The use of Pulse Shape in PD testing of Transmission and Distribution Cable Systems

ICC – PES, Sub. F, Spring Meeting 2010, Nashville USA

Introduction

Partial discharge (PD) measurement is a diagnostic technique widely used to asses the state of the insulation of high and medium voltage cable systems:

- **after-laying PD measurements have become mandatory in many countries as a commissioning test for high voltage cable systems;**
- **in medium voltage cable systems, PD measurements are commonly employed as a tool for condition based maintenance of distribution networks.**

This presentation describes a technique (UWB) for partial discharge detection, processing and diagnosis.

The technique is based on the use of the information borne by the partial discharge pulse waveforms.

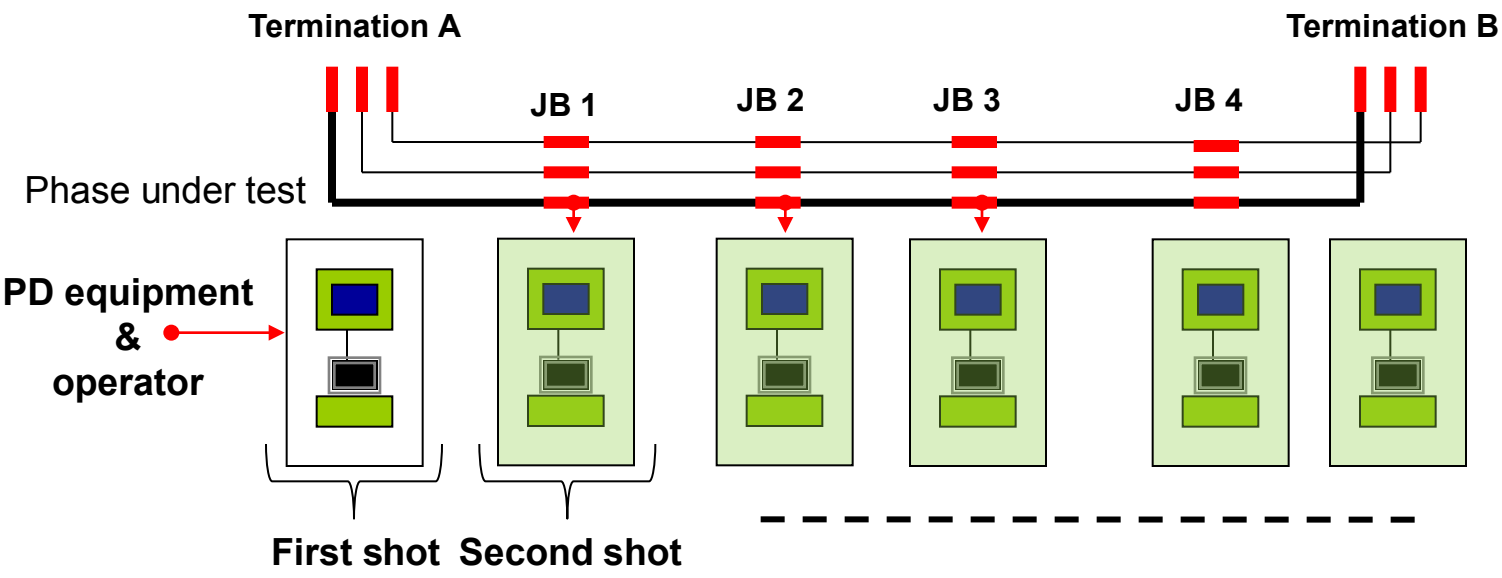
Cable testing: Off/On line sequential PD Test

One operator

$$N_{shots} = N_{acc}$$

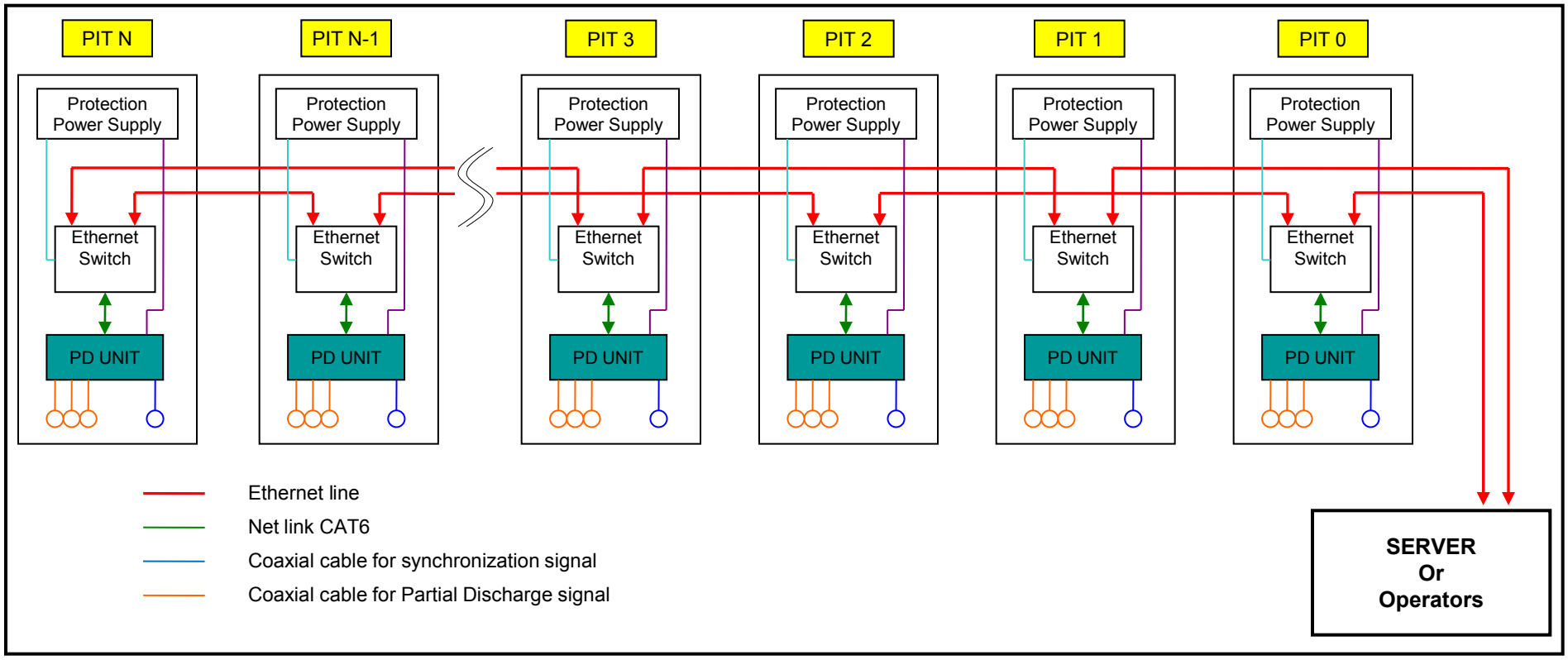
More operators

$$N_{shots} = \frac{N_{acc}}{N_{oper}}$$



- **One operator: difficult to localize the PD source if the PD is not constant**
- **More operators:**
  - **Less shots to measure the entire cable system**
  - **Measurement sensitivity related to the maximum distance between the detection points**

Cable testing: On-Line PD Testing (simultaneous)



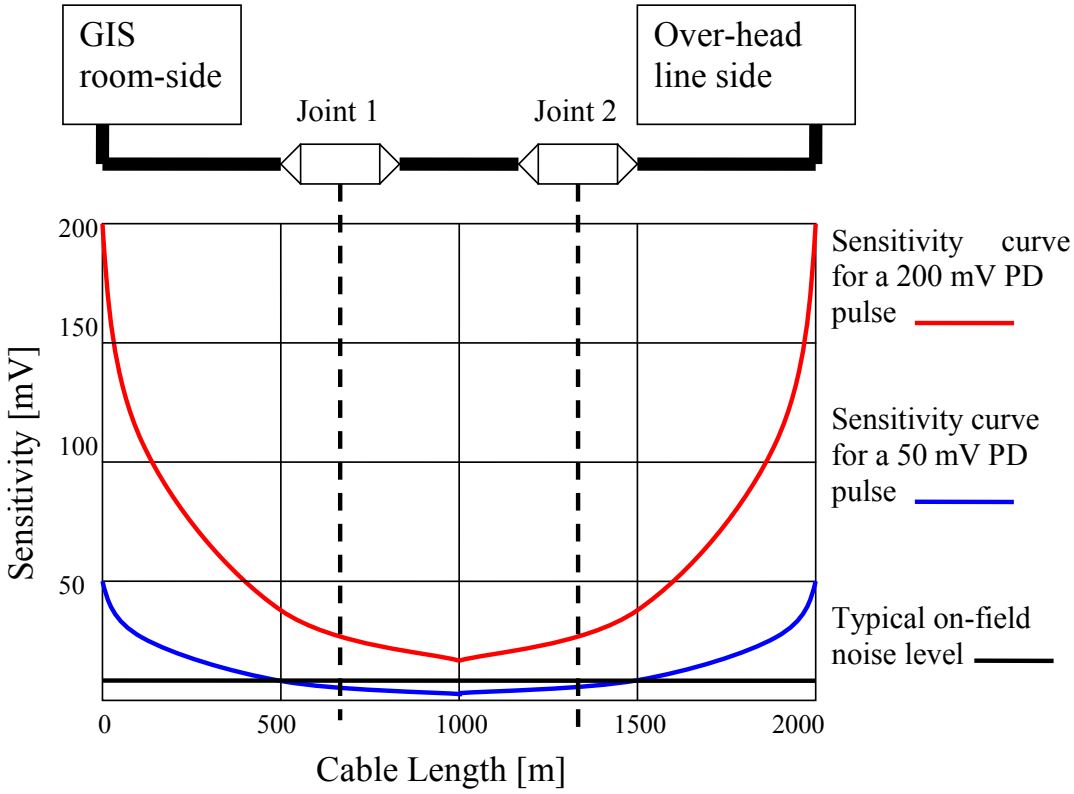
- **Simultaneous acquisition in all the detection points**
  - **Measurement sensitivity related to the maximum distance between the detection points**

Cable testing

Noise and disturbance rejection techniques are required

- **to improve the measurement sensitivity**
- **to allow PD activity of small entity to be detected**
- **to allow PD activity far away from the measurement point to be detected and localized**

