TECHIMP

Italy

TECHIMP **MV CABLES** CASE STUDIES

LIST OF CASE STUDIES

- 20kV MV Cables – On-line PD Test
- 15kV MV Cables – On-line PD Test
- 15kV MV Cables – On-line PD Test
- Up to 33kV MV Cables – On-line PD Test
- 15kV MV Feeder – VLF Off-line PD Test
- 14kV MV Feeder – VLF Off-line PD Test
- 25kV MV Feeder – VLF Off-line PD Test
- 13kV MV Cables – On-line PD Test

LIST OF CASE STUDIES

- 13kV MV Cables – On-line PD Test
- 13kV MV Cables – On-line PD Test
- 11kV MV Cables – On-line PD Test

TECHIMP SpA

LOCATION	**EUROPE**
EUT	**MV CABLES**
RATED VOLTAGE	**20 kV**
INSULATION	**OIL - PAPER**
LENGTH	
VINTAGE	
TYPE OF TEST	**ON-LINE**

CASE STUDY

On-line PD detected in MV Cables

PD measurement setup

PD Sensor

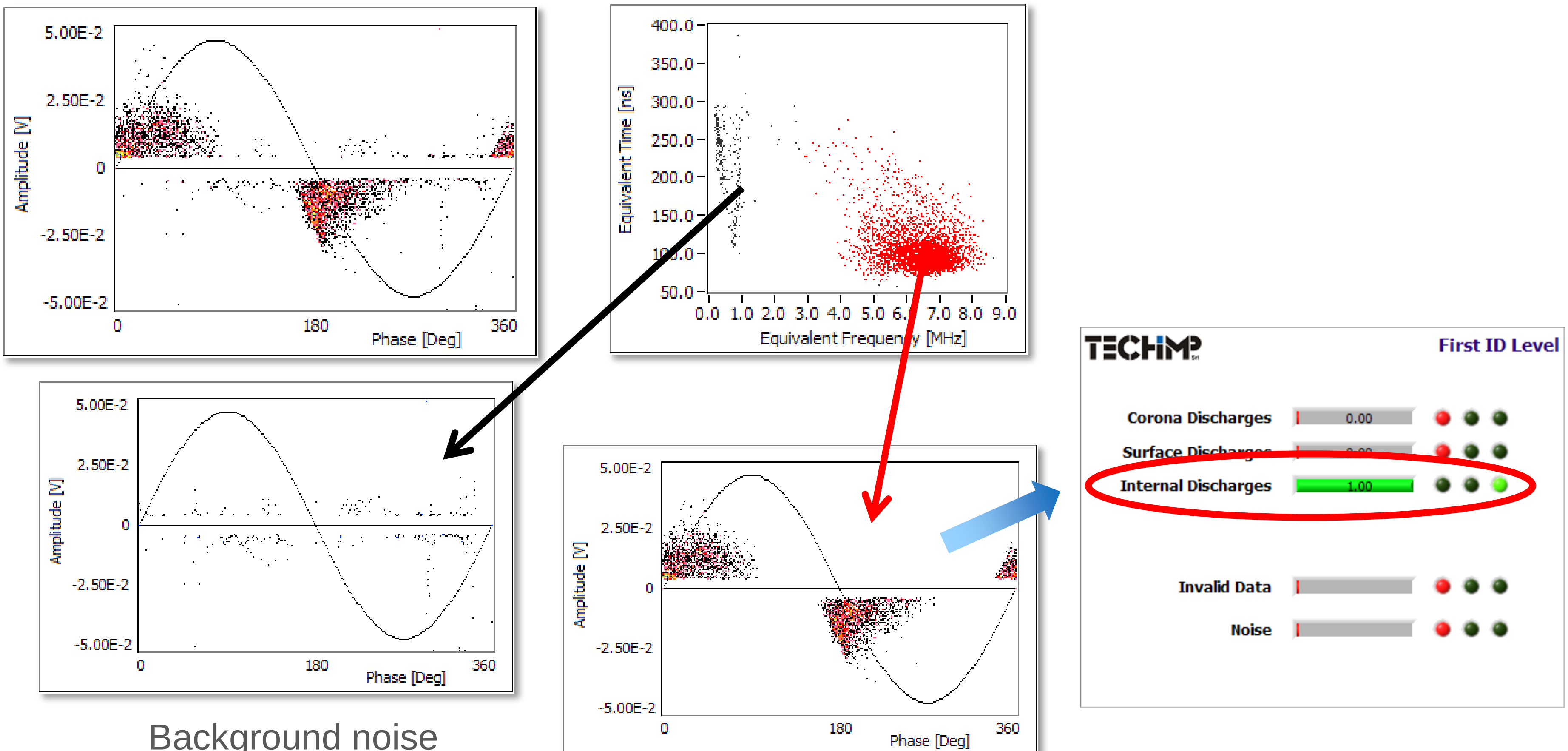
LFCT Sensor

PD SENSORS:
- 3 FMC positioned on MV Cables

SYNCH SENSOR:
- 1 LFCT positioned around one MV Cable

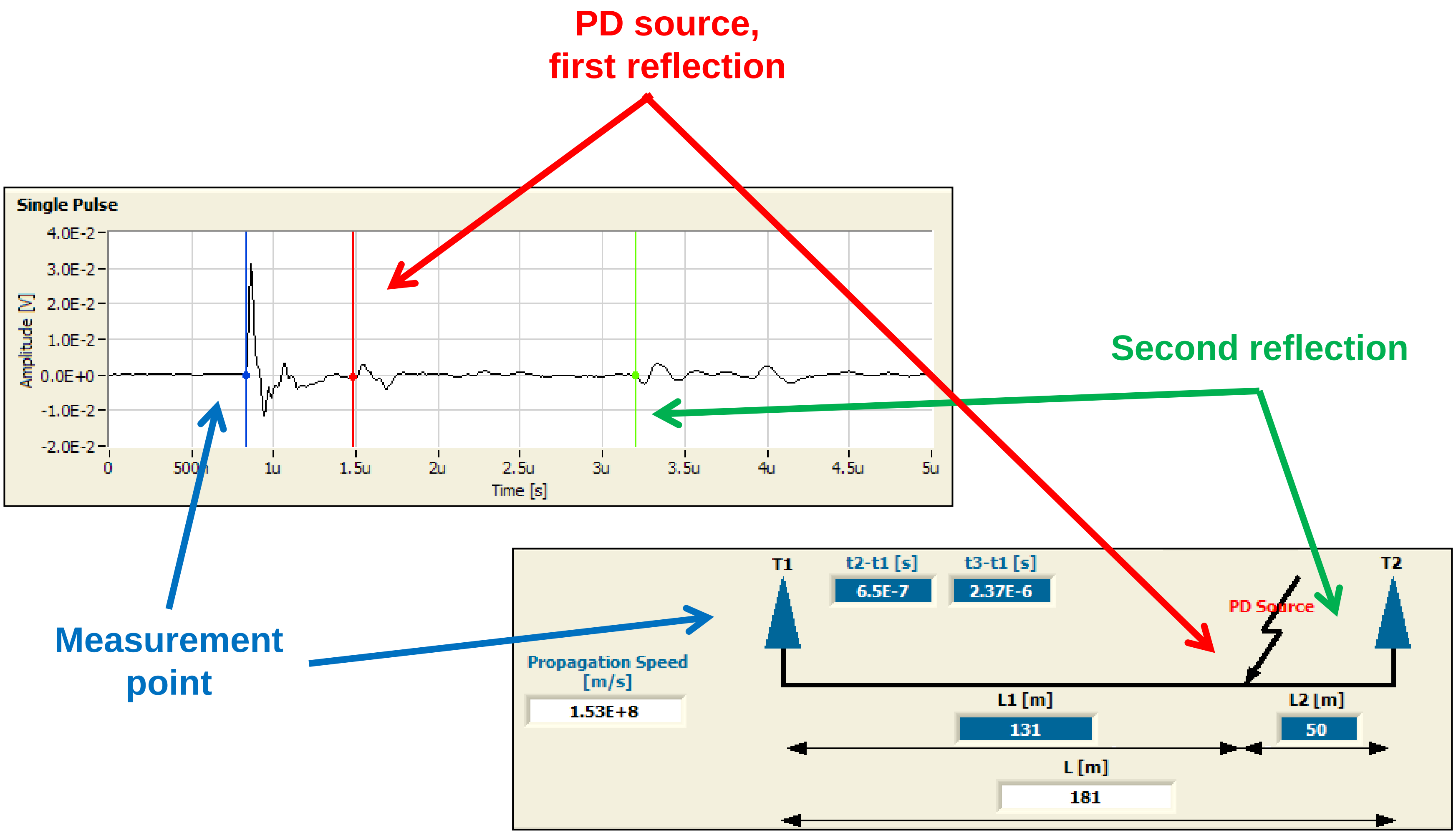
PD measurement results

The PD measurement were performed from only one termination.



Internal PD

PD location through reflectometric technique.



TECHIMP SpA

LOCATION	**SOUTH AMERICA**
EUT	**3-CORE MV CABLES**
RATED VOLTAGE	**15 kV**
INSULATION	
LENGTH	
VINTAGE	
TYPE OF TEST	**ON-LINE**

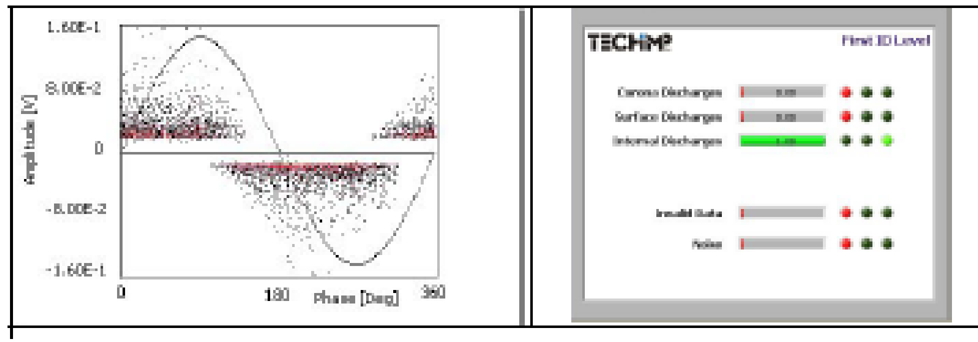
CASE STUDY

On-line PD detected in MV Cables

PD measurement results

On line testing of MV cable in industrial plant (Argentina)

Multiple internal PD activities detected



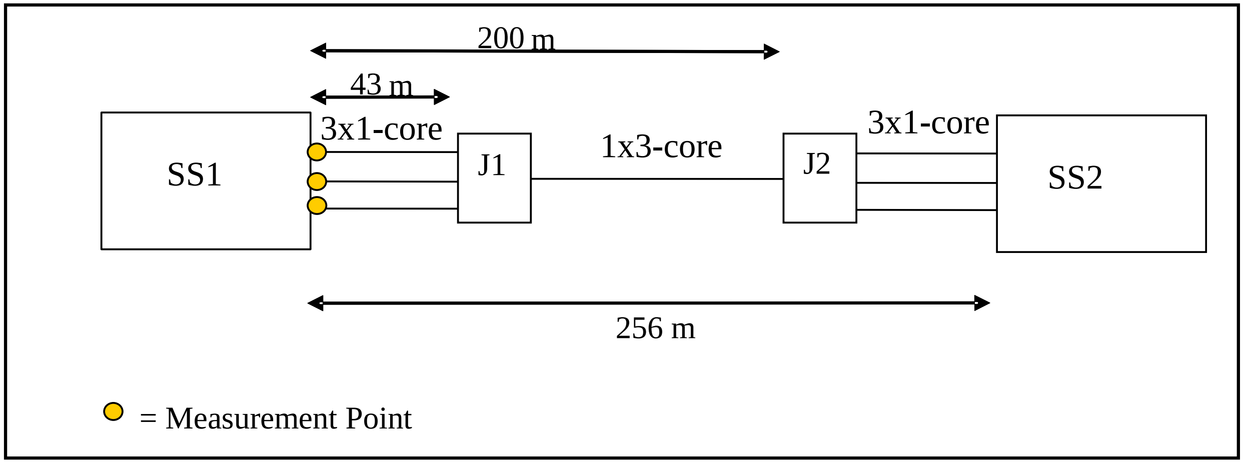
The utility did not carry out any maintenance action….
The cable failed four months later

LOCATION	**EUROPE**
EUT	**3-CORE MV CABLES**
RATED VOLTAGE	**15 kV**
INSULATION	
LENGTH	
VINTAGE	
TYPE OF TEST	**ON-LINE**

CASE STUDY

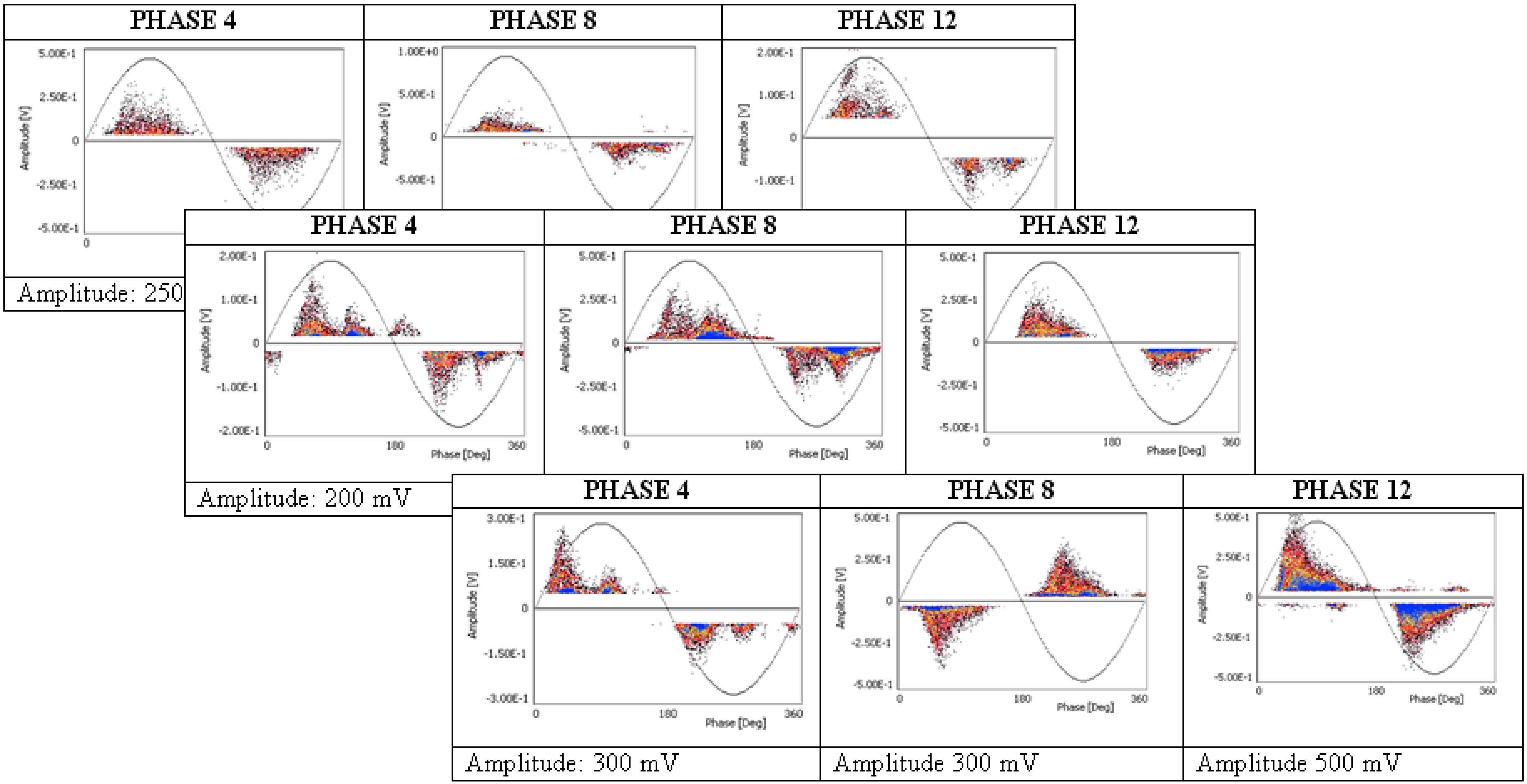
On-line PD detected in MV Cables

PD measurement setup



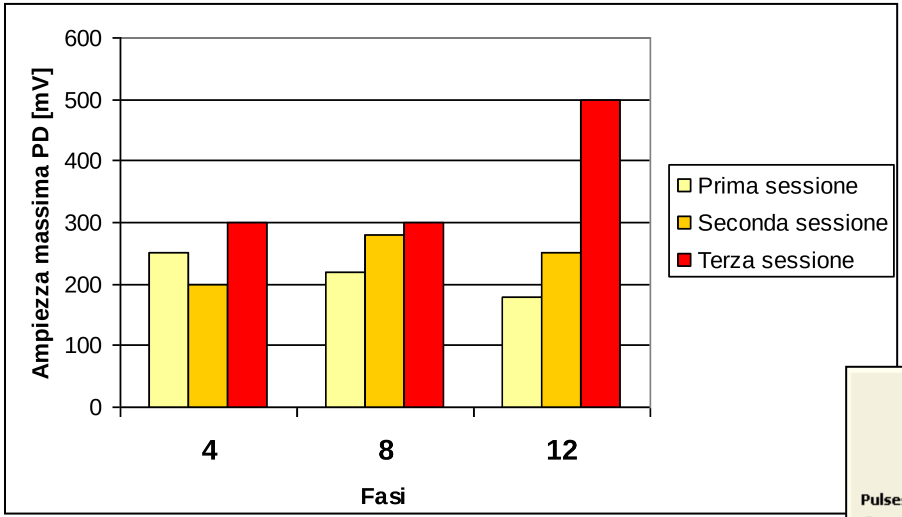
PD measurement results

Internal PD detected in all the phases.

