V[th] Volta Colloquium on Partial Discharge Measurement
PD Measurements in the Field

PD Knowledge Rules for Insulation Condition Assessment of Distribution Power Cables

E. Gulski, F.J. Wester, J.J. Smit, E. Groot(*)
Delft University of Technology, HV Technology & Management, The Netherlands
(*)InfraCore, Alkmaar, The Netherlands

1 Cable Insulation Defects

By registration of the disturbances in the power supply by network owners, statistical analysis can be made to indicate the major failure causes in the medium voltage power network. Still a lot of the breakdown in MV power cables are caused by non-electrical external causes. This can be damages caused by digging activities by other companies for other types of underground cables (e.g. telephone, gas) or caused by the movement of the soft wet ground. But still, most of the breakdowns are caused by internal defects in the insulation systems of the cable network, from which the majority occur in the cable joints. The remaining breakdowns occur in the cable terminations and the cable insulation itself.

Figure C1: *Fault cause analysis of disturbed cable termination. Several sharp edges on the connector were found on all three phases.*

Visual inspection of the disturbed components gives insight in the different types of fault causes resulting in breakdowns. Figure **C1** shows the analysis of a disturbed mass filled cable termination, which showed on all three phases sharp edges on the conductor connectors to the switch gear. On the fault place, two phases were only insulated by the plastic cover of the termination, resulting in a breakdown after several years, caused by PD activity from the sharp edges. As a result of these visual inspections, a list of defects in the different elements of cable network can be made, as reflected in table **C1**.

Table C1*: Typical insulation defects for different types of power cable components.*

Cable type	Joints & Terminations	Cable insulation
PILC	Low oil level	Damaged outer sheet
	Sharp edges on connector	Internal damages (as a result of bending)
	Moisture penetration	
	Air/gas bubbles	
	Bad hardened resin	
XLPE	Bad adjustment of stress cone	Damaged outer sheet
	Air gaps	
	Remaining semicon	

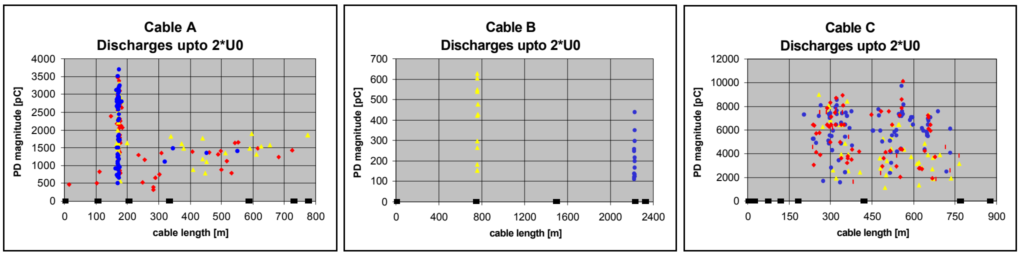

Figure C2 *Examples of different types of PD location in a distribution power cable*
(A) PD concentration in a cable part; in dependence on the PD magnitude as well as the concentration are conclusions regarding local insulation degradation could be made;
(B) PD concentrations in cable joints; ; in dependence on the PD magnitude as well as the concentration are conclusions regarding local insulation degradation could be made;
(C) PD concentration in the cable insulation only; due to temperature/pressure changes temporary PD activity may occur in the cable insulation, no indication on insulation degradation .

2 PD Interpretation

As most of the different types of insulation defect are related to PD activity, high-risk sections in the power cable systems in service can be identified by the detection, location and recognition of partial discharges (PD) at an early stage of possible cable insulation failure are of great importance for maintenance purposes. As a result, maintenance actions can be planned more precisely and unexpected discontinuities in operation of the cable network are decreased. To obtain a sensitive picture of discharging defects 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 this way, the PD quantities are representative for discharging insulation defects in operation. Moreover, based on the travelling wave principle, the particular discharge sites in the cable section can be traced back, see **figure C2**.