Attenuation and distortion of travelling PD pulses limit distance for PD detection in cables, depending on required sensitivity



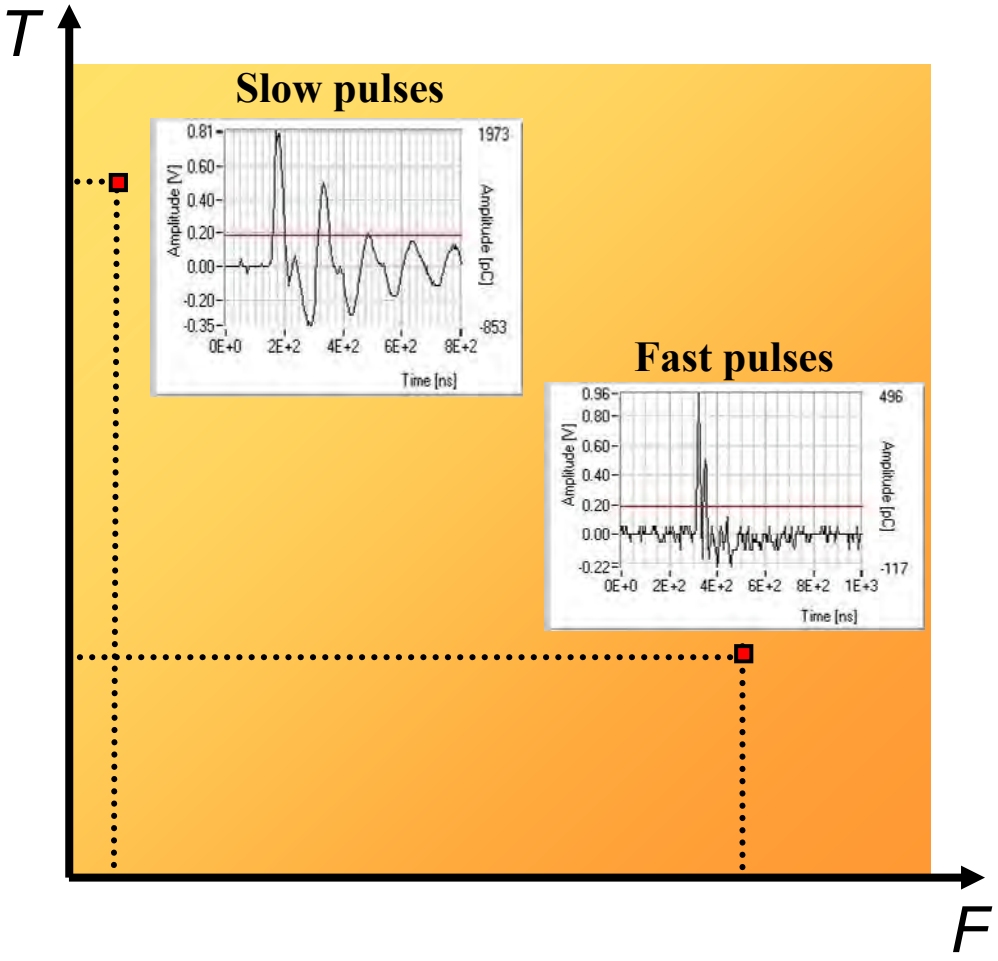
ULTRA WIDE BAND APPROACH FOR PARTIAL DISCHARGES MEASUREMENTS

Ultra Wide Band acquisition allows:

- **Classification by "Time – Frequency" mapping of acquired pulses**
- **Phenomena separation (Noise, Disturbances, Multiple PD activities, etc.)**
- **Noise rejection**
- **Single phenomenon identification**
- **Localization (various techniques)**
- **Pulse waveform and spectrum analysis**
- **Pulse integration**

Classification by T-F mapping

Each acquired pulse is represented with 2 parameters



Normalization of the pulse

$$\tilde{s}(t) = s(t) / \sqrt{\int_0^L s(\tau)^2 \, \mathrm{d}\tau}$$

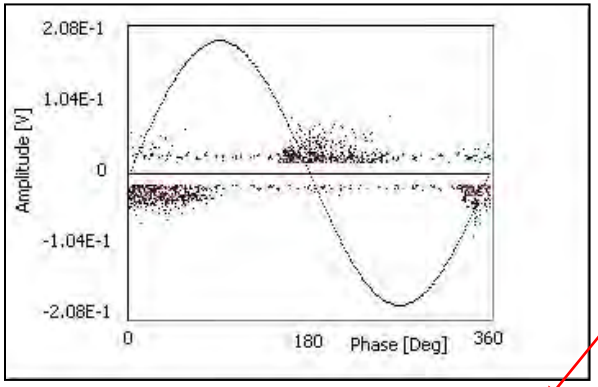
$$\begin{cases} t_0 = \int_0^L t\tilde{s}(t)^2 \, \mathrm{d}t \\ T = \sqrt{\int_0^L (t - t_0)^2 \tilde{s}(t)^2 \, \mathrm{d}t} \\ F = \sqrt{\int_0^\infty f^2 \left|\tilde{S}(f)\right|^2 \mathrm{d}f} \end{cases}$$

S(f) is the Fourier transform of *s*

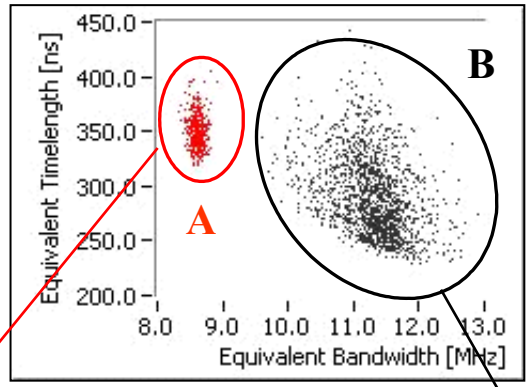
L = time length of the pulse

Example of data processing #1

Entire PD pattern

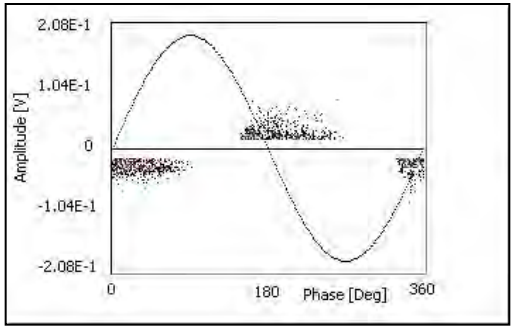


T-F Map

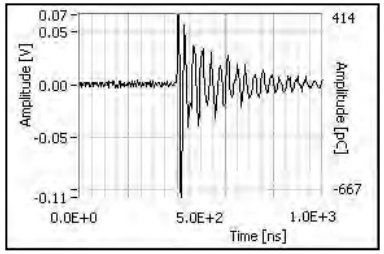


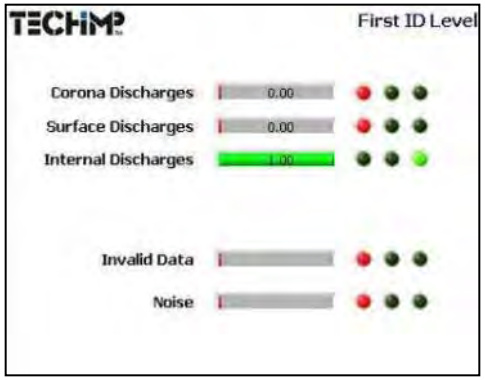
A

Sub-pattern A



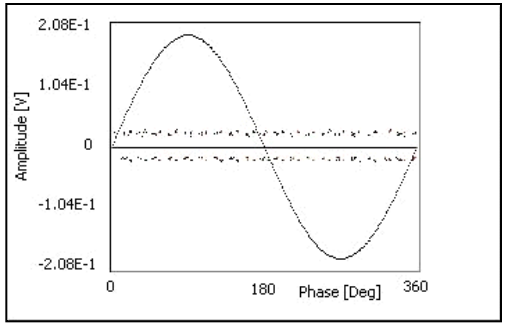
Waveform A



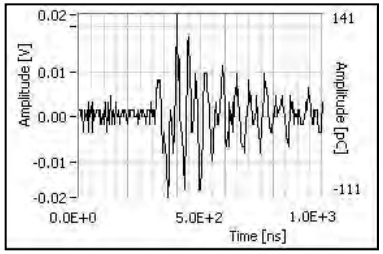


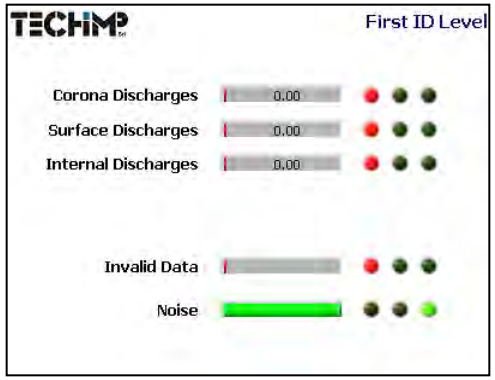
B

Sub-pattern B



Waveform B

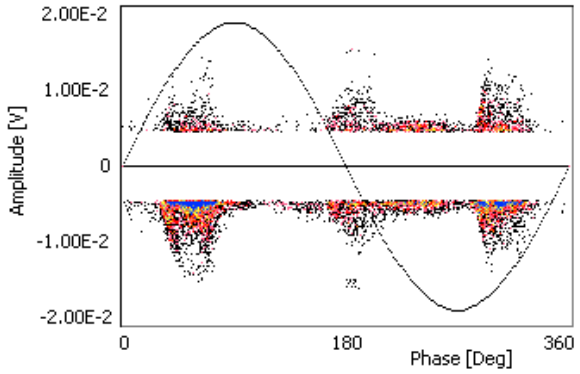




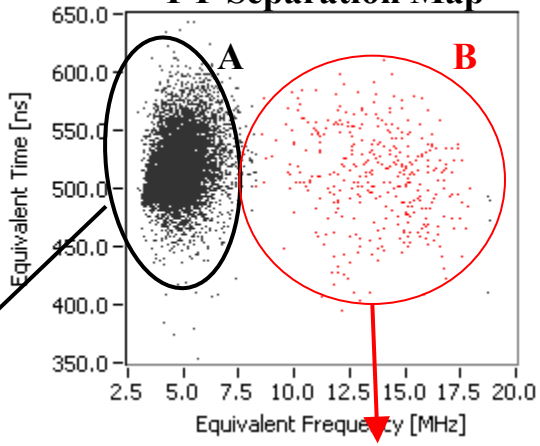
Example of data processing #2

- PD acquisition in correspondence of a 220kV cable - GIS termination
- Apparently only disturbances are present