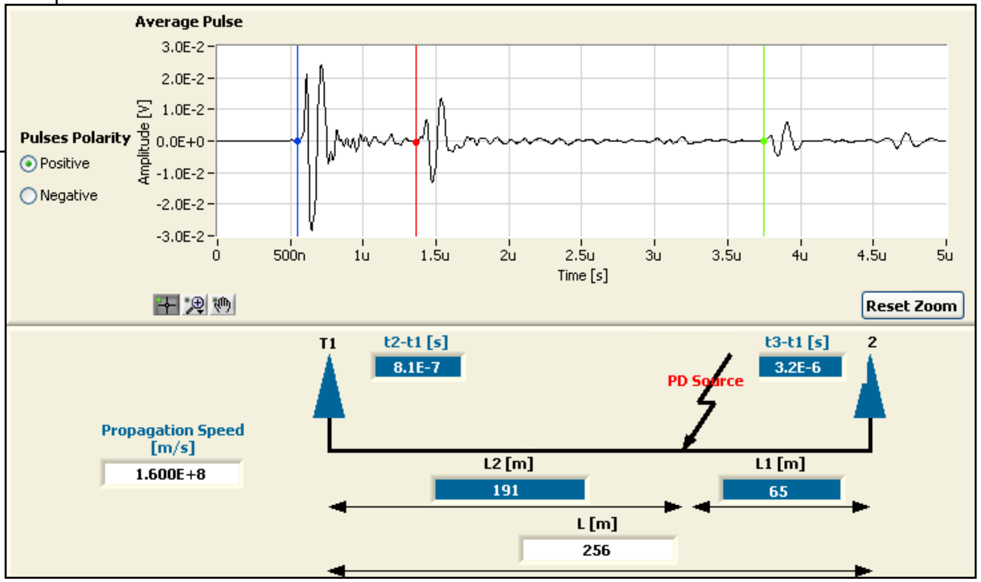


PD measurement results

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!!!

TECHIMP SpA

LOCATION	**EUROPE**
EUT	**3-CORE MV CABLES**
RATED VOLTAGE	**UP TO 33kV**
INSULATION	**XLPE, EPR, PILC**
LENGTH	**VARIOUS**
VINTAGE	
TYPE OF TEST	**ON-LINE**

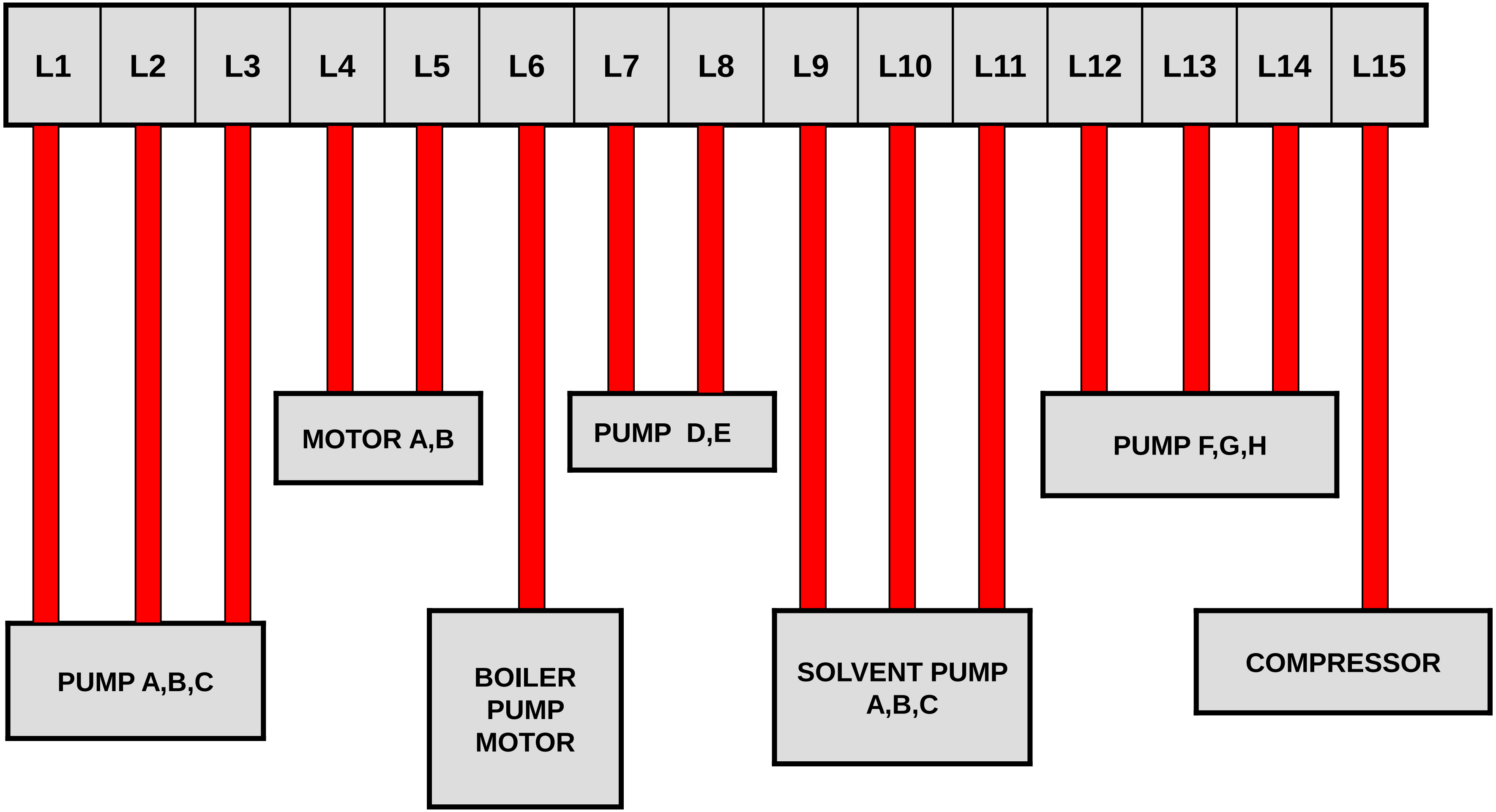
CASE STUDY

On-line PD detected in MV Cables. Three cases.

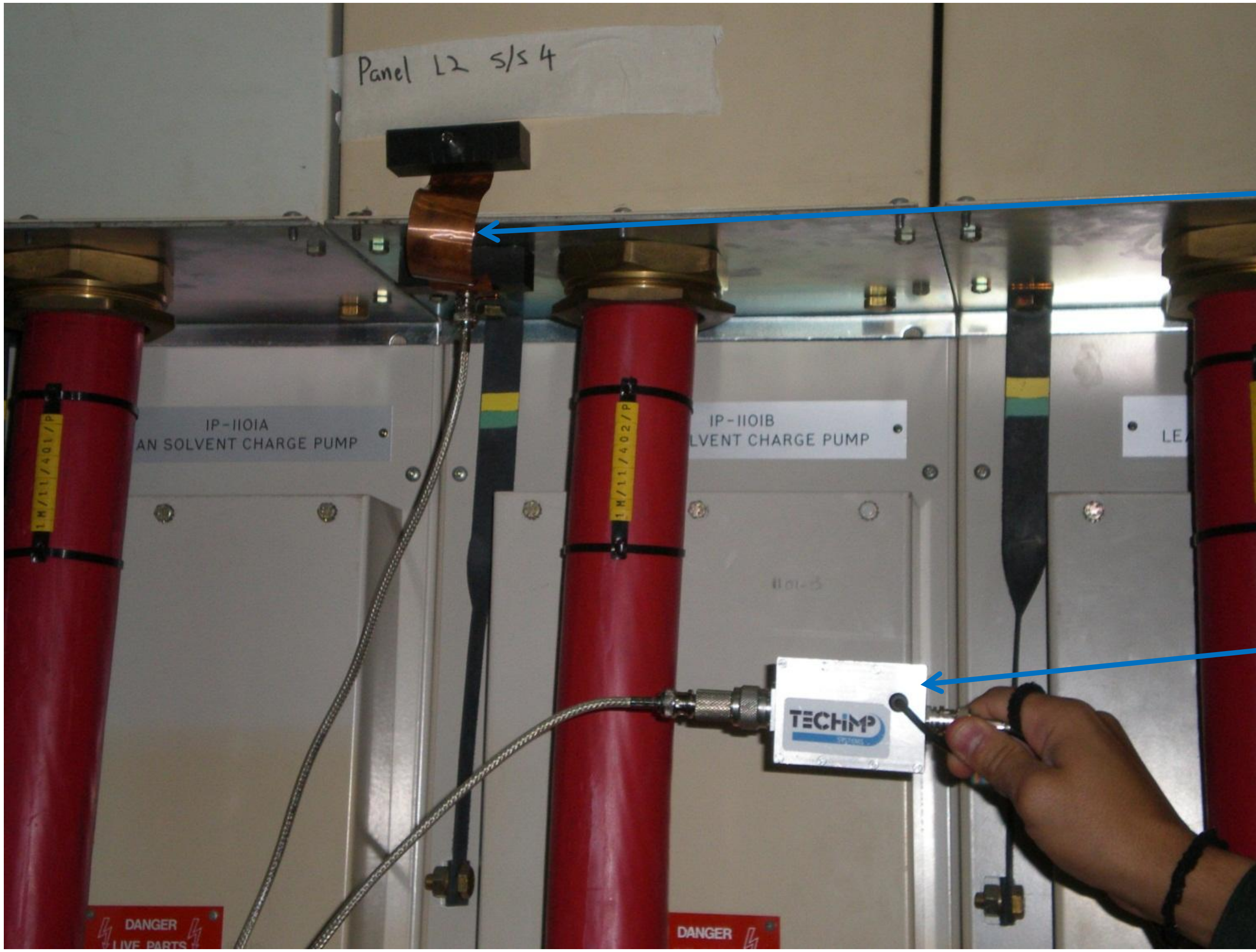
Primary substations and power plants

- Main characteristics:
  - No T-Joints
  - No branches
  - Cables shorter than 2 km
  - Voltage up to 33 kV

Typical layout



PD measurement setup



TEV Sensor

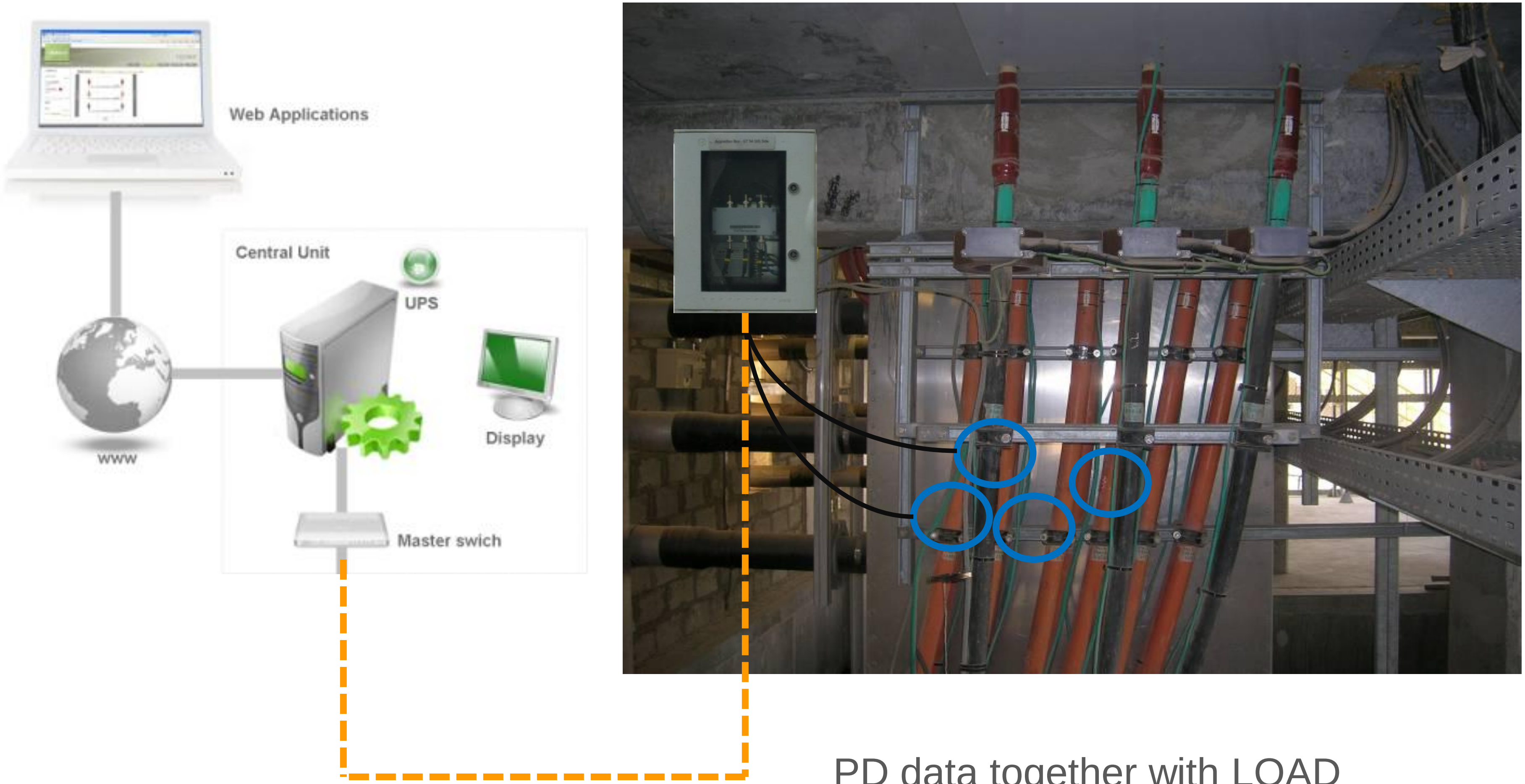
Frequency Shifter

PD measurement setup

Optimal solution (technical)

- Sensors (HFCT or FMC) installed in each cable termination
- One monitoring unit with minimum 6 acquisition channels (2 cable circuits)
- Fiber optic communication to the Local Server (CU) in the substation
- Optional: data transmission via Modem
- Aim of the monitoring system is to Locate Cables and Switchgears having defects, monitor the trend, give alarms
- PD localization done from remote or from local operators using portable units

PD measurement setup



PD data together with LOAD information are sent to the CU

Alternative case #1

- Use portable instruments to carry out on-line screening
- Aim of the test is just to highlight cables having PD
- Carry out the test on ALL switchgears in the same room
- Repeat the test after 2-6 months (depending on PD type) in order to evaluate trend
- Put the data in a DATABASE CU
- On line localization only if PD trend has changed
- Off-line localization only for difficult situations where on line localization can be non effective

Suggested actions

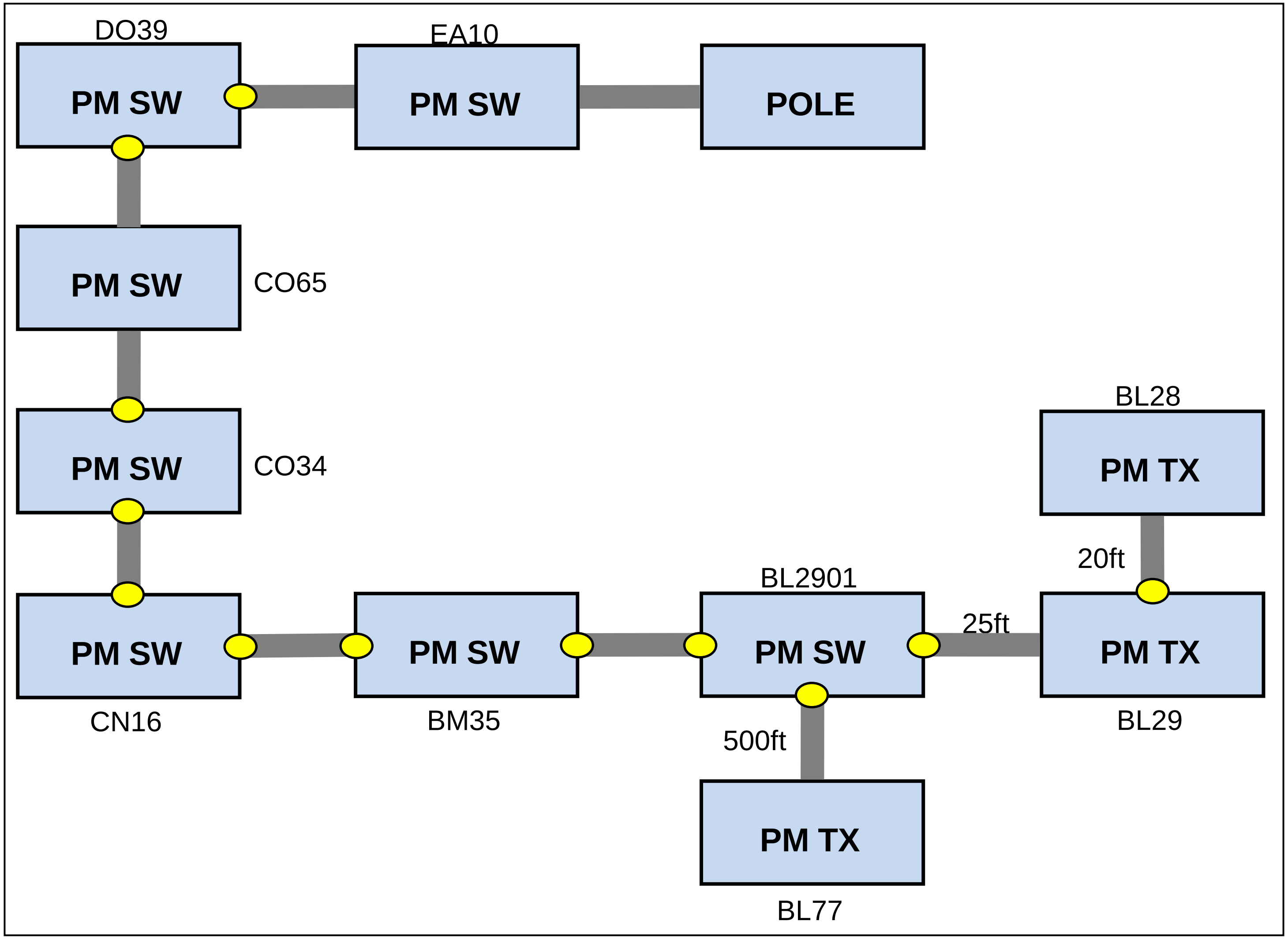
- Individuate one substation for a pilot project
- Install permanent sensors (600 USD/cable)
- Install PD monitoring system
- Average Cost PDM : 10k USD / cable

