Introduction to PD

October 2014

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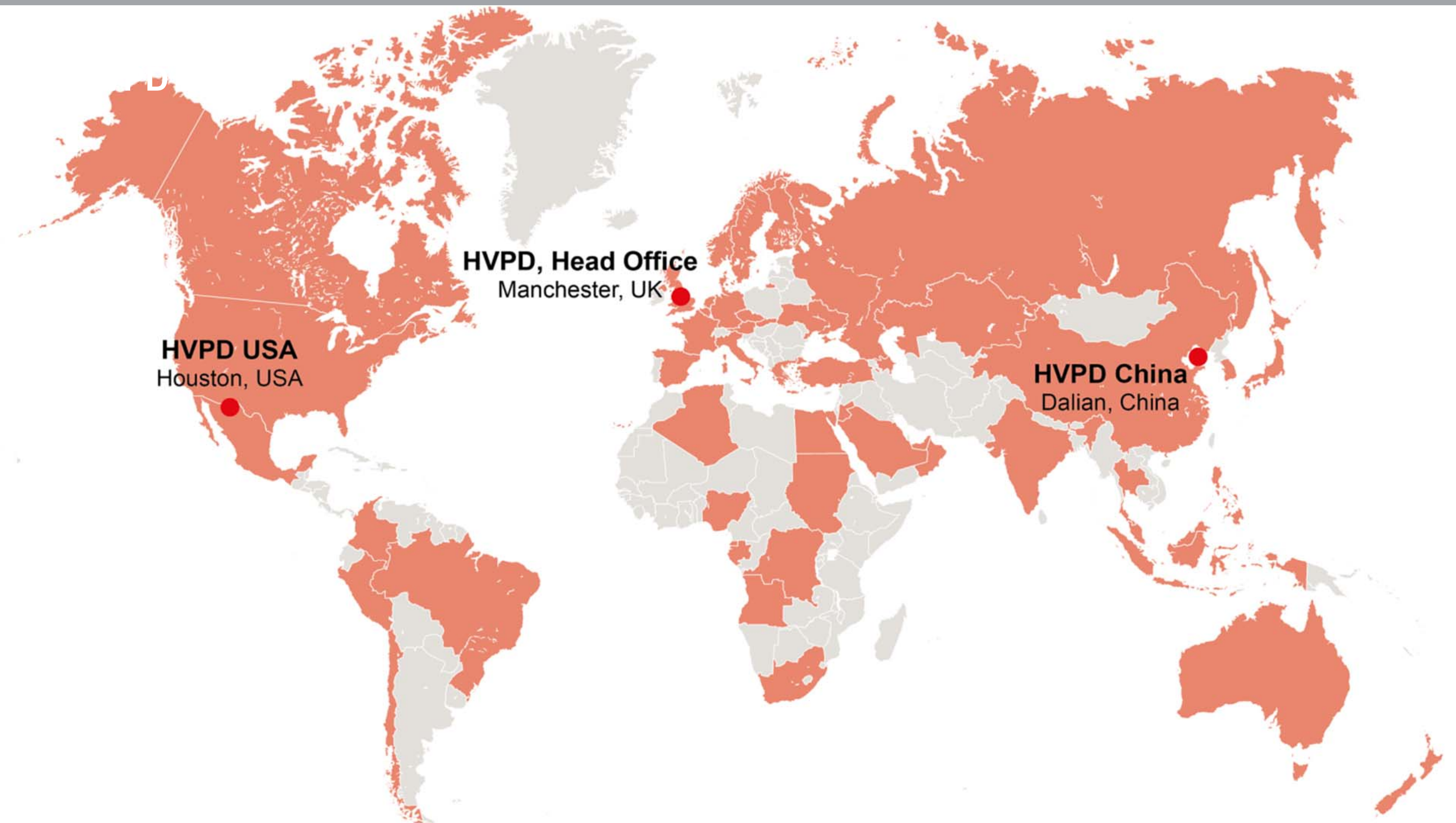
Managing Director
HVPD Ltd

CONTENTS

- PD detection theory
- PD test & monitoring equipment
- Cable PD – detection & location
- Local PD in switchgear
- PD in rotating machines
- Continuous PD monitoring



- HVPD are experts in the growing industry of **on-line partial discharge (OLPD) condition monitoring** and condition based management (CBM) of high voltage networks.
- We supply portable and permanent OLPD surveying, diagnostic test and continuous monitoring solutions, and a complimentary range of on-site services, monitoring services and training.
- Over 350 customers in 100 countries trust our technology.

500+ test and monitoring projects completed over the past 20 years

OUR EXPERTISE

"Our Knowledge is Your Power"

Industry-Specific Condition Monitoring Solutions

Oil & Gas

Offshore Renewables

Transmission & Distribution

Power Generation

Shipping

What is partial discharge?

"A **localised** electrical discharge that only partially bridges the insulation between conductors and which can or can not occur adjacent to a conductor"

IEC60270 Definition

Why test for partial discharge?

PD activity is an indication of an **incipient fault** in HV insulation and is widely regarded as the best **'early warning'** indicator of the deterioration of high voltage insulation.

Common Applications of PD Testing

Power cables, joints/splices and terminations

Switchgear (Air, Solid, Gas-insulated)

Power transformers and bushings

Motors and generators

CT's and VT's

HVPD

The Drivers for Applying OLPD Testing

- Safety – mostly with switchgear, outdoor HV plant and cable sealing ends
- Ageing population problem – life extension, delaying capital replacement
- Condition-Based Maintenance (CBM)
- Avoid unplanned outages and improve network reliability

At Manufacture

- Quality Assurance
- Type/routine tests, e.g. IEEE/IEC standards – test to less than 5 pC on the cables

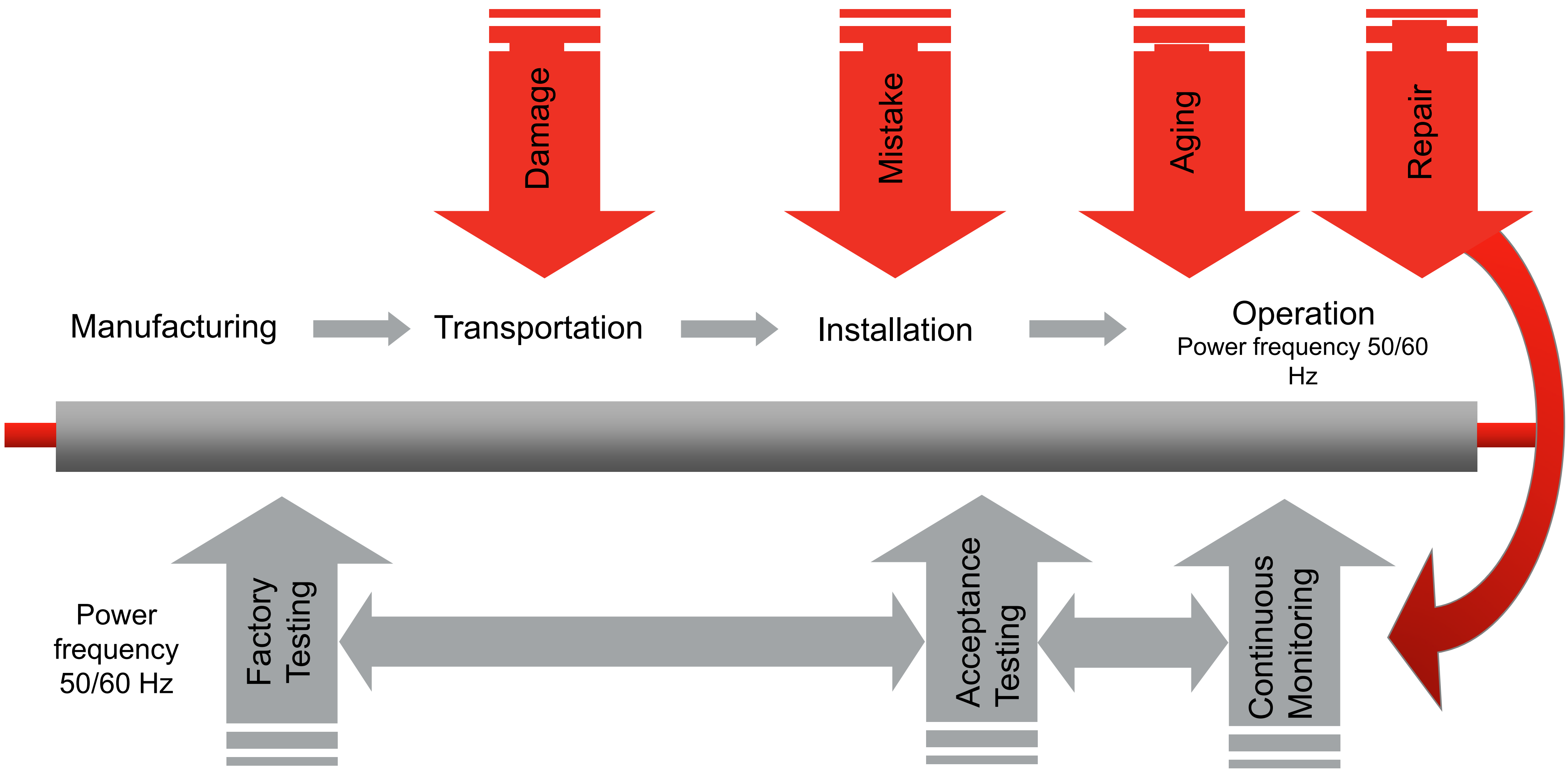
At Commissioning

- To check for transport damage
- To ensure the installation of the cable accessories have made to a good standard (these are the weak points in the cable system)

OLPD Testing During Service?

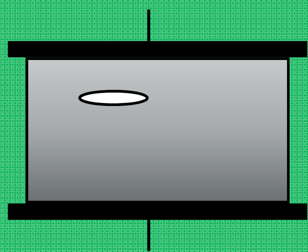
- To get baseline PD readings
- To evaluate insulation quality
- To locate PD activity sites and target repair
- To avoid costly / unplanned outages
- To support Condition-Based Management (CBM) regime

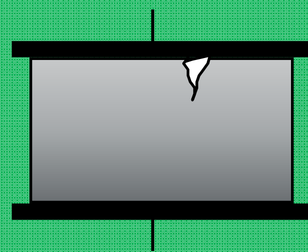
From 'Cradle to Grave' PD Testing and Monitoring Philosophy

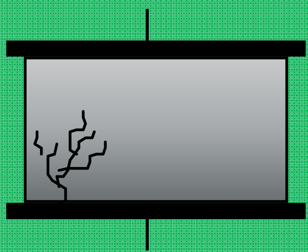


OLPD DETECTION THEORY

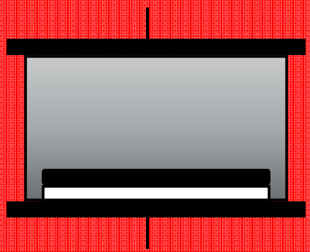
Internal

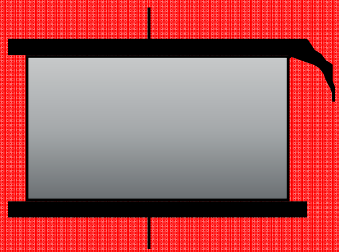

Void in insulation

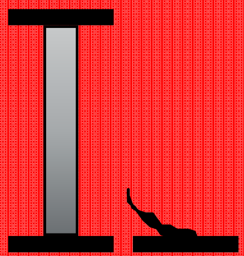

Sharp, irregular surface on conductor

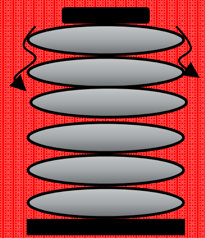

Tree growth in insulation

External


'Floating' metalwork near conductors


Corona from sharp objects at high voltage


Discharges from induced voltages onto sharp points at ground


Surface discharges

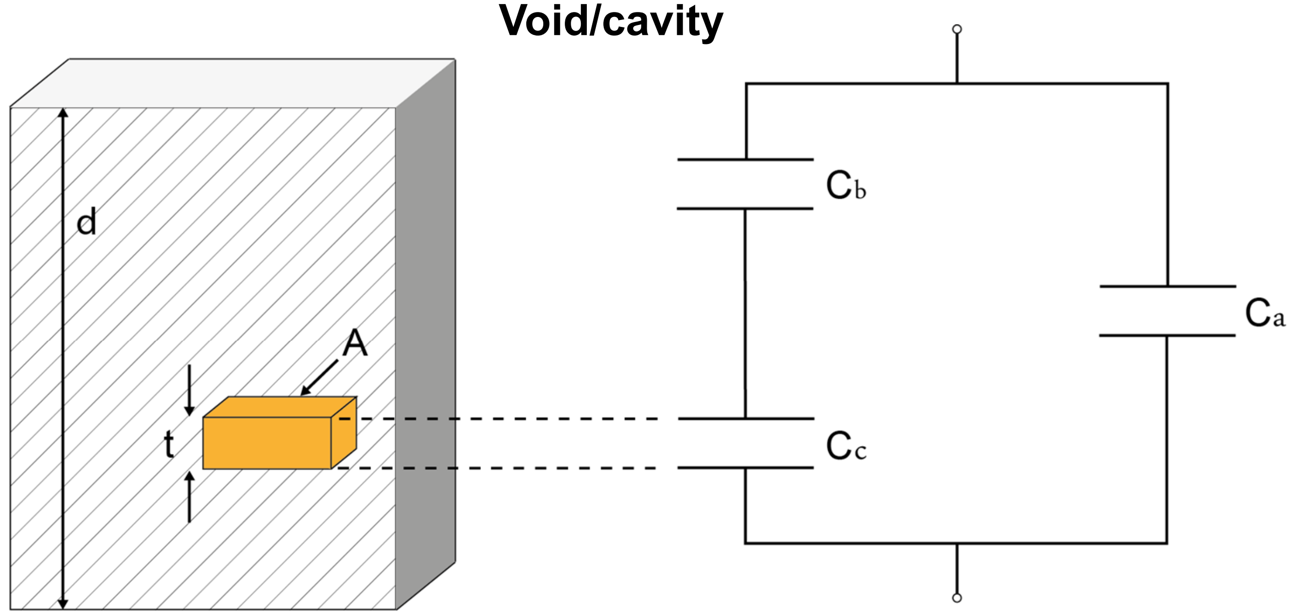
PD Equivalent Capacitance Circuit – ABC Model

C_a = Bulk insulation capacitance

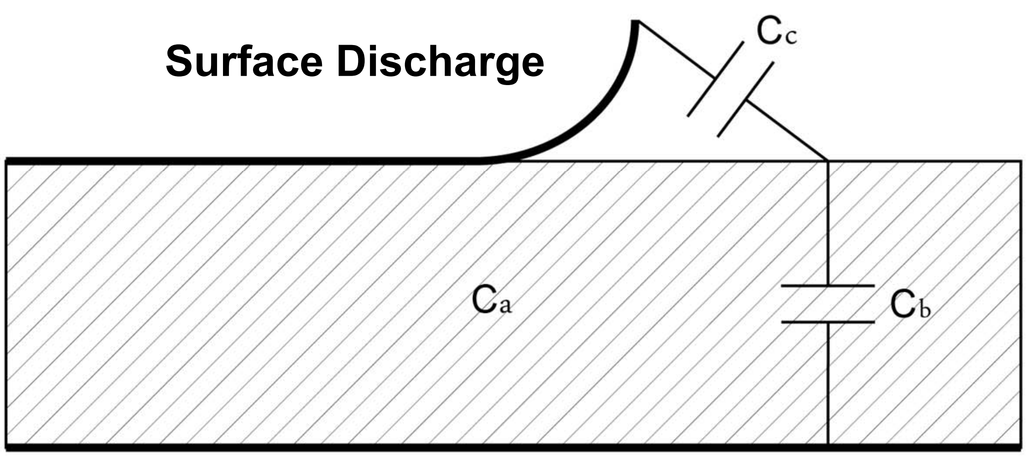
C_b = Capacitance between discharging area and electrodes

C_c = Cavity/surface area in which the PD occurs

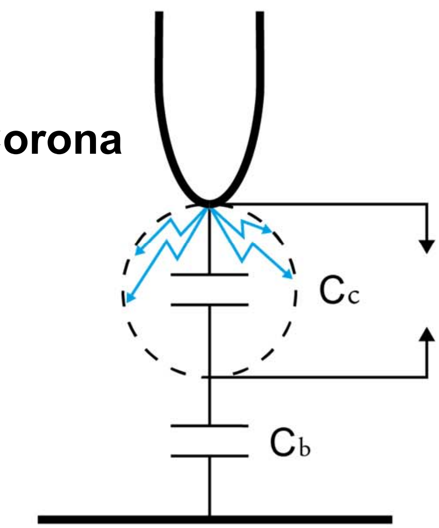
Void/cavity



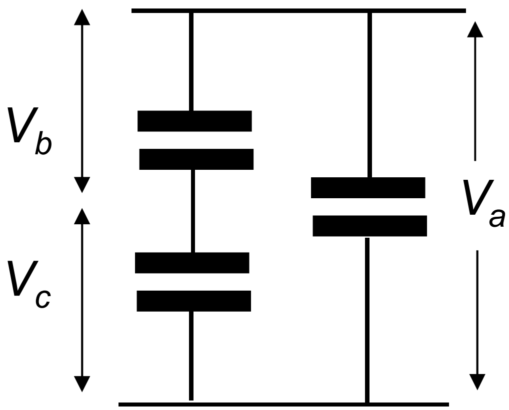
Surface Discharge

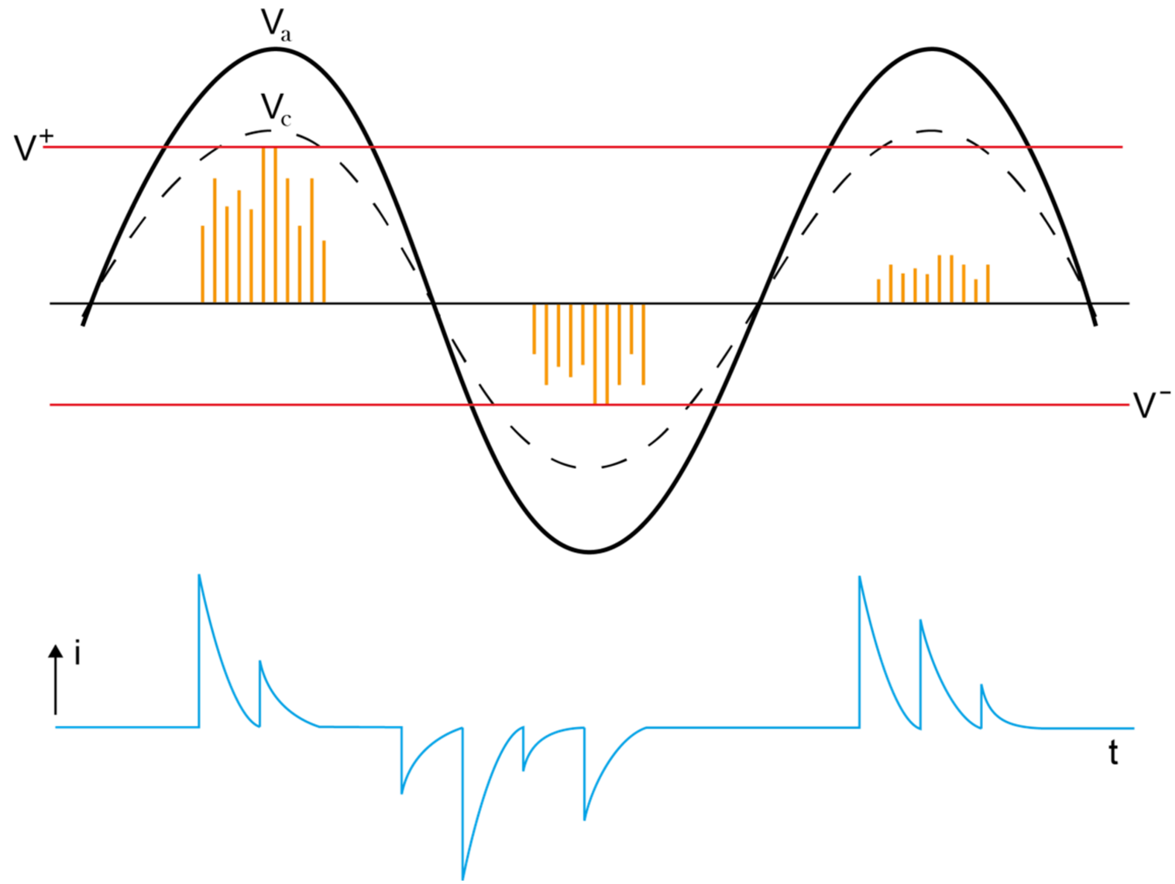


Corona



Voltage Breakdown of Cavity of Surface Area (Cc)



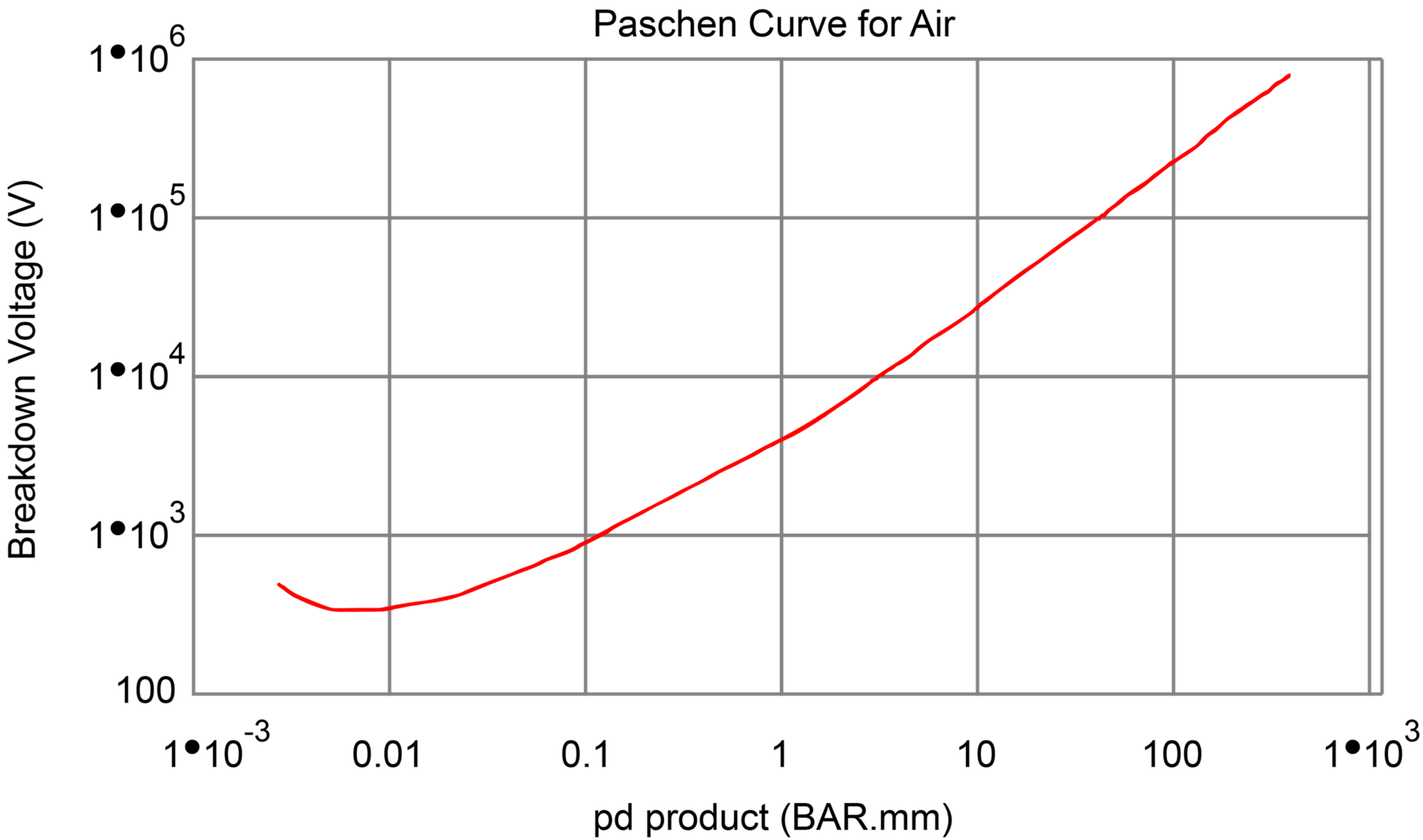


Theoretical

Actual current pulses (stochastically occurring)

V^+, V^- = PD inception voltages

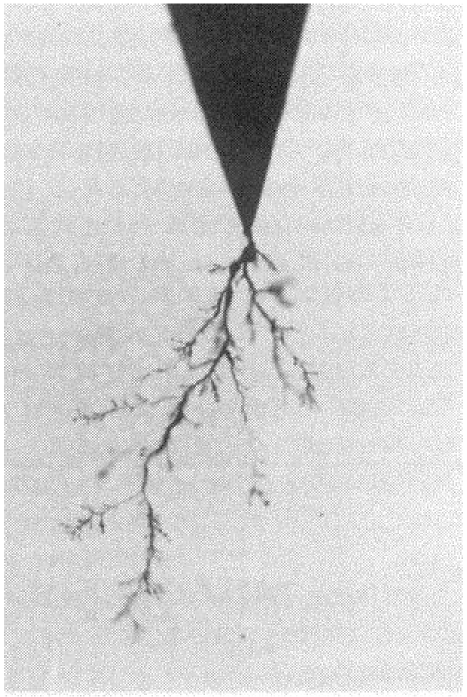
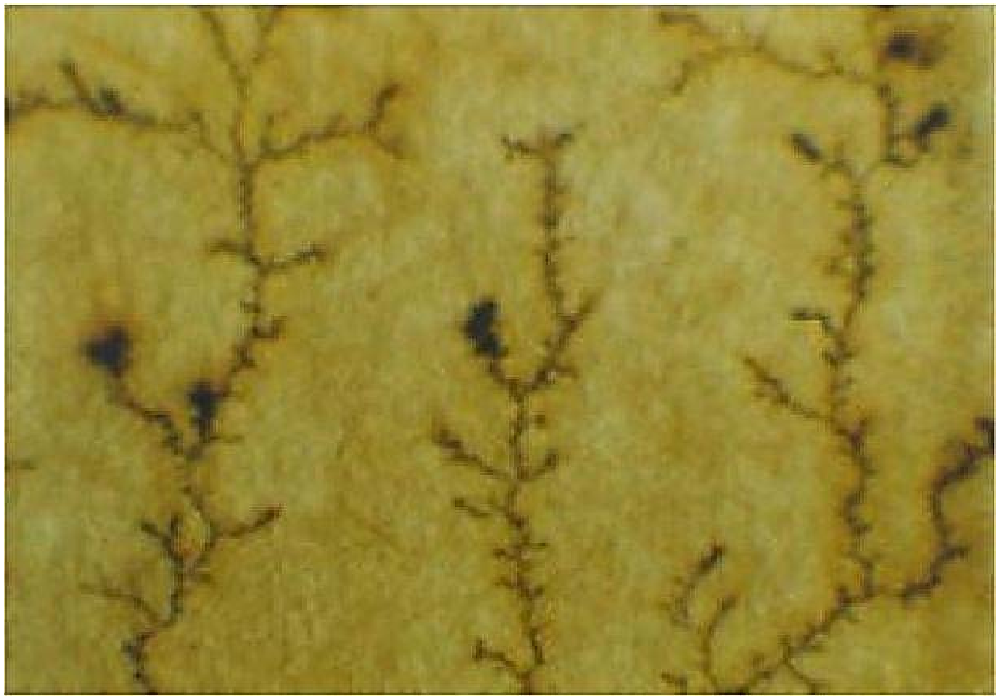
Paschen Curve for Breakdown of Air in Uniform Field



From T.W. Dakin et al "Breakdown of gases in uniform fields" Electra, Vol 32, pp 61-82, 1974.

Internal discharges can be caused by:

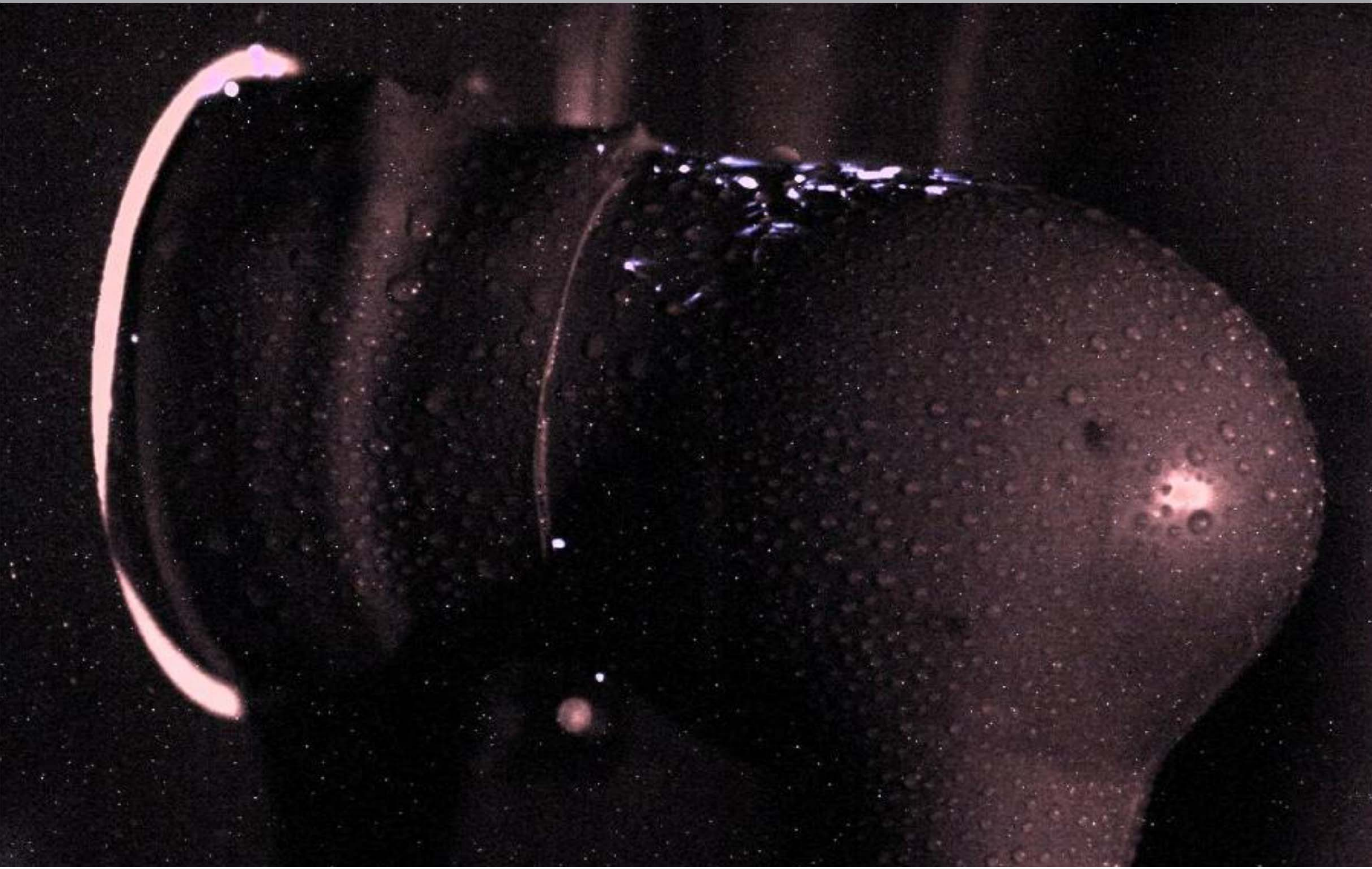
- Voids, cavities, delaminations in solid or liquid insulation
- Electrical trees form from these voids


PD Damage to Cables – Treeing on 66 kV Paper Cable

Insufficient Mastic Around 33 kV XLPE Connector

Surface Discharges on 24 kV Cable Elbow Termination



PD Damage to Cables

Surface Discharge on Dry-Type Termination

- Incepted from sharp points on HV conductors
- Also possible from sharp points on ground

Corona Discharges
400 kV Arcing Horn

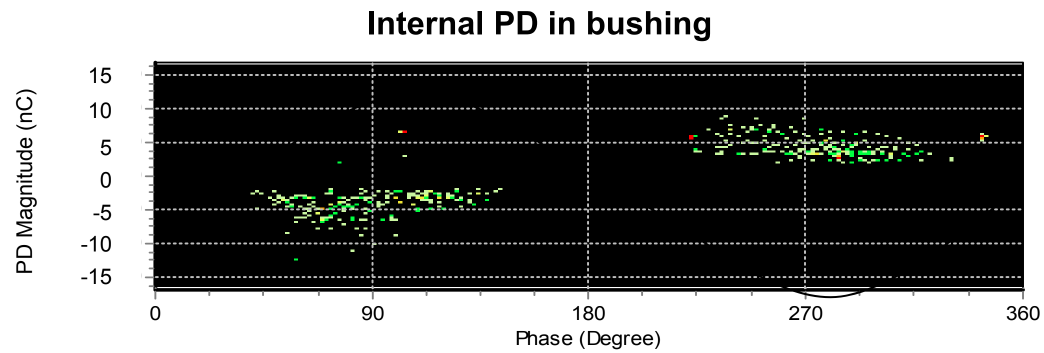
HVPD

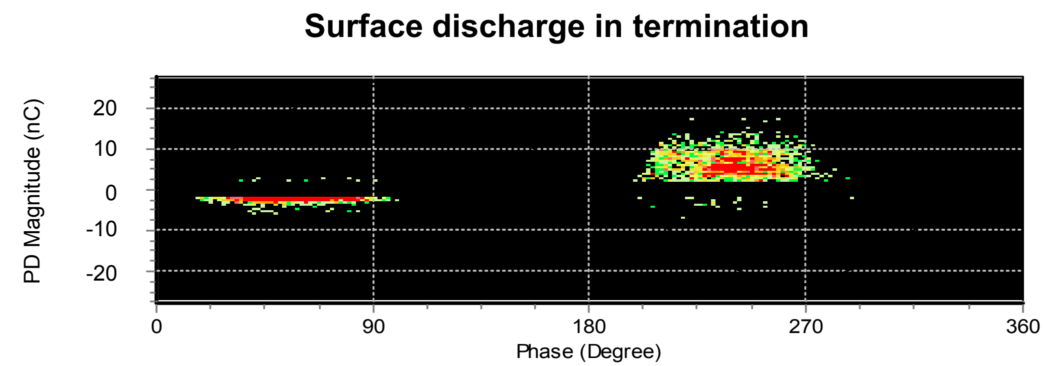
PD Energy and Detection Methods

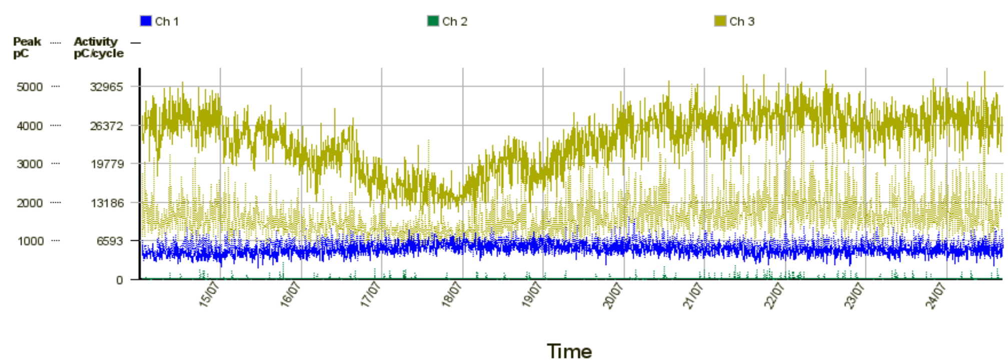
PD

ENERGIES RELEASED	DETECTION METHODS
Electrical Charge	Capacitor/Inductive (HFCT)
Electromagnetic Wave	TEV, VHF/UHF Couplers
Optical	Low-light/UV Cameras
Acoustic Wave	Contact/Airborne Acoustic
Gaseous by-products	Dissolved Gas Analysis
Chemical by-products (such as white deposit oxides)	Visual inspection
Ozone	Smell / Ozone Detector

- PD magnitude
- PD count (number of PD pulses per power cycle)
- Cumulative PD activity
- Phase Resolved PD (PRPD) Patterns
- PD monitoring over time

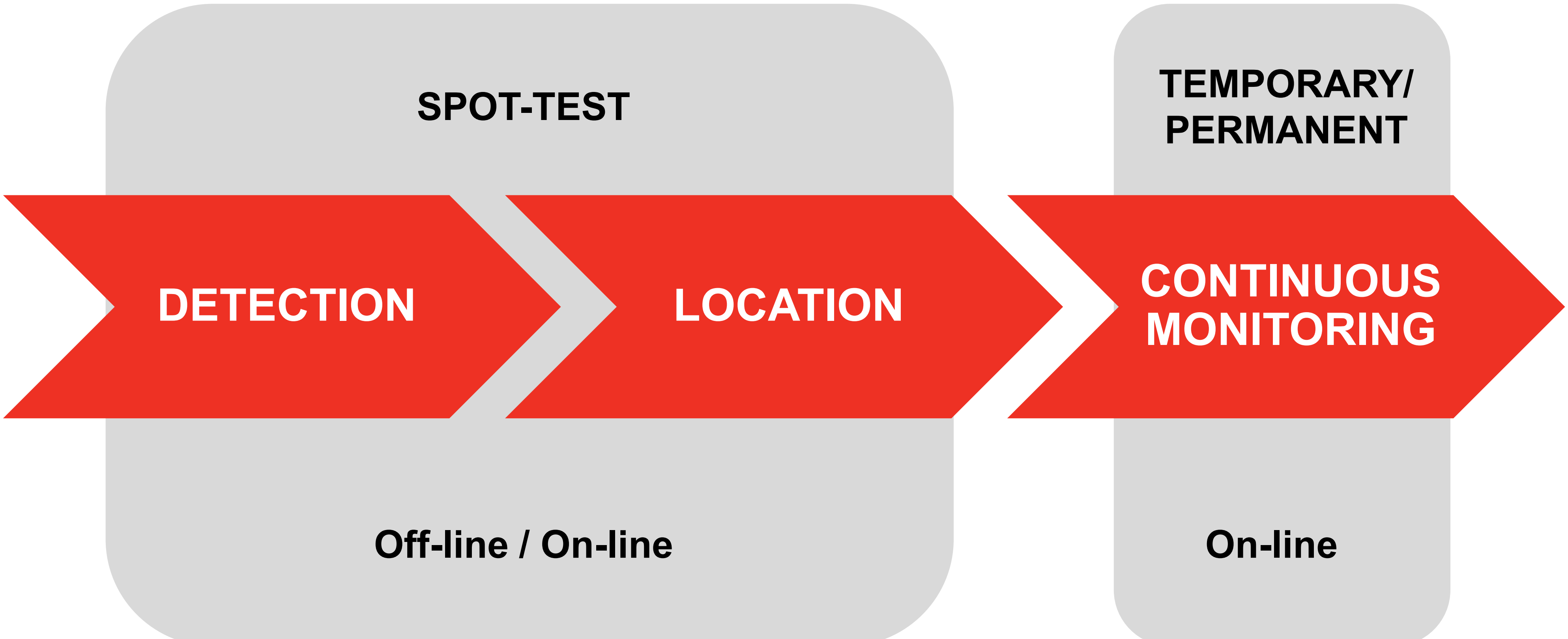






OLPD TEST & MONITORING EQUIPMENT

PD Testing Approach



Phase 1 – Detection

- Simple equipment
- Initial indication of PD level/severity

HVPD PDSAir™
Handheld PD Surveying Tool

Phase 2 – Diagnostics/Location

- More advanced hardware/noise rejection
- PD diagnosis and location within the cable/plant
- Digital PD detector with PC for analysis and reporting