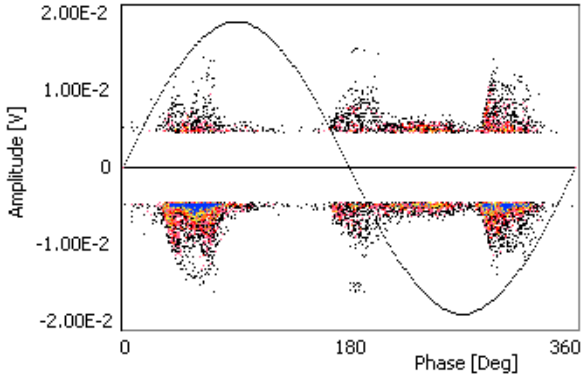
PD Pattern – Complete Acquisition



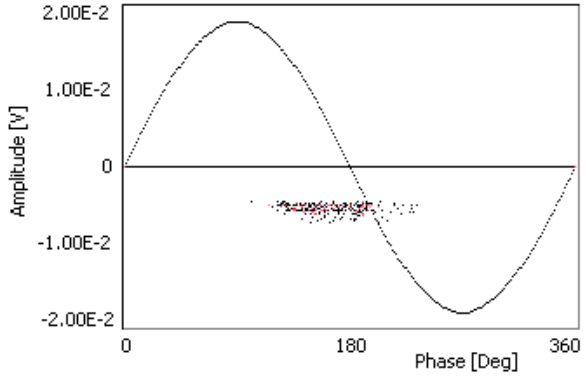
T-F Separation Map



Sub pattern A: Disturbances



Sub pattern B: PD due to internal cavity

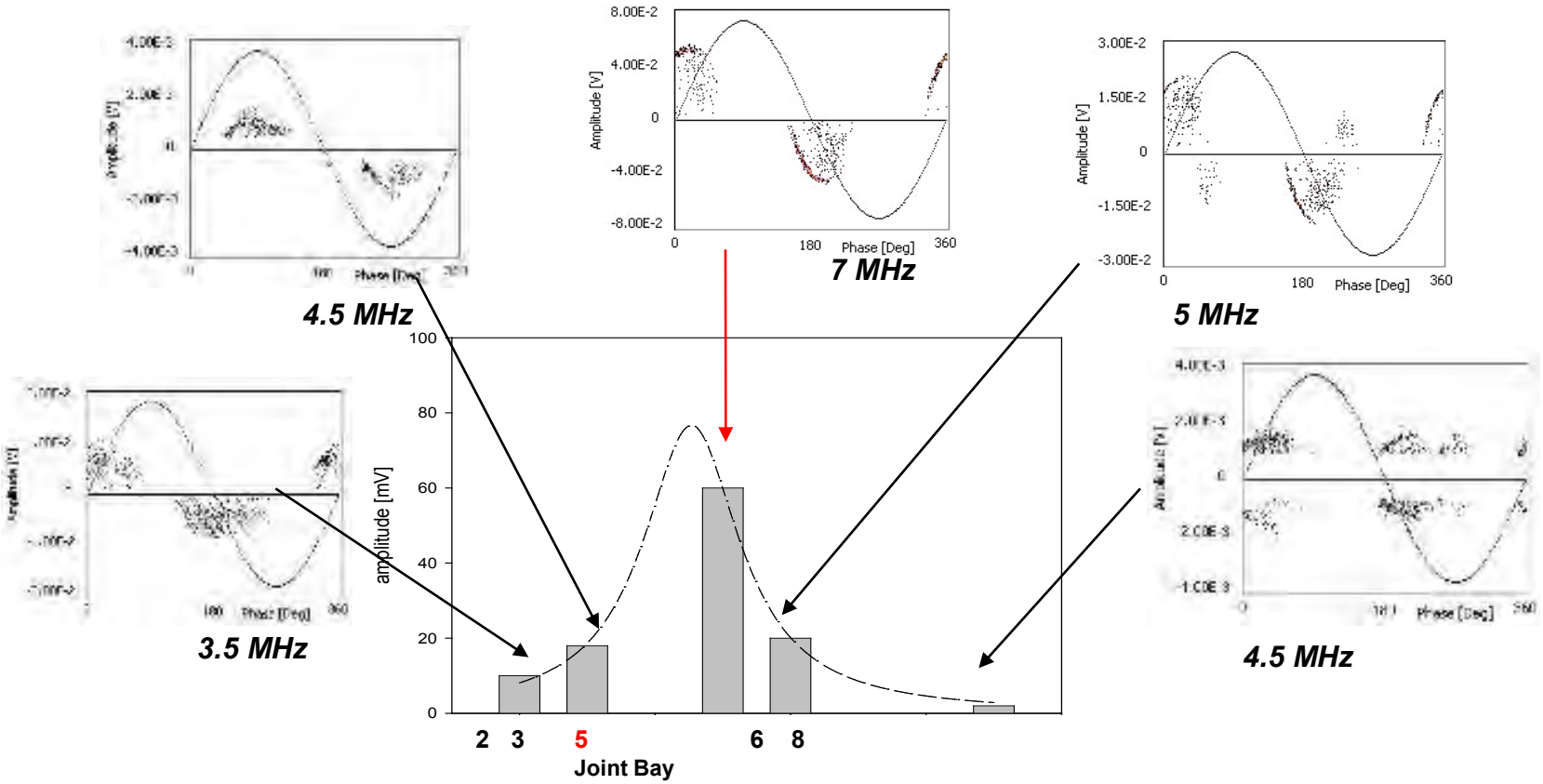


Separation allows dangerous PD to be detected in a noisy environment (effective on-line testing) !

PD source localization #1

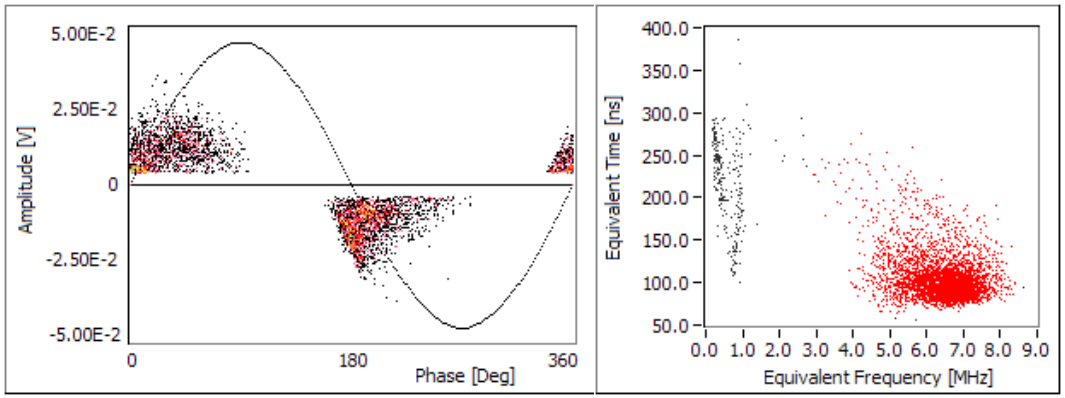
Amplitude – Frequency analysis through T-F map separation

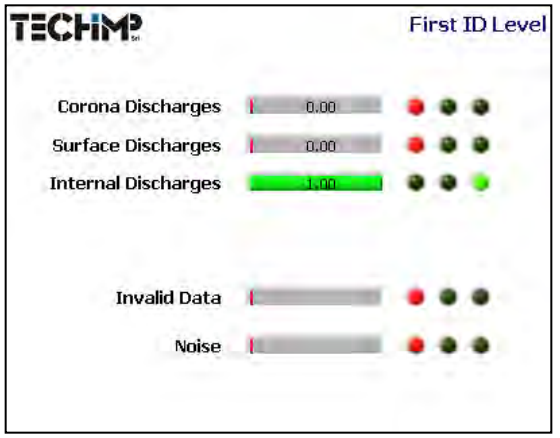
- PD phenomenon acquired in different location of the cable system
- It is possible to localize the PD source



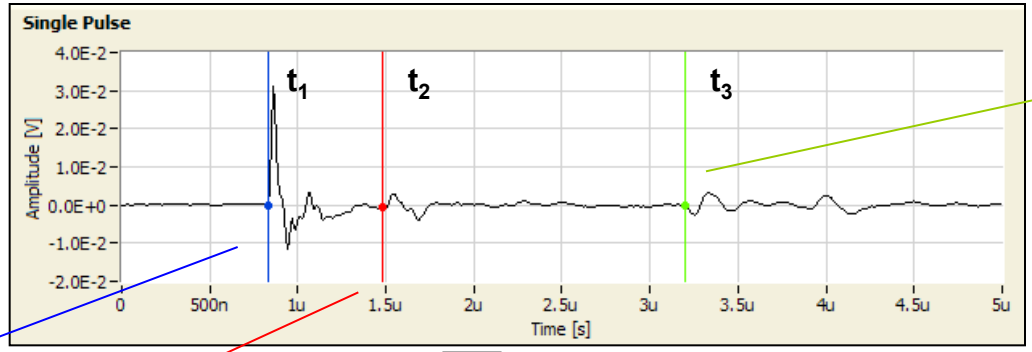
PD source localization #2

Reflectometric technique (TDR)





