The World of Diagnostics

Hungary, 24th April 2008

Hein Putter

Laszlo Tar

Schedule

1.) Introduction to Diagnostics

2.) Integral measurements

- IRC measurement (Isothermal Relaxation Current measurement)
- RVM measurement (Return Voltage Measurement)

3.) Local measurements

- What are Partial Discharges?
- Applications OWTS series

4.) Practical examples

- Examples
- Pinpointing of weak spots with PD-LOC

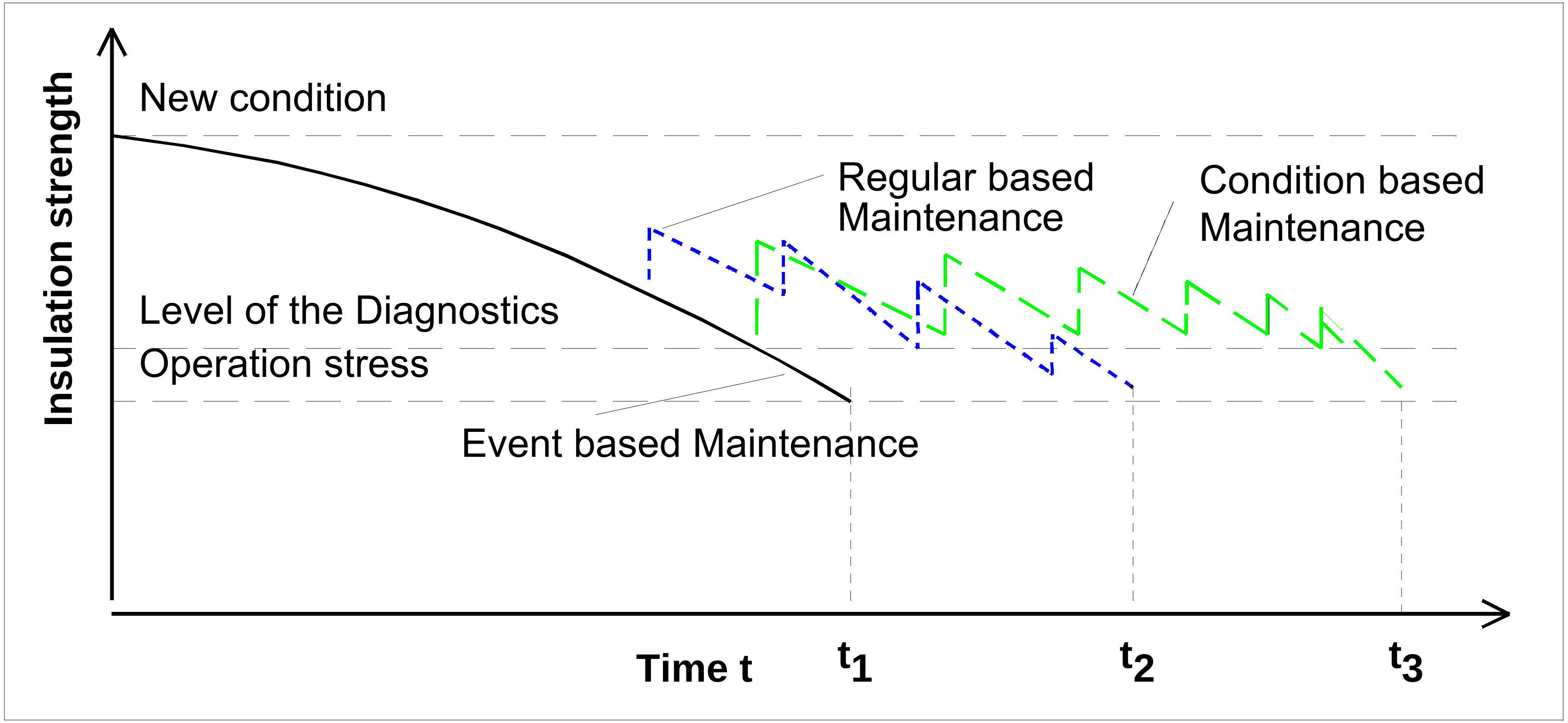
5.) OWTS, CDS and VLF

- Practical experiences with combinations of OWTS, CDS and VLF

Why do we need Diagnosis?

- To obtain information about the condition of cable, joint, and end-termination;
- Quality control: cost reduction leads to lower quality of workmanship on newly installed cable systems and modifications on cable systems due to cable failures;
- To reduce or prevent service interruptions;
- Condition assessment for decision support in the asset-management;
- This all leads to “Cost reduction”.

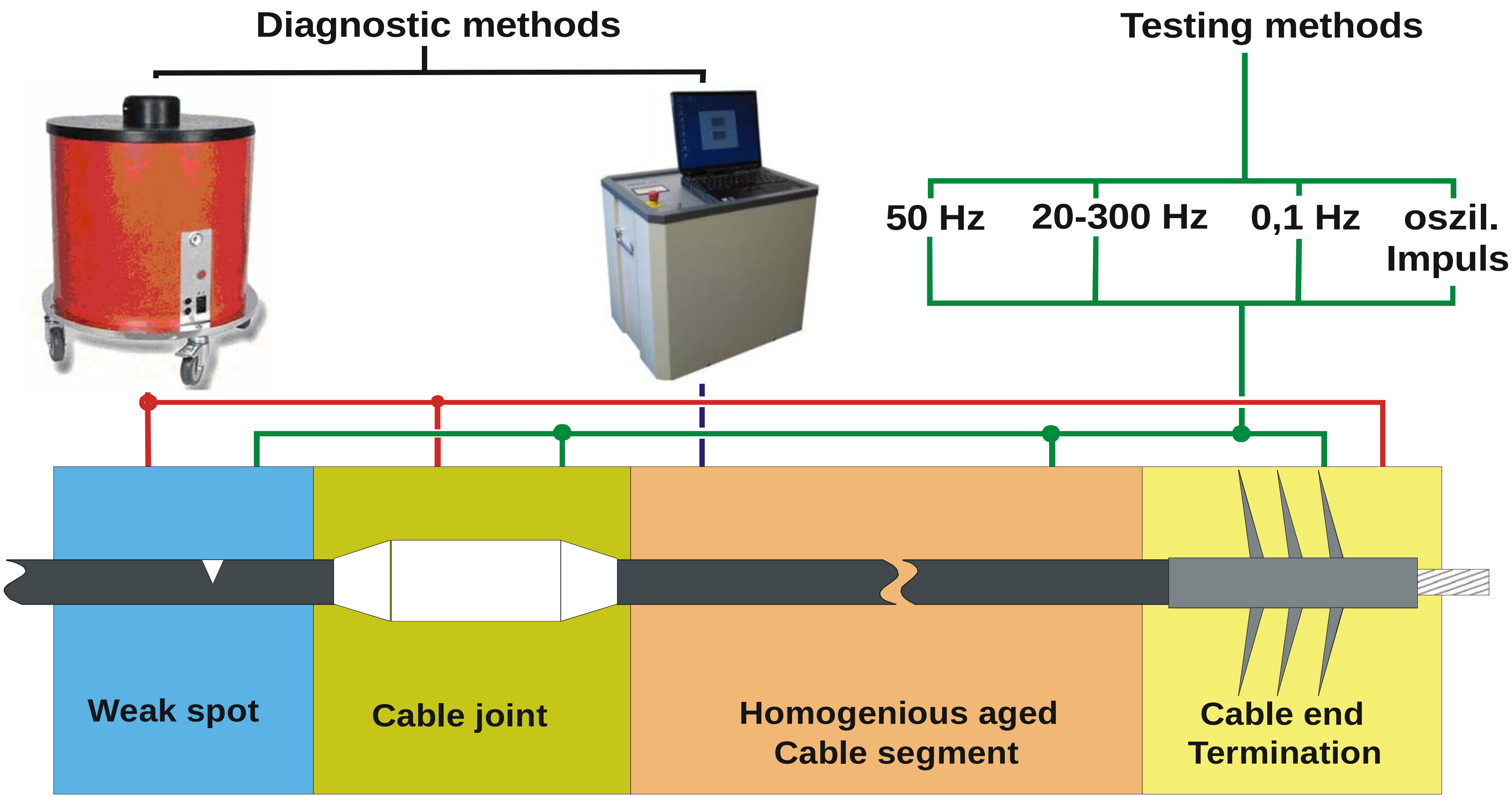
Different maintenance strategies



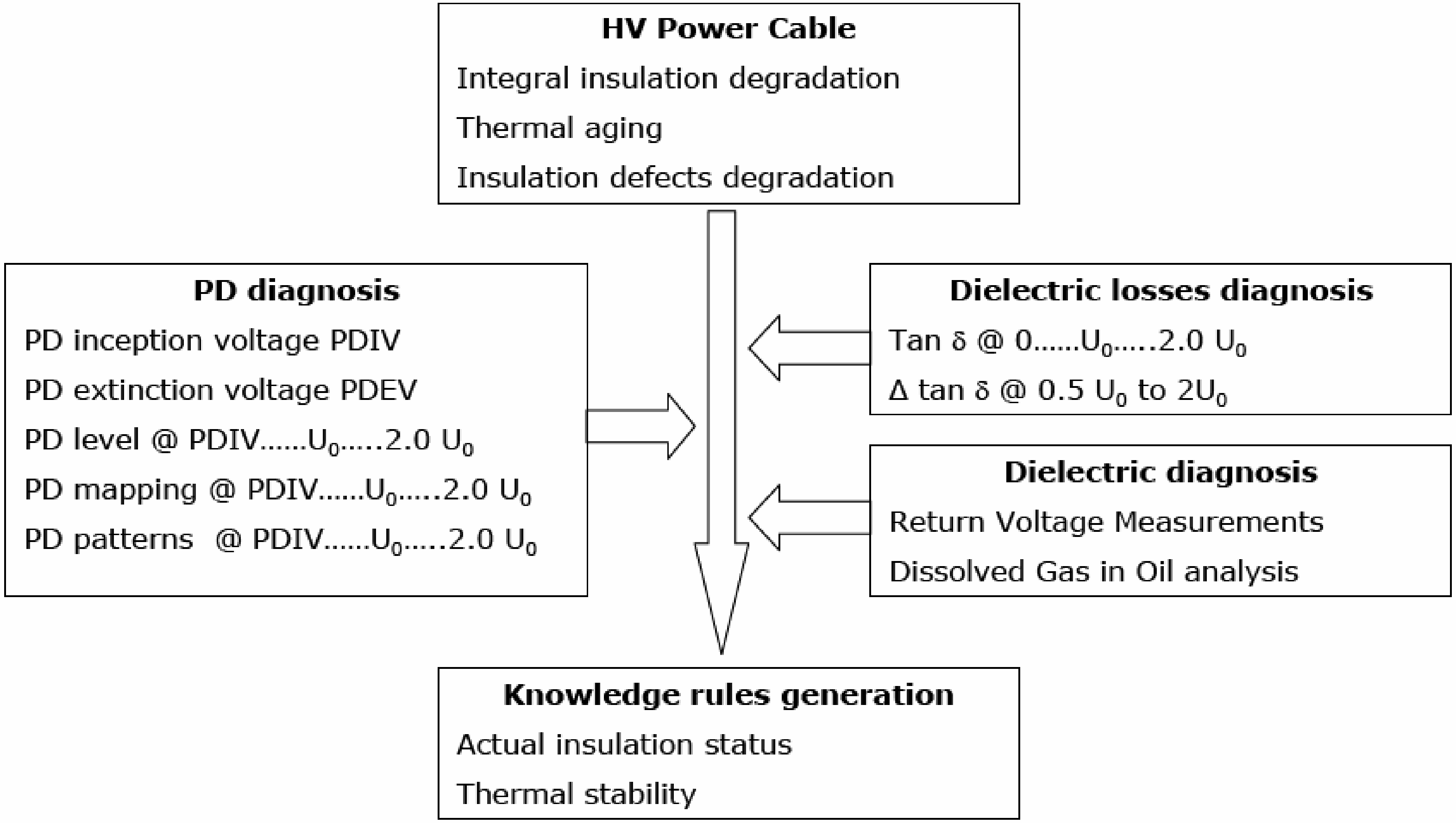
t_1 – End of the average life with Event based Maintenance
t_2 – End of the average life with Regular based Maintenance
t_3 – End of the average life with Condition based Maintenance

TECHNISCHE UNIVERSITÄT CHEMNITZ

Available diagnostic methods



Condition aspects of HV power cable, important diagnostic parameters and knowledge rules generation goals



Integral measurements
CDS

The CDS (Cable Diagnostic System) consists of two dielectric measurement methods integrated in one system:

- IRC-Diagnosis for XLPE Cables

Relaxation current measurement for integral evaluation of a PE/XLPE insulation.

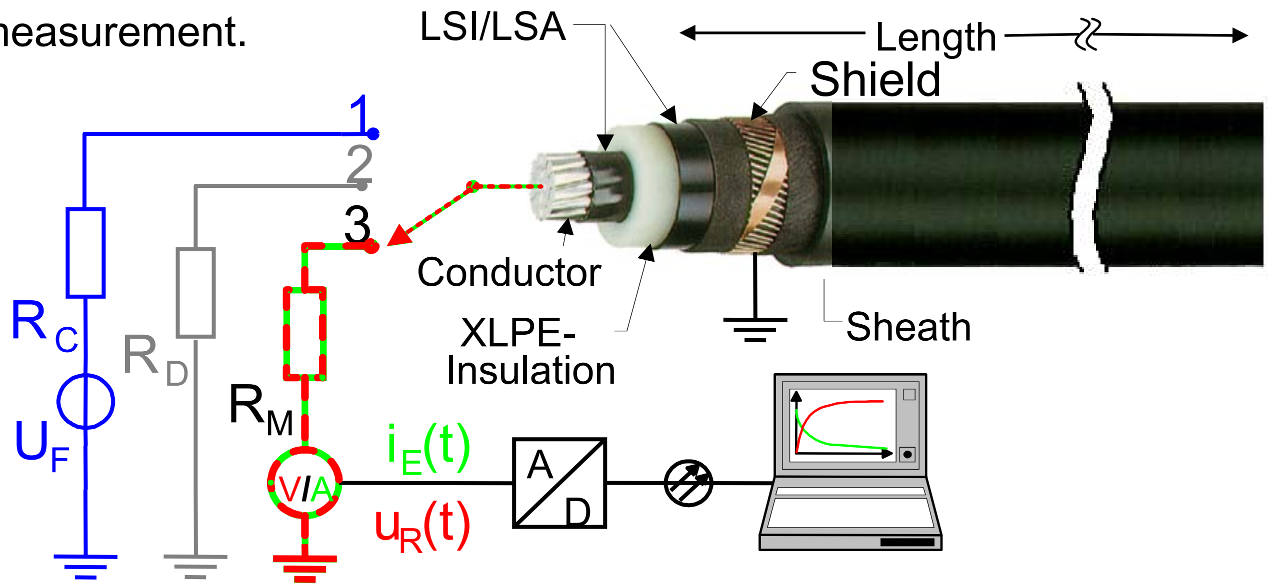
- RVM-Diagnosis for PILC or mixed Cables

Return voltage measurement to assess the condition of PILC cables or mixed cables with up to 20% of XLPE insulation.

Integral measurements

Working principle of CDS

1) Formation/ polarization phase
2) Discharging phase
3) Measuring/ depolarization phase
   a. IRC measurement;
   b. Return Voltage measurement.