Ring Network

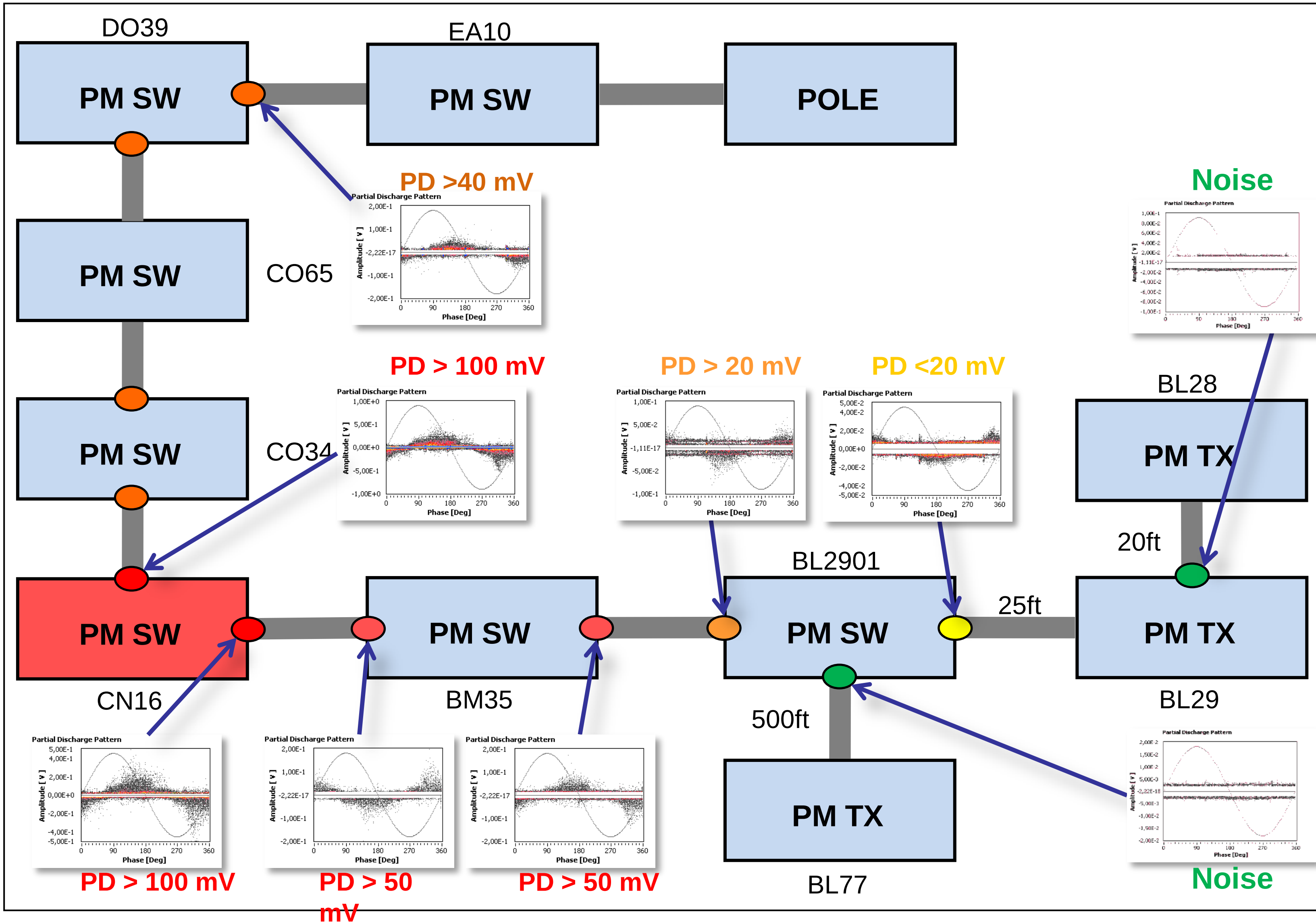
- Main characteristics:
  - Incoming - Outcoming switches
  - No T-Joints
  - No branches
  - Cables shorter than 2 km

PD measurement setup

Typical layout



Patterns of Yellow Phase

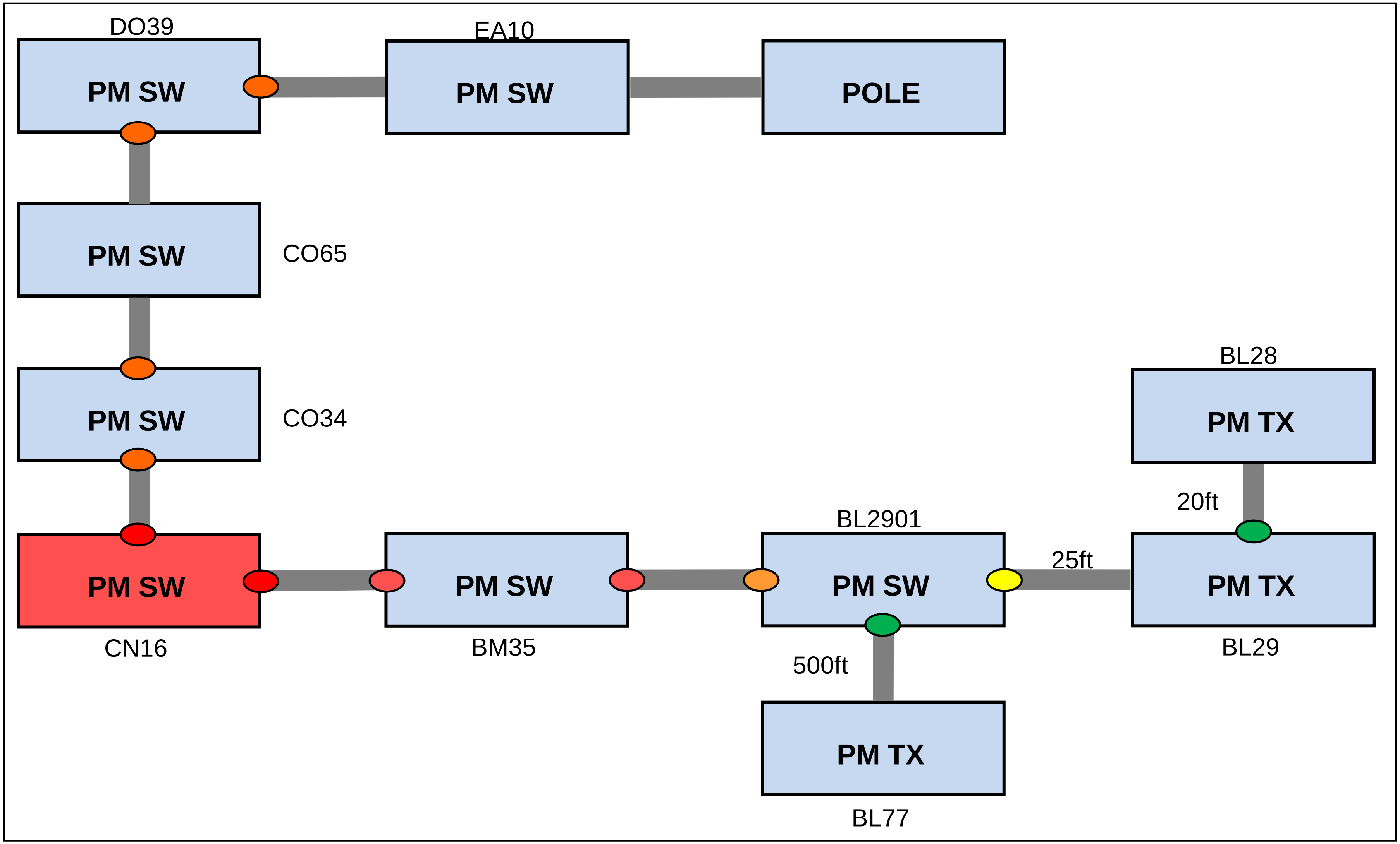


Amplitude and repetition rate evaluation

- Amplitude and repetition rate were evaluated for each PD in each detection point.
- Evaluation is done comparing acquisitions having the same trigger (20 mV).
- This is the result for yellow phase:

Detection point	Amplitude
BL2901 – BL29	12 mV
BL2901 – BM35	29 mV
BM35 – BL2901	45 mV
BM35 – CN16	58 mV
CN16 – BM35	148 mV
CN16 – CO34	125 mV
CO34 – CN16	74 mV
CO34 – CO65	78 mV
DO39 – CO65	78 mV
DO39 – EA10	41 mV

Diagnosis


DO39
PM SW
EA10
PM SW
POLE
PM SW
CO65
PM SW
CO34
BL28
PM TX
20ft
BL2901
25ft
PM SW
CN16
PM SW
BM35
PM SW
PM TX
BL29
500ft
PM TX
BL77

Comments

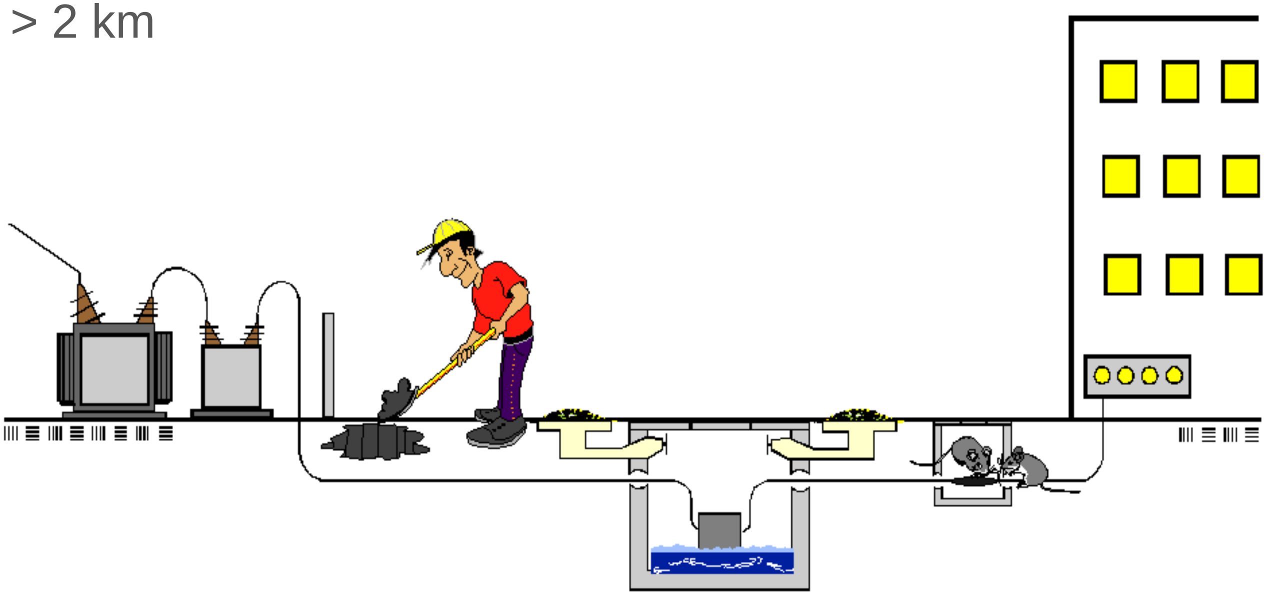
- A PD was detected in the circuit under test.
- The same PD was detected in many points of the circuit due to the propagation properties of the PD
- IT was important to test all (or almost all) cable termination in order to correlate amplitude and repetition rate and locate the position of the PD
- TDR reflectometry methods can not work on line in these kind of circuits becouse this configuration of padmounted cables do not generate significant reflections.
- Firther localization can be however done using TDR just interrupting one switch
- Anyway, this operation can be devised in a second moment, i.e., when the PD increase.

Suggested best practice

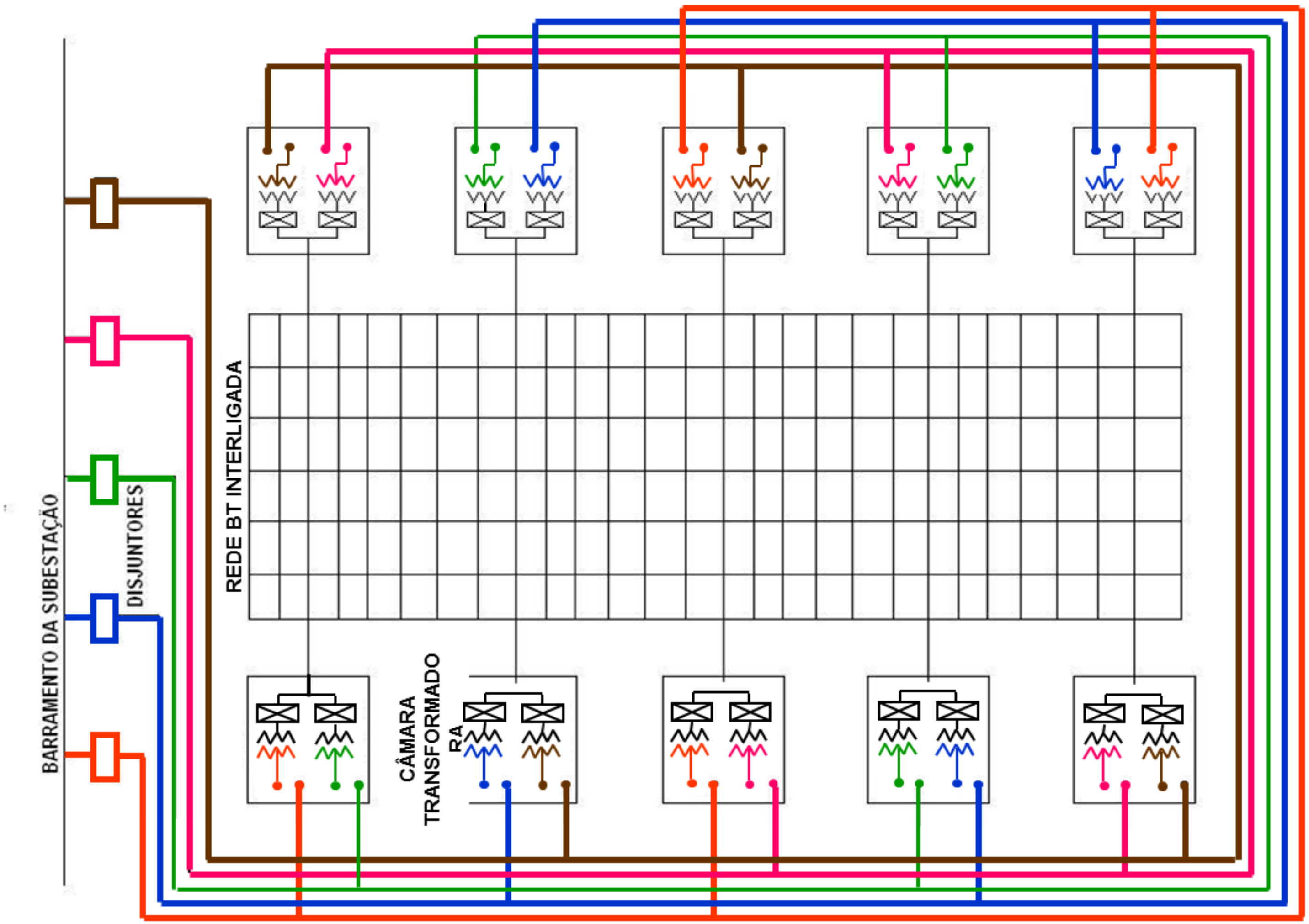
- Use portable instruments to carry out on-line screening
- Aim of the test is to highlight cables having PD
- Carry out the test on ALL sections
- Repeat the test after 2-6 months (depending on PD type) in order to evaluate trend
- On line localization NOT ALWAYS possible (no reflections)
- Off-line localization suggested, but only after having noticed degradation

