High Voltage Tests and Diagnostics in Cables: case studies

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TechImp

Key words:

Electric power supply/ asset management

- QUALITY
- MAINTENANCE
- RELIABILITY

AVAILABILITY MAINTEINABILITY

Financial damage

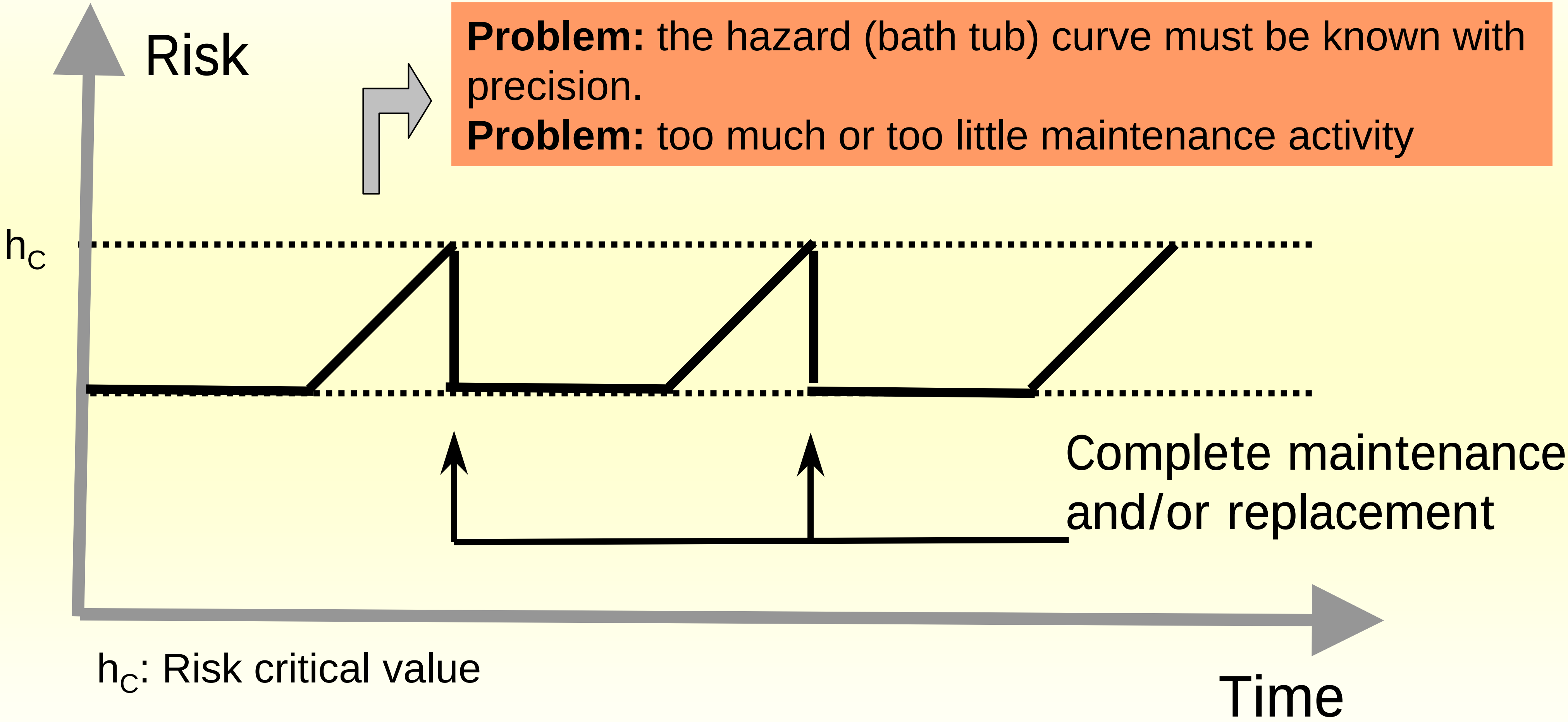
Damage=
failures/year*repairing costs +
failures/year*Mean Time to Repair*hourly revenues
+ lack of revenues

+ possible fines claimed by the Regulation Authority, associated with energy delivery quality (interruptions, etc.)

Investments in power quality → balance cost-saves

Maintenance effect
TBM: time based maintenance

Problem: the hazard (bath tub) curve must be known with precision.
Problem: too much or too little maintenance activity



h_C: Risk critical value

Diagnostic and maintenance (condition based: CBM)

- Best working conditions for a component or a system → minimum and constant hazard (risk) → but not optimised cost/benefit
- Knowledge of the start time of the aging process (3rd part of the bath tub curve) → Condition Based (and not time based) Maintenance → efficient diagnostic techniques are needed

Aging diagnostics

Diagnosis

Bulk degradation

(e.g. oxidation, polymeric chains scission, microcavities formation and enlargement, water treeing, etc.)

measurements of bulk properties e.g. space charge, polarization

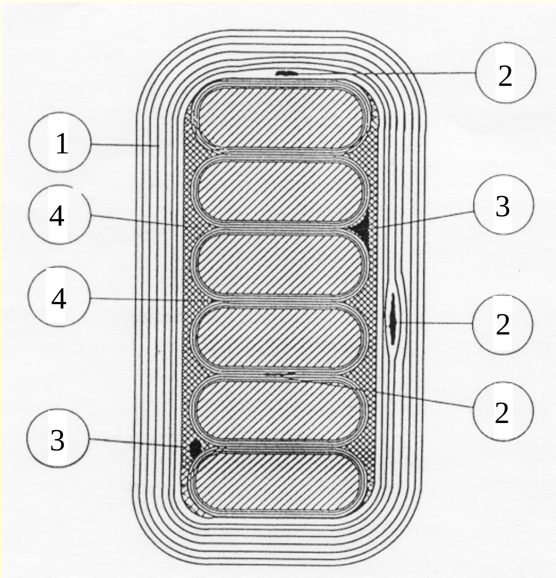
Local degradation

(defects e.g. protrusions, cavities, ...)

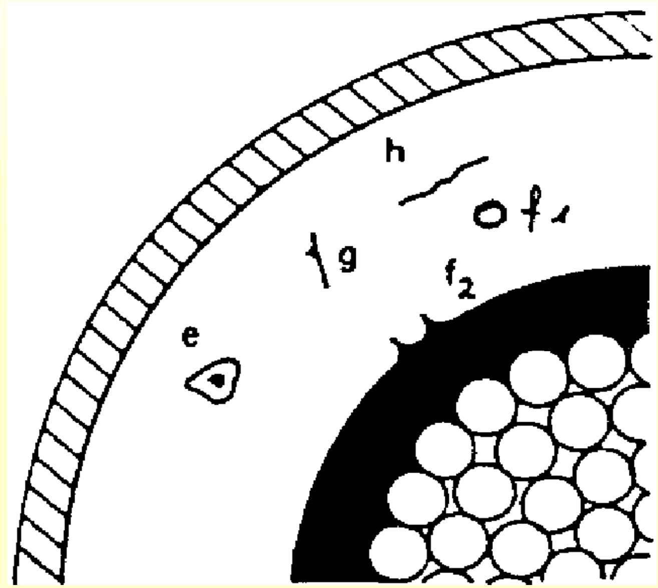
Measurements of localized phenomena (present in weak points), i.e. partial discharges

Aging Diagnosis

Examples of local defects/degradation



Stator Bar



HV Cable

1) Distributed Micro-voids
2) Delaminations
3) Poor impregnation
4) Copper/Stack Insulation detachments

e) Inclusions or alien particles

f1) Micro-voids

f2) Protrusions or points of the Semiconductive screen

g) Splinters

h) Fibers

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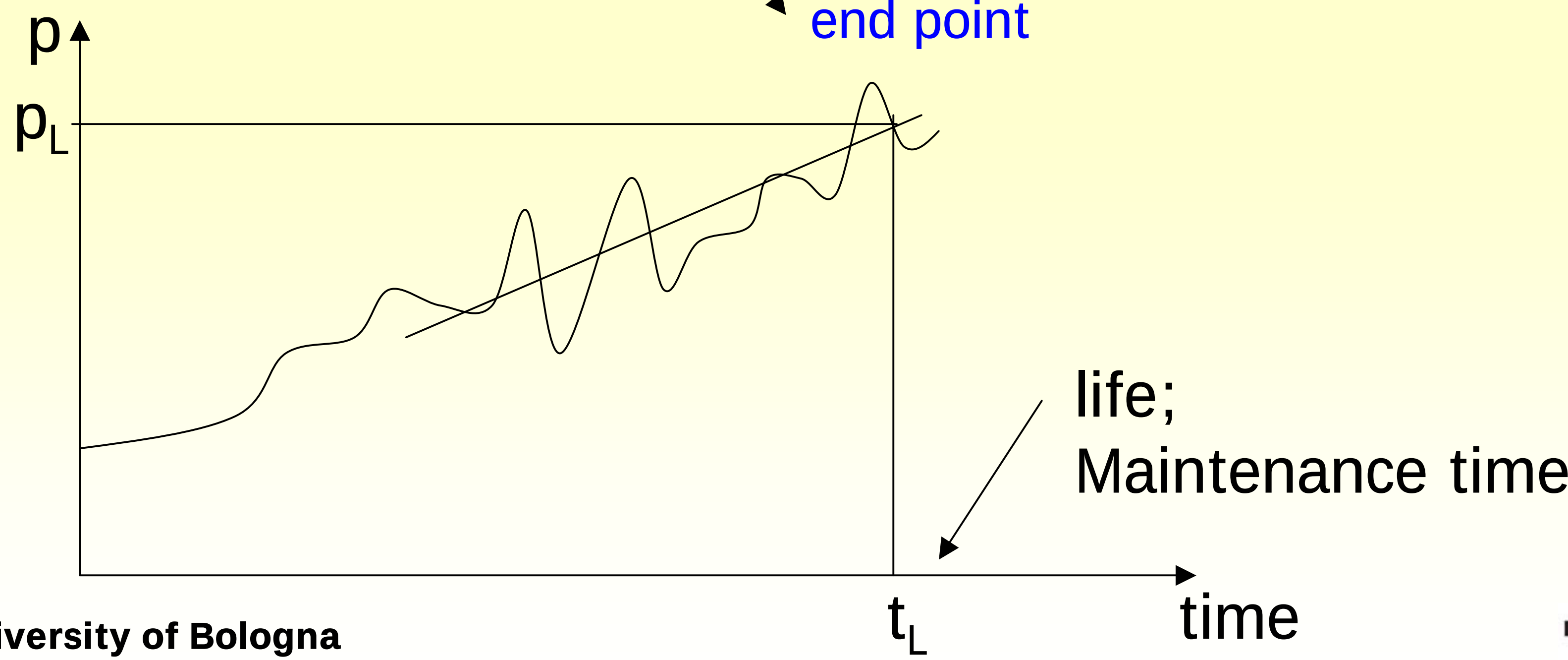
Diagnostic properties

and residual life estimation

Diagnostic properties

- Bulk or local properties
- trend with time under stress
- *off-line* vs. *on-line* measurements
- end point



Diagnostic Properties

ATTENTION!

- The estimated time to failure is related to the selected property, which can be different if global (bulk) or local aging is considered.
- The failure of solid insulation subject to electric stress is related to the failure of the weakest point: times to failure follow extreme values distributions
- However, in presence of considerable thermal and mechanical stresses, the bulk aging could have severe consequences even in case of low electric fields.

- Different maintenance time and residual life estimation in case the considered properties are local or global.