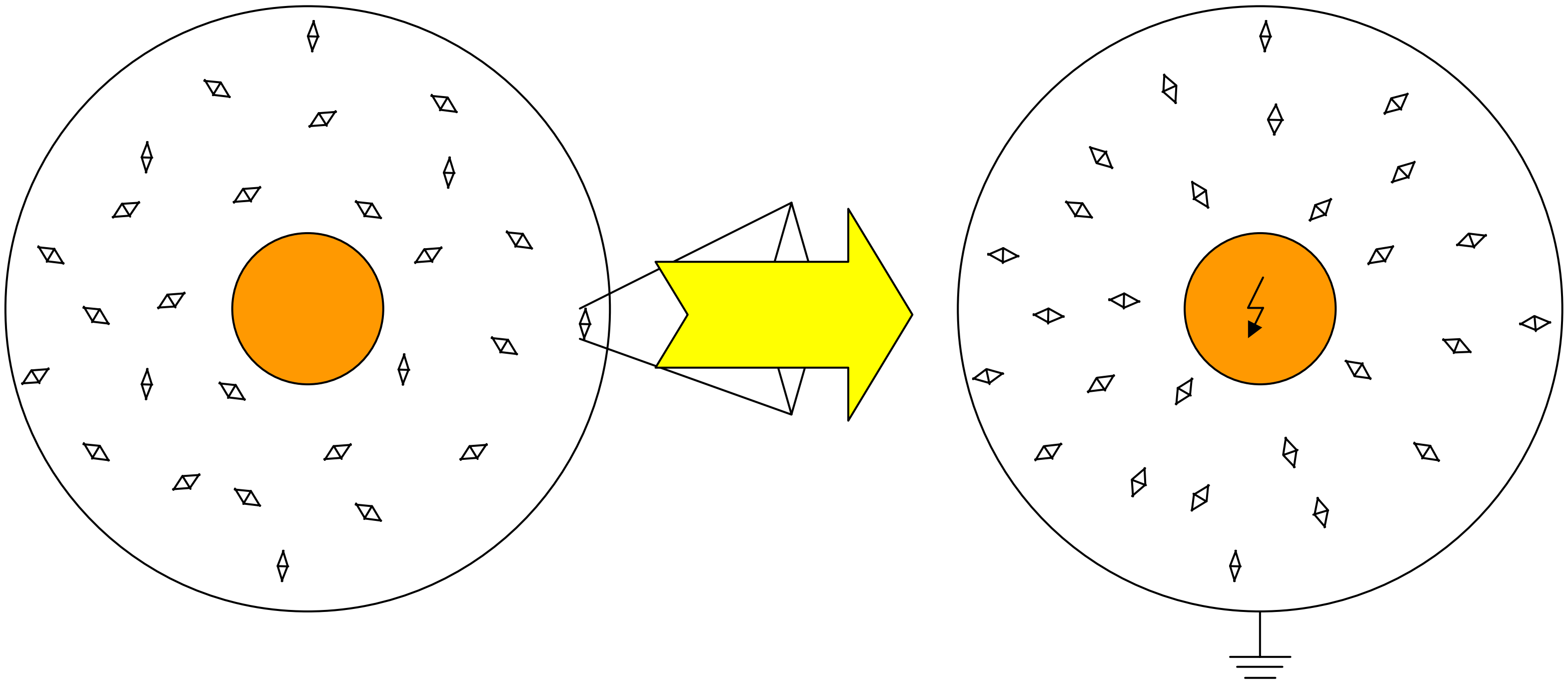
1: Forming (t_F)   2: Discharge (t_D)   3: Measurement (t_M)

Integral measurements

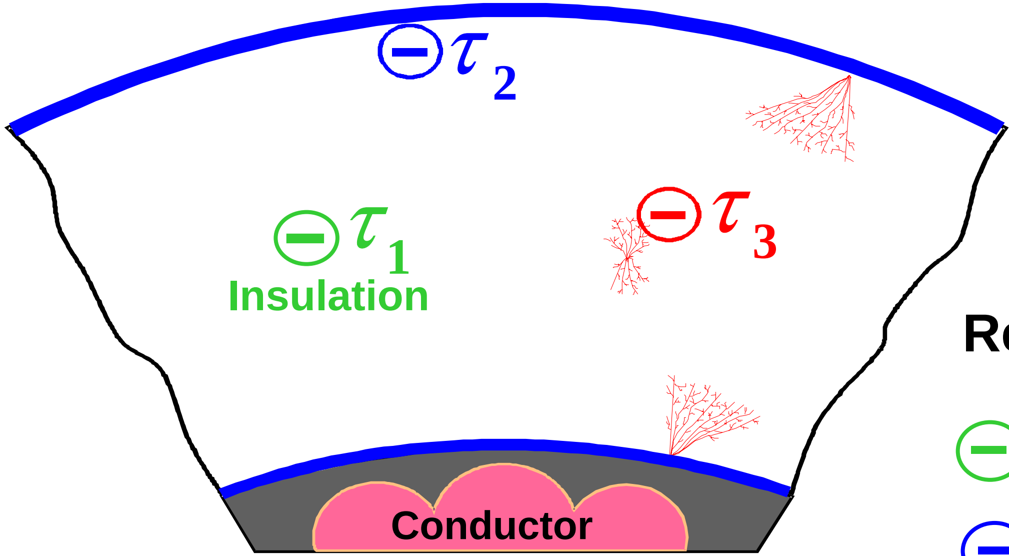
Working principle of CDS

Polarization of the insulation is nothing more then lining up dipoles, compare it with magnetizing a nail.

Insulation defects are proportional with the charge kept in the insulation.



Integral measurements
Working principle of CDS

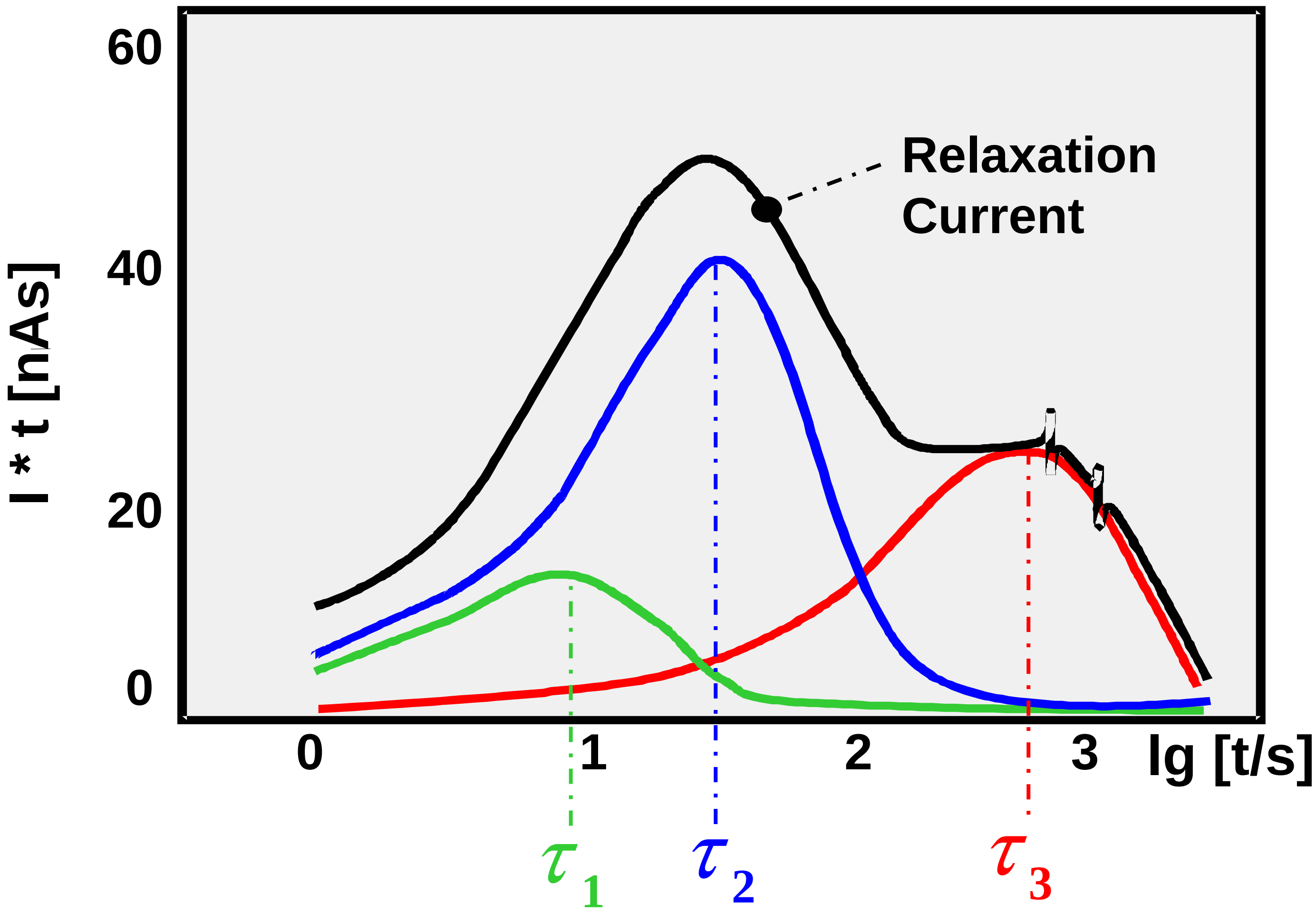


Relaxation times

⊖ τ_1	**5-10 s**	**Sound insulation**
⊖ τ_2	**30-100 s**	**Boundary layers**
⊖ τ_3	**200-500 s**	**Insulation defects e.g. tree structures**

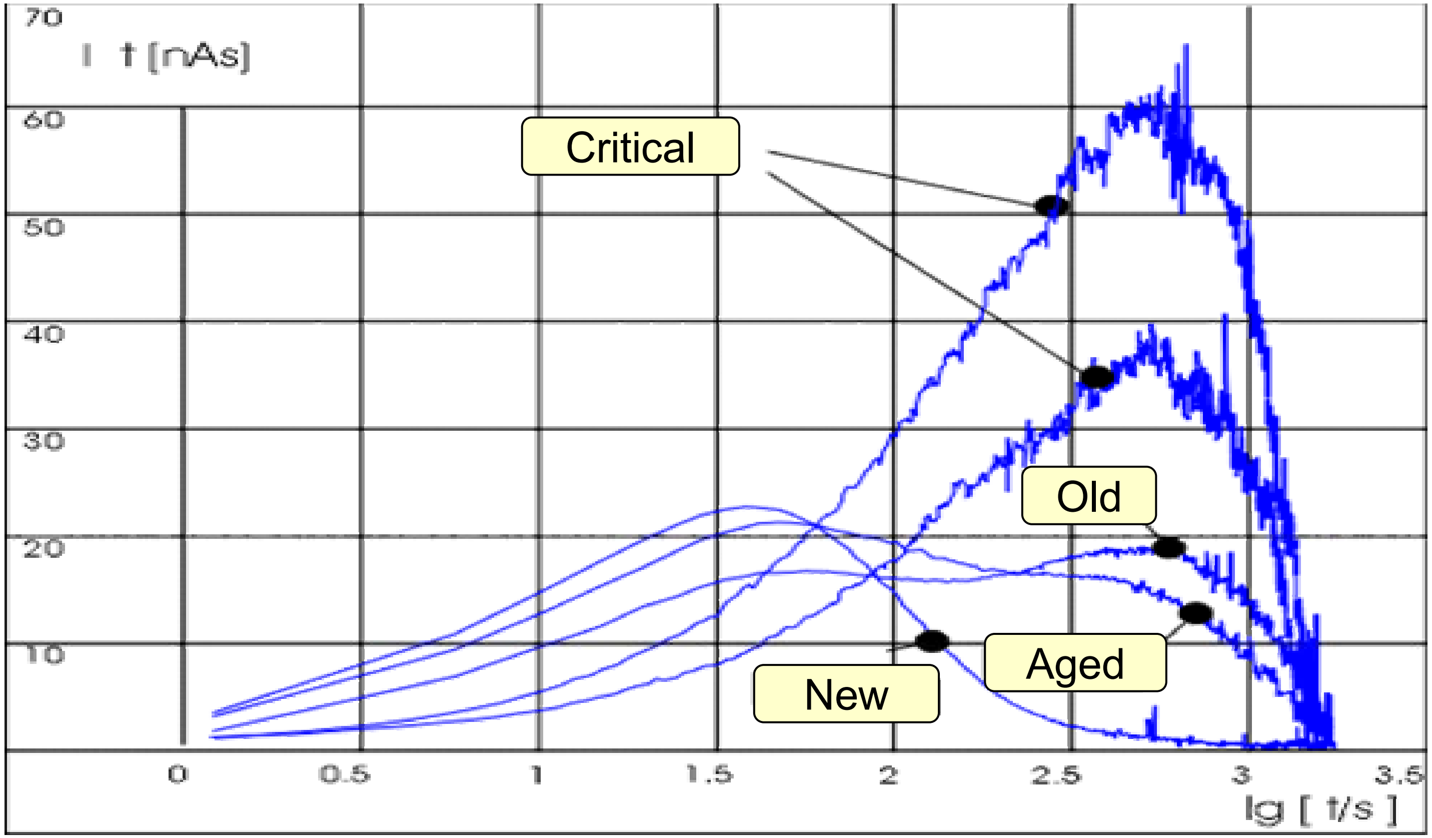
Relaxation times of different trap levels

Combination of all relaxation times



Change of relaxation times during ageing

On-site measurements



Display of measurement results

IRC-measurement

KEL00051.DAT KEL00052.DAT KEL00053.DAT Shortdiagnosis

Short-diagnosis of the IRC-measurement of the segments KEL00051, KEL00052, KEL00053

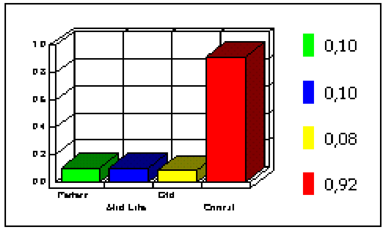
Version: 3.1.0, userkey: XYZ, date: 27.11.00

KEL00051	KEL00052	KEL00053

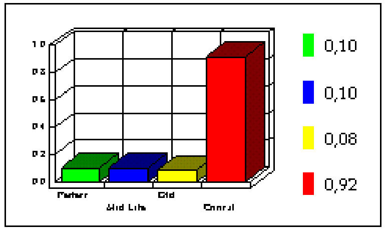
Comparison of the segment-data with 51 entries of the User-Database.

KEL00051	KEL00052	KEL00053
Result: 5 comparable IRC-measurements have been found. The known residual strengths values from the step tests of these cable segments are taken into consideration by the prognosis.	Result: 5 comparable IRC-measurements have been found. The known residual strengths values from the step tests of these cable segments are taken into consideration by the prognosis.	Result: 5 comparable IRC-measurements have been found. The known residual strengths values from the step tests of these cable segments are taken into consideration by the prognosis.

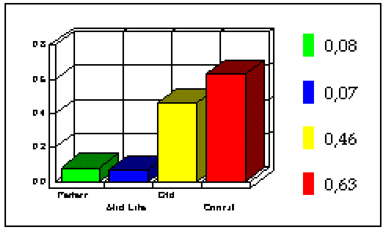
Neuronal determination of the ageing status:



The examined segment KEL00051 was classified into the IRC-ageing class
CRITICAL



The examined segment KEL00052 was classified into the IRC-ageing class
CRITICAL



The examined segment KEL00053 was classified into the IRC-ageing class
CRITICAL

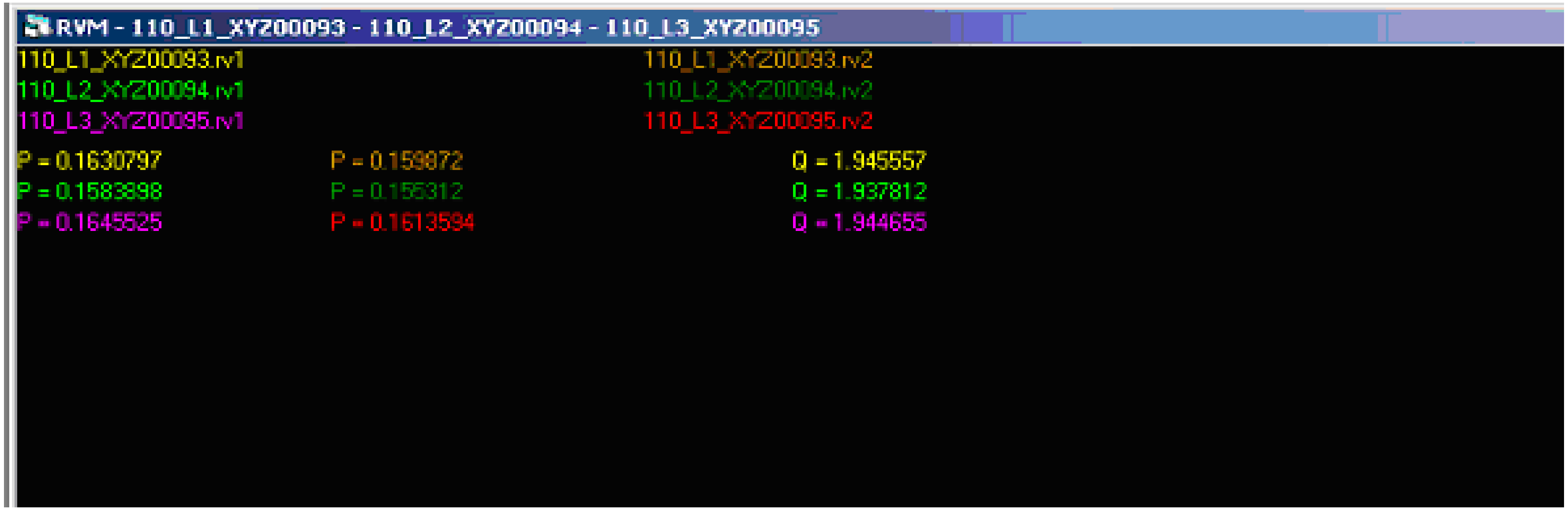
All partial results were taken into consideration for this prognosis.
Residual strength prognosis of the cable-segments

KEL00051	KEL00052	KEL00053
4 Uo	4 Uo	5 Uo
Due to the status of the present knowledge basis (update from 28.6.00) the prognosis is considerably reliable.	Due to the status of the present knowledge basis (update from 28.6.00) the prognosis is considerably reliable.	Due to the status of the present knowledge basis (update from 28.6.00) the prognosis is considerably reliable.

PLEASE NOTE: The prognosis are based on the information taken from the data sheets of the measurements.Singular (local) failures are not evaluated by the IRC-analysis and may result in lower residual strengths.

Display of measurement results

RVM-measurement



The RVM evaluation of paper insulated cables is based on the well known principle with the factor Q (Quotient of the initial slopes) and the threshold values.

Additionally with the factor *p* based on the calculation of (Maximum value of U / initial slope S * time t of the maximum of U).

Partial Discharge measurements

Why do we need Partial Discharge measurements?

- Find weak spots/ defects in the insulation, joints or end-terminations (PE/XLPE and PILC).
  - Assembling failures;
  - External damages;
  - Caused by ageing.

IMPORTANT, Partial Discharge measurements does not give information about the condition of the insulation.
It is possible that a PD-measurement shows no weak spots in the cable, but a breakdown occurs a couple of weeks later on because of water trees.