Although the measurements can be carried out at preferred voltage levels, the following aspects should be considered:

1. A PD measurement should be performed at both U0 as well as at 2 x U0. Partial discharges measured at phase voltage appear constantly and therefore represent a great threat.
2. Partial discharges measured with coupled voltages only appear when there is an earth fault and then it is a question of how long the fault will last. A few minutes is not a problem but several hours duration is a threat.
3. When examining test results in cases where the PD inception voltage is < U0, the growth in PD amplitude and the increase in PD intensity are of great importance.
4. For PD measurements with inception voltages > U0, the increase in PD intensity and PD level should be considered in relation to the permitted values and used as feedback to maintain non-destructive voltage levels.

All relevant information from a PD measurement at a cable section should be collected. This PD information is collected in a so-called ‘fingerprint’ of a power cable section (see figure **C3**), containing the following PD quantities:

- PD inception/extinction voltage (PDIV&PDEV);
- PD magnitudes at different test voltages;
- PD intensity;

- PD pattern (2D&3D);
- PD location.

For optimal interpretation of the results obtained from field measurements, it is important to study the results from several points of view. Combining these interpretation rules for the different PD quantities, the ageing stage of a fault can be recollected. Interpretation of the measured partial discharge is dependent upon the situation i.e. what is valid for one particular cable network situation is not necessarily applicable for another. In order to achieve a good end result it is necessary to have both a good current and historical overview of the cable length.

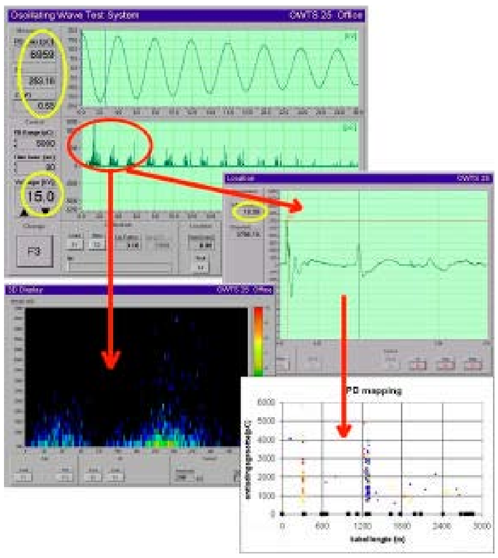

Figure C3: *Example of a cable fingerprint, containing all relevant PD quantities for PD measurements on power cables.*

Comparison of the measured 'fingerprint' with a database of other measured cable sections, gives the opportunity to identify the criticality of a detected PD source and in this way optimise the planning of the possible replacements of cable parts or accessories. In table C1, an example of interpretation rules for PD measurements on power cables is shown. These are rules of thumbs supporting the analysis of the measurement results from a cable section. Different aspects of the 'fingerprint' are used in these interpretation rules.

Regarding the interpretation rule for the PD location, it is very important to keep in mind how a cable joint or cable termination is constructed, because the harmfulness of the defect is depending on the structure of the accessory.

Table C1: *PD quantities and their characteristics used in interpretation rules for PD test on power cables.*

PD inception voltage	*< operation voltage*	*> operation voltage*
PD extinction voltage	*< operation voltage*	*> operation voltage*
PD magnitudes	*< typical values*	*> typical values*
Location in the cable section	*cable insulation*	*cable accessories*
PD mappings	*local concentration*	*distributed along the cable*
PD pattern	*single pulses*	*(no) repetitive*
PD intensity	*low*	*high*