HVPD Longshot™
Diagnostic OLPD Test Unit

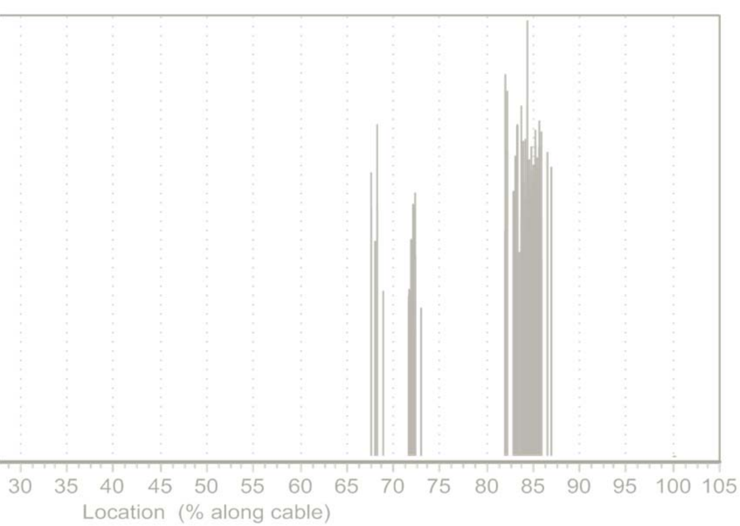
Phase 3 & 4 – Temporary/Permanent Monitoring

- Temporary or permanent hardware
- Trends PD over time and captures any trend to failure
- Web-based UI/SCADA alarms
- Simple and advanced options:
    - Simple hardware without diagnostic capabilities, generates alarm signals only
    - Advanced hardware with diagnostic capabilities

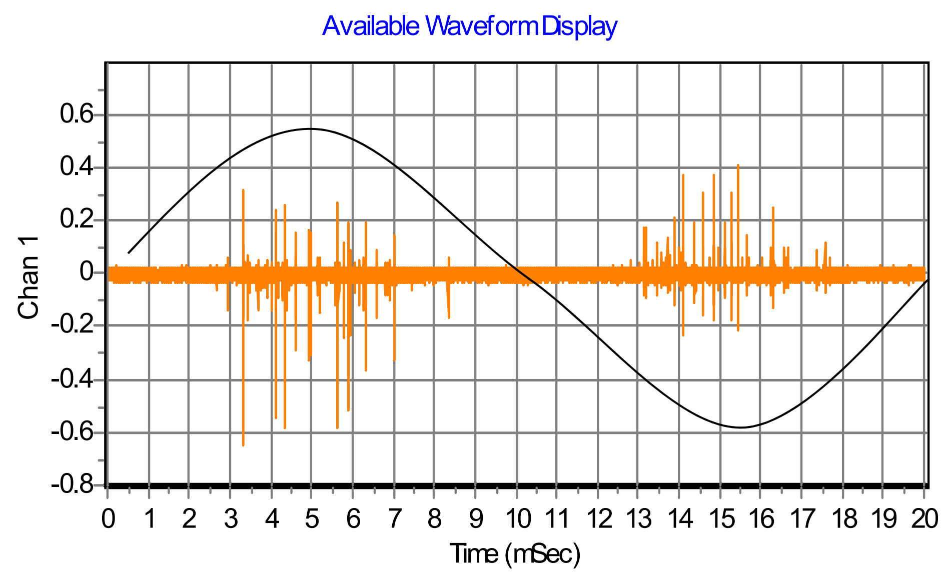
HVPD Multi™
Portable Monitor

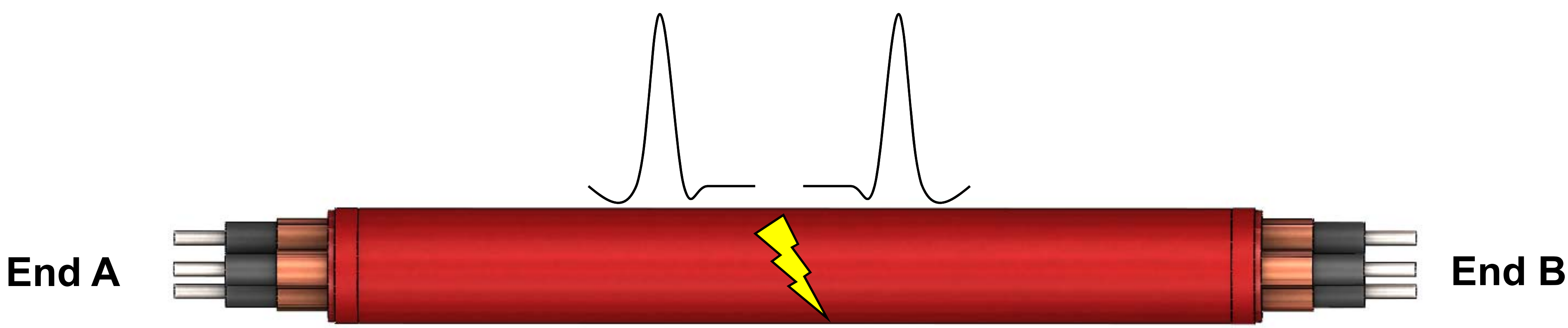
HVPD Multi™
Permanent Monitor

CABLE PD – DETECTION & LOCATION



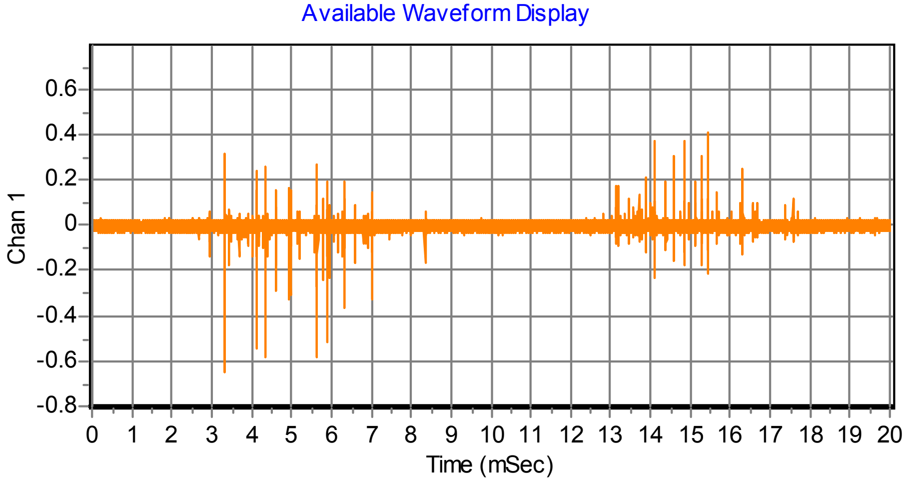
- PDs are incepted by the high voltage applied to cable.
- PD pulses are short duration impulses (ns – μs) that propagate in both directions away from PD site between cable core and sheath.
- Signals can be detected on both the core and earth screen at terminations.



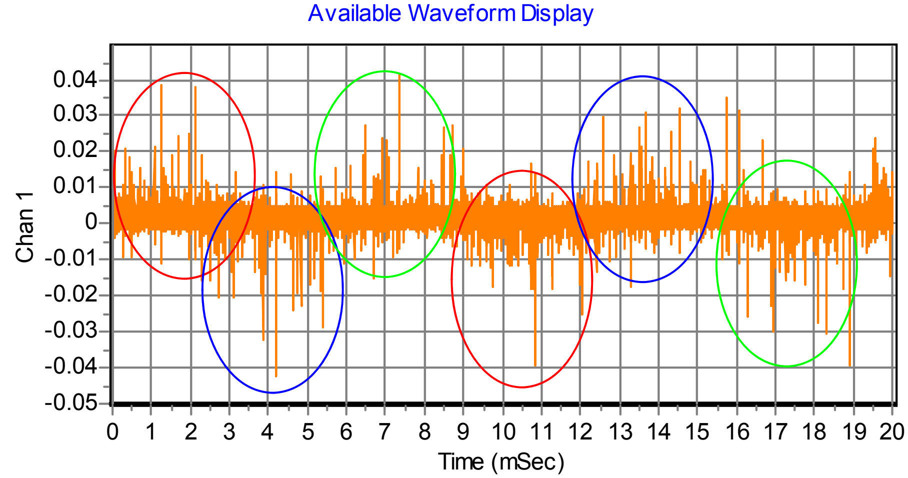


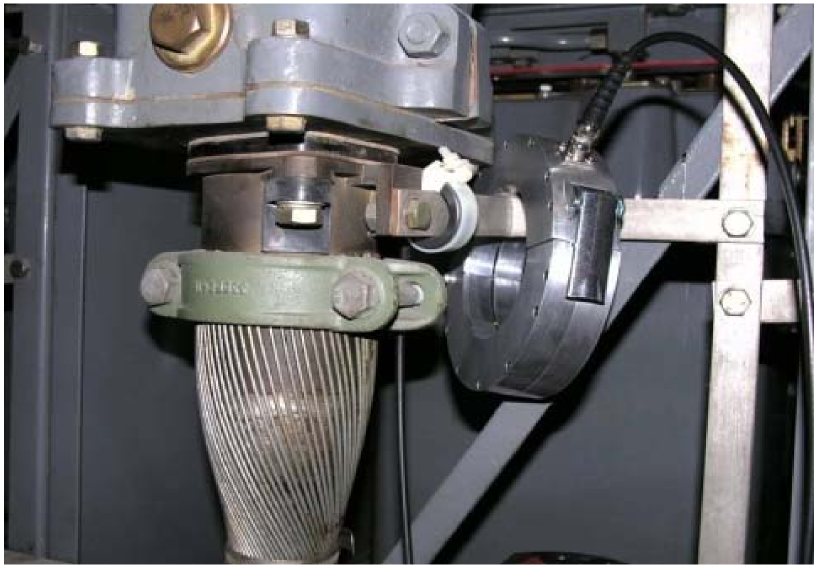
Example of PD Against Phase for Power Cables

Single Core Cable

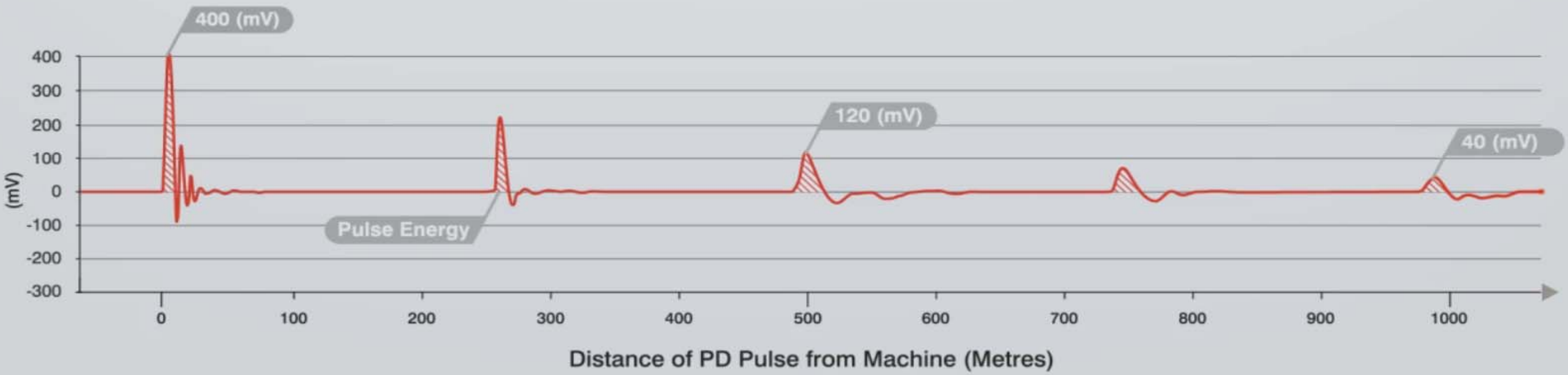


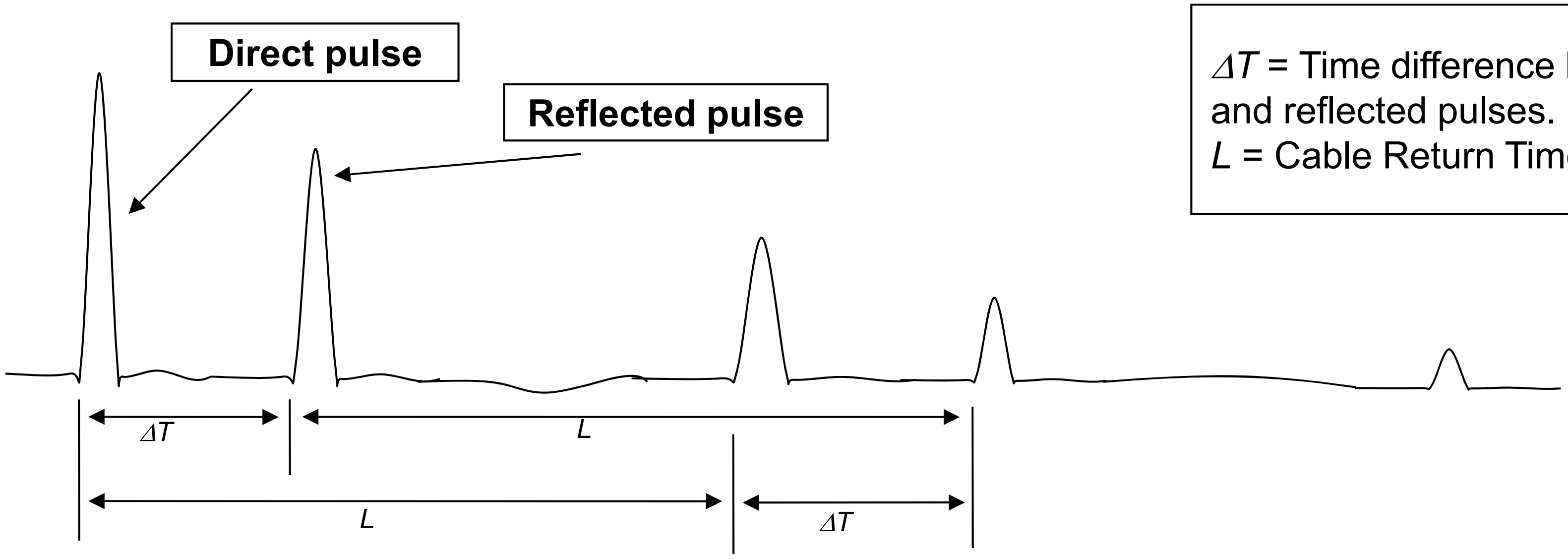
Three Core Belted Cable with HFCT on Common Screen





PD Pulse Propagation Analysis





ΔT = Time difference between direct and reflected pulses.
L = Cable Return Time for cable

PD Pulse Return Speed: V_{PD} = Cable Length/Return Time

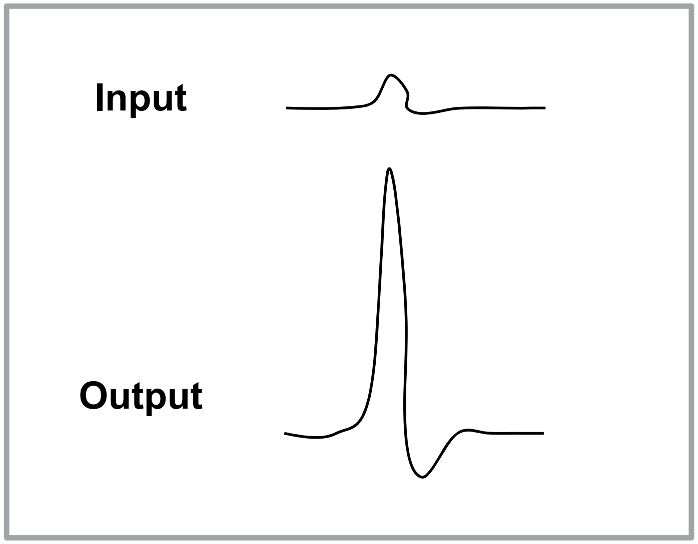
PD Site Location:

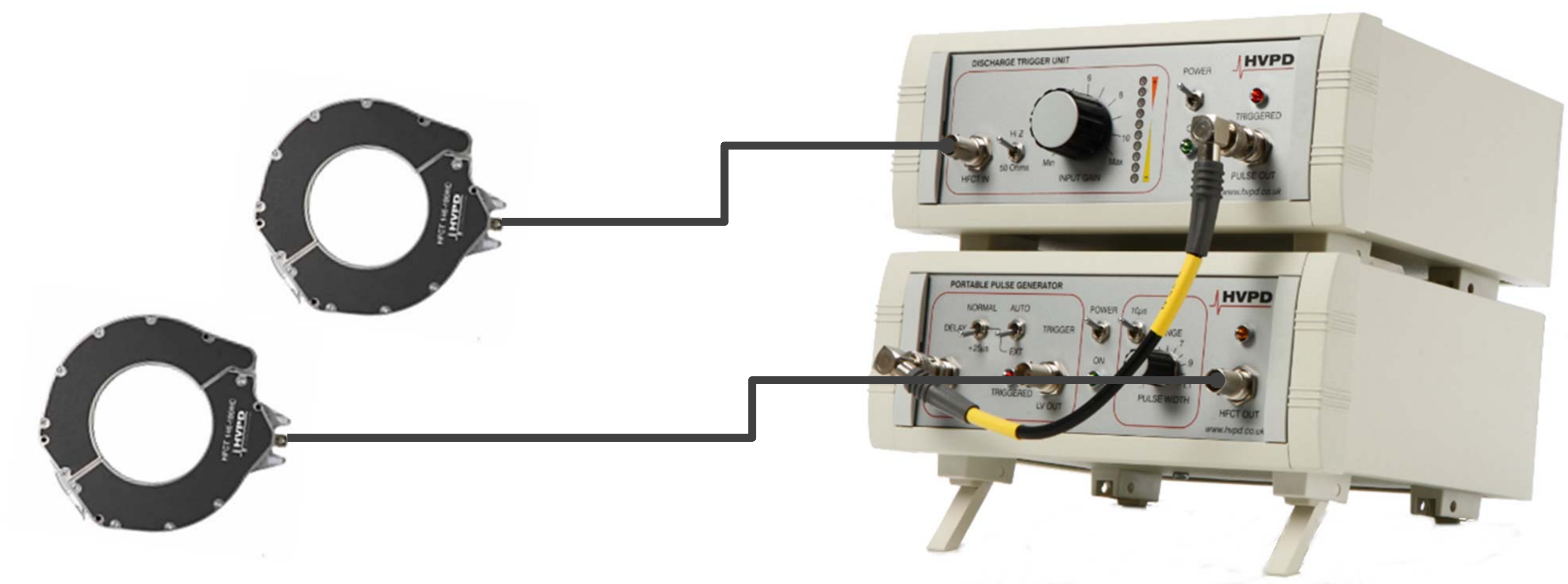
$$PD_{\%} = \left(1 - \left(\frac{\Delta T}{L}\right)\right)100$$

In many on-line cases reflected PD pulses are often not visible:

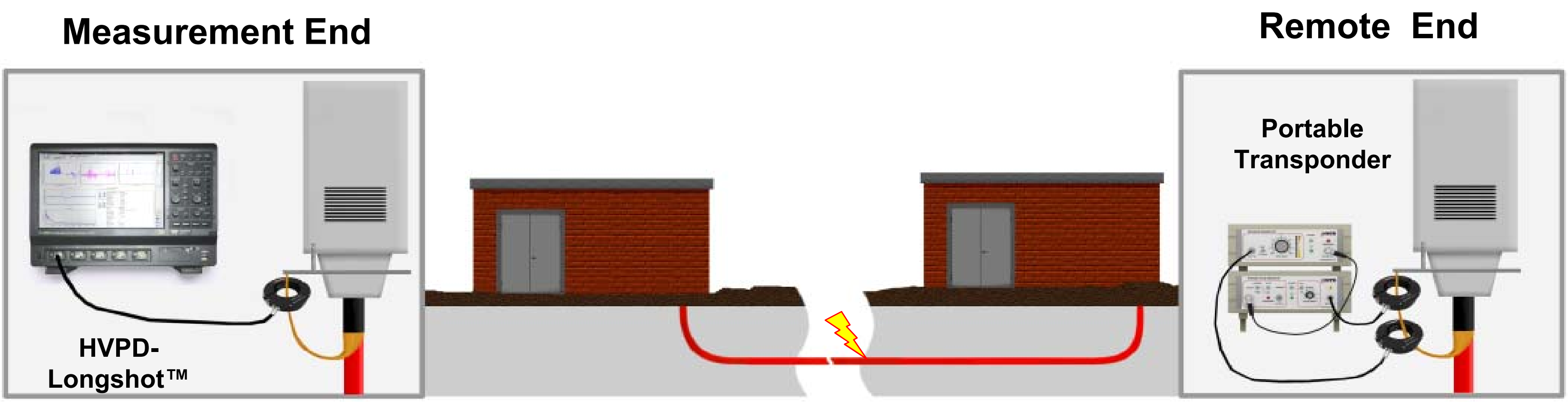
- Attenuation is too large to measure reflected pulses from the far end (long cables)
- Waveforms too difficult to interpret (noisy signals)
- Teed or jointed cables
- Cables with many ring main units or switches
- Cables with no change in impedance at the far end

- Portable Transponder installed at remote cable end
- Compensates for lack of reflected pulse
- Detects PD pulse with Discharge Trigger Unit and re-injects large pulse back into cable with Pulse Generator
- Connects to cable with HFCTs



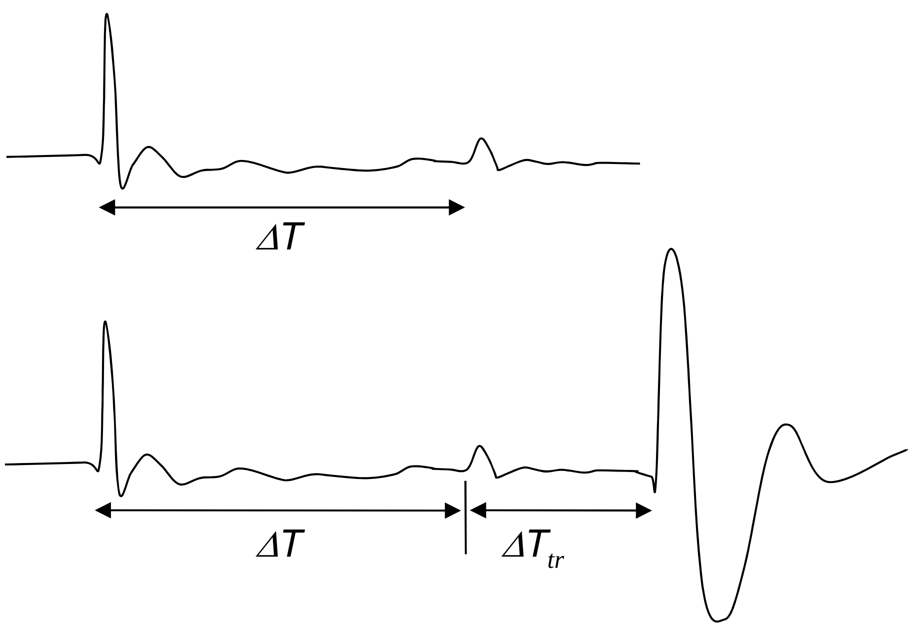


On-line PD Location on Power Cables
Example of Usage



Without Transponder

With Transponder

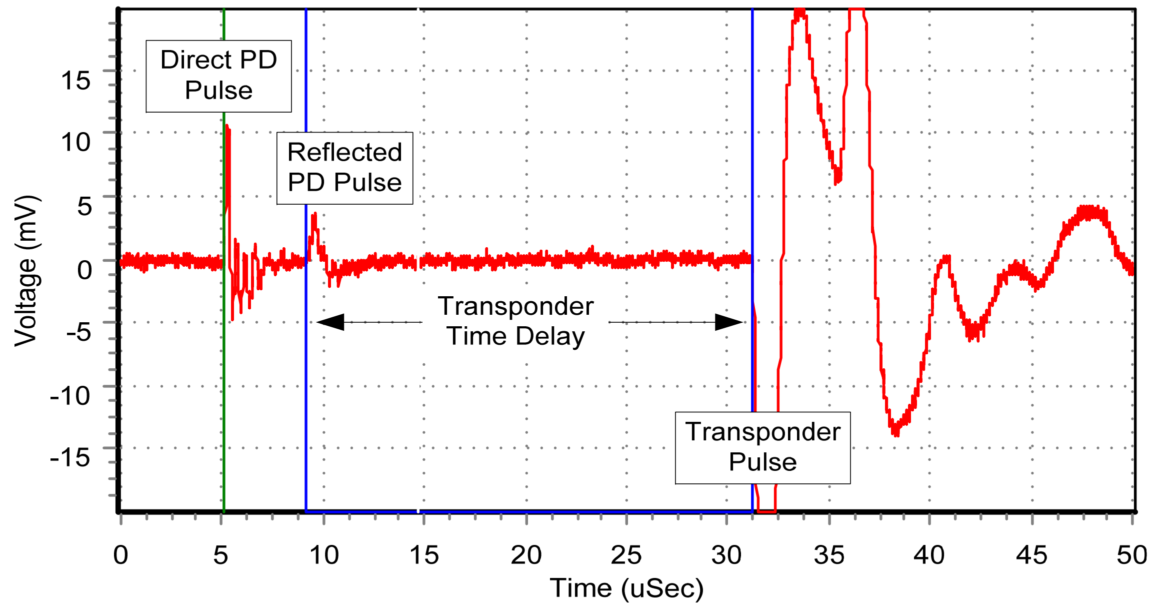


Reflection may not be clearly visible (e.g. due to noise)

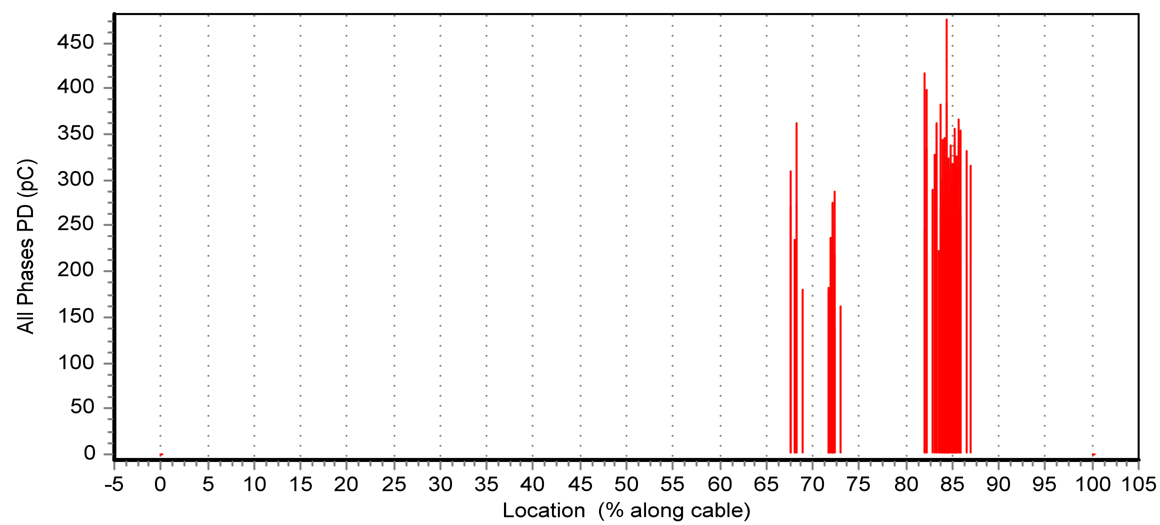
The large transponder pulse removes any confusion

ΔT = Time between direct and reflected PD pulses
ΔTtr = Transponder time delay

On-line PD Location on Power Cables
Example Results

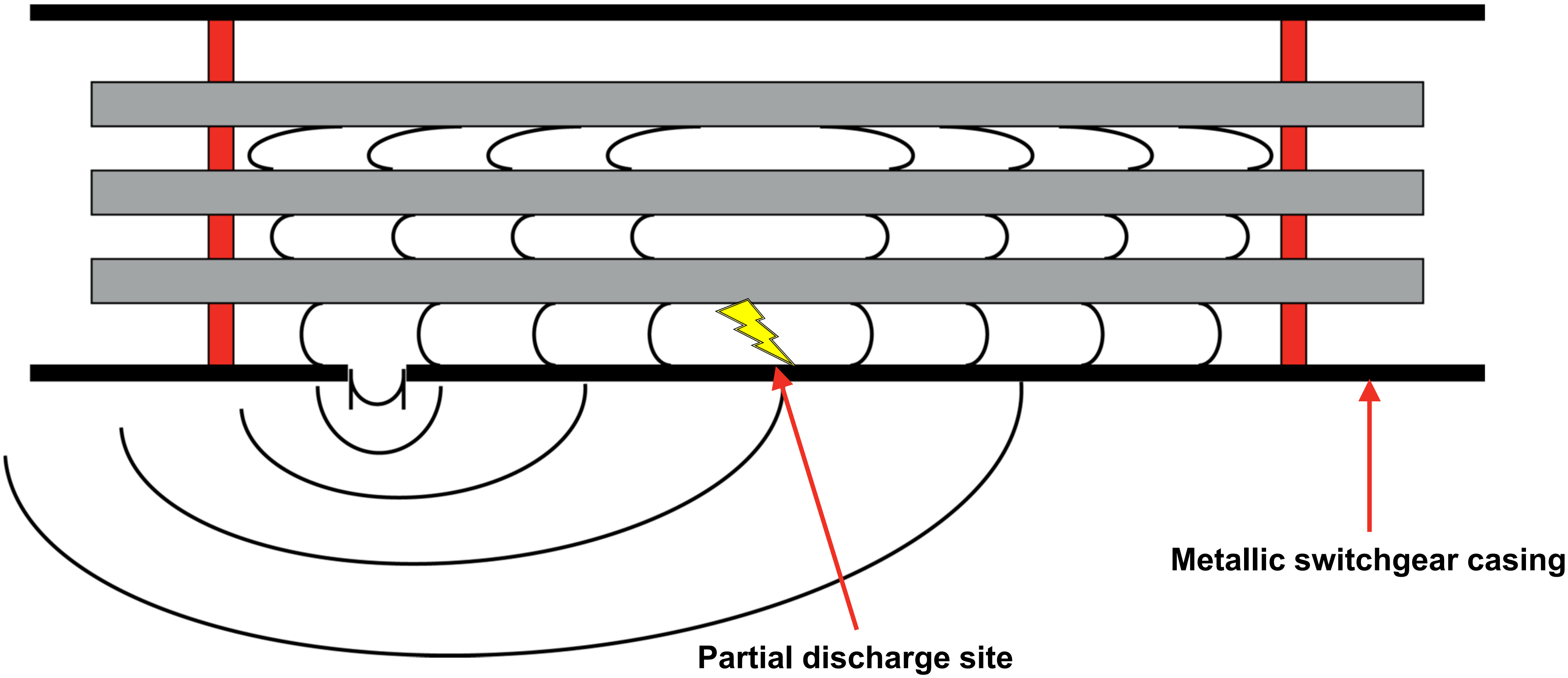


Reflectogram showing PD and transponder pulses



PD location map for all PD pulses in cable section under test

LOCAL PD IN MV SWITCHGEAR

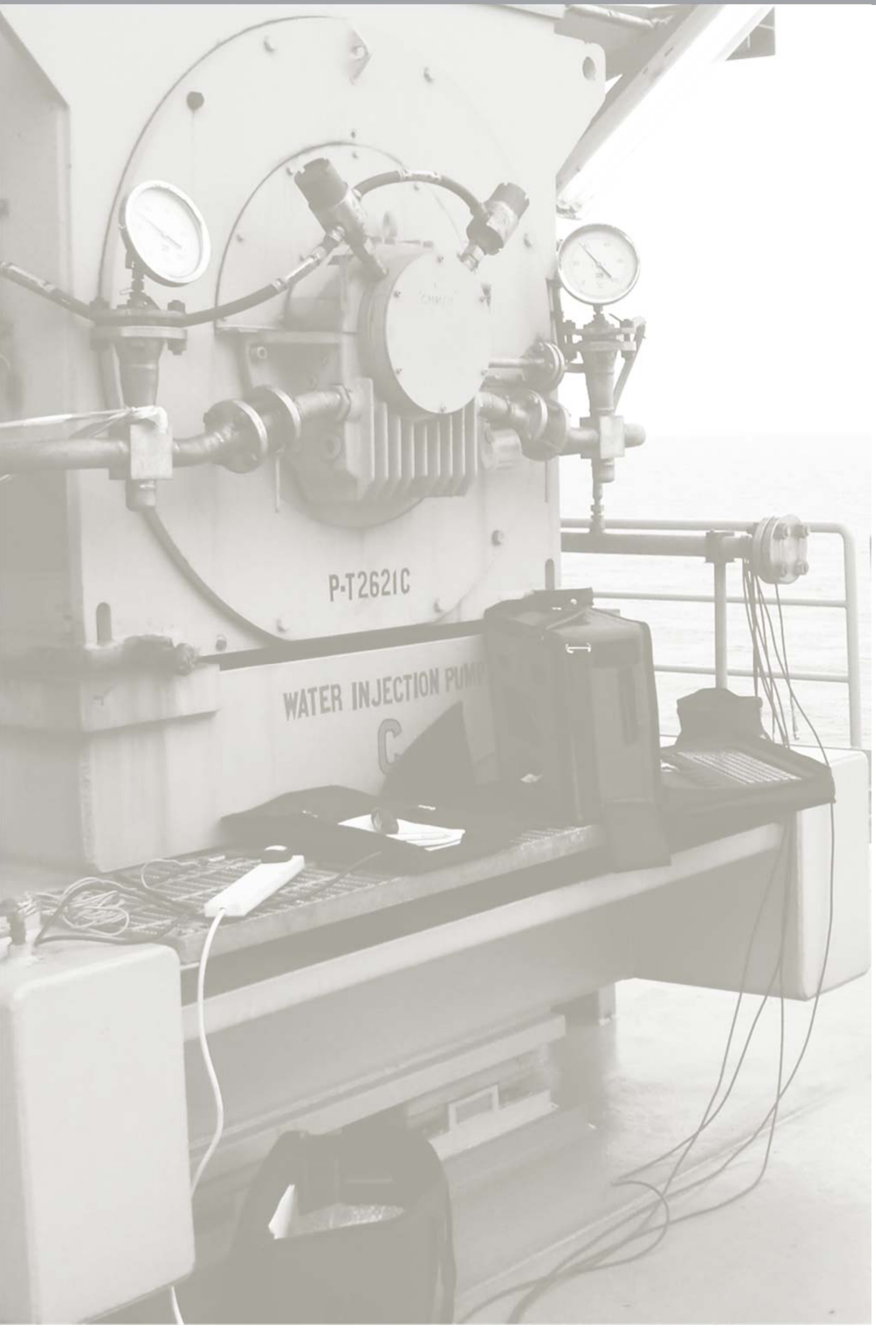


- PD site within switchgear: Phase–Earth discharge
- EM signals radiate from PD site and couple onto metal-clad housing
- Signals emerge on the outer surface at openings in metal housing

Example Use of Detection and Diagnostics

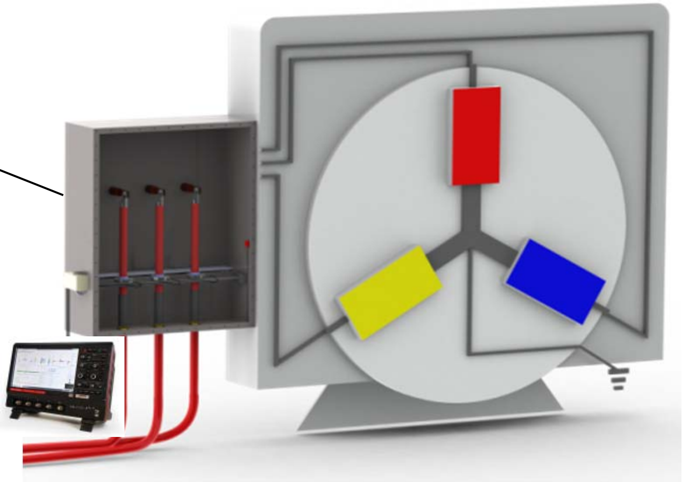
Transient Earth Voltage (TEV) Theory

PD IN ROTATING MACHINES



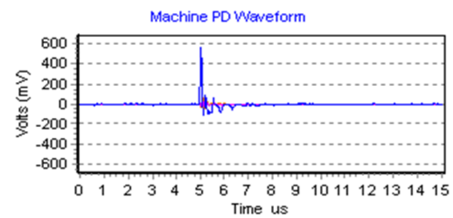
Important to identify type of PD in machine for severity:

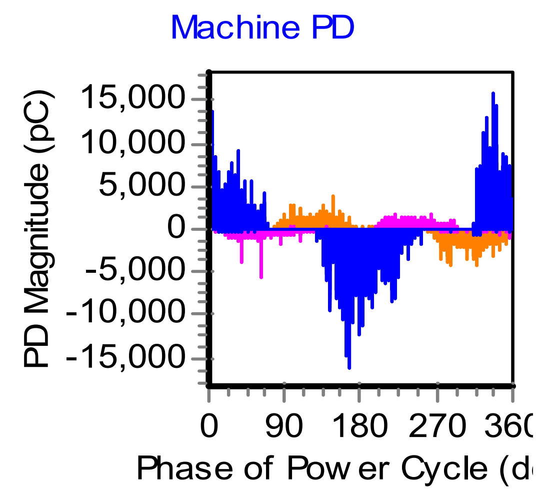
- slot section,
- delamination,
- end windings etc.



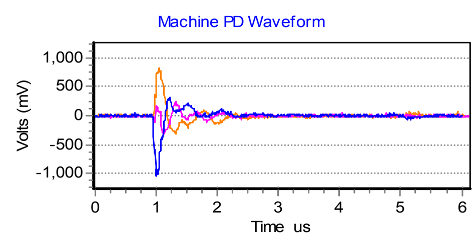
- Signals captured synchronously from sensors on each phase.
- Identification of Phase-Earth PD and Phase-Phase PD.
- Phase Resolved PD (PRPD) patterns indicate the defect type.