What is a Partial Discharge (PD)?

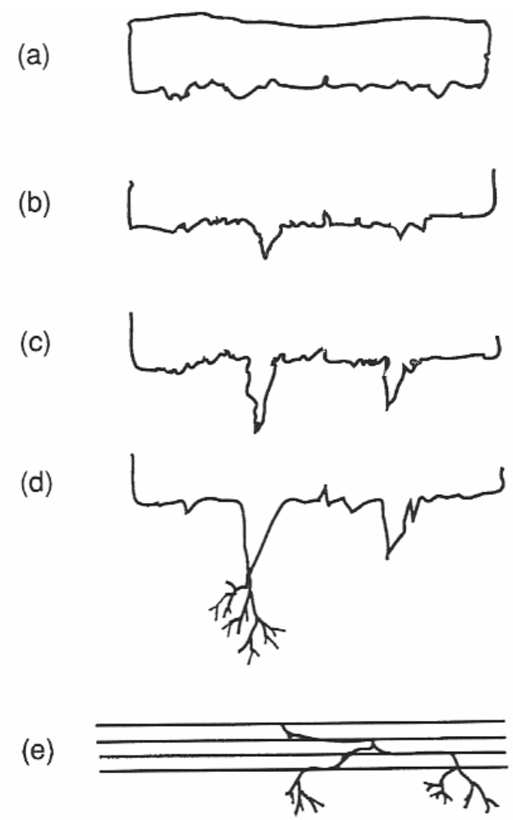
- Partial discharges (PD) are small electric sparks or discharges that occur in defects in the insulation. The discharges do not bridge the insulation between conductors and the defects may be
  - entirely within the insulation (cavities),
  - along interfaces between insulating materials (e.g., at accessories)
  - or along surfaces (terminations or potheads).

- Partial discharge characteristics depend on the type, size, and location of the defects, insulating material, applied voltage, cable temperature, and also vary with time. The damage caused by PD depends on several factors and can range from negligible to causing failure within days to years.

Definition from IEEE 400.3

What is a Partial Discharge – Deterioration

Partial discharges are the main cause of breakdown in case of A.C. voltage. Partial discharges slowly deteriorate the insulation material, this deterioration follows several stages:



a. Erosion
b. Preferential Erosion
c. Pit forming
d. Electrical treeing

→ XLPE

e. Deterioration of composite dielectrics follows more complicated routes.

→ PILC

On-site energizing methods to perform testing and PD diagnosis

Energizing	Voltage type
Continuous	50/60Hz, 20-300Hz AC voltages 0.1 Hz Very Low Frequency Voltage
Temporarily	Damped AC (DAC) voltages: 20-300Hz

IEC 60060-3 *High Voltage test techniques –Part 3: Definitions and requirements for on-site testing*

IEC 60502-2 Design of *Shielded Power Cable up to 30 kV*

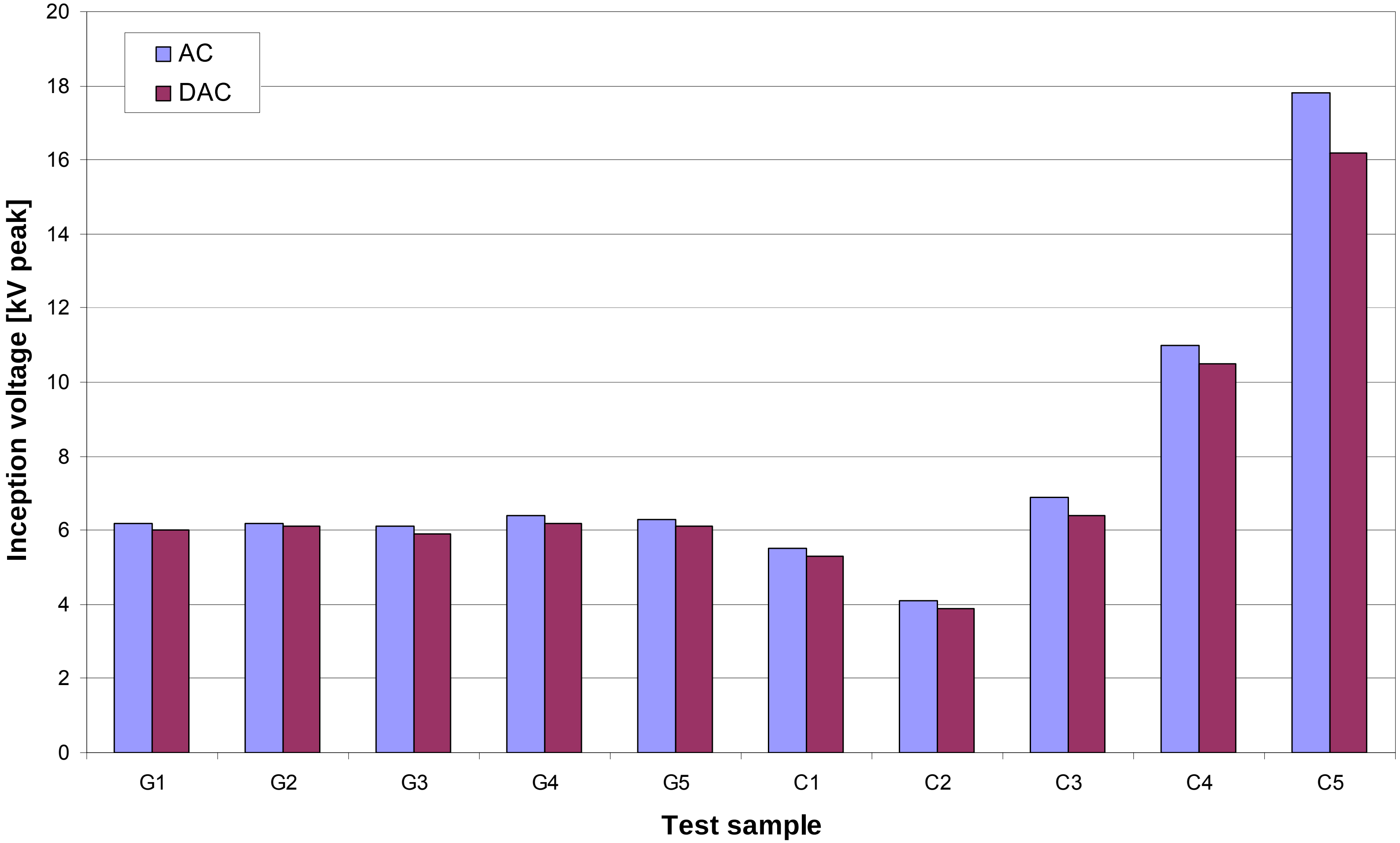
IEEE 400.3 *Guide for PD Testing of Shielded Power Cable Systems in a Field Environment*

IEC 60270, *Partial Discharges Measurements*

IEC 885-3 *Test methods for Partial Discharges measurements on lengths of extruded power cable*

Importance of voltage type equivalence

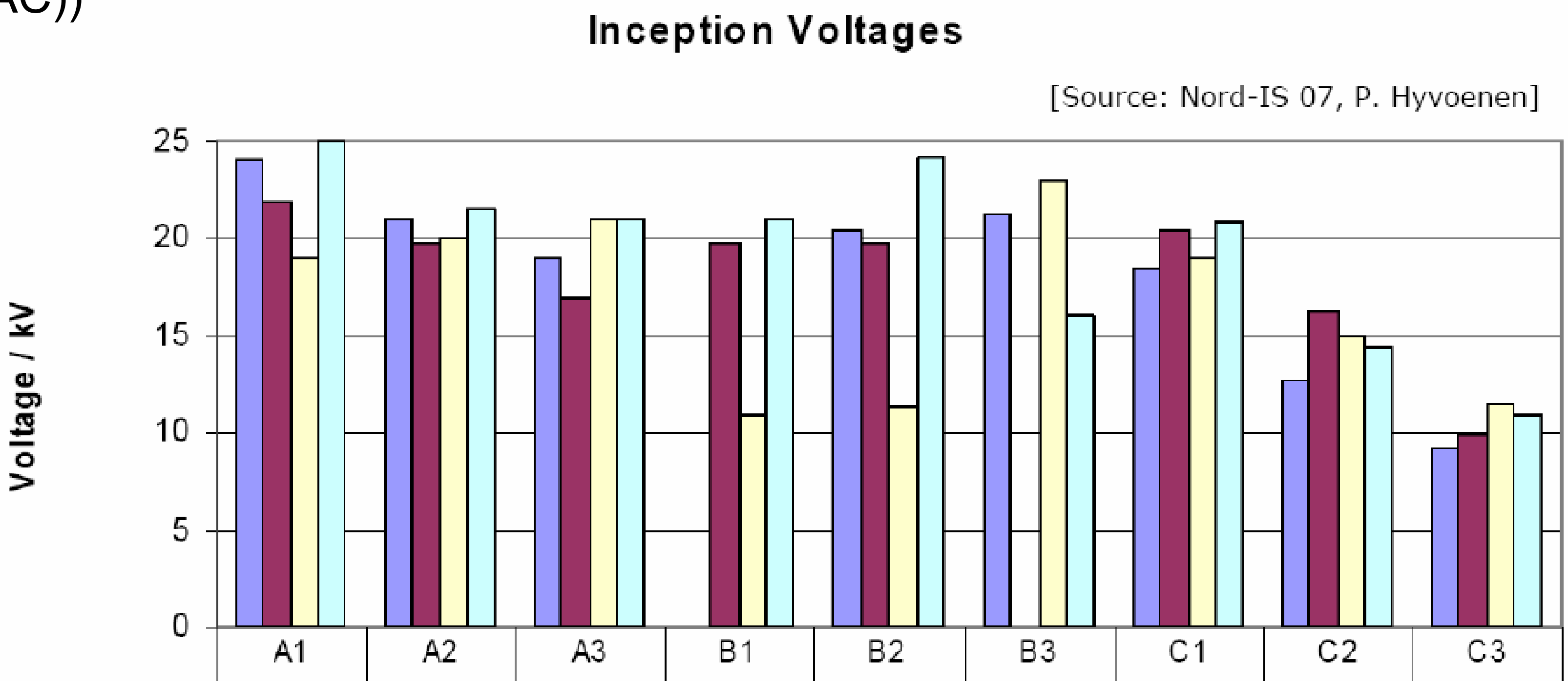
(PDIV of different test samples subjected to both AC voltage (AC) and damped AC voltages (DAC))



[Source: CIGRE D1.33, 2004, E. Lemke, T. Strehl]

Importance of voltage type equivalence

(PDIV of different test samples subjected to both AC voltage (AC) and damped AC voltages (DAC))

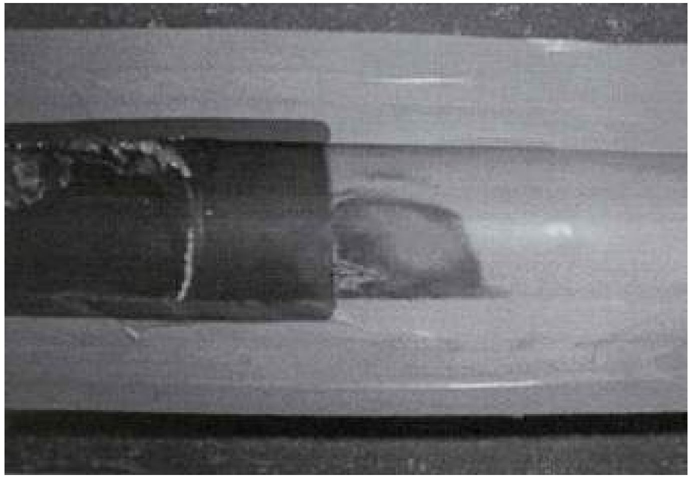


	A1	A2	A3	B1	B2	B3	C1	C2	C3
DAC 1	24	21	19		20.5	21.2	18.4	12.7	9.2
DAC 2	21.9	19.8	17.0	19.8	19.8		20.5	16.3	9.9
50 Hz 1	19	20	21	11	11.4	23	19	15	11.5
50 Hz 2	25	21.5	21	21	24.2	16.1	20.8	14.5	11

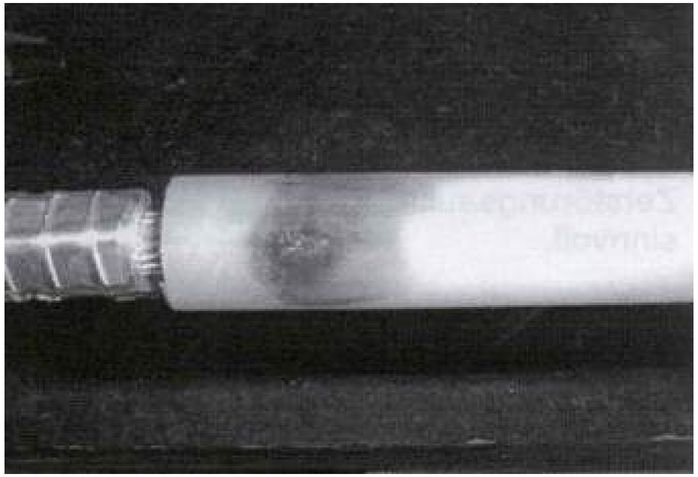
Test sample

Importance of voltage type equivalence
(PDIV of test sample subjected to both AC voltage (AC) and 0,1Hz (VLF))

Cable Type **NA2XS2Y 12/20 kV** (1992) ;
length 1605 m ; PD defect (370 pC) in joint at 850 m



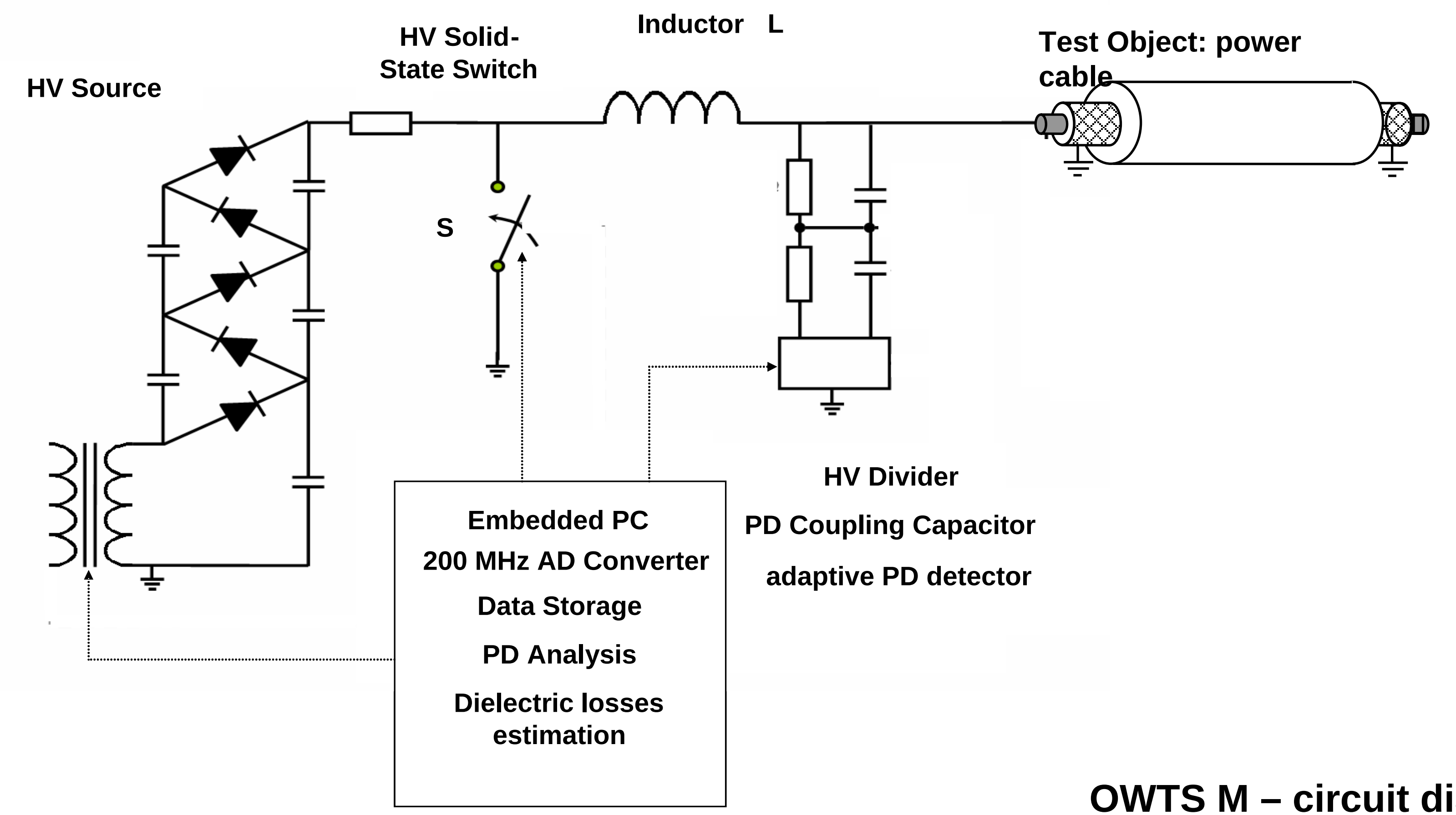
- **50 Hz AC voltage**
  PDIV < Uo = 12 kV rms
- **0,1 Hz VLF sinusoidal voltage**
  PDIV > 2 Uo = 24 kV rms



PD tracks and degradation generated during normal operation - service voltage Uo
Ignition (PDIV) of sliding discharges and surface discharges depends strongly from the shape of the applied voltage !!