Branches

- Main characteristics:
  - Many joints same manhole
  - T-Joints
  - Branches
  - Long cables > 2 km



PD measurement setup



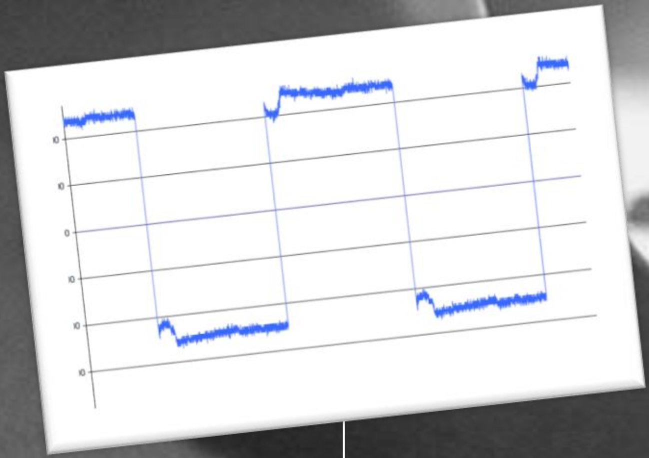
PD measurement setup

PD measurement setup

Suggested best practice

- Aim of the test is to highlight cables having PD
- Carry out the test on ALL sections
- Repeat the test after 2-6 months (depending on PD type) in order to evaluate trend
- On line localization NOT ALWAYS possible (no reflections)
- Off-line localization suggested, but only after having noticed degradation

TECHIMP SpA

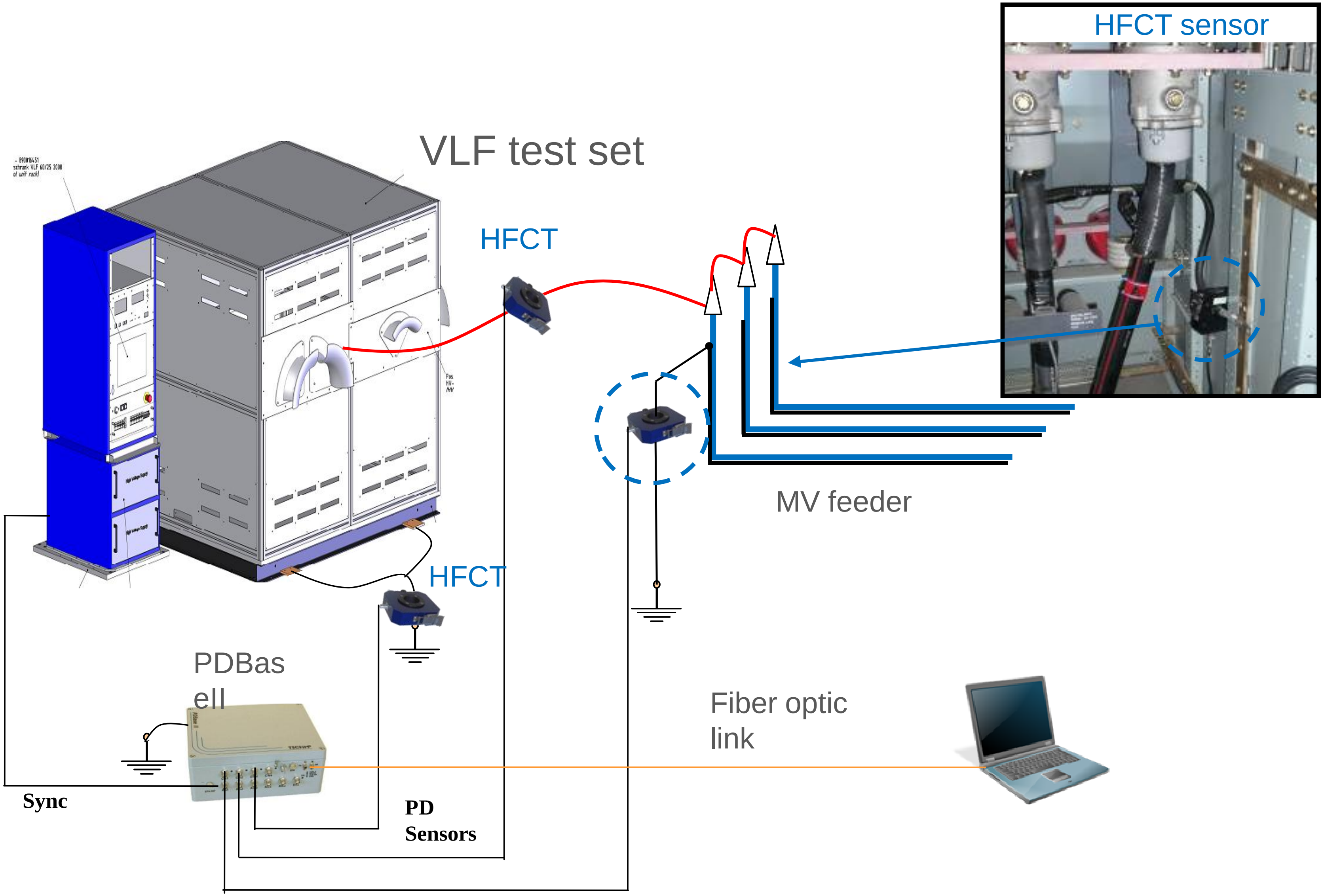


LOCATION	**USA**
EUT	**MV CABLE FEEDER**
RATED VOLTAGE	**15 kV**
INSULATION	
LENGTH	**VARIOUS**
VINTAGE	
TYPE OF TEST	**VLF OFF-LINE**

CASE STUDY

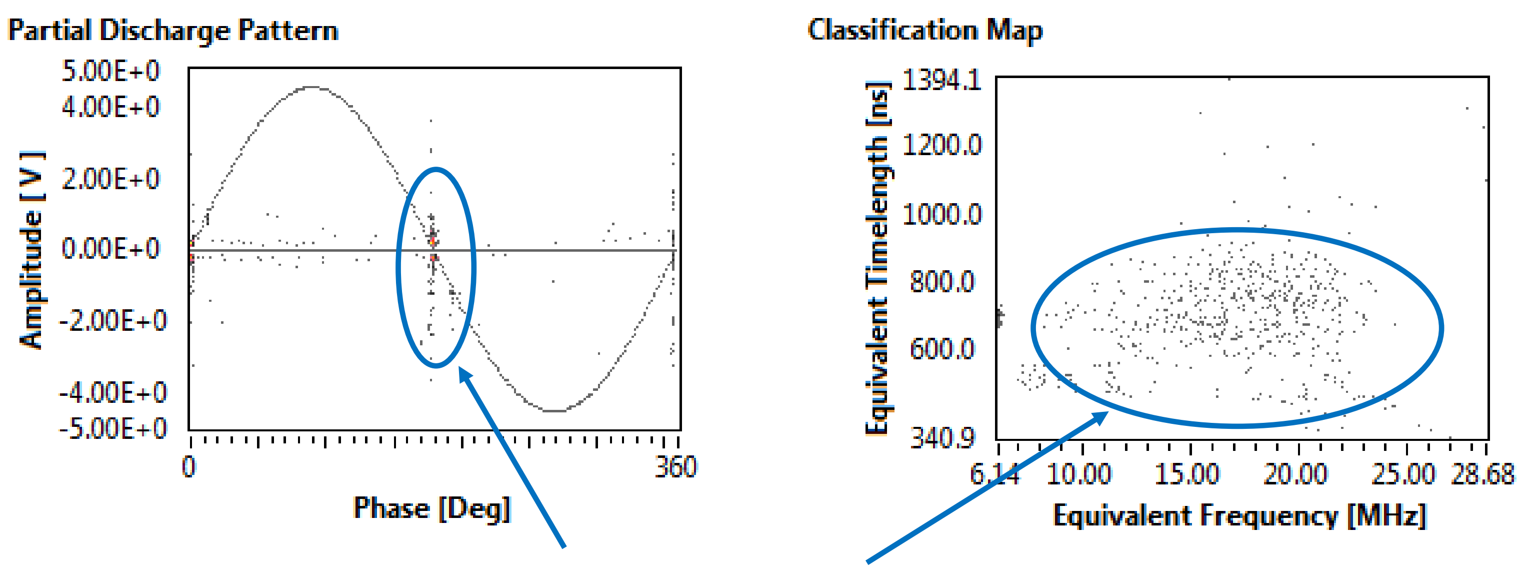
T-F map separation allows PD phenomena to be detected during off-line VLF tests performed with cosine-rectangular voltage

PD measurement setup



Step 1: Dry test

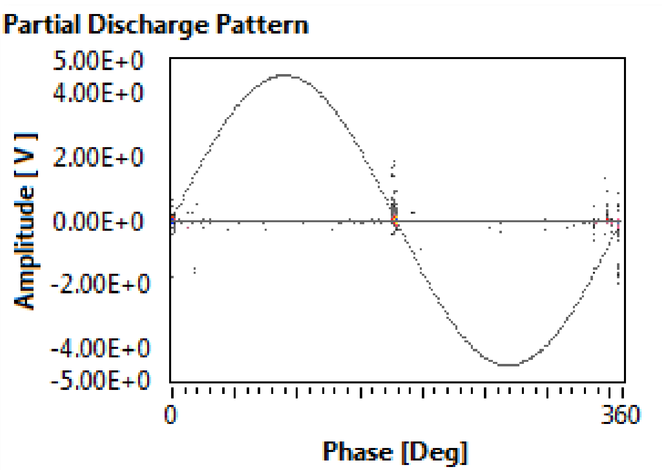
- The VLF supply is energized with no cable connected;
- PD phenomena coming from the VLF are acquired (VLF supply fingerprint)

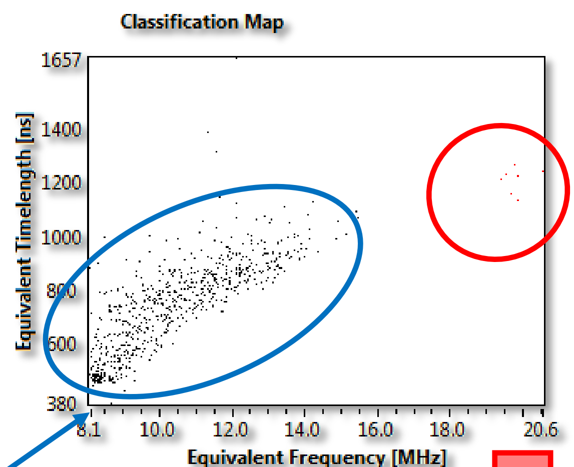


PD from the VLF supply

Step 2: PD test

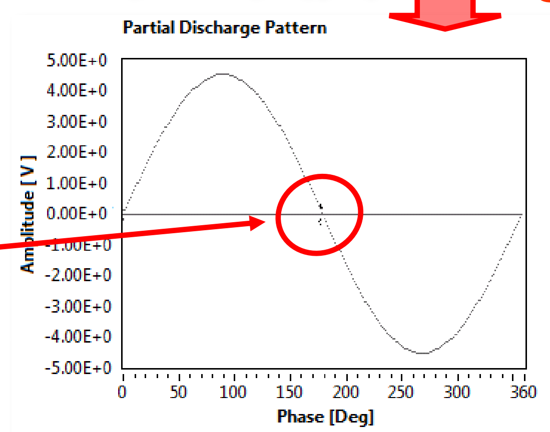
- The feeder is connected to the VLF supply;
- New PD phenomena can be acquired and recognized as coming from the EUT (cable feeder)





PD from the VLF supply

Separation



PD coming from the EUT

PD measurement results

- The decomposition of the pulse frequency and time characteristics allows:
  - Enhanced noise rejection
  - PD **separation**
  - PD **location**
  - PD source **identification** by artificial intelligence methods

- Real time pulse selection based on PD pulse characteristics (in time and frequency domains) allows separation of signals coming from different sources to be performed, in order to focus only on PD activity coming from the cable system under test.

TECHIMP SpA

LOCATION	**USA**
EUT	**MV CABLE FEEDER**
RATED VOLTAGE	**14 kV**
INSULATION	
LENGTH	**VARIOUS**
VINTAGE	
TYPE OF TEST	**VLF OFF-LINE**

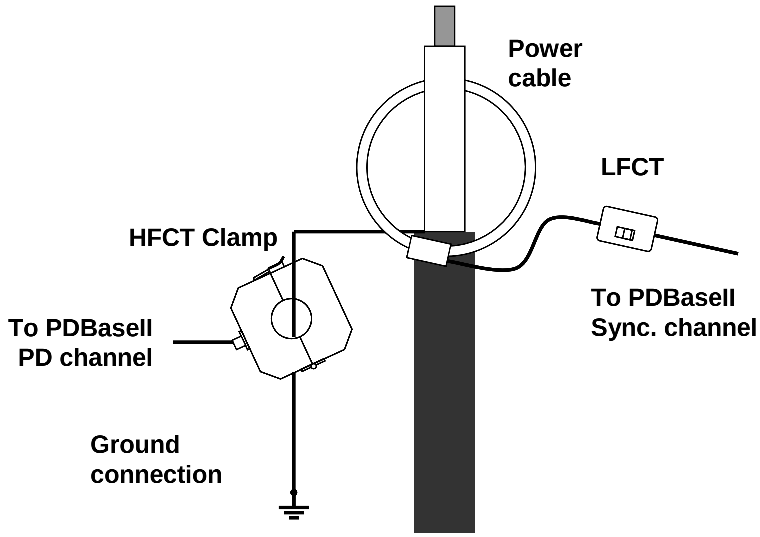
CASE STUDY

Application of PD phenomena separation by T-F mapping, on-line and at sinusoidal VLF

PD measurement setup

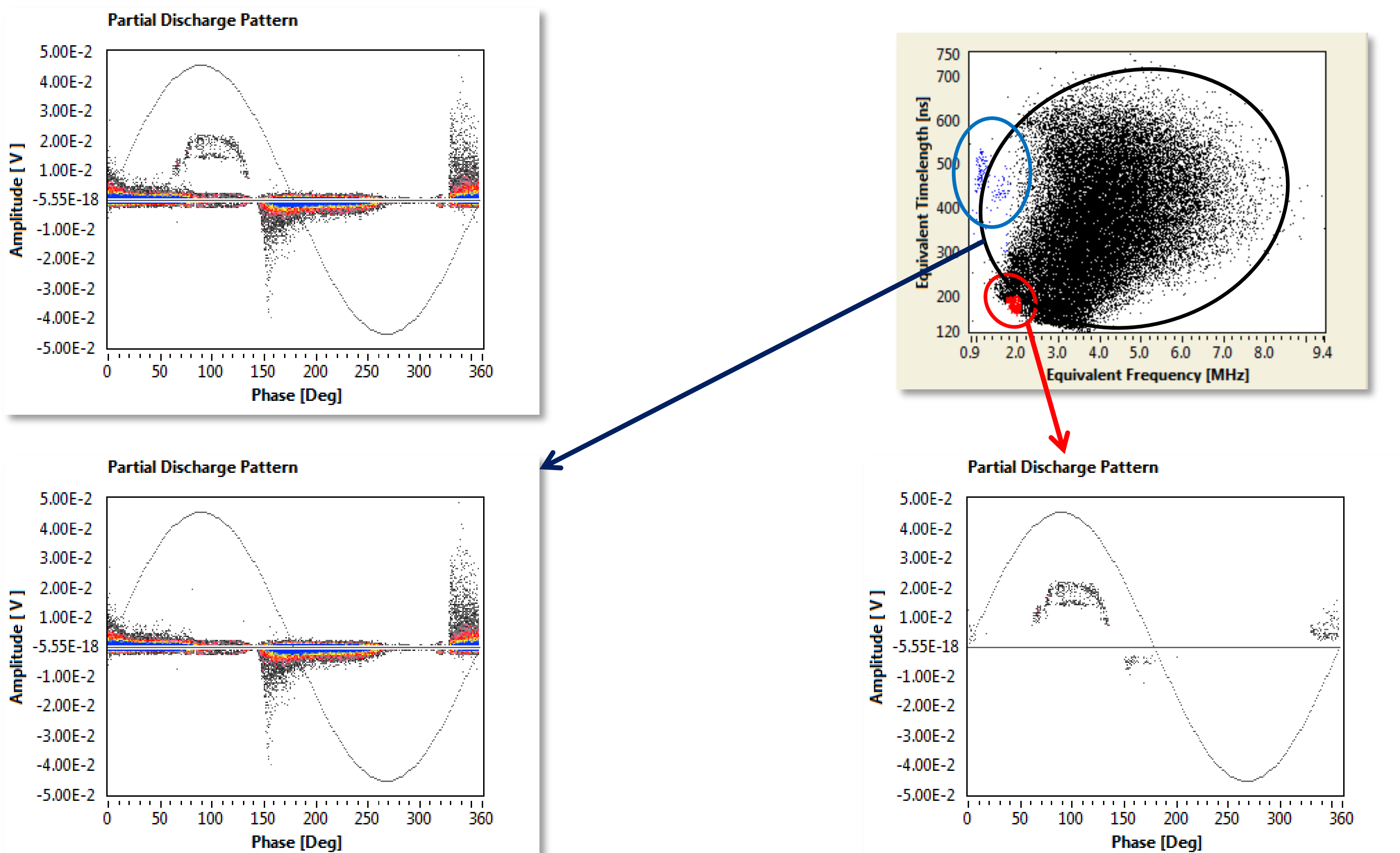
- **PD signals:**
  - HFCT (High Frequency Current Transformer) clamped around the ground lead of the cable termination

- **Synchronization signal:**
  - through a Low Frequency Current Transformer clamped around the cable termination for on-line measurement;
  - through a capacitive divider for the off-line VLF test.