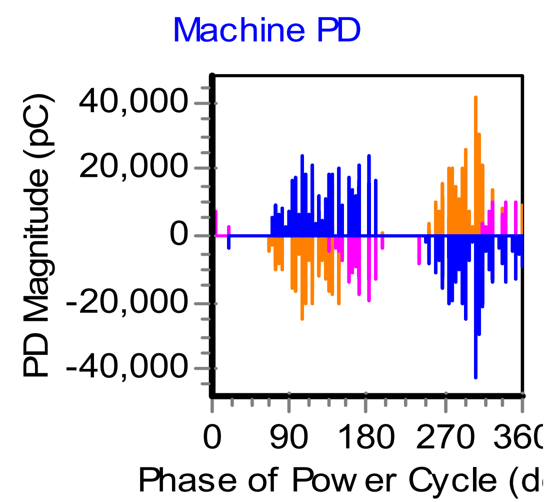
Phase-Earth PD on RYB phases



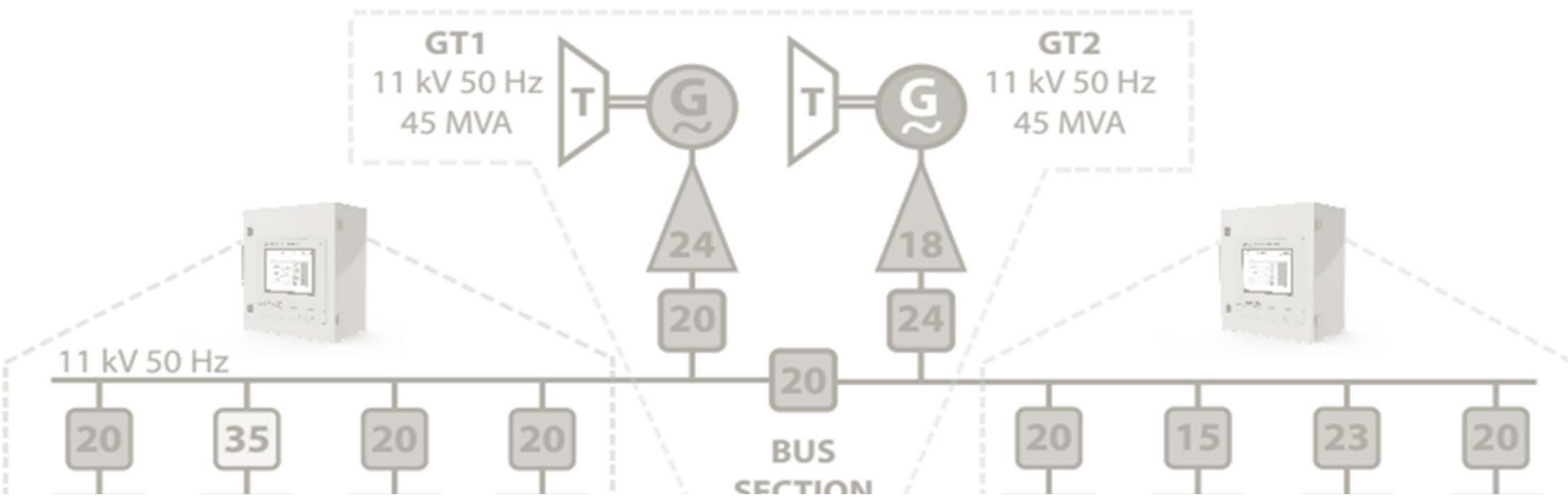


Phase-Phase PD (Y-B)

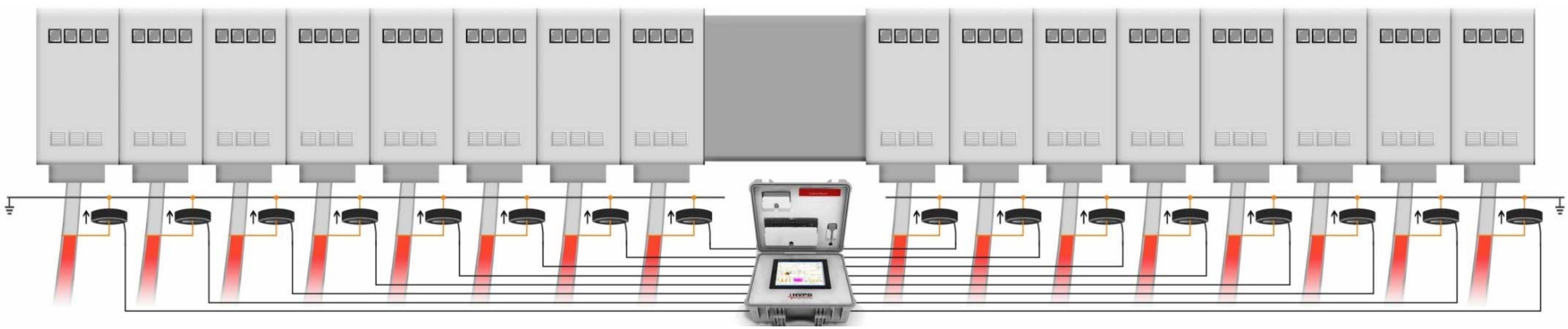




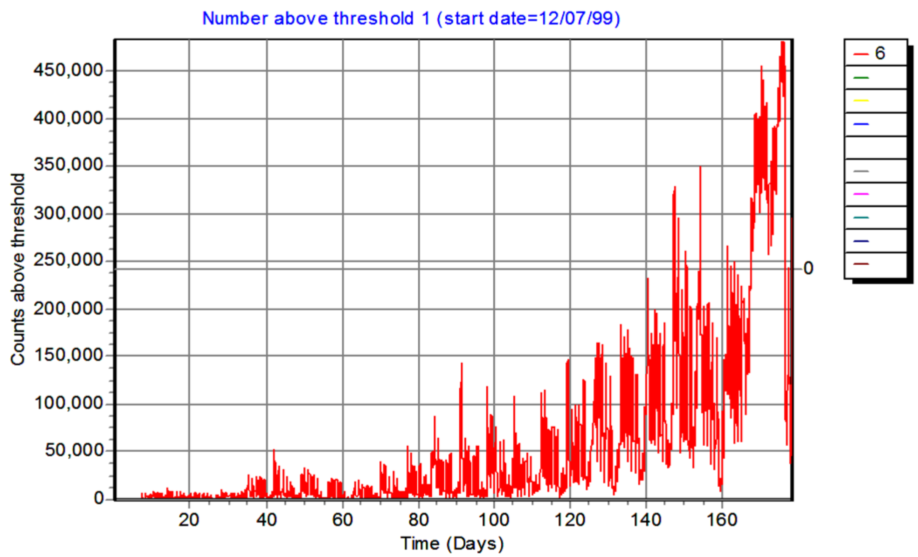
CONTINUOUS OLPD MONITORING



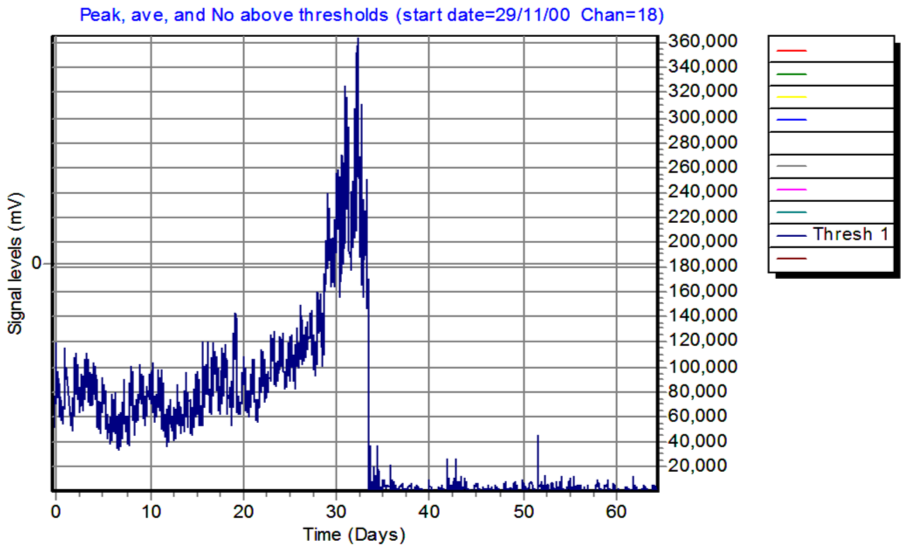
- Important/high-value/critical plant items
- Plant with known PD variations in time – paper cables, rotating machines, AIS/GIS.
- Plant with high PD identified in spot-tests



Continuous Monitoring
PD Rise to Failure



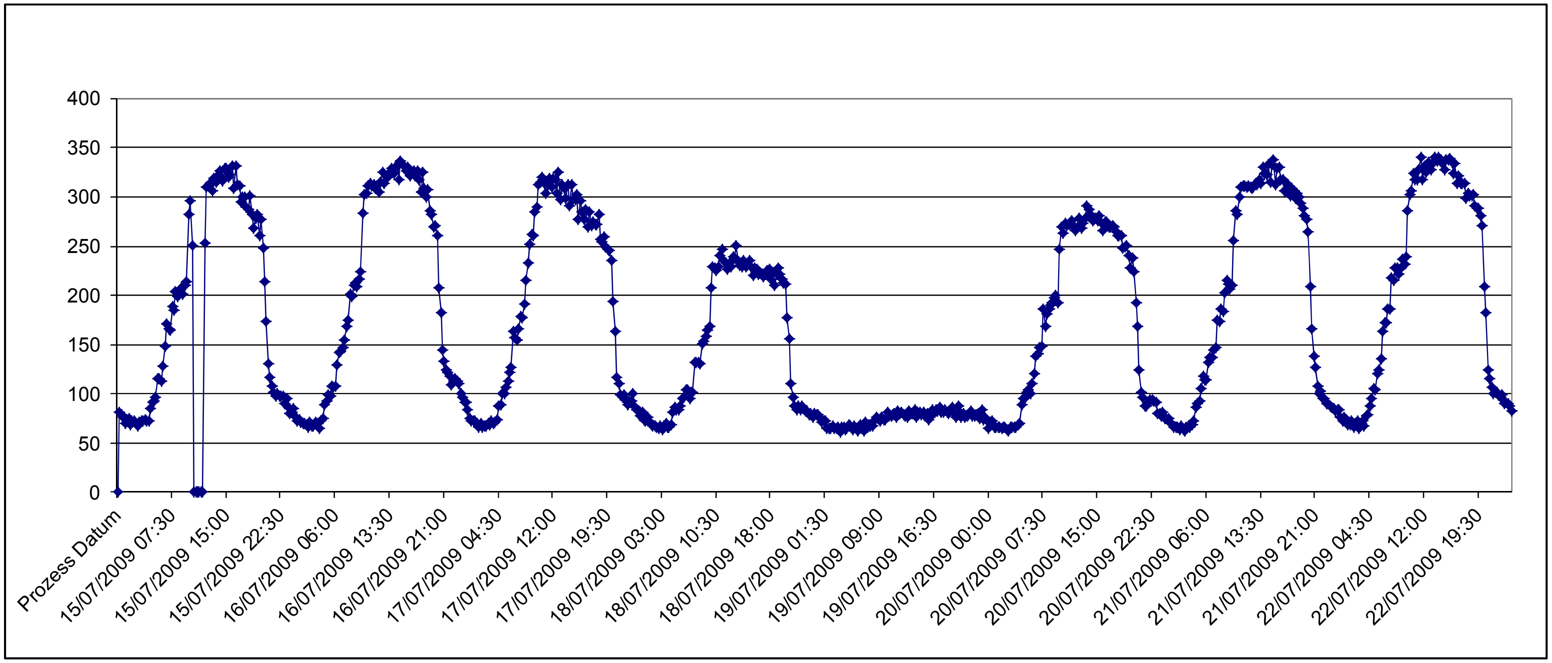
PD rise to failure over 100 days

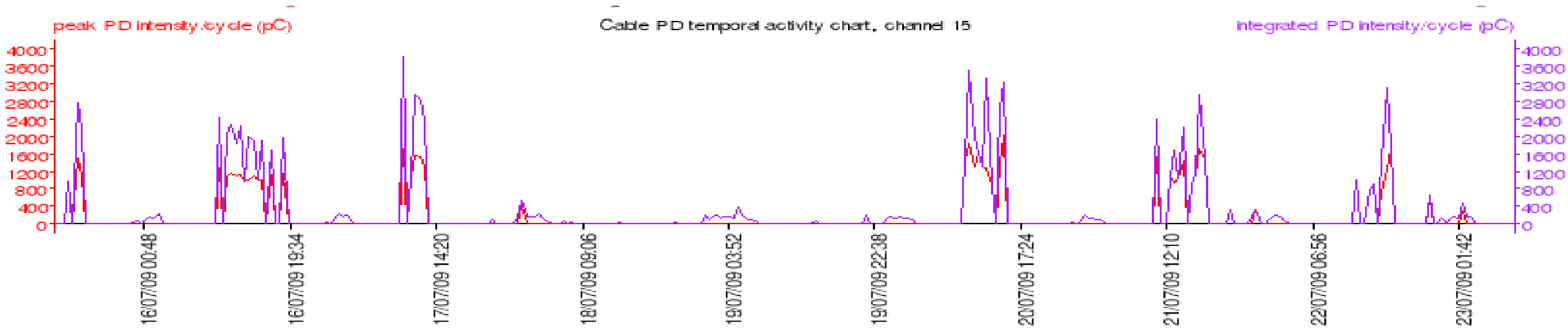


PD rise to failure over 20 days

Continuous Monitoring

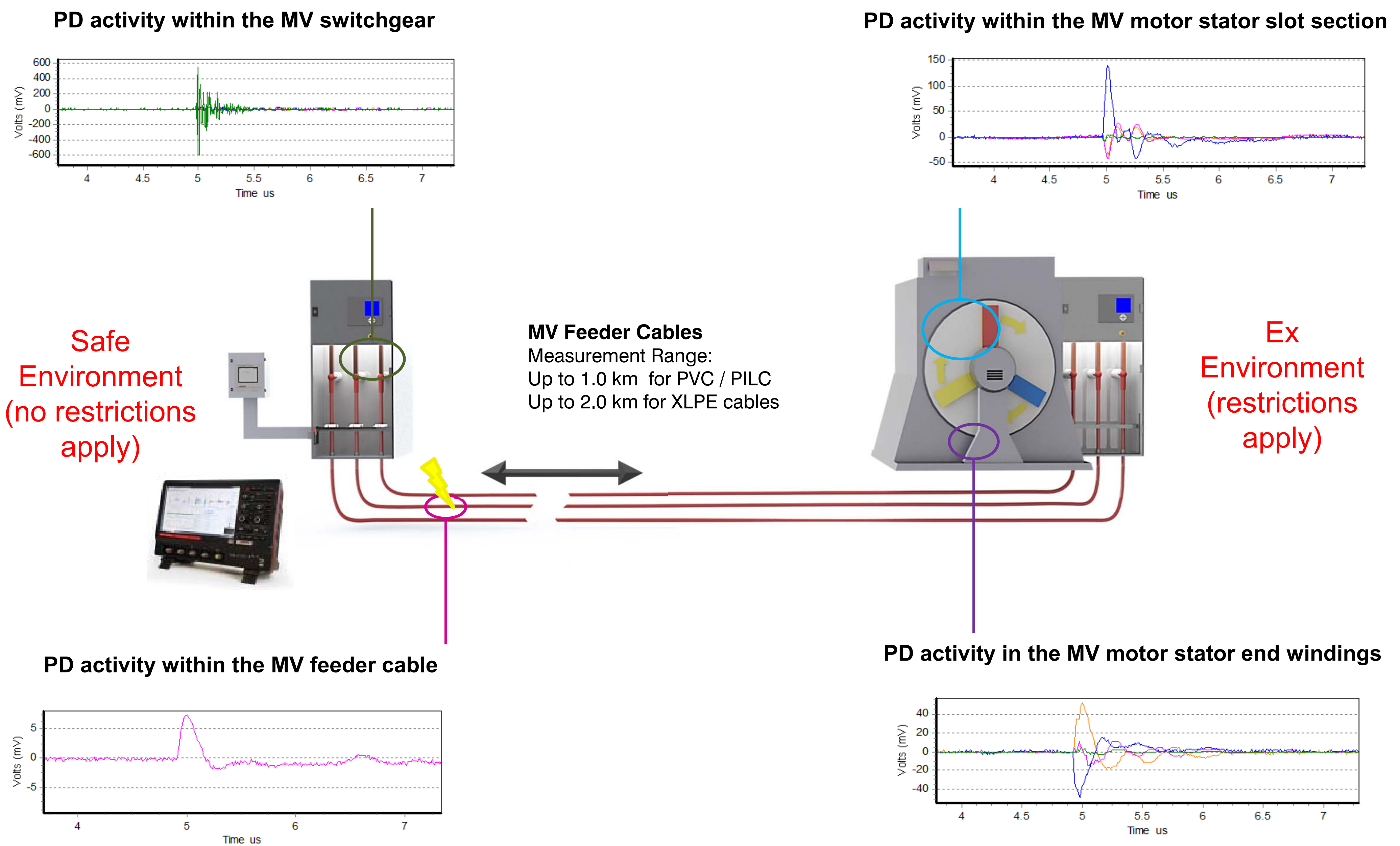
PD Variation with Load on PILC Cable





PD burns in a hot cable: electrodes expand - possible movements inside accessories lead to increased field strengths in dielectrics – PD in accessories.

Remote OLPD Monitoring of Ex/ATEX HV Motors in Hazardous Gas Zones



HVPD's Network OLPD Monitoring System User Interface - Oil Refinery

HVPD TCO Monitoring Database

Analysis / Reports Substations / Network Selection

Local Area Network Criticality League Table

Networks	Criticality (0-100)	
	Cable	Local
Grid Connection 400 kV	0	0
Offshore 132 kV Export	0	0
Trans Network 110 kV	47	26
Industrial Network 110 kV	0	0

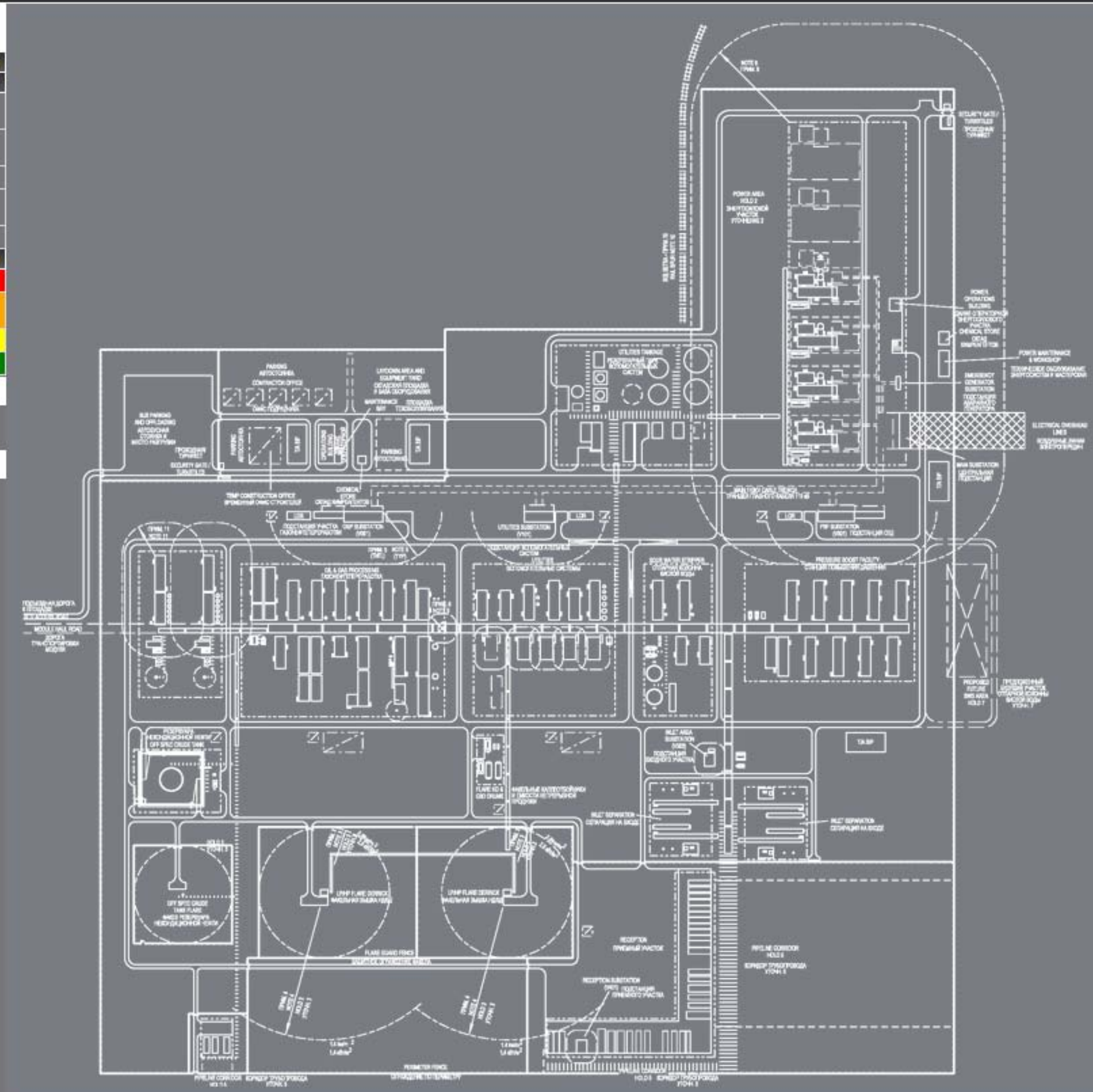
Condition/Action Guideline	Criticality (0-100)
High PD / Diagnostic	76-100
Moderate to High PD / Investigate	51-75
Moderate PD / Monitor	26-50
Plant OK / No Action	0-25

Key

- Cable / Machine PD Activity
- Local PD Activity

Monitoring Period

- Last Hour
- Last 24 Hours
- Last Week
- Last Month



Network Options

View Level

- GEO : TCO Overview
- SLD : TCO Overview
- Substation : select
- Location : select

Networks

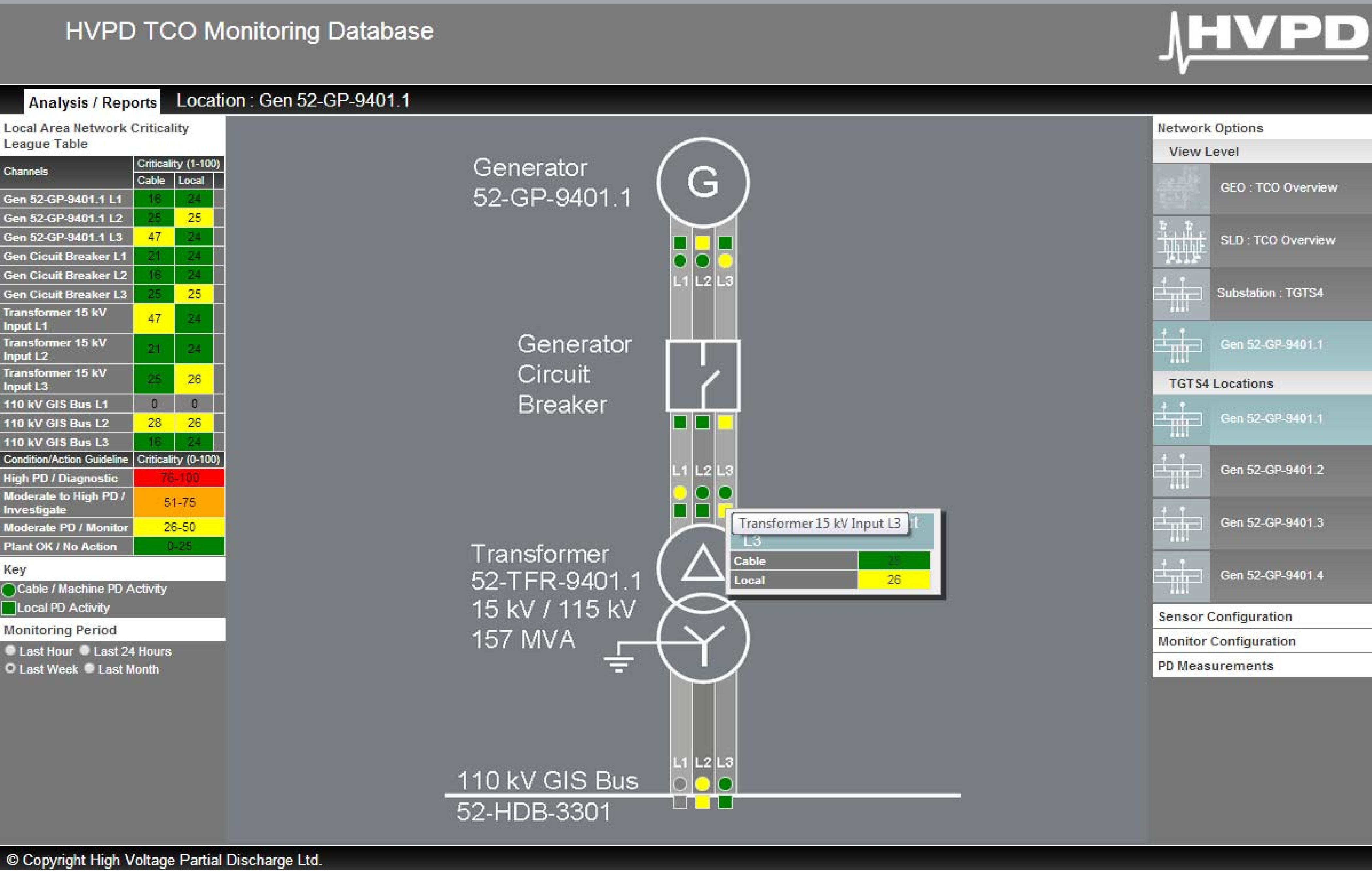
- Grid Connection 400 kV
- Offshore 132 kV Export
- Trans. Network 110 kV
- Industrial Network 110 kV

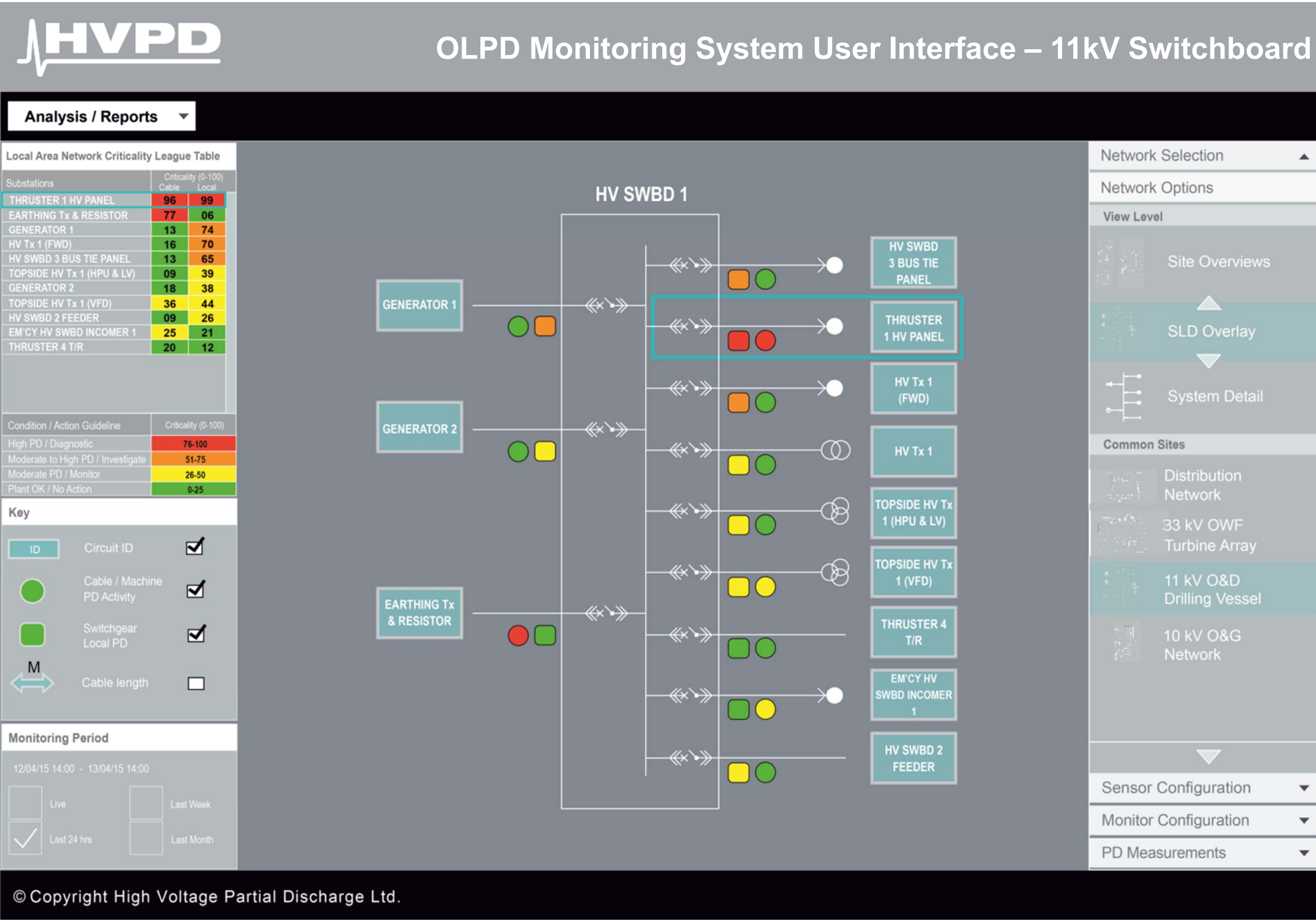
Sensor Configuration

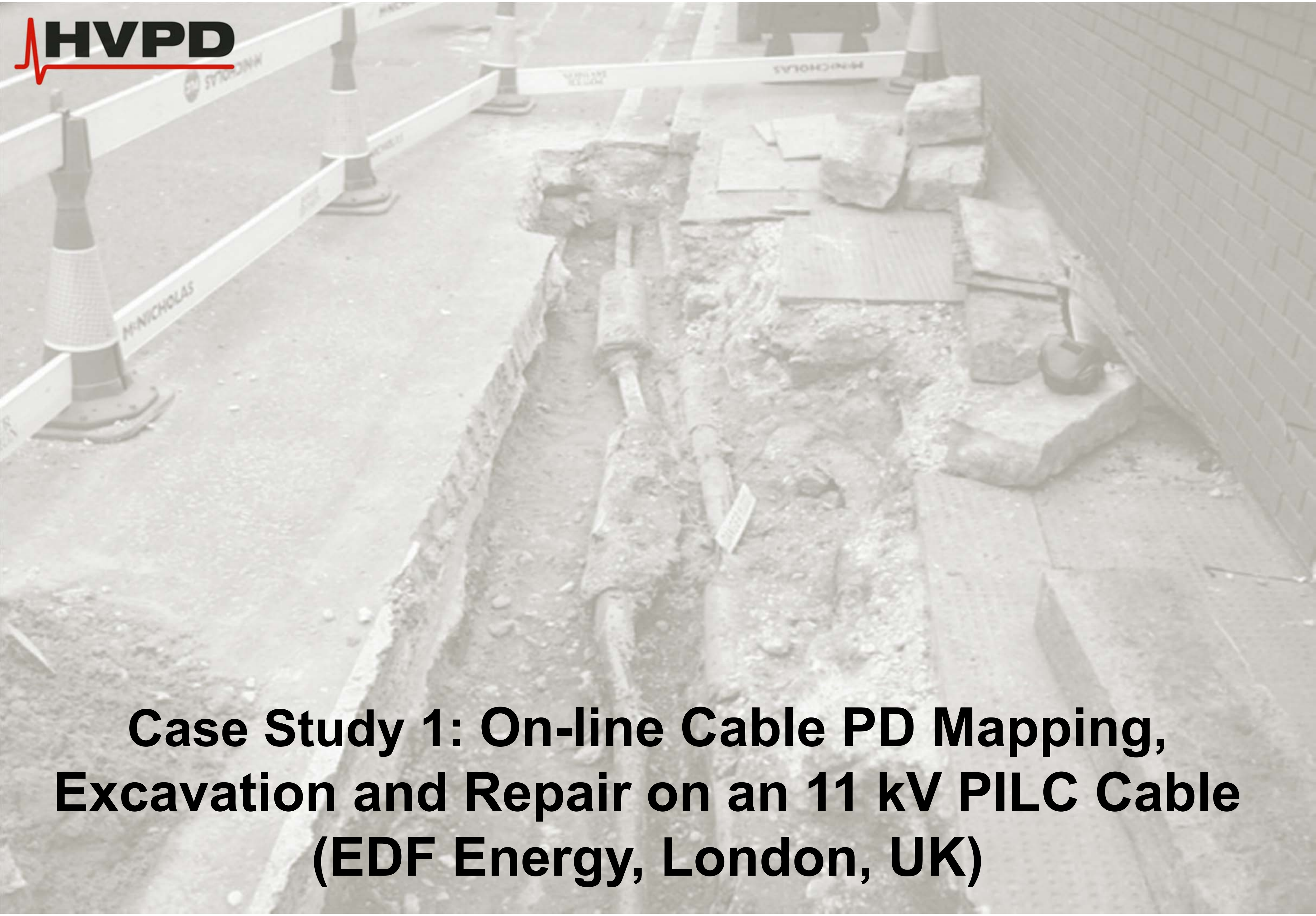
Monitor Configuration

PD Measurements

OLPD Monitoring System User Interface - Generator and Transformer

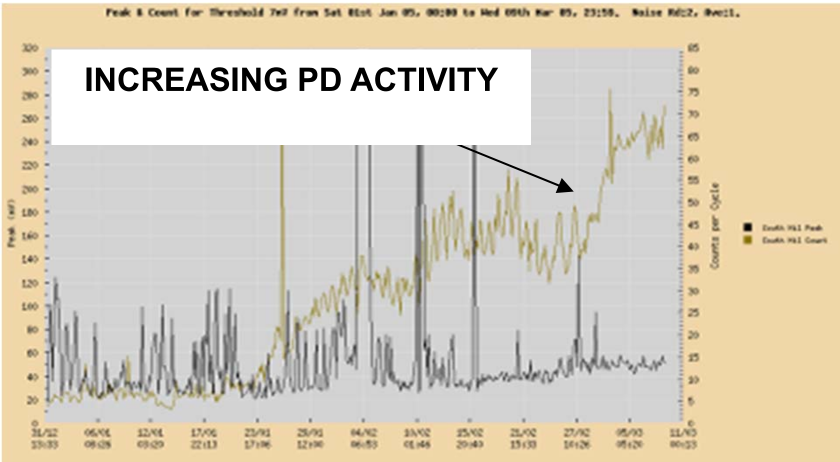



HVPD
OLPD Monitoring System User Interface – 11kV Switchboard
Analysis / Reports
Local Area Network Criticality League Table
Substations
Criticality (0-100)
Cable
Local
THRUSTER 1 HV PANEL 96 99
EARTHING Tx & RESISTOR 77 06
GENERATOR 1 13 74
HV Tx 1 (FWD) 16 70
HV SWBD 3 BUS TIE PANEL 13 65
TOPSIDE HV Tx 1 (HPU & LV) 09 39
GENERATOR 2 18 38
TOPSIDE HV Tx 1 (VFD) 36 44
HV SWBD 2 FEEDER 09 26
EM'CY HV SWBD INCOMER 1 25 21
THRUSTER 4 T/R 20 12
Condition / Action Guideline
Criticality (0-100)
High PD / Diagnostic 76-100
Moderate to High PD / Investigate 51-75
Moderate PD / Monitor 26-50
Plant OK / No Action 0-25
Key
ID
Circuit ID
Cable / Machine PD Activity
Switchgear Local PD
M
Cable length
Monitoring Period
12/04/15 14:00 - 13/04/15 14:00
Live
Last Week
Last 24 hrs
Last Month
HV SWBD 1
GENERATOR 1
GENERATOR 2
EARTHING Tx & RESISTOR
HV SWBD 3 BUS TIE PANEL
THRUSTER 1 HV PANEL
HV Tx 1 (FWD)
HV Tx 1
TOPSIDE HV Tx 1 (HPU & LV)
TOPSIDE HV Tx 1 (VFD)
THRUSTER 4 T/R
EM'CY HV SWBD INCOMER 1
HV SWBD 2 FEEDER
Network Selection
Network Options
View Level
Site Overviews
SLD Overlay
System Detail
Common Sites
Distribution Network
33 kV OWF Turbine Array
11 kV O&D Drilling Vessel
10 kV O&G Network
Sensor Configuration
Monitor Configuration
PD Measurements
© Copyright High Voltage Partial Discharge Ltd.

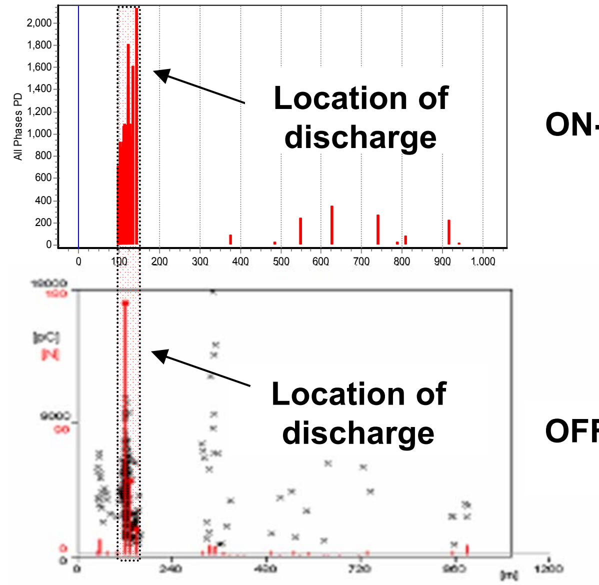


Case Study 1: On-line Cable PD Mapping, Excavation and Repair on an 11 kV PILC Cable (EDF Energy, London, UK)

Case Study: On-line Cable PD Mapping, Excavation and Repair on 11 kV PILC Cable

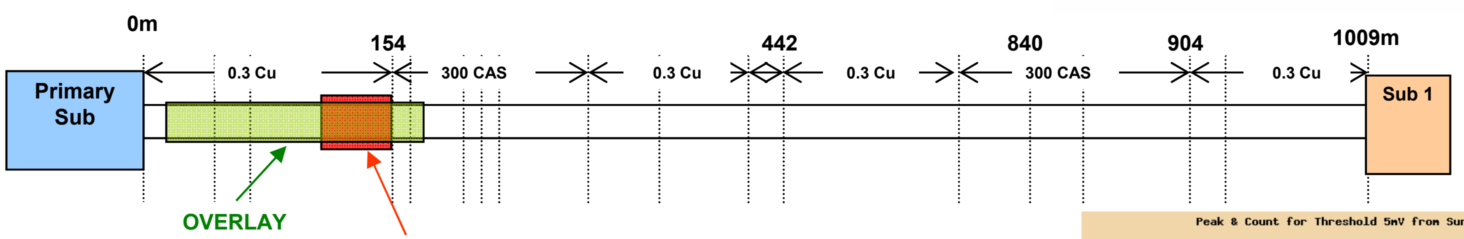


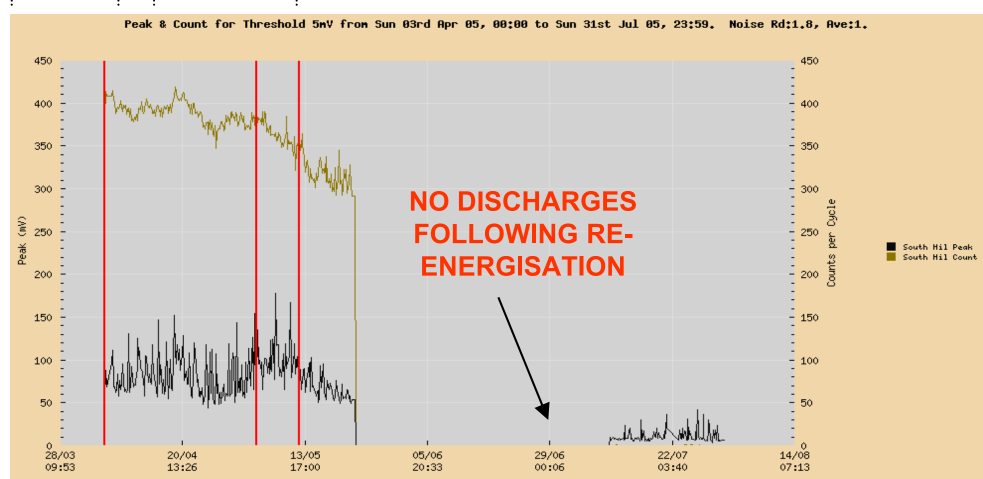
STAGE 1: On-line monitoring



ON-LINE MAPPING

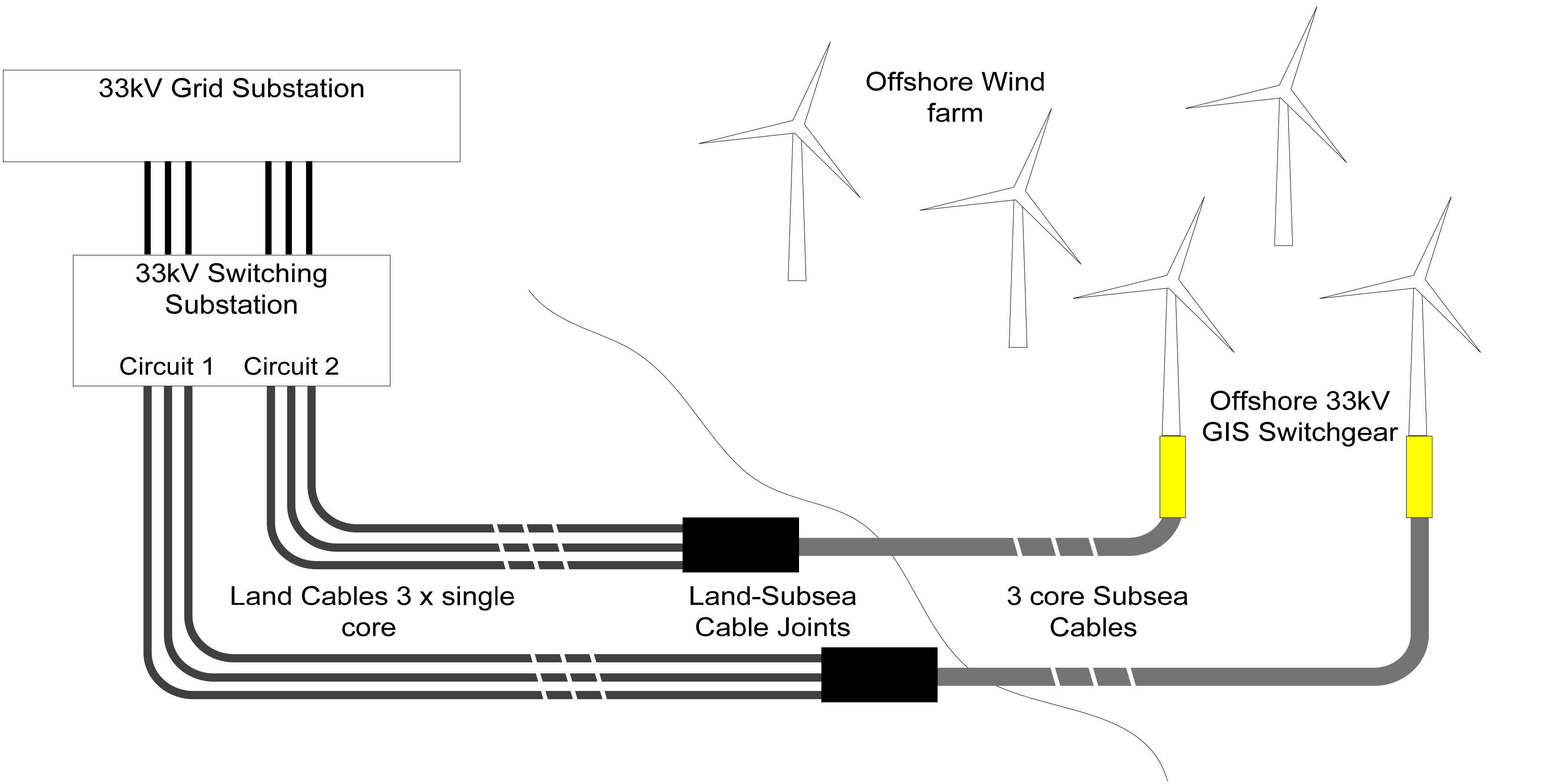
OFF-LINE MAPPING



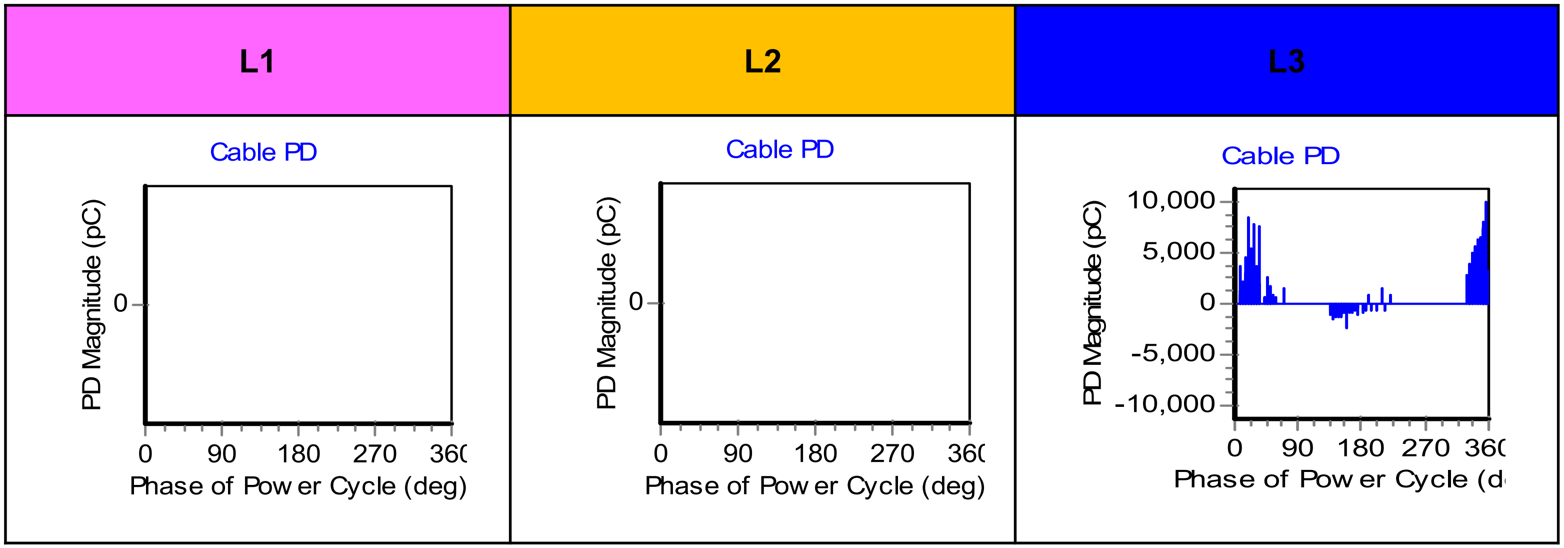


Case Study 2: OLPD Testing, Location, Monitoring with Preventative Maintenance on a 33 kV Land-Sea Offshore Wind Farm Export Cable