Source : VWEW Infotag; contribution EON

Partial discharge diagnosis – Damped AC technology



OWTS M – circuit diagram

Partial discharge diagnosis

First generation of OWTS 25 (Over 100 systems in service)

Partial discharge diagnosis

New generation of OWTS M series, OWTS M 28 and OWTS M 60

OWTS M 28

OWTS M 60

Partial discharge diagnosis – OWTS M 28

Max. output voltage	28 kV peak / 20 kV rms
Coil resistance	app. 20 Ohm
Max. oscillating current	100 A
Frequency range DAC	50 Hz / 800 Hz
Capacitance range	0,05 µF – 2 µF
HV charging current	10 mA
PD measuring range	1 pC … 100 nC
PD measurement bandwidth	acc. to IEC 60270
PD location bandwidth	150 kHz … 45 MHz , wide range automatic bandwidth selection for short
Accuracy of PD localisation	1 % of cable length, (min. 3m)
Tan delta range	0,1 % ... 5%
Weight, size in mm	Unit 1: 55 kg, Æ: 600, H: 550
Embedded controler	Celeron M, XPE, Flashdisc 512 MB
RAM	512 MB
USB Port	integrated V.2.0
Protocoll feature	integrated
HV Switch	LTT
Data acquisition unit	Integrated DAQ / embedded controller
Operation control	W LAN link to embedded controller 802.11a, optional optical link (100 Fx)
Calibration mode	Automatic / manual
TDR joint location	Integrated Part of calibration mode
power supply	115 V / 230 V 50/60 Hz wide range
User interface	Remote client (Notebook or Tablet PC)
HV source	integrated

Partial discharge diagnosis – OWTS M 60

Max. output voltage	60 kV peak / 42 kV rms
Coil	app. 1,6 H / 40 Ohms
Max. oscillating current	150 A
Frequency range DAC	50 Hz / 800 Hz
Capacitance range	0,05 µF – 2 µF
HV charging current	7 mA
PD measuring range	1 pC … 100 nC
PD measurement bandwidth	acc. to IEC 60270
PD location bandwidth	150 kHz … 45 MHz , wide range, automatic
	bandwidth selection for short and long range
Accuracy of PD localisation	1 % of cable length, (min. 3m)
Tan delta range	0,1 % ... 5%
Weight, size in mm	Unit 1: 80 kg, Æ: 650, H: 1100
Embedded controler	Celeron M, XPE, Flashdisc 512 MB
RAM	512 MB
USB Port	integrated V.2.0
Protocoll feature	integrated
HV Switch	LTT
Data acquisition unit	Integrated DAQ / embedded controller
Operation control	W LAN link to embedded controller 802.11a, optional optical link (100 Fx)
Calibration mode	Automatic / manual
TDR joint location	Integrated Part of calibration mode
power supply	115 V / 230 V 50/60 Hz wide range
User interface	Remote client (Notebook or Tablet PC)
HV source	integrated

Partial discharge diagnosis – OWTS HV 150 kV

Weight: 300kg
Supply voltage: 220V
Max. load at 150kV: 13µF
Output: DAC voltage 150kV (20 Hz - 500 Hz)
Test object: power cables: 100m -20km

Shipping boxes, volume 10 m^3

Partial discharge diagnosis – OWTS HV 150 kV

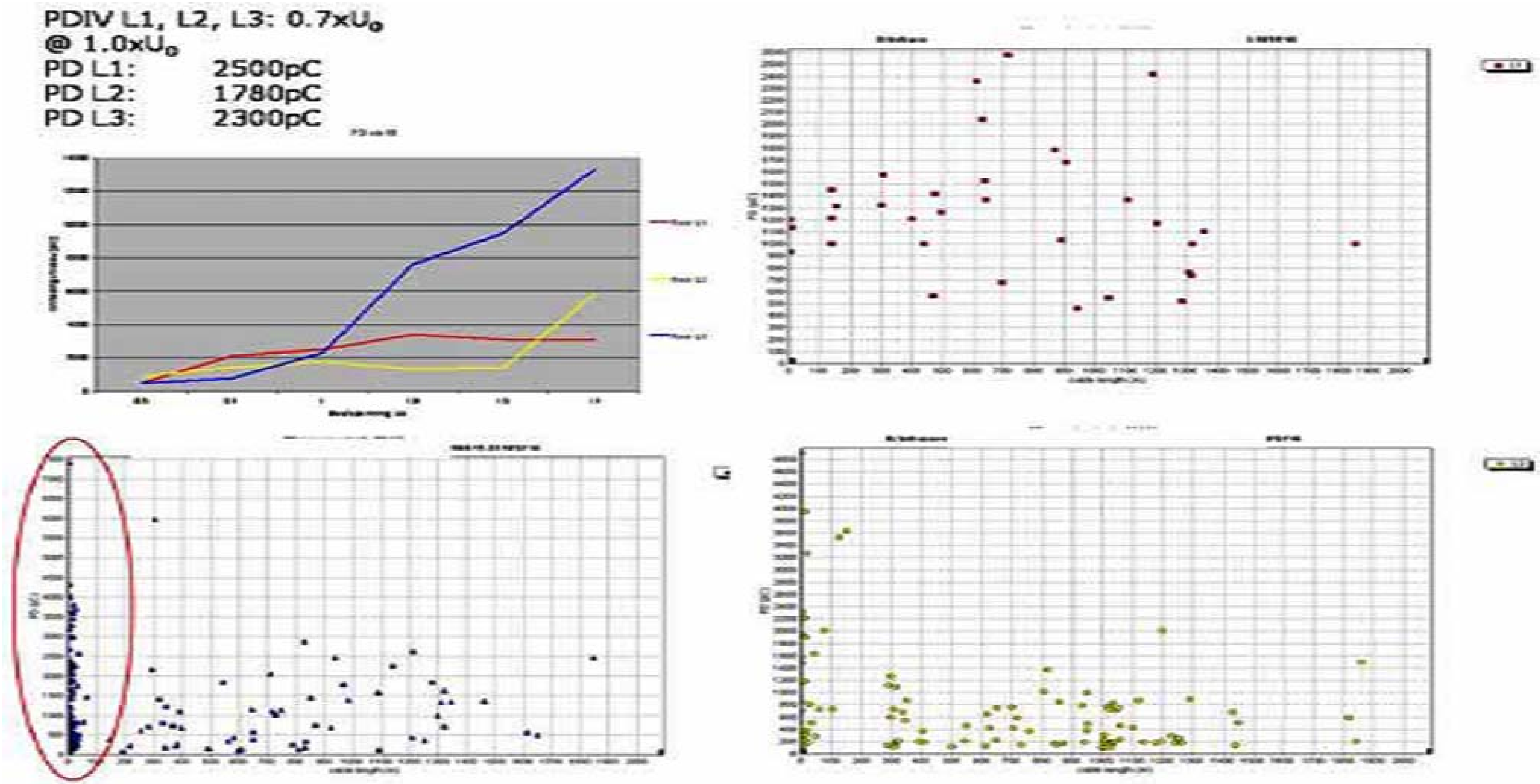
Maximum test voltages of a 150kV test system	
Network voltage [kV]	OWTS HV 150 [x U_0]
50	3.6
66	2.7
110	1.6
132	1.4
150	1.2

Examples of typical damped ac voltage frequencies for different lengths of two typical 150kv power cables		
Length [km]	XLPE (C=154pF/m) [Hz]	Oil filled (C=373pF/m) [Hz]
0.25	300	194
0.5	213	137
1	151	97
2	107	69
4	76	49
8	53	34
16	38	24
20	34	22

Technical parameters system	
Max. DAC output voltage	150 kV_{eff} / $106kV_{peak}$
DAC frequency range	20 Hz ... 500 Hz
Test object capacitance range	0,025 µF ... 13 µF
HV charging current	10 mA
PD measuring range	1 pC ... 100 nC
PD detection	acc. to IEC 60270
Bandwidth for PD-localization	150 kHz ... 45 MHz
Dissipation factor	0,1 % ... 10 %
Power supply	115/230 V 50 / 60 Hz
Weight	app. 300 kg

Partial discharge diagnosis – OWTS HV 150 kV

Additionally with HV-cables the dielectric losses (Δtanδ) becomes a very powerful tool to asses the condition of the cable as well.



Partial discharge diagnosis – OWTS HV 250 kV

Weight: 300kg
Supply voltage: 220V
Max. load at 250kV: 8μF
Output: DAC voltage 250kV (50 Hz - 500 Hz)

Test object: power cables: 100m -20km

Partial discharge diagnosis – Applicability of OWTS

The OWTS can be used for several purposes:

1. After-laying test/ commissioning test for newly installed cables at $2U_0$. This to check poor workmanship.

2. After repairement test (Quality control), also to test bad workmanship e.g. external contractors.

3. Gain information about the present state of the cable, joints and end-terminations.

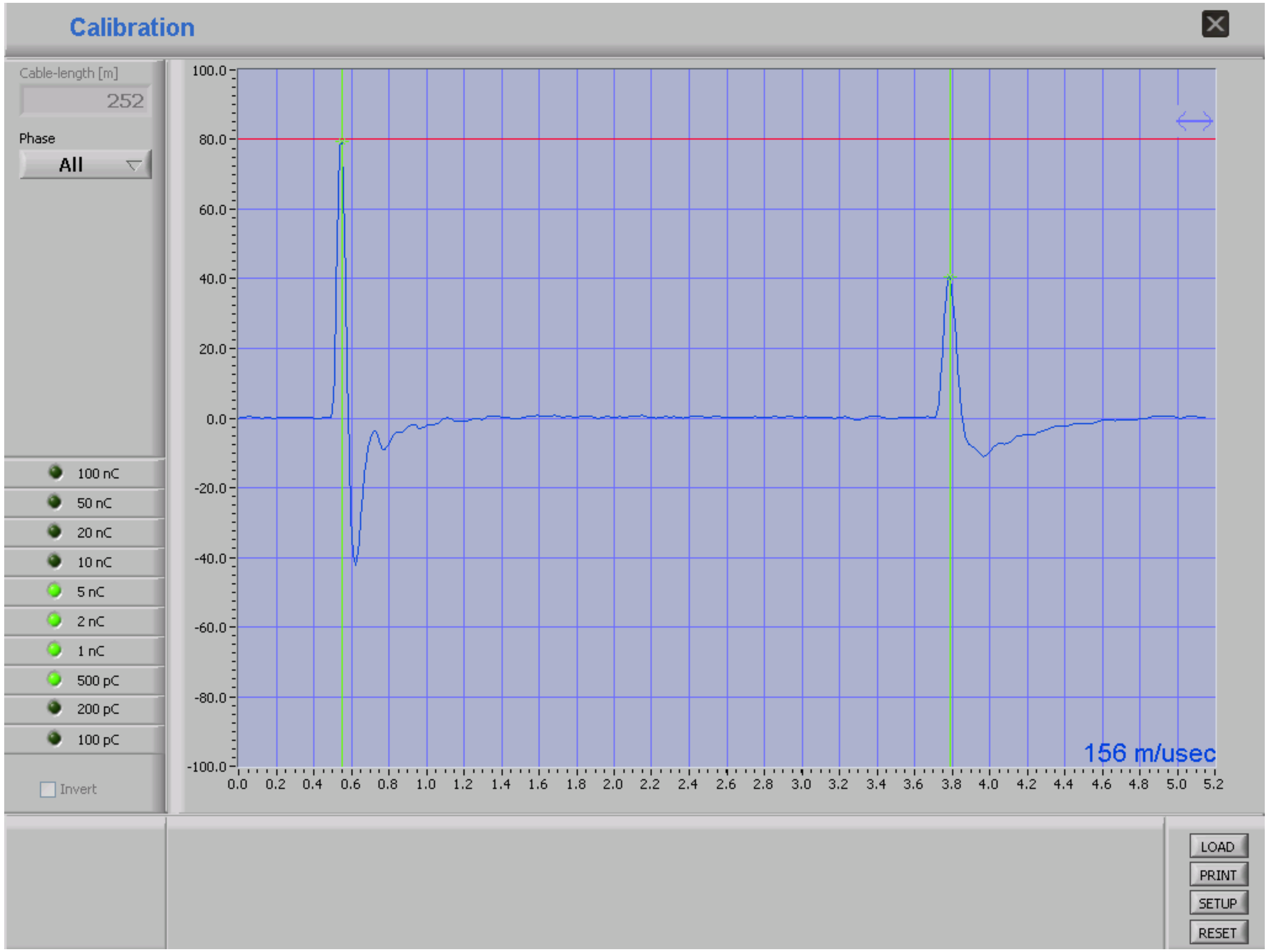
4. When performing repetitive measurements e.g. after each year, the condition of the cable can be monitored.

Partial discharge diagnosis – OWTS voltage table

Voltage		Test at 1,2 Uo		Test at 1,7 Uo		Test at 2 Uo		Maximum Test Voltage Level (rms) @ Uo			
U	Uo	RMS	Peak	RMS	Peak	RMS	Peak	OWTS M 28	OWTS M 60	OWTS 150	OWTS 250
kV	kV	kV	kV	kV	kV	kV	kV	x Uo	x Uo	x Uo	x Uo
10	5,8	6,9	9,8	9,8	13,9	11,5	16,3	3,4			
11	6,4	7,6	10,8	10,8	15,3	12,7	18,0	3,1	6,7		
15	8,7	10,4	14,7	14,7	20,8	17,3	24,5	2,3	4,9		
20	11,5	13,9	19,6	19,6	27,8	23,1	32,7	1,7	3,7		
22	12,7	15,2	21,6	21,6	30,5	25,4	35,9	1,6	3,3		
25	14,4	17,3	24,5	24,5	34,7	28,9	40,8	1,4	2,9		
30	17,3	20,8	29,4	29,4	41,6	34,6	49,0	1,1	2,4	6,1	
33	19,1	22,9	32,3	32,4	45,8	38,1	53,9	1,0	2,2	5,6	
36	20,8	24,9	35,3	35,3	50,0	41,6	58,8	1,0	2,0	5,1	
45	26,0	31,2	44,1	44,2	62,5	52,0	73,5		1,6	4,1	6,8
66	38,1	45,7	64,7	64,8	91,6	76,2	107,8		1,1	2,8	4,6
110	63,5	76,2	107,8	108,0	152,7	127,0	179,6			1,7	2,8
132	76,2	91,5	129,3	129,6	183,2	152,4	215,6			1,4	2,3
150	86,6	103,9	147,0	147,2	208,2	173,2	245,0			1,2	2,0
220	127,0	152,4	215,6	215,9	305,4	254,0	359,3				1,4
330	190,5	228,6	323,3	323,9	458,1	381,1	538,9				0,9
380	219,4	263,3	372,3	373,0	527,5	438,8	620,5				