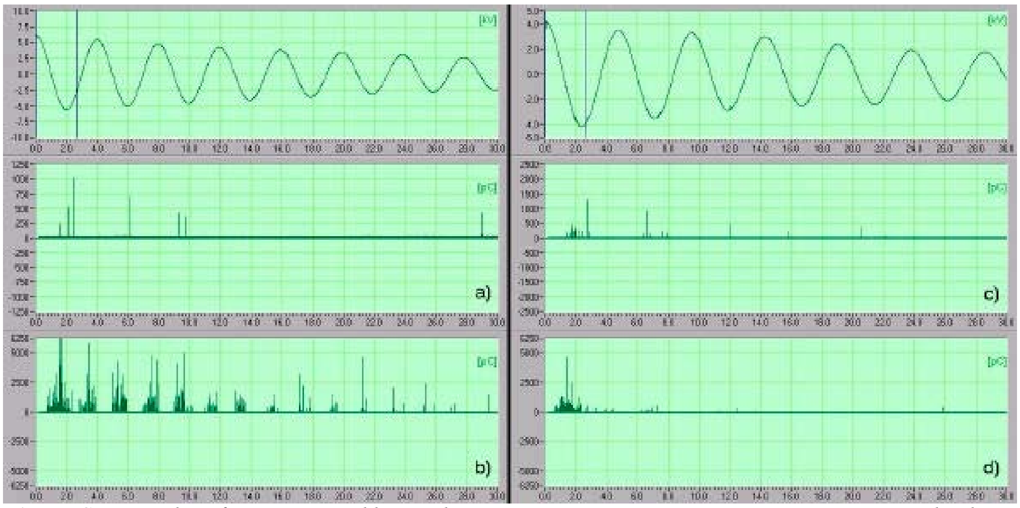

Figure C4 *Examples of MV power cable PD diagnostic on-site. PD quantities: PD inception, PD level, PD pattern of two cable sections of different age of the same type of paper/oil cable insulation and oil filled joints are compared here. In both cases using traveling wave method the discharges were located in oil filled joints.*
a) 2870m long section from 1960: 1 nC PD inception at 6 kV; PD intensity low; PD pattern single pulses,
b) 2870m long section from 1960: 6 nC PD at 18 kV; PD intensity high; PD pattern repetitive,
c) 1606m long section from 1973: 1.5 nC PD inception at 4 kV; PD intensity low; PD pattern repetitive,
d) 1606m long section from 1973: 4 nC at 18 kV; PD intensity high; PD pattern no repetitive.

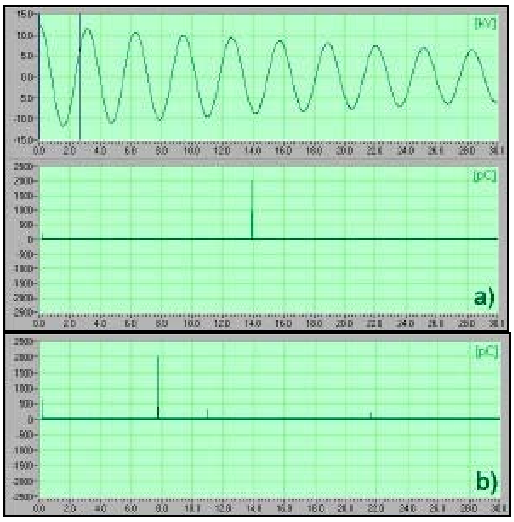

Figure C5: *PD measurement results on a 10kV XLPE power cable (3-core,96Al,1076m): a) at inception voltage (12 kV_{top}); b) at 2*U0 (18 kV_{top}). PD activity originating from the cable switch gear.*

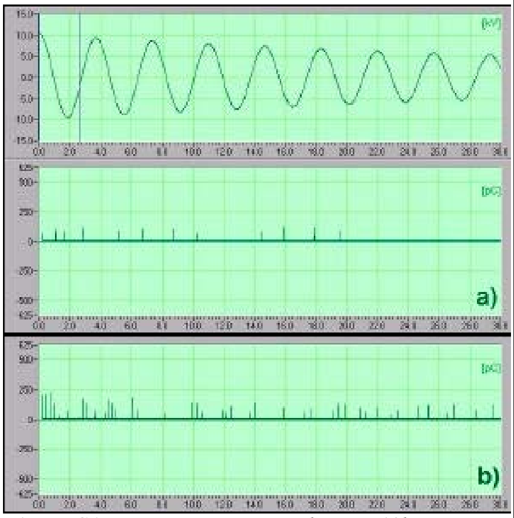

Figure C6: *PD measurement results on a 10kV XLPE power cable (3-core, 240Al,1166m): a) at inception voltage (10 kV_{top}); b) at 2*U0 (18 kV_{top}). PD activity originating from the cable termination on the measuring*