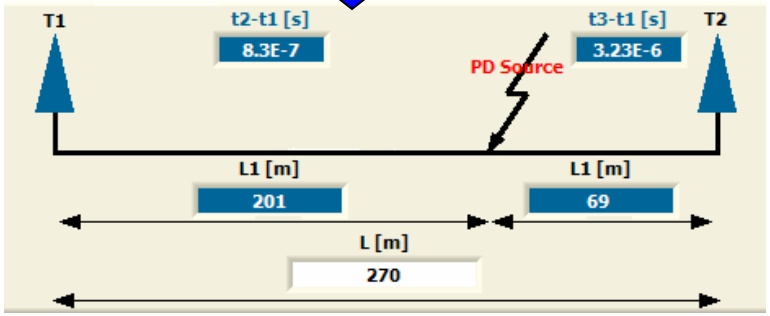
Only one cluster PD pulses analysis



Second reflection

Measurement point

PD source, first reflection



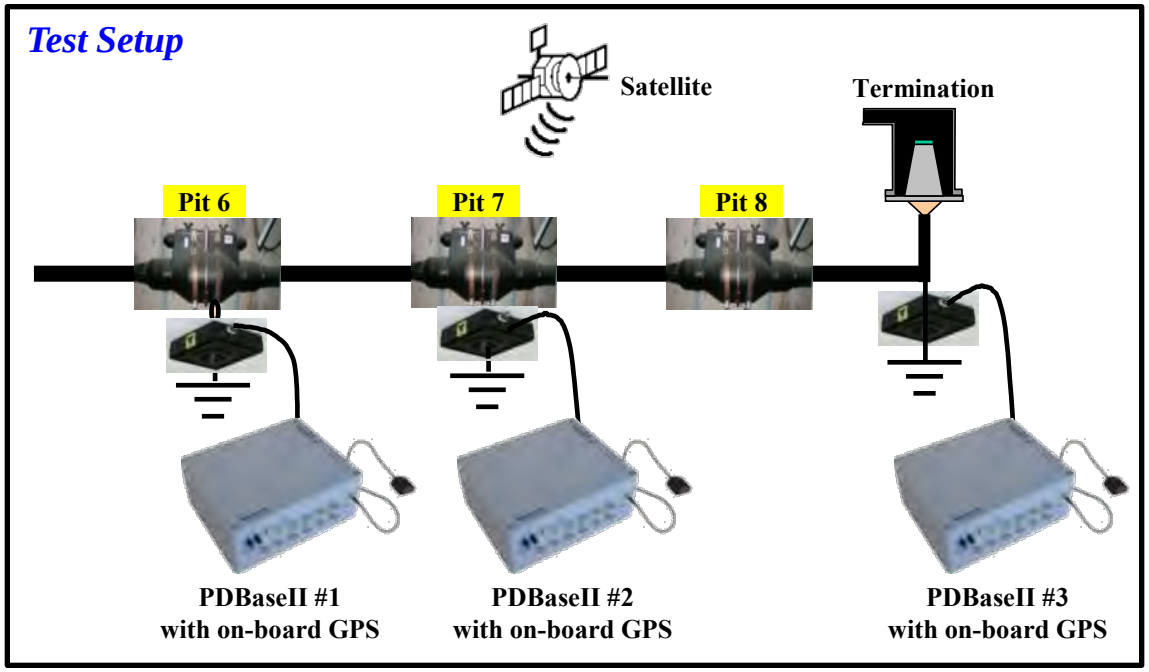
the cable failed exactly in the joint indicated as affected by PD, after having shown a growing amplitude trend

PD source localization #3

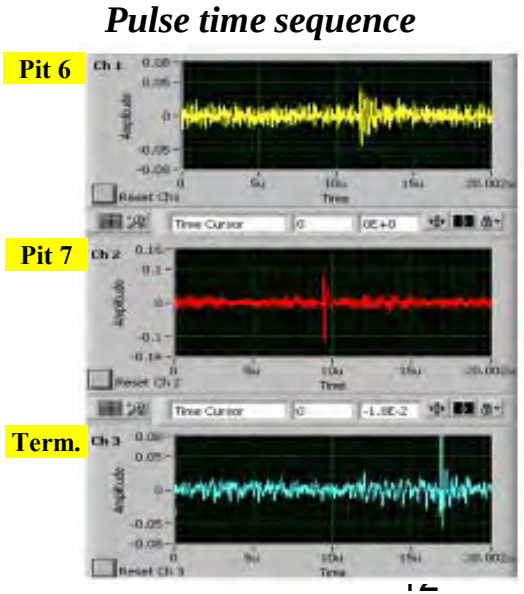
PD pulse arrival time (ATA)

- 3 sensors installed in 3 different locations
- Sensors connected through fiber optic link or other means to 1 oscilloscope
- Simultaneous actuation from the 3 channel
- Post processing software analysis for localization of the PD source

This analysis is 100% effective and conclusive to locate PD sources



Results



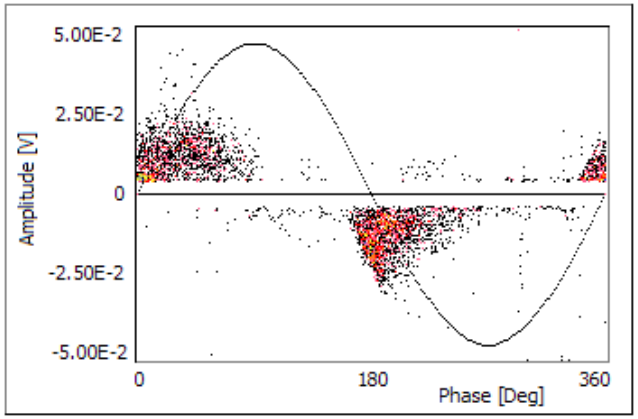
Working cases

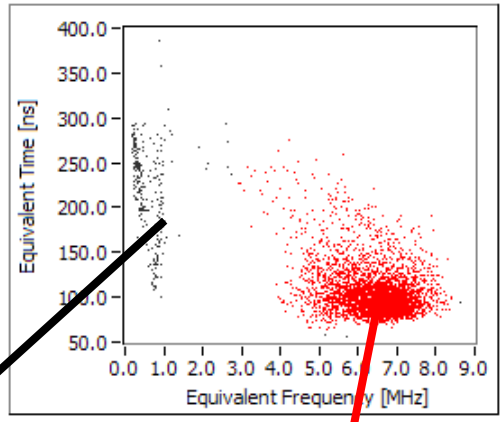
Case #1
Online PD test on oil-paper MV cable

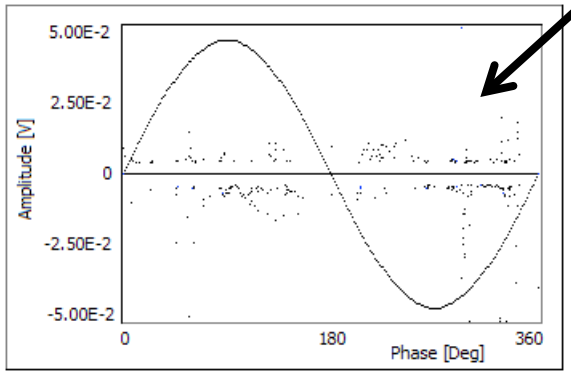
Apparatus: MV cable
Voltage level: 20 kV
Location: Europe

On line PD test on MV Cable: **PD measurement result.**

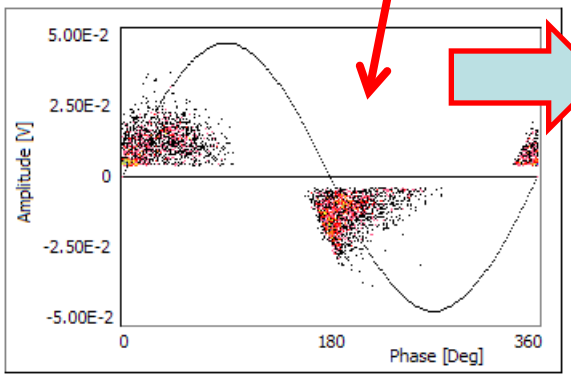
The PD measurement were performed from only one termination.