Case Study: Circuit Details

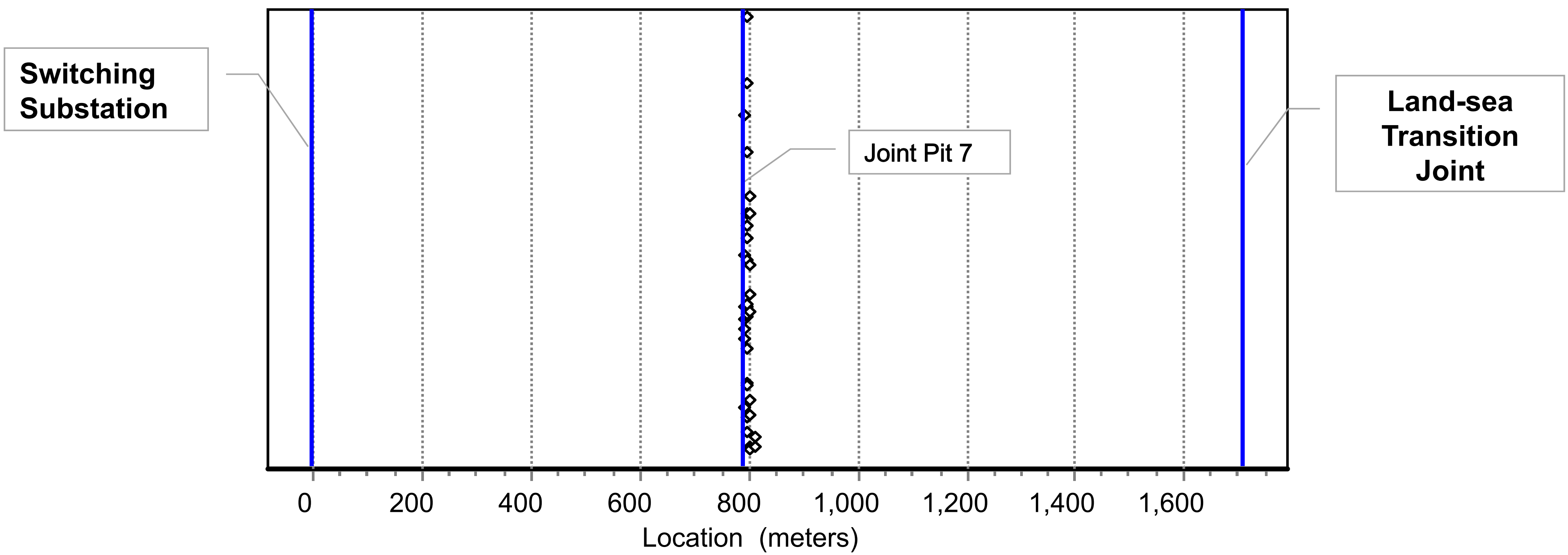


- 1.7 km single core XLPE land cable
- 9.6/11.5 km 3 core XLPE subsea cable



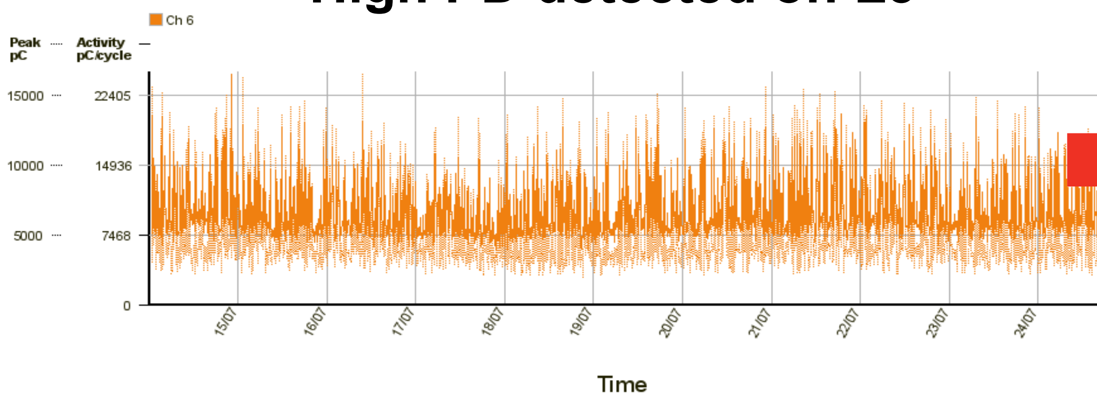
High levels of PD (of up to 10,000 pC / 10 nC) measured on **Circuit B, Phase L3.**

Case Study: PDMap© Graph Showing PD Location

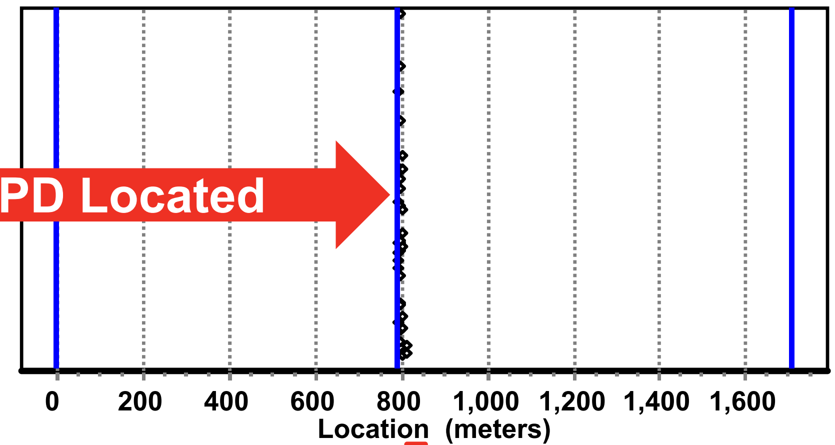


BEFORE

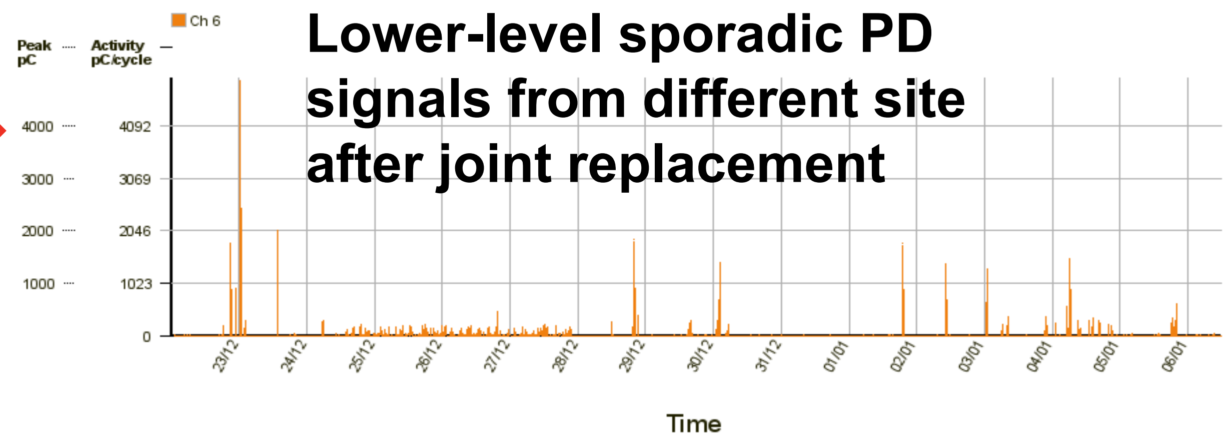
High PD detected on L3



PD Located



Joint 7 with PD removed and replacement cable section installed



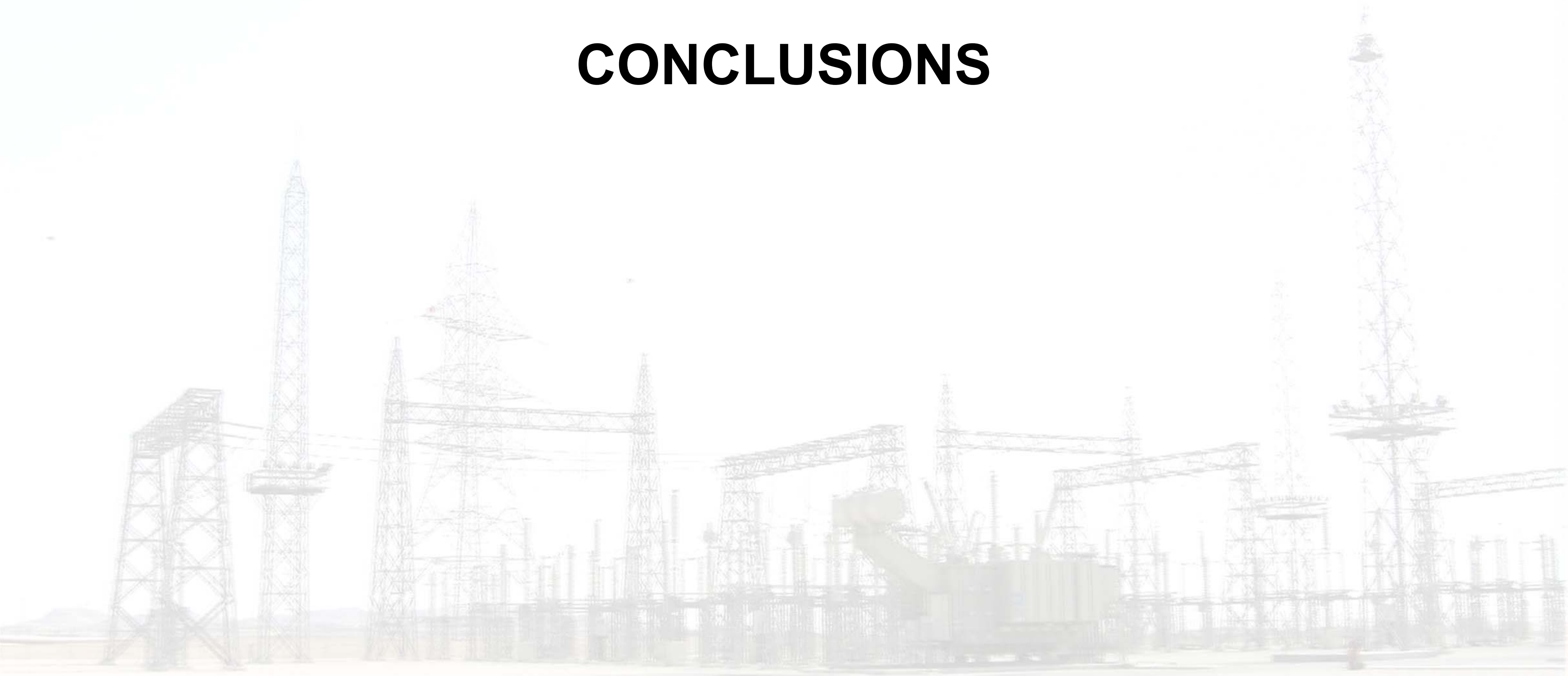
Lower-level sporadic PD signals from different site after joint replacement

AFTER

HVPD

Case Study: Circuit B – Evidence of Surface Degradation Due to Bad Fitting Heatshrink Stress Control

CONCLUSIONS



- OLPD testing is widely adopted for testing many types of MV & HV plant.
- The technologies enable the assessment of the health of MV/HV network with minimal disruption and cost.
- Equipment is tested under both normal (and abnormal) working conditions.
- PD can be detected, located and monitored, without the need to de-energise the plant.
- OLPD testing is an essential tool for the effective implementation of condition-based management (CBM) techniques to MV and HV power networks.

End of Presentation

Thank you for your time

Q&A?

Overview of On-line and Off-line PD Test Methods

HVPD

CONTENTS

- On-line & off-line testing methods
- Overview of PD sensors
- MV/HV cable AC withstand voltage commissioning testing options
- Case studies

On-line

- In-service, under normal working conditions
- Various sensor options

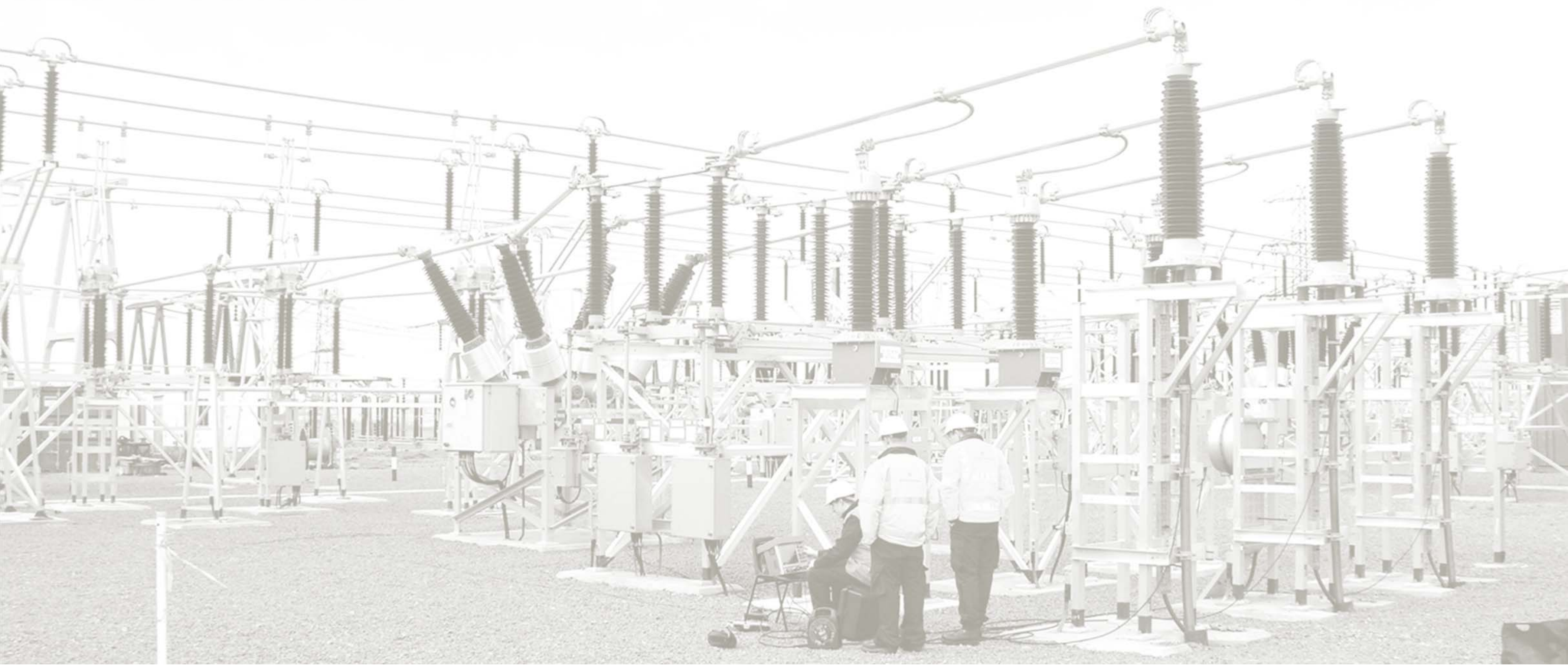
Off-line

- Energised with external supply
- Usually HV Coupling Capacitor sensor used

On-line vs Off-line

ON-LINE	OFF-LINE
Advantages	**Advantages**
No need to isolate the circuit	Proven technology
Circuit loaded when tested	Better sensitivity
Economical & non-invasive	**Drawbacks**
Teed circuits can be tested	Circuit not loaded during testing
Drawbacks	Outage required
Data interpretation can be difficult	Expensive & time-consuming
Earthing pre-requisites	Teed circuits cannot be tested easily

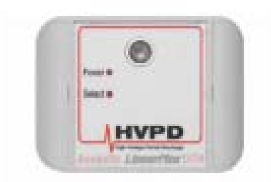
ON-LINE TESTING METHODS



High Frequency Current Transformers (HFCT)
Detects PD in cables and remote plant (e.g. transformers/ rotating HV machines).

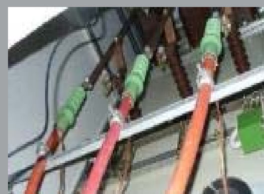
High Voltage Coupling Capacitor (HVCC)
Mainly applied to the PD monitoring of rotating HV machines.

Transient Earth Voltage (TEV)
Detects local PD within plant under test.



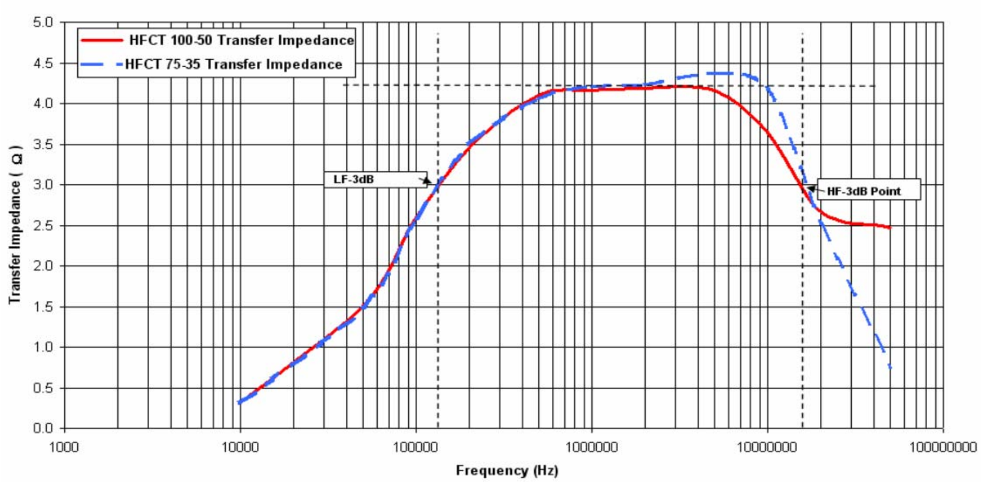
Airborne Acoustic (AA)
Detects airborne PD signals with direct line of sight to PD source.

Common Sensor Usage for OLPD in Different Plant Items

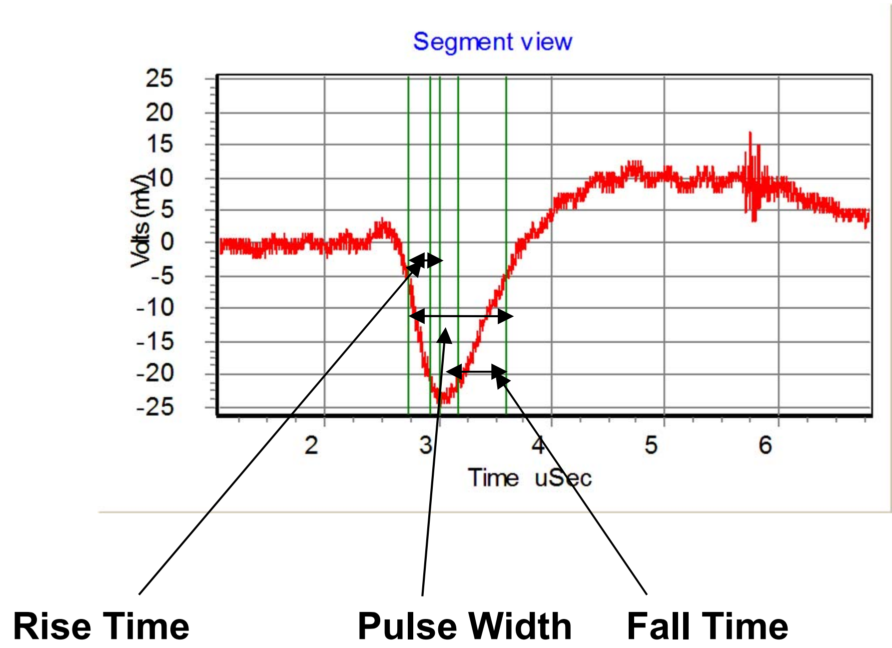
	Power Cables	Cable Terminations	Metal-clad AIS	HV/EHV GIS	Rotating Machines	MV Transformers	HV Transformers
Plant							
Sensors	HFCT	HFCT	TEV	UHF Coupler	HV Capacitor	Contact Acoustic	UHF Coupler
		TEV	Airborne Acoustic	Contact Acoustic	HFCT	HFCT	Contact Acoustic
		Airborne Acoustic	UHF Coupler		Rogowski Coil	TEV	Bushing Tap Adapters
		Contact Acoustic	HV Capacitor		RTD Sensor		HFCT
			HFCT		VHF Probes		TEV

High Frequency Current Transformer (HFCT) Sensors

- Detect PD in cables and connected plant
- Wide bandwidth (from 100 kHz to 20 MHz)
- Attach to power cables at terminations and earthing links of HV equipment
- Installation inside or outside of cable box
- Temporary or permanent



- Cable PD is measured in terms of charge.
- It is important to measure the number of PD pulses/power cycle (i.e. the cumulative PD activity).



The PD magnitude (in pC) is the area under the PD pulse.

This can be calculated from the output voltage of the HFCT using the HFCT's ***Transfer Impedance, Z_{TR}***

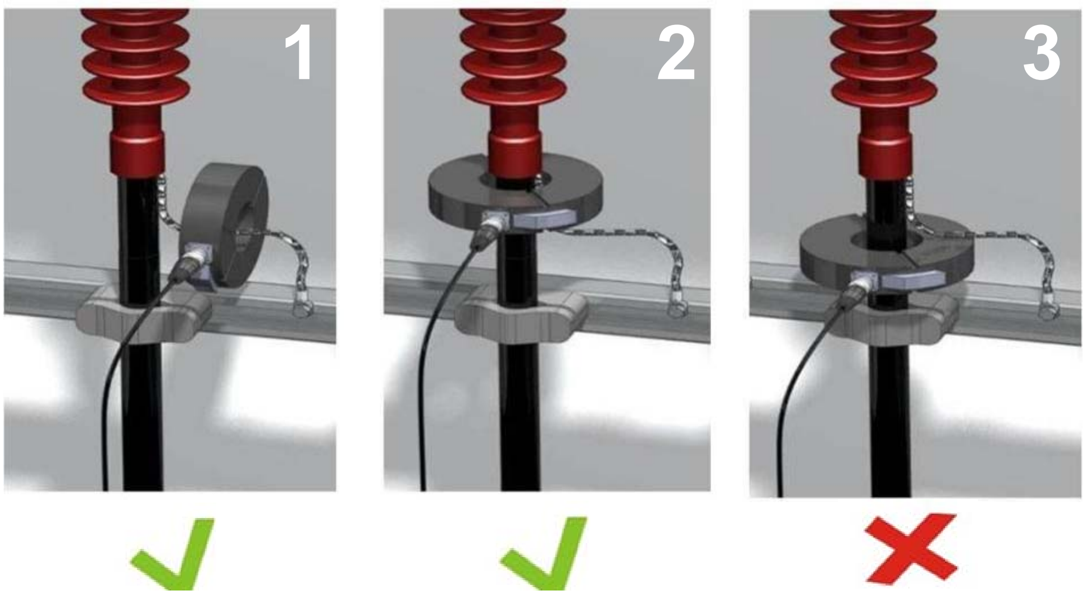
$$Q_{app} = \frac{1}{Z_{TR}} \int_{pulsestart}^{pulseend} V_{out}\, dt$$

The HFCT sensor should be attached to intercept *either* the conductor PD current (**i+**) or the earth PD current (**i-**)

HFCT on Earth (**i-**)

HFCT on cable with Earth brought back through (**i+**)

HFCT around cable (**i-** + **i+** = **0**)



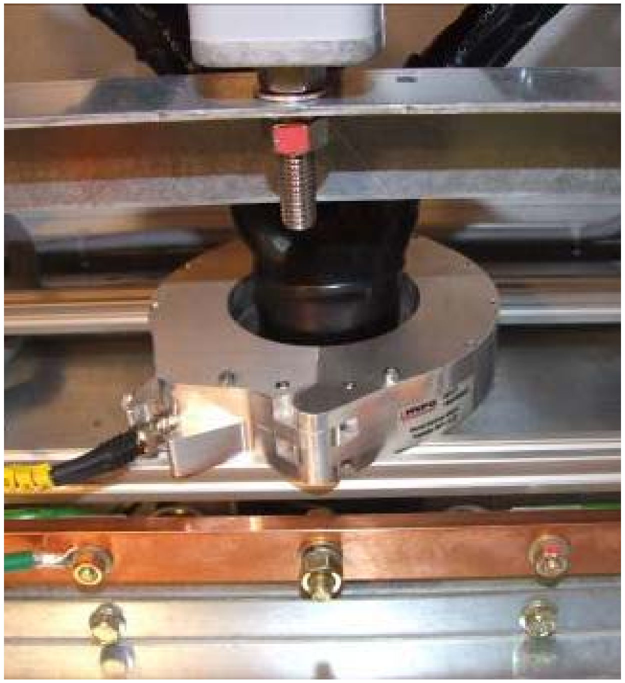
Cable Terminations Not Suitable for PD Testing due to Solid Bonding

Solidly bonded - lead plumbed

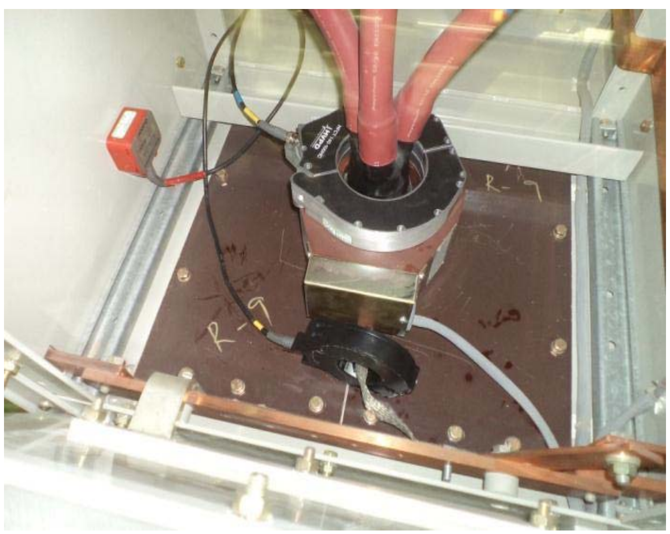
Solidly bonded - No insulated gland

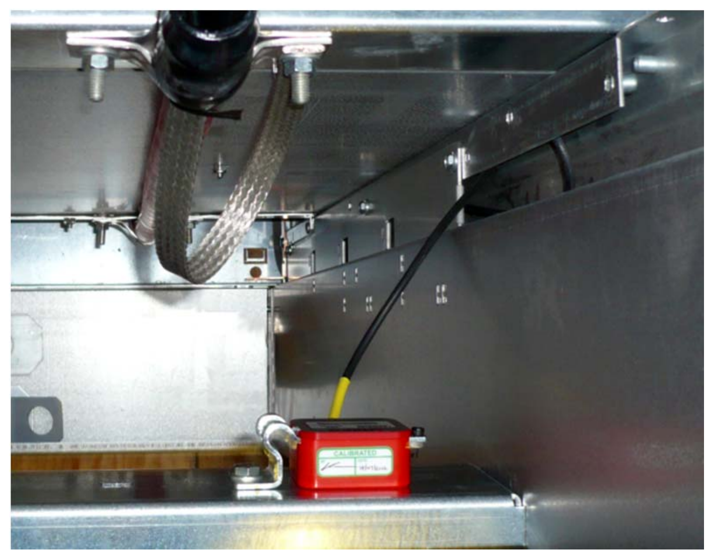
Shorting links

- Short outage to attach
- Permanent installation with external connection point
- Periodic testing/monitoring without subsequent outages



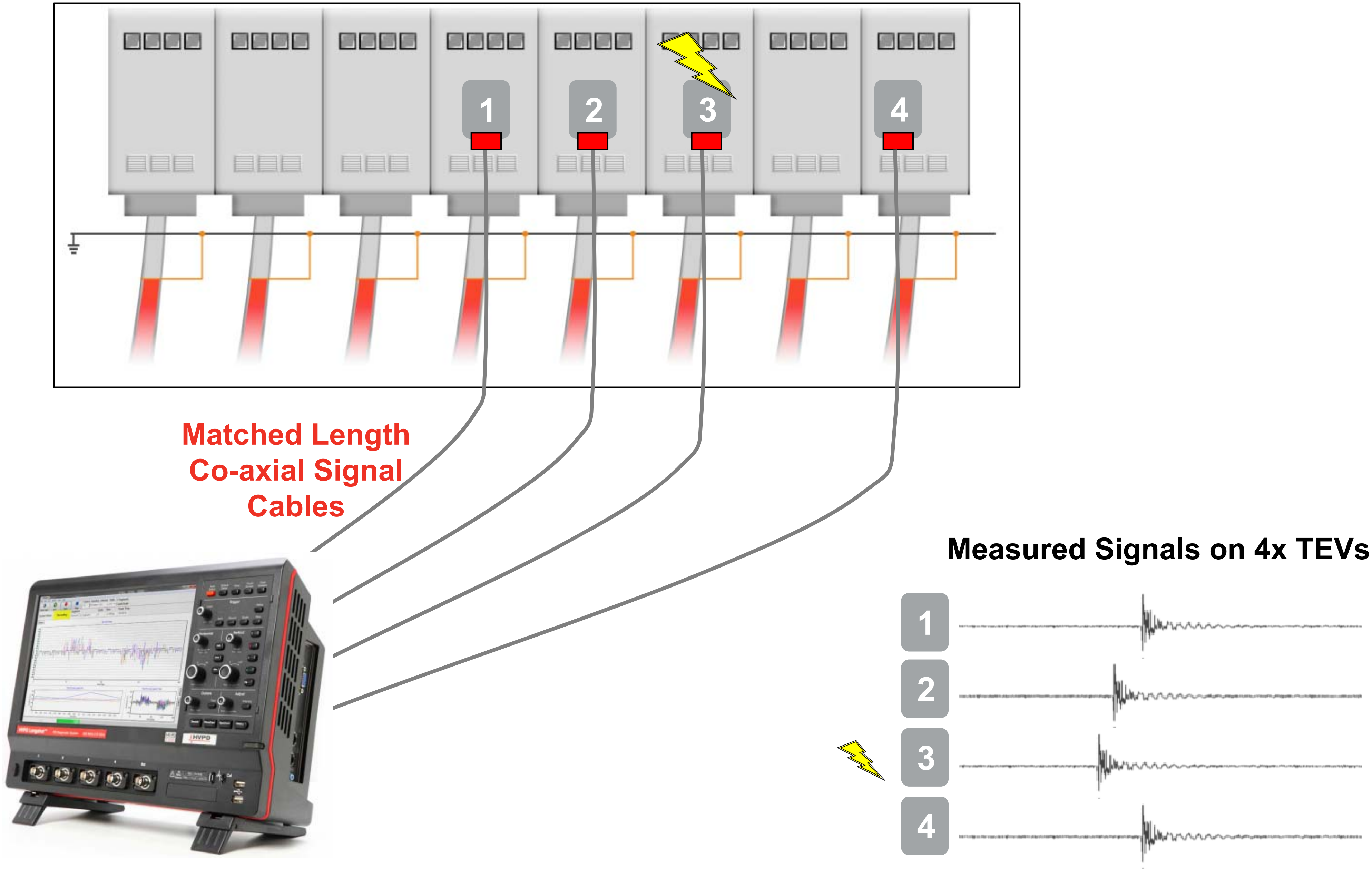
- Electromagnetic radiation from PD sites
- High frequency >5 MHz
- Main application: metal-clad AIS and SIS
- Sensitive to local (nearby) PD sites
- Also used at cable terminations and transformers
- Local PD magnitude is measured in dB





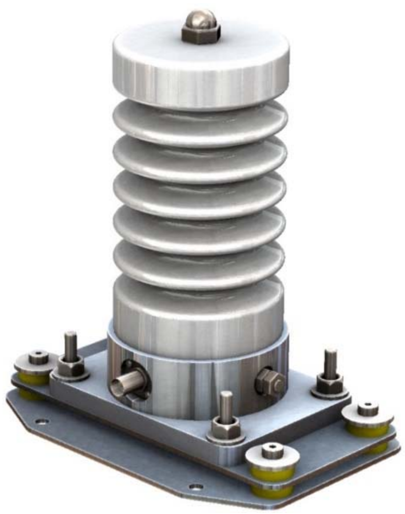
Example Use of Detection and Diagnostics

Time of Flight Measurements in MV Switchgear



HVPD

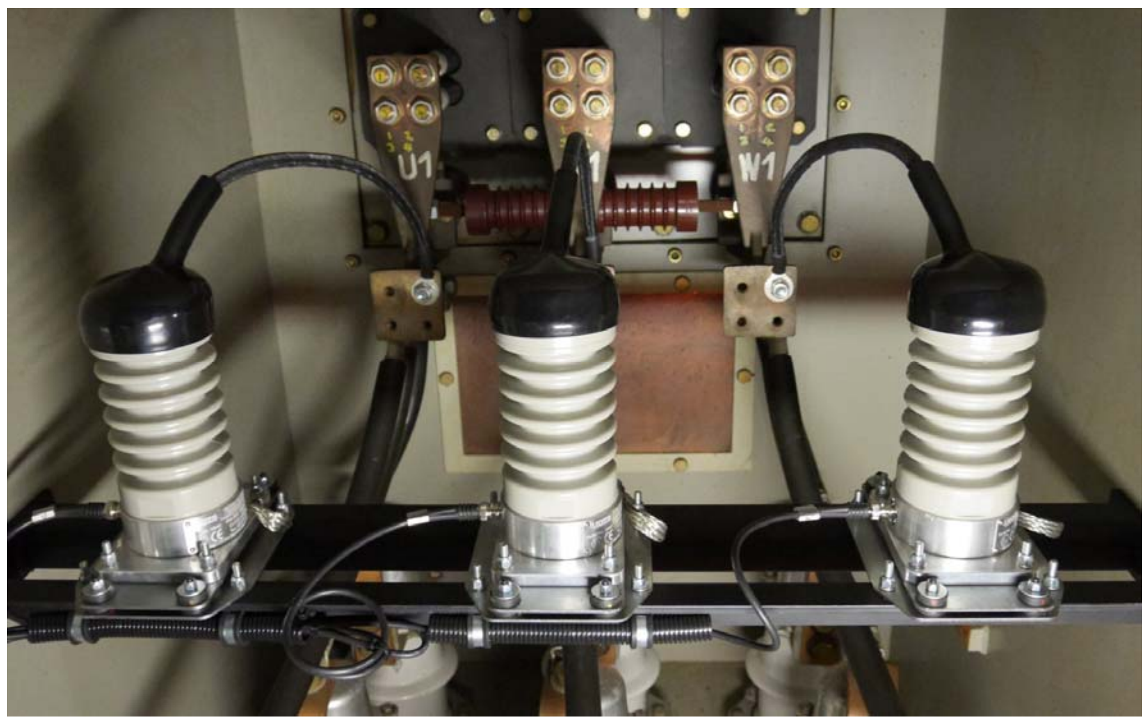
High Voltage Coupling Capacitor (HVCC) Sensors



