Application of Damped AC Voltages for Testing Power Cables

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New installed / repaired cables

e.g.

- Knife cuts;
- Contamination (dust, grease, sand);
- Wrong dielectric field distribution (field enhancement) inside accessory as a result of missing or wrong materials;
- Mechanical damages as a result of wrong tools;
- …….

Serviced aged cables

e.g.

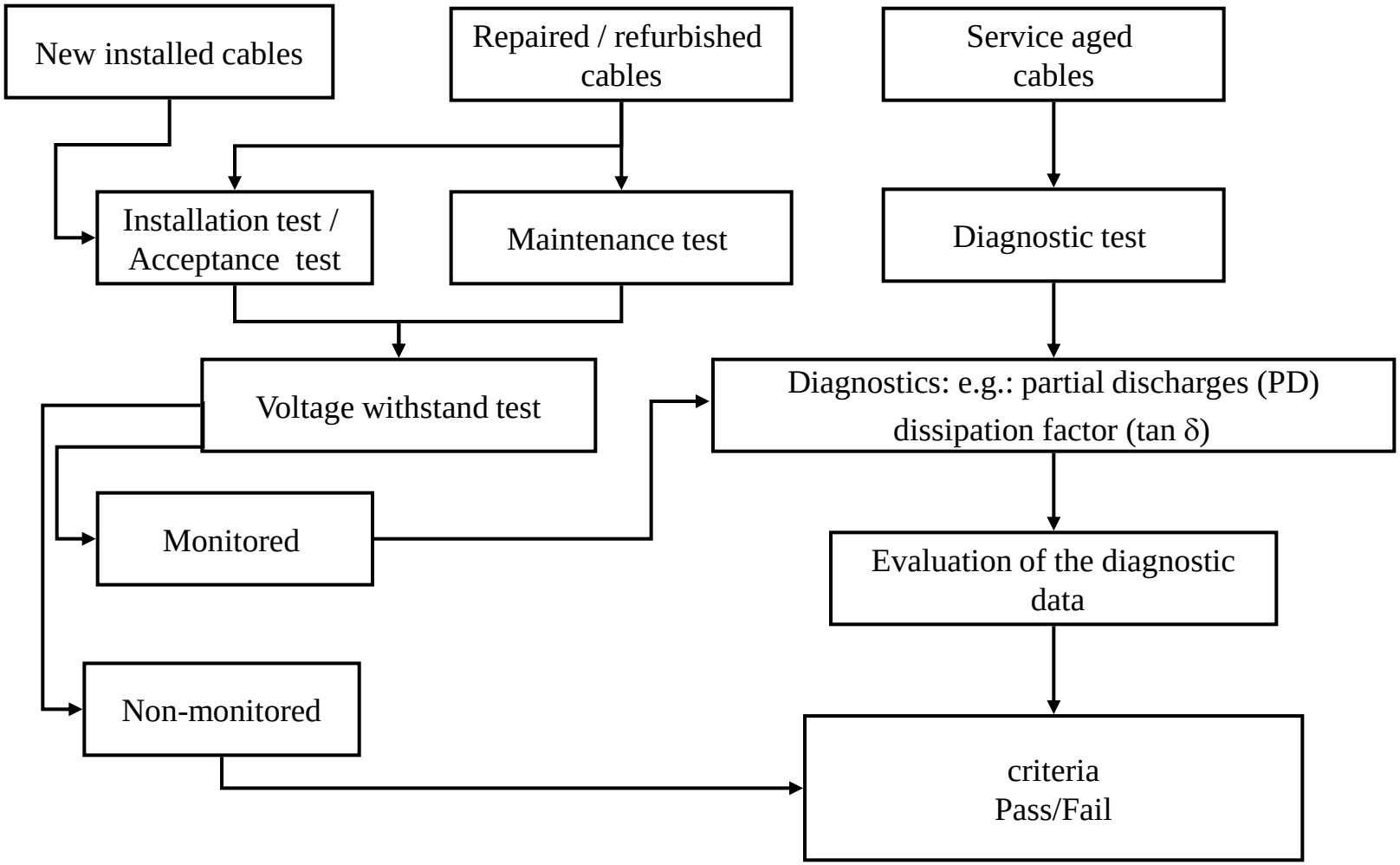
- Paper delaminating;
- Cracks and voids;
- Movement of cable due to contraction, soil topological changes;
- Oil leakages and dry out of insulation;
- Impregnating oil contamination;
- Under high temperature decomposition of cellulose bonds resulting in decrease dielectric strength of insulation;
- ……

‘’Quality / system integrity of the cable circuit’’

‘’Availability / reliability of the cable circuit’’

For more details see Cigre WG B1.04, Cigre Brochure 279

Types of on-site electrical tests on power cables using damped AC (DAC)



Basic consideration of voltage withstand HV test

1. Withstand HV test is the most fundamental of all electric tests on cable insulation and since the test voltage is higher than the rated voltage it is considered as an over-voltage test.

2. It has been introduced many years ago (to find serious insulation defects) because the over-voltage test was the only available electrical test.

3. A breakdown of the insulation may occur on the insulation weak-spot and it can be sometimes accompanied by pre-breakdown phenomena (in-homogeneity with local high E-field) -> partial discharges.

4. The test shall be designed in such a way that the life time consumption due to the on-site test of a healthy insulation is negligible, whereas the impact on that of a defective insulation is high enough to cause a breakdown.

5. A healthy (defect-free and/or non-aged) insulation can withstand high level of voltage stresses and insulation which is aged and/or consists of insulation defects should have lower level of withstand voltage.

6. Due to higher than operational voltage stresses the test may be destructive even if no failure has occurred. Moreover due to the fact that the duration of the over-voltage is arbitrary selected e.g. 10 minutes it can not be excluded that after 11 minutes a failure will occur.

Effectiveness of routine HV withstand testing

Type of insulation defect		Example	Failure type	Breakdown test effectiveness / PD presence effectiveness		
				AC	DAC	24Uo
A.	Homogenous	e.g. less or no insulation, moisture	Breakdown depends on test voltage level and not on the duration; No partial discharges	/ --	/ --	/ - **
B.	Weak inhomogeneous	e.g. missing field grading	Not necessary a breakdown; possible partial discharges	/ -+ *	/ -+ *	/ - **
C.	Strong inhomogeneous	e.g. sharp edges, cavities, small installation defects	Possible breakdown; Partial discharges	/ ++ *	++ *	/ -+ **

* If no PD -> than no breakdown -> Type A insulation defect

** The breakdown voltage has to be ≤ Uo

State of the art

Cable type			DC	VLF 0.1 Hz	AC 20-300Hz	DAC 20-300 Hz
MV (6kV ….36 kV)	**XLPE**	Installation test / Acceptance test	**No**	**Yes***	**Yes**	**Yes**
		Maintenance test / Diagnostic test	**No**	**Yes***	**Yes**	**Yes**
	PILC	Installation test / Acceptance test	**Yes**	**Yes**	**Yes**	**Yes**
		Maintenance test / Diagnostic test	**Yes**	**Yes**	**Yes**	**Yes**
(E) HV (36 …..500 kV)	**XLPE**	Installation test / Acceptance test	**No *****	**No ******	**Yes**	**Yes**
		Maintenance test / Diagnostic test	**No *****	**No ******	**Yes**	**Yes**
	Oil-filled	Installation test / Acceptance test	**Yes**	**No ******	**Yes**	**Yes**
		Maintenance test / Diagnostic test	**Yes********	**No ******	**Yes*********	**Yes*********

Internationally not recommended | Internationally recommended

* Partial discharge (PD) inception voltage (PDIV) can be different as compared to continuous and damped AC stresses

** according to

IEC 60840 Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) Test methods and requirements.