Diagnostic Approach

- **Quantities for bulk aging investigation (e.g. space charge, dissipation factor). They depend on global degradation, e.g.:**
  - **Oxidation**
  - **Chain scission**
  - **Environmental contamination, etc.**
- **Partial Discharge as property for local aging investigation:**
  - **Weak points**
  - **Formation or enlargement of cavities in the insulating system**
  - **Electric Tree**

together for a thorough diagnostic approach

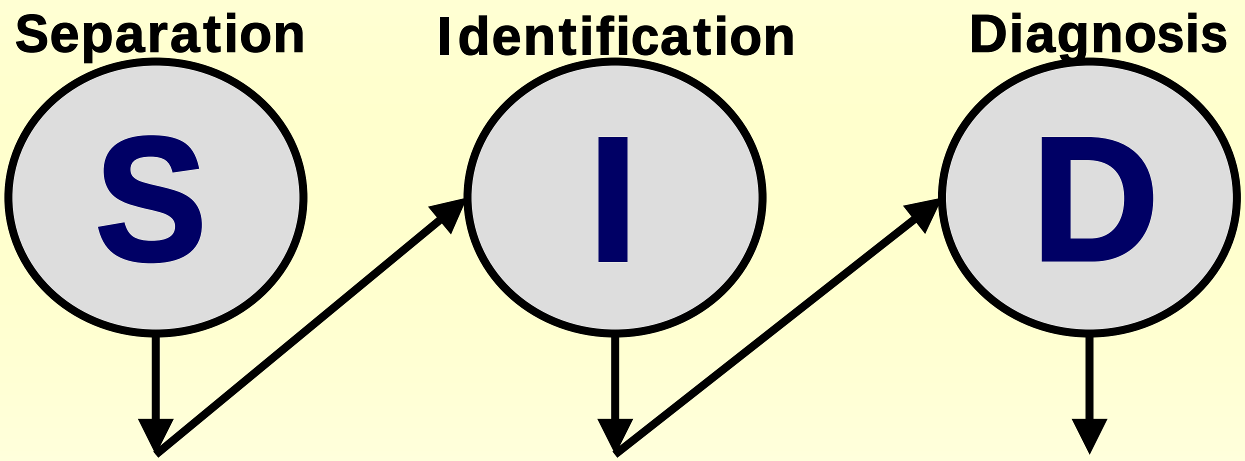
Diagnostic by means of Partial Discharge measurements

- Partial Discharges are symptoms (and cause) of the presence of defects in the insulating system.
- Effectiveness of PD measurement debatable → Effective PD inference shall be based on:
    - Acquisition of significant data (homogeneous and not affected by external noises);
    - Processing data with effective tools, estimating the values of diagnostic quantities, suitably selected (robustness);
    - Evaluating these quantities on the basis of physical understanding of the discharge mechanisms and available databases, using AI systems (no experts needed).

Diagnostic procedure:

INNOVATION

PD inference is the prerequisite for correct diagnosis

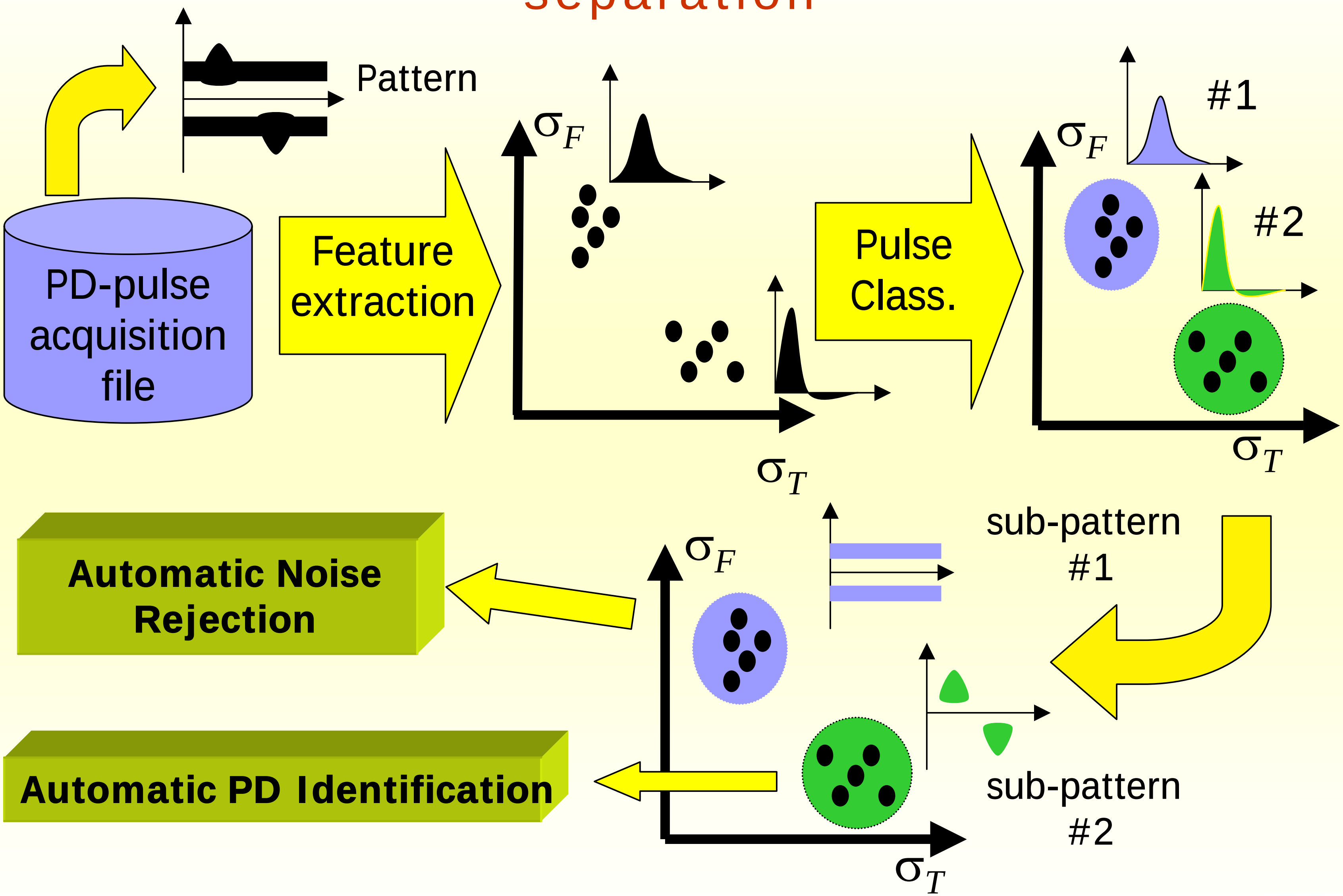


Separation
- Noise rejection
- Source separation

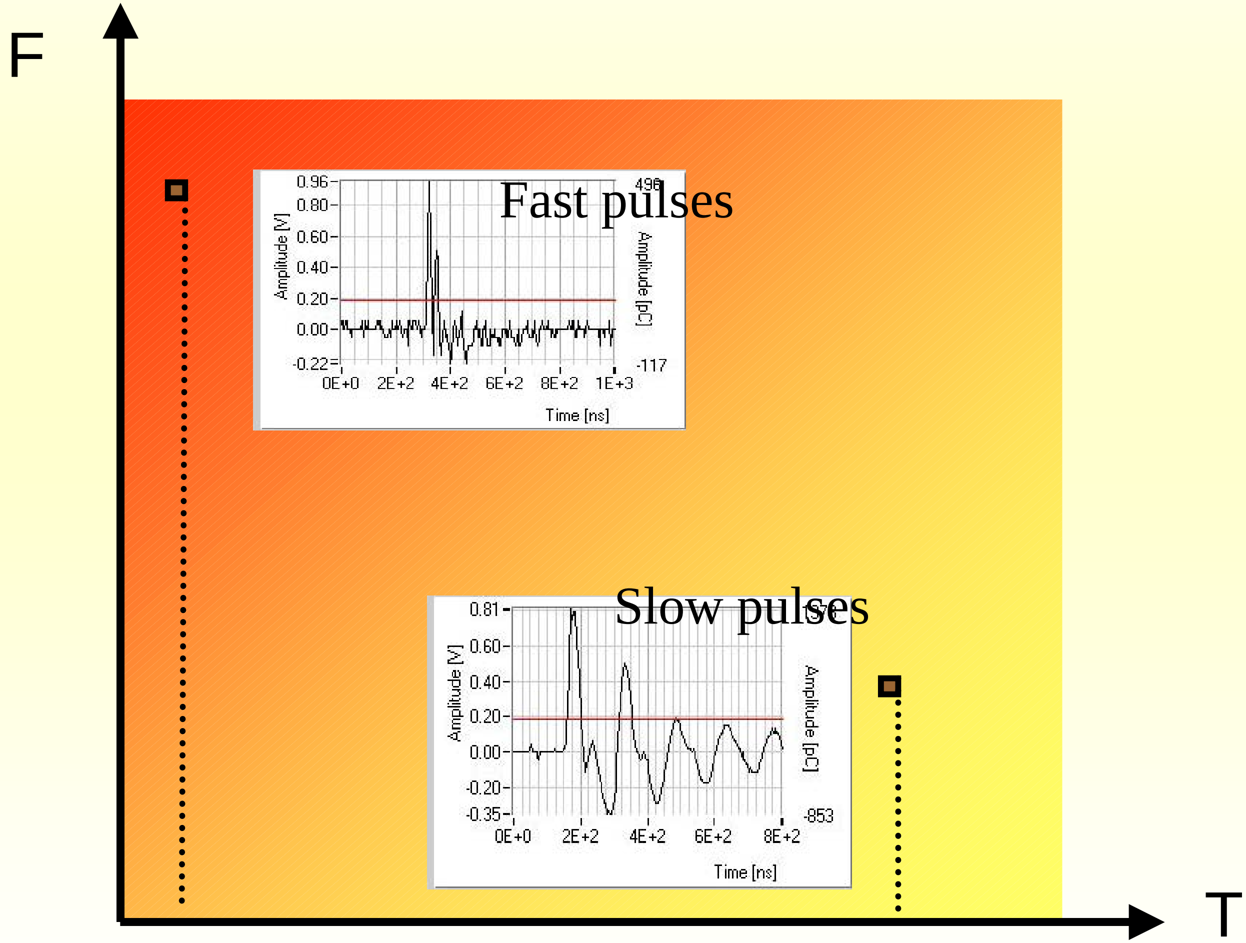
Identification
- Potential defect harmfulness (one source at a time)

Diagnosis
- Risk assessment
- Maintenance program
- Life extension (trend of the weakest spots, time to end point)

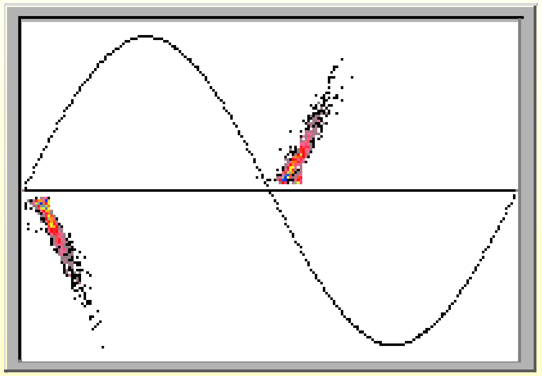
Innovative diagnostics by means of PD measurements: noise rejection and source separation



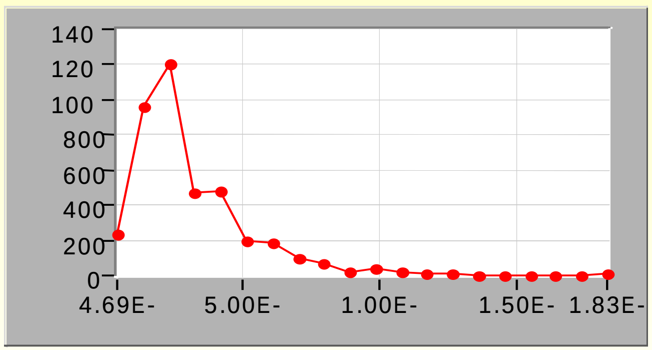
Separation (categorization) induced by TF mapping