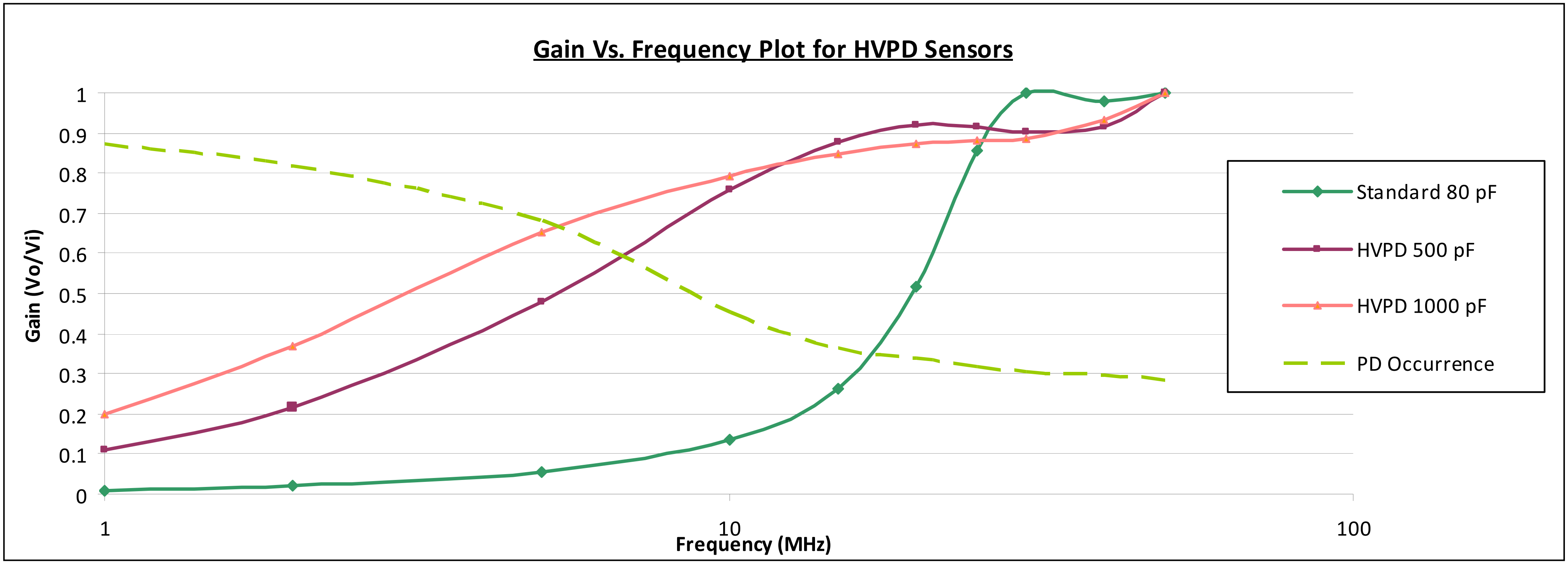
Permanent on-line unit

Off-line unit

- Conventional sensor for factory/lab tests
- Placed in parallel with cable/plant under test
- Requires galvanic connection to the plant under test
- Common application for rotating machines/switchgear



Higher capacitance = higher bandwidth = higher sensitivity to PD deep in machine windings



Airborne Acoustic Probe and Amplifier

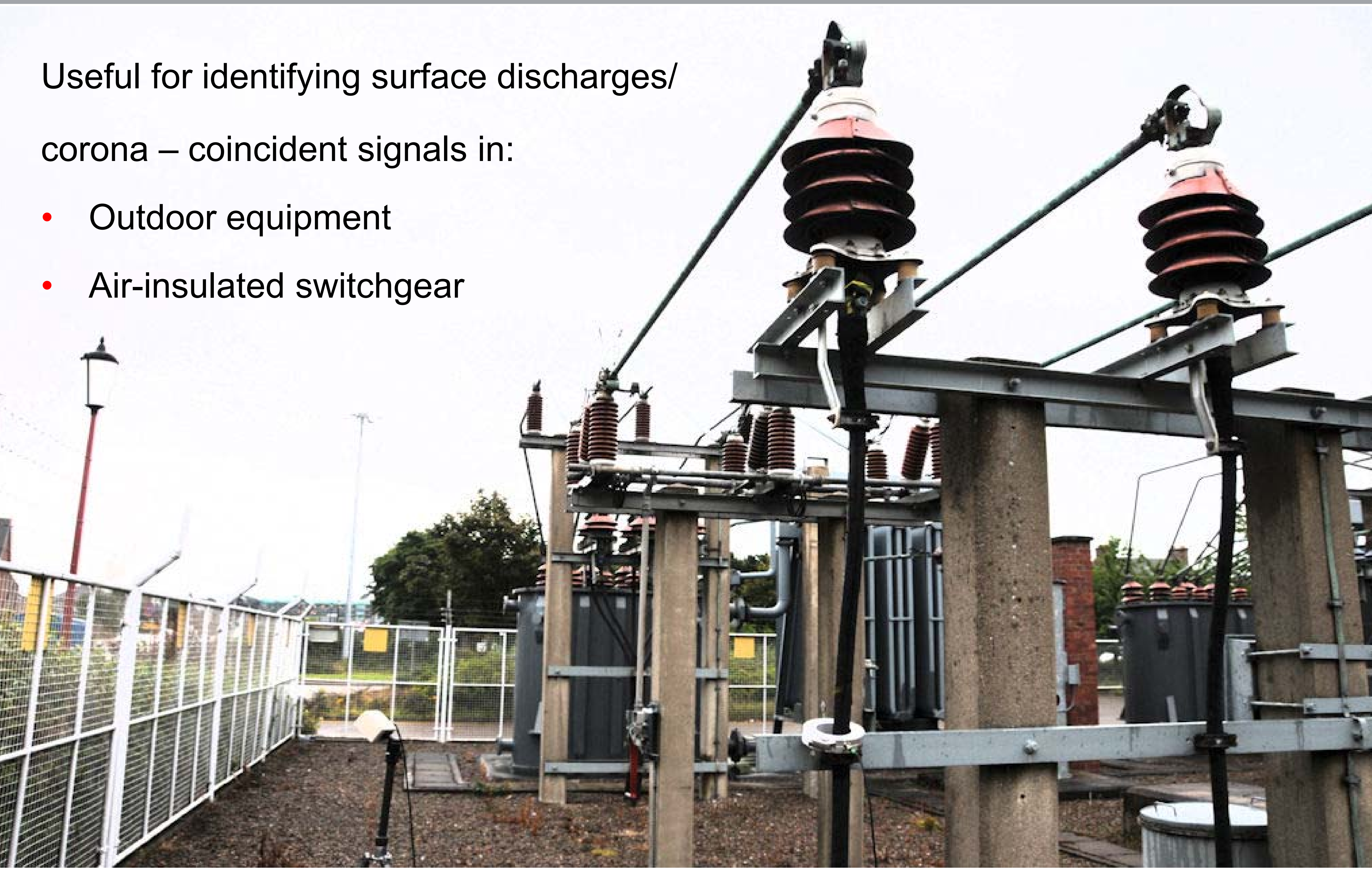
- Sensitive to local PD sites
- From 10 kHz to 1.2 MHz (≈40 kHz common)
  - Airborne – line of sight
  - Corona
  - Surface discharge

Airborne Acoustic Linearplex Sensor

- Contact
  - Vibration of equipment housing
  - Internal PD
  - Surface discharge

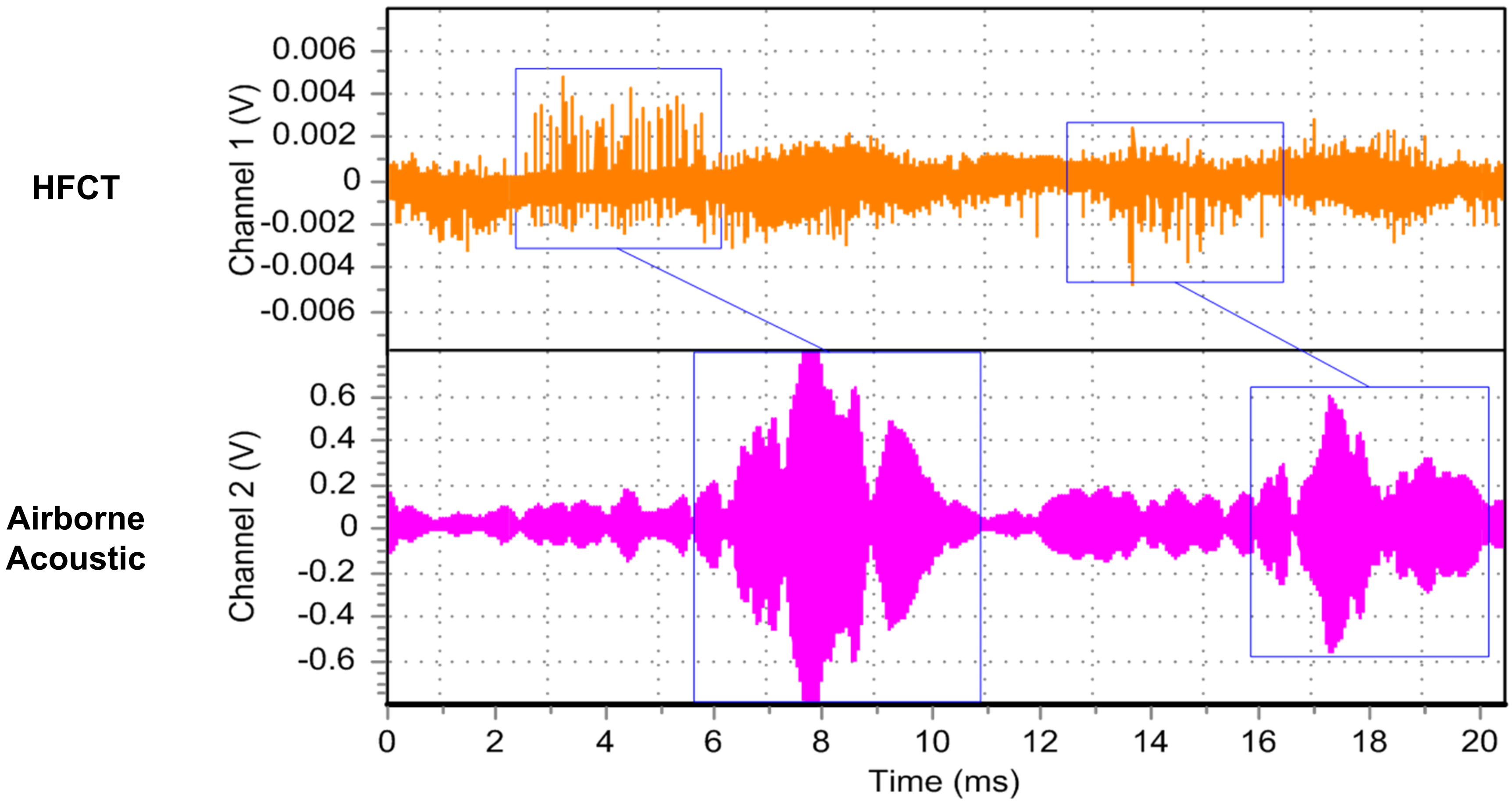
Useful for identifying surface discharges/ corona – coincident signals in:

- Outdoor equipment
- Air-insulated switchgear



Combined Acoustic and Electromagnetic Detection

Across Power Cycle



Delay due to difference between speed of light and speed of sound

HVPD

OFF-LINE TESTING METHODS

- New cable systems require AC withstand acceptance tests at commissioning.
- PD testing is now included as part of the field acceptance tests for HV and EHV cables.
- Some test specifications reference acceptance criteria from conventional, laboratory PD testing (5/10 pC).
- Whilst factory PD tests are performed at power frequency, field tests are often not.

Off-line power supplies must be dimensioned for the charging current of the plant under test.

$I = j\omega CV$ $\quad$ I=Charging current, ω=Test Frequency, C= Cable Capacitance, V=Test voltage

MV/HV Cable AC Withstand Voltage Commissioning Testing Options

1. VLF (Very Low Frequency) (0.01–0.1 Hz)

example supplier: Baur (Austria), B2HV (Germany)

2. Resonant Test Systems (RTS)

example supplier: High-Volt (Germany)

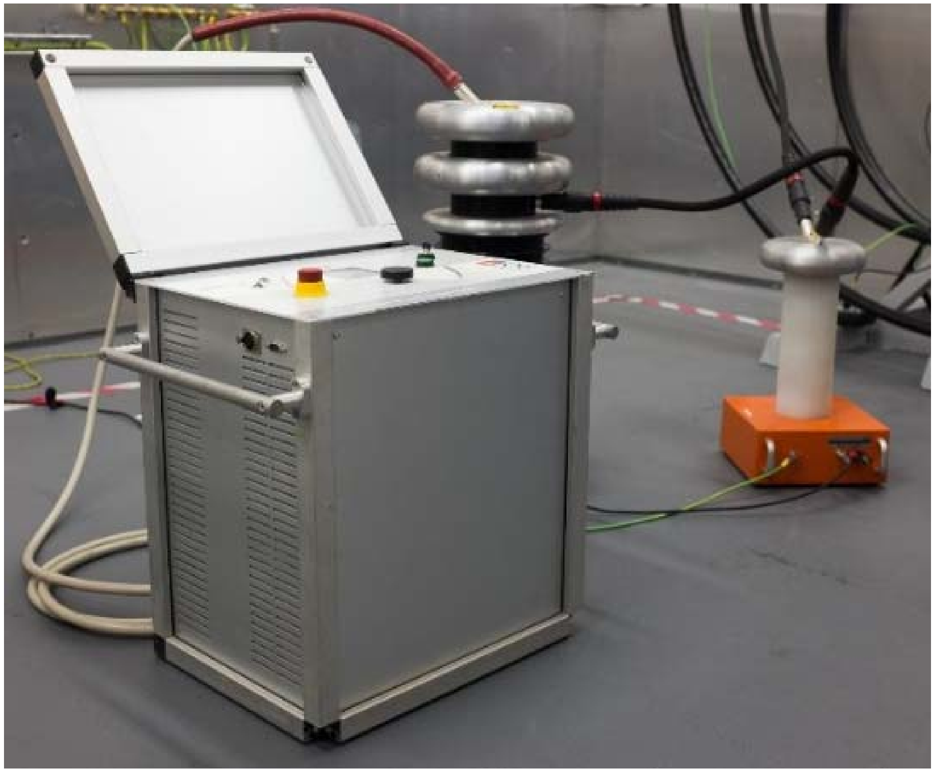
3. 24-Hour Soak Test (at U_0)

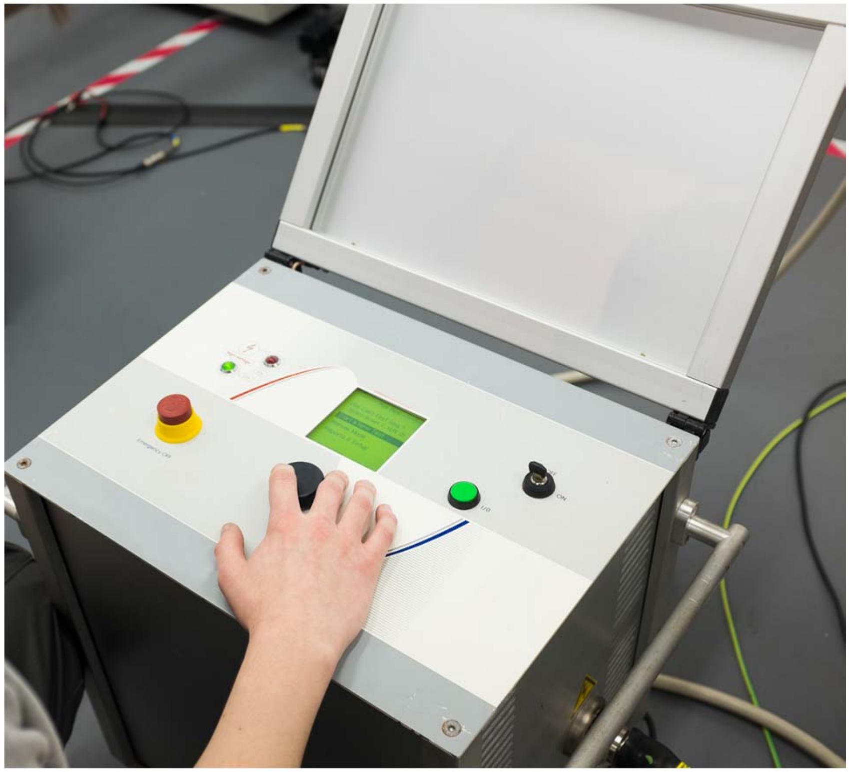
No external power supply is required but extended, 24-hour PD monitoring is necessary.

4. Damped AC / Oscillating Wave (OWTS)

example suppliers: Seitz, SEBAkmt (Germany)

Option 1: VLF (Very Low Frequency) PD + Tan Delta (TD) Testing





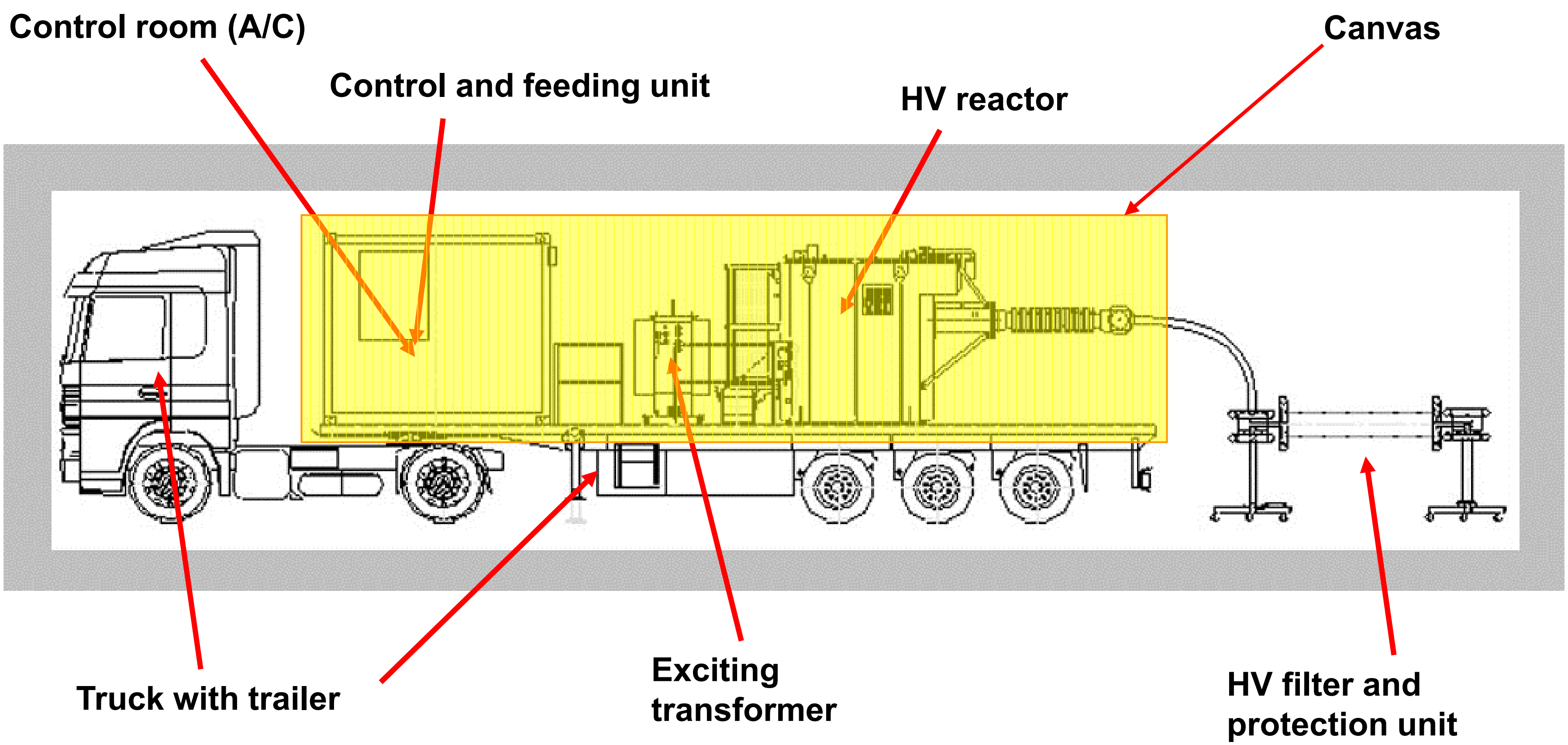
Pros

- Inexpensive, ***portable*** equipment
- Effective in finding water-treed cables for shorter lengths.
- Easy to perform, non-expert test
- IEEE Standard 400.2.

Cons

- PD at VLF not directly comparable to PD at AC power frequency.
- 'Noisy' test sets, filtering required.
- Concerns about trapped charges at frequencies less than 0.1 Hz.

Option 2: Variable Frequency Resonant Test System (RTS)



83 A/260 kV (1650 nF) AC Resonant Test System (for 132–220 kV cables)

Option 2: RTS (Variable Frequency Resonant Test System)

Pros

- Allows direct comparison of factory PD tests to the field tests.
- Provides continuous, near power frequency AC withstand voltage.

Cons

- Large, expensive test equipment (for HV/EHV cables) although more compact RTS technology is available for MV cables.

Commissioning Testing (Off-Line)

- Measure PDIV, PDEV.
- Measure PD Level & Intensity.
- Identify PD pattern.
- Identify location of PD source.

⇒ Guiding criterion is that the cable system should be **PD free** (<5 pC) at the specified test voltage ($1.7U_0$) for the HV cable systems.

⇒ Less then 10 pC for MV systems using conventional test systems.

Maintenance Testing (On-Line)

- Assess individual PD sources separately.
- Measure PD level & intensity.
- Identify the location of the PD source(s) by PD mapping.
- Assess impact of individual PD sources against cable design (i.e. insulation materials, experience, etc).

⇒ Develop individual assessment and ranking of cable joints, terminations and cable sections.

Option 3: Damped AC – OWTS (Commissioning)

Pros

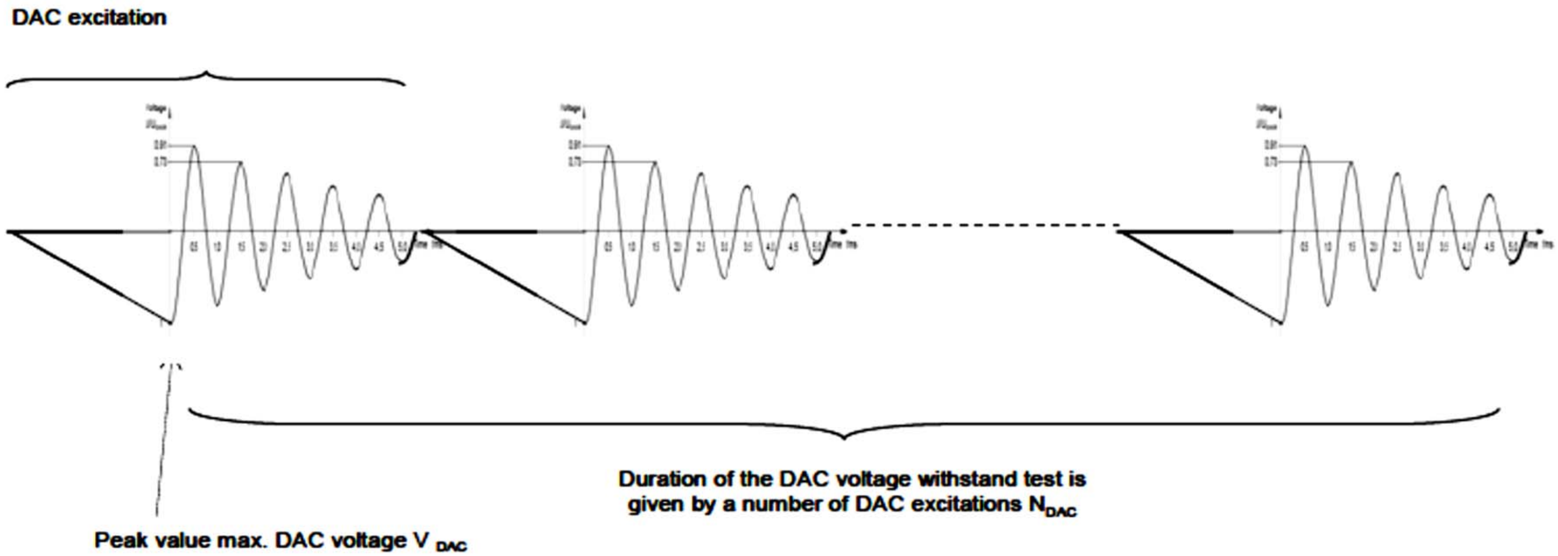
- Can energise long lengths of cable with smaller power supply.
- Easy to perform, non-expert test.

Cons

- Only limited number of over voltage cycles (2–3) applied.
- Difficult to do PD reading reliably (distributed PD).
- Tan Delta / Loss factor measurements are derived, not measured.

Option 3: Damped AC - OWTS

- 50 shots of individual discharges.
- Not continuous AC.



Wide variation of test voltage parameters:

DC charging time:	**0.25–62.5 s**
DAC frequency:	**38–368 Hz**
DAC damping:	**3.7–20.4%**

The different scales of the DC charging and the DAC oscillation create a wrong impression!

Option 4: 24-Hour Soak Test (at U_0)

Pros

- Inexpensive as they do not require an external power supply
- Energised at line voltage U_0 only.
- Low risk of failure during test.
- Can perform extended PD testing and monitoring over the entire 24-hour soak test.

Cons

- May not find incipient insulation defects at U_0
- Not fully diagnostic or predictive as there is no overvoltage.

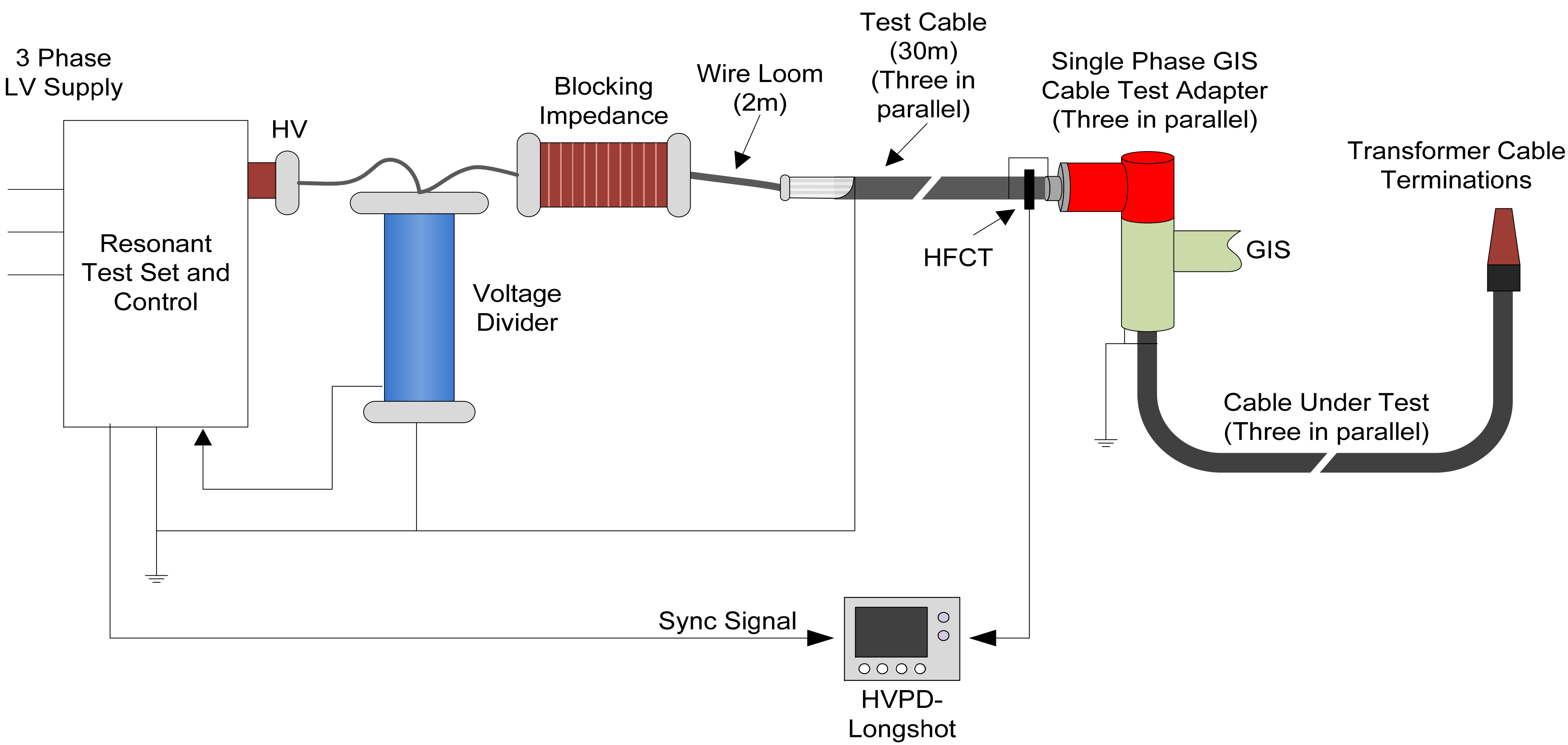
CASE STUDY 1: RESONANT TEST SYSTEM (RTS) TESTING

- The distance from RTS to cable under test could be tens of metres.
- Exposed HV connections pickup noise and generate corona.
- Length of exposed HV connections (and interference) minimised with test cable.

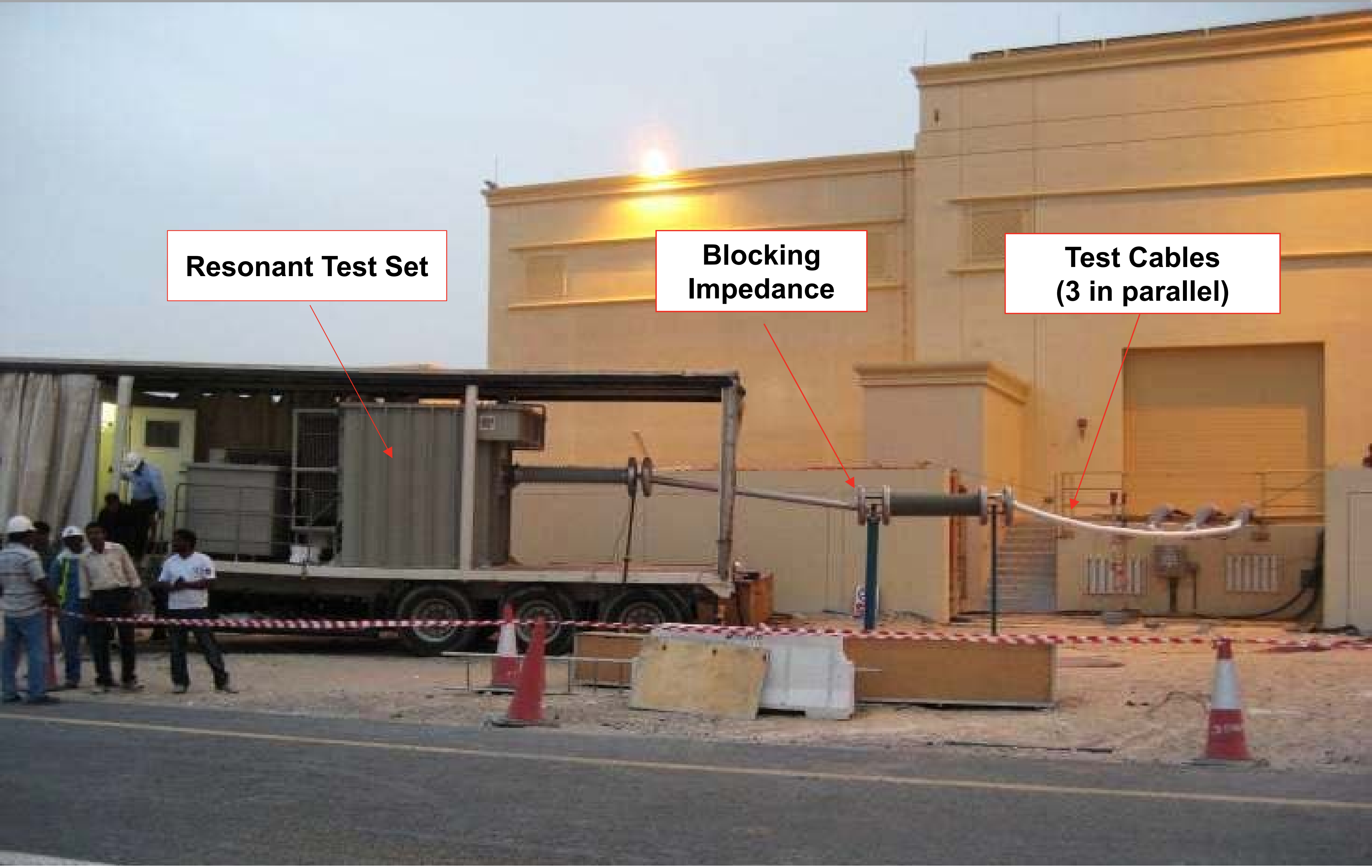
PD signals were measured using:

- HFCT sensors placed around the earth jumper cable between the cable termination and GIS housing.
- 8.3 nF coupling capacitor placed on the feeding end of the resonant test set to discriminate any noise or interference from the test set.

Case Study: Typical Test Set-Up



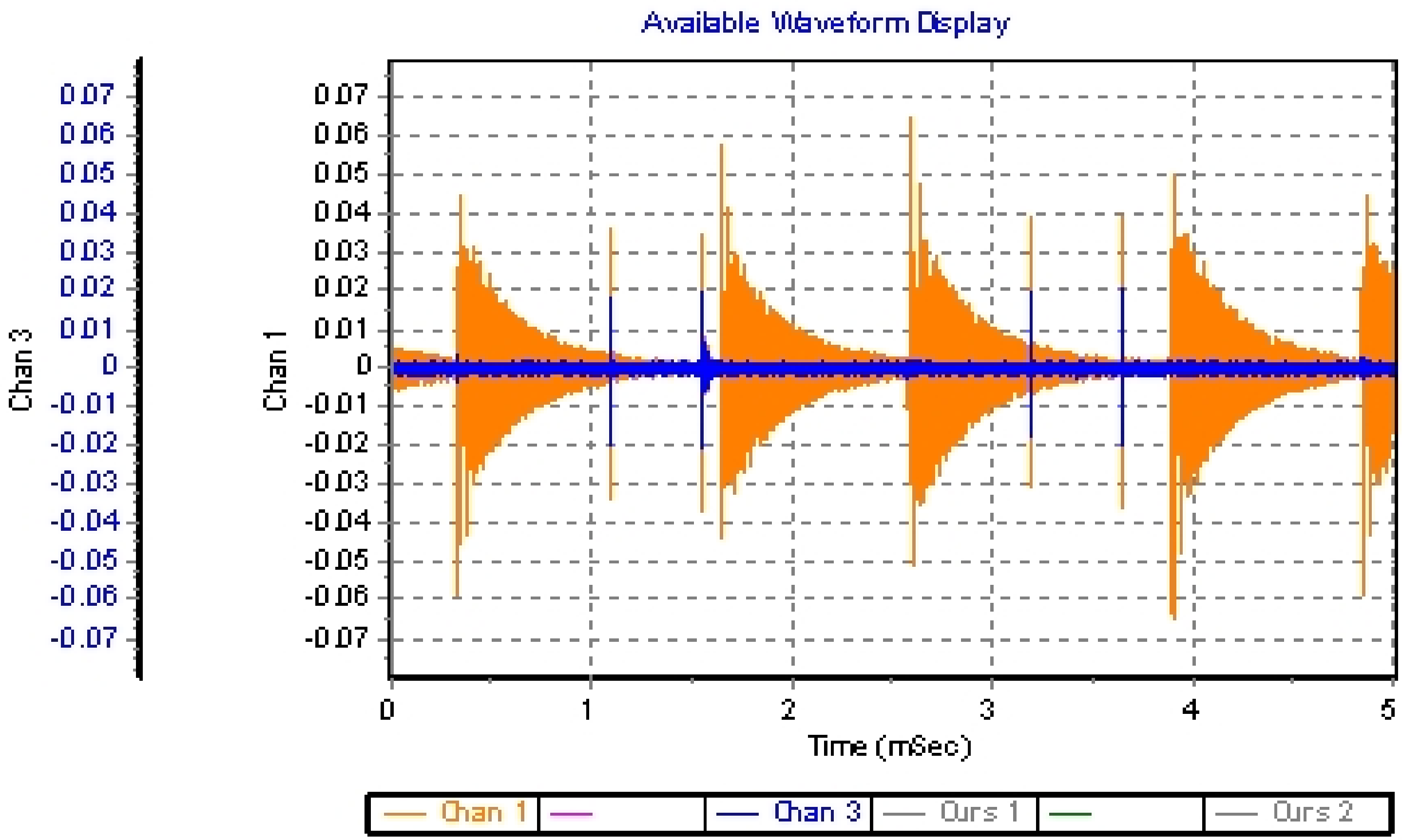
Case Study: Typical Test Set-Up



Case Study: Wire Loom Connection from RTS to Cable Under Test

Case Study: Wire Loom Connection from RTS to Cable Under Test

- Noise generated by RTS frequency convertor.
- Blocking impedance helps with filtering.
- Can be gated out with dedicated channel.
- PD event recognition or high pass filters often more effective.



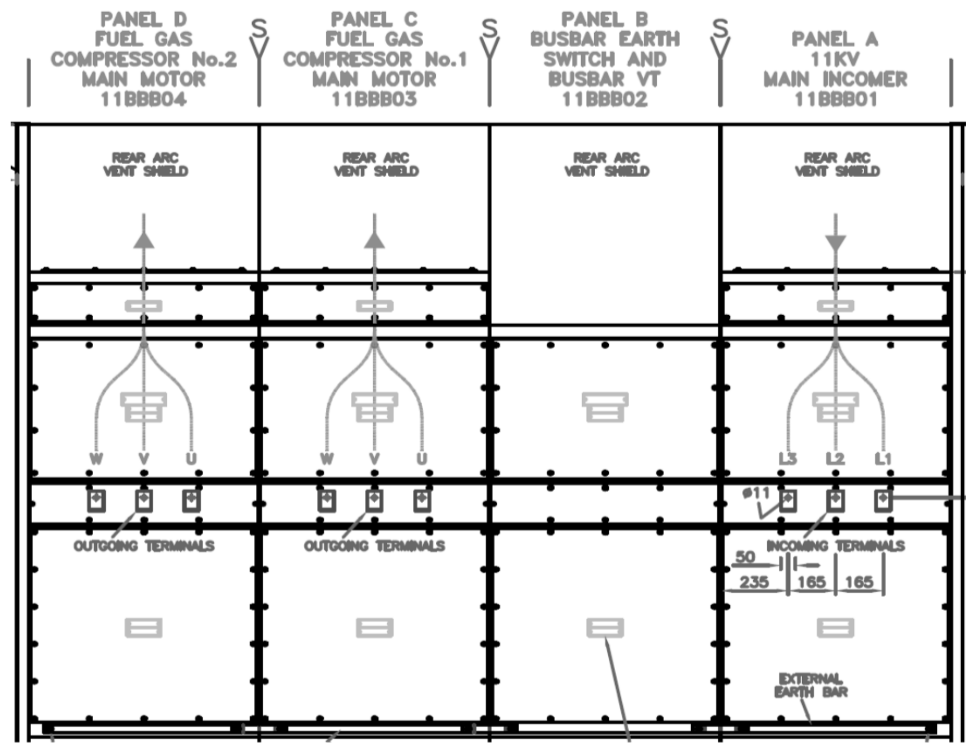
- PD measurements made at various voltage steps.
- Ensure cables are PD-free.

Circuit:	Circuit 1							
Test Date:	13/05/10							
Test Voltage (kV)	Current (A)	Frequency (Hz)	Power (kVA)	Reactor Temp. (°C)	PD Level R (pC)	PD Level Y (pC)	PD Level B (pC)	Result
76	3.4	221.33	250	42	no PD	no PD	no PD	Ok
114	5.1	221.33	561	42	no PD	no PD	no PD	Ok
132	5.8	221.28	777	42	no PD	no PD	no PD	Ok
76	3.4	221.33	250	42	no PD	no PD	no PD	Ok
114	5.1	221.33	561	42	no PD	no PD	no PD	Ok

- PD measurements were made at 76 kV, 114 kV and during the 132 kV HVAC withstand test.
- No PD signals were detected.
- Corona interference was detected in some cases and remedial action was taken to remove this so that this did not confuse measurements.
- The background noise levels on the HFCT sensors were relatively low in all tests, allowing good sensitivities of down to 20pC to be achieved.
- Noise interference from the resonant test set was detected with two 150 μs pulses at the zero crossing points of the voltage waveform.
- The HVPD PDGold© *'EventRecogniser'* software was able to classify and discount these signals as noise.

CASE STUDY 2: OFF-LINE PD TESTING OF 11 KV METAL-CLAD AIS SWITCHGEAR

- Off-line PD testing of the newly installed 11 kV Air-Insulated Switchgear following a failure.
- Measurements made to determine insulation was in good condition prior to putting it into service.
- Portable power supply used to energise the busbar to 1.1 U_0 (13.2 kV).