IEC 62067, Standard Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um

*** according to

Recommendations for a new after laying test method for HV extruded cable systems CIGRE 1990, Paris, paper 21-105

CIGRE WG 21-09; After-laying tests o HV extruded cable systems; Elektra 173, August 1997

**** according to

IEEE P400.1 Guide for Field-Testing of Laminated Dielectric, Shielded Power Cable Systems Rated 5kV and above with High Direct Current Voltage.

***** according to

IEC 60141 Tests on oil-filled and gas-pressure cables and their accessories up to and including 400kV;

Recommendations for power cables up to 500kV

VOLTAGE shape and duration:
…… The AC test voltage to be applied shall be subject to agreement between the purchaser and the contractor. **The waveform shall be substantially sinusoidal and the frequency shall be between 20Hz and 300Hz.** The voltage shall be applied for …… either with a voltage according to ……, depending on practical operational conditions.

Monitored Testing:
If possible for HV circuit PD measurements parallel to voltage test can be applied [TB CIGRE D1.33, IEEE 400]

Rated voltage [kV]	Uo [kV]	Vt [kV]	N x Uo
6	*3.6*	*9*	*1.7-2.5*
10	*6*	*15*	*1.7-2.5*
15	*8.7*	*22*	*1.7-2.5*
20	*12*	*30*	*1.7-2.5*
30	*18*	*45*	*1.7-2.5*
45-47	26	52	2
60-69	36	72	2
110-115	64	128	2
132-138	76	132	1.73
150-161	87	150	1.73
220-230	127	180	1.42
275-287	160	210	1.31
330-345	190	250	1.32
380-400	220	260	1.18
500	290	320	1.1

[**IEC60502** Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) - Part 1: Cables for rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV)]

[**IEC 60840,** Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) Test methods and requirements]

[**IEC 62067**, Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) - Test methods and requirements.]

Importance of monitored voltage testing

1. AC voltage withstand testing only is not always sufficient to identify all manufacturing and installation problems.

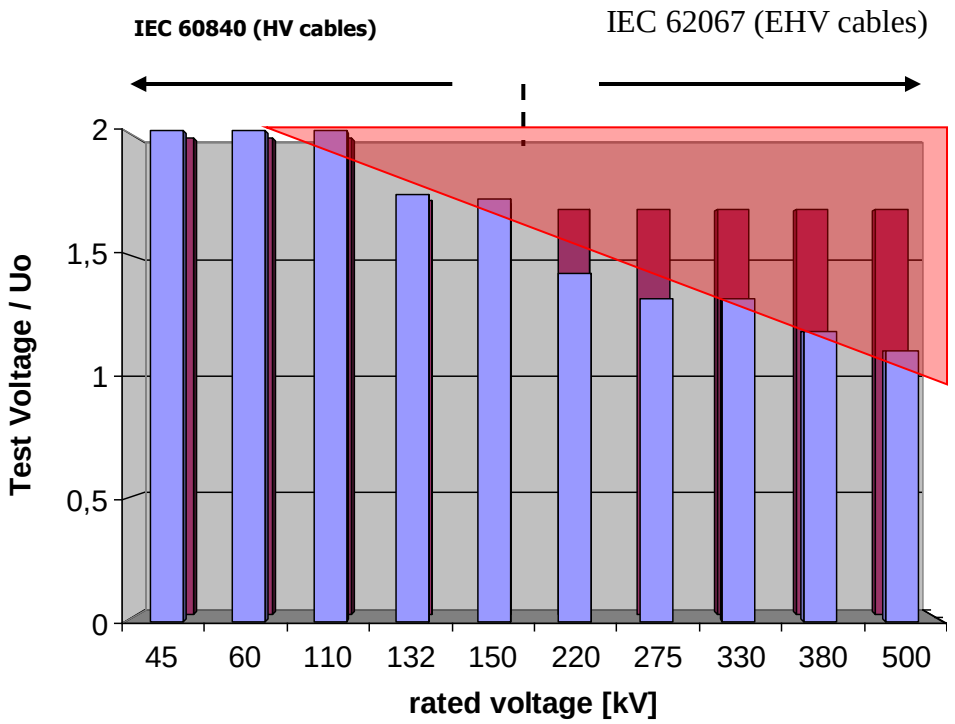
2. It has been observed that after successful voltage withstand tests, during initial operation failures may occur.

3. It has been found that insulation defects in the cable insulation and cable accessories are responsible for these failures.

4. To detect during after-installation testing those weak spots in the cable insulation and cable accessories monitored testing is now more and more the common practice.

[Ref1] Practical aspects of on-site testing and diagnosis of transmission power cables in China, CMD2010
[Ref2] Cigre WG D1.33 Technical Brochure *On-site testing and PD measurements*, (2010)
[Ref3] IEEE 400 Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5KV and Above.

Importance of monitored voltage testing



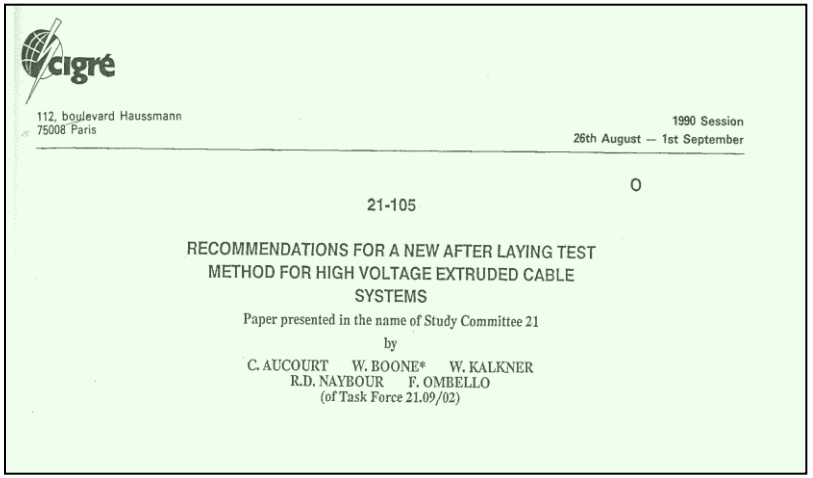
PD detection is an important parameter (monitored withstand testing)

- To limit the test voltage / test energy
- When a defect is present, the probability of breakdown increases with the electric stress level
- EHV cable accessory → designed for high stress level

[Source, R. Bodega, Cigre Joint Colloquium D1/A1, Korea, 2007]