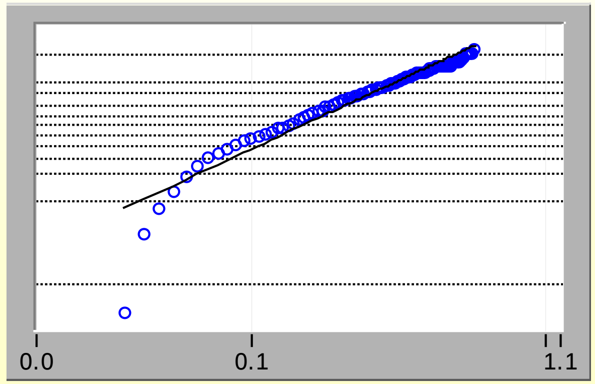
Statistical analysis and diagnostic quantity evaluation (robustness)



Acquisition Pattern



Discharge inter-time Distribution

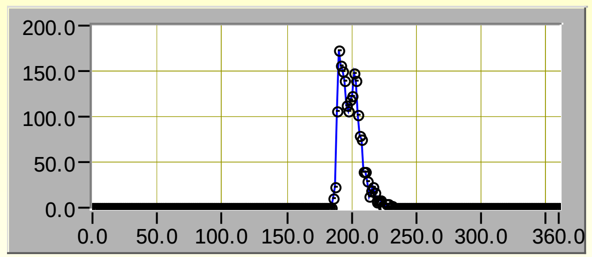


Amplitude Weibull Distribution

Parameter estimation:

α *scale parameter*

β *shape parameter*



Phase Distribution

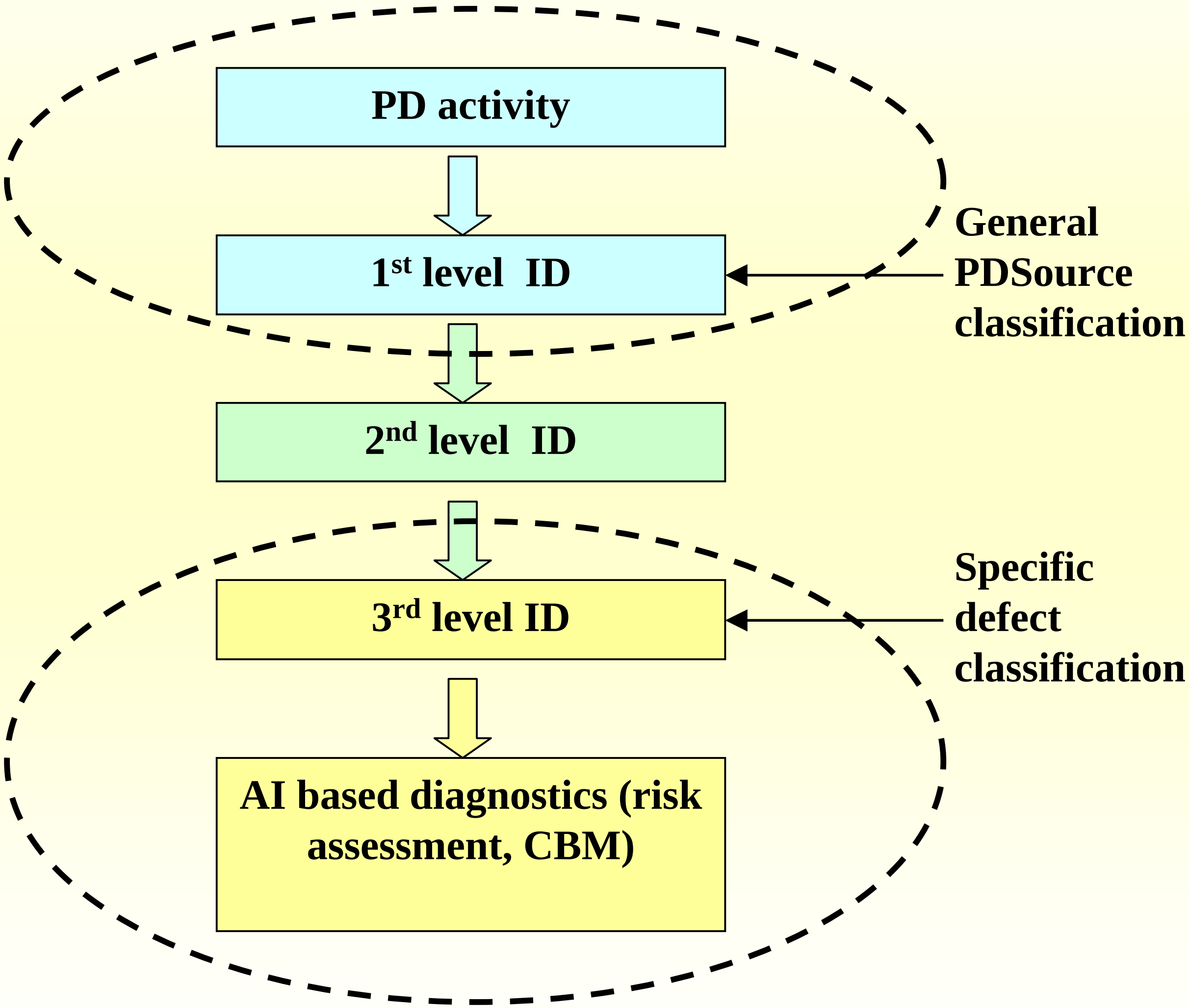
Parameter estimation:

Sk *skewness*

Ku *kurtosis*

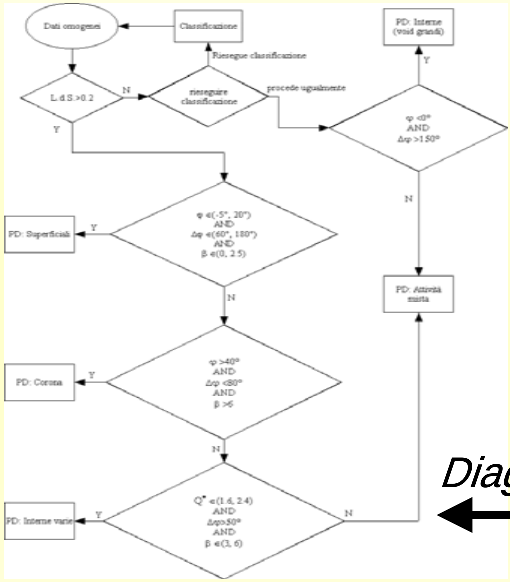
φ *Inception phase*

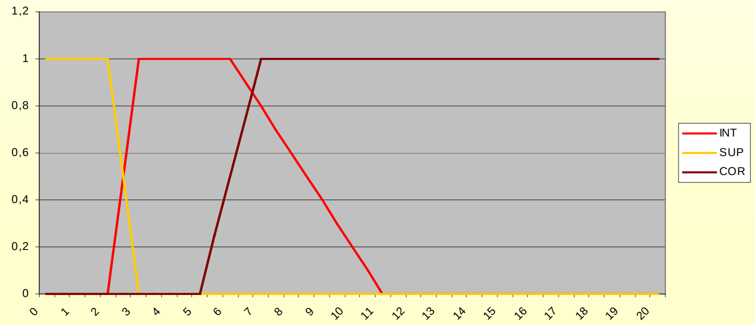
Innovative diagnostics by means of PD measurements: Identification



Innovative diagnostics by means of PD measurements: Identification and risk assessment

- Automatic (fuzzy logic) Identification (diagnostic evaluation)

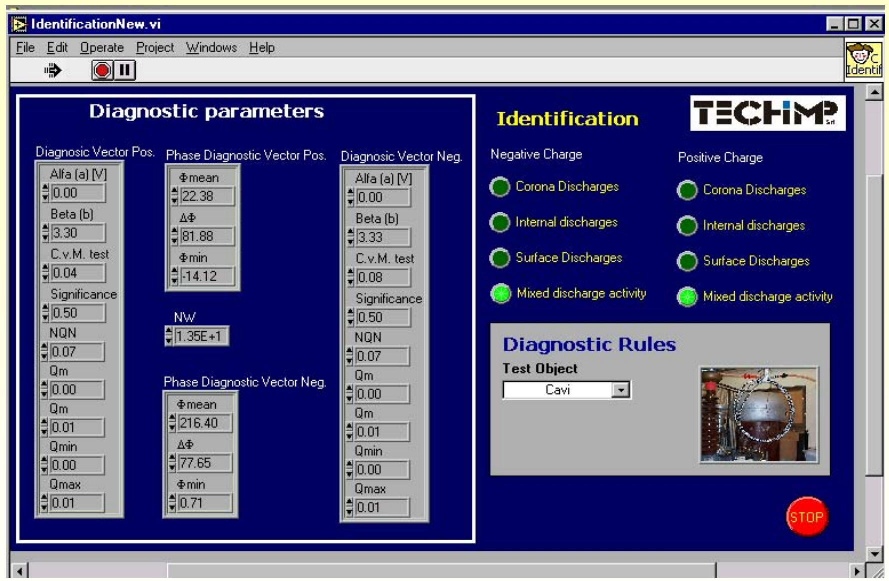




Fuzzy numbers

Implementation

Diagnostic Rules



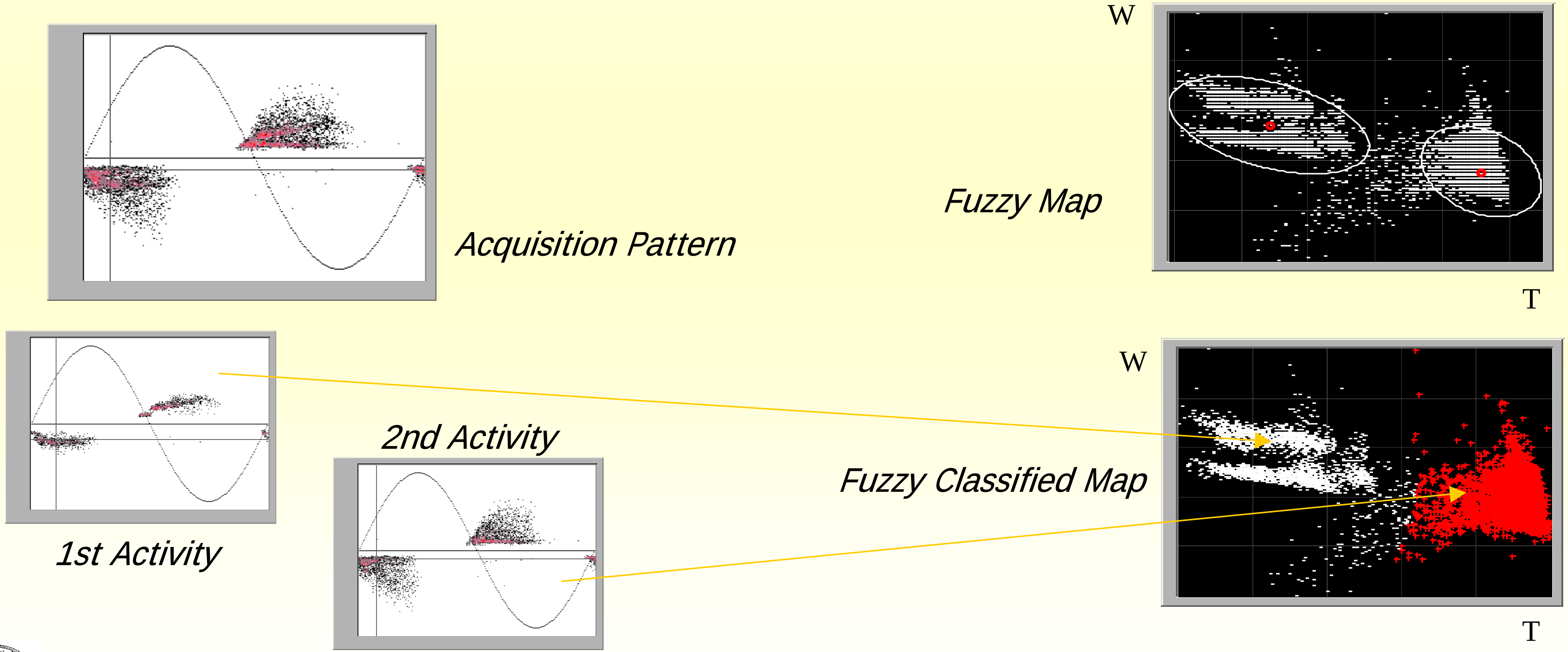
Diagnostic Database:

Each acquisition is made up of a vector of diagnostic parameters, can be stored in a data-base which will be the basis for the system set-up and the improvement of the diagnostic rules.