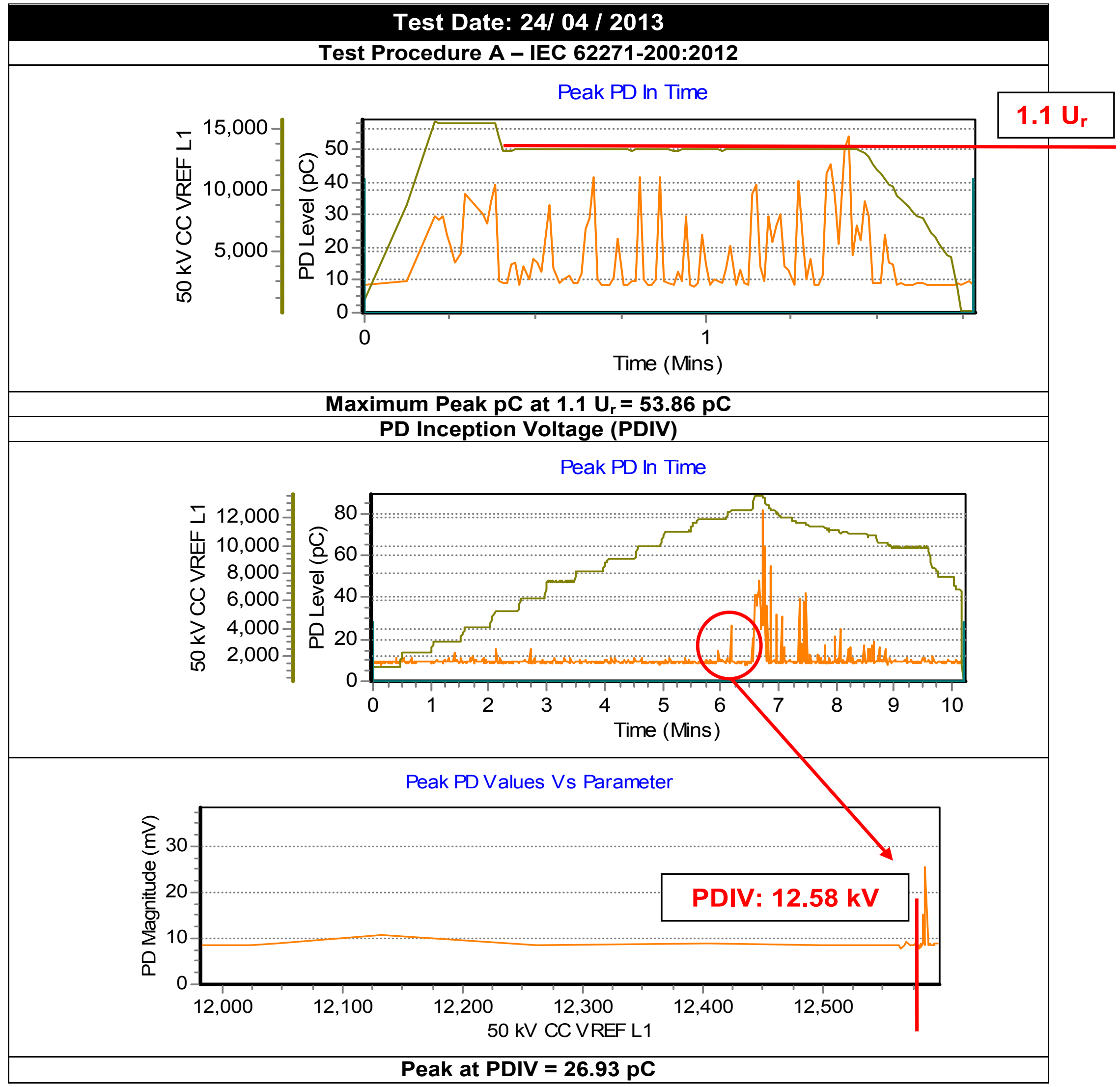


Case Study: Off-line Test Set-up

- The off-line test equipment and HVPD Longshot™.
- Voltage was applied (as per IEC 62271-200:2012) to each individual phase in turn with other phases isolated.

Case Study: Example Test Results

- Low levels of PD with peaks up to 54 pC were detected at 1.1 U_0 (13.2 kV phase to ground)
- Concluded the PD was not originating in the breaker sections (Breaker open and closed). PD was isolated within the Bushing and visual inspection was recommended (dirt, moisture or signs or tracking).
- The PD levels detected were considered to be low however maximum permissible partial discharge quantity at 1.1 U_0 shall be ultimately agreed between the manufacturer and the end user as per IEC 62271-200:2012.



CONCLUSIONS

On-line PD Testing

- Provides good data.
- Quick compared to off-line PD testing.
- Test under normal working conditions.
- Allows continuous monitoring.
- Does not require any HV power supply.

Off-line PD Testing

- Useful for factory and commissioning tests.
- Allows easy isolation of plant under test.
- Offers better sensitivity than on-line PD testing.
- Has a longer history.
- Allows testing at elevated voltages.

End of Presentation

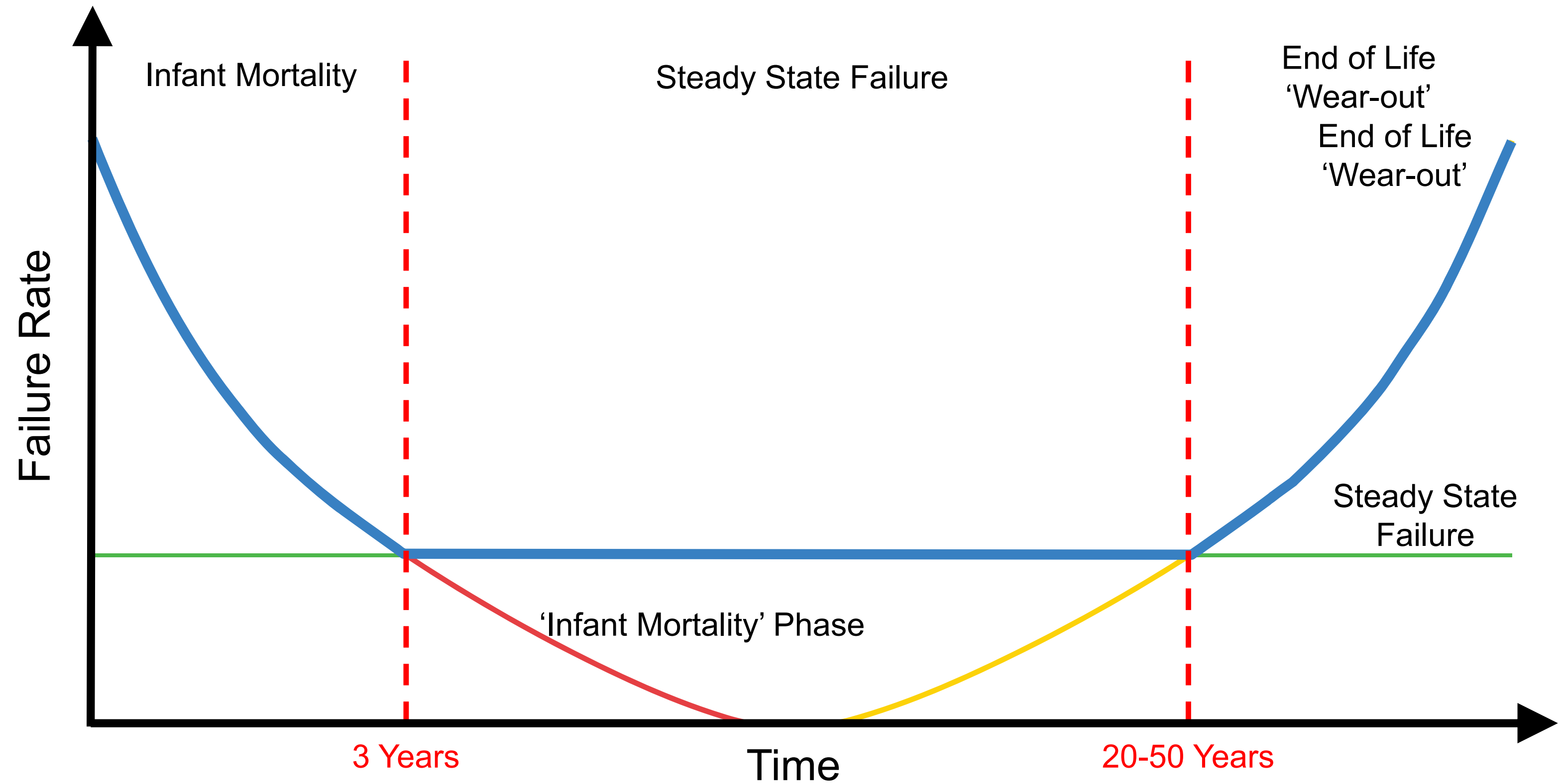
Thank you for your time

Q&A?

On-line PD Testing & Diagnostics for MV and HV Equipment – Case Studies

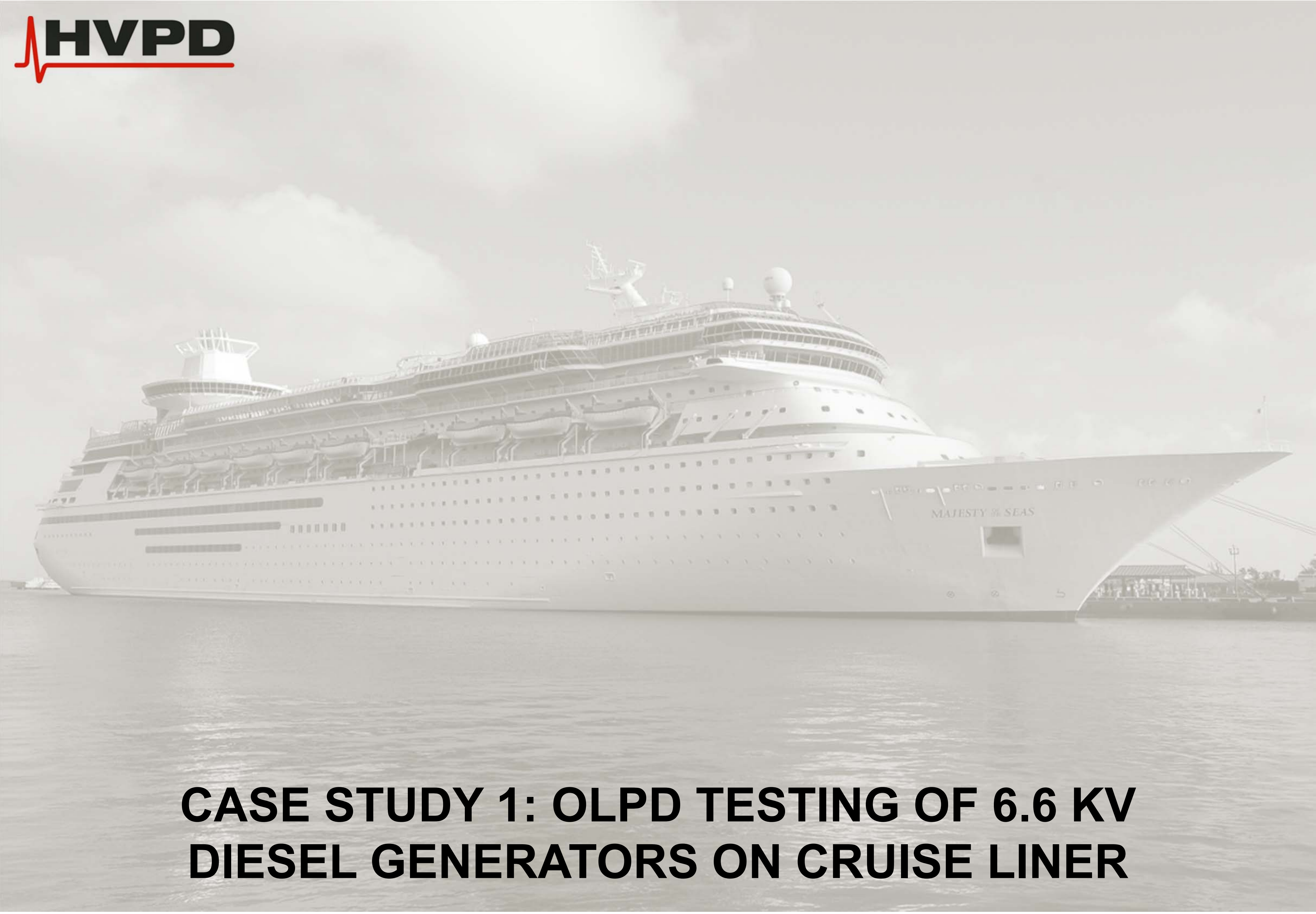
CONTENTS

- Reliability centred maintenance
- Application-specific examples of OLPD testing
- Insulation condition monitoring strategies



- **Infant Mortality Phase:** the initial 'bedding in' period
- **Steady State Failure Phase:** the 'normal' operating lifetime up to the 'Design Life' of the asset
- **End of Life 'Wear-out':** up to the manufacturer's recommended replacement time of the asset

HVPD



CASE STUDY 1: OLPD TESTING OF 6.6 KV DIESEL GENERATORS ON CRUISE LINER

Case Study: League Table of OLPD Test Results

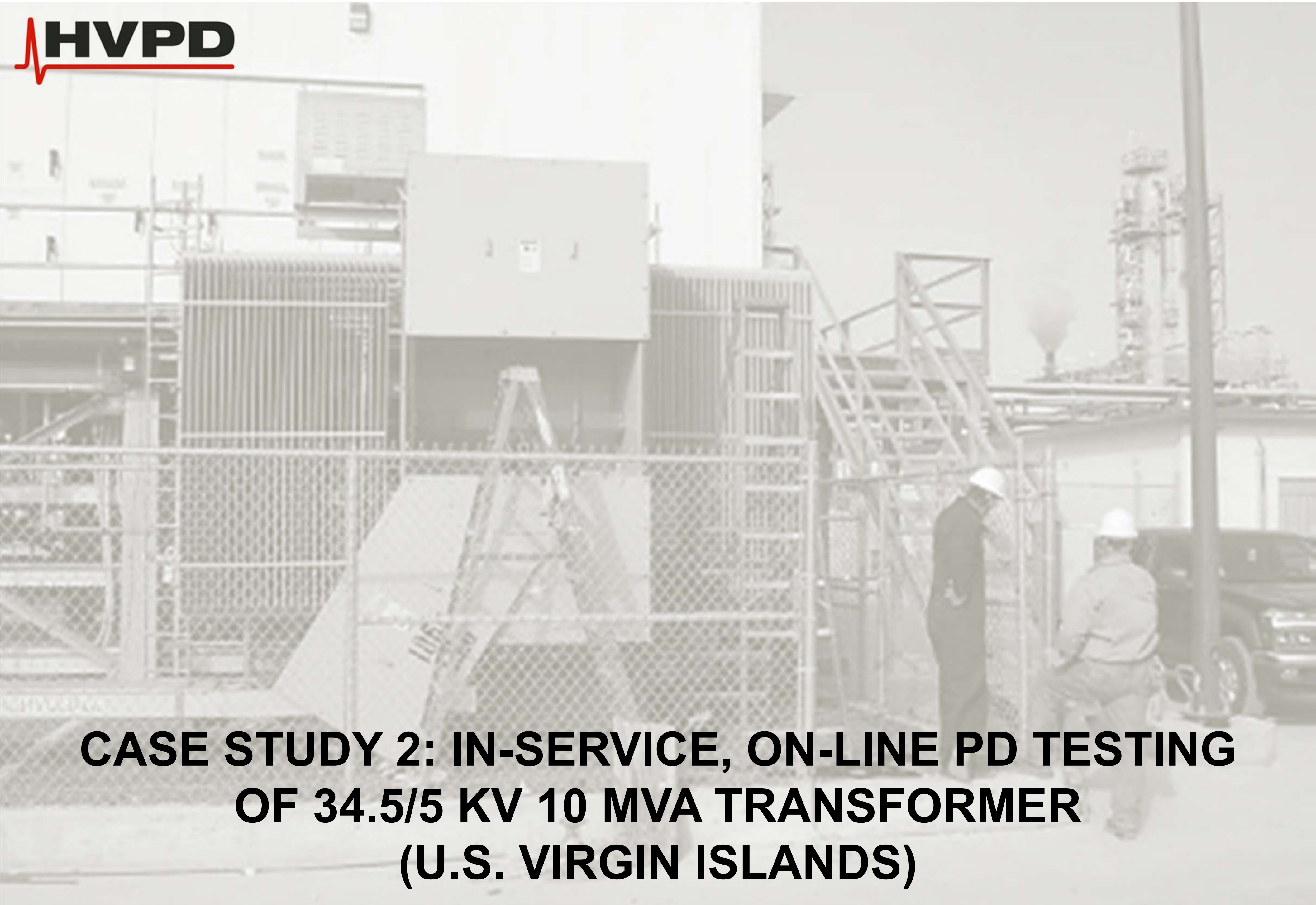
Vessel	Generator	PD Level 1st Test	PD Level 2nd Test	PD Level 3rd Test	PD Level 4th Test
Vessel 1	1	-	18,412	-	5,239
	2	17,416	-	-	4,259
	3	15,854	-	-	7,866
	4	29,248	21,637	5,800	9,466
Vessel 2	1	2,162	5,891	7,340	
	2	16,696	2,094	1,474	
	3	-	520	3,790	
	4	12,986	4,557	6,644	
Vessel 3	1	1,969			
	2	3,470			
	3	3,833			
	4	2,251			
	5	5,001			
Vessel 4	1	439			
	2	542			
	3	1,610			
	4	2,643			
	5	510			

- White oxide deposits at the end windings of the stator: a by-product of surface discharge activity
- The problem caused by a coolant leak.
- Recommendations: clean the end windings, fix the coolant leak and re-seal access hatches.

Case Study: PD Trending Results Before and After Maintenance to Generator

Vessel	Generator	July 2008	August 2008	November 2008	August 2009
Vessel 1	1	-	18,412 pC	-	5,239 pC
	2	17,416 pC	-	-	4,259 pC
	3	15,854 pC	-	-	7,866 pC
	4	29,248 pC	21,637 pC	5,800 pC	9,466 pC
Vessel 2	1	2,162 pC	-	5,981 pC	7,340 pC
	2	16,696 pC	-	2,094 pC	1,474 pC
	3	-	-	520 pC	3,790 pC
	4	12,986 pC	-	4,557 pC	6,644 pC

- Tests performed over 12 months to trend PD data.
- Low-cost, simple maintenance performed on generators in 2008 to remove dust, dirt and oil mist observed.
- PD levels after maintenance reduced from ‘Red = Unreliable’ to ‘Green = OK’.

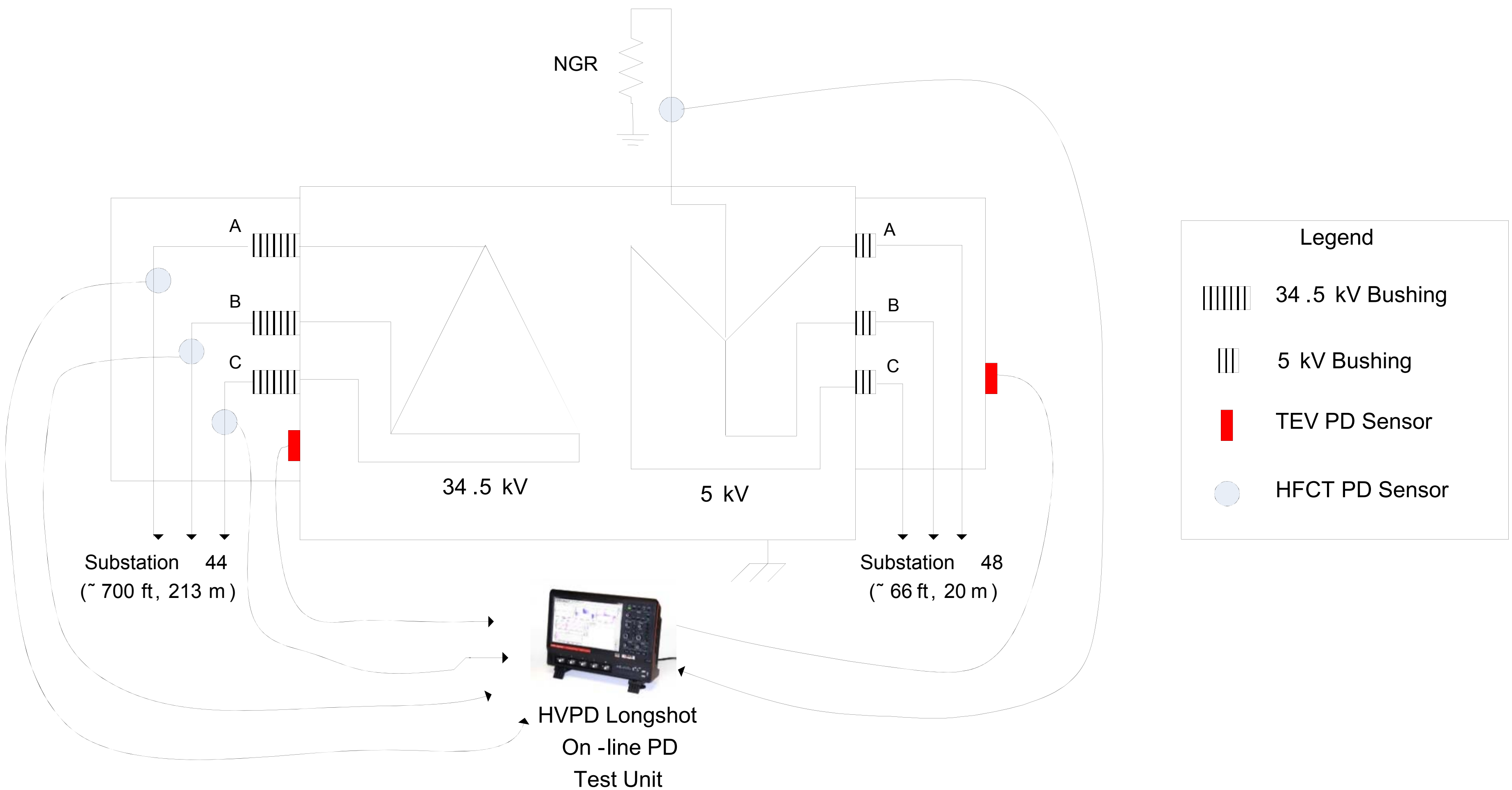


CASE STUDY 2: IN-SERVICE, ON-LINE PD TESTING OF 34.5/5 KV 10 MVA TRANSFORMER (U.S. VIRGIN ISLANDS)

- Following a failure of a 34.5/5 kV 10 MVA transformer, it was decided to carry out OLPD testing on the 'sister' transformer.
- Tests were carried out on-line, measurements made at both transformer and 34.5 kV Substation – takes into account possible radiation of PD signals from other items of plant (i.e. connecting cables & switchgear).

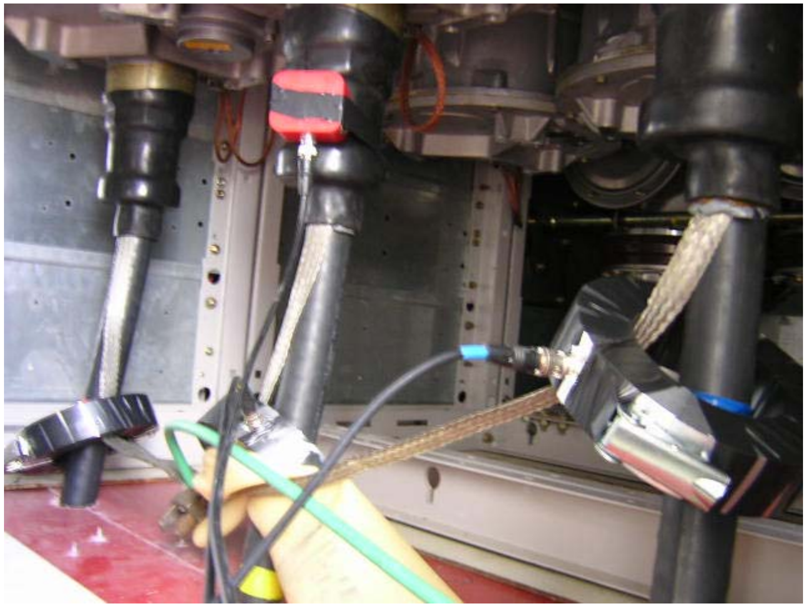
Case Study: PD Propagation from Transformer on to Network

Case Study: Sensor Connection

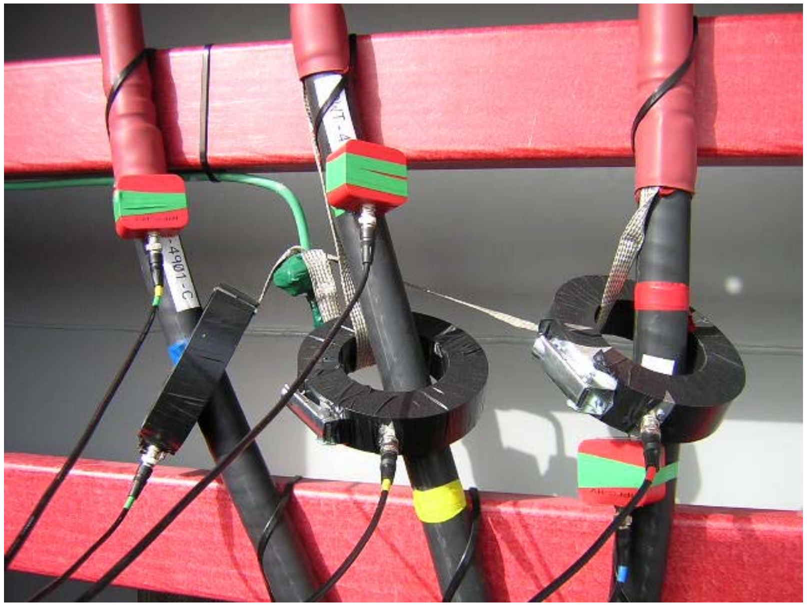


HVPD

Case Study: HFCT and TEV Sensor Connection on 34.5 kV Cable Cores



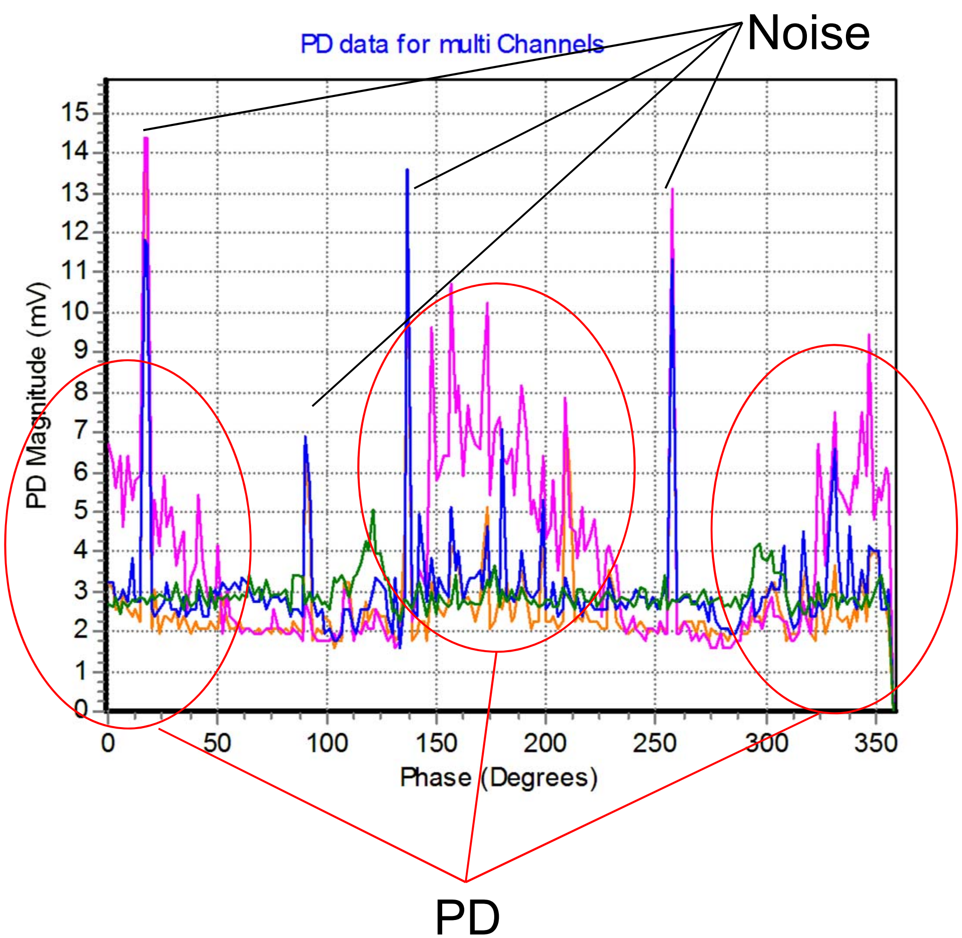
Sensor Connections at Substation End



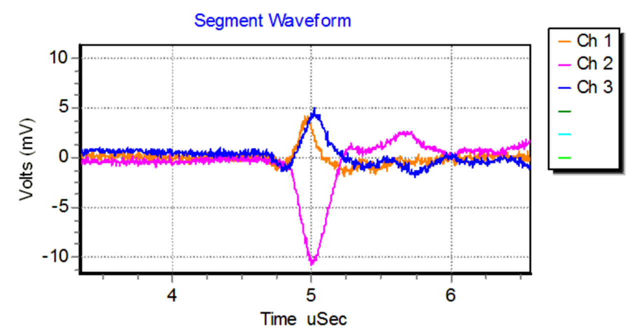
Sensor Connections at Transformer

- PD activity was found on the circuit and isolated to the transformer side of the cable.
- Further tests at the transformer revealed the likely source of the PD was in the *Phase B* of the 34.5 kV cable termination, transformer bushing or end winding.
- To isolate the PD source to either the cable or transformer components, the 34.5 kV cables on phases A, B and C were disconnected from the transformer and tested under working voltage supplied from the substation.
- No PD was detected on this test and thus through process of elimination it was concluded that the PD pulses originate from the transformer.

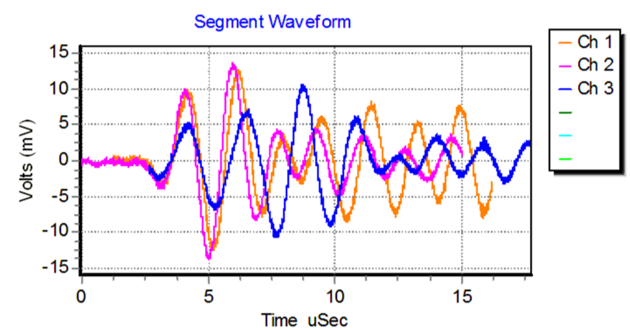
Case Study: OLPD Test Results

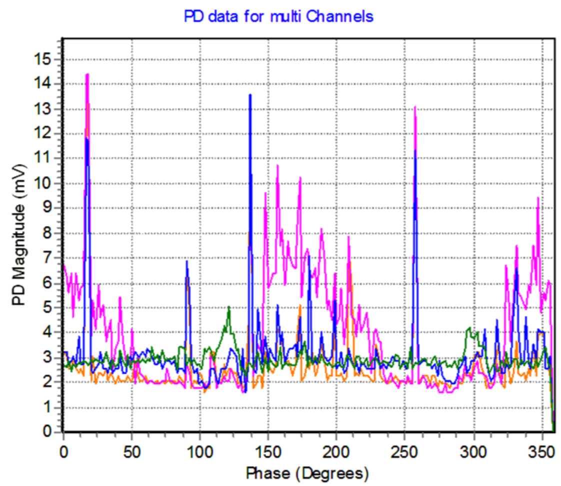


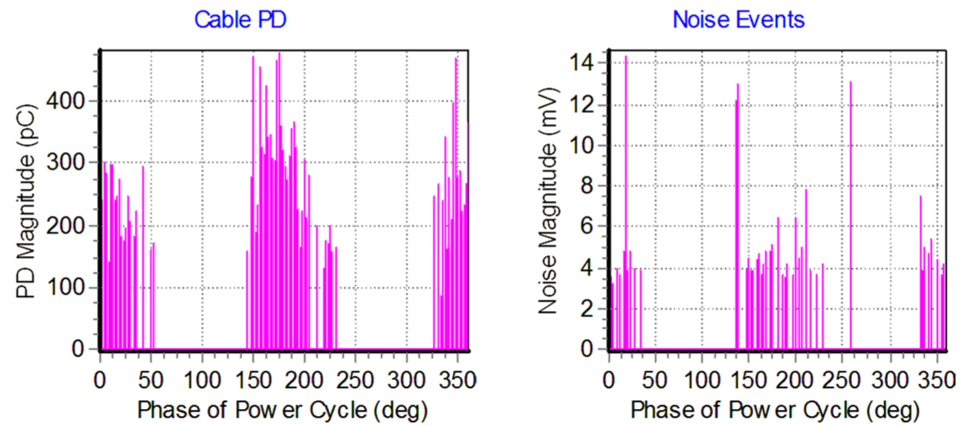
PD Waveform



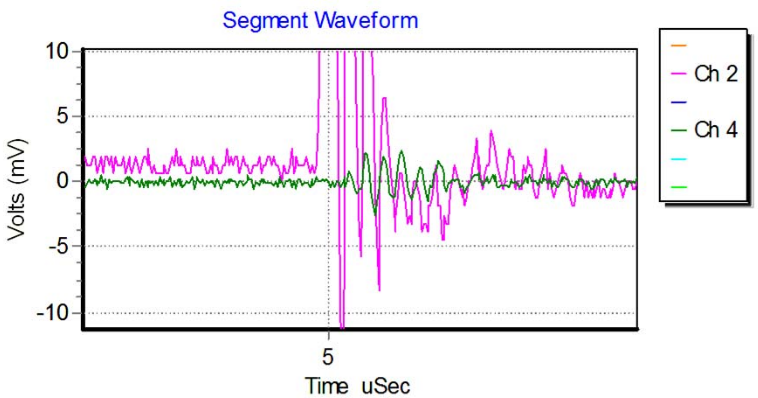
Noise Waveform





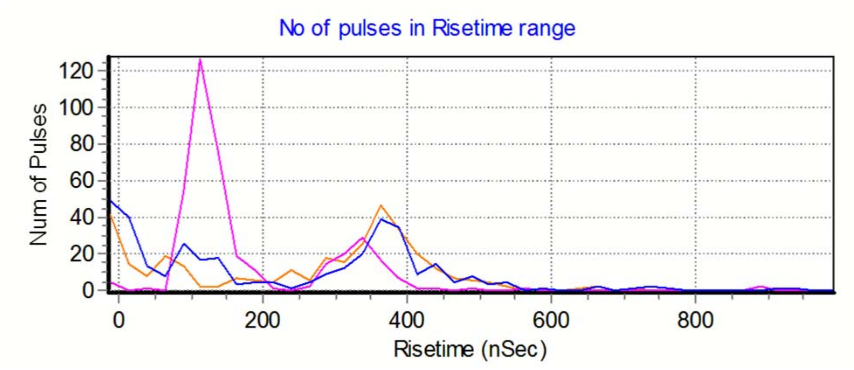


Separated PD and Noise against Power Cycle

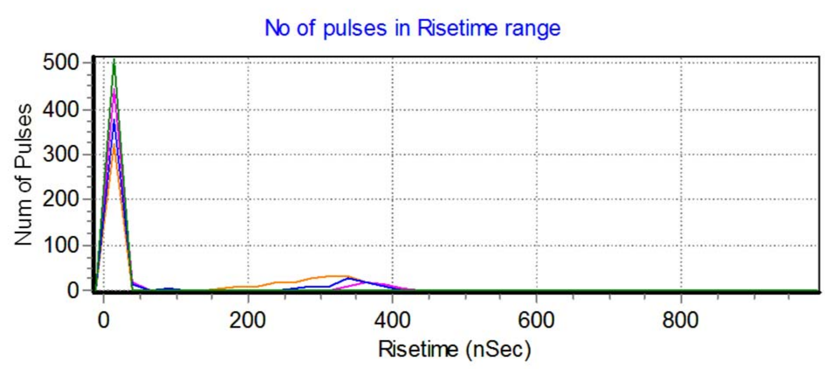


Waveform Measured at Transformer HFCT B Phase with HFCT on LV Neutral

Case Study: Comparison of Pulse Rise Time Distribution at Both Cable Ends



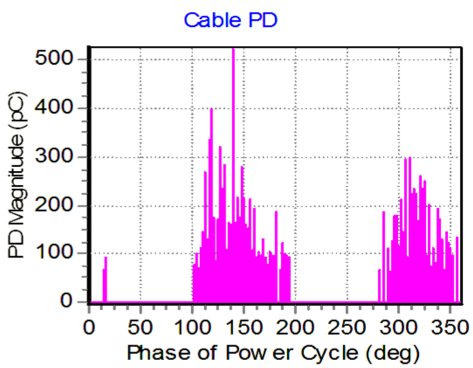
Substation End



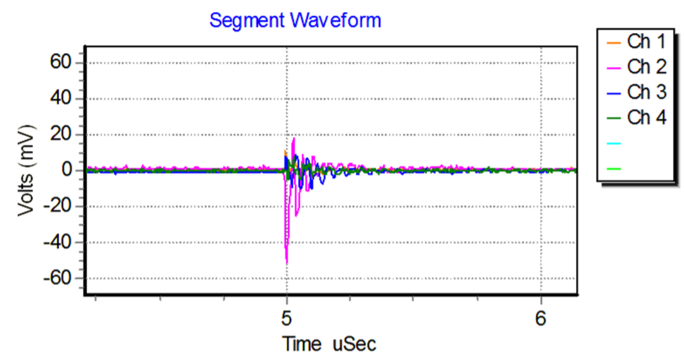
Transformer End

Case Study: OLPD Testing of 34.5/5 kV 10 MVA Transformer

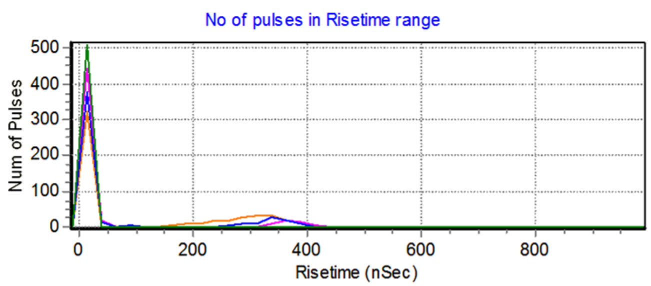
B Phase PD Data from Online Test (Purple Colour)



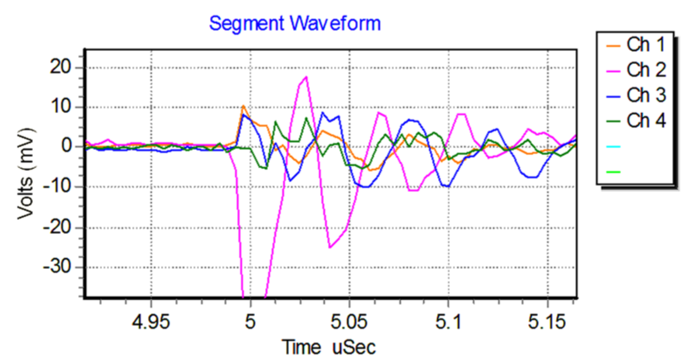
PD Across 60Hz Power Cycle



PD Waveform Shape (expanded trace below)

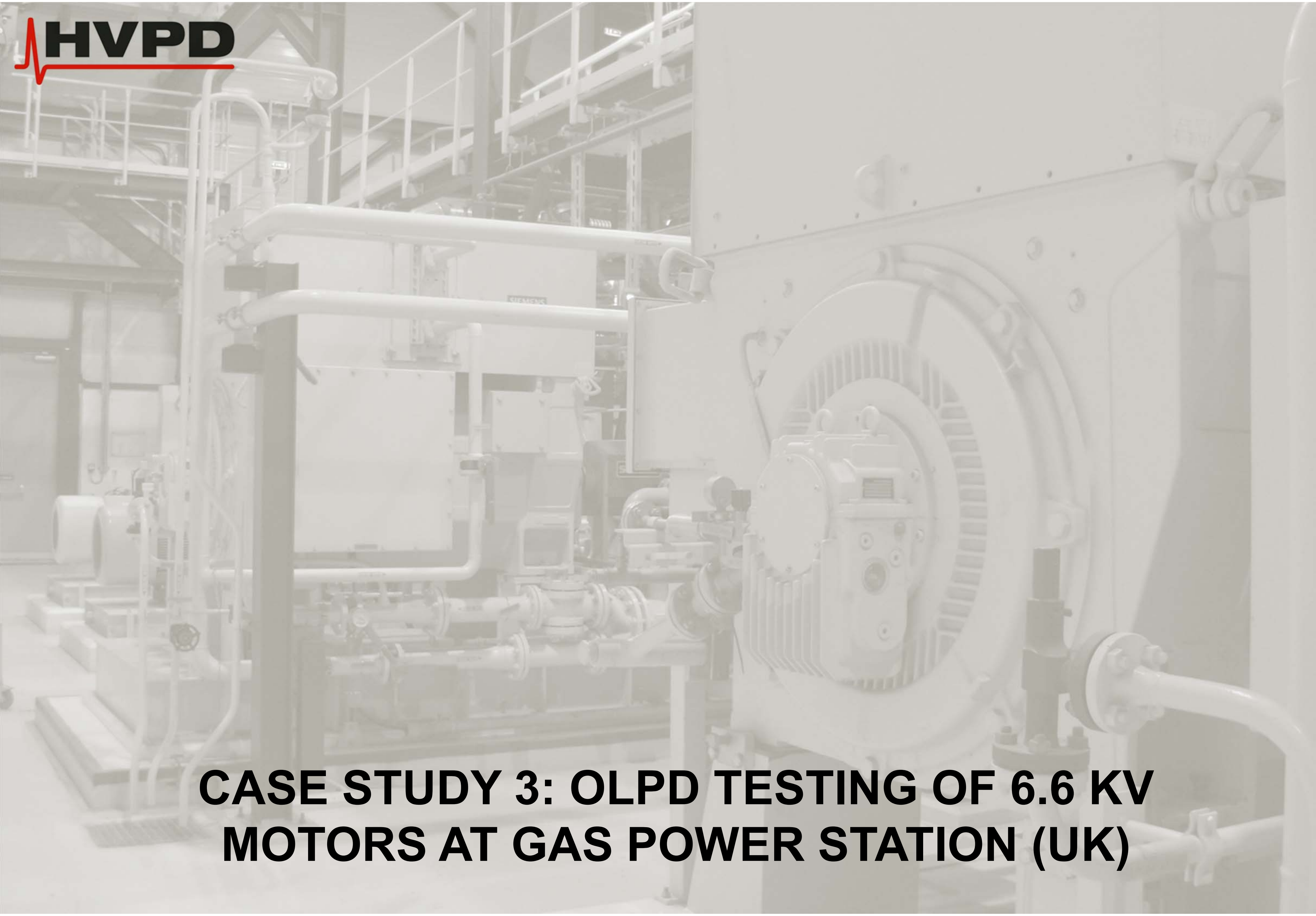


Pulse Risetime Graph



- The peak levels of PD detected were 500 pC which is a reasonably moderate level for MV cable accessories and transformer bushings.
- The PD detected was not thought to be an imminent threat but should have definitely been regularly monitored/tested.
- The presence of PD, even at relatively moderate levels, does make the risk of failure higher than that on a discharge free component.
- Regular on-line testing and monitoring of PD activity was recommended to ensure the PD in Phase B does not escalate to an unacceptable level.