DAC voltage type equivalence to continuous AC voltages

[Ref] Aucourt, C., Boone, W., Kalkner, W., Naybour, R.D. Ombello, F. "Recommendations for a New After Laying Test Method for High Voltage Extruded Cable Systems." CIGRE Paper No. 21-105, August, 1990


cigré

112, boulevard Haussmann
75008 Paris

1990 Session
26th August — 1st September

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21-105

RECOMMENDATIONS FOR A NEW AFTER LAYING TEST METHOD FOR HIGH VOLTAGE EXTRUDED CABLE SYSTEMS

Paper presented in the name of Study Committee 21

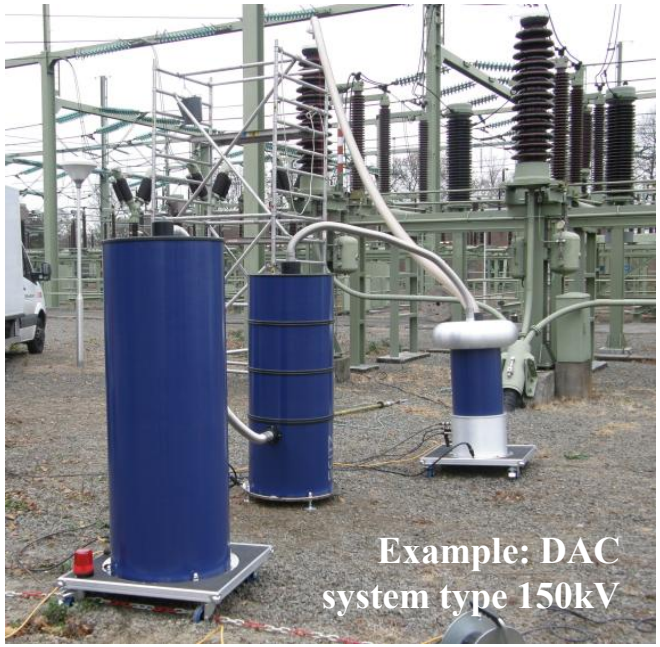
by

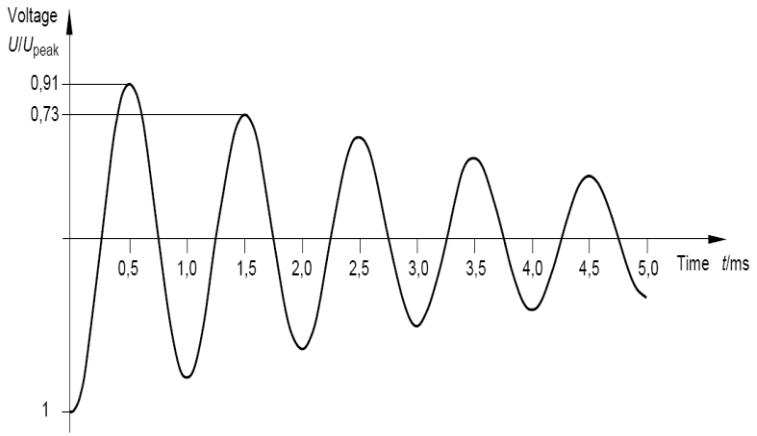
C. AUCOURT W. BOONE* W. KALKNER
R.D. NAYBOUR F. OMBELLO
(of Task Force 21.09/02)

1. Electrical stress versus withstand destructiveness:
   a) breakdown effectiveness for insulation defects**: AC and DAC are complementary /alternative methods,**
   b) harmless or harmful for defect free insulation: **is harmless for the dielectric, if no artificial defects are present,**

2. Influences of the DAC test parameters:
   a) DAC frequency: **no significant effect**
   b) the damping rate: **does not play an important role**
   c) number of excitations: **appears to be an important parameter; the breakdown voltage decreases as the number of shots increases e.g. 50 excitations** was found to be a representative number
   d) charging time: **does not seem to have an important effect**