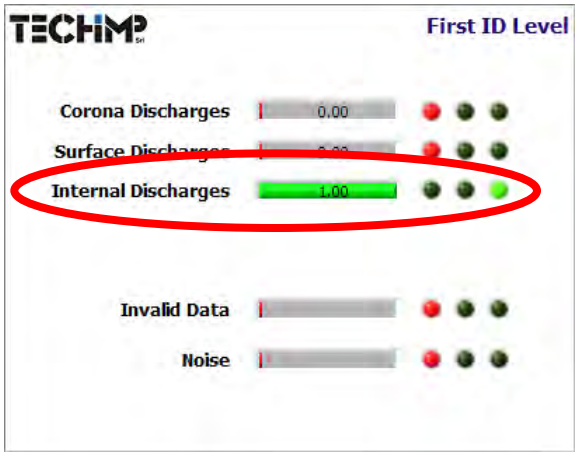




Background noise



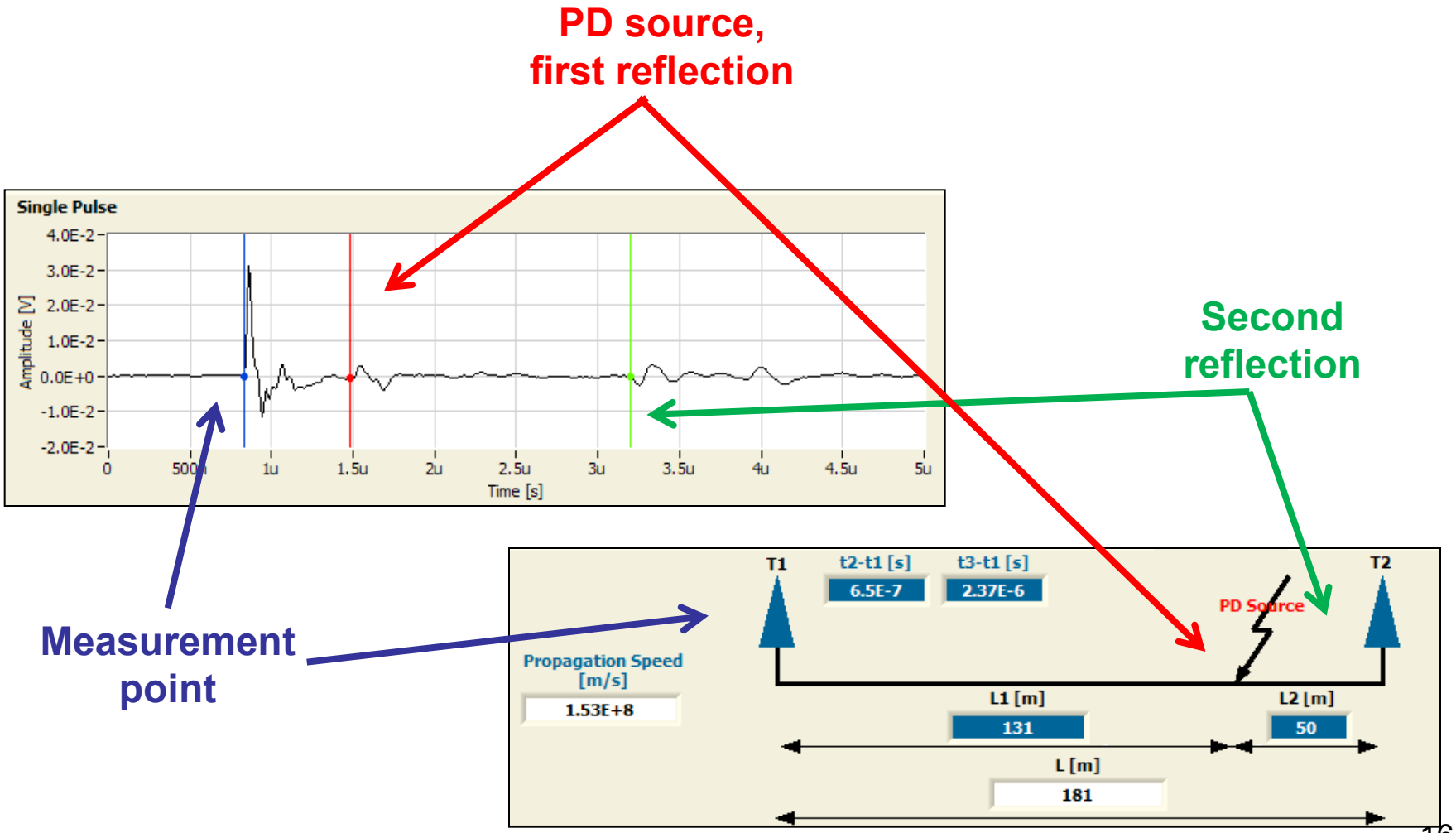
Internal PD



Case Study

ONLINE PD TEST ON MV CABLE: LOCALIZATION

On line PD test on MV Cable: **PD location through reflectometric technique.**



Case Study

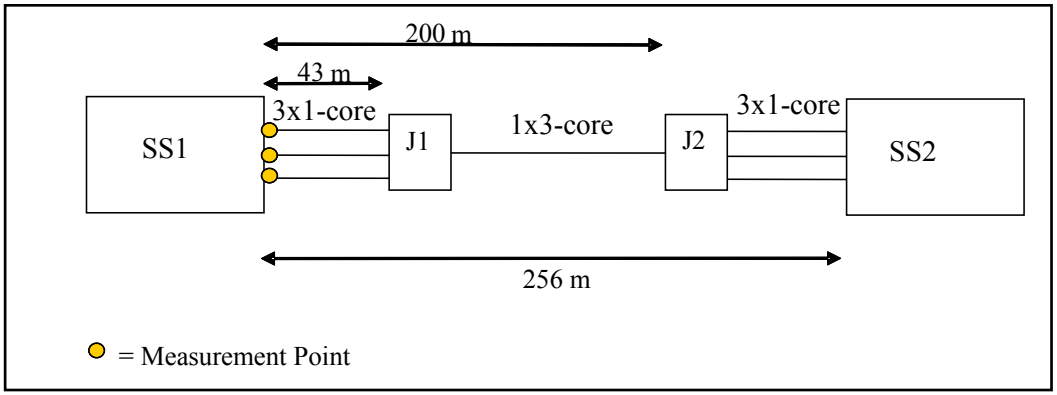
Case #2
Medium Voltage (MV) distribution cable online test

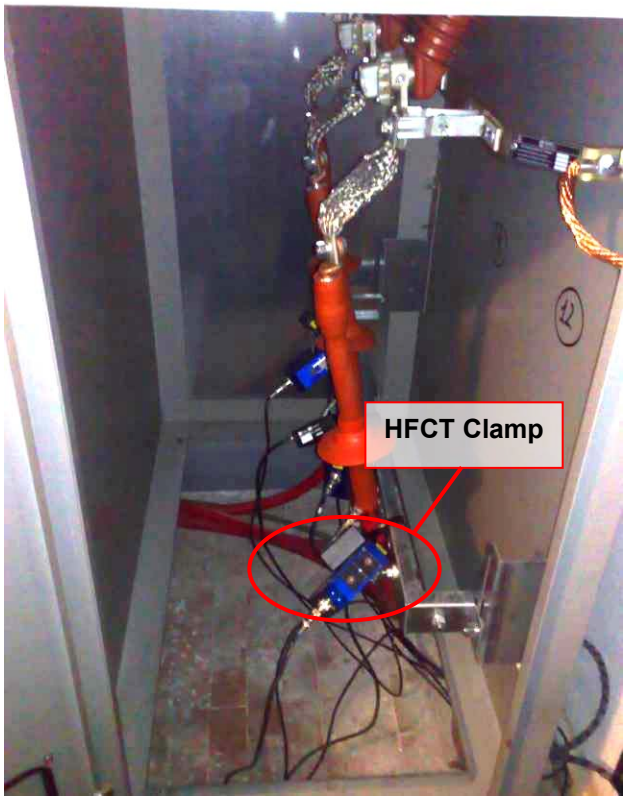
Apparatus: Three-core cable system
Voltage level: 15 kV
Location: Europe

Three PD measurement sessions performed during 1 year showing a really bad PD trend which brought the cable system to fail… You better trust PD measurements and diagnosis!!!