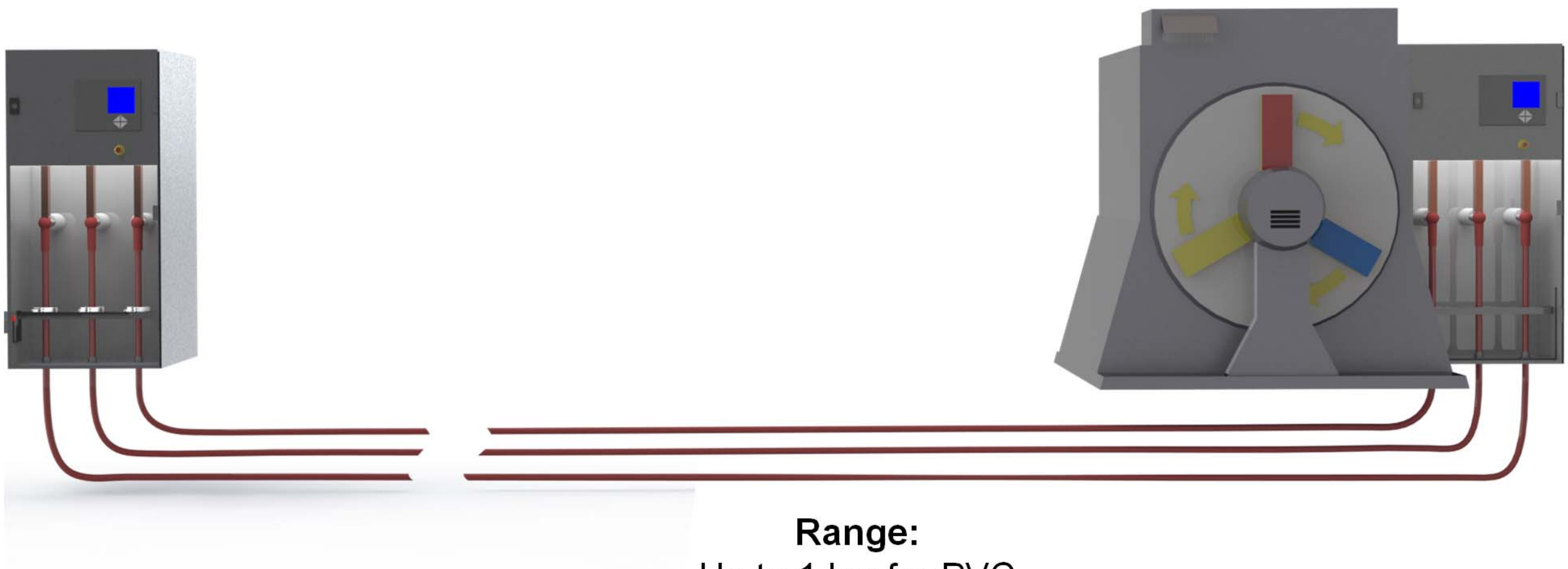
HVPD



CASE STUDY 3: OLPD TESTING OF 6.6 KV MOTORS AT GAS POWER STATION (UK)

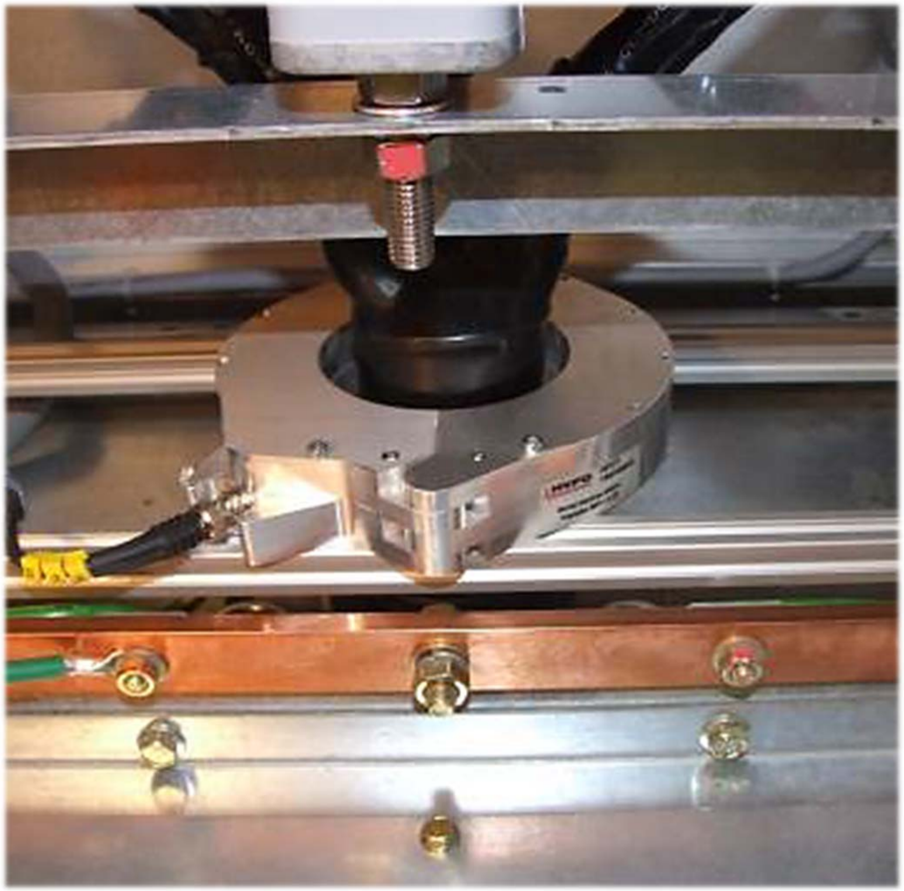
HFCT Sensors located at
HV Switchboard Cable End

Rotating HV Machine End



Range:
Up to 1 km for PVC
Up to 2 km for XLPE

Case Study: 6.6 kV Motors, OLPD Sensor Installation



Case Study: Summary of Initial OLPD Test Results

Motor Ref	PD Level [pC]	PD Activity [nC/Cycle]
Manufacturer A – Motor 1	**12,152**	**95**
Manufacturer A – Motor 2	**3,123**	**12**
Manufacturer A – Motor 3	**3,165**	**4**
Manufacturer B – Motor 1	**52,589**	**296**
Manufacturer B – Motor 2	**33,135**	**370**
Manufacturer B – Motor 3	**68,071**	**85**

Case Study: Off-line PD Test Results Circulating Water Pumps

Motor	U Phase PD (IEC) Magnitude		V Phase PD (IEC) Magnitude		W Phase PD (IEC) Magnitude		All Phases PD (IEC) Magnitude	
	2010	2011	2010	2011	2010	2011	2010	2011
Motor 1	10,530	30,260	12,870	24,960	7,865	4,846	17,180	44,040
Motor 2	14,920	30,620	17,730	27,070	15,640	22,100	26,390	42,520
Motor 3	15,140	30,890	16,920	31,040	16,530	24,410	26,780	44,370

All off-line PD measurements showed an increasing trend from the 2010 tests to the 2011 tests with an average increase in PD levels across all 3 motors of around 100% i.e. the PD levels **had doubled over the 12 months between these tests**.

Case Study: Visual Inspection after Off-line PD Tests

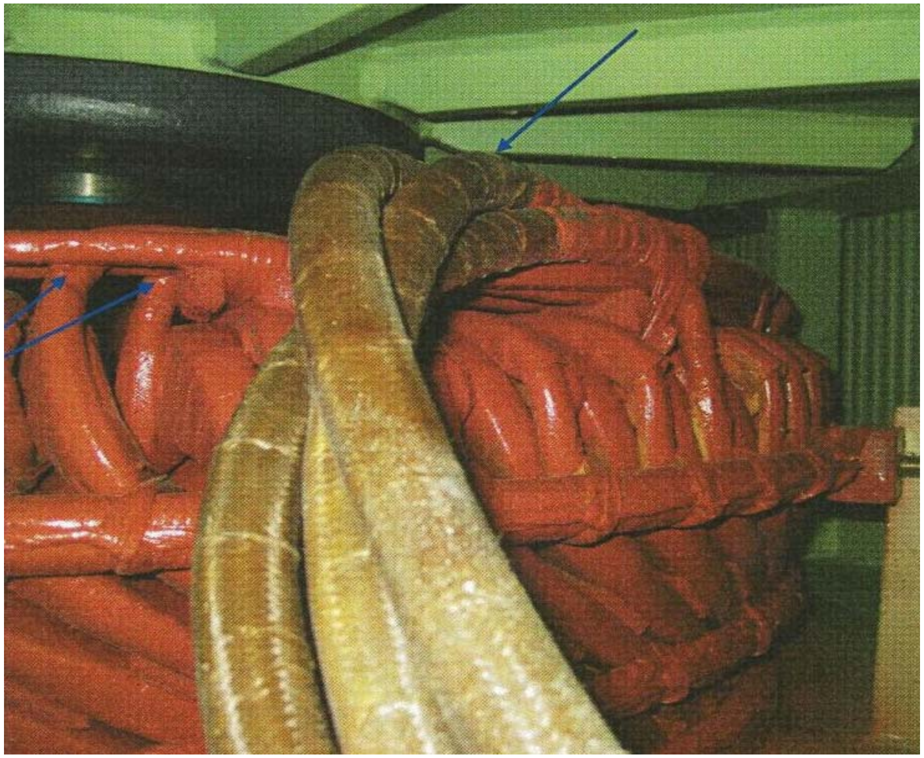


Image of Neutral Terminal Box. The Glass Cover (arrowed) was removed to inspect the windings

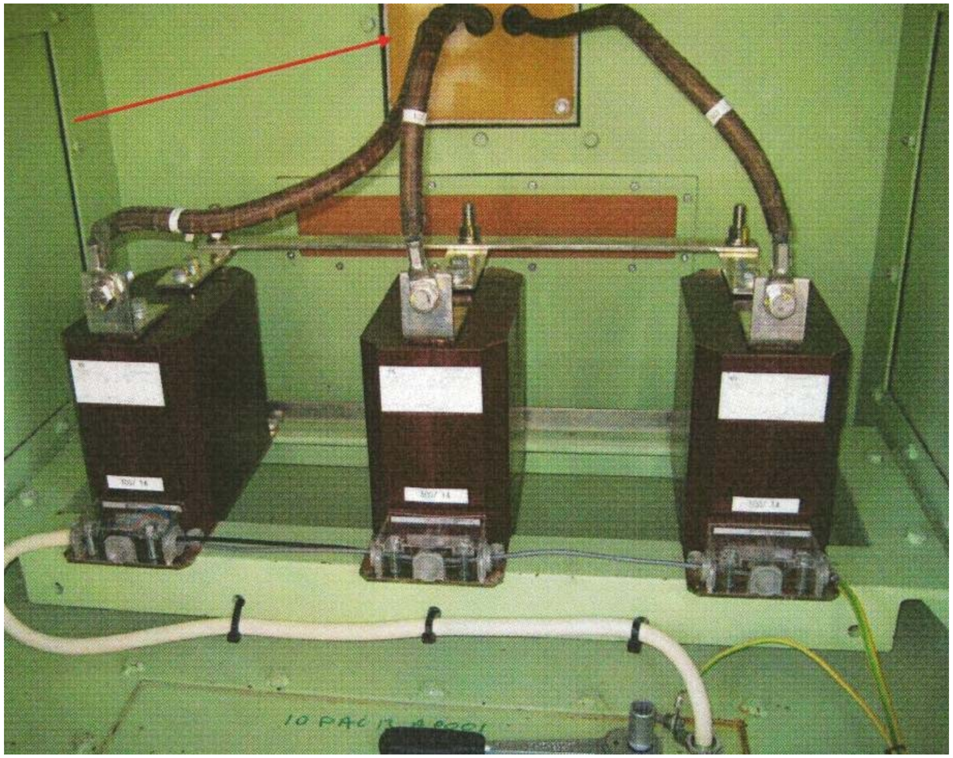


Image of winding connections. Neutral Cables and internal connections not spaced apart (arrowed)

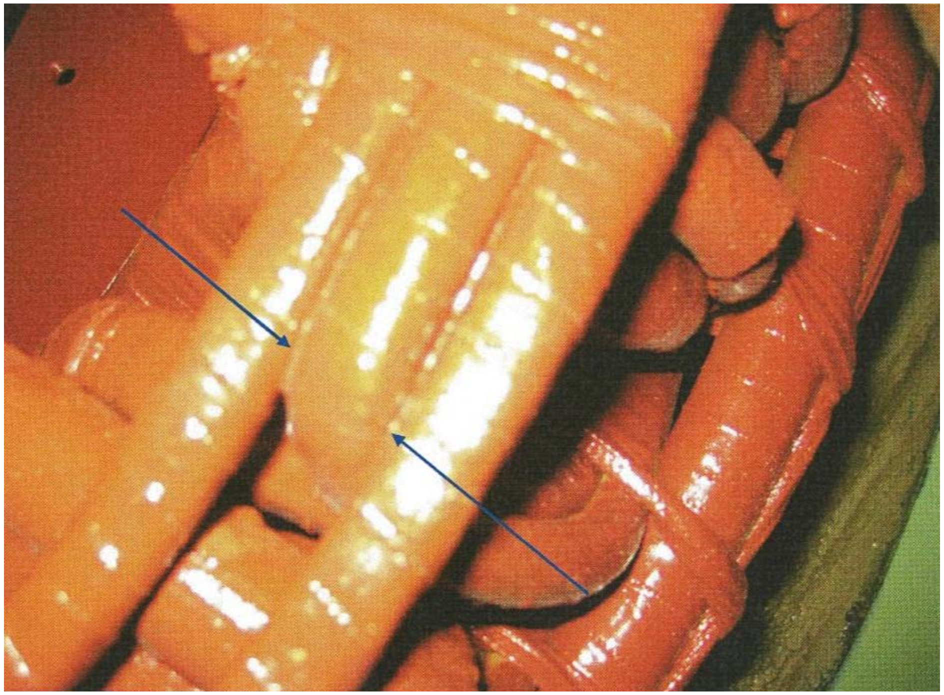


Image of connections not adequately spaced (arrowed) = design issue

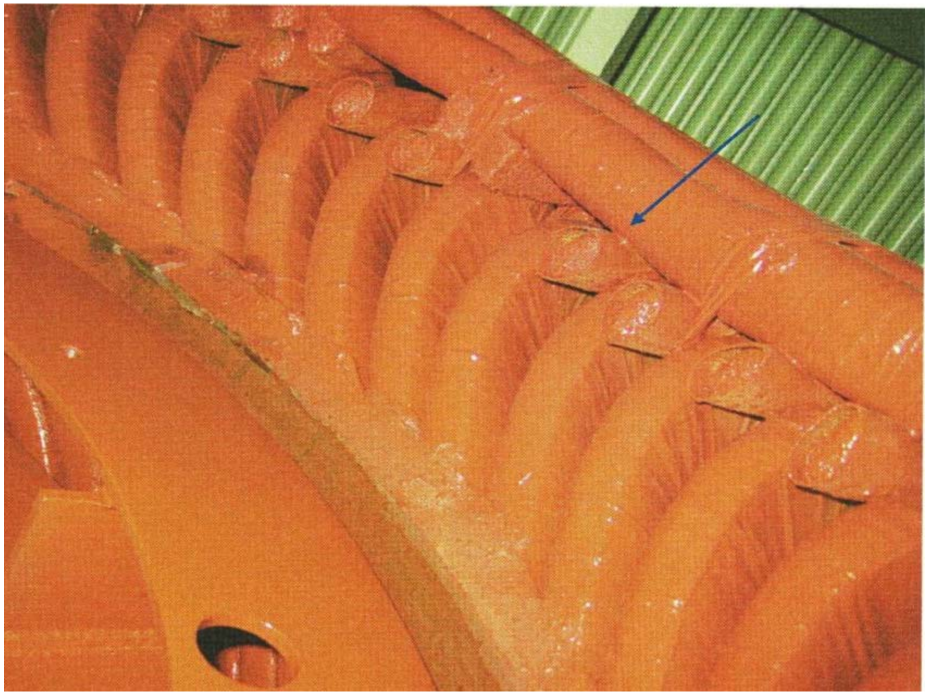


Image of coil – coil connections touching a neutral cable (arrowed) = design issue

Warranty Claim with Motor Manufacturer

Motor Manufacturer dismissed the validity of HVPD's on-line PD tests

Two separate third party, **off-line** PD tests backed up HVPD's findings.

Motors rewound and repaired under warranty!

Customer's feedback:

'Thanks for your support throughout the whole process, your equipment and advice has played a big role in a fairly complicated warranty claim that enabled us to successfully identify and rectify a defect, which with PD was always going to be a difficult one to secure.'

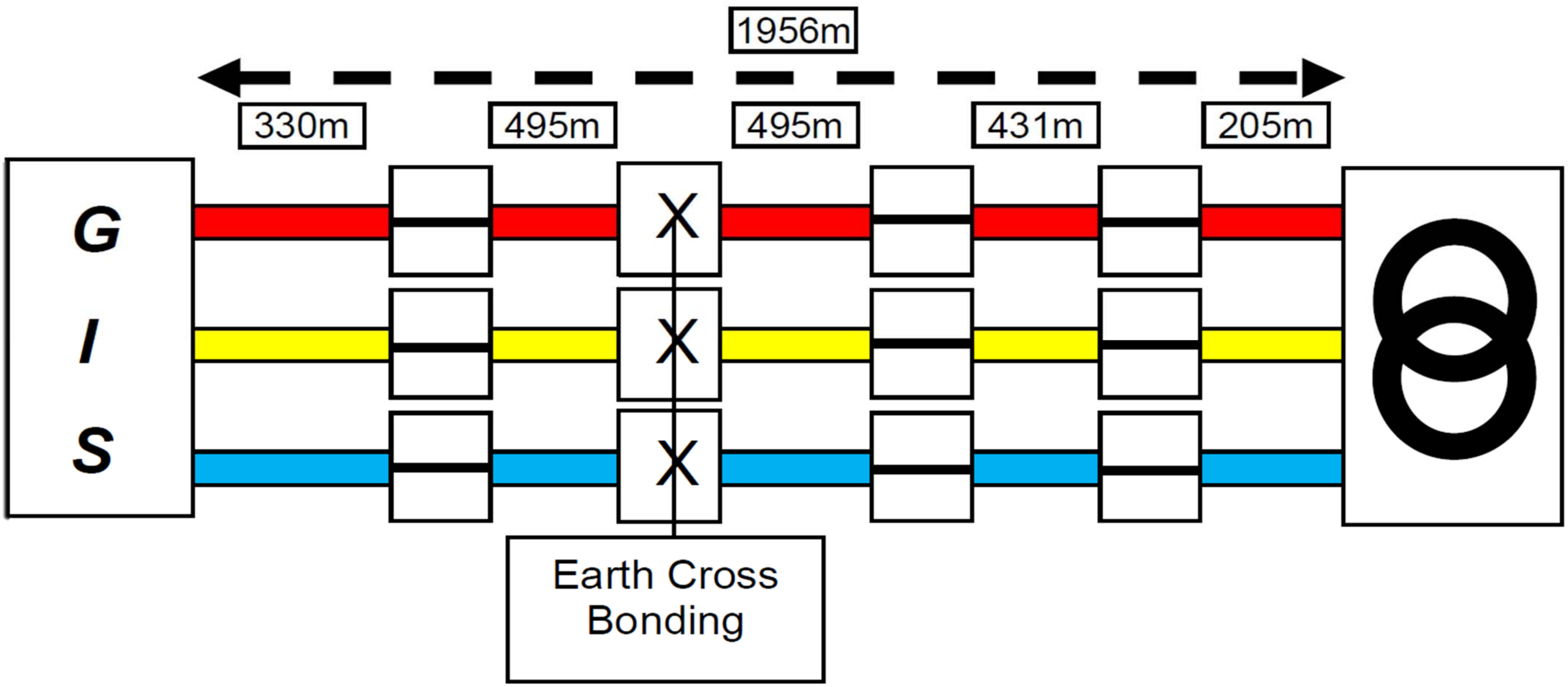
CASE STUDY 4: OLPD TESTING AND MAPPING OF 34.5 KV XLPE CABLES FOR A PROCESS INDUSTRY CLIENT (SAUDI ARABIA)

- OLPD tests on a number of cable circuits **where recent cable joint failures had occurred**.
- Four cable circuits that were known to have been subjected to heavy circulating currents in the earth screen & armour (in excess of 80 Amps) which had led to **catastrophic in-service failures**.
- The previously failed joints showed evidence of tracking.

- OLPD tests on a number of cable circuits where recent cable joint failures had occurred.
- Four cable circuits that were known to have been subjected to heavy circulating currents in the earth screen & armour (in excess of 80 Amps) which had led to catastrophic in-service failures.
- The previously failed joints showed evidence of tracking.

Severely Damaged 34.5 kV XLPE Failed Cable Joint

The 1.9 km long, 34 kV XLPE cable circuit had 5 jointed sections with only one cross-bond point.



Case Study: OLPD Screening of the Cables

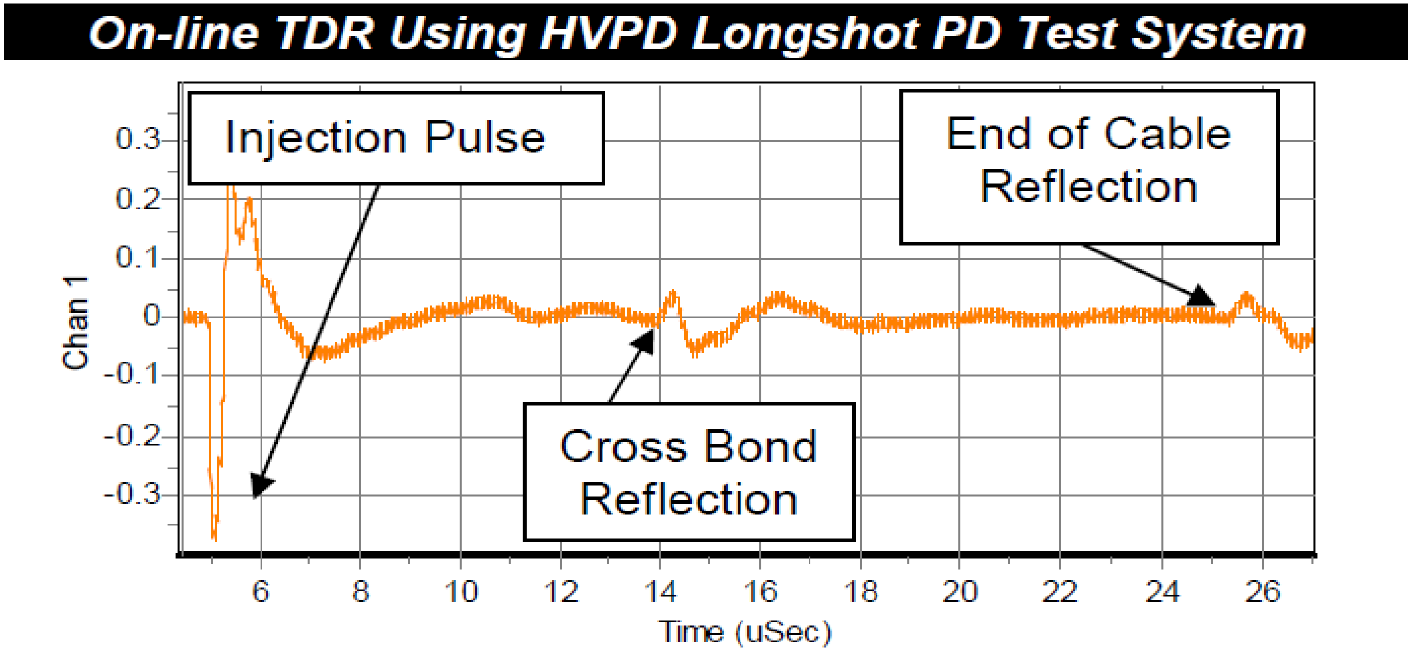
The HVPD PDSurveyor™ was used to detect any Local PD in the cable terminations / joints and switchgear panels.

The HVPD Longshot™ unit was used to test and locate the discharging joints.

Case Study: Sensor Attachment at Seawater Pump Transformers

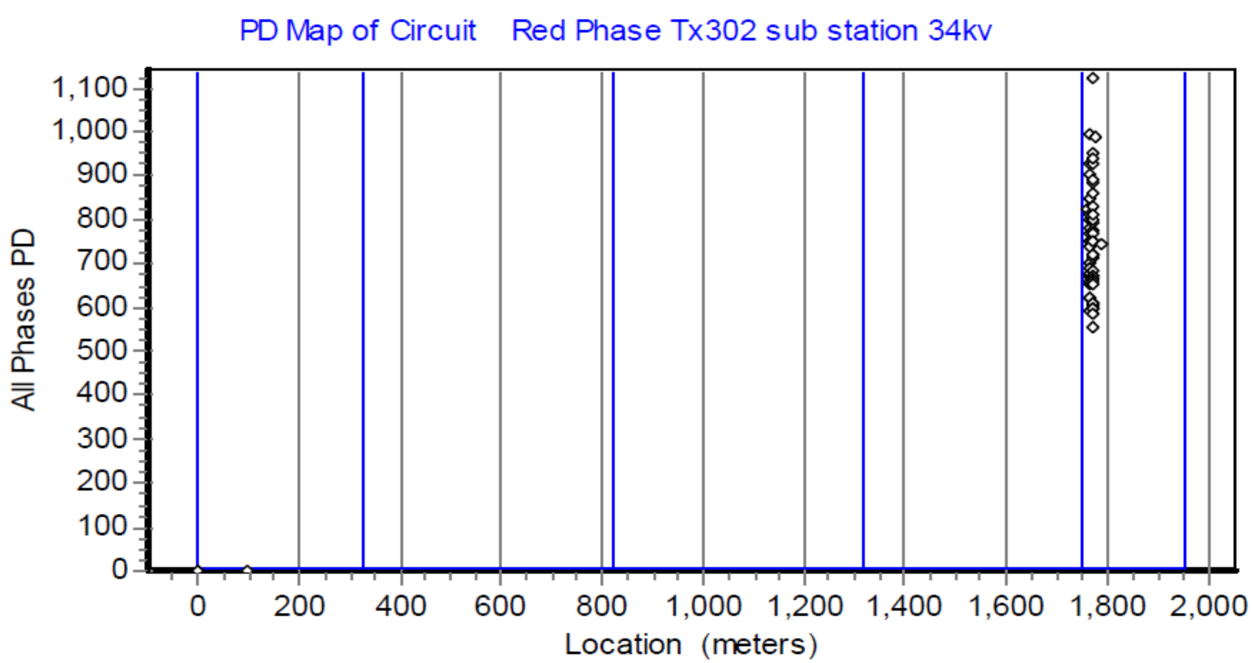
HVPD

Case Study: Sensor Attachment at GIS Switchgear Terminations

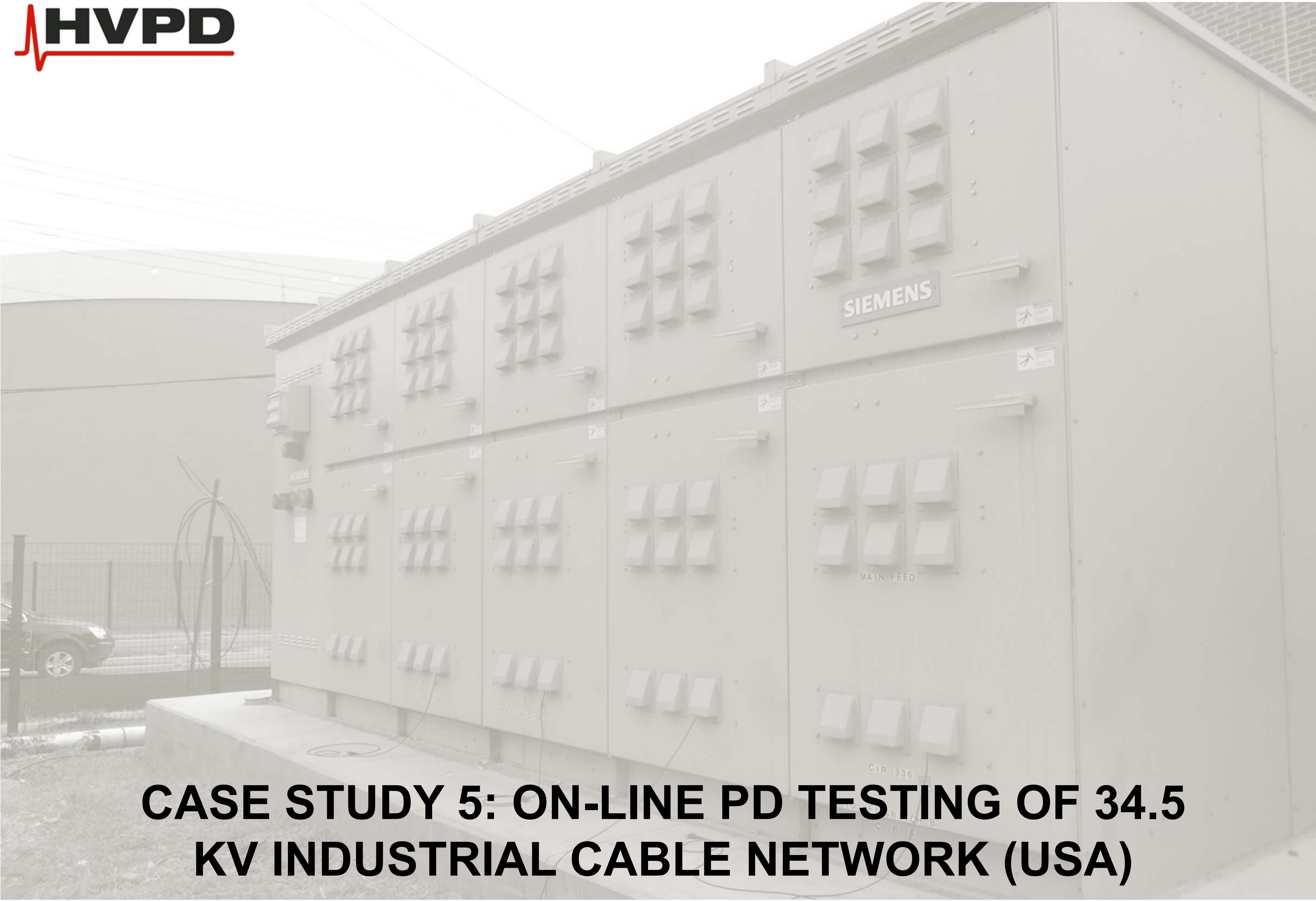


- The measured **Cable Return Time** for the pulse injected at the switchgear to travel to the far end of the seawater feeders and back was **20.4 µsec**.
- Given that the seawater feeder cable is 1956 metres in length, this gives a **return speed** for the 34.5 kV XLPE cable of **95.9 m/µsec**.

- PDMap© software was used to create a map of the 1956 m cable.
- The source of PD activity was located within the Red Phase cable of seawater pump Tx302 at 1770 metres out from the 34.5 kV main substation (or 185 metres out from the Seawater Pump Transformers).
- This corresponds with the location of Joint No.3 on this cable as shown below.



The cable joint was replaced, re-tested and found to be discharge-free.



CASE STUDY 5: ON-LINE PD TESTING OF 34.5 KV INDUSTRIAL CABLE NETWORK (USA)

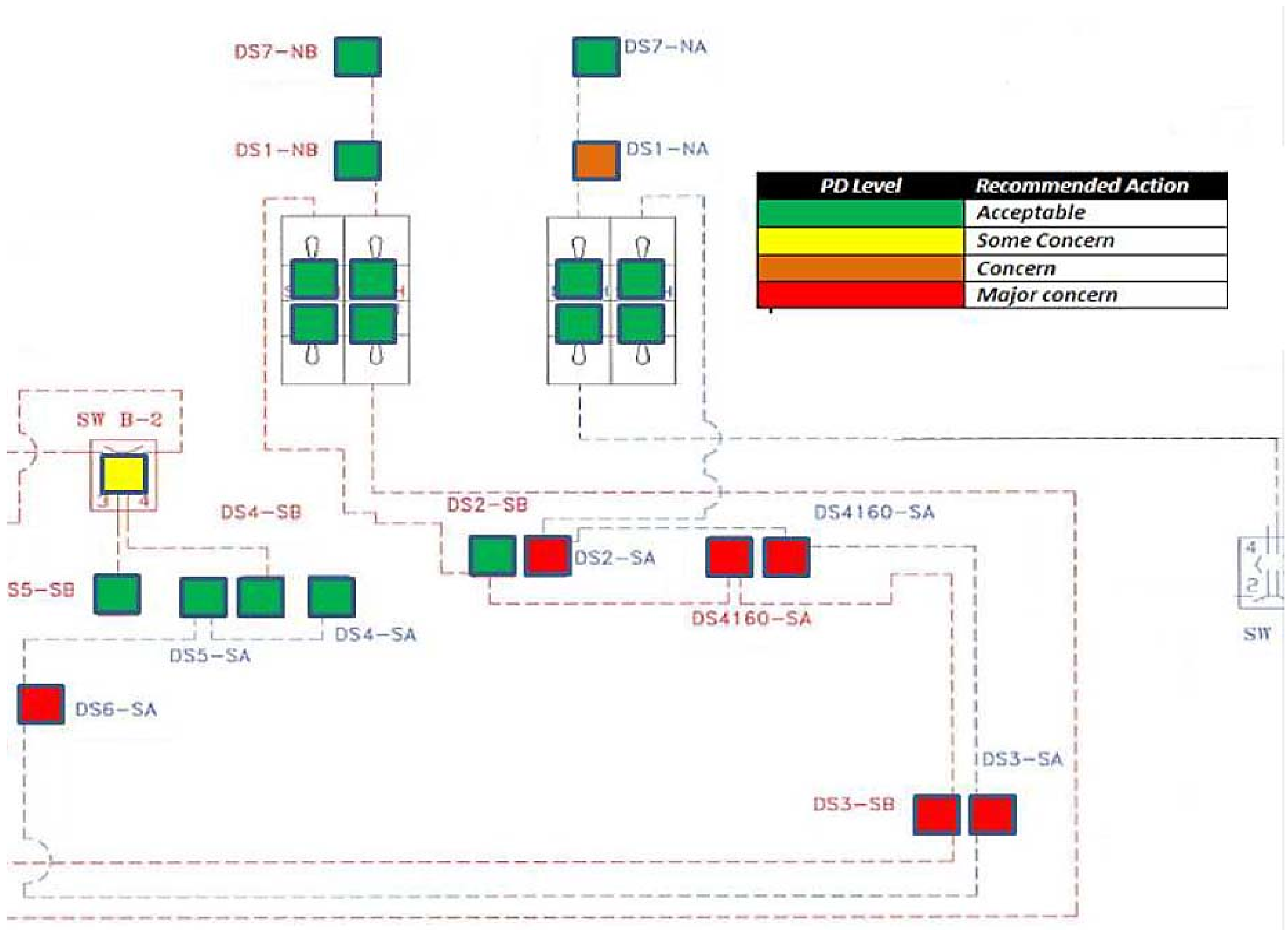
Case Study: Introduction

- OLPD tests were conducted within the 34.5 kV XLPE cable terminations at the padmount transformers in follow up to recent in-service failures of cable terminations.
- 21 cable circuit terminations were tested with 42 points of attachment (POA) with the PDSurveyor™, HVPD Longshot™, and temporarily installed HFCT sensors.

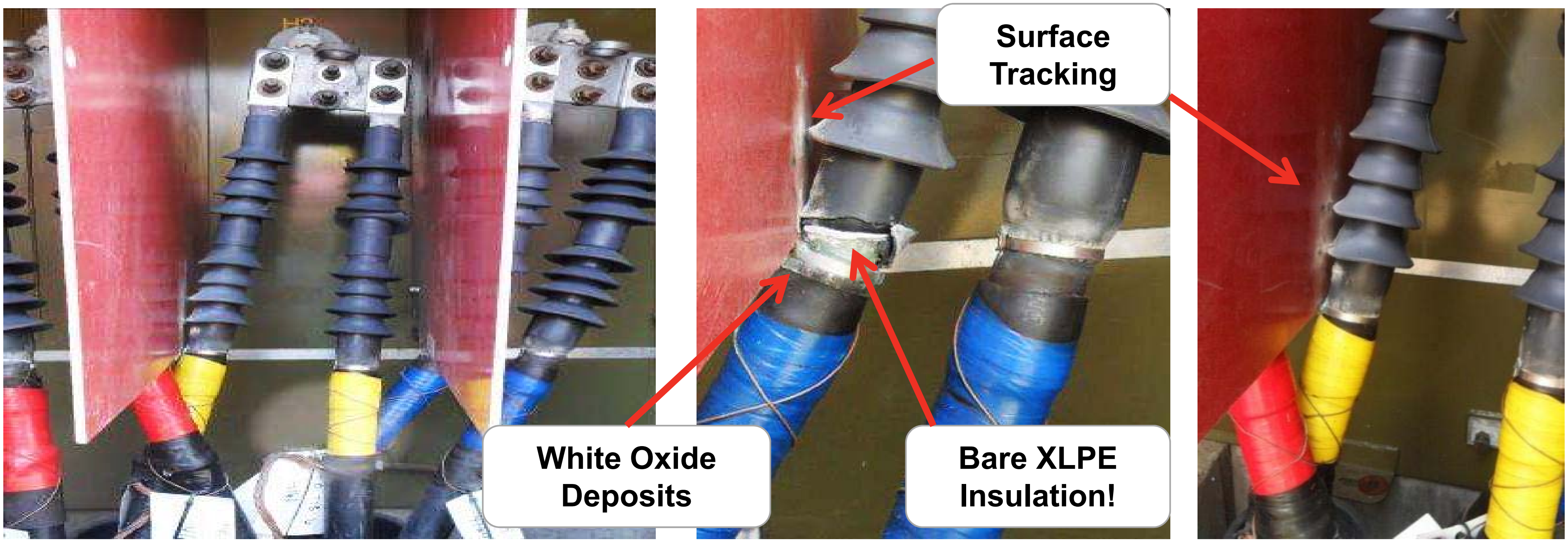



Case Study: OLPD Measurement Results across Network Diagram

- Considerable cross-coupling of the PD signals at each padmount.
- PD signals propagate far into the cable network from source.
- Four sources of this type of activity located.