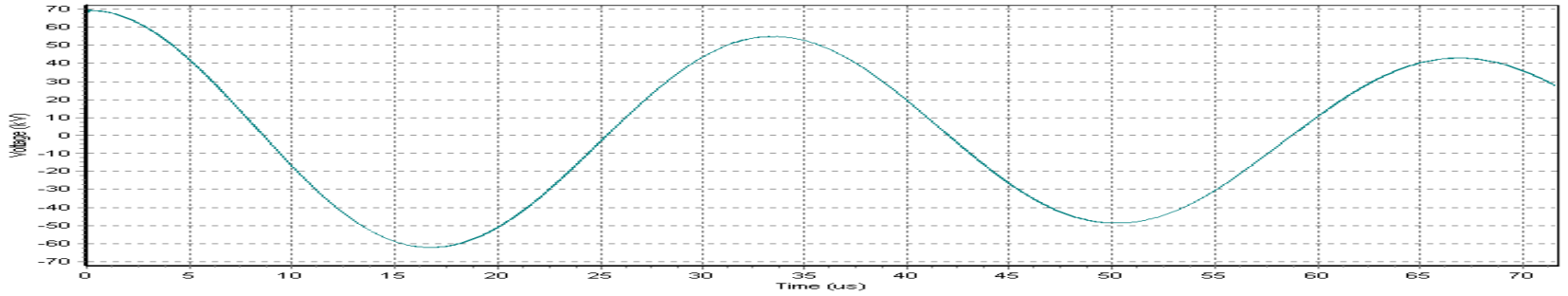
Damped AC Voltages





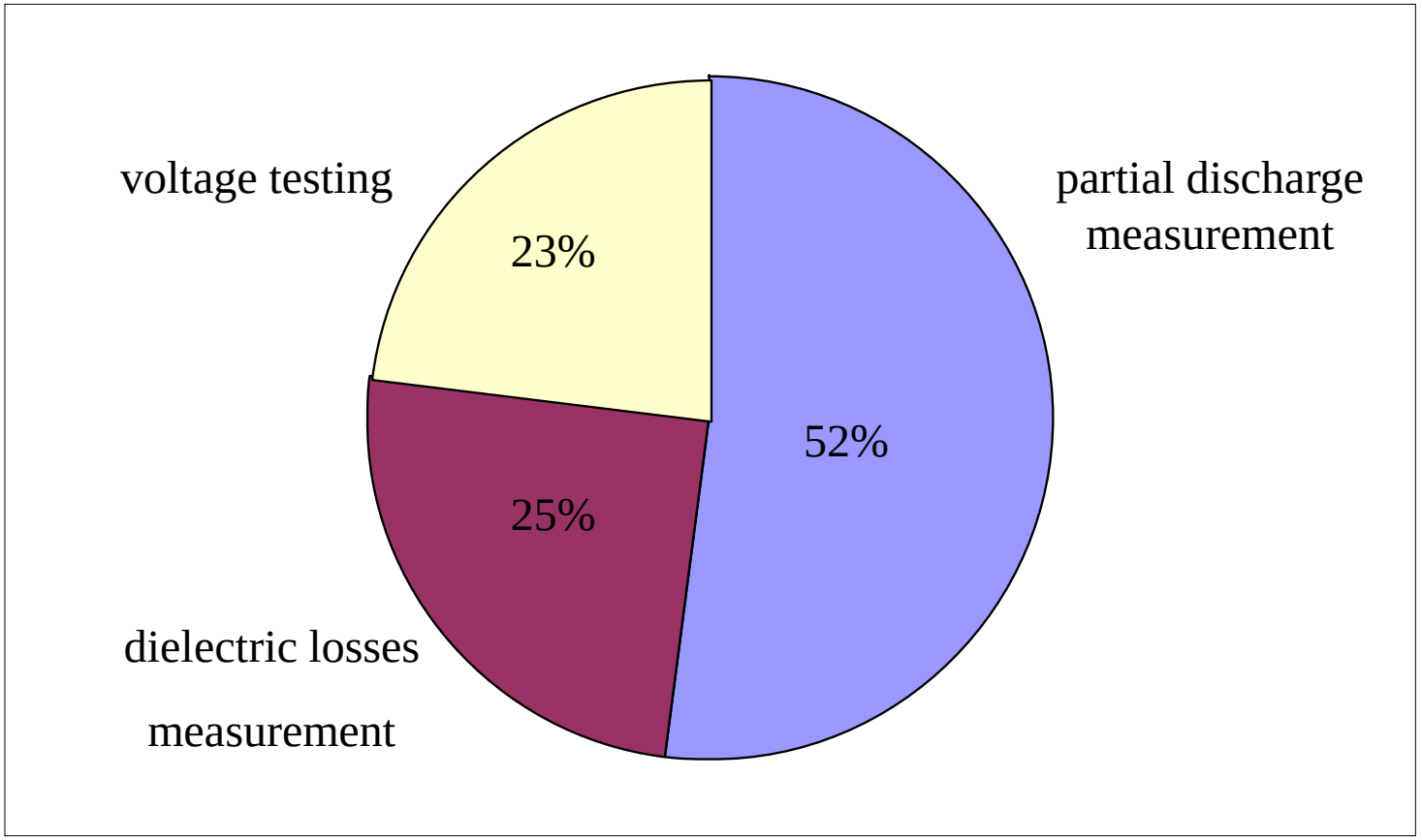
IEC 60060-3 Damped alternating voltage

The damped alternating voltage (dac) is an oscillating switching impulse voltage (OSI) of quite low damping and a frequency in the range of 20Hz up to 400Hz



International survey about using damped AC voltages (2007)

Purpose of testing using DAC voltages



Relevance of combining PD test and the voltage test

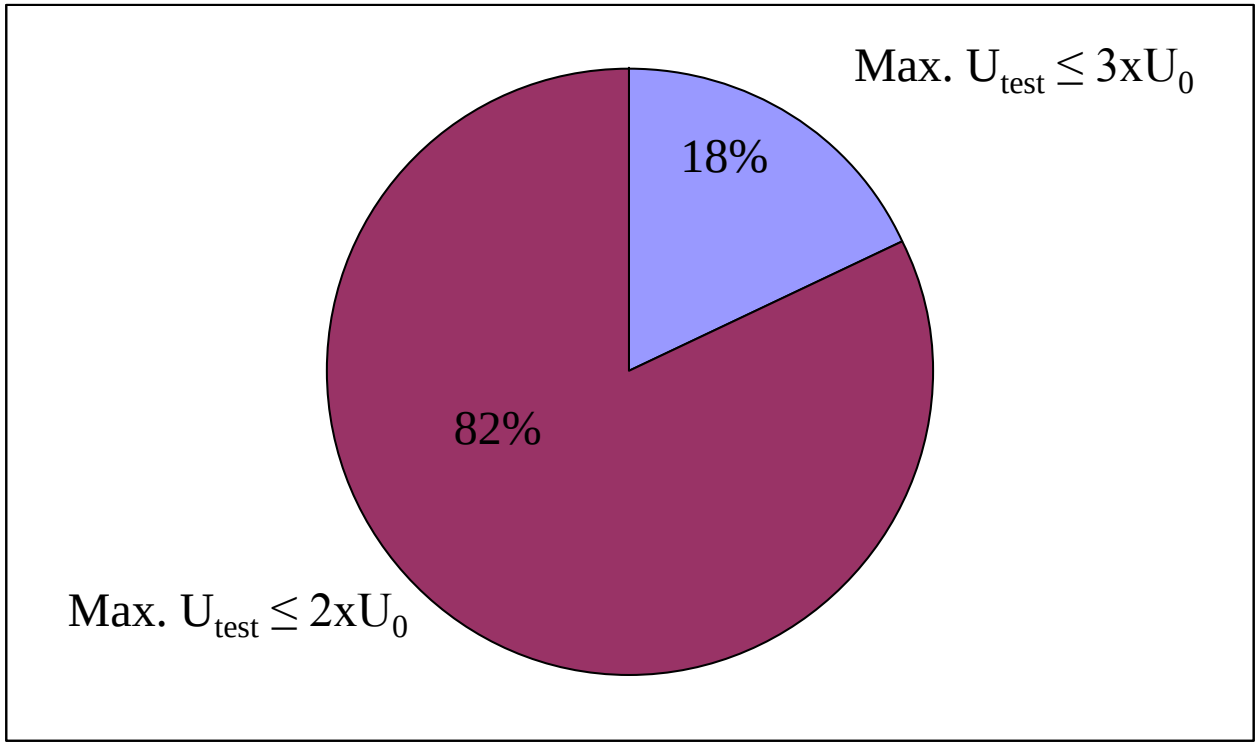
Yes: 50%

No: 50%

[Ref] IEEE PES Insulated Conductor Committee Spring 2008 Meeting, Minutes F05D Damped AC Voltages Testing

International survey about using damped AC voltages (2007)