Innovative diagnostics by means of PD measurements: separation example

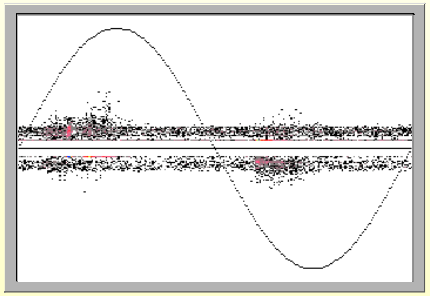
- Data Acquisition and separation in homogeneous classes

Discharge phenomena separation:



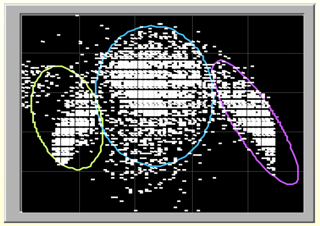
Innovative diagnostics by means of PD measurements: Separation

PD phenomena and noise separation

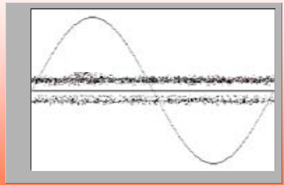
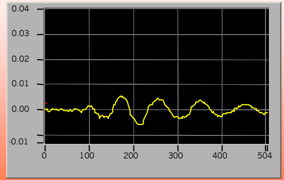
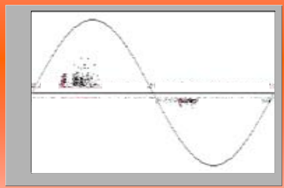
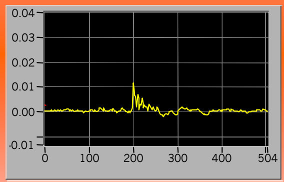
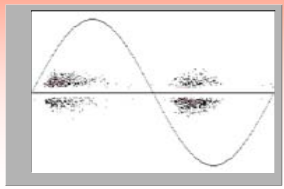
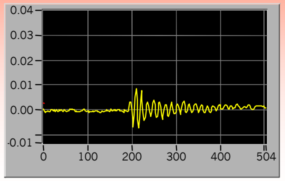


PD pattern of a complete dataset

Fuzzy classification



Separation

	Class Pattern	*Class Pulse*
Background Noise		
Interface		
Micro-voids		

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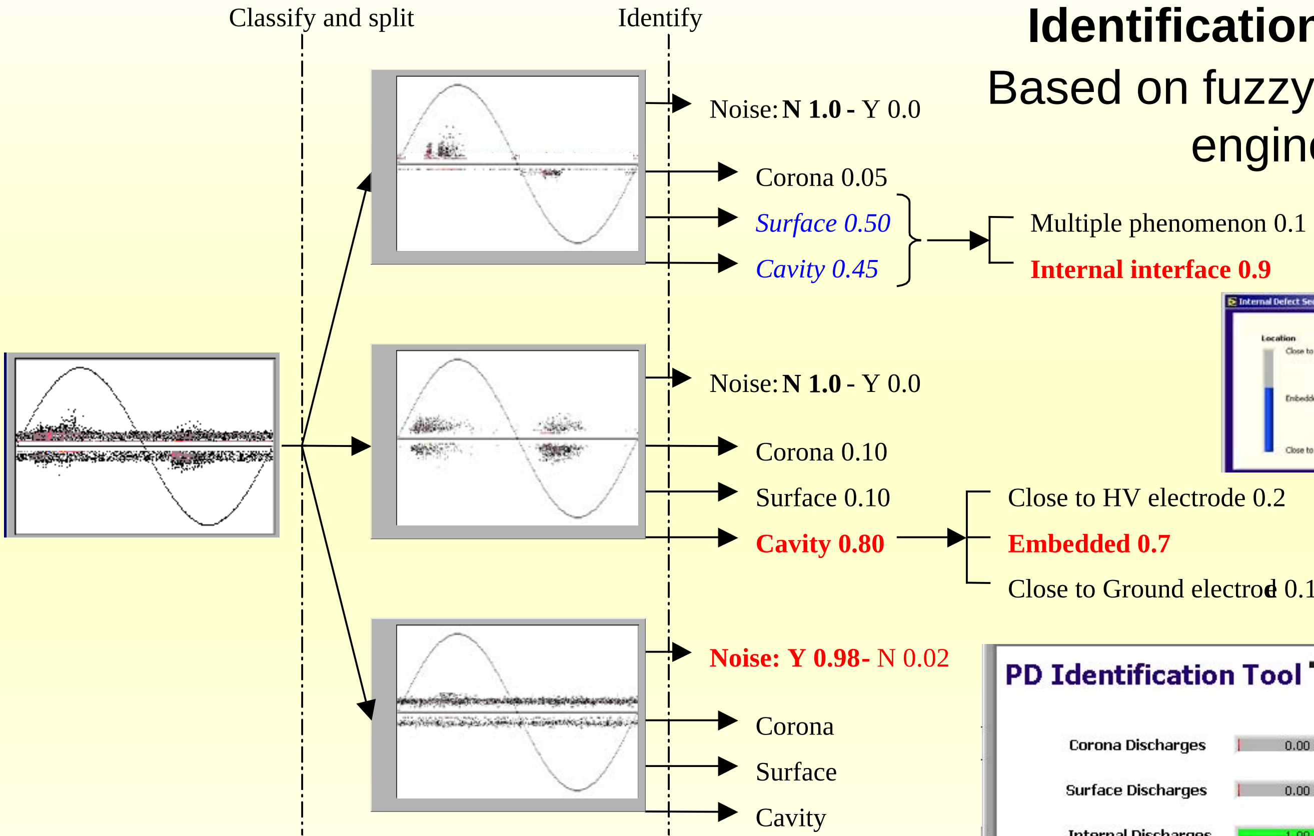
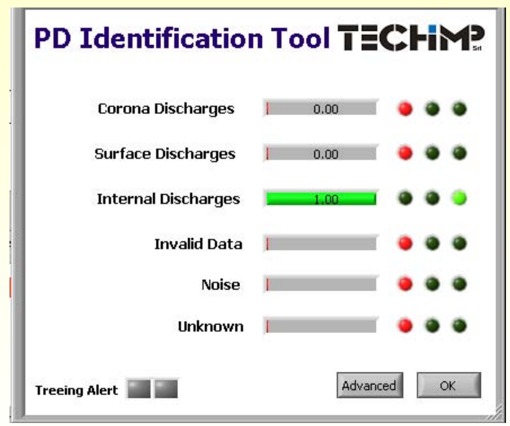
Innovative diagnostics by means of PD measurements: Separation and Identification



Identification system

Based on fuzzy inference engine

Identification procedure



Man/machine interface

Case studies of PD measurements in polymeric cables

MV, HV and EHV CABLES

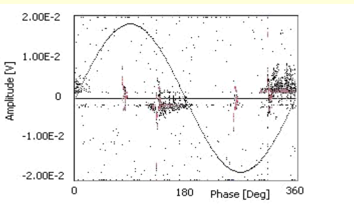
Case 1: PD test on 220 kV XLPE cable

Off-line, sequential, CT installed in link boxes

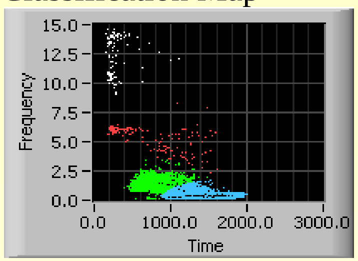
Location: **Joint Bay** NN (**RAL1R**); **V= 146 kV**