Step 1: On-line test 14kV (phase to ground) @ 60 Hz

- Feeder supplied by the grid (no loads connected)



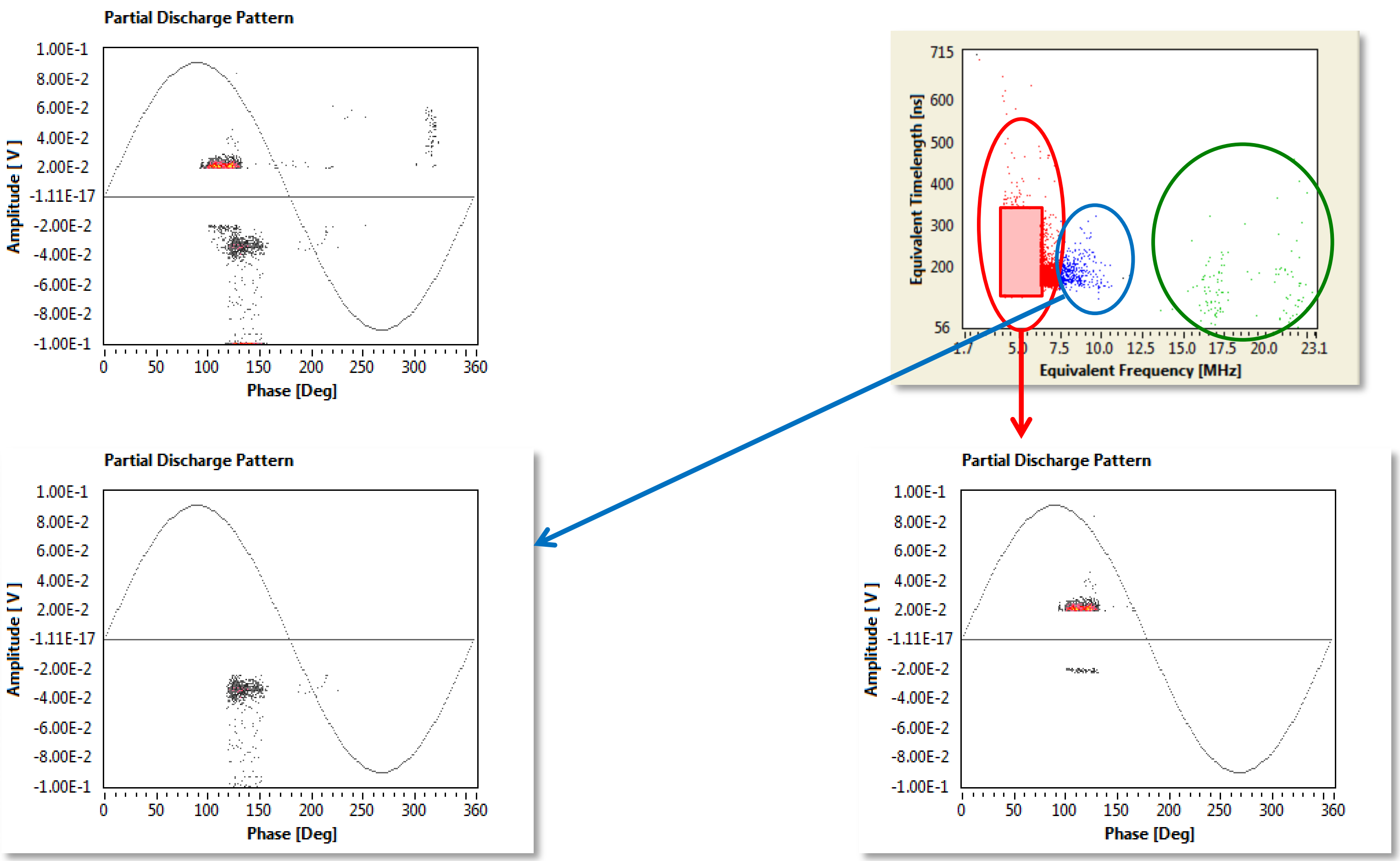
Internal PD (black cluster high repetition rate)

Corona PD (red cluster, low repetition rate)

PD measurement results

Step 2: Off-line VLF test 23kV (phase to ground) @ 0.1 Hz

- 0.1 Hz sine-wave compact VLF unit



Internal PD (blue cluster)

Corona PD (red cluster)

LOCATION	**USA**
EUT	**MV CABLE FEEDER**
RATED VOLTAGE	**25 kV**
INSULATION	
LENGTH	**VARIOUS**
VINTAGE	
TYPE OF TEST	**VLF OFF-LINE**

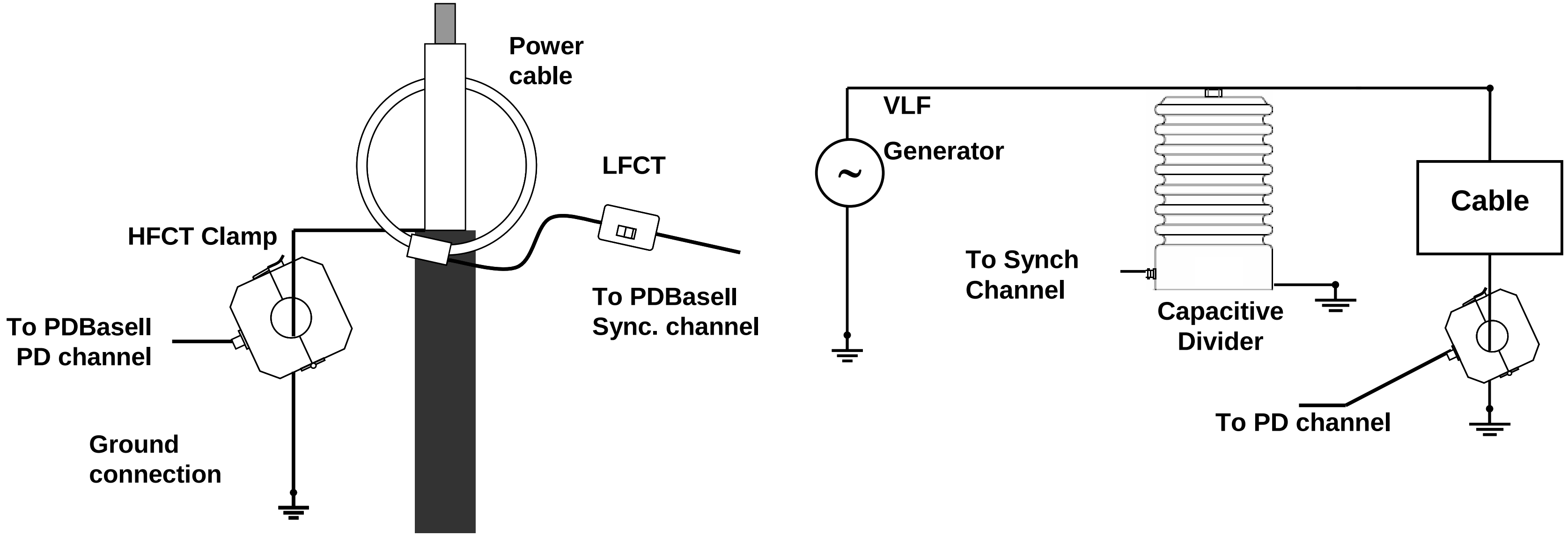
CASE STUDY

Application of PD phenomena separation by T-F mapping, on-line and at sinusoidal VLF PD. Localization through TDR method

PD measurement setup

- **PD signals:**
  - HFCT (High Frequency Current Transformer) clamped around the ground lead of the cable termination

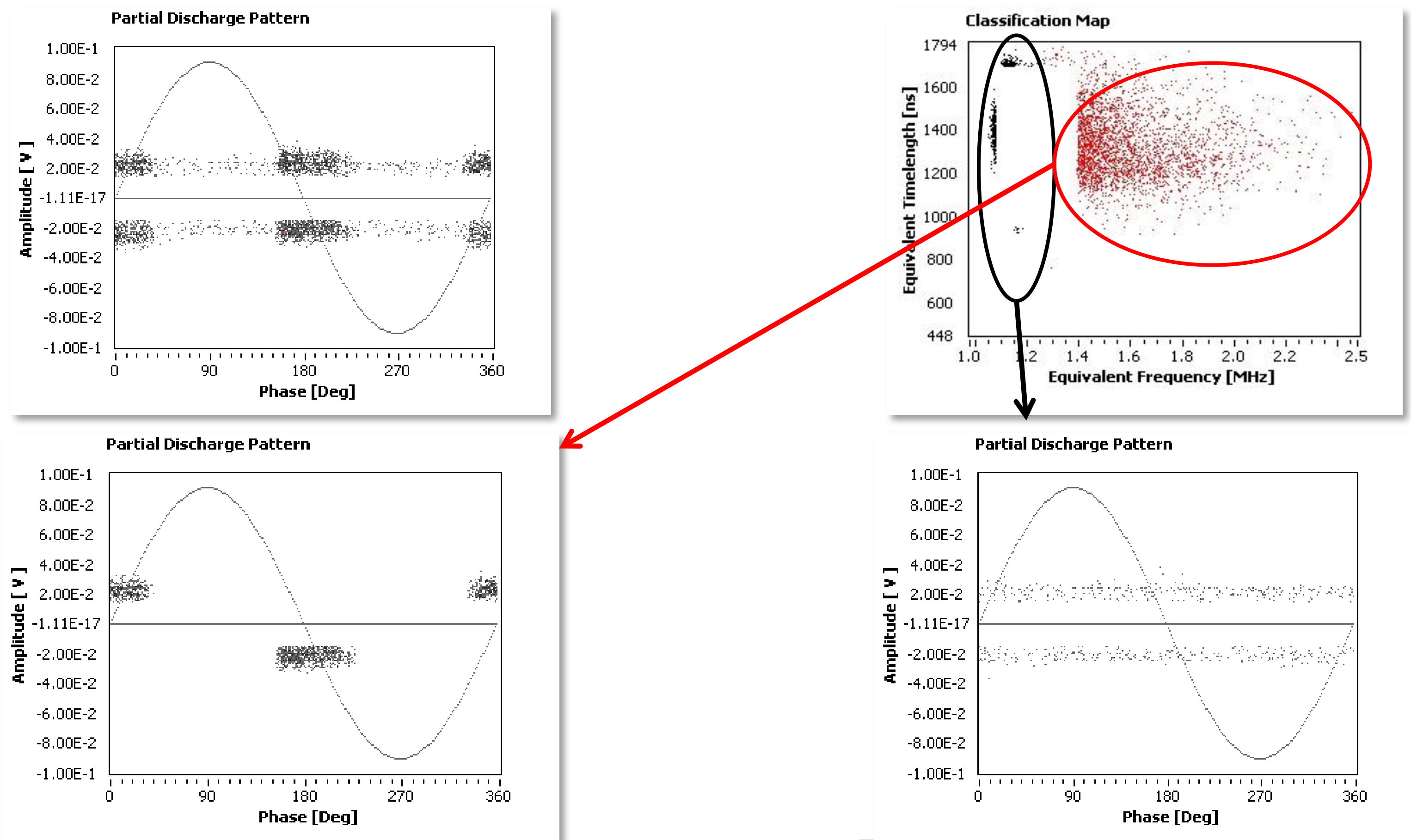
- **Synchronization signal:**
  - through a Low Frequency Current Transformer clamped around the cable termination for on-line measurement ;
  - through a capacitive divider for the off-line VLF test (VLF scope output can be used as well if available).



PD measurement results

Step 1: On-line test 14kV (phase to ground) @ 60 Hz

- Feeder supplied by the grid (no loads connected)
- Noise level is high (SNR ≈ 1), TF map allows to separate patterns



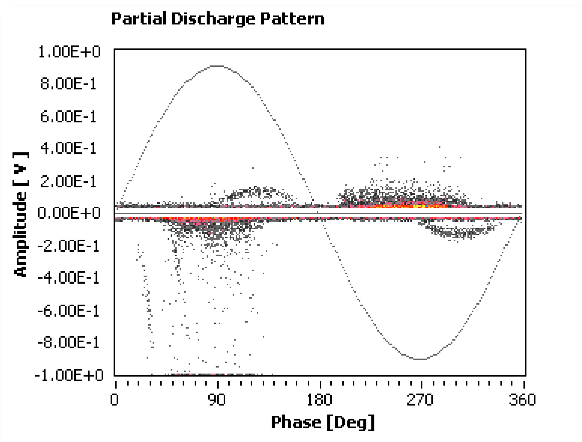
Red Cluster (Internal PD)

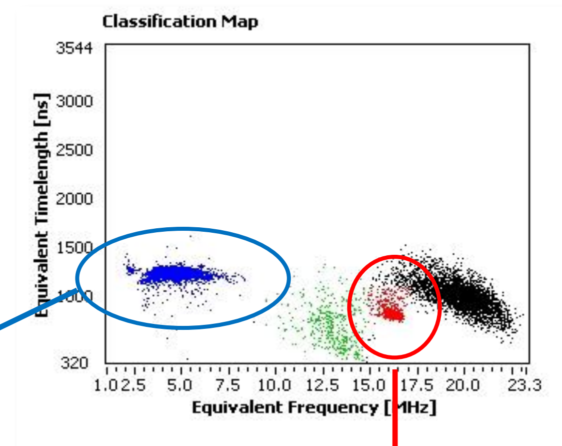
Black Cluster (Background noise)

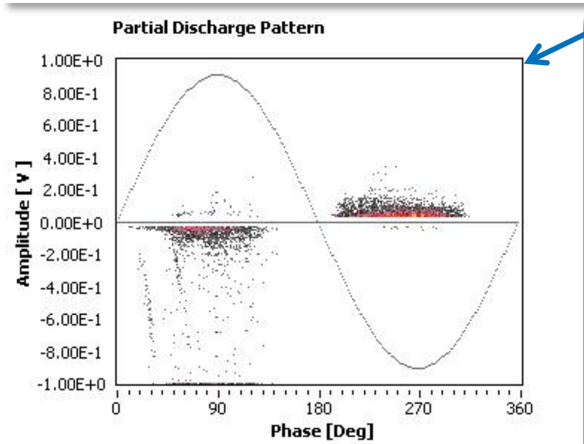
PD measurement results

Step 2: Off-line VLF test 23kV (phase to ground) @ 0.1 Hz

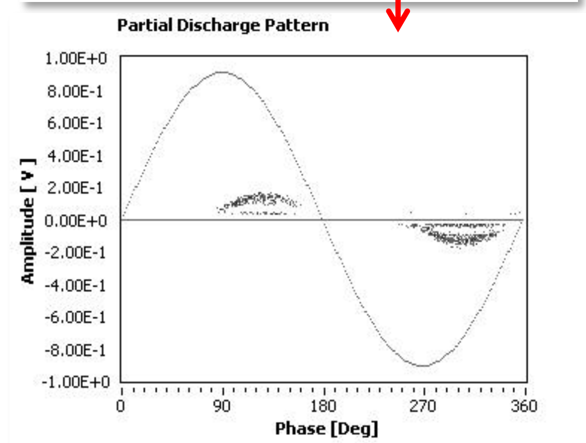
- 0.1 Hz sine-wave compact VLF unit;
- During off-line test the background noise is much lower than on-line (cable disconnected from the grid), but disturbances from VLF arise.
- PD activity is detected off-line as well, together with other phenomena







Disturbance from VLF Unit (blue cluster)

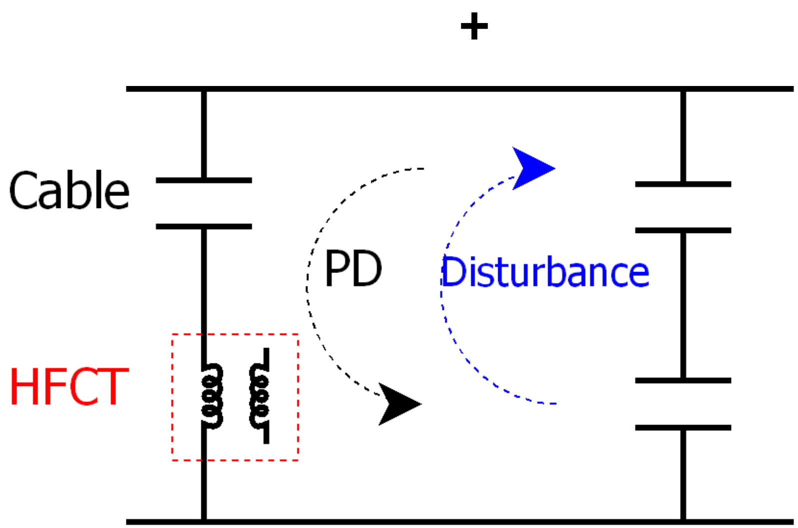


Internal PD (Red cluster)