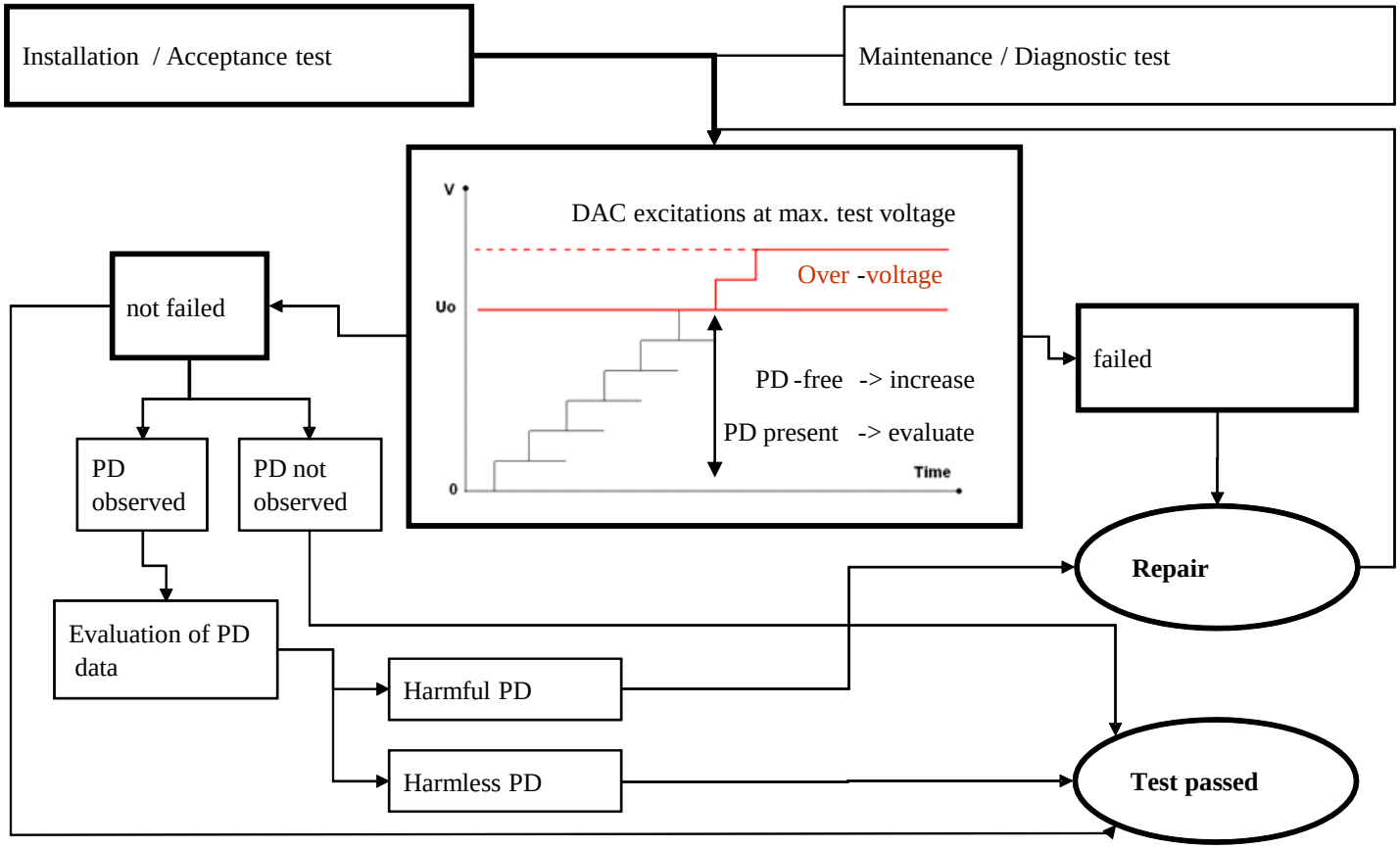
Voltage testing



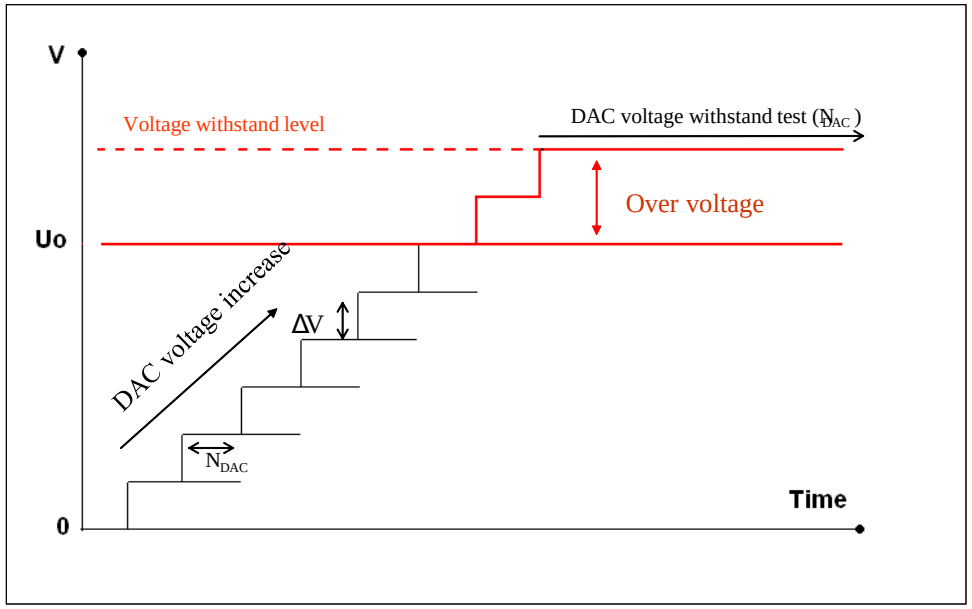
Breakdown during voltage testing:	0% …. 2%
Before breakdown PD has been measured:	81%

[Ref] IEEE PES Insulated Conductor Committee Spring 2008 Meeting, Minutes F05D Damped AC Voltages Testing

On-site electrical tests using damped AC voltages



On-site electrical tests using damped AC voltages



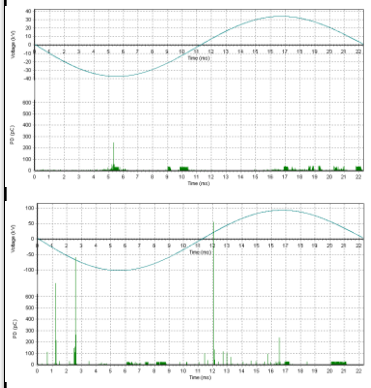
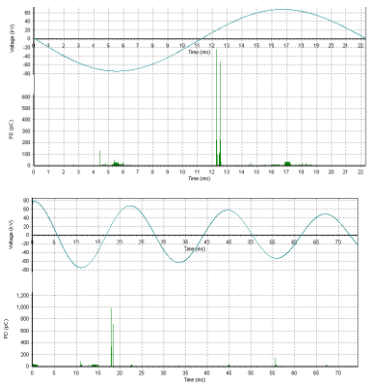
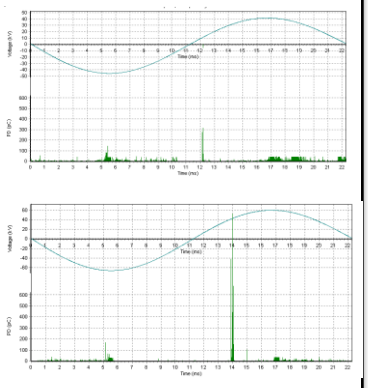
the number of DAC excitations is in accordance to Cigre 21.09/02 and IEEE 400 documents or conform the IEC recommendations on time duration [IEC 60502, IEC 60840, IEC 60027]

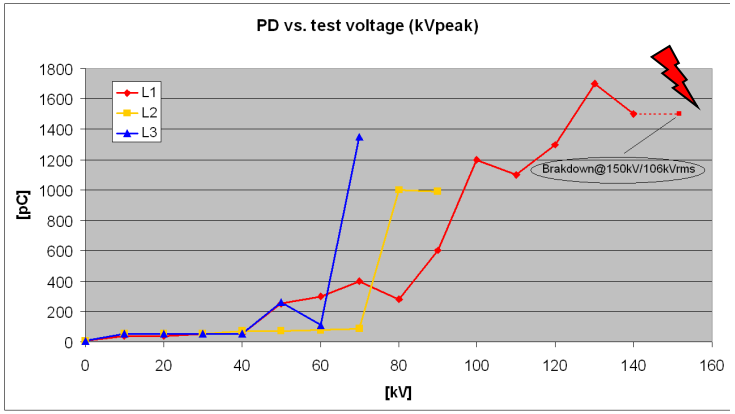
Power cable rated voltage	Ref	(*) DAC voltage test level Installation / Acceptance test	(*) DAC voltage test level Maintenance test
< 30kV	IEC 60502	Max. 2.5….1.7xUo	In general i has to be lower than acceptance test e.g. 80%
30kV-150kV	IEC 60840	Max. 2.0…1.7xUo	
150kV-500kV	IEC 60067	Max. 1.7…1.1xUo	

Example 1 (monitored withstand test)

132kV XLPE (1st test)