MV distribution cable online test

On line PD test on MV Cable: **System layout**

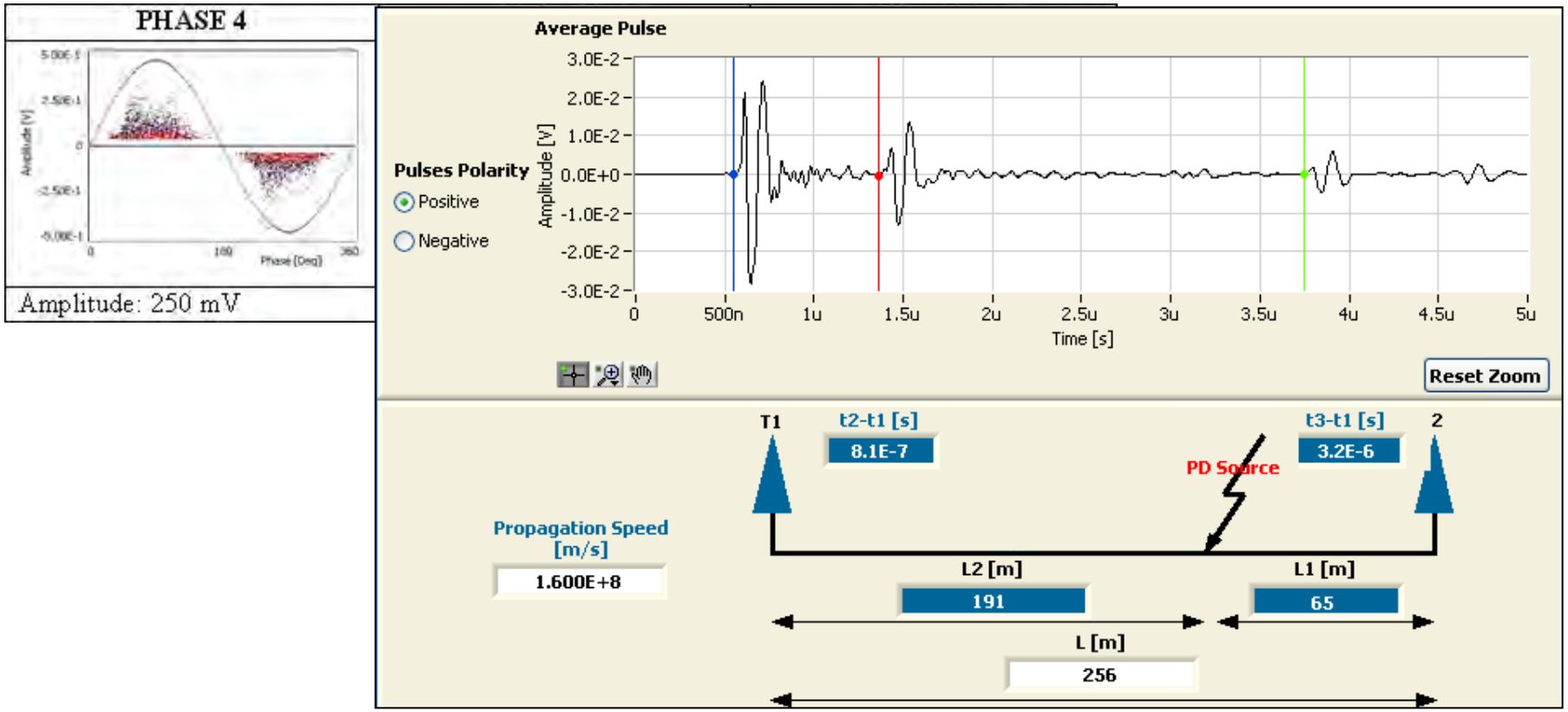




Case Study

MV distribution cable online test

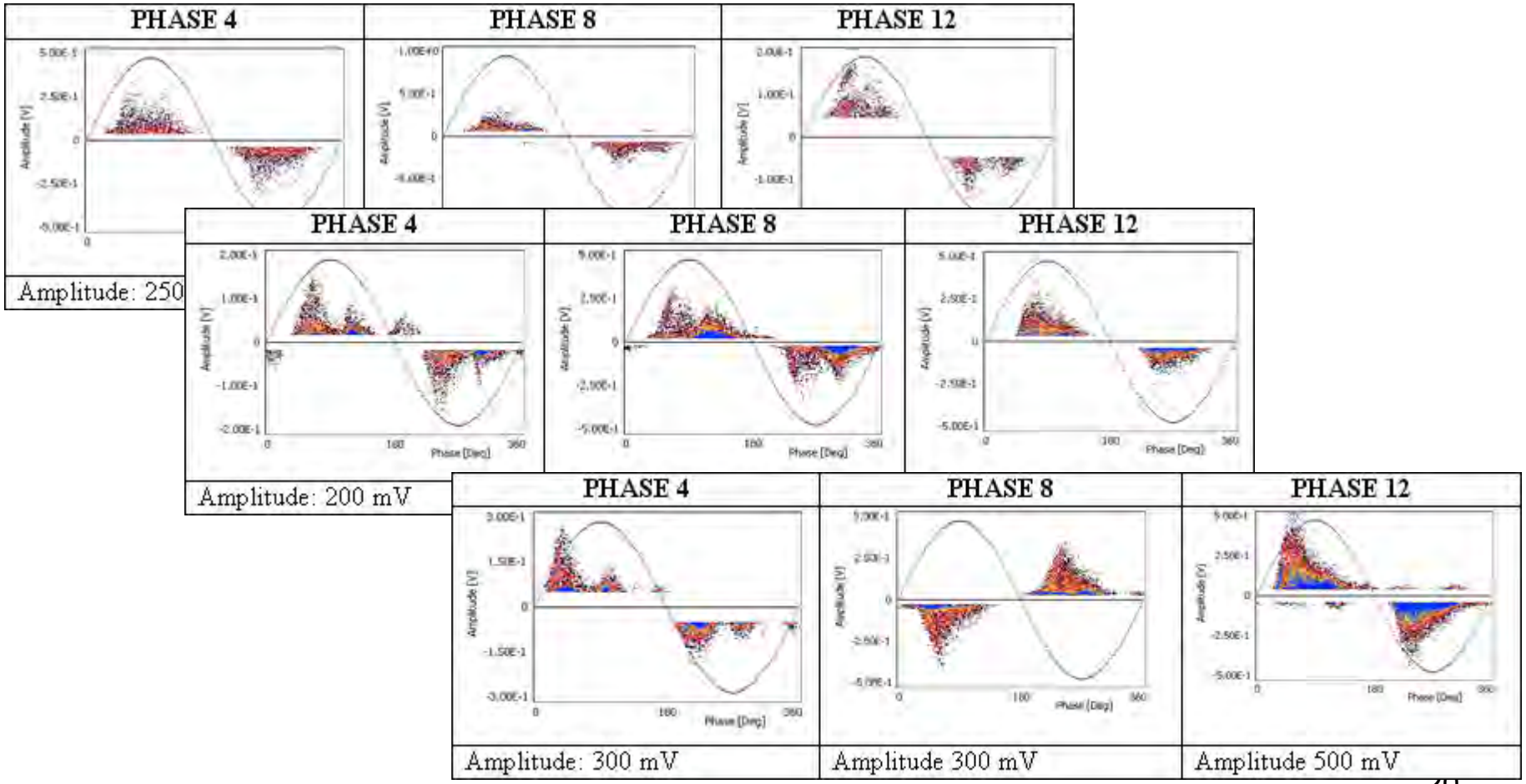
On line PD test on MV Cable: **PD measurement results.**
Internal PD detected in all the phases.



Case Study

MV distribution cable online test

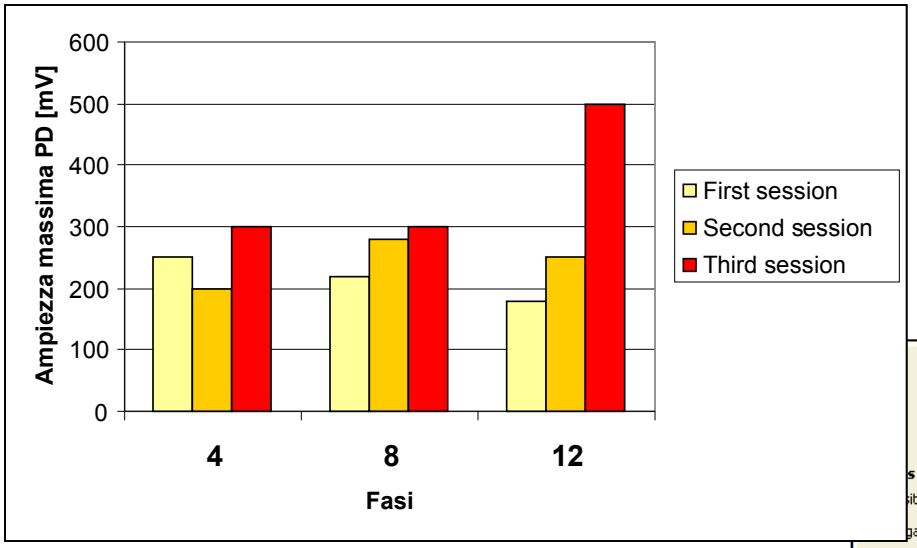
On line PD test on MV Cable: **PD measurement results.**
Internal PD detected in all the phases.



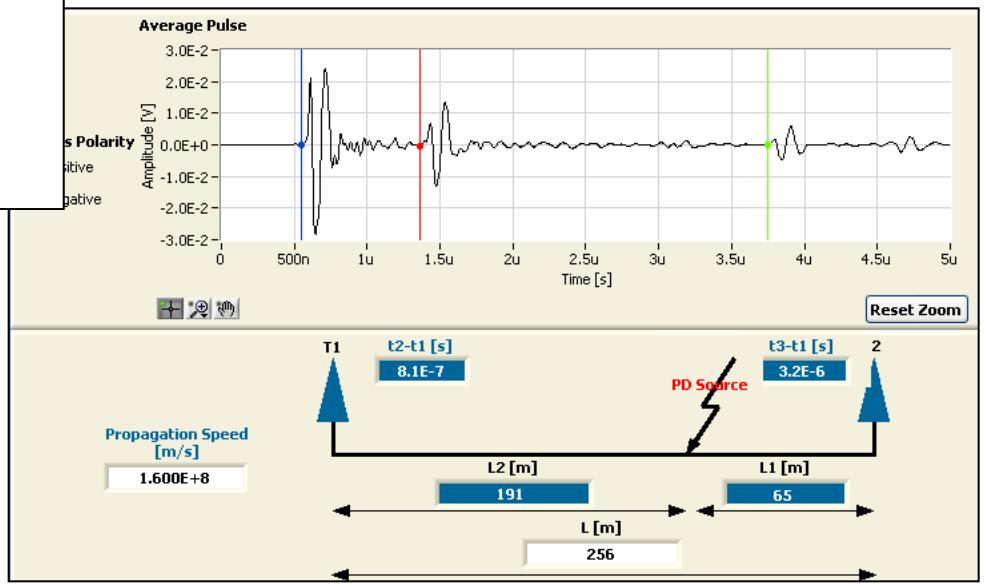
Case Study

MV distribution cable online test

On line PD test on MV Cable: **PD trend and location.**



Internal PD increased its amplitude very fast.



Localization through reflectometric techniques highlight that the source was located in joint 2.

During a DC test phase 12 had a breakdown. Online PD measurement and trend analysis were effective!!!

Case Study

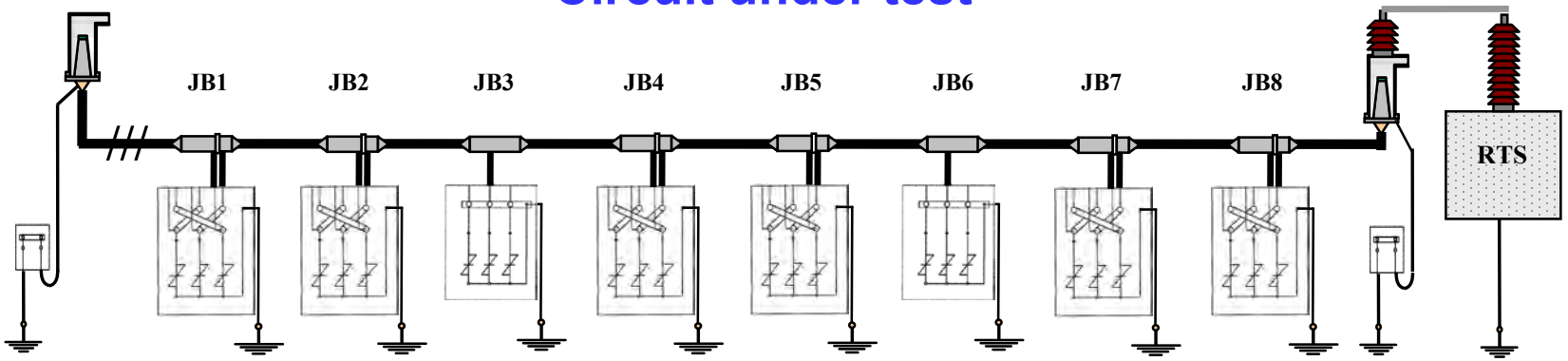
Case #3
Extra High Voltage (EHV) cable offline testing

Apparatus: Cable system
Voltage level: 400 kV
Location: United Arab Emirates

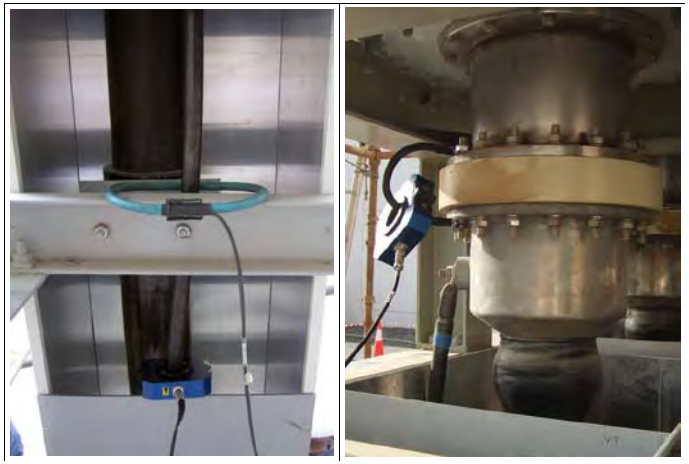
Quality control really highlights defects