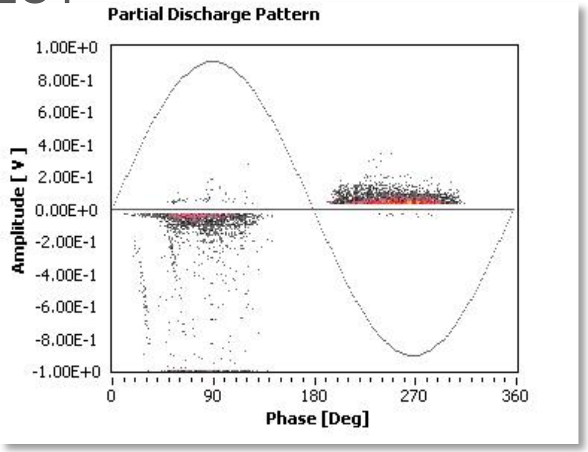
PD measurement results

Comments

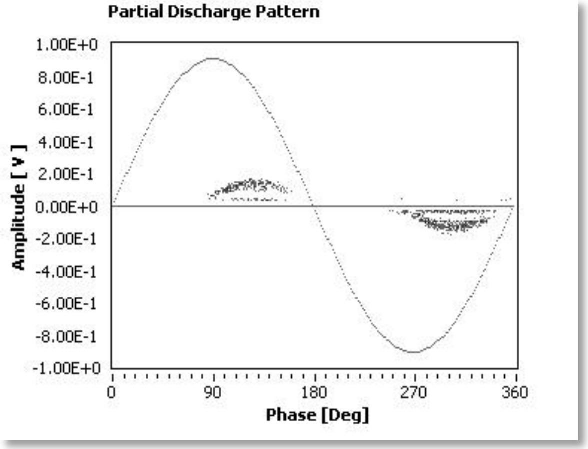
- Using HFCT (around the ground lead) as sensor and UWB detector allows to the information provided by the PD pulse polarity to be used to understand if detected pulses are generated inside or outside the EUT



Disturbance
(Opposite polarity)

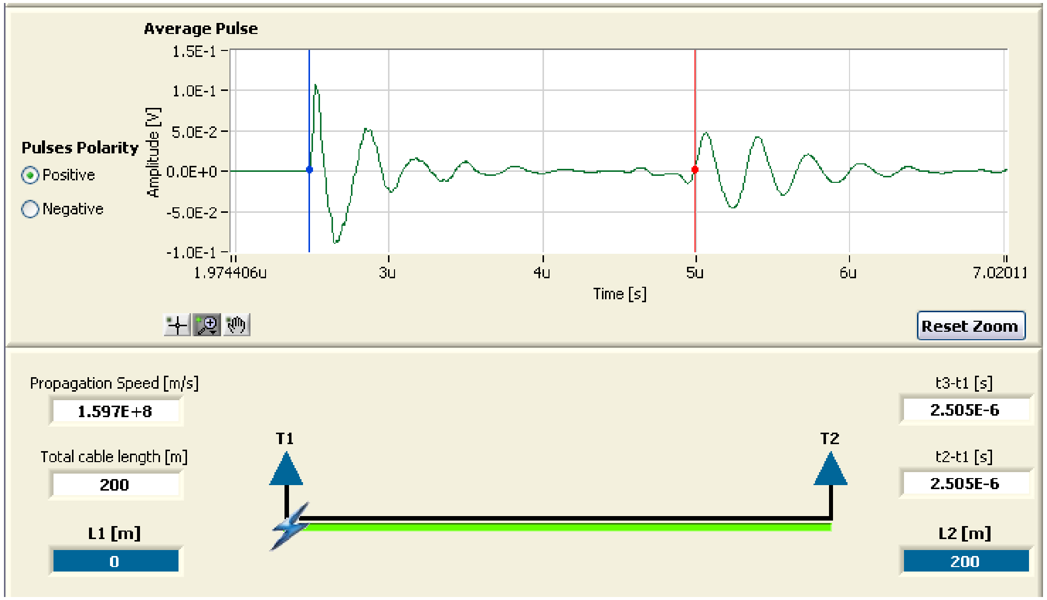


Internal PD
(Direct Polarity)



TDR Location: 1) Evaluation of cable length

- Thanks to the separation capability it is possible to apply the TDR location tool to homogeneous clusters of pulses (i.e. groups of pulses all coming from the same source).
- In a first step the TDR tool is applied to disturbance pulses coming from the VLF generator in order to evaluate cable length and / or to check the cable propagation speed.

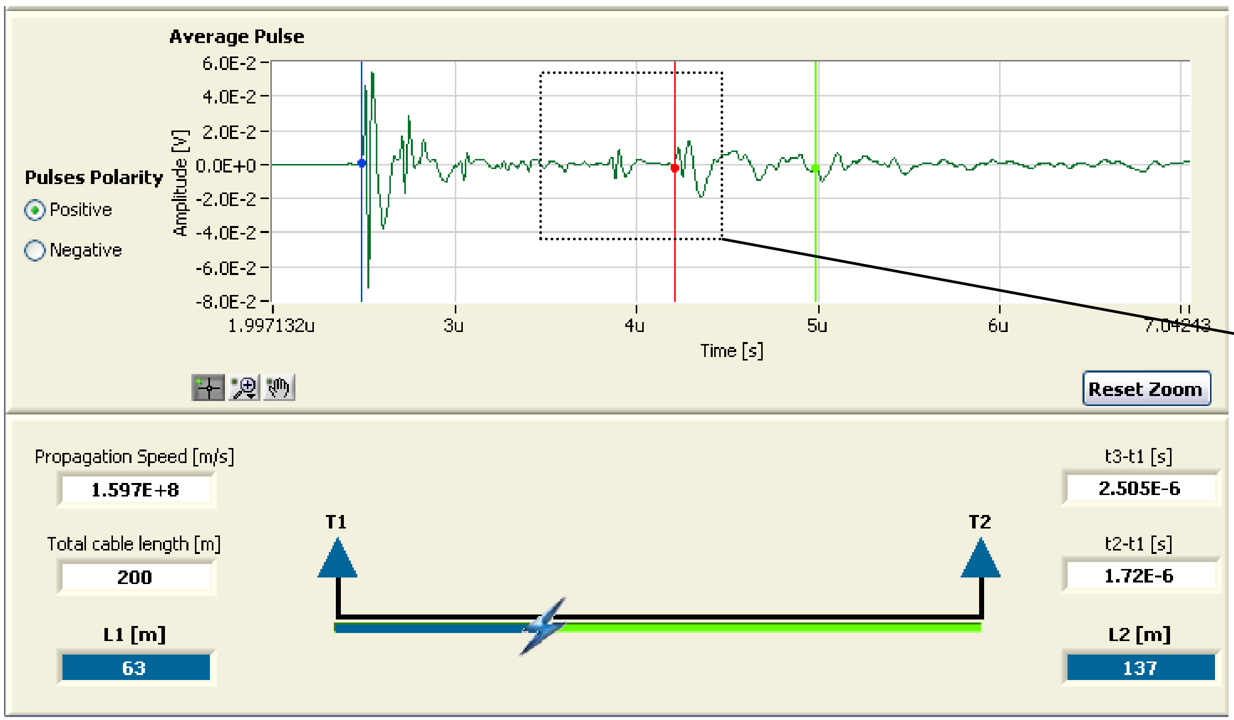


The length of the cable under test found to be longer than given by the customer (650 ft, instead of 500 ft)

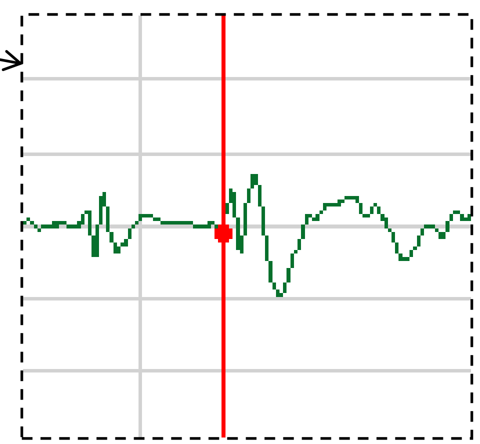
PD measurement results

TDR Location: 2) PD Source

- After checking cable length it is possible to apply the TDR localization tool to the PD source. Just need to place a third cursor on the biggest intermediate reflection



PD was located at 63 m from the measurement point



Conclusion

- Combining PD testing with VLF withstand allows for PD source localization;
- Combining PD testing with VLF allows for testing at lower voltages, minimizing any risk of damage during the VLF test;
- Using PD with a VLF source, compared with a 60 Hz power source, provides the same PD information with a smaller, more compact, test system;
- The use of information provided by the PD pulse shape (only possible through UWB PD analyzers) is very important in order to perform:
  - Enhanced noise rejection
  - Separation of PD signals from disturbances
  - PD source location through TDR technique

TECHIMP SpA

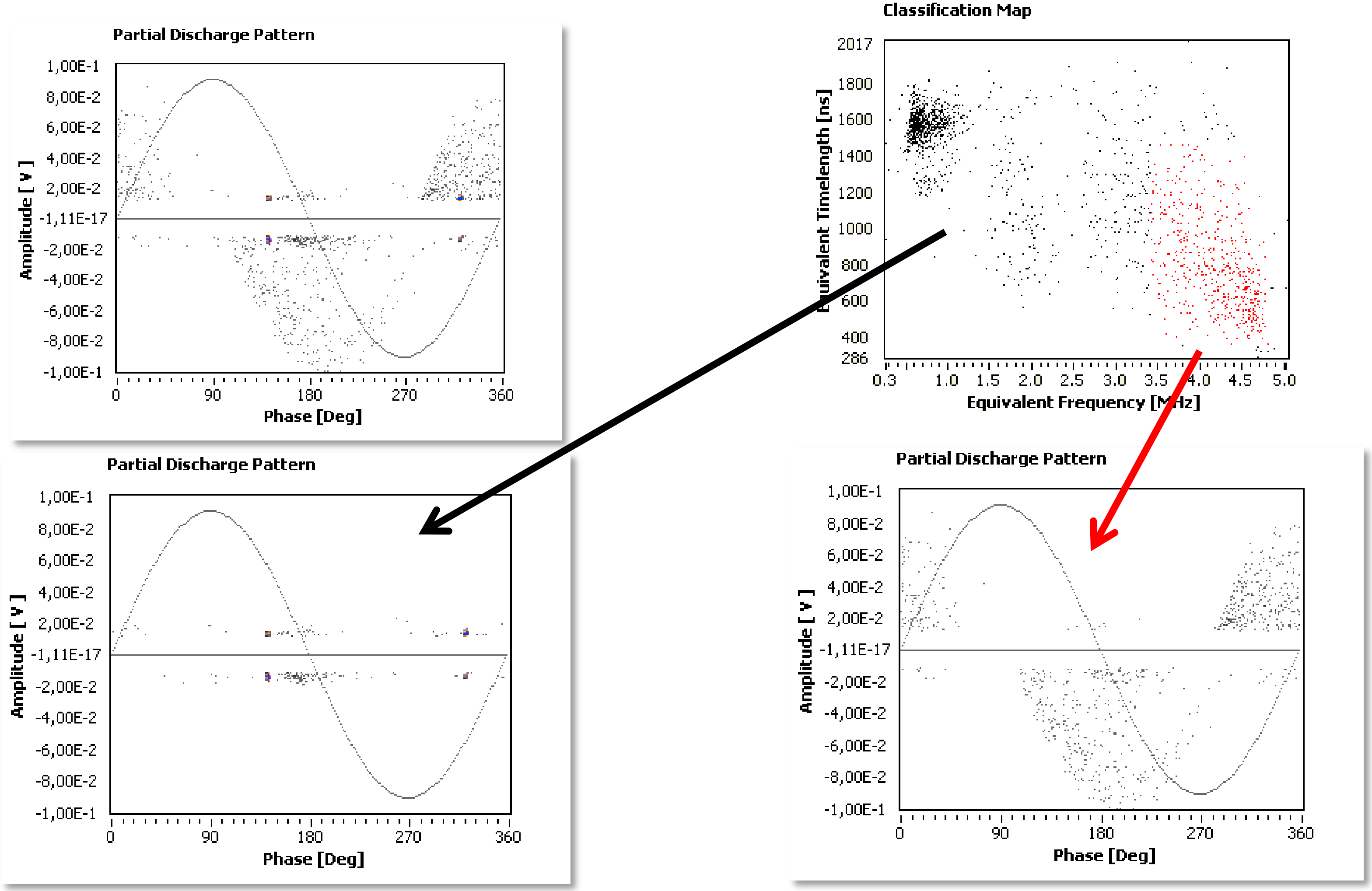
LOCATION	**EUROPE**
EUT	**MV CABLES**
RATED VOLTAGE	**13 kV**
INSULATION	
LENGTH	**VARIOUS**
VINTAGE	
TYPE OF TEST	**ON-LINE**

CASE STUDY

ON-Line PD test separation and diagnosis. Three PD measurement sessions performed during 2 years. Amplitude and Trending.

PD measurement results

The PD measurement were performed using HFCT installed around the ground connections.

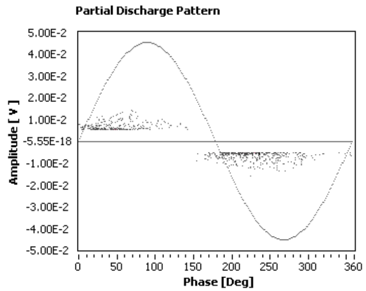


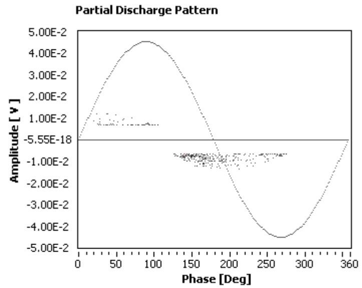
External distrurbances

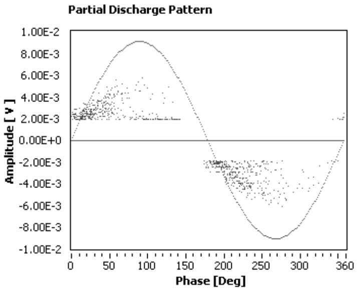
Internal PD

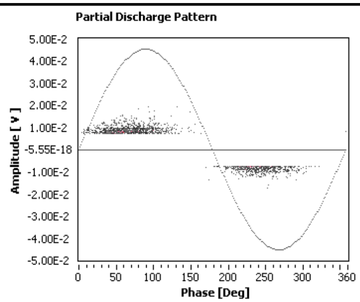
PD measurement results

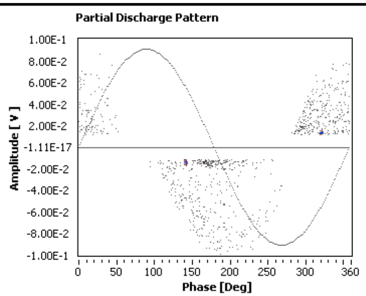
Three measurement sessions were performed on the cable system. PD constant in Phase 4 and PD amplitude and repetition rate increased in phase 8.

<table>
<tr><th></th><th>FIRST SESSION
21/05/2008</th><th>SECOND SESSION
13/01/2009</th><th>THIRD SESSION
25/11/2009</th><th></th></tr>
<tr><td>Phase 4</td><td>


Qmax 95%=11 mV
Nw=3,8</td><td>


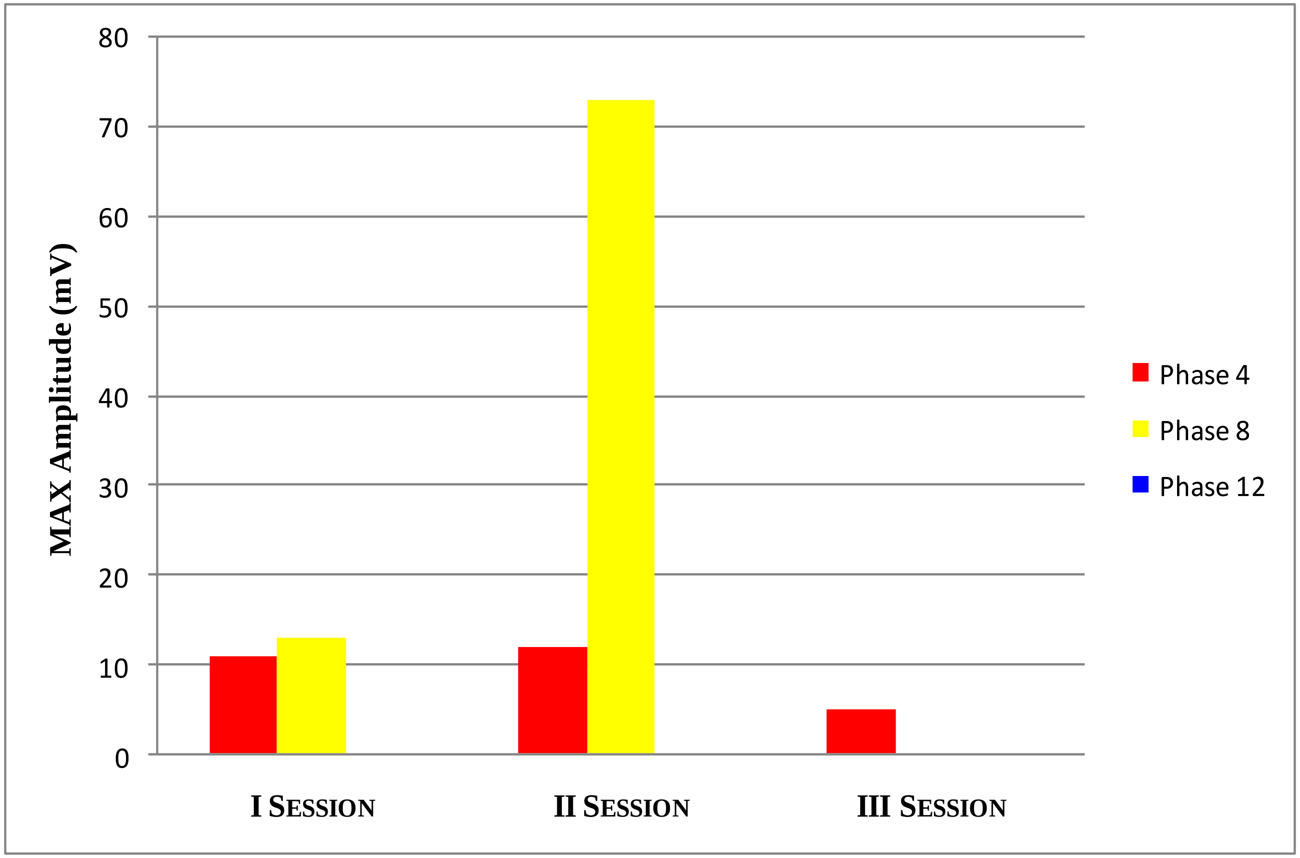
Qmax 95%=12mV
Nw=1</td><td>


Qmax 95%=5mV
Nw=1,5</td><td>Y</td></tr>
<tr><td>Phase 8</td><td>


Qmax 95%=13mV
Nw=1,2</td><td>


Qmax 95%=73mV
Nw=3</td><td>BAD DATA</td><td>R</td></tr>
<tr><td>Phase 12</td><td>PD FREE</td><td>PD FREE</td><td>PD FREE</td><td>G</td></tr>
</table>

Shows the significant increase of amplitude in phase 8 during the three session of measurement.