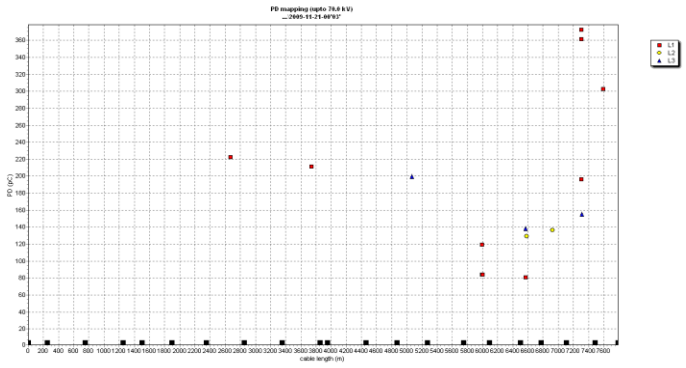
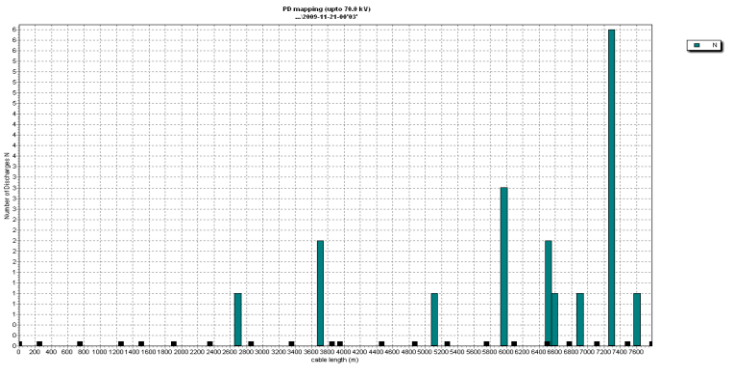
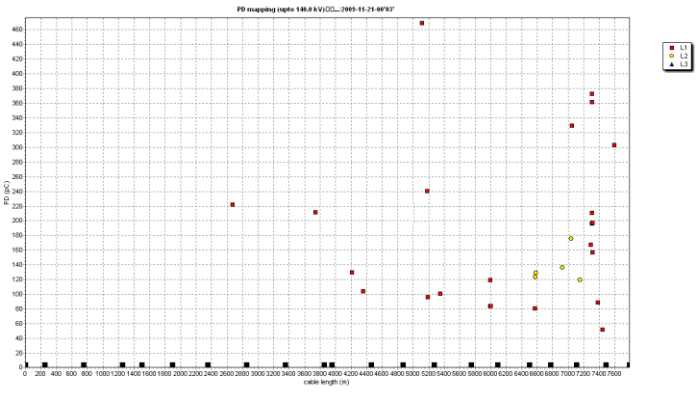
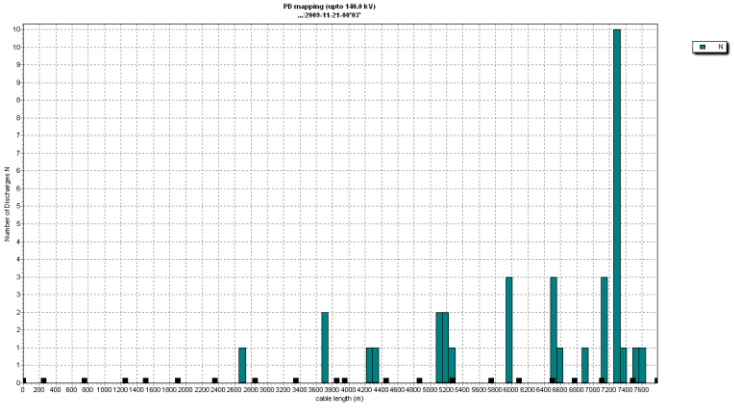
Installation year: 2009
Cable length: 7700m
Operation voltage: Uo= 76kVrms
Damped AC frequency during test: 44Hz
Cable capacitance (one phase): 1.64uF

L1 (PDIV @ 0.5xUo)	L2 (PDIV@0.75xUo)	L3 (PDIV@0.5xUo)
		



132kV XLPE (1st test)

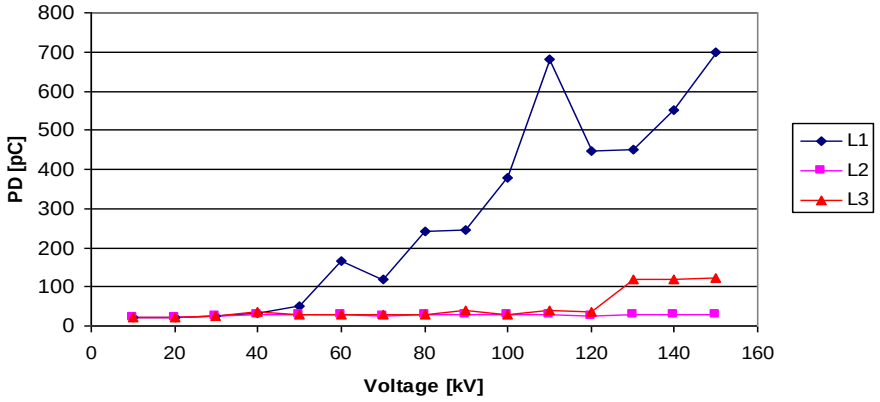
PD mappings and histograms:

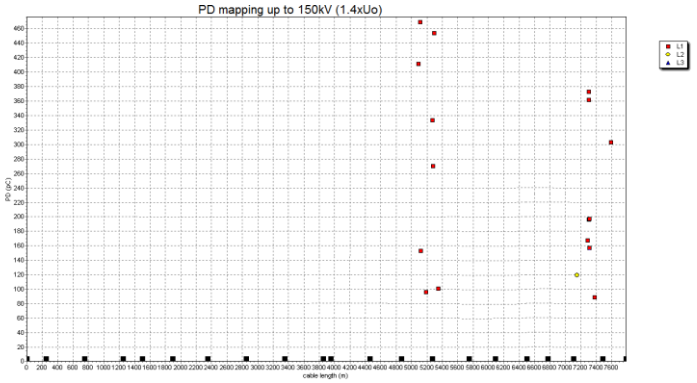
Voltage	PD Mappings	PD Histograms
70kV		
110kV		

Example 1 (monitored withstand test)

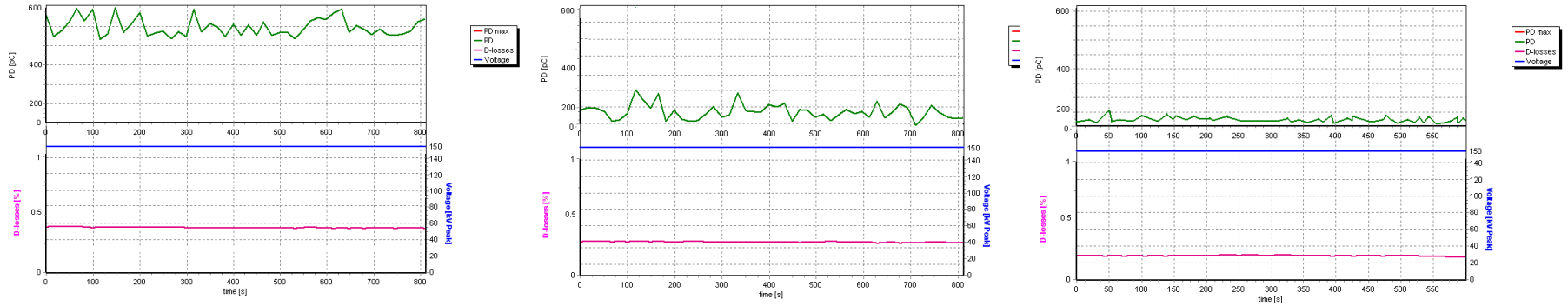
132kV XLPE (2nd test after repair)

PD measurements results (after repair):





Voltage Withstand Test @ 1.4xUo (50 excitations-30min per phase):