EHV Cable offline testing

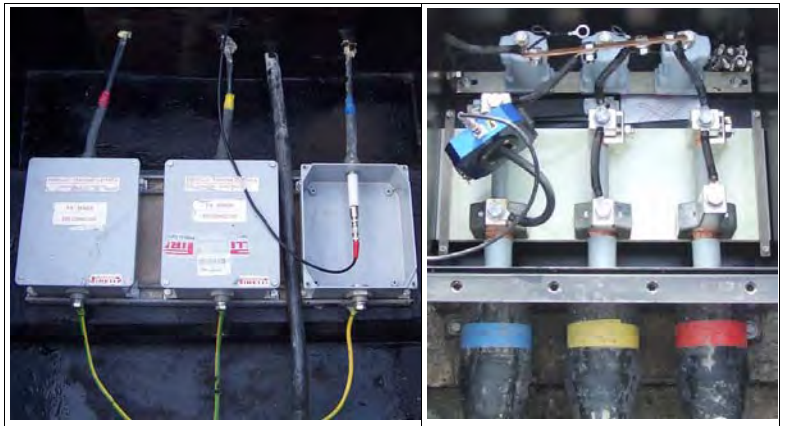
Circuit under test



Sensors connection at terminations



Sensors connection at link boxes

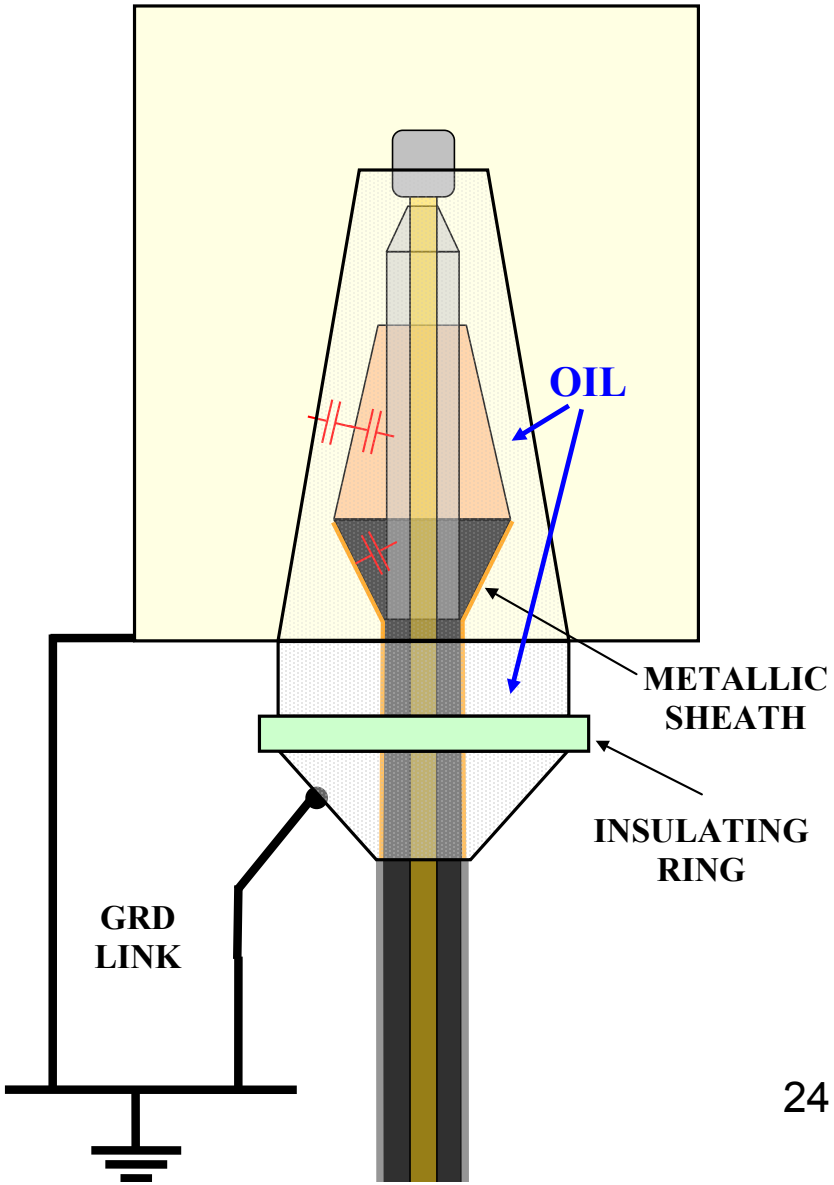


Case Study

EHV Cable offline testing

Insulation technology of terminations:

- **EPR stress cone**
- **immersed in oil**



Case Study

EHV Cable offline testing

1° PD measurement Results:

- **PD activities** detected at one side terminations of yellow and blue phases

Taken action:

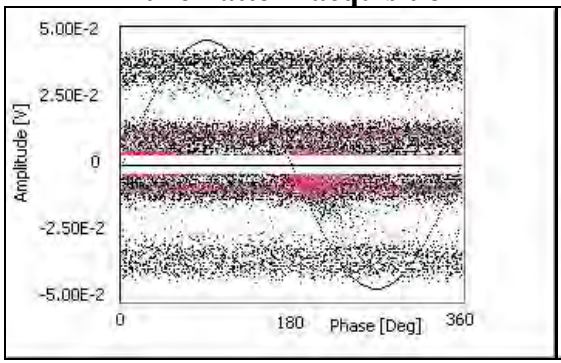
- inspection and **cleaning** of the outer part of the insulation system of two terminals

Re-installation..

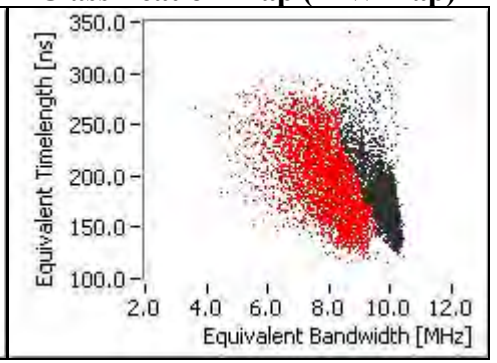
…2° PD measurement…

Case Study

Entire Pattern acquisition

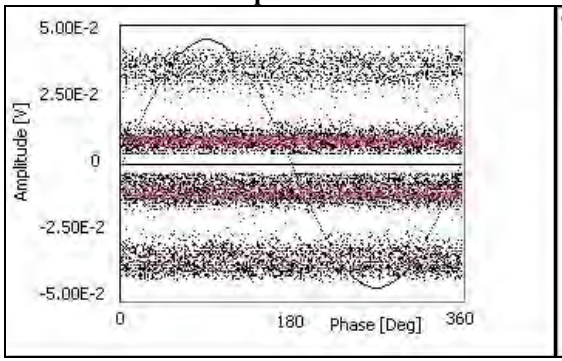


Classification Map (T-W map)

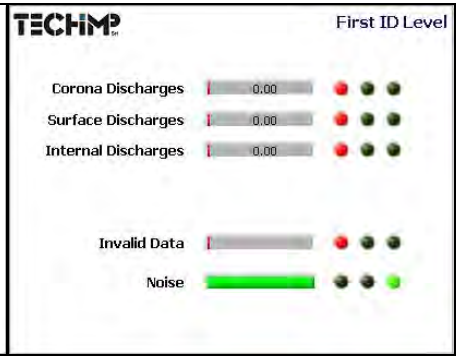


Black phenomenon(background noise

Sub-pattern

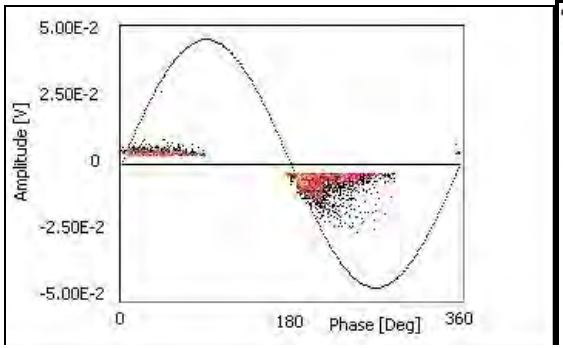


Automatic Identification

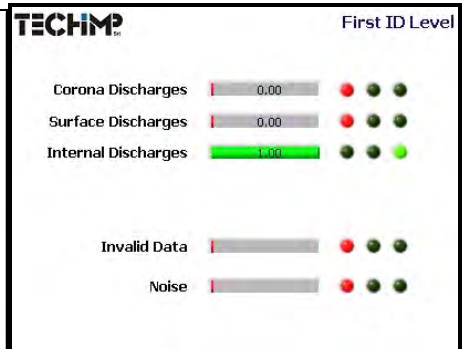


Red phenomenon(internal discharges)

Sub-pattern



Automatic Identification



EHV Cable offline testing

2° PD measurement Results:

- Again **PD activities** detected at the same terminations of yellow and blue phase

Taken action:

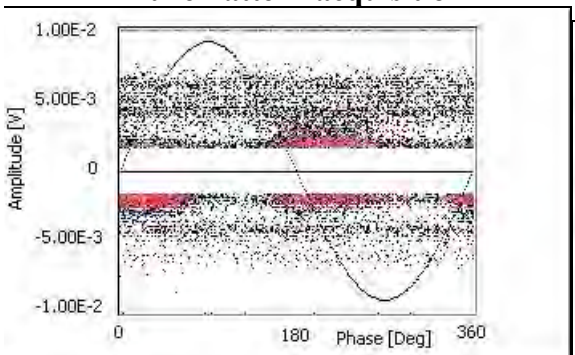
- **To replace terminations!!!**

After replacement..