Advanced features OWTS M series

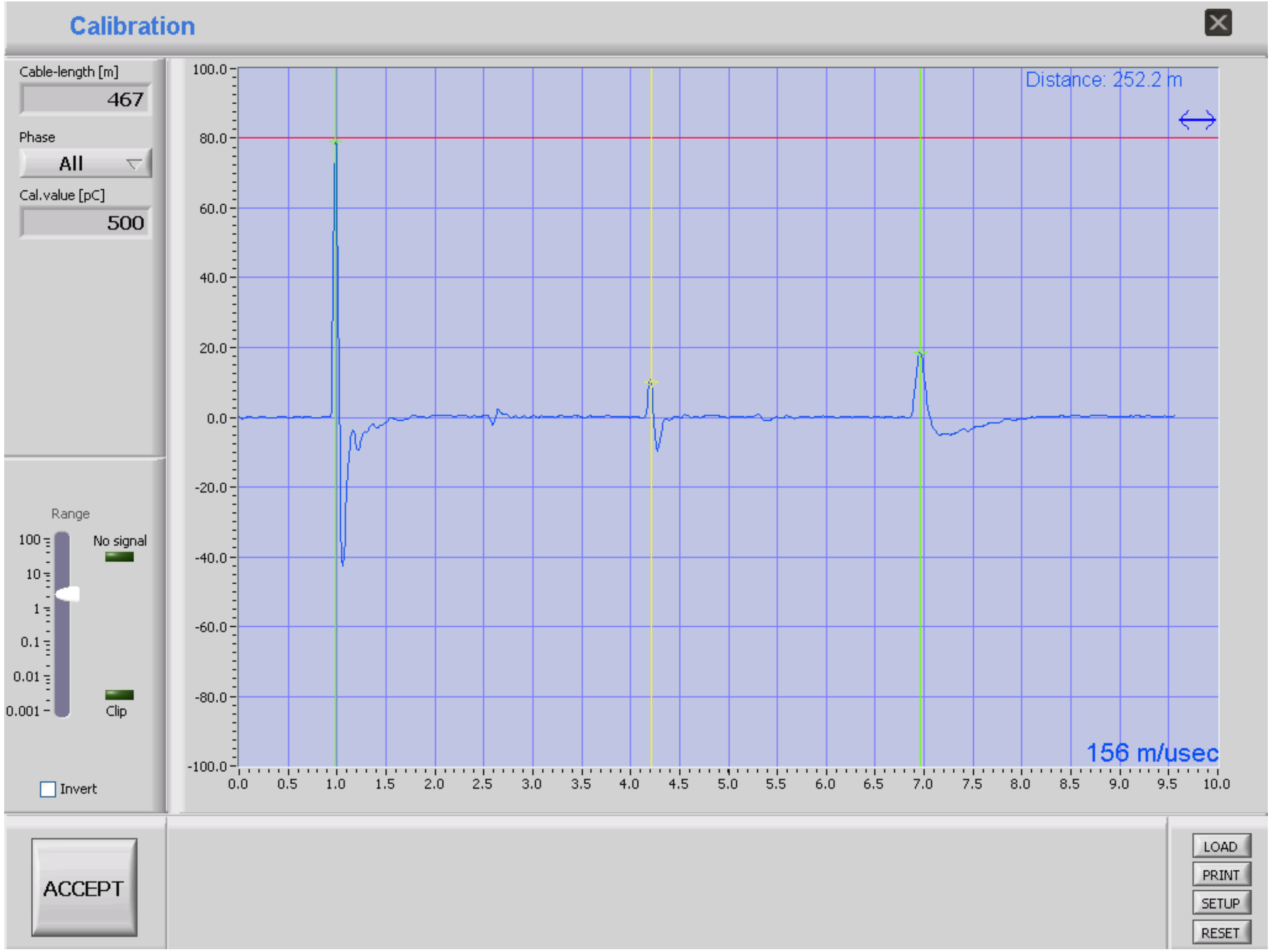
Fully automatic calibration function



Advanced features OWTS M series

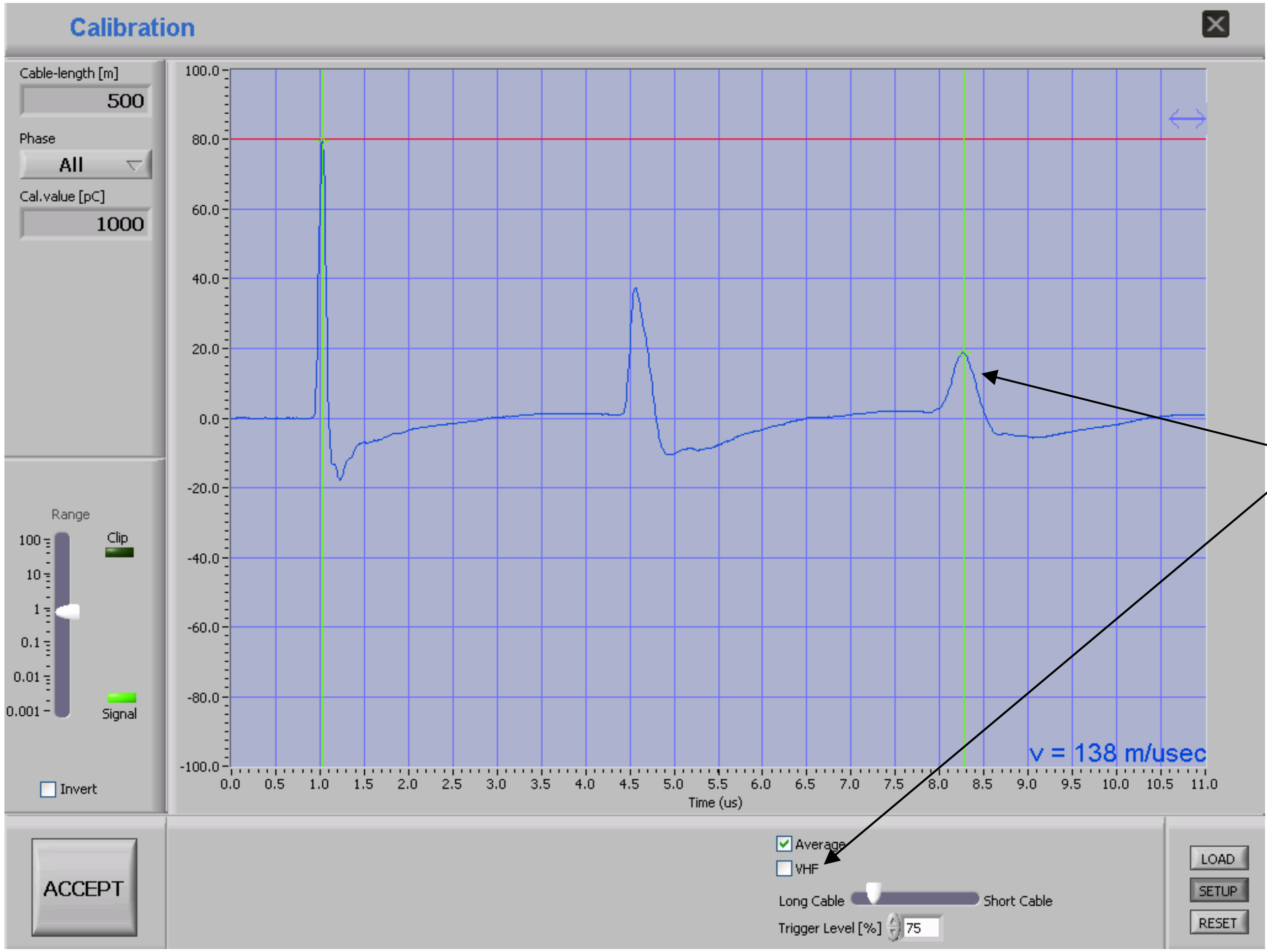
Localisation of joints

in calibration mode



Advanced features OWTS M series

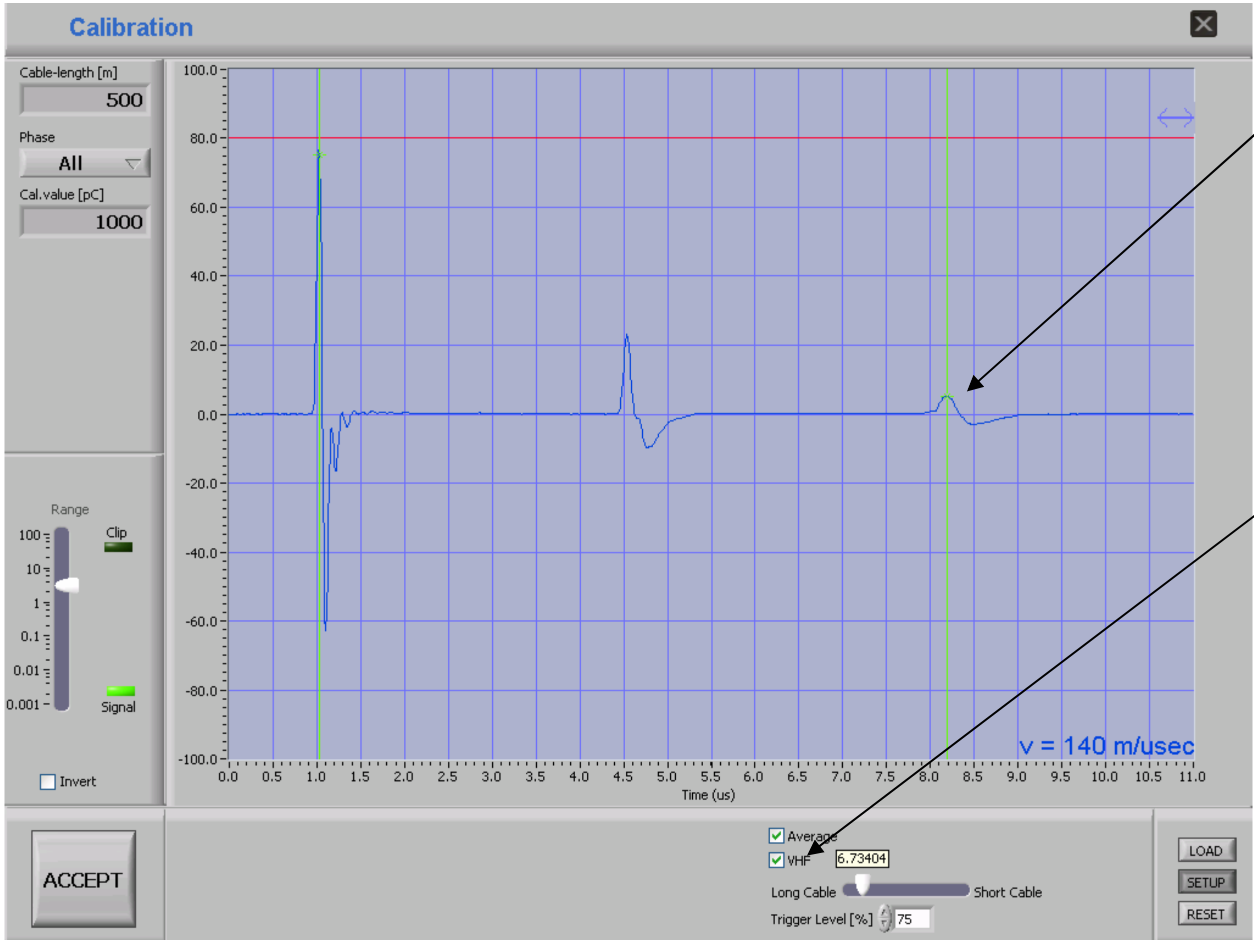
The frequency dynamic of the PD quadripole will be adopted for higher frequencies; this feature is useful for short cable lengths or if the PD activity has been observed at the location close to far cable end.



Bandwidth adaptation results in better signal to noise ratio and clearly visible reflections of the PD.

Advanced features OWTS M series

Adaptation of the quadripole in “high resolution VHF-mode” for PD-fault location on XLPE cables till 1000m and PILC cables till 500m. Result precise fault location, also in close distance of end-termination!!!!

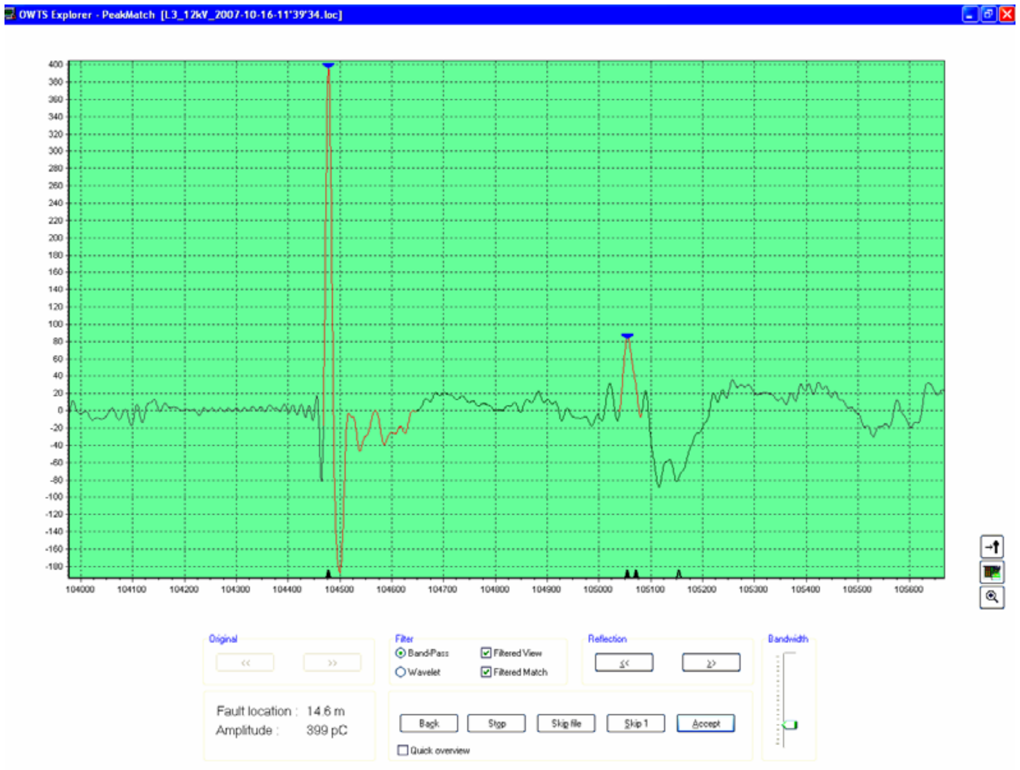


High-frequent signals will be highly attenuated therefore the VHF function is only applicable on short cables.

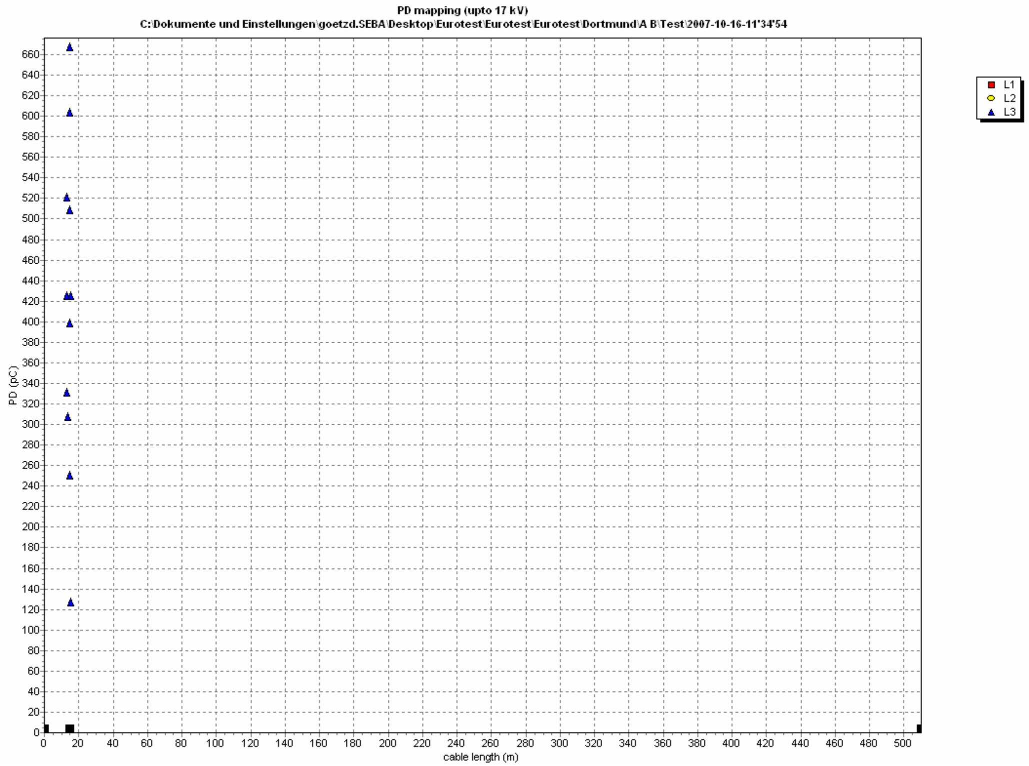
VHF-mode (7MHz to 50 MHz) activated.

Advanced features OWTS M series

PD-fault 15m from the near end-termination

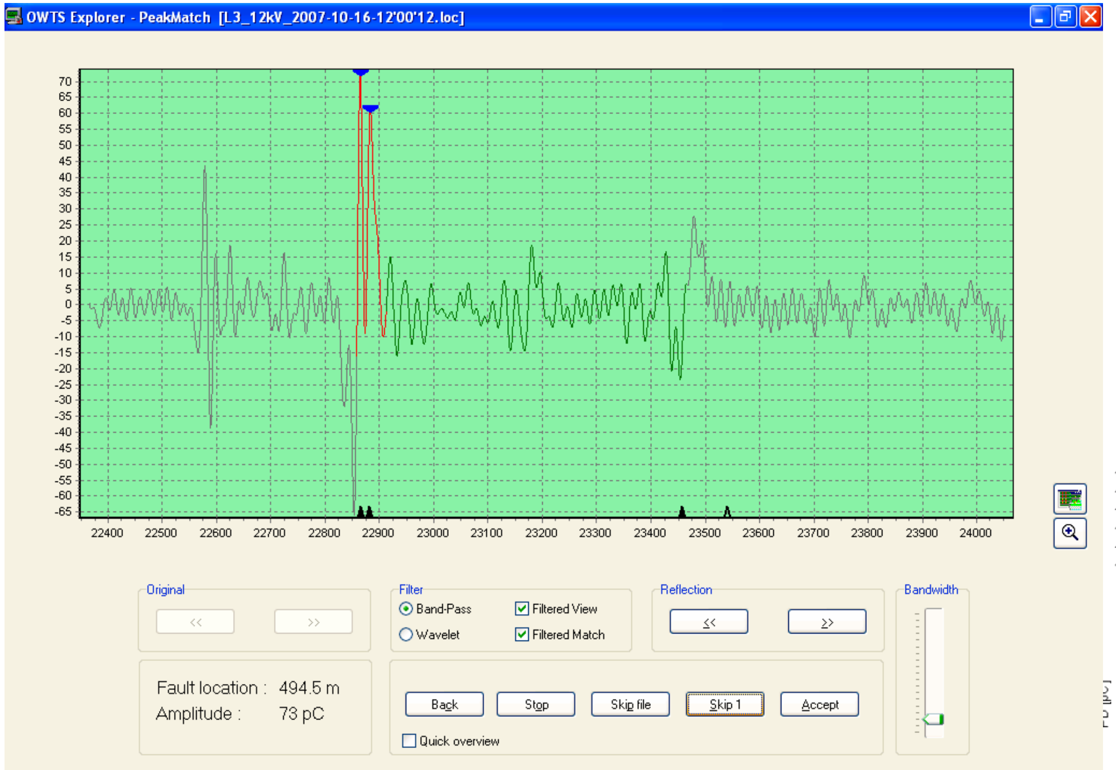


PD fault close to near end termination.