TECHIMP SpA

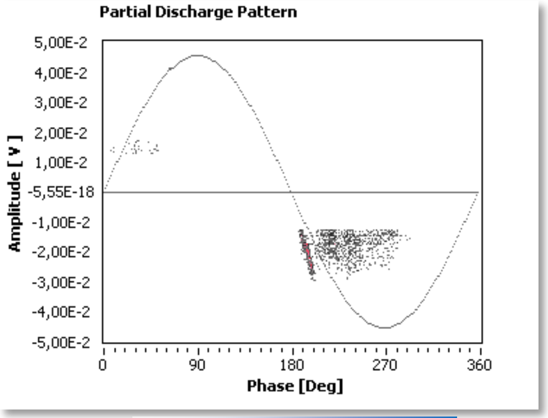
LOCATION	**EUROPE**
EUT	**MV CABLES**
RATED VOLTAGE	**13 kV**
INSULATION	
LENGTH	**VARIOUS**
VINTAGE	
TYPE OF TEST	**ON-LINE**

CASE STUDY

Example of on–line trending
PD source location with TDR

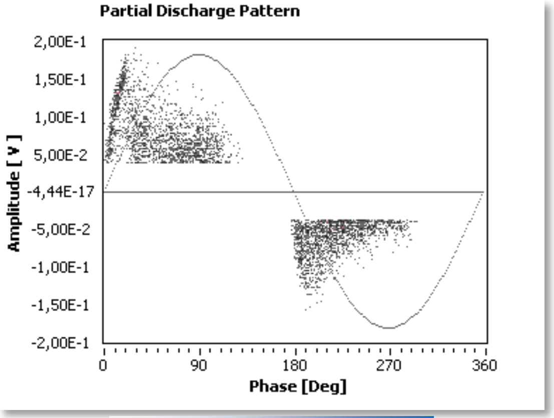
Three measurement campaigns were performed on the circuit and a PD phenomenon was detected on phase 12.

First session



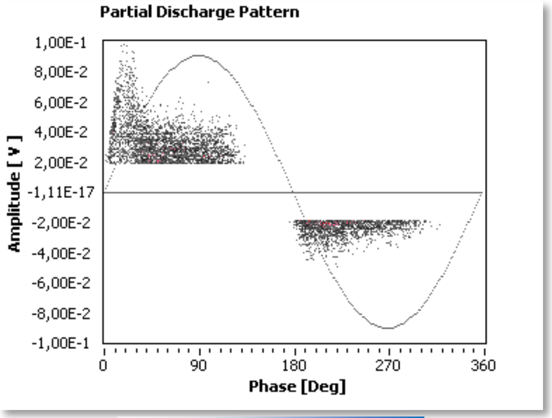
Qmax 95%=26mV
Nw=3

Second session



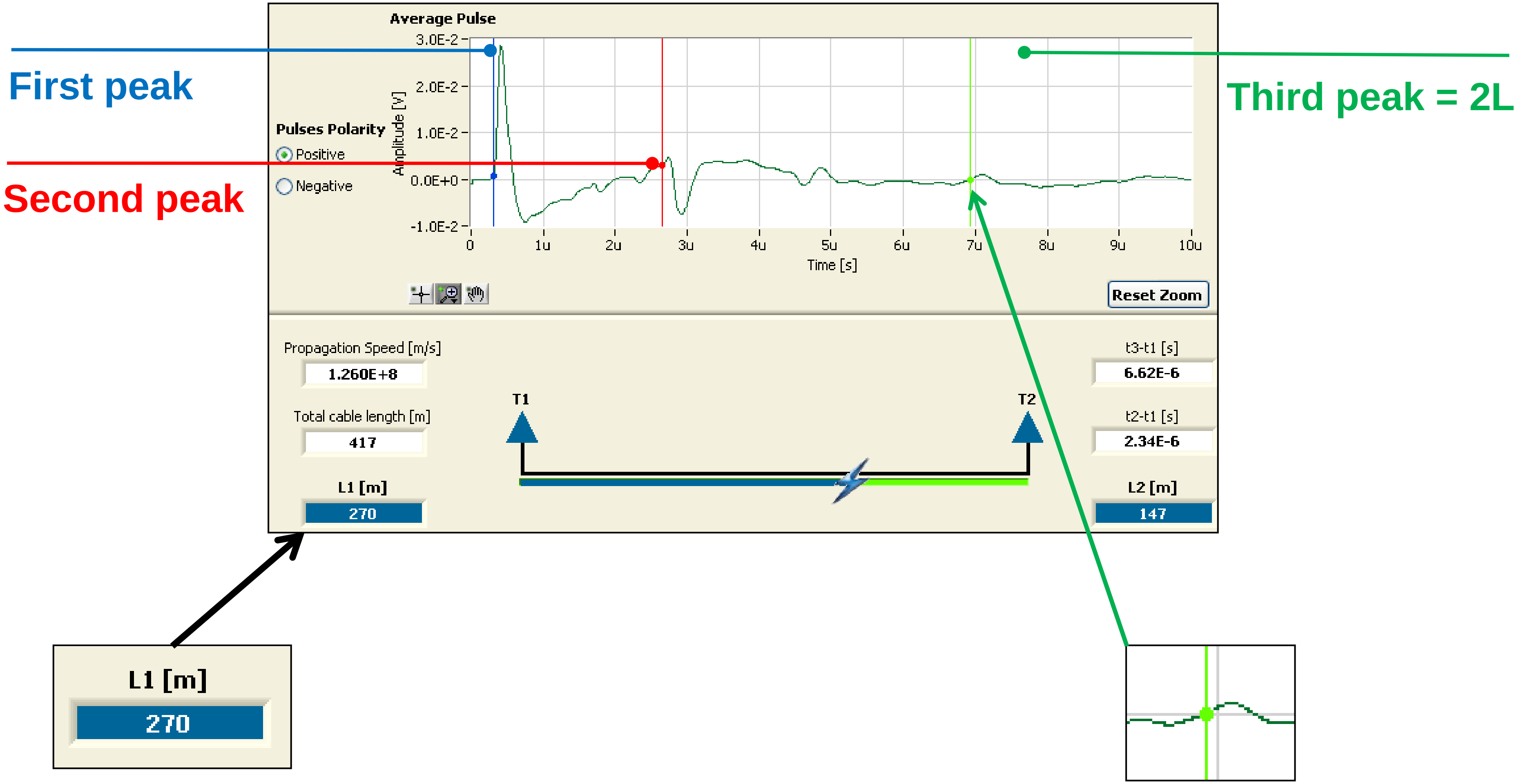
Qmax 95%=140mV
Nw=8

Third session



Qmax 95%=55mV
Nw=19

TDR location



TECHIMP SpA

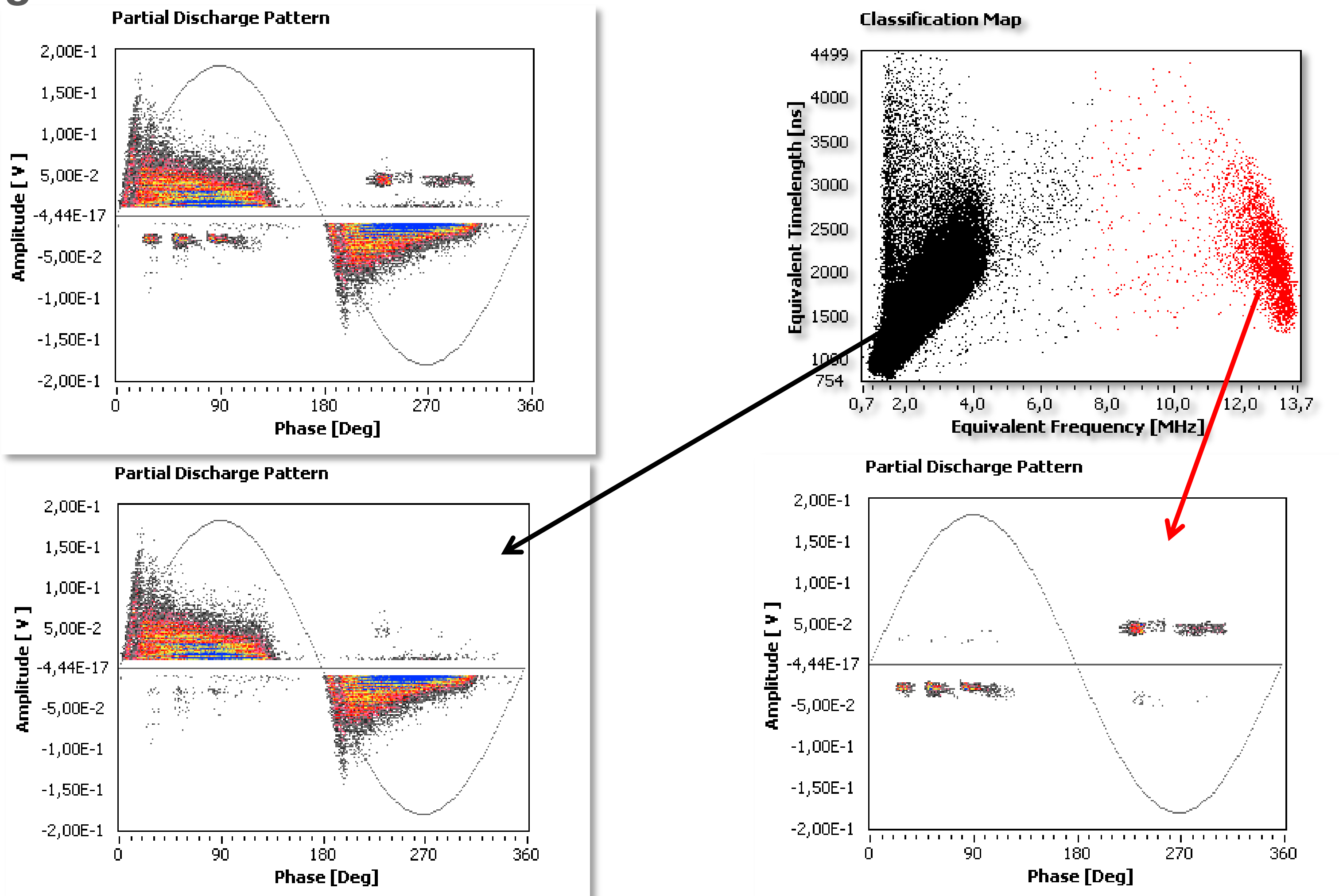
LOCATION	**EUROPE**
EUT	**MV CABLES**
RATED VOLTAGE	**13 kV**
INSULATION	
LENGTH	**VARIOUS**
VINTAGE	
TYPE OF TEST	**ON-LINE**

CASE STUDY

ON-Line PD test separation and diagnosis. Three PD measurement sessions performed during 2 years. PD source location with TDR

PD measurement results

The PD measurement were performed using HFCT installed around the ground connections.

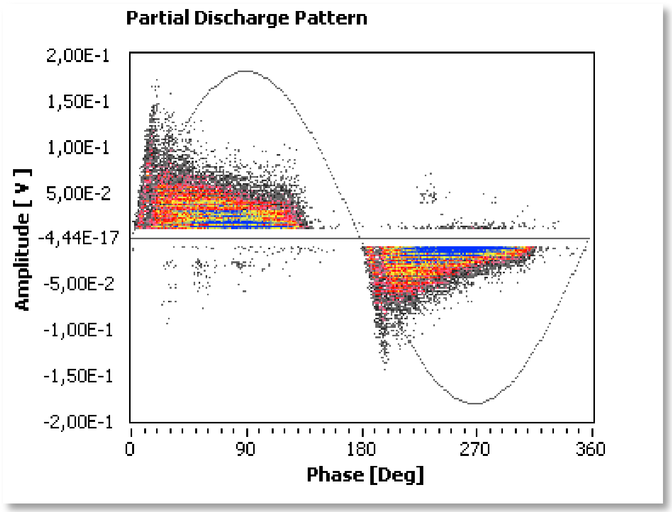


Internal PD

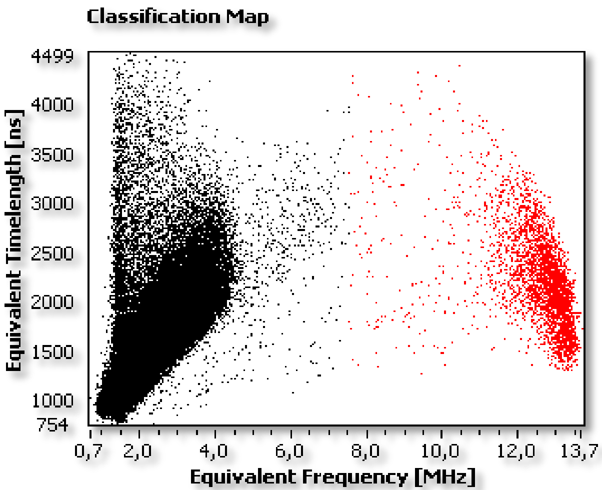
External disturbances (corona)

PD measurement results

This is an estimated value of PD amplitude at the PD source is calculated for PD pulses arriving far from the detection point through a correction factor which depends on frequency range.



Internal PD



Black cluster

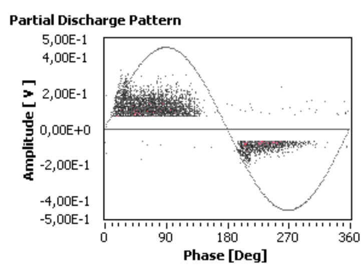
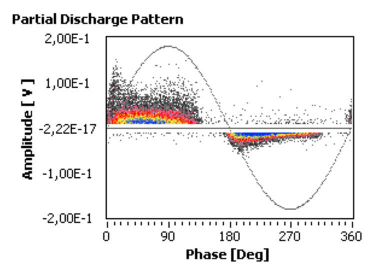
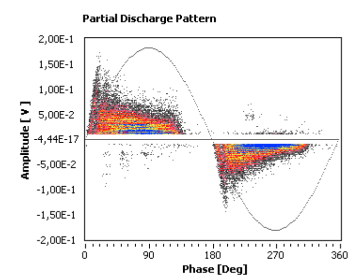
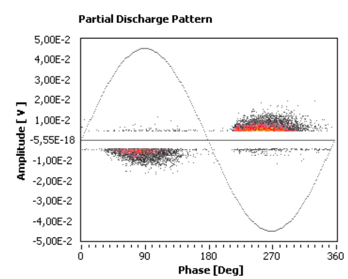
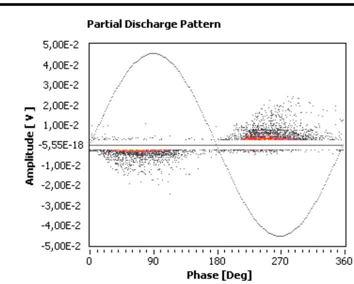
$k = F_0/F_{eq}$ → $F_{0\text{-}XLPE} = 9MHz$ → $F_{eq} = (F_{eq\ max} + F_{eq\ min})/2 = (6+1)/2 = 3.5\ MHz$

k=2.57 ; A=100mV **A_{eff} = A*k=257 mV**

[A_{eff} is the effective amplitude to be used for the diagnosis !]