Entire Acquisition

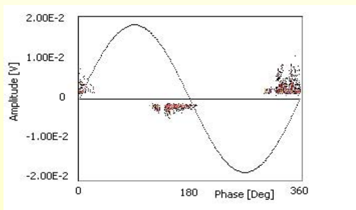
Pattern

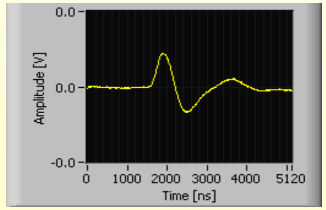


Classification Map

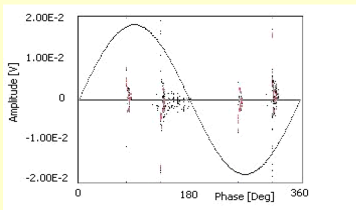


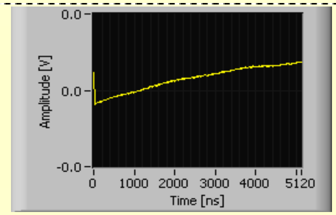
Subpattern | Typical Pulse | Check



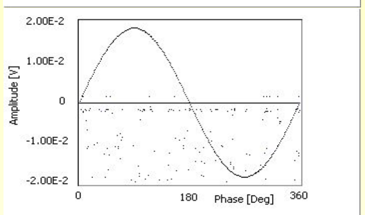


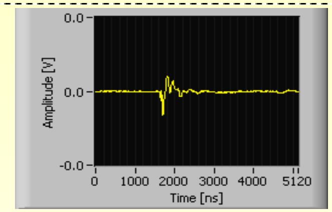
A
ID:
PD from HV source



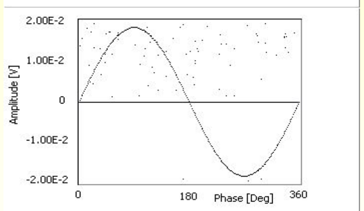


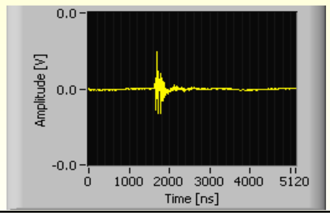
B
ID:
Voltage correlated noise



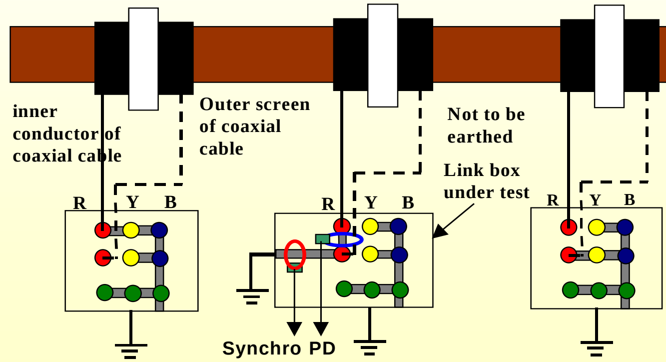


C
ID:
HF noise





E
ID:
HF noise



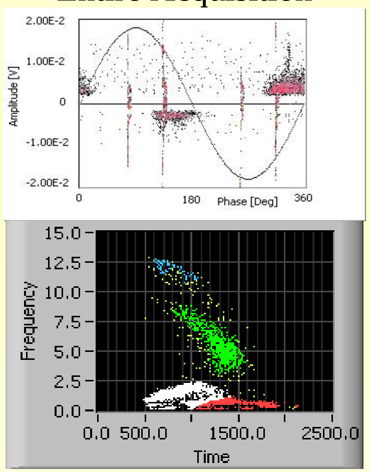
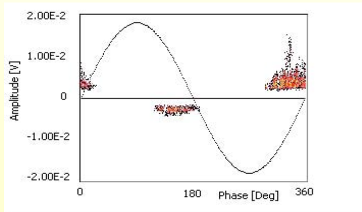
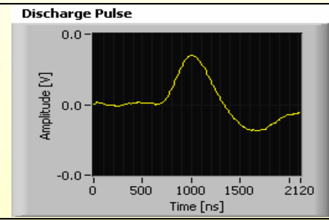
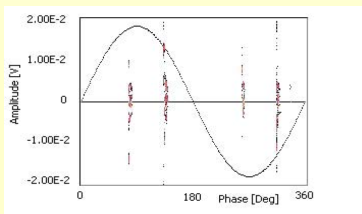
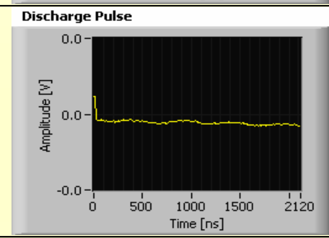
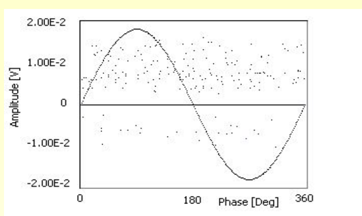
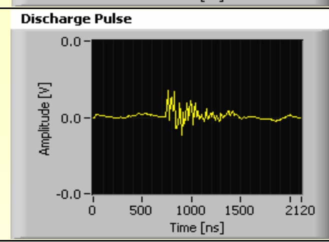
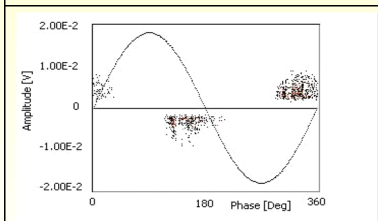
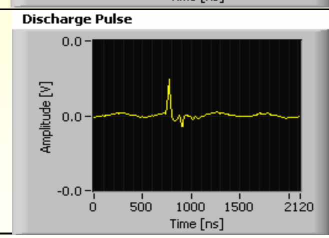
Measurement Configuration

Test Results for a joint:

No partial discharge originated by the joint

Case 1: PD test on 220 kV XLPE cable

Location: **Joint Bay** XX (**RAL1R**); **V= 146 kV**

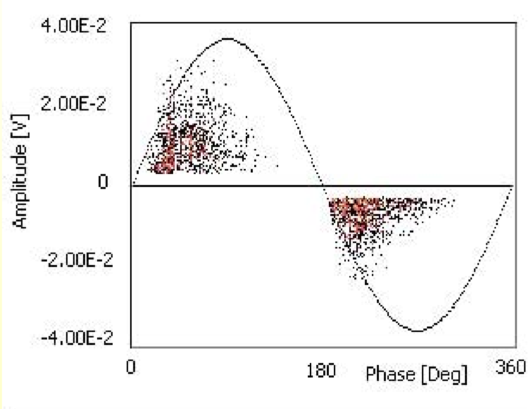
Entire Acquisition	Subpattern	Pulse	
			**A** **ID:** PD from HV source
			**B** **ID:** Voltage correlated noise
			**C** **ID:** HF noise
			**D** PD in a Joint

Results of a test on a joint:

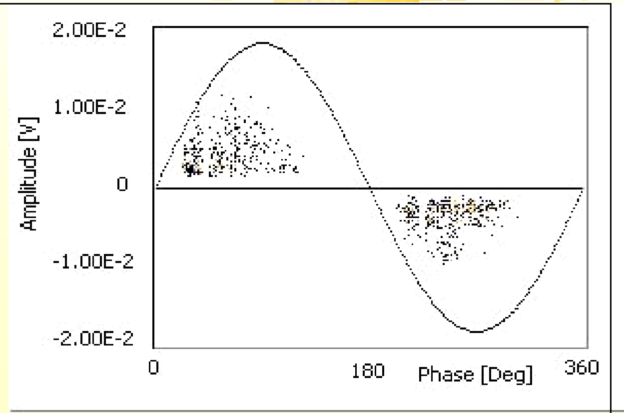
PD originated inside the joint

Conclusions drawn by the pattern and time-frequency map analysis

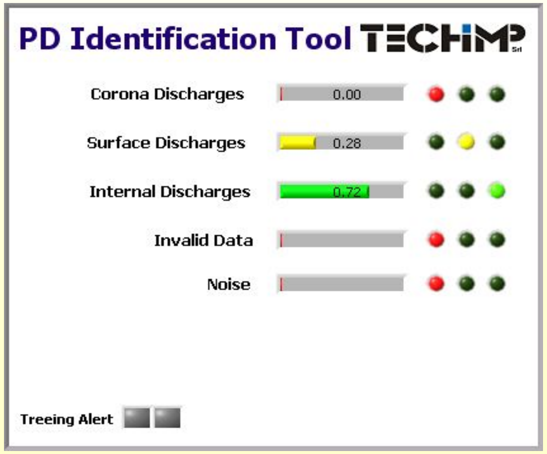
Case 1: PD test on 220 kV XLPE cable

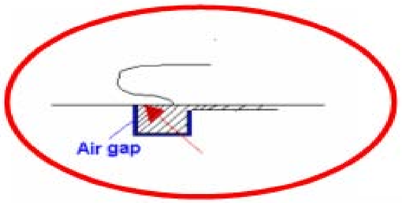


(a)

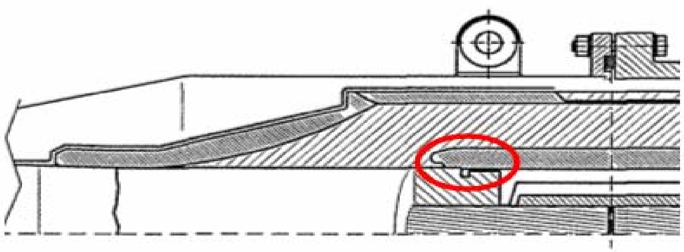


(b)





Defect identification:

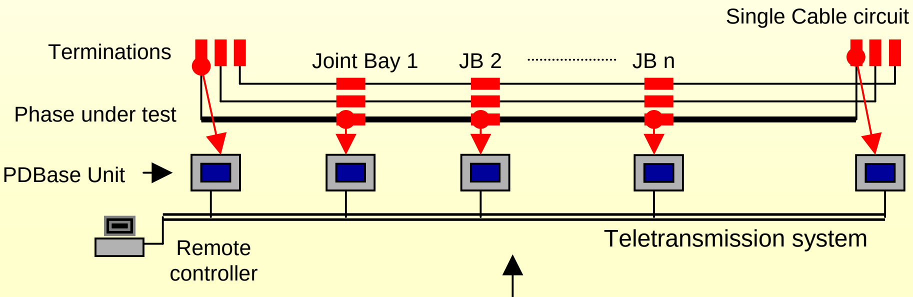


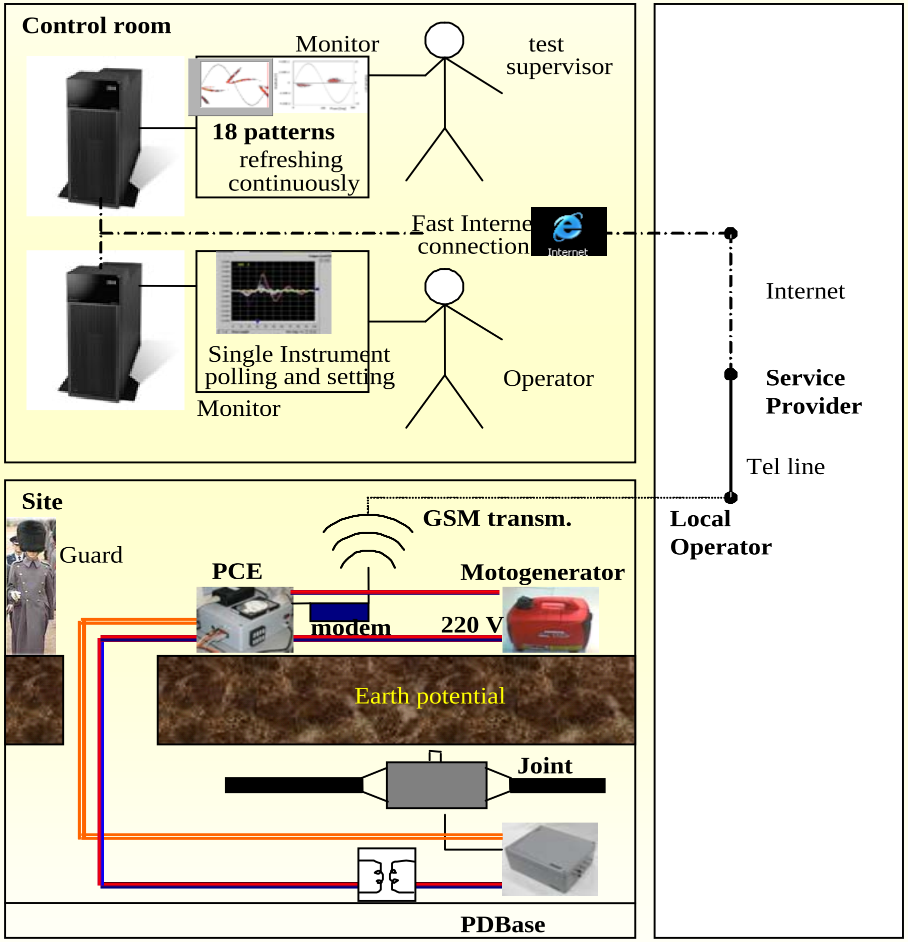
Wrong assembly of the joint

Case 2: PD test on 400kV XLPE cable

Off-line, simultaneous, capacitive sensors

Installation scheme

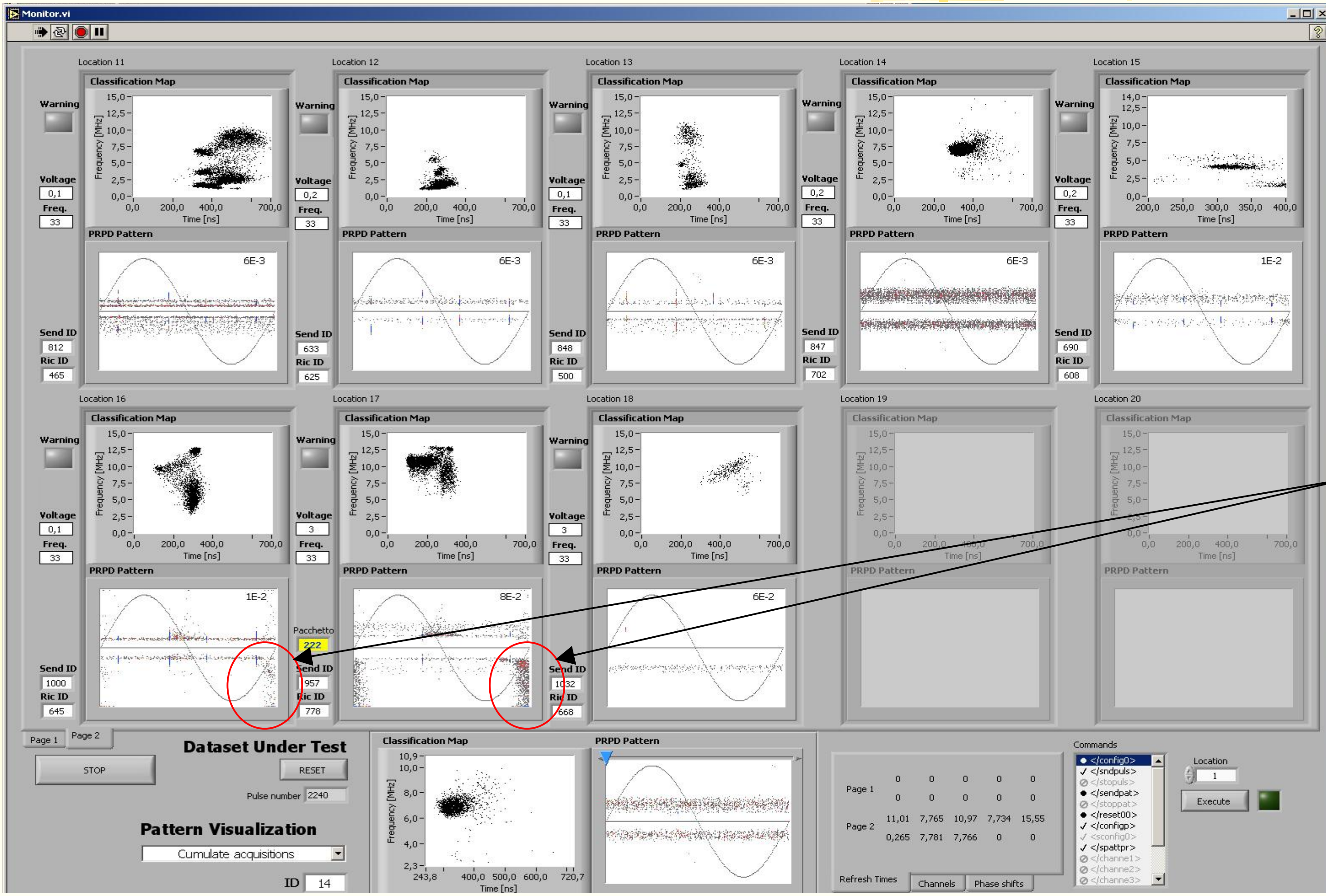




Monitoring System Overview

Single Monitoring Position

Case 2: PD test on 400kV XLPE cable

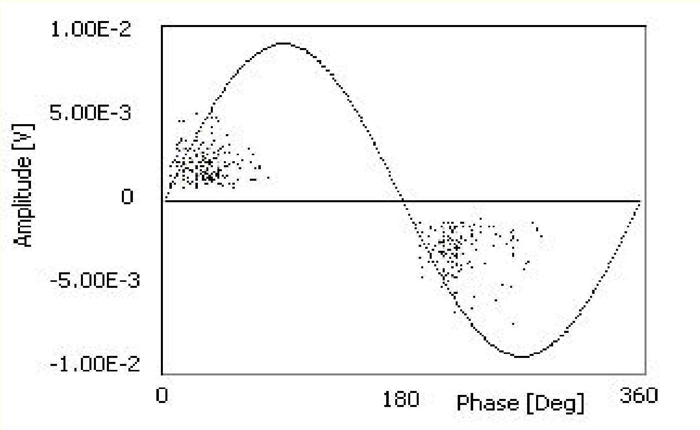


Real time pattern and *T-W* map analysis

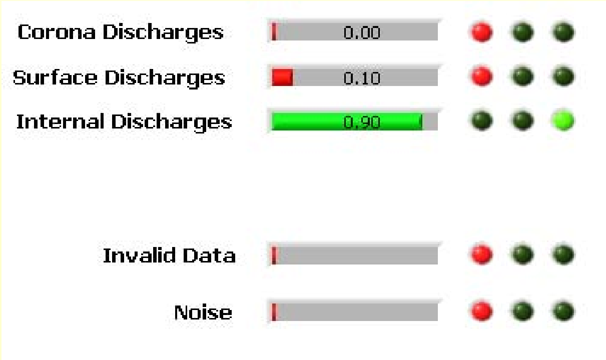
PD on bushings

Case 2: PD test on 400kV XLPE cable

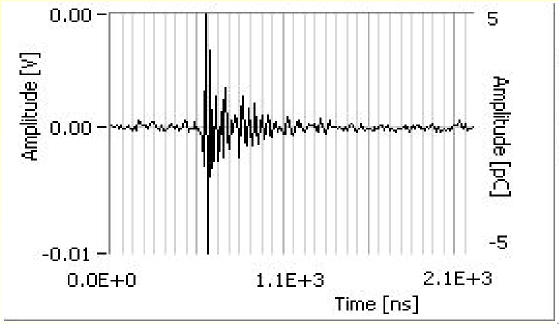
PD Pattern taken at joint

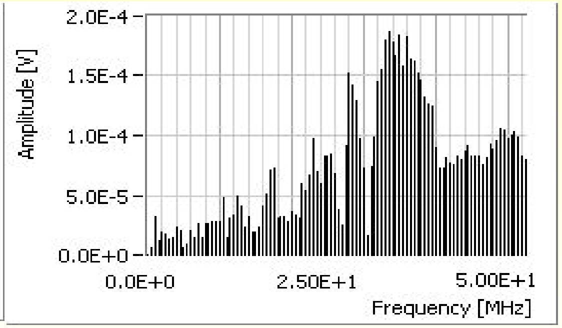


Reduced Amplitude: less than 5 pC



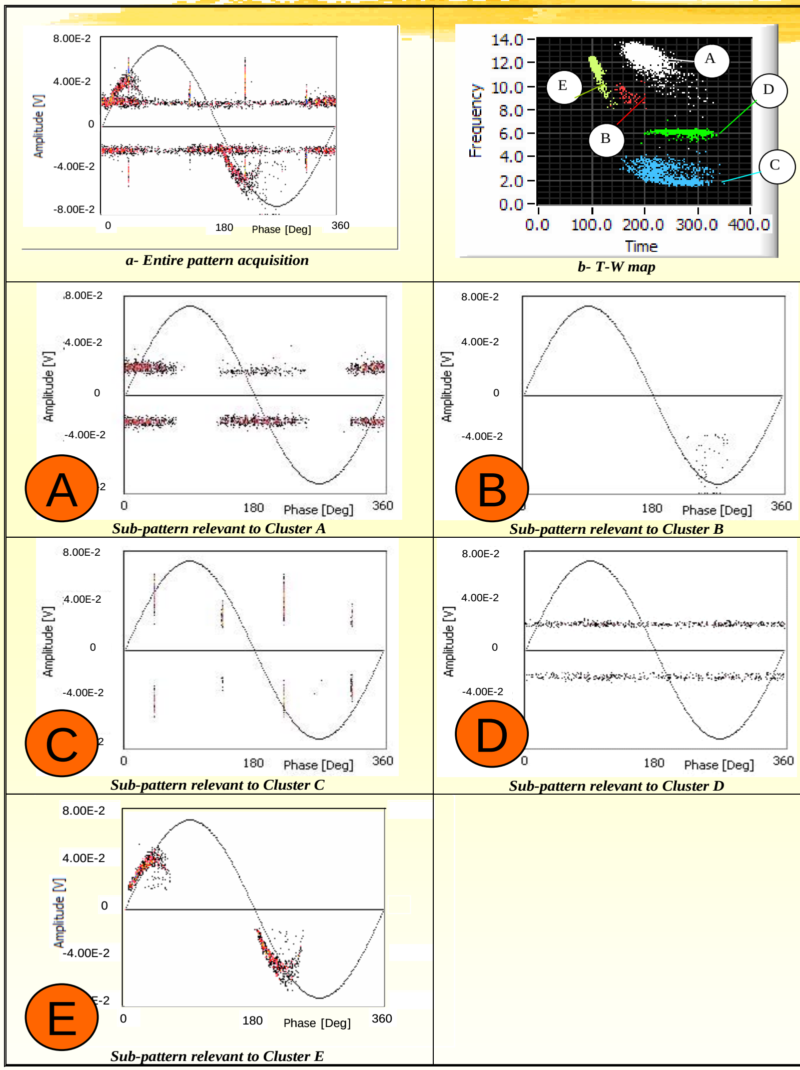
Impulse characterisation: high spectral HF content





Case 3: PD test on 400kV XLPE cable

Off-line, sequential, CT installed in link boxes

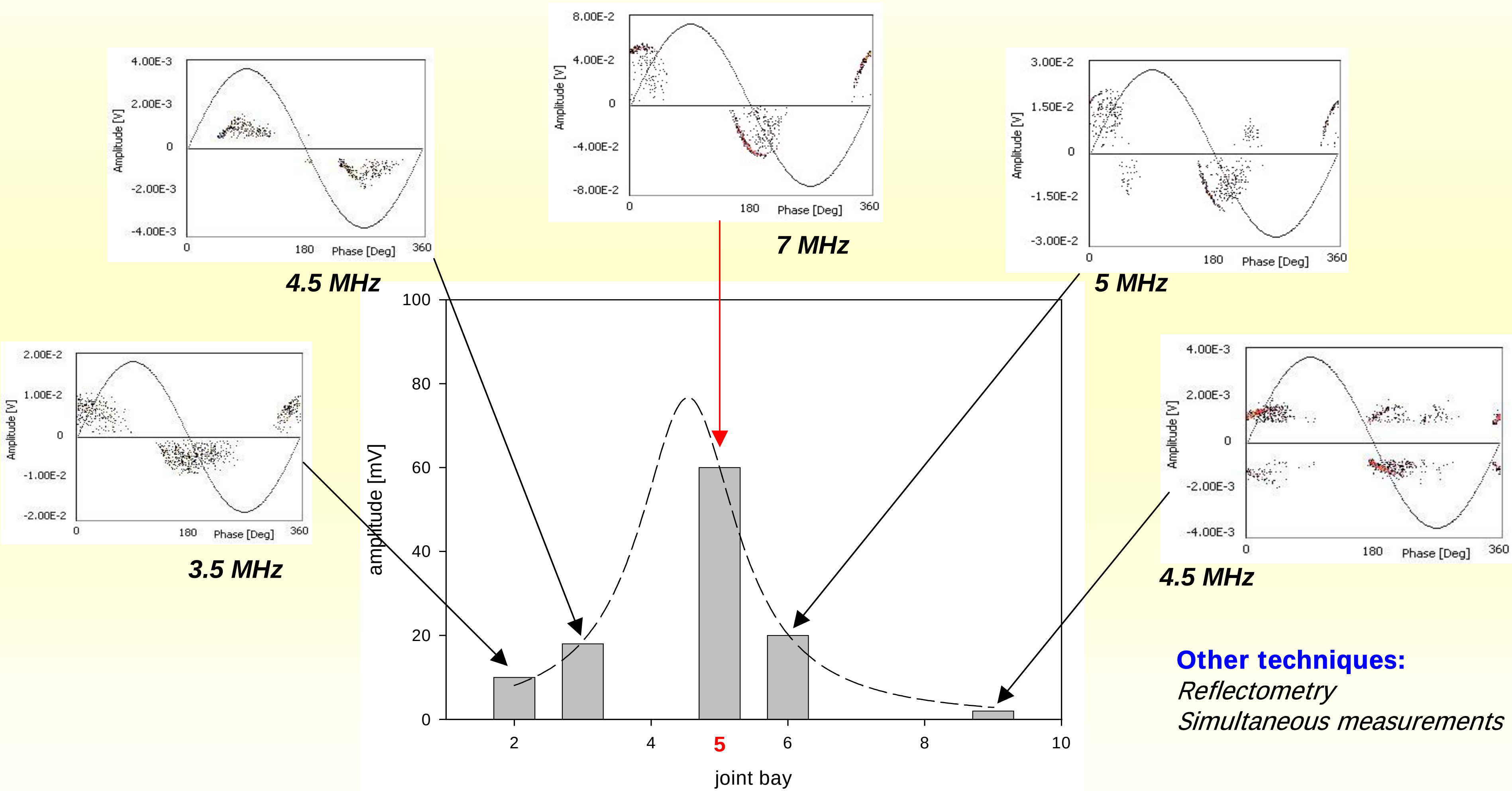


PD activities:

A. Resonant test set induced disturbance
B. Corona in HV connections
C. Correlated disturbance due to the switching devices of the AC resonant test set
D. HF noise due to external sources
E. PD from a Joint

Case 3: PD test on 400kV XLPE cable

PD location



Other techniques:

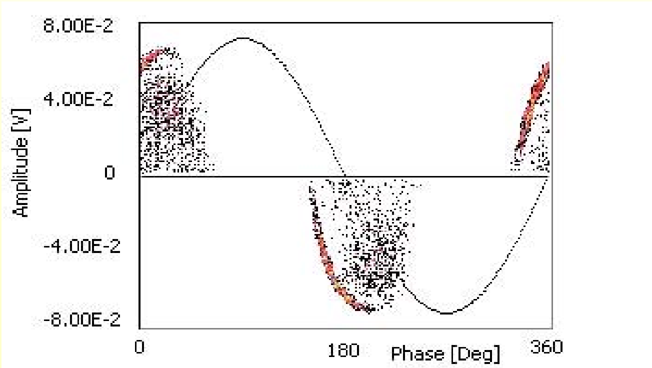
Reflectometry

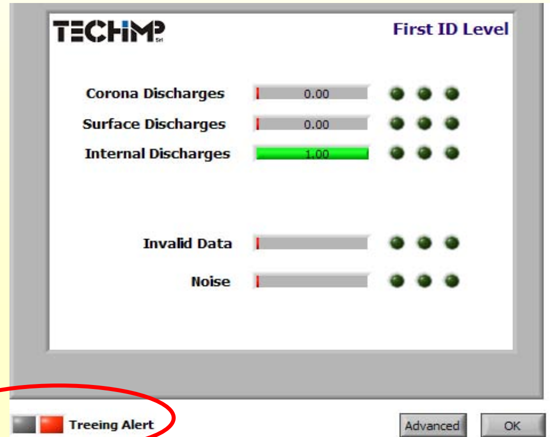
Simultaneous measurements

Case 3: PD test on 400kV XLPE cable

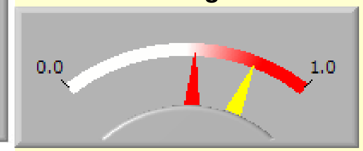
PD detection and identification

Detection and Identification



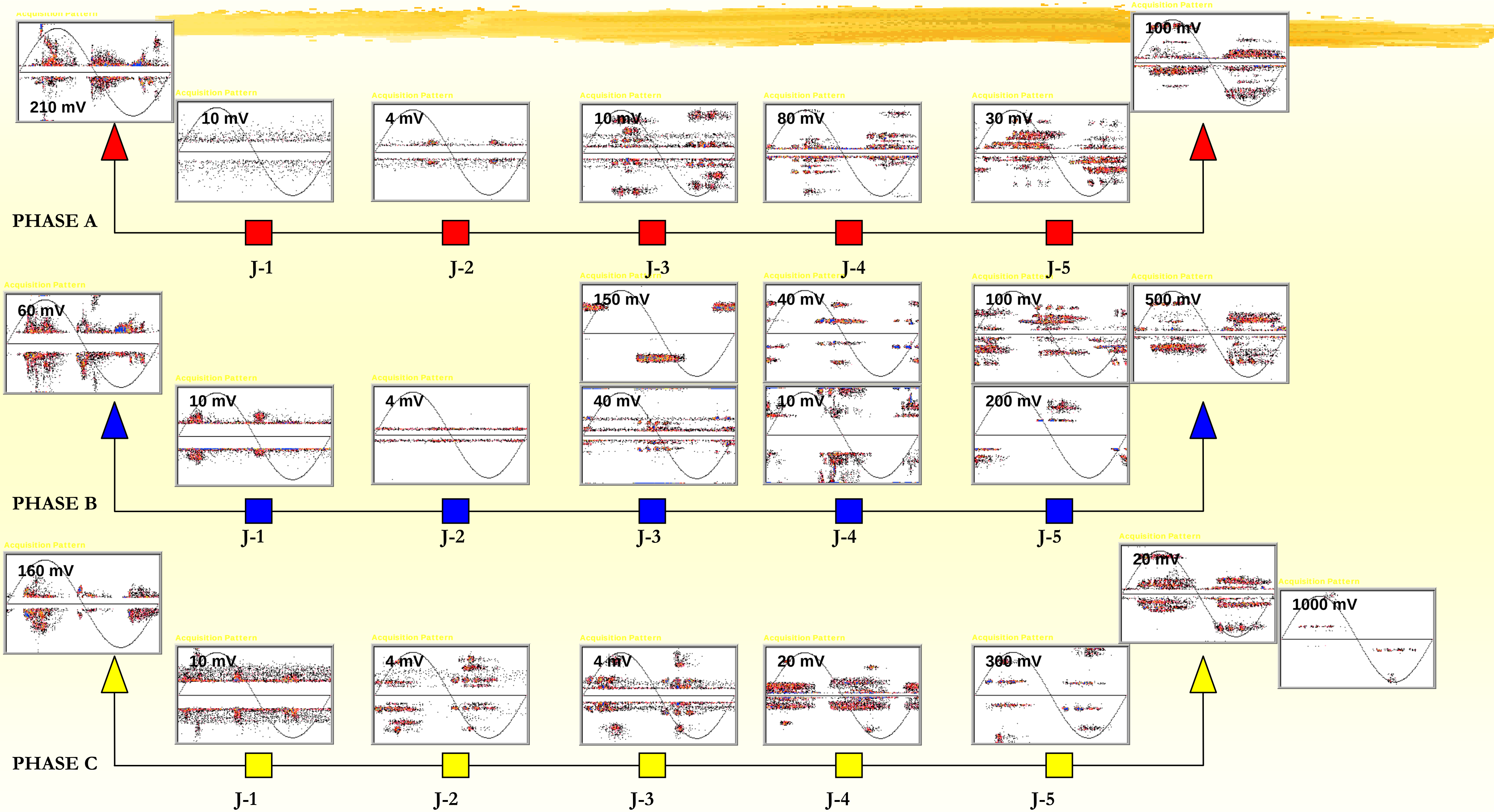


Allerta Treeing



Inspection

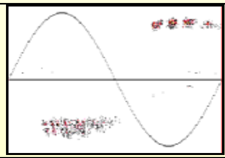
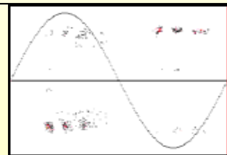
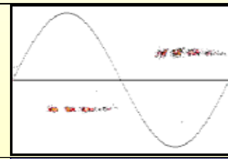
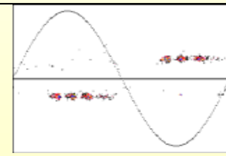
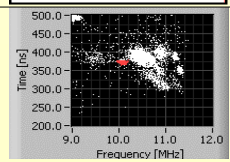
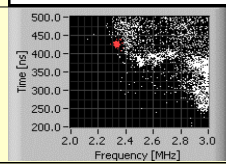
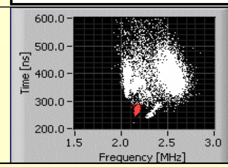
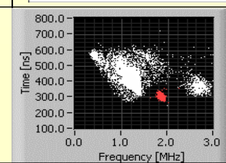
Case 4: PD test on 130 kV XLPE cable
On-line, sequential, CT installed in link boxes

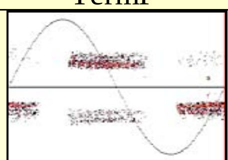
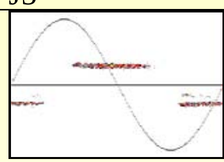
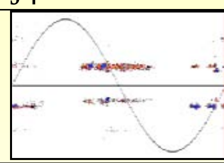
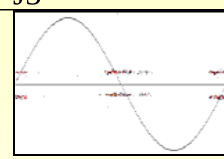
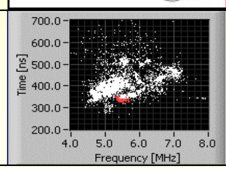
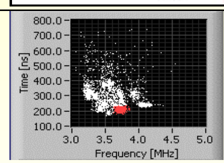
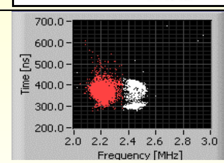
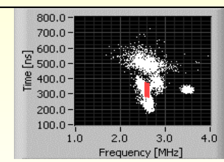


University of Bologna

Case 4: PD test on 130 kV XLPE cable

Noise rejection: several activities are generated in correspondence of HV bushings and can be detected along the cable route attenuated and distorted.

	Term P	J5	J4	J3
Pattern				
TF map				
Amplitude	90 mV	25 mV	25mV	8mV
Frequency	10 M Hz	2.3MHz	2.2MHz	1.9MHz

	TermP	J5	J4	J3
Pattern				
TF map				
Amplitude	250 mV	40 mV	15 mV	10 mV
Frequency	5.5 MHz	3.7 MHz	2.3 MHz	2.4 MHz

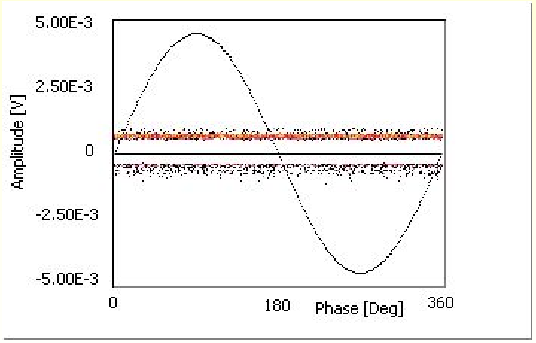
TechImp/Pirelli evaluated the circuit to be PD free within the measurement sensitivity

Case 4: PD test on 130 kV XLPE cable

Forensic investigation

J5B (one of the joints showing the largest amount of pulses in the PD pattern) was cut and tested in laboratory

The joint was tested at 1.45 U_0 presented no PD at all (sensitivity: less than 5 pC)