(single pulses) occur at random periods of the oscillating voltage and that the PD magnitudes at increased voltage are equal. Internal PD activity however will show an increase of PD intensity and PD magnitudes, see figure C6.

seba KMT AUS
Advanced Utility Solutions Pty Ltd. T/A.
Phone 02 9972 9244 Fax 02 9972 9433
Unit 1, 176 South Creek Road, Cromer NSW 2099
Email sales@sebakmtaus.com
www.sebakmtaus.com

3.2 PD inception/extinction Voltage

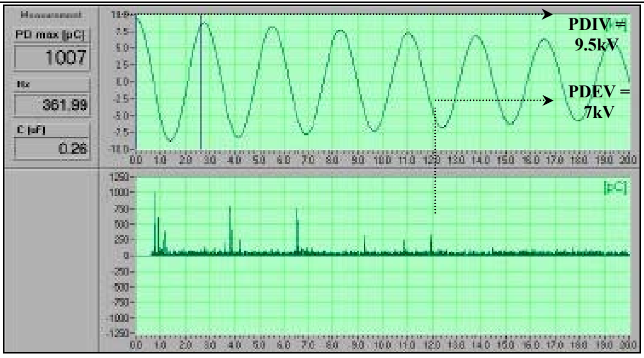

Figure C7: *PD measuring result where PDIV is just above U0 and PDEV just below U0 (8.2kV). If an overvoltage occurs, the PD source can be ignited and continue discharging in service.*

To describe the PD process in the cable section under investigation PD diagnostics method generates several 1D, 2D and 3D quantities. 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. All relevant PD quantities can have influence on the ageing processes. The PDIV and for certain the PDEV are very important parameters for implementation of PD measurements. If the PDEV is lower than the operation voltage of the cable section, PD can occur continuously during service of the cable section, which results in a degradation of the insulation material at the PD location.

In figure C7, the PDIV measurement result on a 10kV XLPE cable section, where the detected PD source was located in one of the cable terminations. In this case, the PDEV is 7 kV_{top} (0.9*U0), lower than the nominal voltage. This means that in a case of just a small overvoltage, as a result of for example switching, the PD source will be ignited and will be discharging continuously during operation. This will accelerate the ageing of the cable insulation located at the PD source.

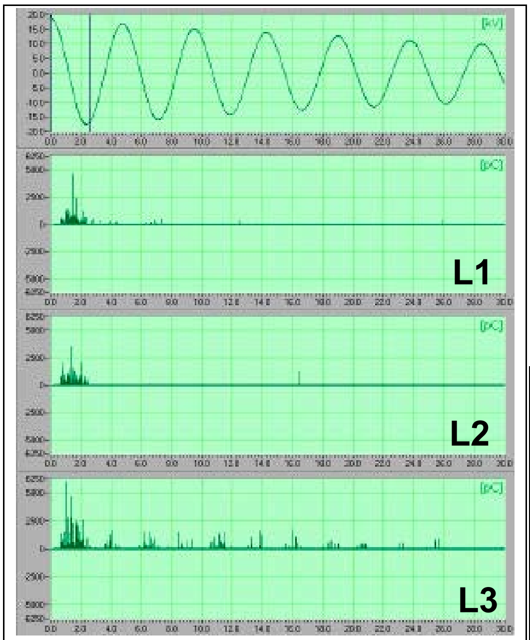

Figure C8: *Measurement result obtained from a 3-phase PILC section, where the PD pattern from phase L3 differs from the patterns from phases L1 and L2. The PD in phase L3 is located at a different joint type.*

3.3 PD levels and PD patterns

In the power cable network, different types of cable insulation and accessories are used over the years. It is known that depending on the design (construction, materials) of the different cable elements, the critical PD levels are different for these elements. For example, due to the layered design and the paper/oil insulation, high PD activity is less harmful to PILC than for XLPE cables. At