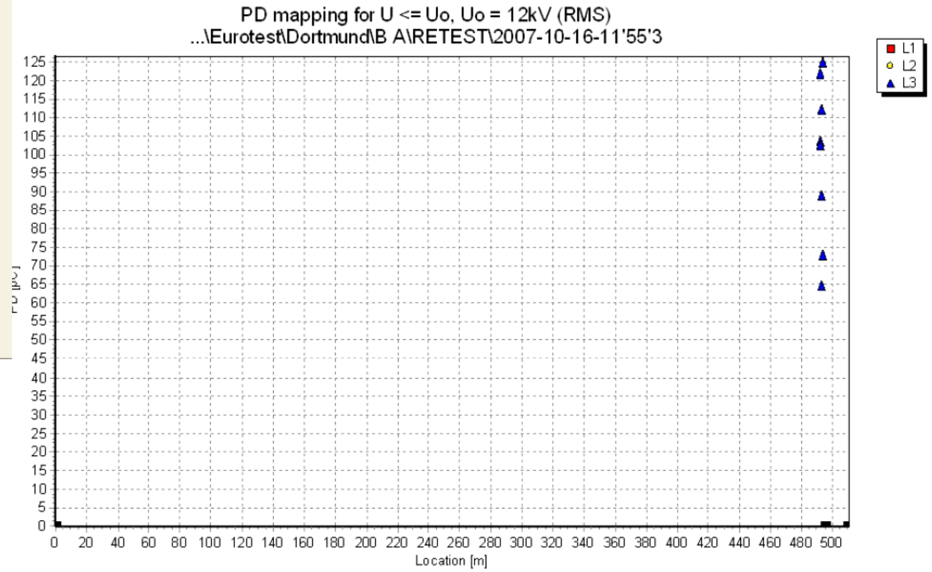


Advanced features OWTS M series

PD-fault 15m from the remote end-termination



PD fault close to remote end termination.



Partial discharge diagnosis – Trending limits MV-Cables

Cable Element	Type	Trend / Limit
Insulation	Paper	up to 10.000 pC
	PE /XLPE	< 20 pC
Joints	Oil Insulation	> 10.000 pC
	Oil /Resin Insulation	5.000 pC
	Silicone / EPR Insulation	500 to 1.000 pC
Terminations	Oil Termination	6.000 pC
	dry Termination	3.500 pC
	Shrink-/ Slip-on Terminations	250 pC

Source : Noun NL ; Statistic from Nuon Alkmaar

Partial discharge diagnosis – Trending limits HV-Cables

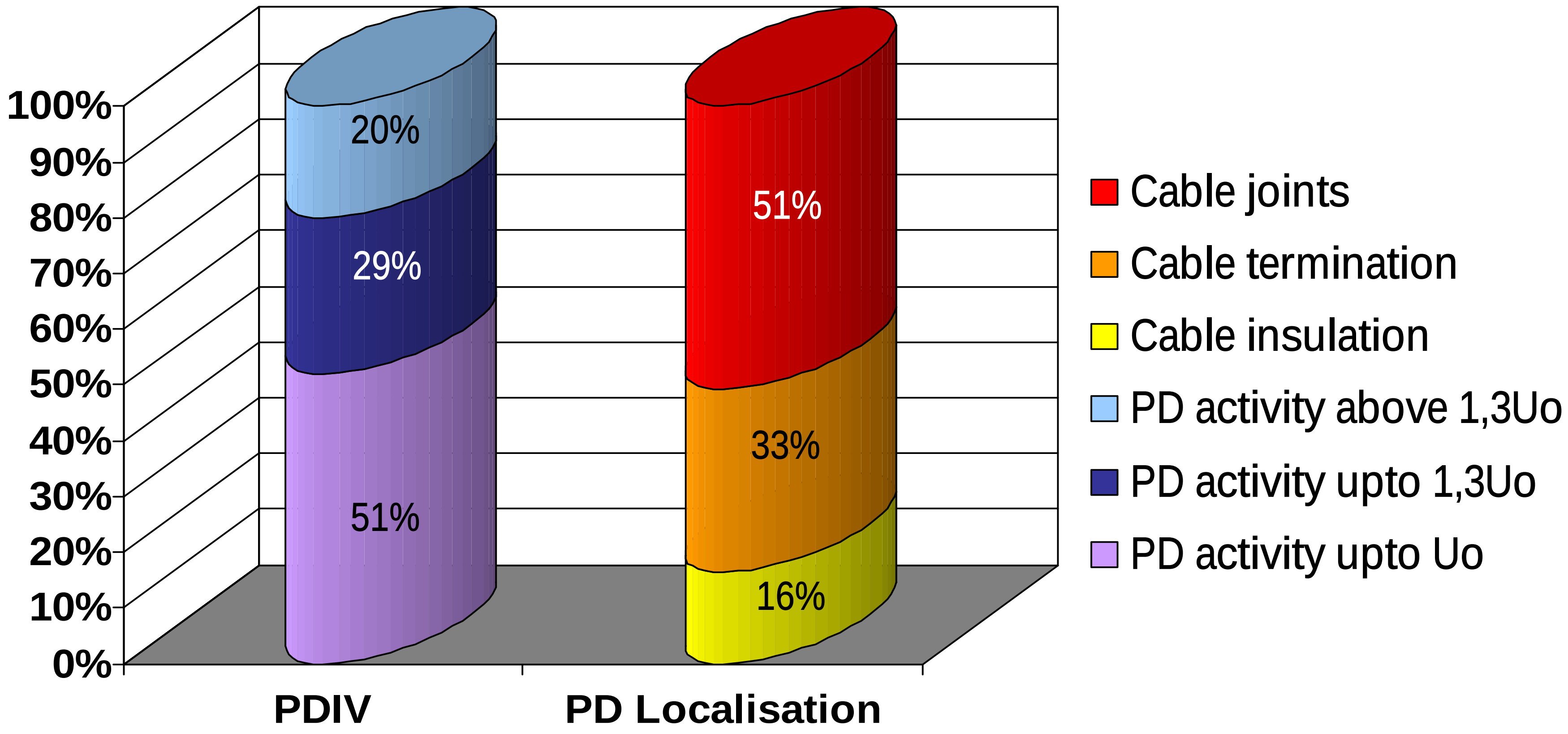
HV power cables condition assessment knowledge rules for on-site PD and tan δ diagnosis.

Condition Category	PD [pC]	tan δ @ Uo [%]	Advise
A	≤ 250	≤ 0.3	Condition o.k.
B	≤ 1000	≤ 0.5	Condition o.k.
C	≤ 1000 or ≤ 5000 and no local PD concentrations	≥ 0.5 and ≤ 0.8	Follow trend by inspections
D	≤ 1000 and local PD concentrations	≥ 0.8	Follow trend by inspections Repair on PD location
E	≥ 5000 and no local PD concentrations	>> 0.8	Cable replacement

Source : Delft University of Technology

Partial discharge diagnosis – Trending limits

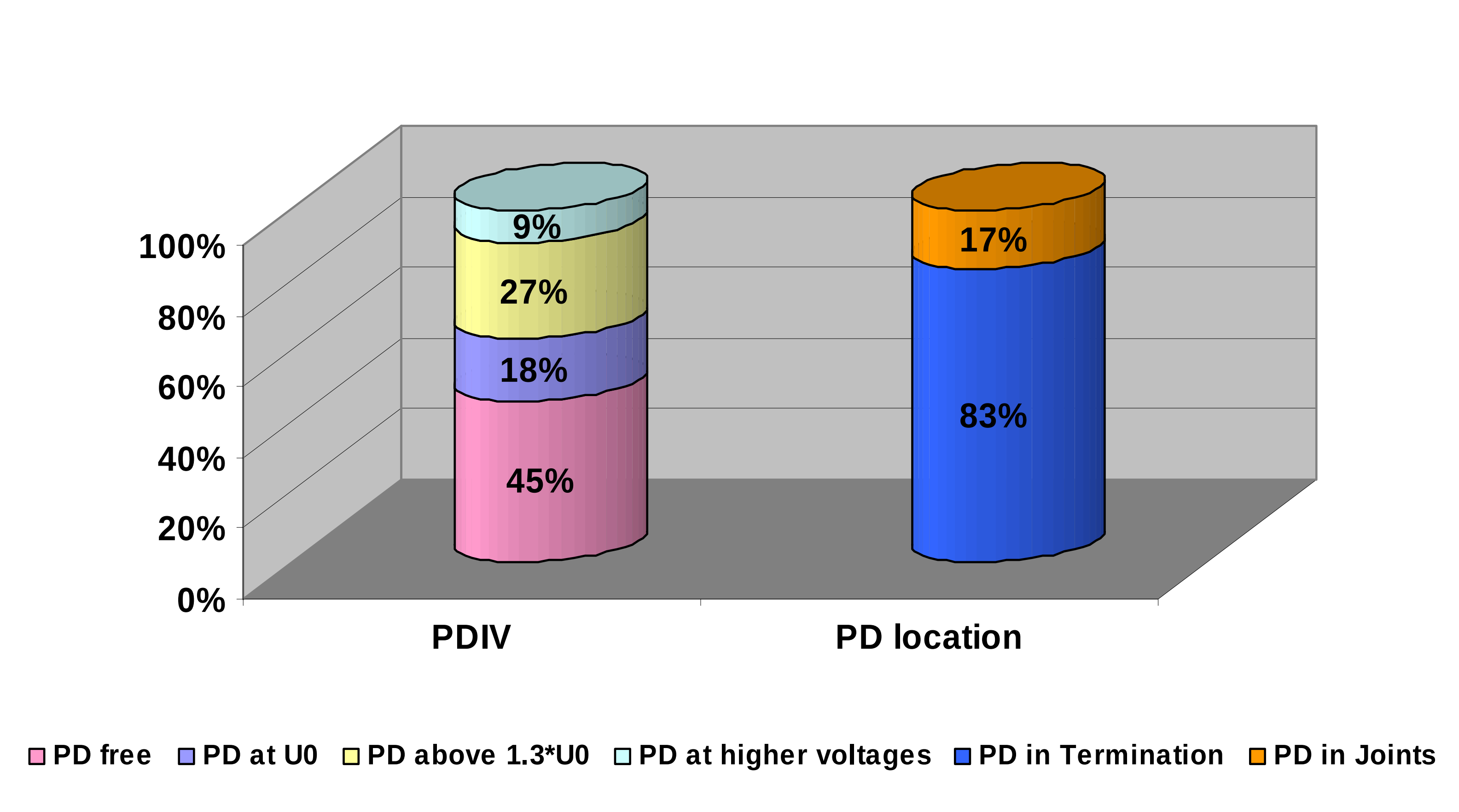
Experiences PDIV and PD locations in PILC



Source : Noun NL ; Statistic from Nuon Alkmaar

Partial discharge diagnosis – Trending limits

Experiences PDIV and PD locations in XLPE cables



NUON

Source : Noun NL ; Statistic from Nuon Alkmaar

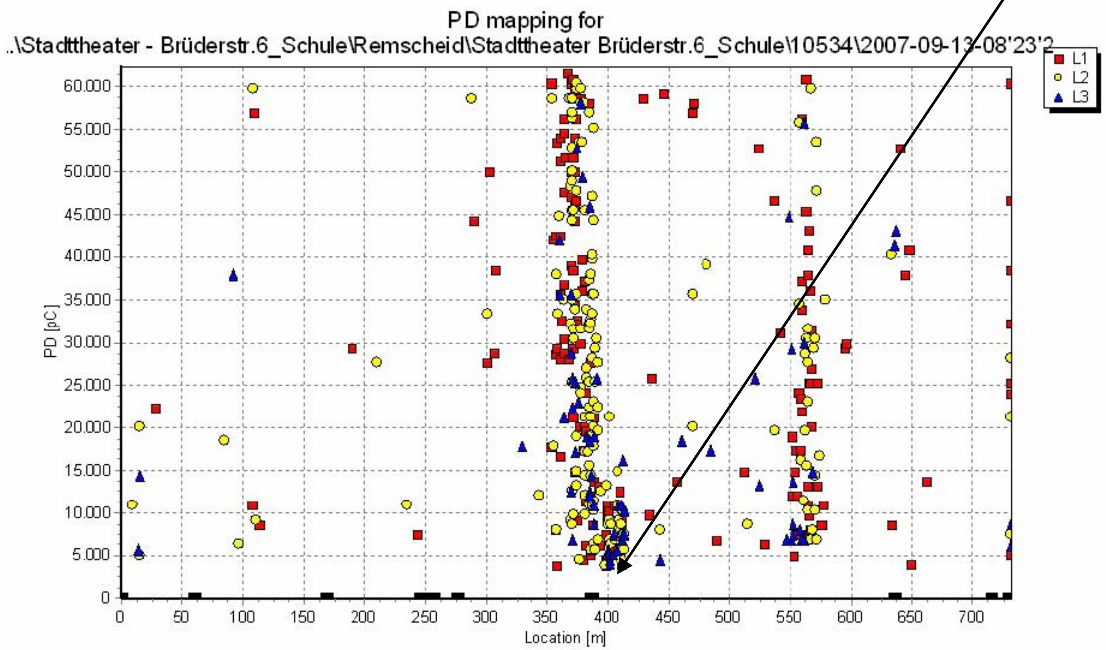
Field results

Example 5

OWTS MEASUREMENT REPORT

Date	Donnerstag, 13. September 2007 08:23		
Engineer	Vos		
Location	Remscheid		
Cable from	Stadttheater to Brüderstr.6_Schule		
CableSection	10534	Year	0
Phase to Ground Voltage	6 kV (RMS)	Length	732 m

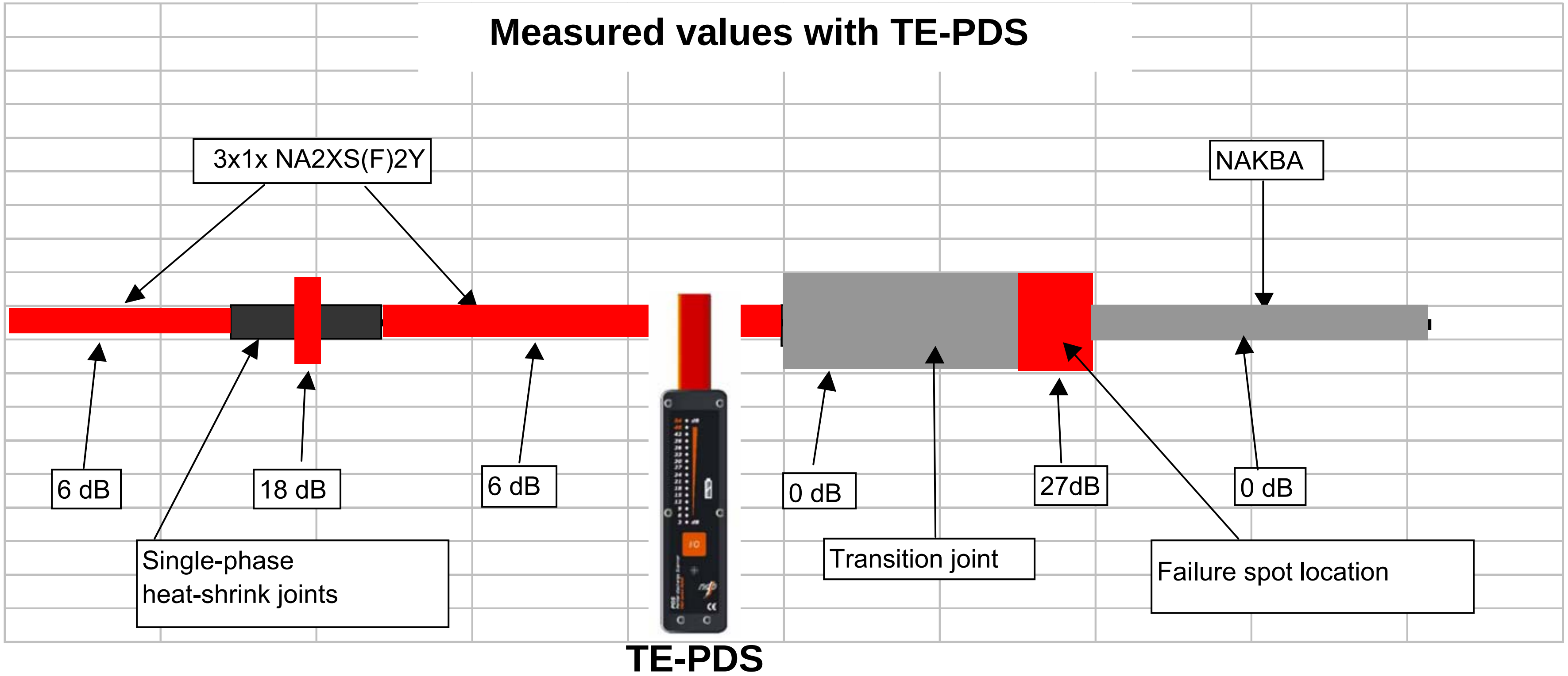
Transition joint with PDIV at 2 kV.



Field results

Example 5

Pinpointing with TE PDS on exposed cable (at operating voltage) clearly showed discharges in the transition joint.

