises the cable sample.

During the oscillating voltage waves, PD are initiated in a similar way to 50 (60) Hz inception conditions [5]. All of these PD pulses are measured using a fast digitizer. The localization of the PD activity is obtained by using the travelling wave principle. Further description of OWTS is given in [4,5,6].

Result of an OWTS measurement is a 'fingerprint' of a power cable section as reflected in figure 2, containing the following aspects:

- PD inception voltage;
- PD magnitudes at different testvoltages;
- PD intensity;
- PD pattern;
- PD location.

OWTS diagnosis can be applied for the following purposes:

- Diagnoses of existing cable network;
- Diagnosis of repaired cable sections;
- Diagnosis of new cable sections.

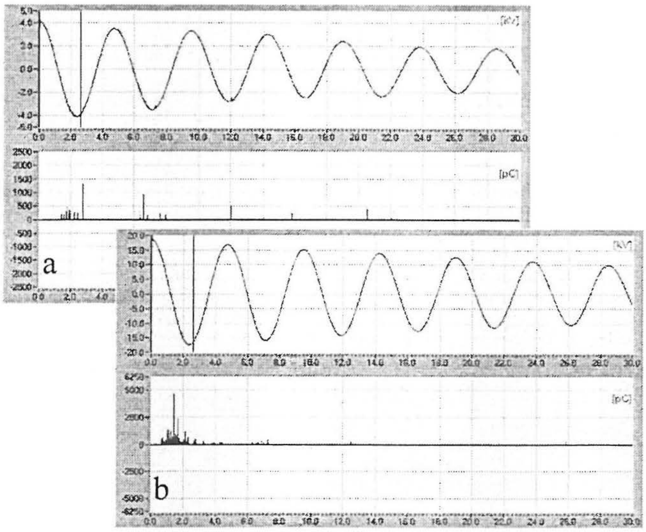

Figure 3: PD measurement results from a 10kV 1606 m long paper/oil power cable, installed in 1973:
a) PD pattern at inception voltage;
b) PD pattern at $2{*}U_0$.

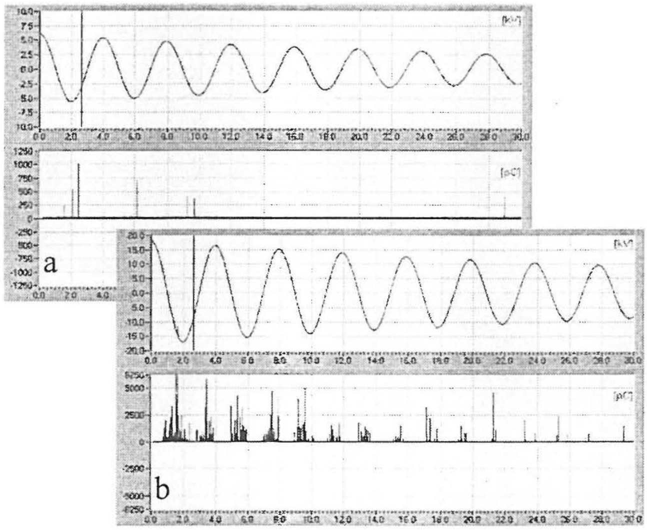

Figure 4: PD measurement results from a 10kV 2870 m long paper/oil power cable, installed in 1960:
a) PD pattern at inception voltage;
b) PD pattern at $2{*}U_0$.

APPLICATION OF OWTS DIAGNOSTICS

Based on three examples from field experiences, several relevant aspects, regarding the interpretation of the measurement data, are discussed. More examples are described in [7].

OWTS on Existing Cable Network

Detection of weak spots in the cable insulation, caused by internal as well as external factors, is the most important goal for PD diagnostics on the existing power cables.

Example 1
Measurements discussed in this example have been performed on two 10 kV paper/oil power cable sections:

Table 1: **PD magnitudes versus testvoltage of a repaired 10 kV paper/oil power cable (red phase).**

Testvoltage	PD magnitude
10 kV_{max} (V_{inc})	980 pC
12 kV_{max}	1210 pC
15 kV_{max}	1730 pC
18 kV_{max}	2340 pC

a) 3-core 150 mm2 Al cable section of 1606 metres, installed in 1973;
b) 3-core 95 mm2 Cu cable section of 2870 metres, installed in 1960.

The PD measurement results from the two cable sections are shown in figures 3 and 4. Figures 3a) and 4a) show the PD patterns at the comparable PD inception voltages. Figures 3b) and 4b) show the PD patterns at a testvoltages of $2*U_0$ ($18kV_{max}$).

Making a comparison between the measurements on the two cable sections, the following can be noticed:

- at PD inception voltage:
  - PD magnitudes are compatible for both cable sections;
  - PD intensity is compatible for both cable sections;
- at testvoltages of $2*U_0$:
  - PD magnitude of cable section b) is approximately 3000 pC higher than cable section a);
  - PD intensity in cable section b) is much higher than in cable section a).

The detected PD sources have both been located in oil-filled cable joints. In a) the cable joint was a standard oil-filled joint, in b) extra synthetic sheets are fixed around the connectors. Unless the same PD inception conditions at high voltages, the PD patterns are totally different. The measured patterns are related to the construction of the cable joint.

It seems from the comparison, that the type of PD source can be deduced from the measured PD pattern in a cable section. From earlier experiences it is known that due to the construction of the cable joint in section b), high PD intensity and magnitudes are less harmful than in other types of oil-filled cable joints.

Not only the location, cable insulation or cable accessories, of a PD source in a cable section is important, but also the construction at that location.

OWTS on Repaired Cable Sections

The intention for PD measurements on cable sections after repair is to detect possible mounting faults in the installed cable accessories and remaining faults in the rest of the cable section. In this way possible future breakdown can be prevented at an early stage.