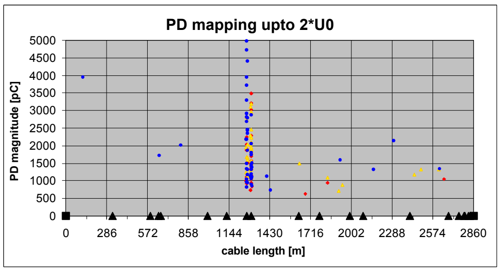

Figure C9: *PD mapping from the PD measurements on a 3-phase PILC section, where the PD in phase L3 is mostly located in the joint at 1260m. Phases L1 and L2 are located in the joint at 1300m.*

the same time, PD patterns will also vary, depending in which cable element the PD source is located.
Figure C8 shows the measuring results on a 3-phase PIL cable section with two aged joints. The PD pattern of phase L3 differs from L1 and L2; in L3 PD occurs in the negative as well as the positive side of the oscillating voltage. As known this refers to different PD source types, which is true in this particular case.
The PD mapping of the cable section in figure C9, shows that the detected PD is originating from two different types of joints at 1260 and 1300 m from the measuring side.

sebaKMT AUS
Advanced Utility Solutions Pty Ltd. T/A.
Phone 02 9972 9244 Fax 02 9972 9433
Unit 1, 176 South Creek Road, Cromer NSW 2099
Email sales@sebakmtaus.com
www.sebakmtaus.com

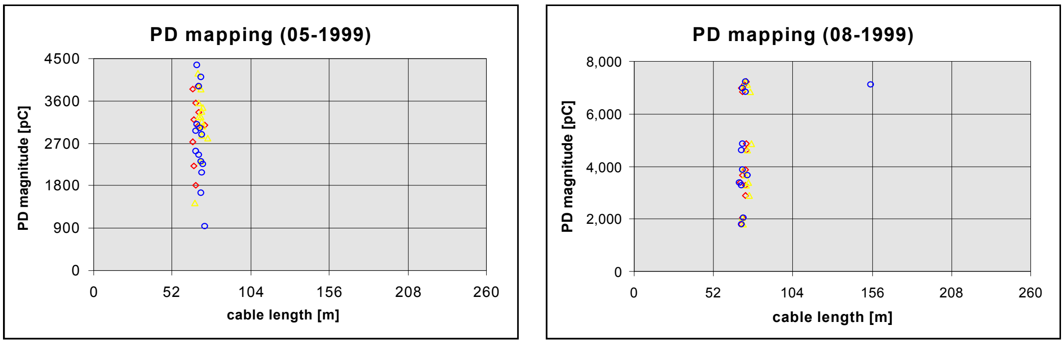

FIGURE C10: *Example of insulation aging assessment in a PILC distribution power cable using phase-resolved PD patterns. Two PD mappings with a time interval of three months. Due to the decrease in inception voltage and the increase in PD amplitudes, two times, the defective part of the cable was replaced.*

3.4 PD Trending and PD Database

To assess the insulation condition of a power cable based on the PD quantities the evaluation can be performed in two ways:

1. comparing actual values to those obtained for the particular cable section in the past and analysing/trending the differences in the terms of critical changes increases/decreases, see **figure C10**;
2. comparing actual values to those obtained once for similar cable sections or particular elements and evaluating the similarities/differences in insulation conditions.

4. PD Knowledge Rules

After measuring and analysing PD activity in a cable section, the second step is to make a decision on the insulation condition of the tested cable sample. Using the measured PD quantities and their interpretation rules (table C1), four condition classes can derived from the analysis:

1. cable section NOT OK: weak spot in the cable section should be replaced;
2. cable section NOT OK?: trending on the cable component is required (e.g. 1 year);
3. cable section OK?: trending on the cable component is required (e.g. 3 years);
4. cable section OK: no weak spots in the cable section, cable section is OK.

Figure C11 shows the decision diagram for power cables. Analysing the derived measurement data through the diagram, the cable systems insulation condition can be determined in one of the four classes. The decision diagram is based on all PD quantities for measurements on power cables.