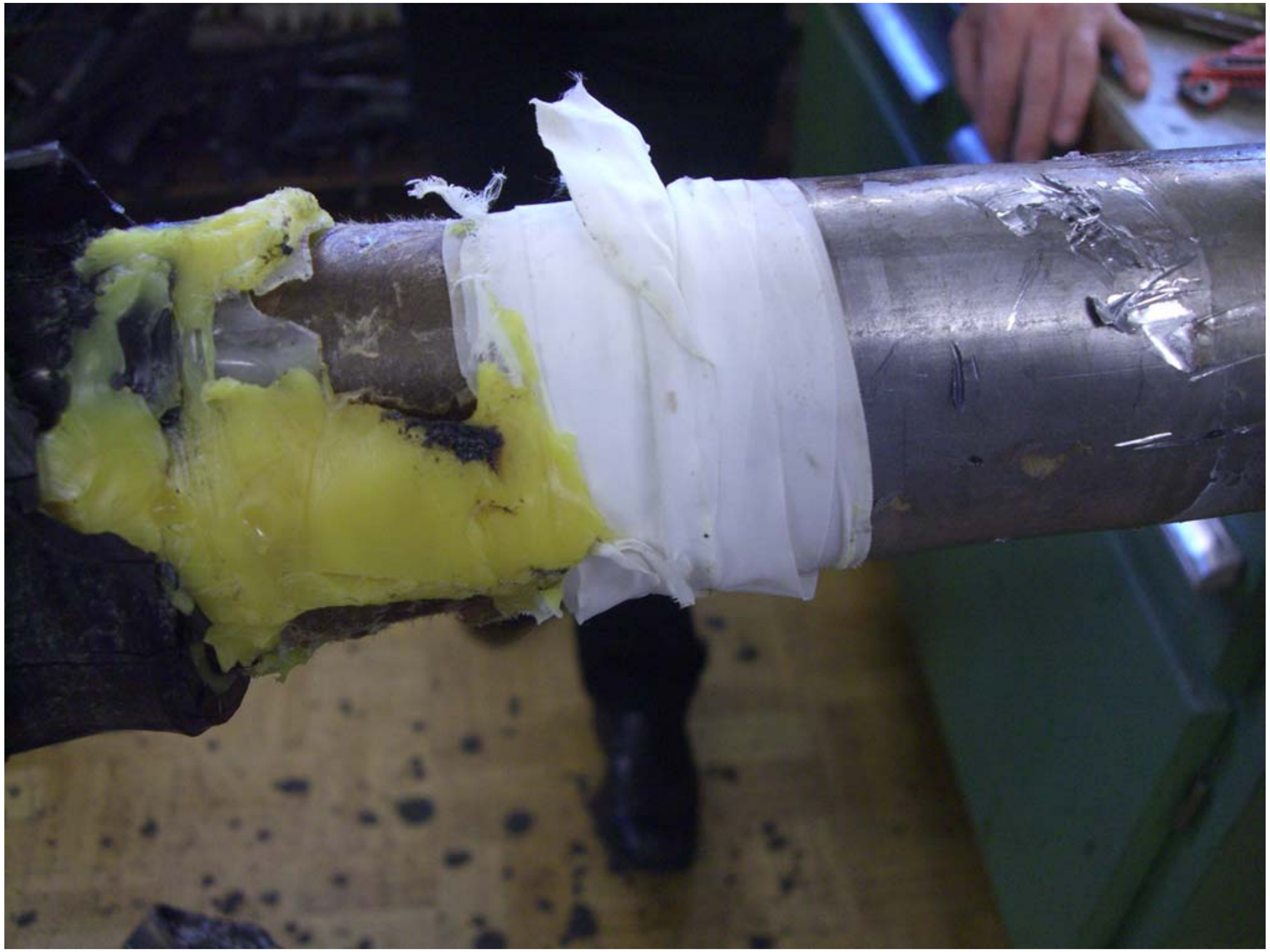


The high PD pulses are coupled through the armour of the joint.

Field results

Example 5

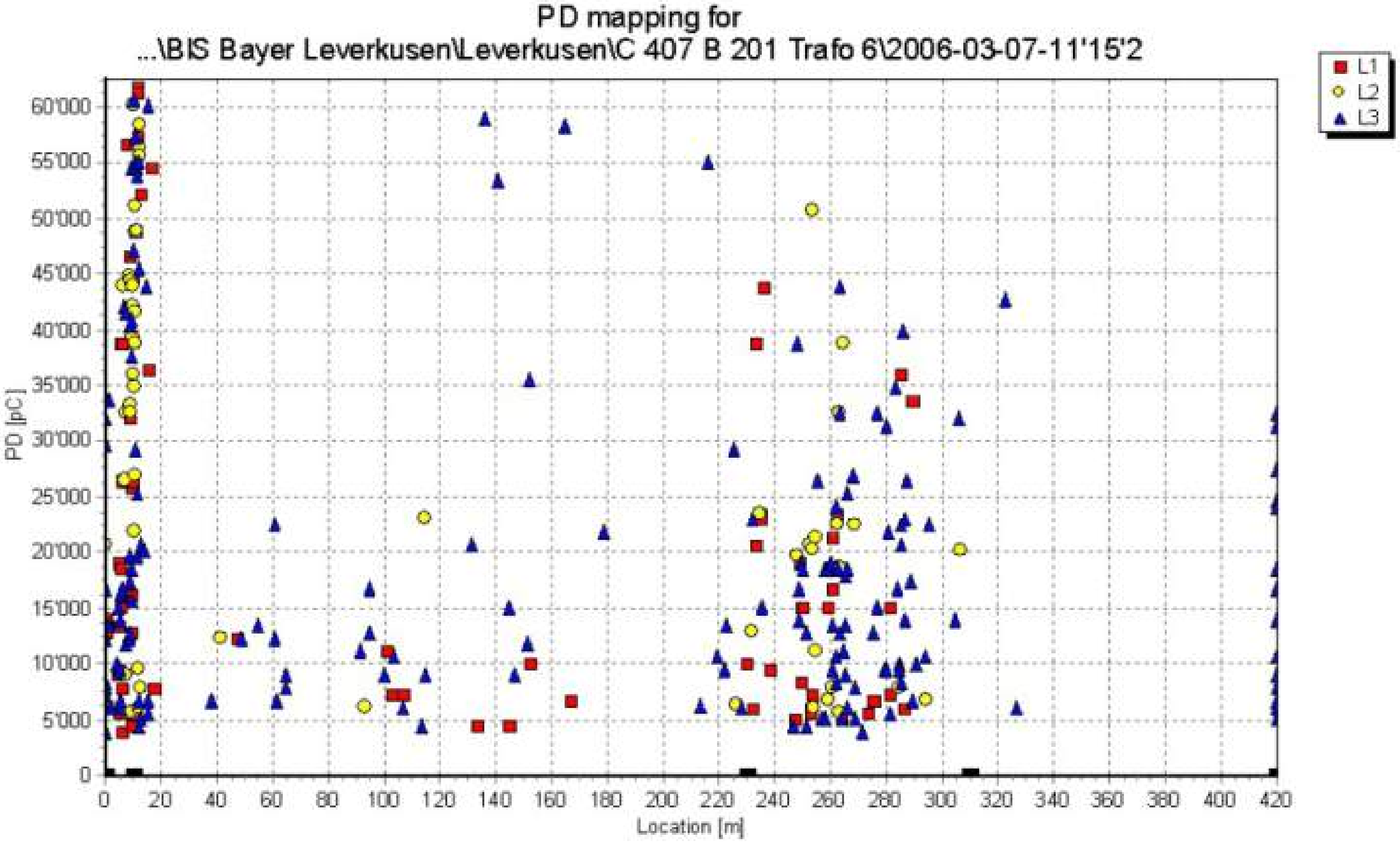
Field results
Example 5



Assembling failure:
forgotten to remove the assisting bondage, this bondage distorted the field grading of the joint and caused PD.

Field results

Example 11



PD in transition joint XLPE/ PILC, PD-level @ 1.7U_0 up to 60.000 pC.

Field results

Example 11

1. Yellow mastic-tape bridges over insulation distance between main conductor connector and insulation shield on PILC side.
2. Uncompleted shrinking of insulation-tube.

Field results

Example 19

OWTS MEASUREMENT REPORT

Date	Mittwoch, 19. Juli 2006 07:45		
Engineer	Kamenka		
Location	Ingolstadt		
Cable from	Pumpwerk Uns. to Unsernherrnerstr.28		
CableSection	44	Year	1960
Phase to Ground Voltage	12 kV (RMS)	Length	1714 m

PD measurement on mixed cable.

Discharges in XLPE connection joints at 700 m and 1238 m.

PD-level @ U_0 app. 1.100 pC.

Cable W5 from Pumpwerk Uns to Unsernhernstr 28		
Pumpwerk Uns	luftisoliert	
Unsernhernstr 28	SF6	
L1,L2,L3:		
0 m	Termination	Oel EV Ka Dr
	Cablepart 44 m	NEKBA 3x95
44 m	Joint	Ue-Tyco Schrump
	Cablepart 661 m	NA2XS(F)2Y
705 m	Joint	Tyco Schrumpf
	Cablepart 533 m	NA2XS(F)2Y
1238 m	Joint	Tyco Schrumpf
	Cablepart 476 m	NA2XS(F)2Y
1714 m	Termination	Elast Schiebe

After replacement of both joints PD level @ Uo ca. 200 pC (located in the PILC part of the cable).

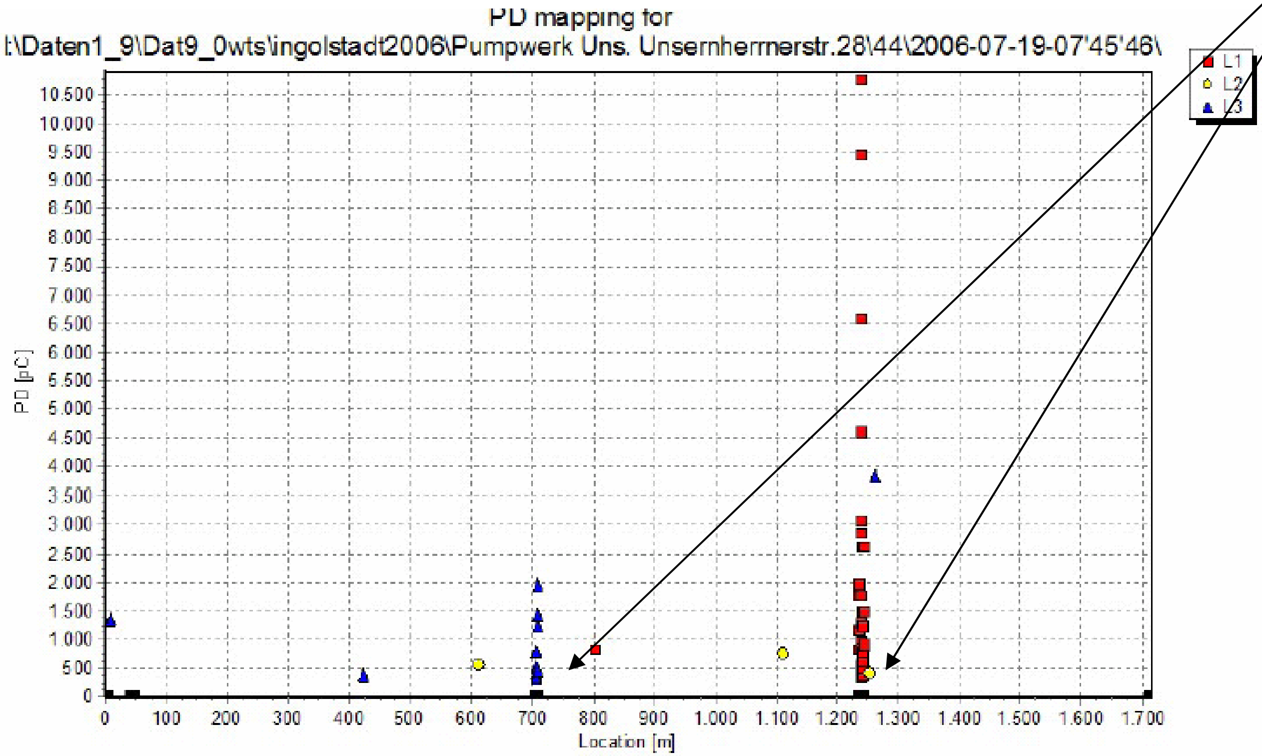
	L1	L2	L3
GroundNoise [pC]	12	12	12
PDIV [kV RMS]	15.6	16.8	18.0
PDEV [kV RMS]	12.9	-	12.5
PDmax [pC] (PDIV)	299	339	384
PDlevel [pC] (PDIV)	257	286	311
PDmax [pC] (Uo)	241	215	258
PDlevel [pC] (Uo)	202	194	232
PDmax [pC] (1.7*Uo)	1056	582	391
PDlevel [pC] (1.7*Uo)	701	389	339
PDmax [pC] (2*Uo)	-	-	-
PDlevel [pC] (2*Uo)	-	-	-
Capacitance [uF]	0.439	0.443	0.446
Frequency [Hz]	303.03	305.34	298.51
Diel. Losses	1.11E-3	1.05E-3	1.03E-3

Field results

Example 19

OWTS MEASUREMENT REPORT

Date	Mittwoch, 19. Juli 2006 07:45		
Engineer	Kamenka		
Location	Ingolstadt		
Cable from	Pumpwerk Uns. to Unsernherrnerstr.28		
CableSection	44	Year	1960
Phase to Ground Voltage	12 kV (RMS)	Length	1714 m



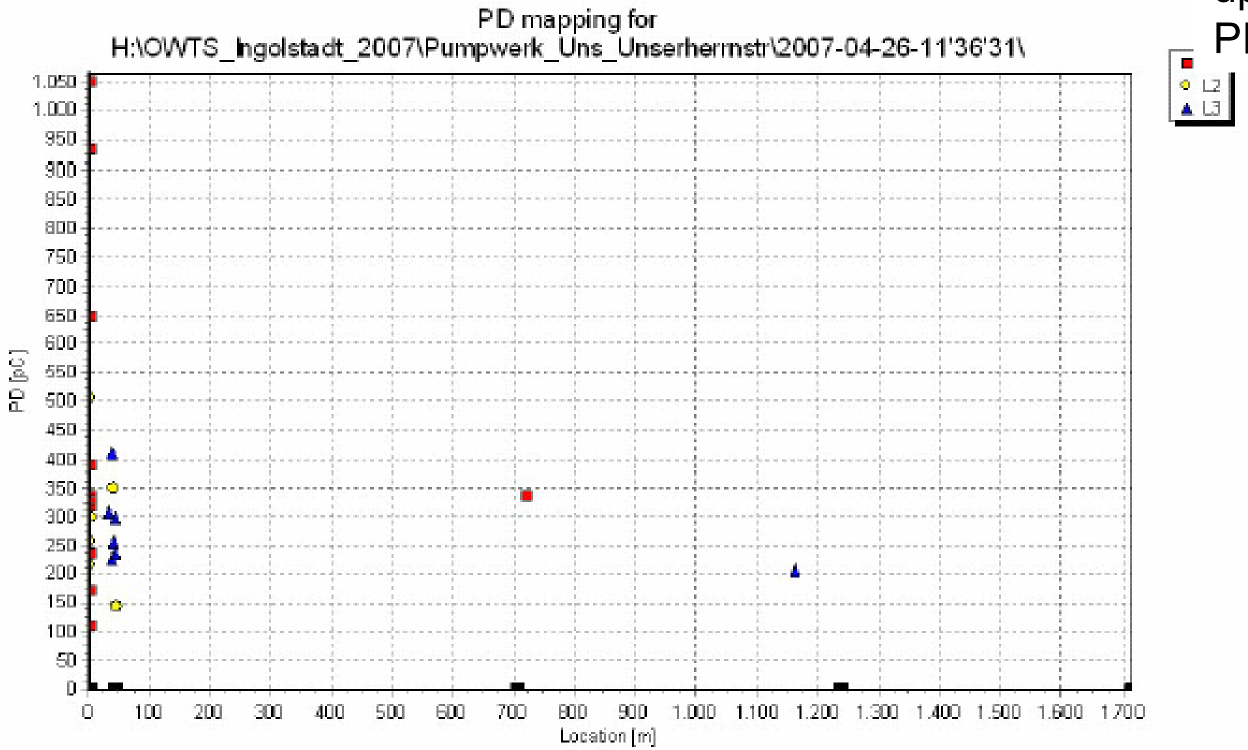
PD-level in connection joints @ U_0 of 1.100 pC.

Field results

Example 19

OWTS MEASUREMENT REPORT

Date	Thursday, April 26, 2007 11:36 AM		
Engineer	Kamenka		
Location	Ingolstadt		
Cable from	Pumpwerk Uns to Unsernhernstr 28		
CableSection	W5	Year	1960
Phase to Ground Voltage	12 kV (RMS)	Length	1714 m



After connection joints have been replaced a repeated measurement has been performed one year later on, now the discharge level is only up to 200 pC and only located in the PILC part of the cable.

Partial Discharge Diagnosis – Pin-pointing

Situation:

Because PD's are not complete breakdowns it is not possible to detect the PD location with conventional fault locating methods.

Also PD's are not detectable above ground!!

Assignment:

Just like fault locating, precise pin-pointing is desired.

How do I pin-point the PD spot without damaging the cable????

Solutions:

-Pin-pointing by using the PD-loc;

-Pin-pointing by using audio-frequency.