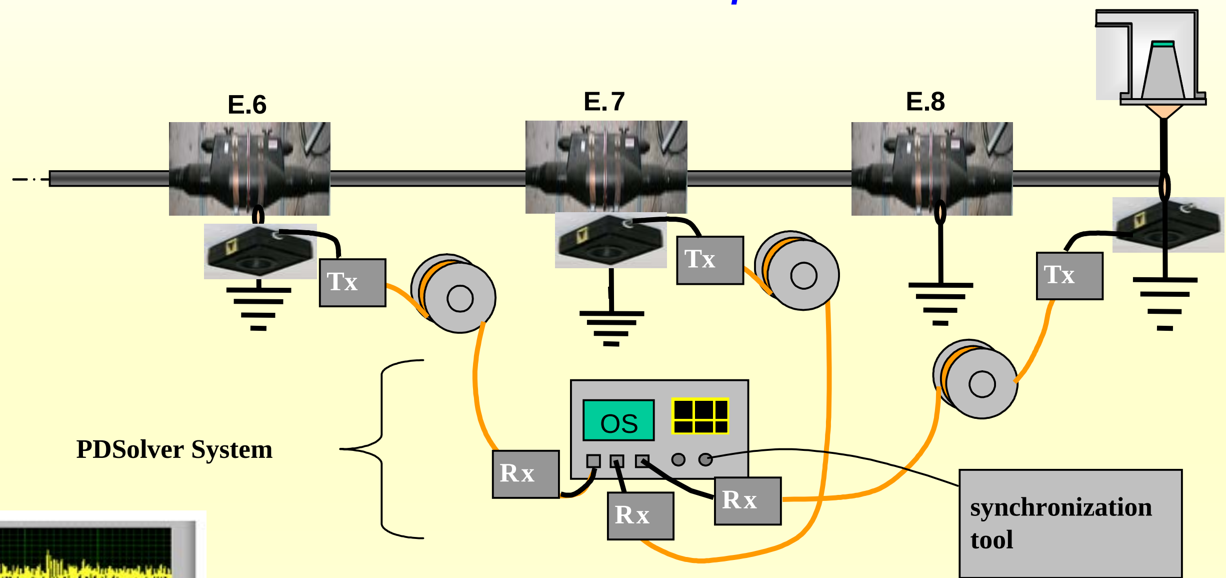


Pattern at 1.45 U_0

Off Line Cable Diagnosis: PD Location

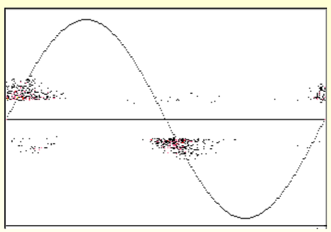
Location carried out through arrival time analysis of signals from different joints

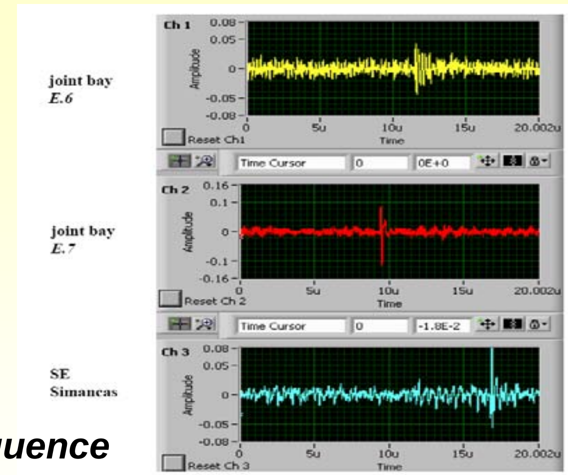
Setup



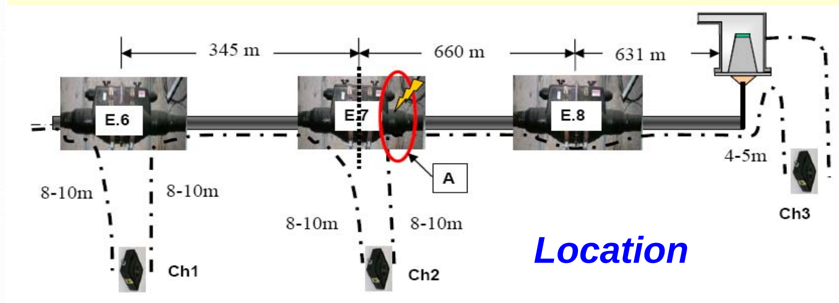
Results

Pattern





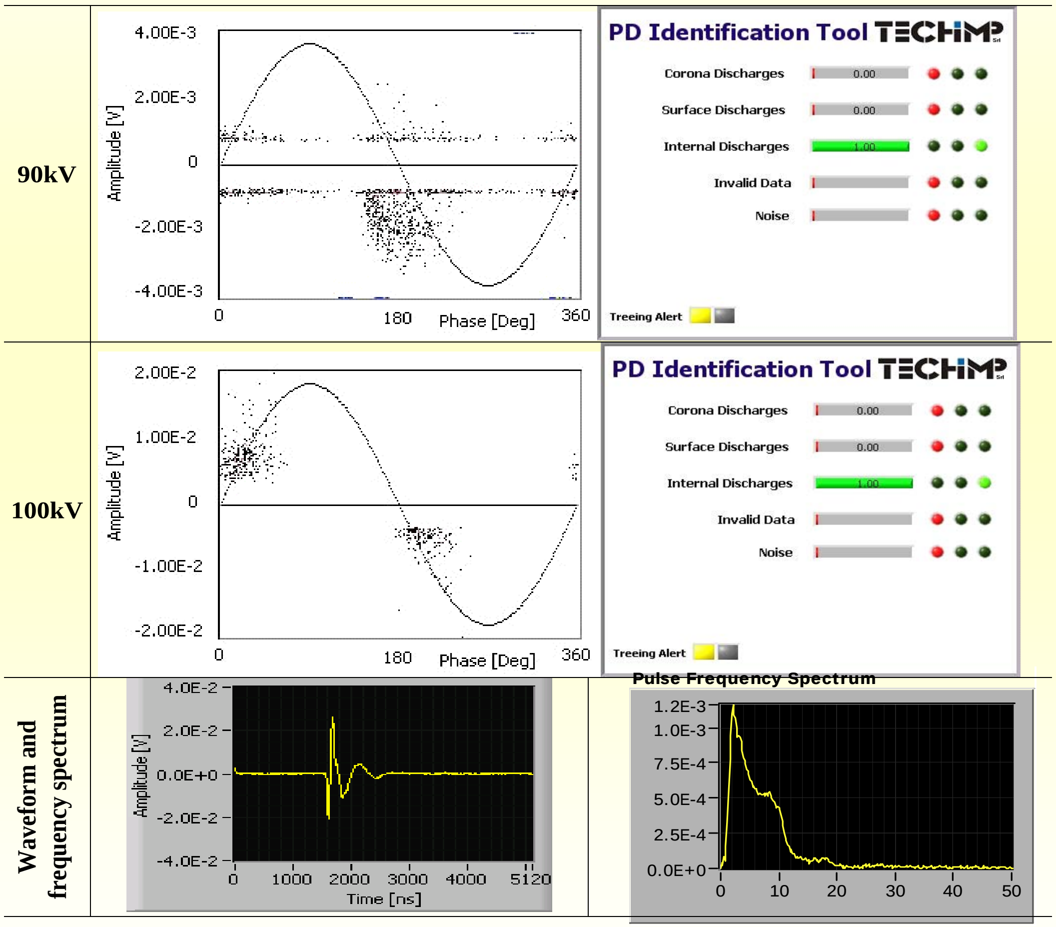
Pulse time sequence



Location

Off line Cable Diagnosis: Pre-breakdown Evidences

Also low PD level can be extremely alarming! (depending on the origin of PD)



220kV XLPE cable circuit, 4 km

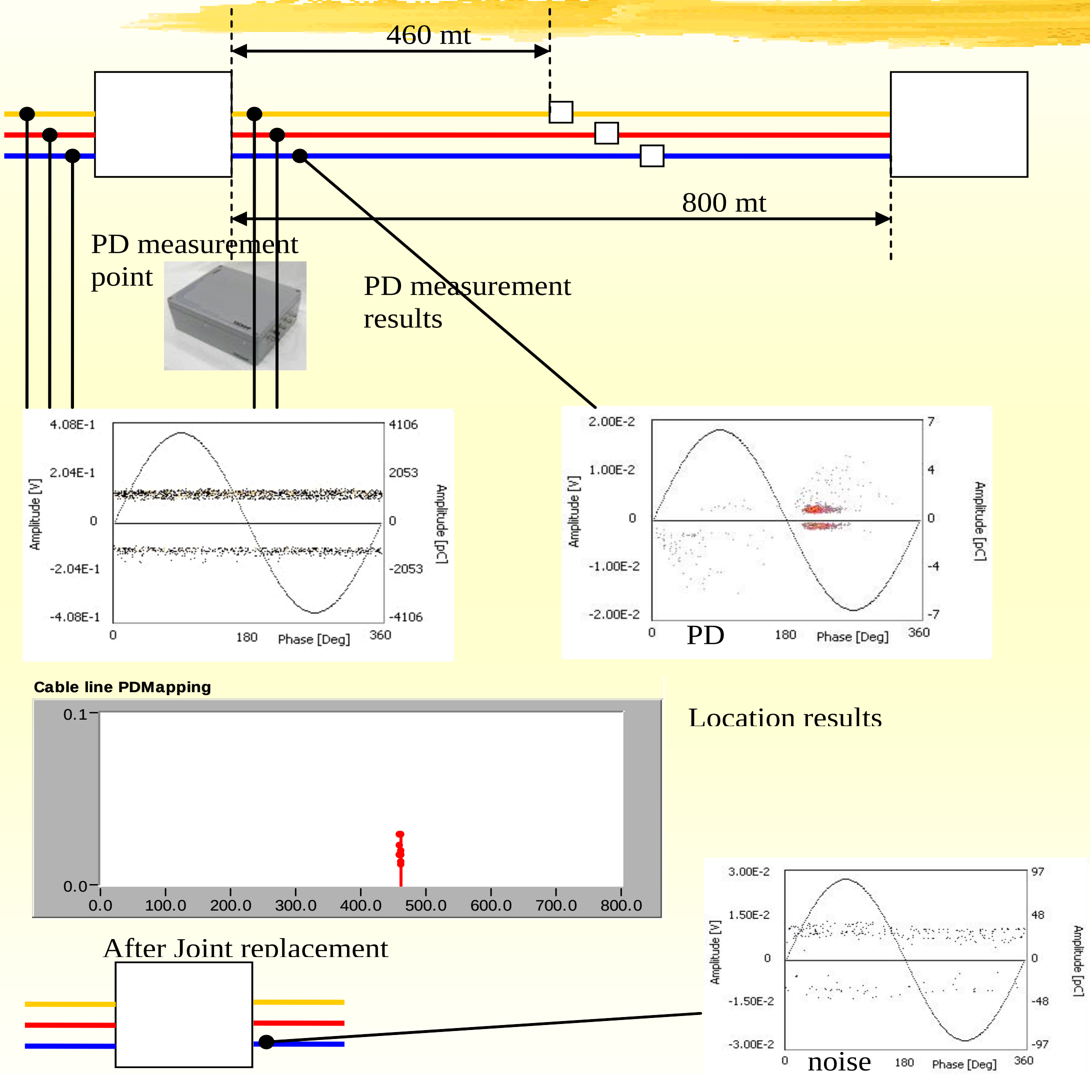
20mV phenomena was the only alert before a breakdown in a joint (occurred a few seconds after reaching 100kV)

The activity was identified as internal and a treeing alert was active

Joints have been observed withstand much larger surface phenomena

Risk assessment based on PD identification

Off line HV/MV Cable Diagnosis. Location and Identification



Measurements carried out from termination (short cable length)

Location performed trough reflectometric technique

After replacement test confirmed the validity of the inference

Conclusions

- PD measurements carried out by techniques that enable enhanced noise rejection and PD typology identification constitute a fundamental tool for risk assessment of electrical systems.
- Applications on polymeric cables have been proved to be successful for quality control of new installations and diagnosis of cable already in service (useful support from dissipation factor measurements).
- Other applications: generators and motors, transformers, outdoor insulators, GIS, oil-paper cables.