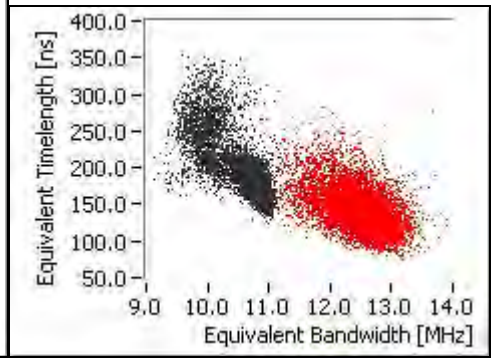
…3° PD measurement…

Case Study

Entire Pattern acquisition

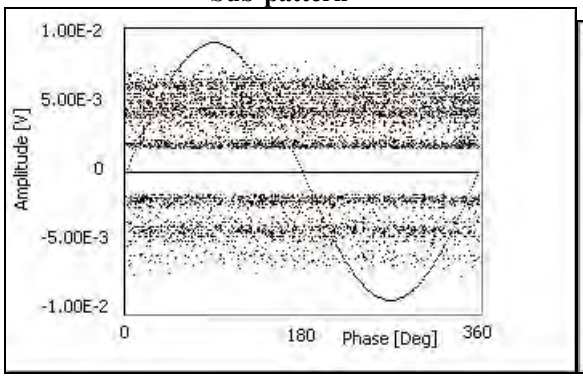


Classification Map (T-W map)

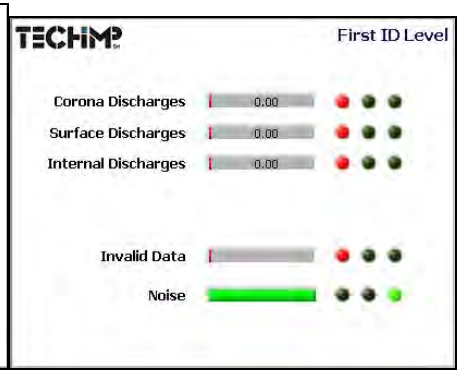


Black phenomenon (background noise)

Sub-pattern

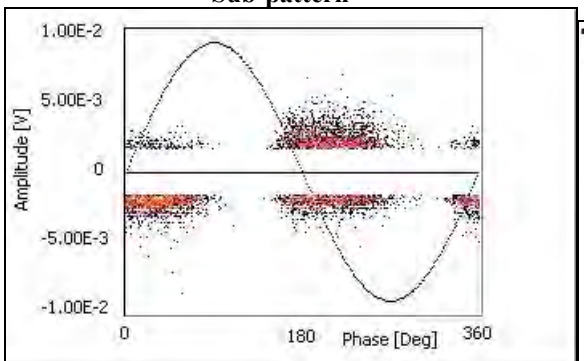


Automatic Identification

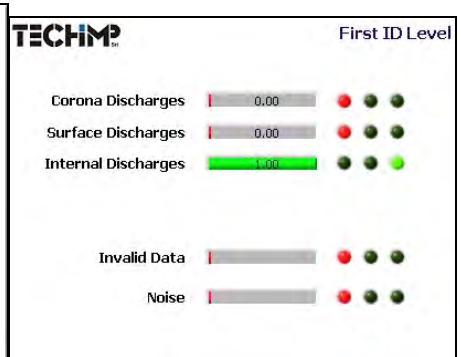


Red phenomenon (internal discharges)

Sub-pattern



Automatic Identification



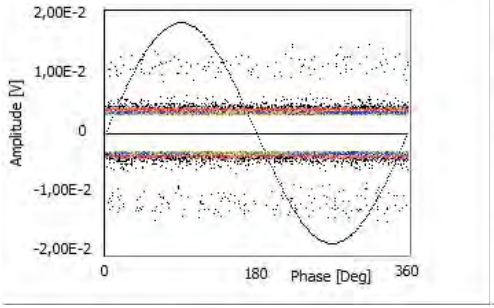
EHV Cable offline testing

…3° PD measurement after terminals replacement….

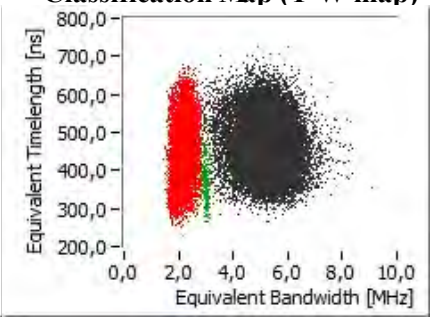
PD FREE!!

…

Entire Pattern acquisition

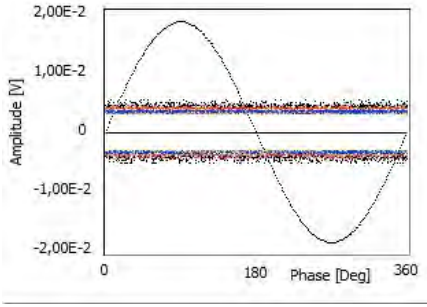


Classification Map (T-W map)

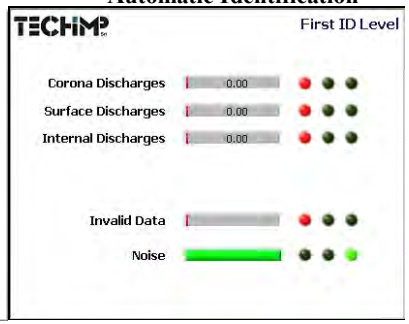


Black cluster (background noise)

Sub-pattern

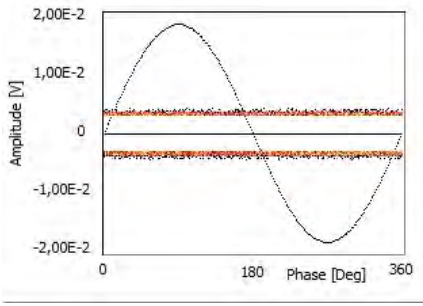


Automatic Identification

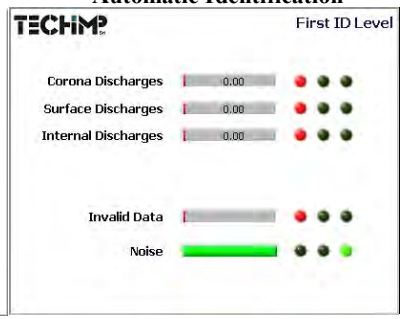


Red cluster (background noise)

Sub-pattern

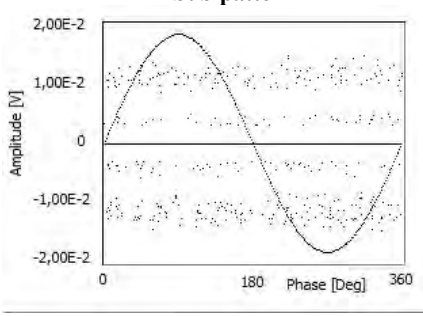


Automatic Identification

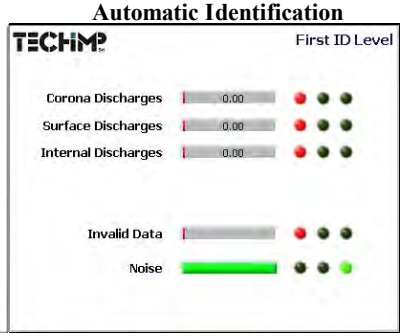


Green cluster (background noise)

Sub-pattern



Automatic Identification

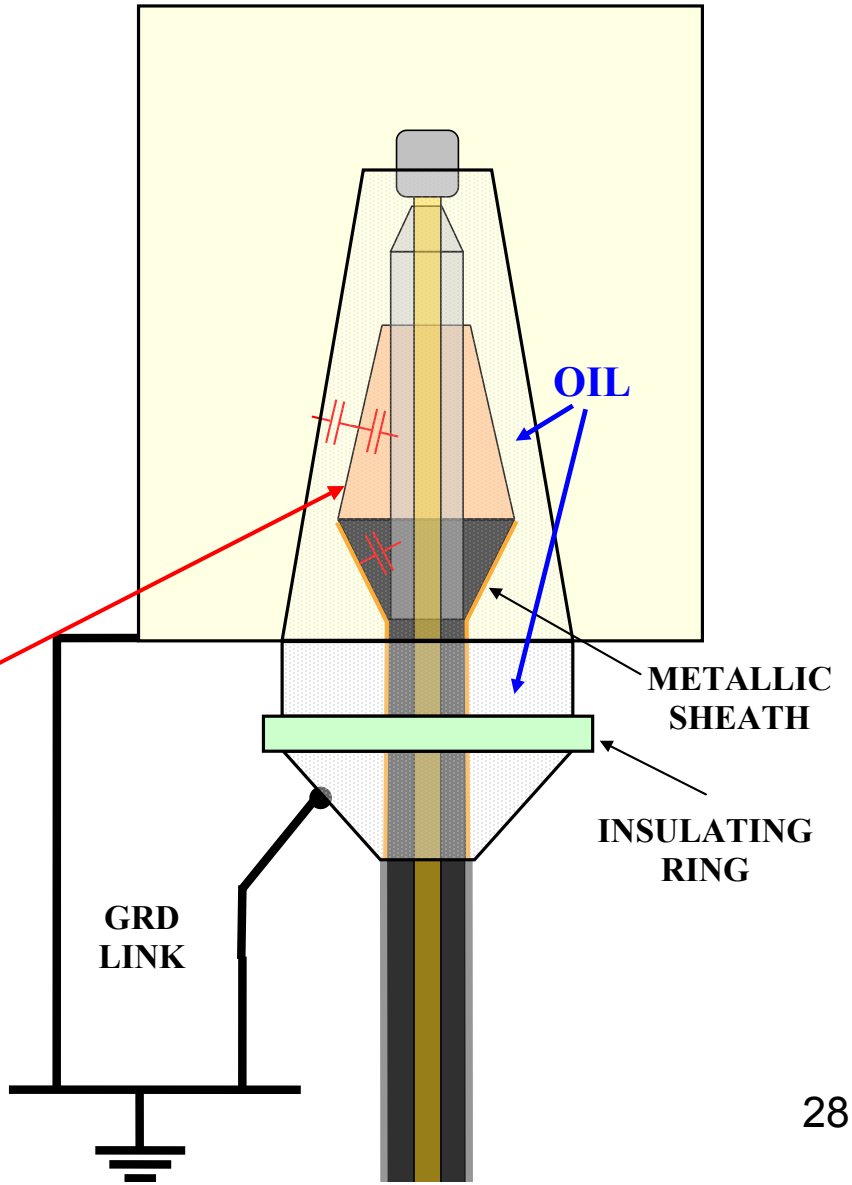


Case Study

EHV Cable offline testing

PD inference resulted to be effective:

during inspection a defect was found in the stress cone immersed in oil



Case Study

Conclusions

- The decomposition of the pulse frequency and time characteristics allows:
  - Enhanced noise rejection
  - PD **separation**
  - PD **location**
  - PD source **identification** by artificial intelligence methods
- The combination of “separation and identification” leads to improved reliability of PD evaluation and diagnosis
- The presented technique provides information that can be exploited to enhance maintenance procedure plans (CBM), fundamental in reducing operational costs in a utility cable network

Thank You