Not concentrated PD in the cable insulation is not an indication of ageing of the cable insulation materials, see figure C2. For PILC related insulation, certain levels of PD can be accepted in the cable insulation, joint and termination, depending on the design of the component, table C2. Also, XLPE related accessories can stand certain PD levels (generally lower pC levels compared to PILC). However, XLPE cable insulation is required to be PD free (PDIV>1.3U0, PDEV>1.1U0), where the background noise during the measurement is not allowed to exceed 20pC. The typical PD values for the different components can be derived from the statistical analysis of all required measurement data in a database.

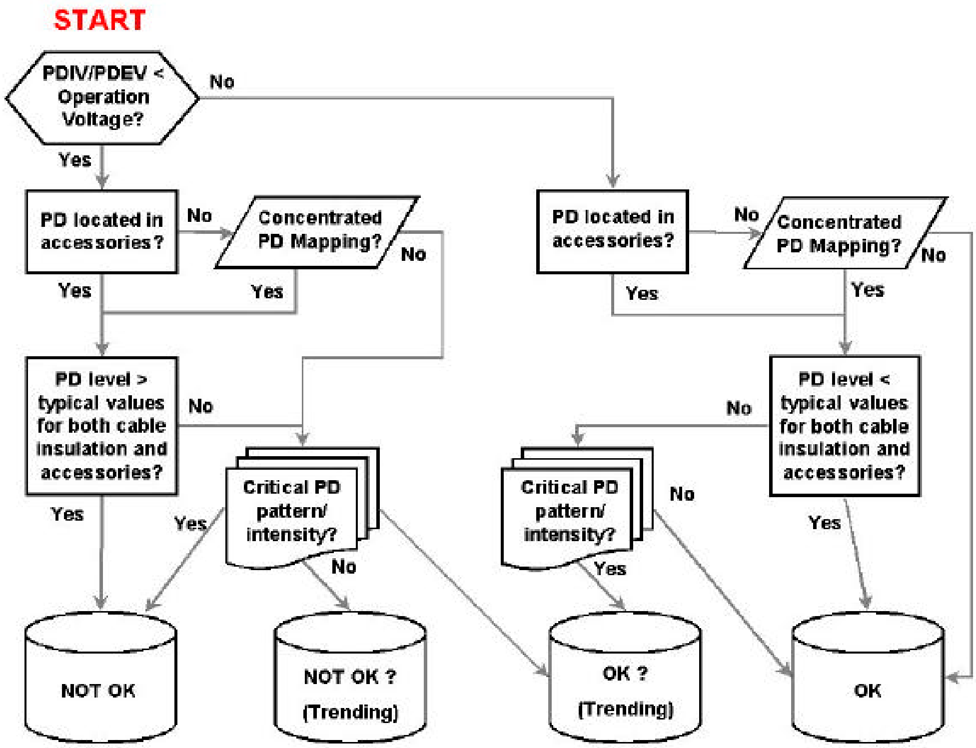

Figure C10: *Decision diagram for power cables. Analysis of measuring data through the diagram categorizes the insulation condition in one of the four condition classes.*

Table C2: *Indication of some typical PD levels for different types of cable insulation and accessories, based on experiences from the Netherlands.*

Cable element	Type	Trend values
Cable insulation	PIL	10.000pC
	XLPE	<20 pC
Cable joint	Oil-joint	5.000pC
	Nekaldiet (resin insulation*)	500pC (asymmetric)
	Kabeldon (oil insulation)	>10.000 pC
	Lovinol (oil/resin insulation)	5.000 pC
	TECE (resin insulation*)	4.000 pC
Cable termination	Oil-termination	6.000 pC
	Dry termination	3.500 pC
	ABB termination	250 pC

5. Conclusions

1. Studying fault statistic and providing visual inspection of disturbed components results in the identification of dominant faults. As most of these dominant faults will be PD related, PD measurements on power cables are a useful diagnostic tool;
2. Using PD diagnostics, important information can be collected in the PD ‘fingerprint’ of a cable section, containing PD inception/extinction voltage, PD levels, PD patterns and PD locations;
3. Standard interpretation rules which are used in a decision diagram, can be used for optimal decision-making on the insulation condition of a cable section;
4. Trend-analysis and databases are important tools for condition assessment.