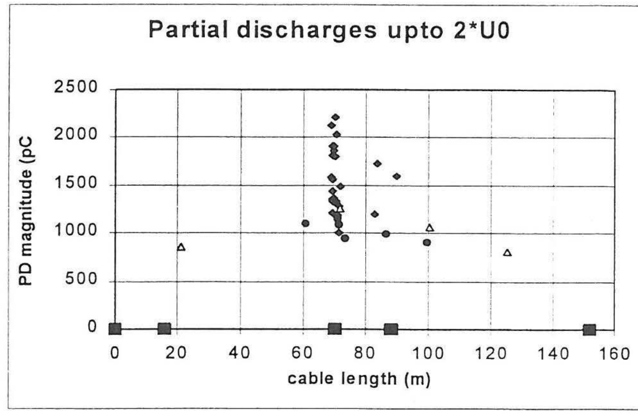

Figure 5: PD discharge mapping from a 10 kV paper/oil power cable (260m long, dating from 1992).

Example 2
Table 1 and figure 5 show the results of OWTS measurements on a 10 kV cable section (152 metres long 3-core 95mm^2 Cu), two days after repair. The cable joints at 70 and 88 metres from the measuring side of the cable section, are new installed.

Figure 5 shows that a concentration of PD is located at the new installed cable joint at 70 metres from the measuring side. The PD inception voltage is just higher than the operating voltage of the cable section (see table 1). The PD magnitudes and the PD intensity are not extremely high compared to other measurements on similar cable joints.

Direct actions are not required in this case, but the PD conditions could change during and the source can grow to become harmful. Therefore, it is recommended to perform measurements on the cable section periodically to detect any changes according to the current measuring quantities.

OWTS on New Cable Sections

Just as in the case with after-repair tests, the intention for PD measurements on new cable sections is to detect possible mounting faults in the cable accessories.

Example 3
Several PD measurements on new polymeric insulated cable sections are performed. In this example the measurements on one of these cable sections (1166 m long 3–core 240 mm^2 Al) will be discussed.

One of the three phases contains PD, with an inception voltage of 10 kVmax located in the cable termination at the measuring end. From figures 6 and 7, which reflect the PD patterns at 10 kV_{max} and 18 kV_{max}, it is clear that raising the testvoltage results in a growth of the PD magnitudes. It is also visible that the intensity of the PD grows as the testvoltage is increased.

Faults can always occur during mounting of new cable section. In the case of new XLPE cable sections it is important to make an after-laying test to detect these faults, because they are more harmful in comparison with paper/oil cable sections.

INTERPRETATION RULES

As discussed in the previous examples, for good interpretation of field measurements, it is important to look at the measuring results from several points of view, collected in the 'fingerprint' (figure 2) of a cable section.

Comparison of the measured 'fingerprint' with a database of

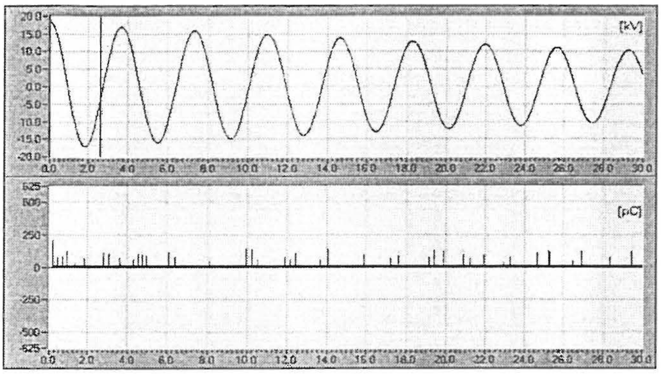

Figure 7: PD pattern at 2*U0 (18 kVmax) of a 10kV XLPE power cable.

other measured cable sections, gives the possibility to identify the criticality of a detected PD source, optimize the planning of replacements of cable parts.

In table 2, an example of interpretation rules for PD measurements on power cables with OWTS is shown. These are rules of thumbs supporting the analyzing of the measurement results. Different aspects of the 'fingerprint' are used. Regarding the interpretation rule for the PD location, it is also important to know the construction of the cable accessories, because the harmfulness of the defect is depending on this construction, see example 1.

CONCLUSIONS

This paper presents the application of advanced diagnostic on medium voltage power cables. Based on the obtained research the following conclusions can be drawn:

- OWTS diagnostics can be used for existing network, for after-repair tests and for after-laying tests;
- discharge defects can be related to different insulation systems of a cable section, either the cable accessories or the cable insulation itself;
- important information of a cable section is collected in the PD 'fingerprint' of a cable section;
- standard interpretation rules are used for optimal decision-making for cable repair before failure occurs.

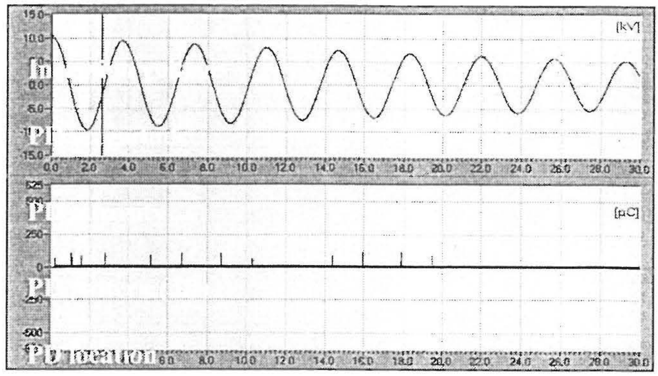

Figure 6: PD pattern at inception voltage (10 kVmax) of a 10kV XLPE power cable.

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