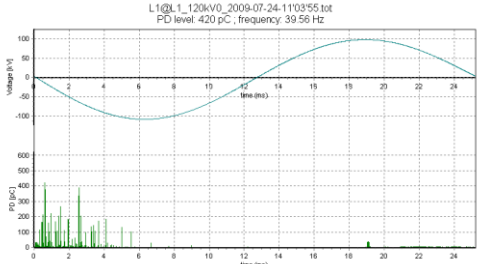


Voltage Withstand Test passed by three phases; in L1 PD were localized

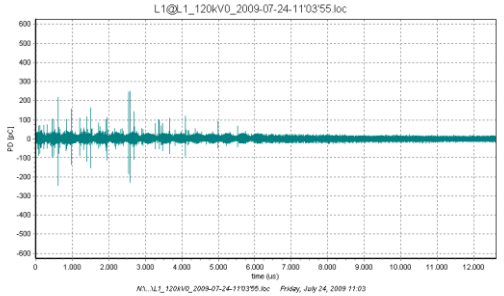
Example 2 (maintenance test)

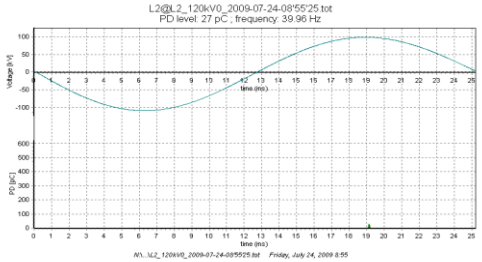
Testing 110kV external gas- pressure cable circuit (2.2 μF), length 8.5 km using damped AC voltages (40 Hz)

Example 2 (maintenance test)

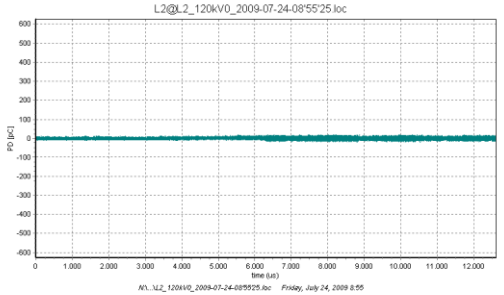


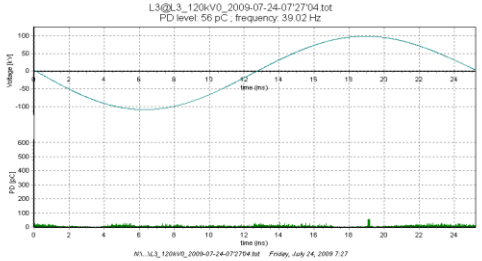
L1



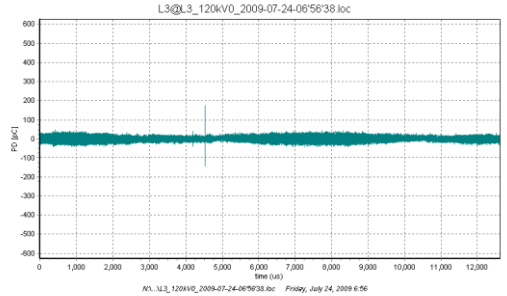


L2



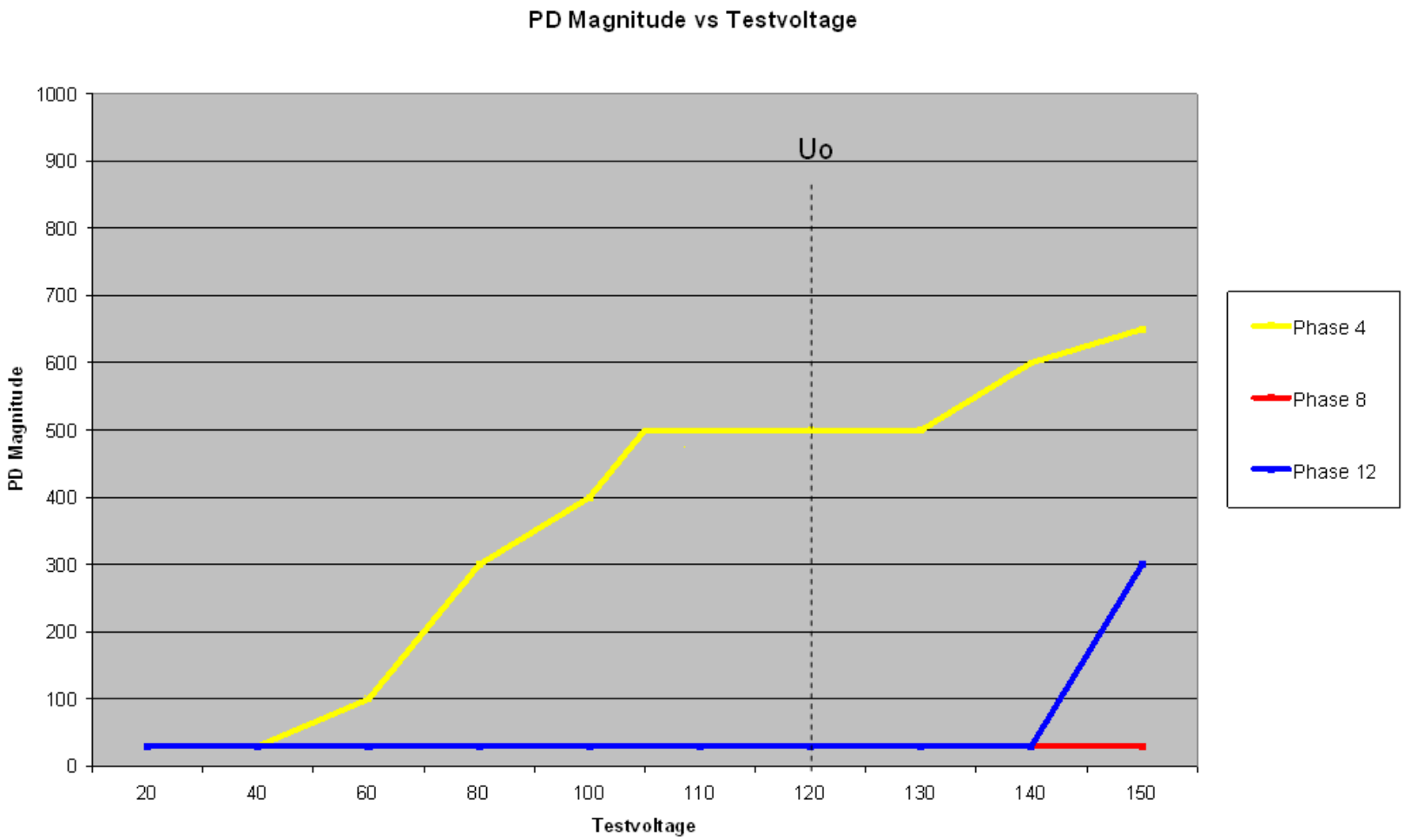


L3



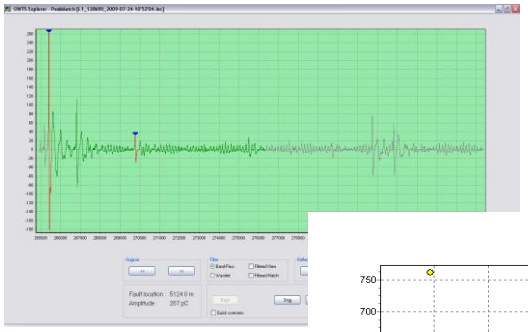
PD at Uo diagnostic results:
left: IEC 60270 phase revolved PD pattern, right: HF PD pulse sequences