Partial Discharge Diagnosis – Pin-pointing

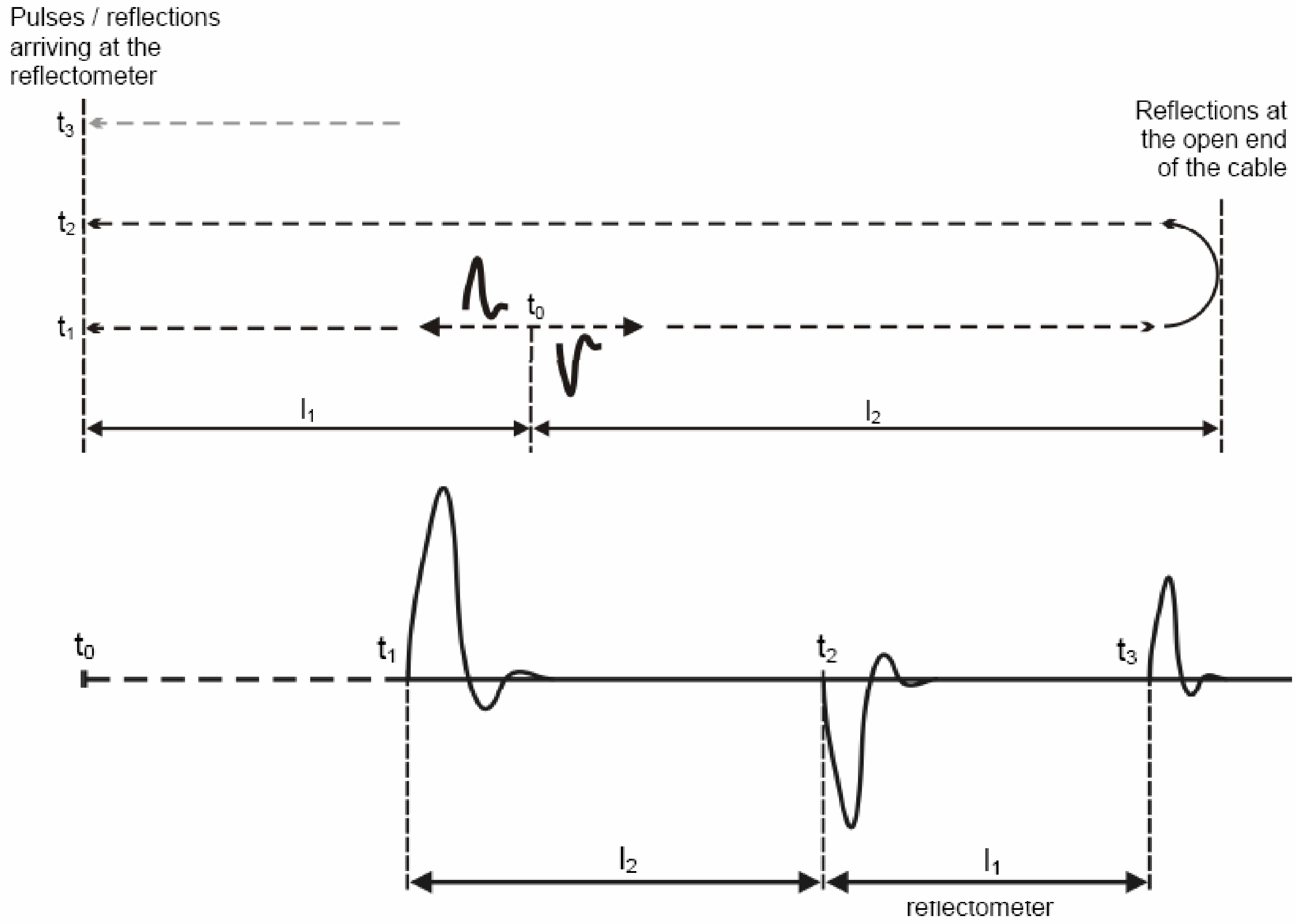
PD-Loc

Teleflex T30-E-PD

Impulse transmitter

Partial Discharge Diagnosis – Pin-pointing

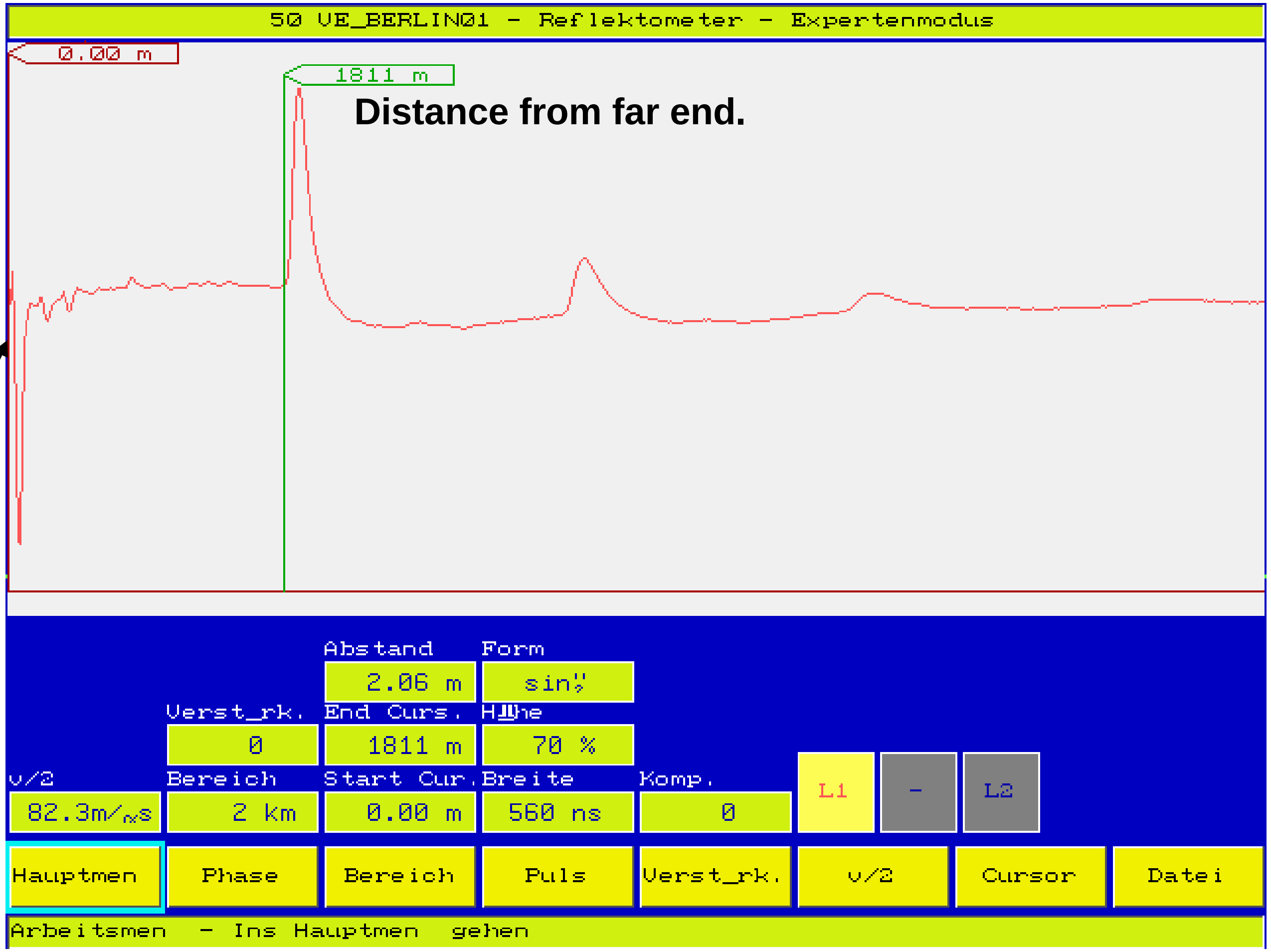
PD-Loc



Partial Discharge Diagnosis – Pin-pointing

PD-Loc

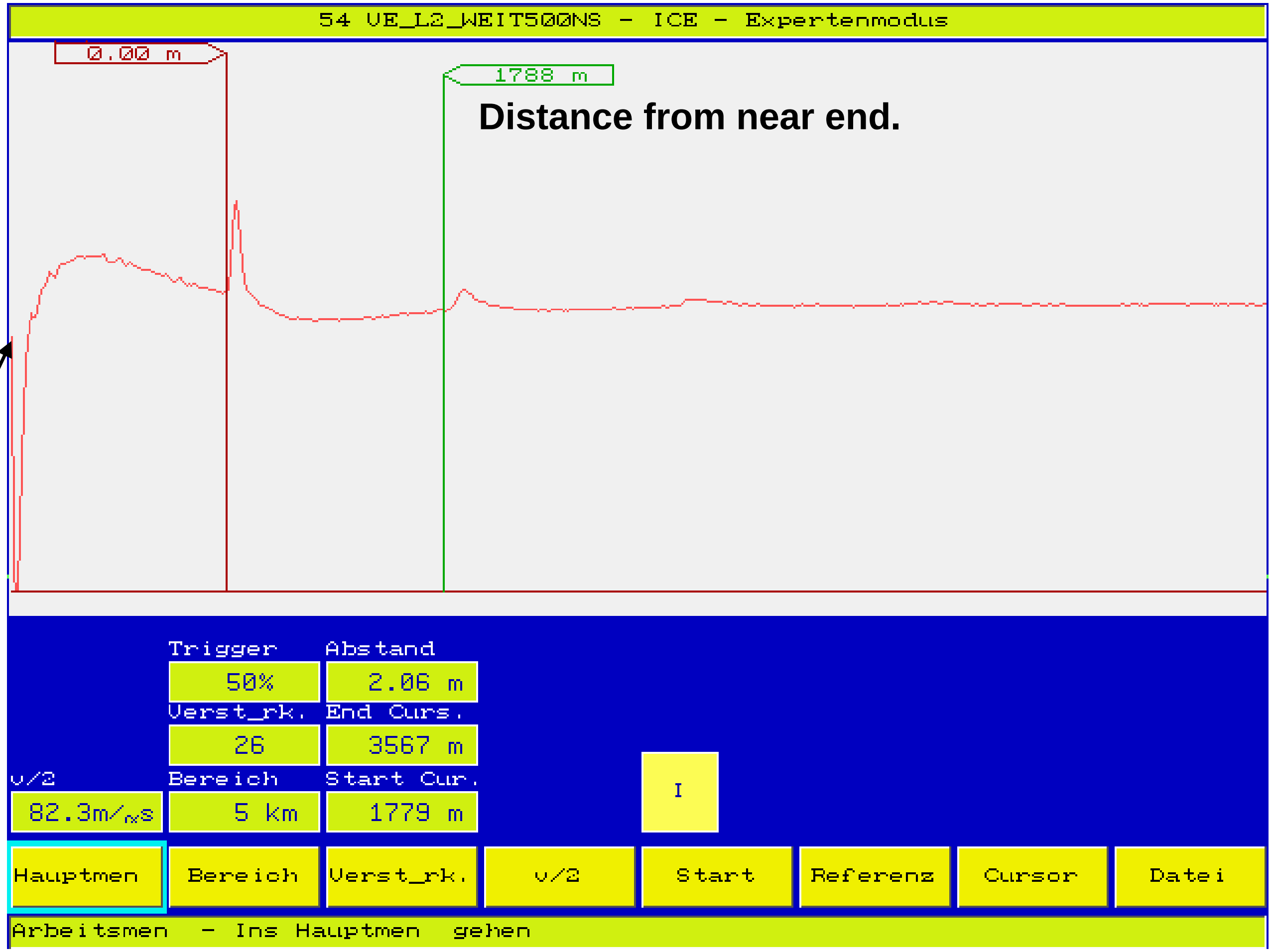
Polarity of first pulse depending on direction of sensor.



Partial Discharge Diagnosis – Pin-pointing

PD-Loc

Polarity of first pulse depending on direction of sensor.

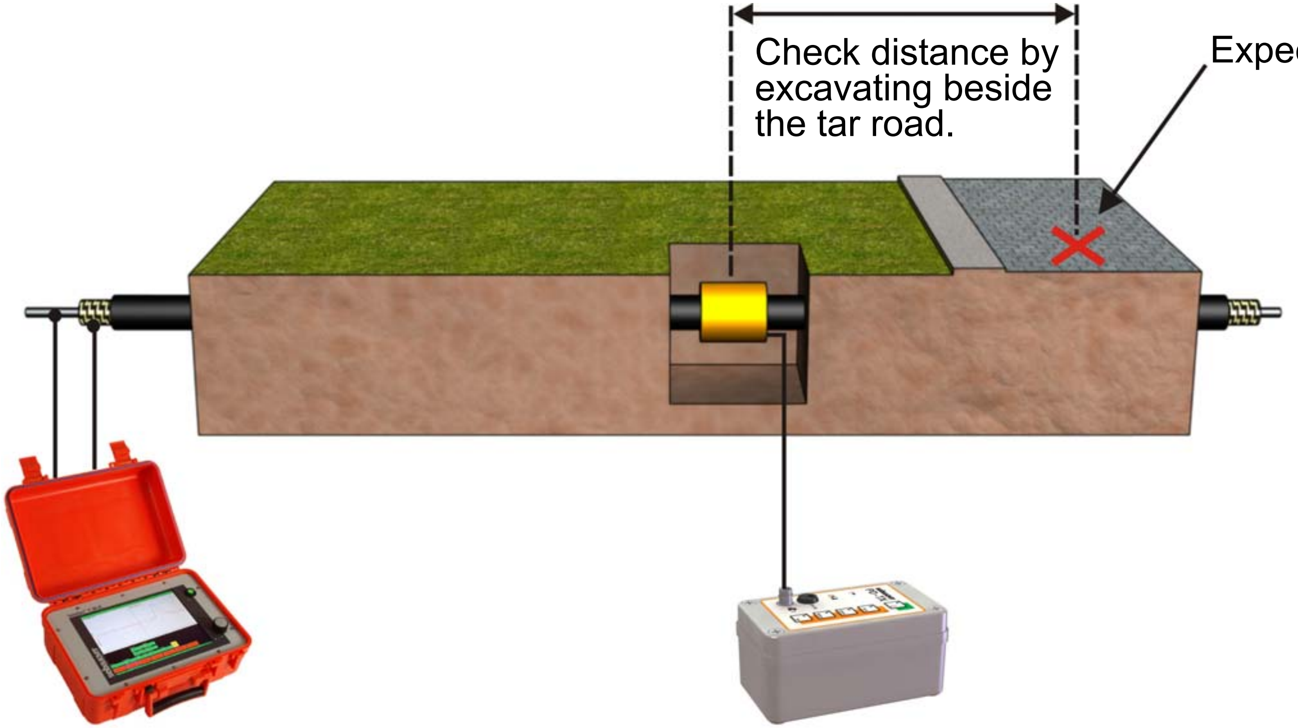


Partial Discharge Diagnosis – Pin-pointing

PD-Loc

Practical example:

Save costs and time by leaving the tar road untouched.



Partial Discharge Diagnosis – Pin-pointing

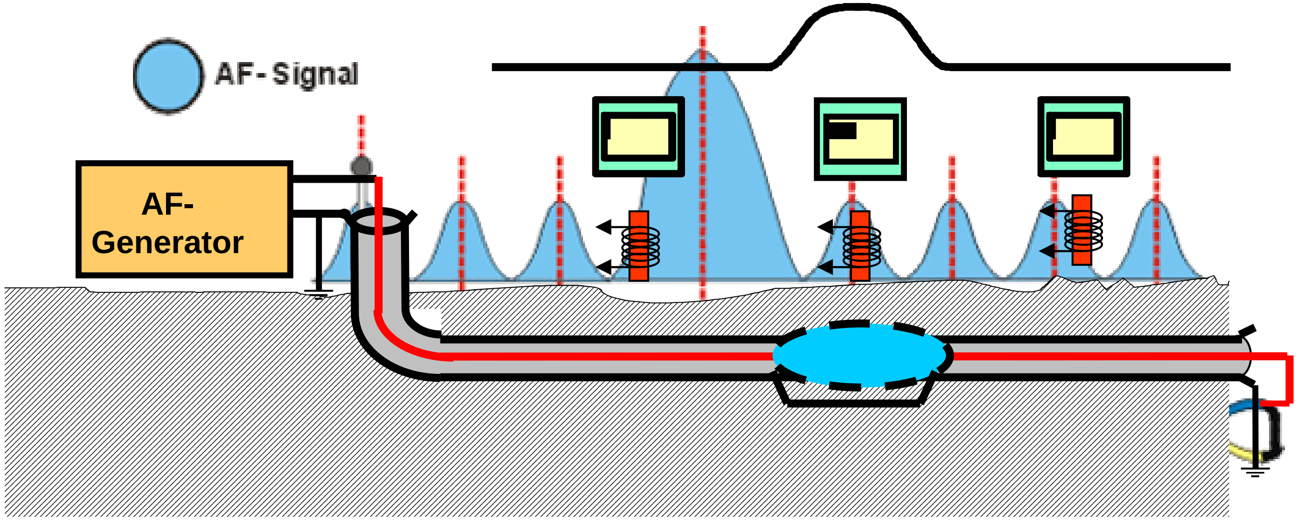
Audio-frequency

The other possibility is using the audio-frequency methods:

-Twisted-field method in case of PILC or 3-core XLPE cables;

-Maximum amplitude method in case of 1-core cables with unshielded joints.

Since most of the PD-spots are in joints the exact location can be found, when the PD-spot is not in the joint then find the closest joint near the PD-spot and measure back.



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