PD measurement results

Three measurement sessions were performed on the cable system, PD were detected in the phase 8 and 12

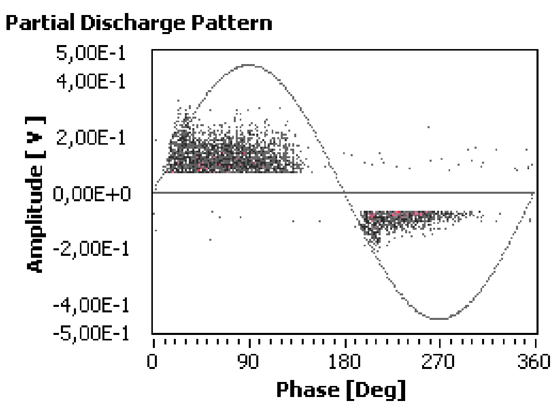
	FIRST SESSION 7/05/2008	SECOND SESSION 16/01/2009	THIRD SESSION 23/11/2009	
Phase 4	PD FREE	PD FREE	PD FREE	G
Phase 8				R
Phase 12	PD FREE			Y

PD measurement results

Focusing on the PD activity of the phase 8:

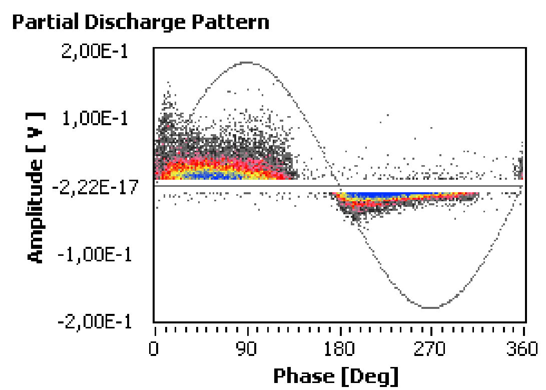
- amplitude decreases from I to II session
- Nw increases (≈ 5 TIMES) → DEGRADETION OF THE INSULATION MATERIAL → ONLY AMPLITUDE IS NOT ENOUGH TO PERFORM DIAGNOSIS

First session



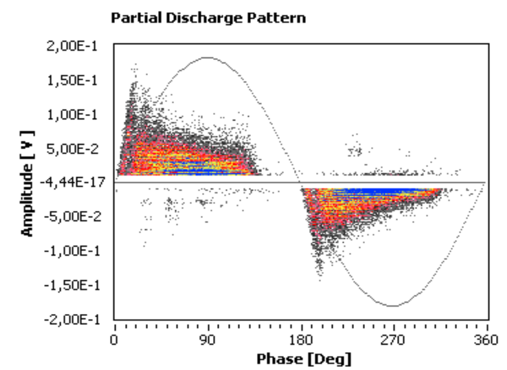
Qmax 95%=200mV
Nw=9

Second session



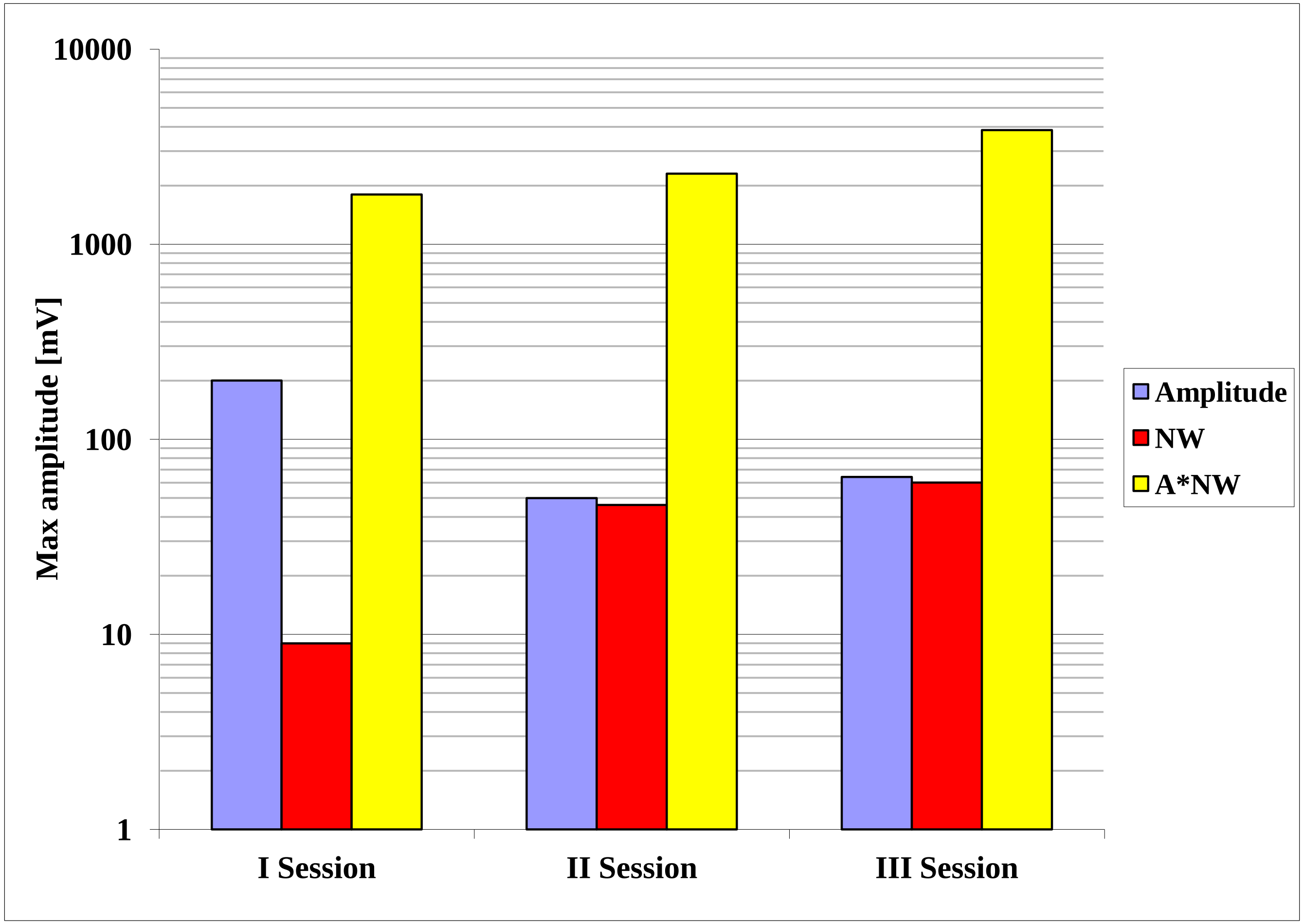
Qmax 95%=50mV
Nw=46

Third session



Qmax 95%=64mV
Nw=60

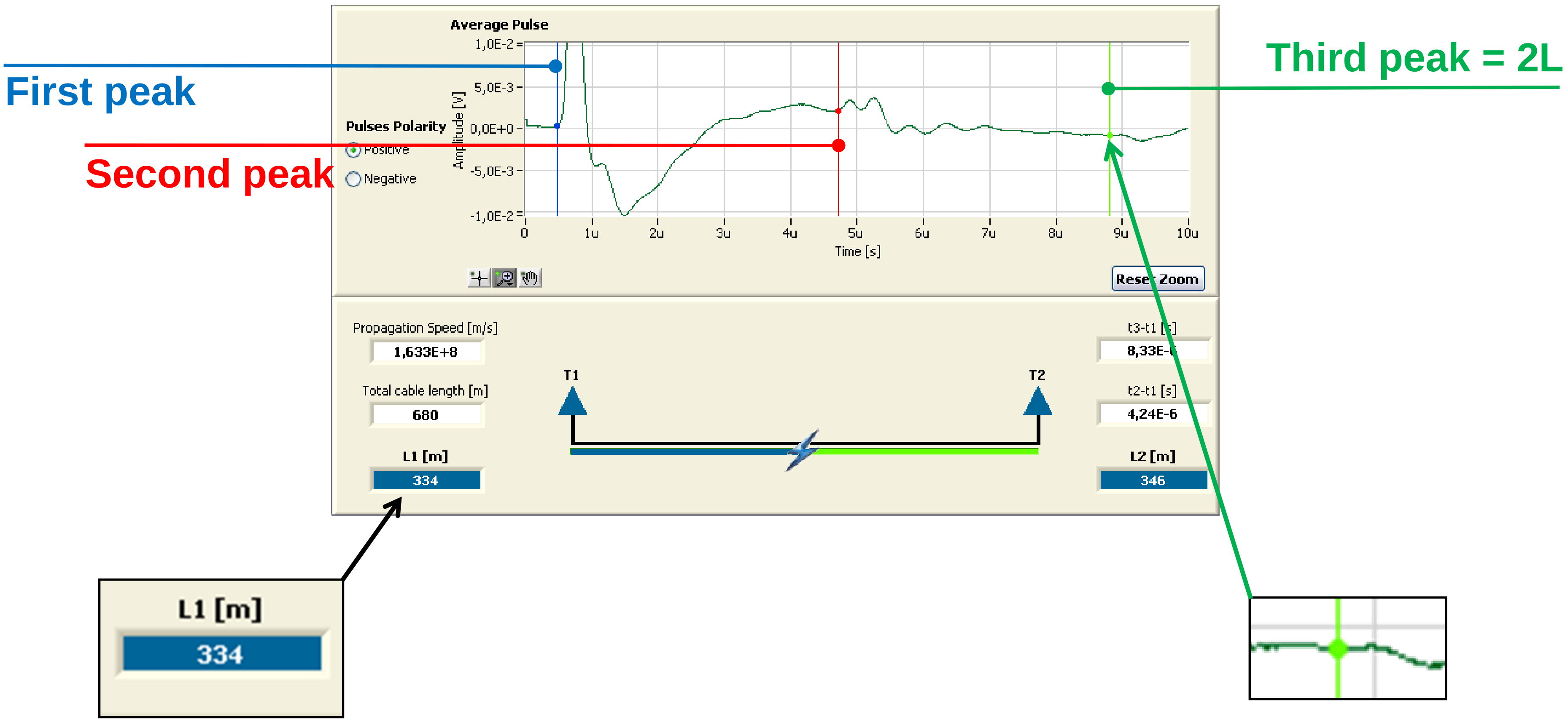
Shows the significant increase of A*NW in phase 8 during the three session of measurement.



PD measurement results

TDR location

Tree measurement campaigns were performed on the circuit and a PD phenomenon was detected on phase 12.



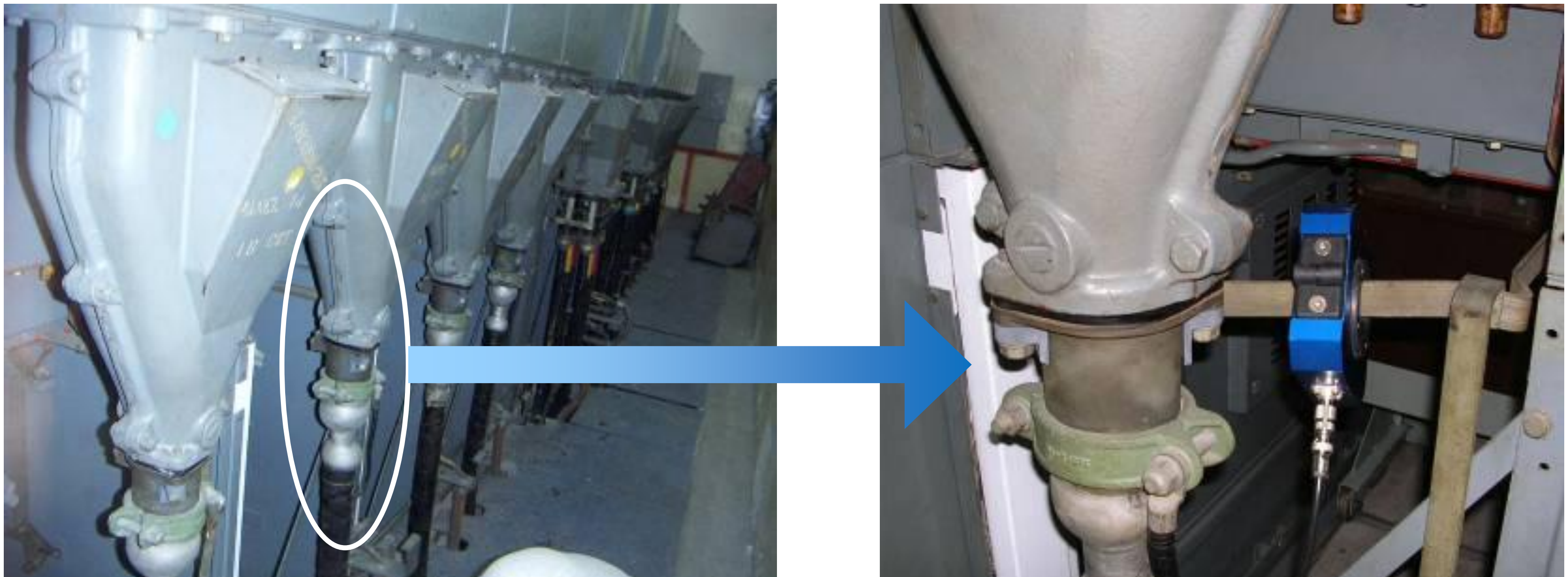
TECHIMP SpA

LOCATION	**FAR EAST**
EUT	**MV CABLE**
RATED VOLTAGE	**11 kV**
INSULATION	
LENGTH	**VARIOUS**
VINTAGE	
TYPE OF TEST	**ON-LINE**

CASE STUDY

ON-Line PD test separation and diagnosis.

PD measurement setup



11kV three core cable

PD sensor:

- clamp HFCT connected around the grounding lead of the cable board

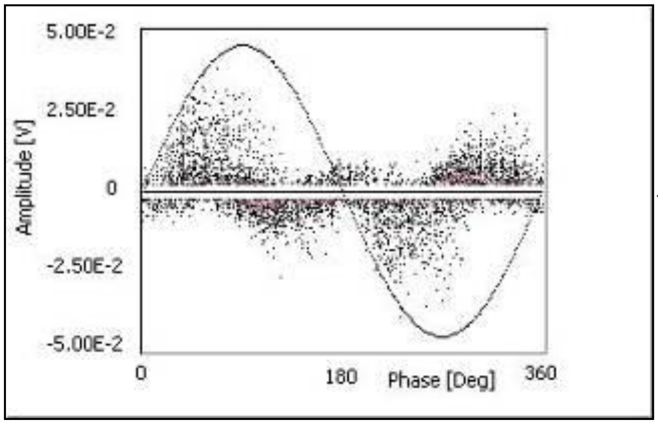
Single PD reading for the entire 3 core cable

PD measurement results

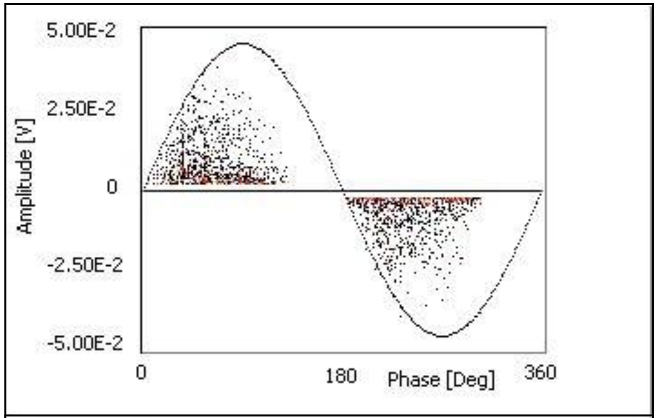
Separation through classification map :

- Three different activities

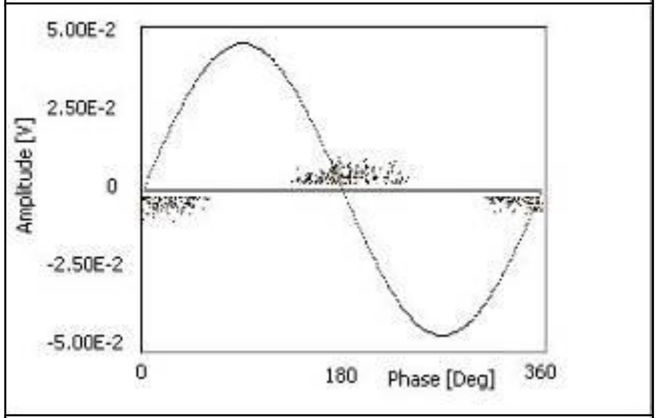
Entire acquisition pattern



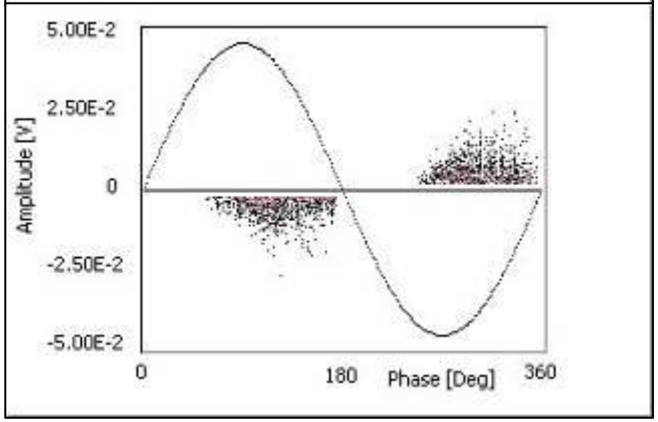
PD Activity 1



PD Activity 2



PD Activity 3



PD measurement results

Once properly shifted, each activity can be correctly identify

PD activity in MV cable systems can be correctly detected, identified and located ON LINE

The ON LINE testing session does not require any outage of the asset and can be very cost effective

Red Phase

Yellow Phase

Blue Phase