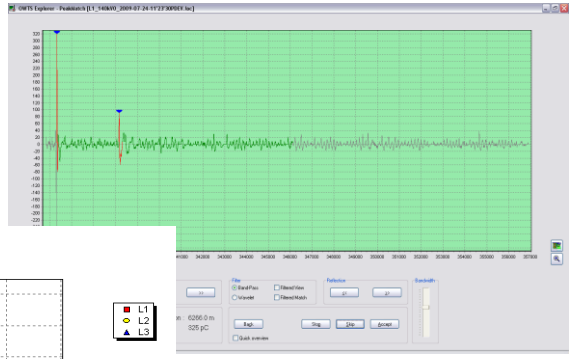
Example 2 (maintenance test)

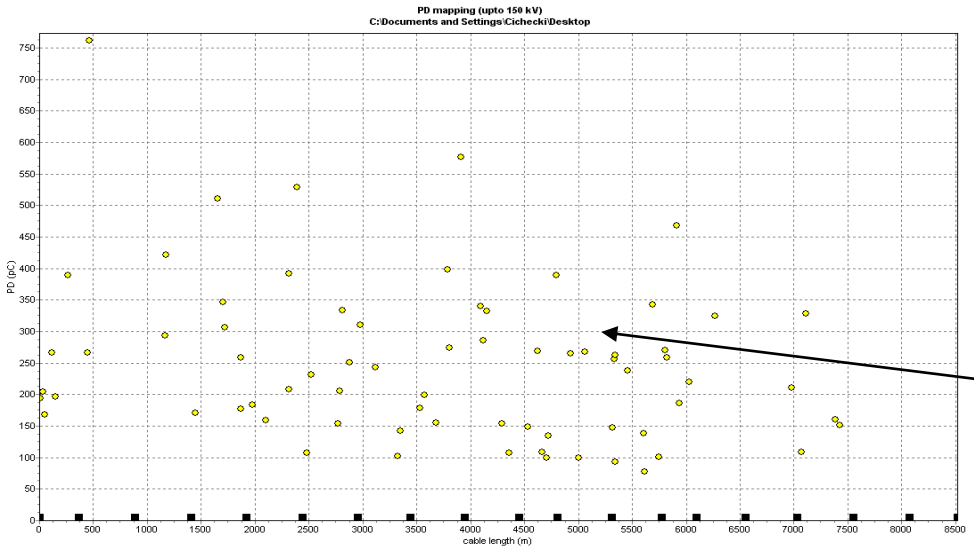


Phase 4 (yellow) shows different behavior as compared to other phases:
at Uo voltage PD activity has been observed.

Example 3 (maintenance test)



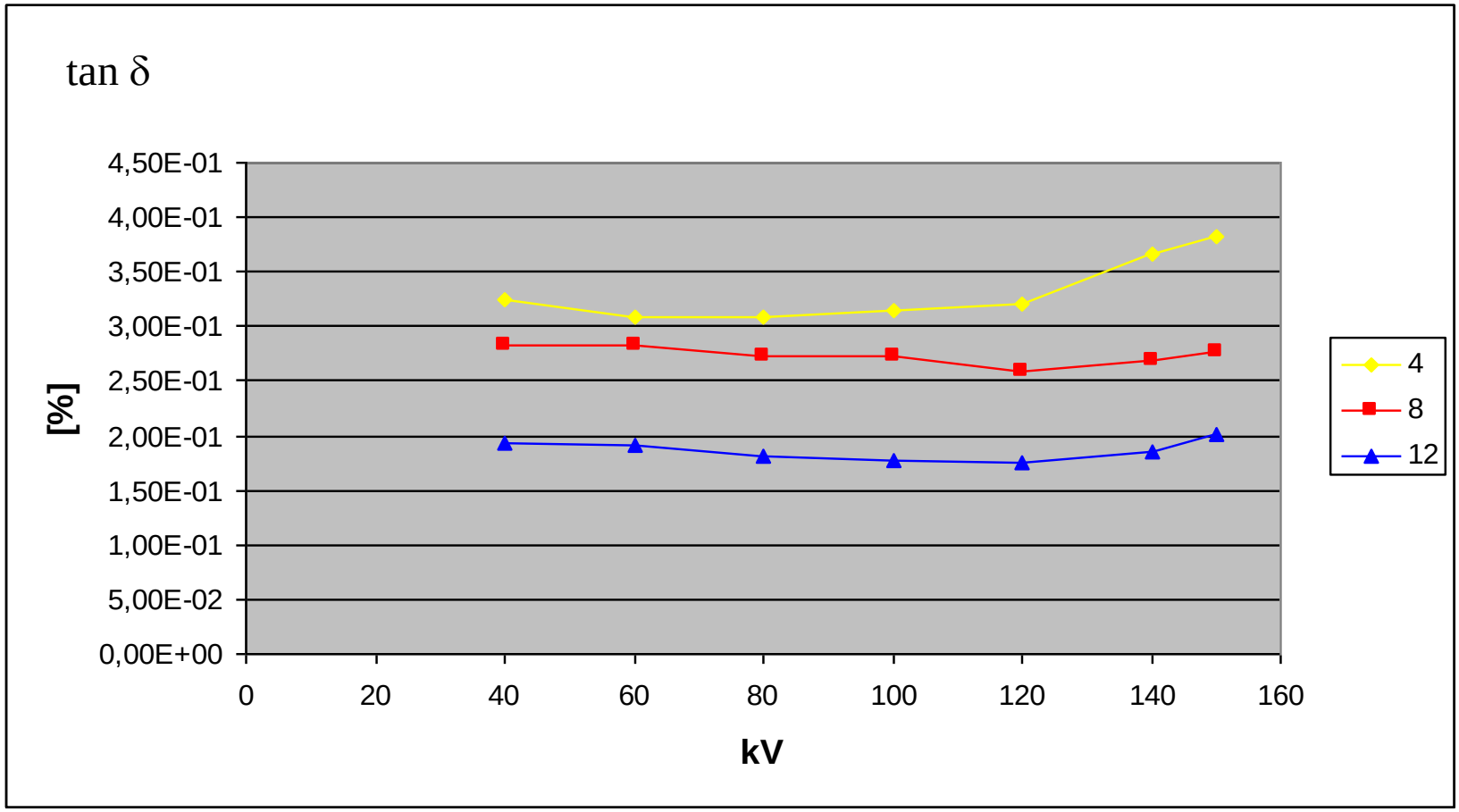




TDR analysis of data from phase 4 (yellow) shows that there are no significant concentrations of PD activity in the cable insulation and cable accessories.
A number of PD-pulses have been localized in the total length indication distributed characteristics.

Example 2 (maintenance test)

Testing 110kV external gas- pressure cable circuit (2.2 μF), length 8.5 km using damped AC voltages (DAC 40 Hz)



Difference in tanδ value between phase 4(yellow) and phase 12(blue) is about 0,15%.

Conclusions

1. On-site testing is important for new installed, repaired and service aged power cable circuits.

2. The effectiveness of withstand voltage testing (Criteria Pass/Fail) depends on type of a particular defects and the over-voltages stress.

3. According to newest development monitored voltage withstand testing is becoming more and more a common practice.

4. For testing HV and EHV cables in addition to continuous AC test voltages also damped AC voltages can be applied.

5. Regarding breakdown and as compared to continuous AC voltages in case of inhomogeneous defects (PD present) damped AC voltages can be less destructive.

6. It is recommended due to (5) to perform damped AC voltage testing as monitored testing (PD).

Example: DAC system type 350kV