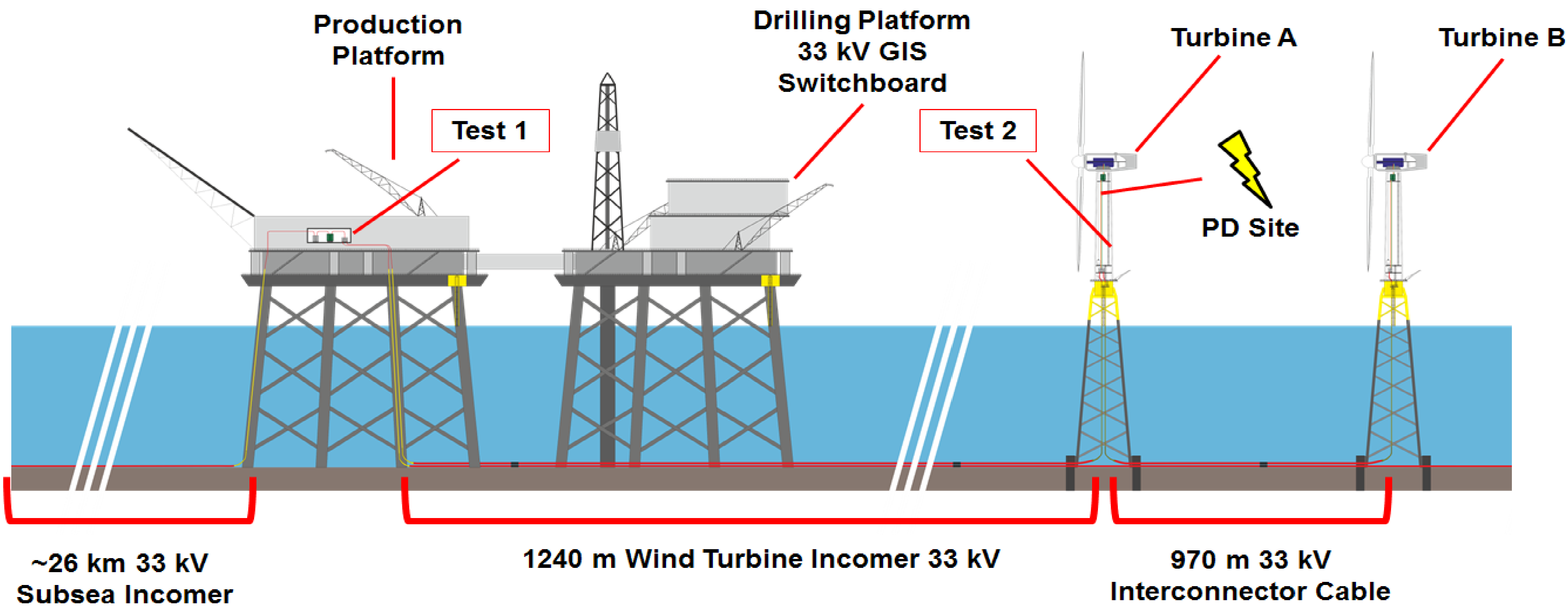
Case Study: Targeted Investigation Locates Probable Cause



- **Poor workmanship** was the main contributing factor to the surface PD activity detected.
- **Signs of PD activity** on the cable terminations
- The rubber stress cone termination had been completely eroded.

- Re-termination of the cables into the six ‘RED PD Level’ padmounts.
- Further OLPD tests showed no PD activity and confirmed the rework had been effective.
- The customer was advised that regular, periodic OLPD ‘screening’ tests should be carried out.

CASE STUDY 6: OLPD TESTING AND LOCATION ON OFFSHORE WIND TURBINE TO OIL & GAS PLATFORM 33 KV CABLE FEEDER

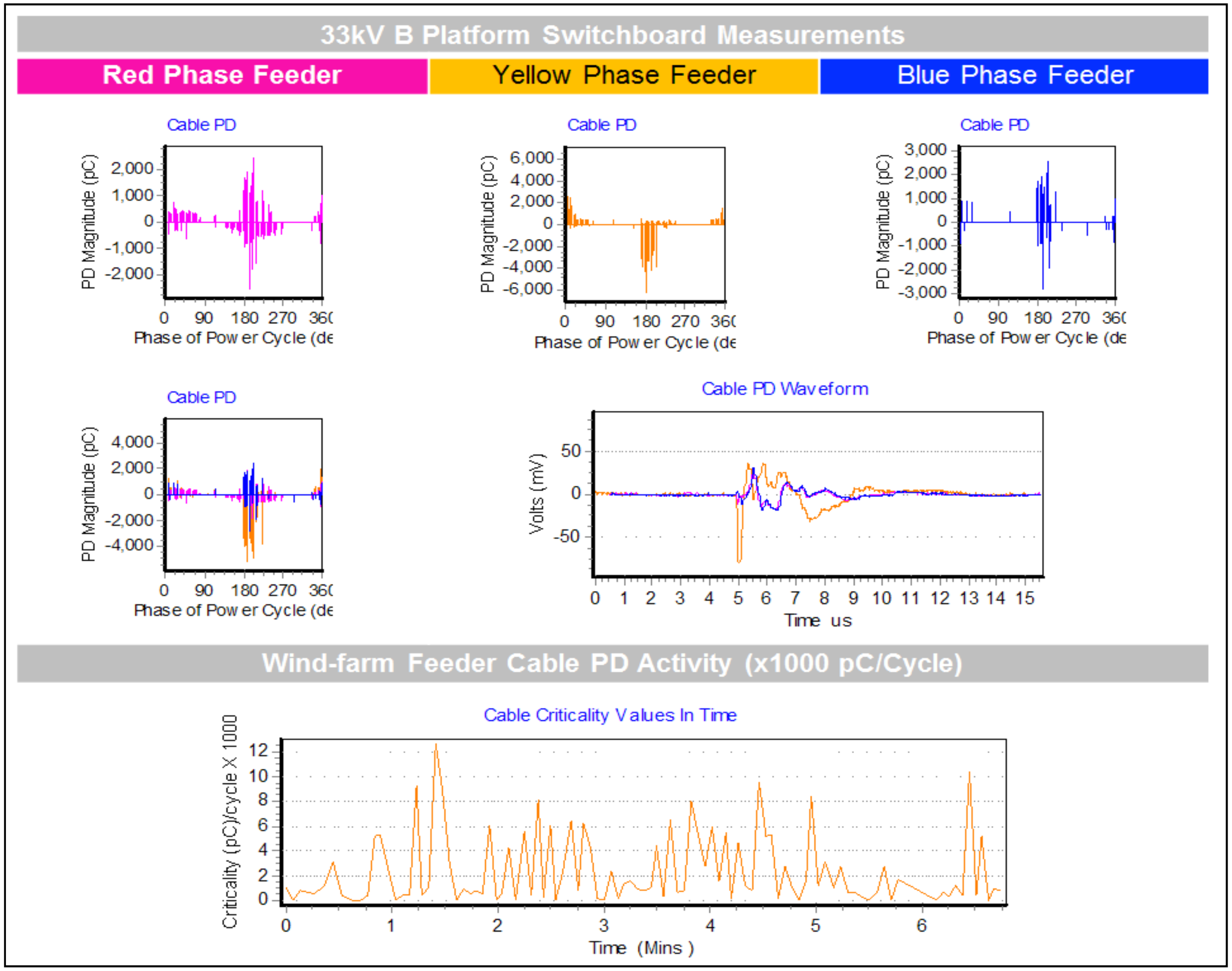


- Two deep-water wind turbines supply power exclusively to an oil production platform 2km away.
- Two on-line PD tests were performed to assess the condition of the turbine feeder cables.

Case Study: Test 1 – OLPD Test of 33 kV Switchgear on Platform

Case Study: OLPD Test of 33 kV Switchgear on Platform

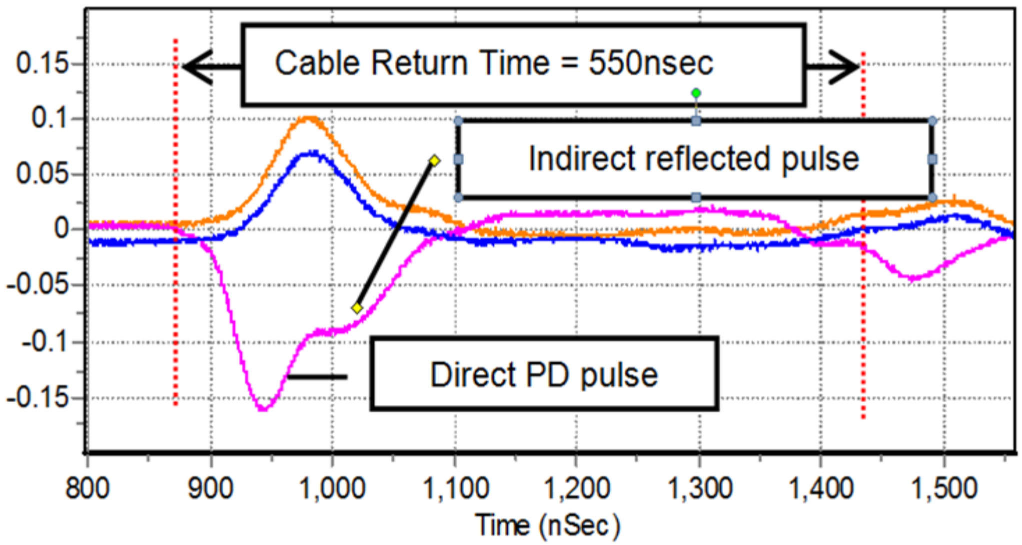
- **PD on Turbine A Feeder was detected** and was considered to be remote source based on pulse properties.
- Analysis predicted the **location to be near the far end of the Turbine A feeder cable**. Mapping recommended.

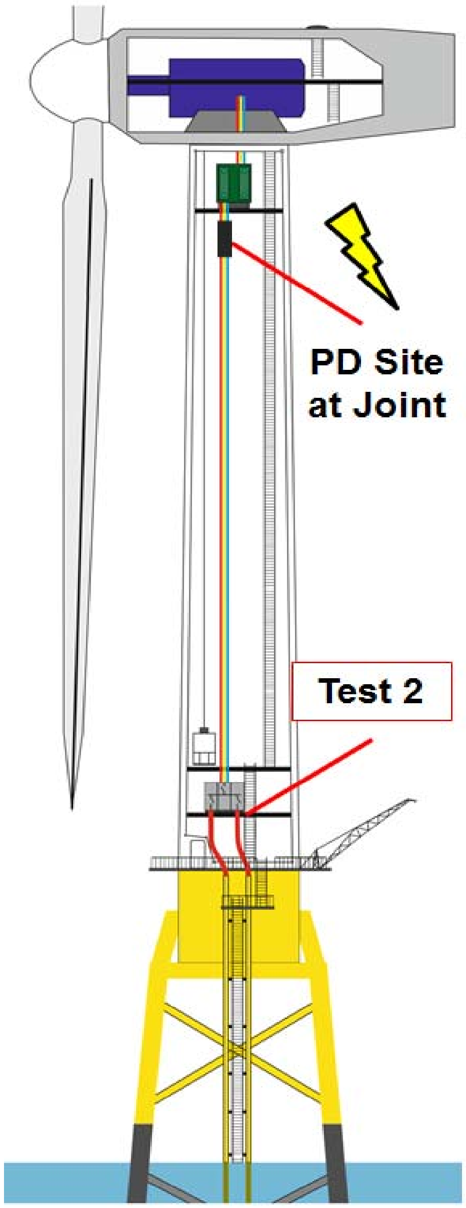


Case Study: Test 2 – PD Location at Wind Turbine 33 kV Feeder RMU

Case Study: PD Location at Wind Turbine 33 kV Feeder RMU

- High PD magnitudes in excess of 6,000 pC, with average levels of 1,871 pC detected on Yellow phase.
- Test identified the PD source was the Yφ local turbine 33 kV transformer/cable joint.
- Measurement of PD pulses on wind turbine cable feeder show clear direct & indirect reflected pulses.
- Joint location was confirmed at 52 metres from the RMU.





CONCLUSIONS

- Insulation Condition Monitoring (CM) using OLPD requires **a continuous evaluation** of the HV insulation's dielectric integrity throughout the service life of the asset.
- **Continuous OLPD monitoring** should be carried out throughout the first 3 years of service - the 'bedding in' period.
- **Test and monitor after any repairs to faults** – to ensure the repair has worked!
- **Continuous OLPD monitoring is recommended throughout the service design life** (of 20–25 years+).

End of Presentation

Thank you for your time

Q&A?

Deployment of OLPD Testing in Asset Management Systems

CONTENTS

- HVPD 4-Phase approach for OLPD monitoring of MV networks
- PD trending
- Plant condition analysis
- OLPD league tables
- Examples of deployment of PD testing in asset management systems

HVPD

HVPD 4-Phase Approach for OLPD Monitoring of MV Networks

- A complete solution for the OLPD screening, diagnostic testing and extended monitoring.
- Identify, locate and monitor PD activity in the **‘Worst 5%’** of the customer’s network.
- A range of portable and permanent OLPD test and monitoring technology can be applied to achieve this.

The HVPD Integrated OLPD Test and Monitoring Solution For Medium Voltage (MV) Networks (Voltage Range: 3.3–36 kV)

Phase 1

100% of the network

OLPD 'Pre-screening' with Handheld OLPD Surveying Technology

'Look-see' tests, only requiring 10–30 second test per plant item

PDS Air™ with TEV, HFCT and Acoustic Sensors

Phase 2

~20% of the network (as identified in Phase 1)

Diagnostic OLPD Testing & PD Site Location with Cable Mapping

PD Testing: 5–10 minutes
PD Mapping – 10 minutes to 1 hour

HVPD Longshot™ 4-channel Diagnostic OLPD Spot Tester

Phase 3

~10% of MV plant (as identified in Phases 1 and 2)

Temporary OLPD Monitoring with Portable OLPD Monitors

Periods from 1 day up to 3 months

HVPD Multi™ Portable & HVPD Mini™ Portable OLPD Monitors

Phase 4

~1–5% of MV Plant (as identified in Phases 1, 2 and 3)

Continuous OLPD Monitoring with Permanent OLPD Monitors

3 months+

HVPD Multi™ Permanent Monitor (16 to 96 Channels)

12 Month Iterative Process

Our Knowledge is Your Power

Phase 1: OLPD Surveying of MV Cables and Plant

The HVPD PDSAir™ Surveying Tool

- Used for initial, quick screening of large numbers of MV plant items.
- The MV cable/plant can be tested in-service under normal operating conditions, no outage required!
- Easy to read, 7-level, colour-coded PD level indication panel.

HVPD PDSAir™ Handheld Surveying Tool


HVPD
DANGER
Treat as Live

Why Use the PDS Air™

- Combines HFCT, TEV and AA sensors to enable OLPD testing of both cables and switchgear.
- A look-see OLPD scan, indicating the plant which requires further diagnostic testing.
- Low cost, lightweight & portable, easy to use.
- Test the insulation condition of the plant in seconds.

On-Line Partial Discharge Surveying System

PD Level Guide:

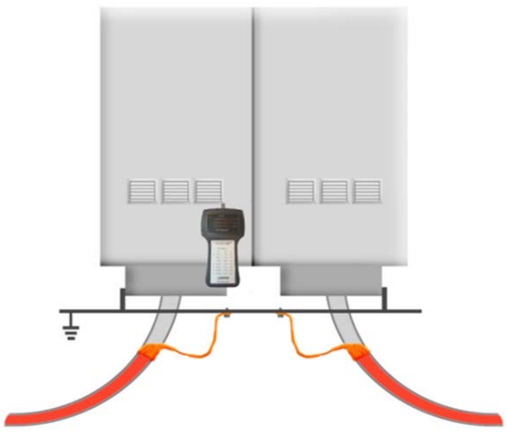
	CT	AA	TEV
● (green)	300 pC	8 dB	15 dB
● (yellow)	600 pC	12 dB	20 dB
● (yellow)	1200 pC	15 dB	25 dB
● (orange)	3000 pC	19 dB	30 dB
● (orange)	7800 pC	22 dB	35 dB
● (red)	20000 pC	26 dB	40 dB
● (red)	30000 pC	30 dB	45 dB

www.hvpd.co.uk

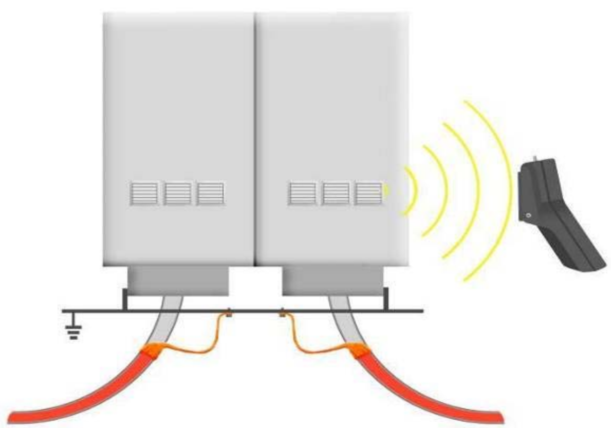
- LED 1 – Green (Plant OK)
- LED 2 & 3 – Yellow (Moderate PD – Monitor)
- LED 4 & 5 – Orange (Moderate To High PD – Investigate Source Of PD)
- LED 6 & 7 – RED (High PD – Test & Restrict Access)

NB: It should be noted that the PD levels & actions recommended are guideline levels only and are based on HVPD's experience in testing MV Plant

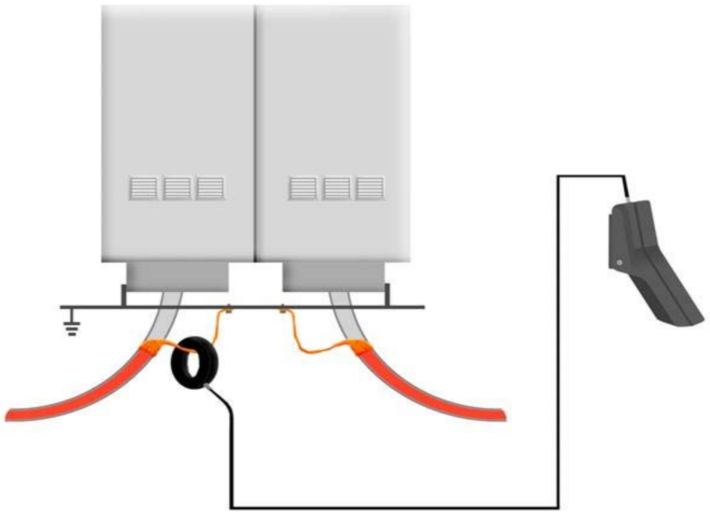
TEV Sensor



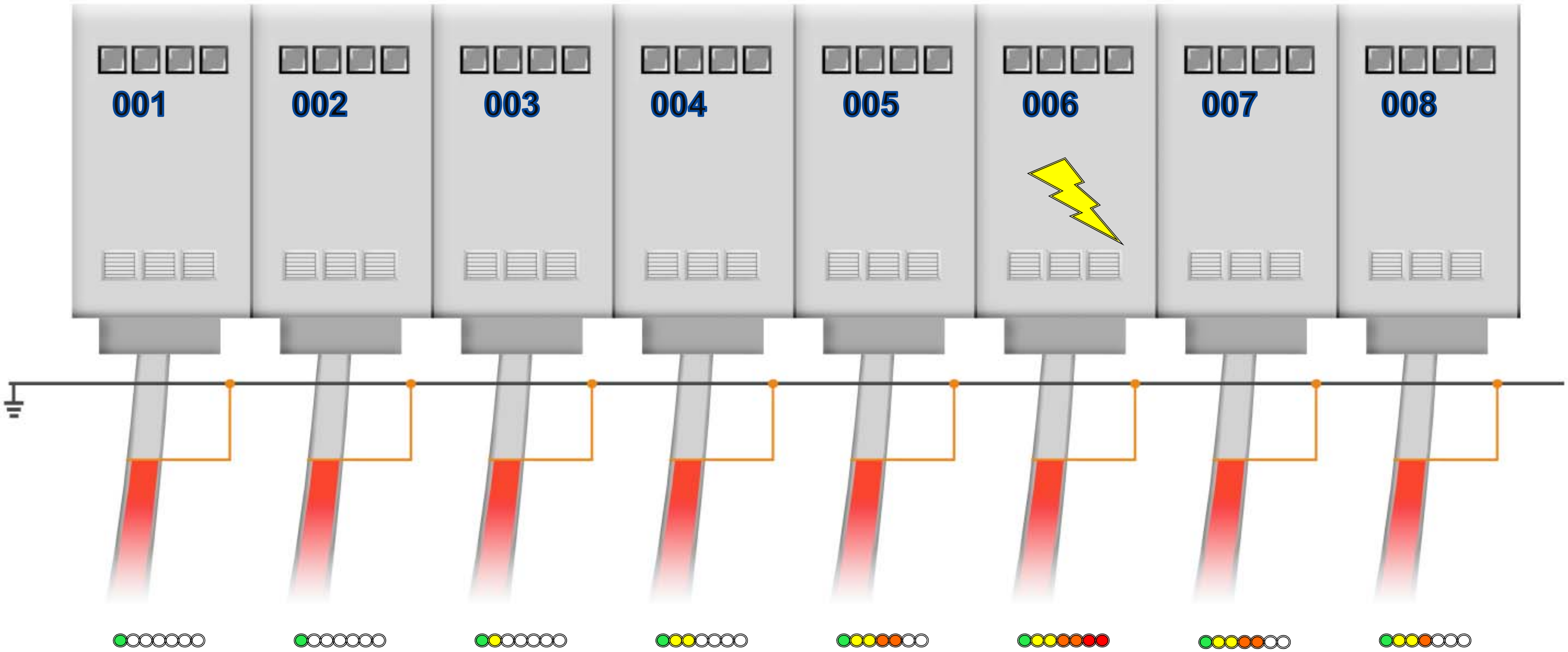
Airborne Acoustic Sensor



HFCT Sensor



Example Use of Detection and Diagnostics
MV Switchgear with TEV



Very High Level Local PD Activity >48 dB (Panel 006)
Further Investigation Recommended

Phase 2: HVPD Longshot™ Diagnostic OLPD Test Unit

- 4-Channel, synchronous OLPD test unit
- Captures PD activity using very high speed data acquisition capability (100–500 MS/s)
- Diagnostic PDGold© v7 software with unique *‘Event Recogniser©’* software modules differentiates between PD activity and any electrical noise and RF interference.
- An automatic, detailed analysis of pulse frequency, waveshape and other signal waveform characteristics.

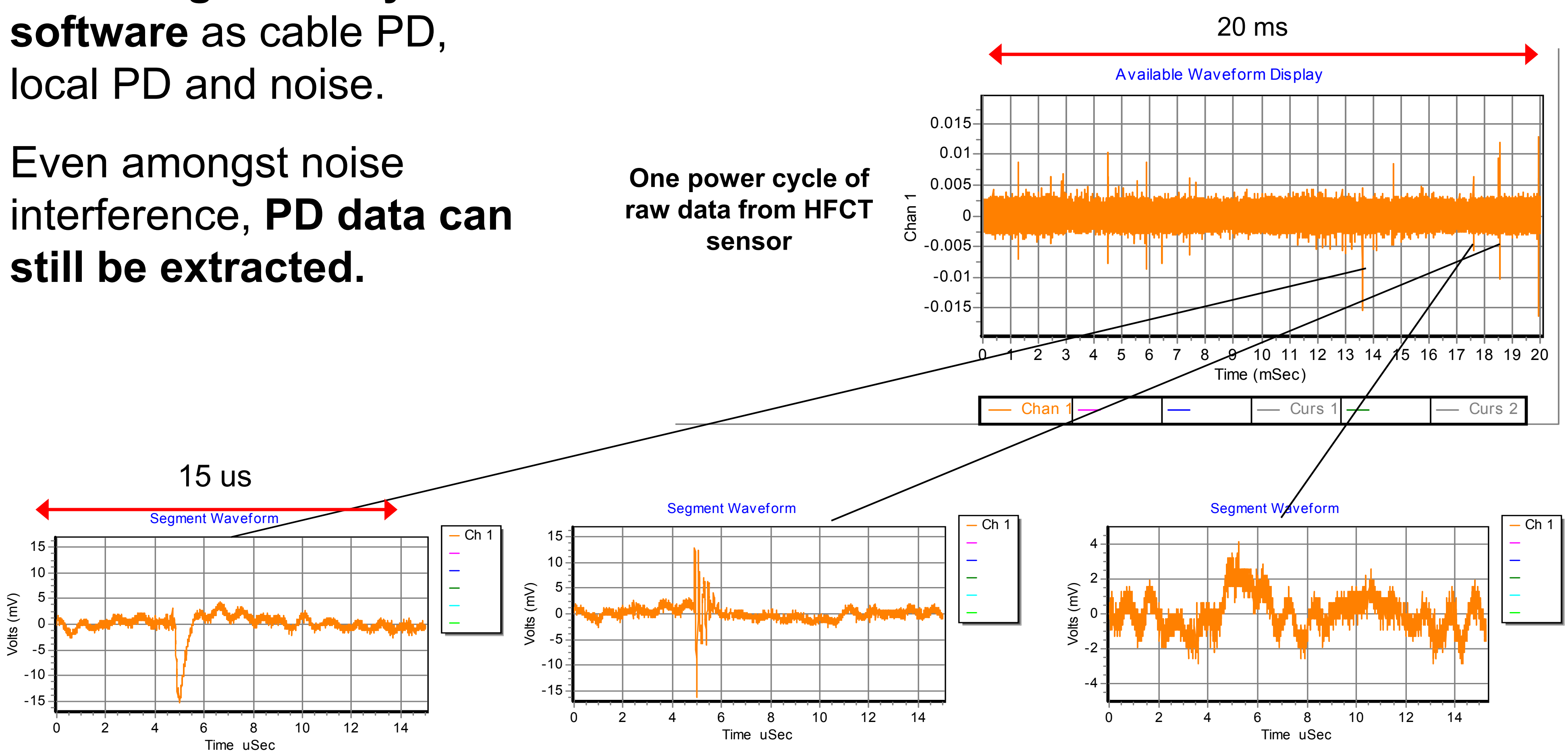
HVPD

HVPD Longshot™

On-line PD Testing of an 11kV Motor

PD Data Analysis

- Impulsive events **extracted and categorised by software** as cable PD, local PD and noise.
- Even amongst noise interference, **PD data can still be extracted.**



Cable PD Pulse: 16 mV, 1160 pC

Local PD Pulse: 15 mV, 24 dB

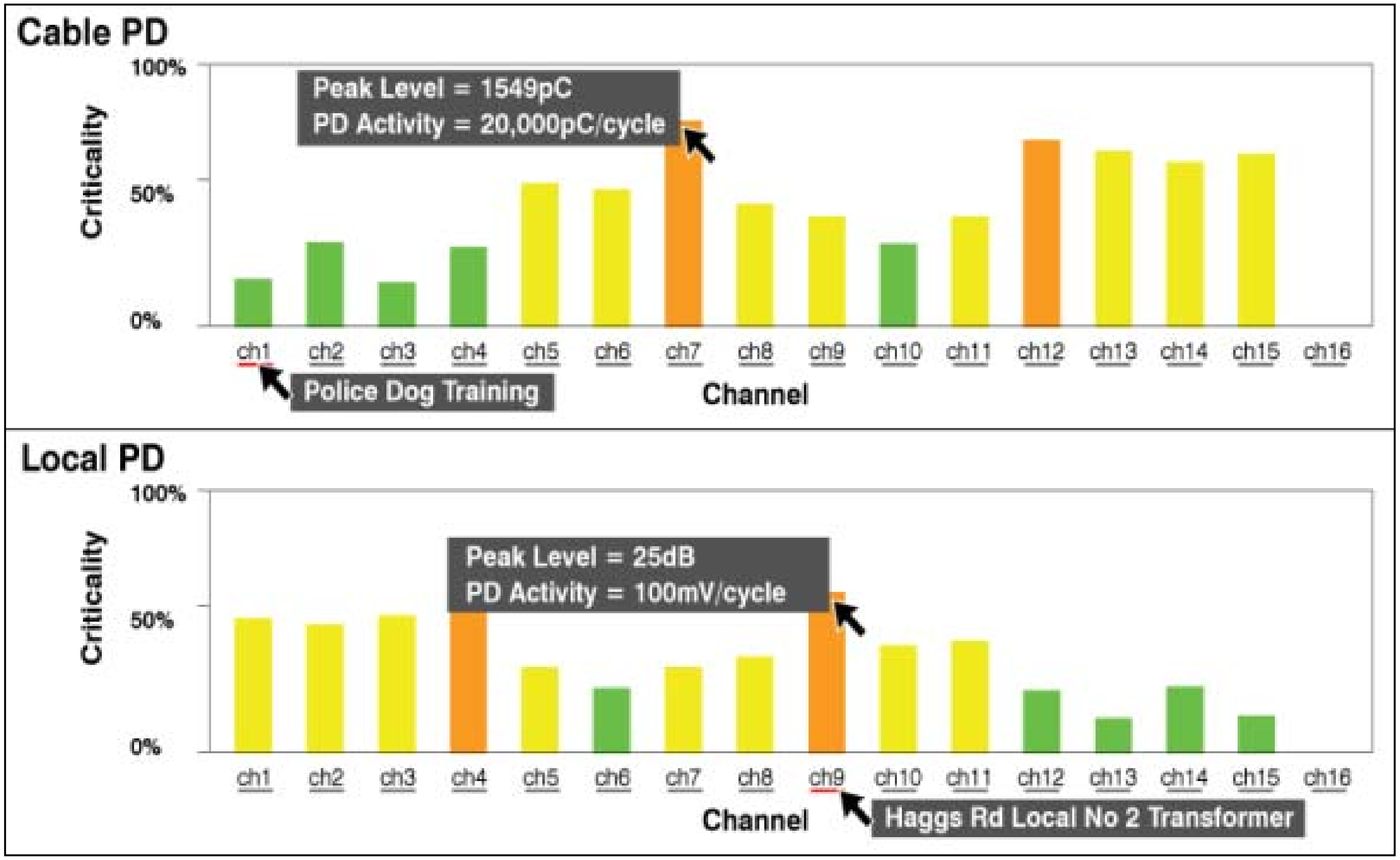
Noise Pulse: 6 mV

HVPD

Phase 3 – Temporary Monitoring HVPD Multi™ Portable 16-Channel OLPD Monitor

- 24/7 diagnostic portable OLPD monitoring technology for MV and HV Plant
- Measures, analyses and logs Cable PD, Local PD and Noise
- 'Knowledge-Rule' based PD criticality measurement (0–100)
- Remote access connection via LAN/Modem
- 16-Channel (HFCT/TEV/HVCC) with optional add-on 32x channel AA sensor modules

- Criticality league table
- Highlights most critical circuits
- Updated every 24 hours
- Link to data graphs
- Criticality algorithm, specific to plant



- Small PD-activity
- Moderate PD-activity
- Intensive PD-activity
- Critical PD-activity

HVPD

Phase 3 – Plant Condition Analysis

- Criticality league table
- Highlights most critical circuits
- Updated every 24 hours
- Link to data graphs
- Criticality algorithm, specific to plant

◉ Cable ○ Local

Circuit	Sensor	PD Peak (pC)	PD Activity (pC/cycle)	Criticality
Police Dog Training	HFCT	2671	4523	
Haggs Rd Local No 1 Transformer	HFCT	5375	9119	
Shawhom Crescent	HFCT	2546	2647	
Pollockshaws commercial centre	HFCT	1994	4924	
Rossendale Rd South	HFCT	1977	11990	
Green Park	HFCT	2286	3873	
145 Shawhill Rd tee Shawhill Rd	HFCT	2837	5202	
Craigholme School	HFCT	2046	2120	
Haggs Rd Local No 2 Transformer	HFCT	4200	4333	
Millwood Street	HFCT	4898	4898	
Shawmoss Rd	HFCT	697.4	922.9	
Wellgreen Court	HFCT	1094	1285	
Shawbridge Street South	HFCT	740.6	858.1	
Shawbridge Street	HFCT	1338	1455	
Rossendale Rd	HFCT	491	688.1	

◉ Last 24hrs ○ Last Week ○ Last Month ○ Entire Test Monitoring Period: 2/07/09 12:00pm - 3/07/09 12:00pm

- Small PD-activity
- Moderate PD-activity
- Intensive PD-activity
- Critical PD-activity

Phase 3 – Temporary Monitoring HVPD Mini™ Portable 4-Channel OLPD Monitor

- Low-cost 24/7 PD monitoring technology for MV cables, switchgear & other plant
- Incorporates up to 4x portable PD sensors
- Measures and logs both cable PD and local PD (PD magnitude & ‘count’ – no. of pulses)
- Stores up to 12 months of data on local flash memory
- Uploads PD data to server every 24 hours via GSM/GPRS Modem
- Compact, lightweight and easy to set up unit for portable installations

HVPD Mini™ Monitor

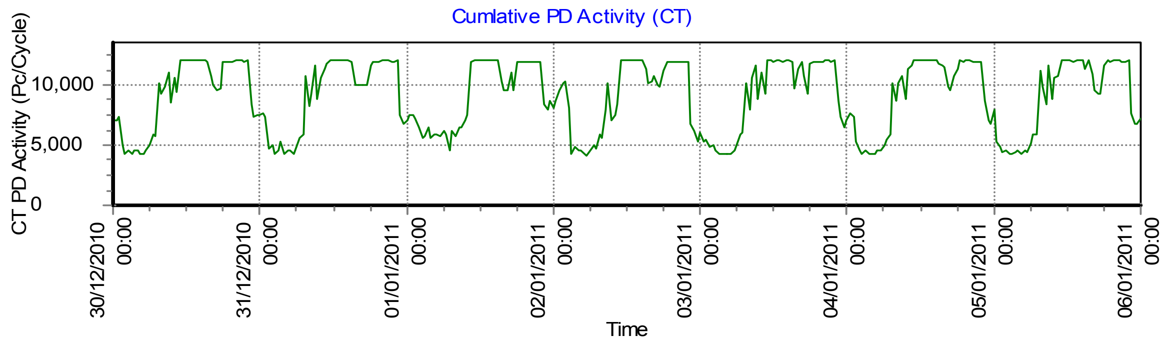
Example Installation

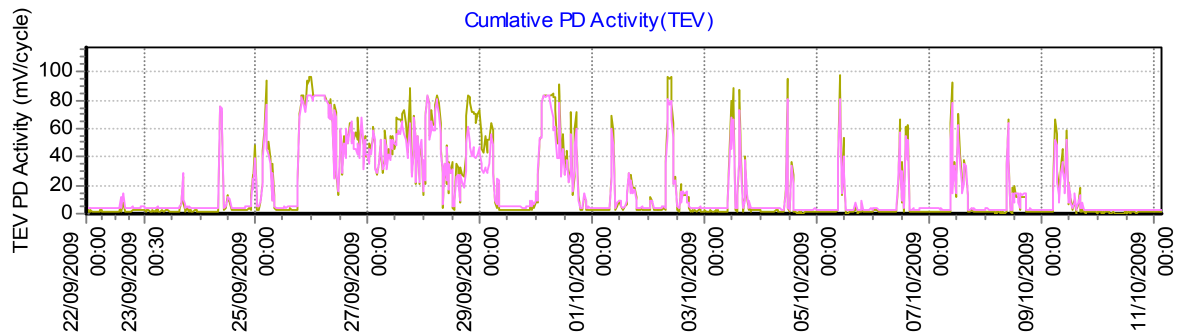
HVPD

HVPD Mini™ Monitor

Distributed TEV Sensors

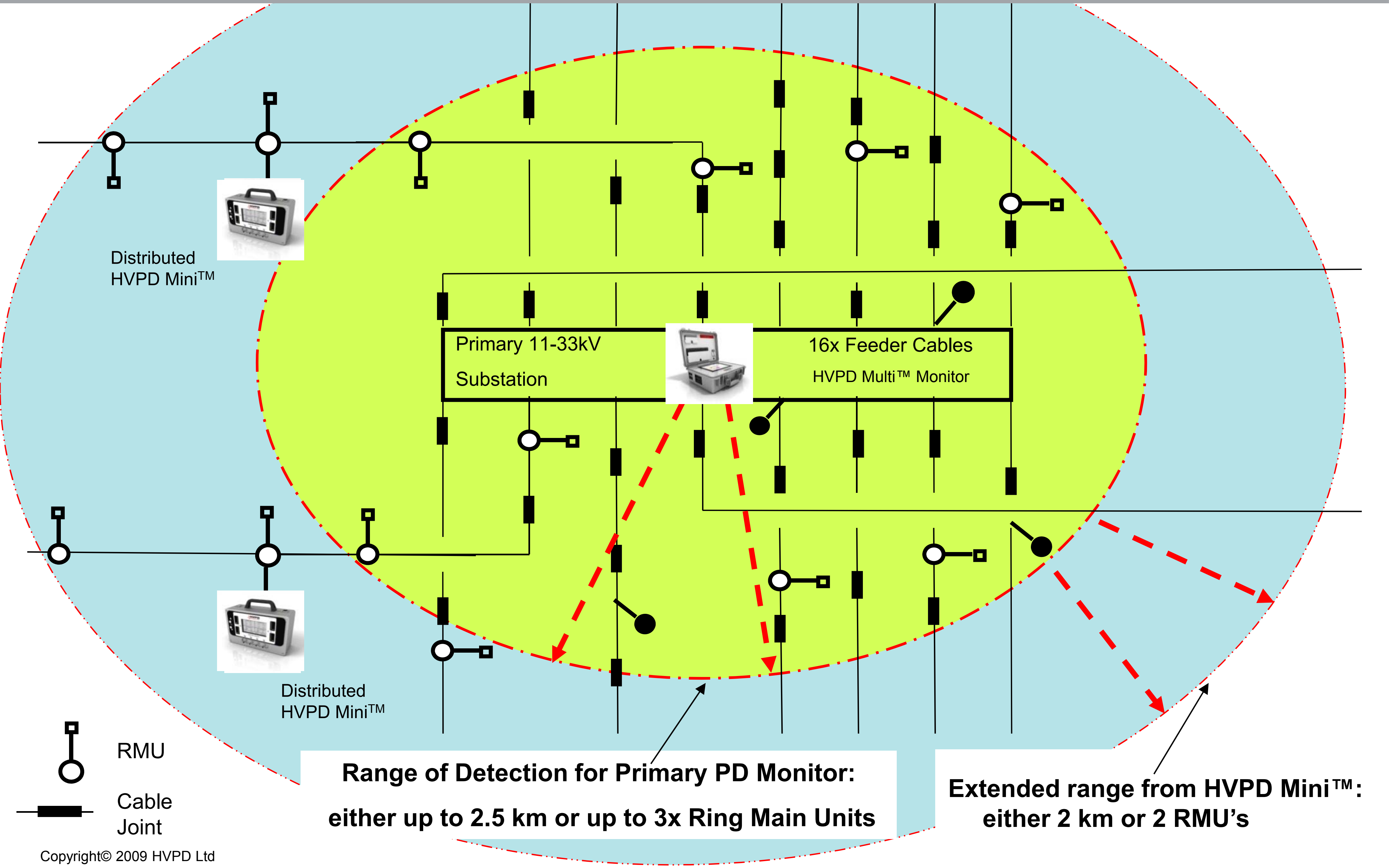
- Provides an early warning against incipient faults to be indicated through changes in PD activity over time.
- PD activity can vary in relation to load, local temperature and humidity.
- Distributed temperature and humidity modules monitor these variations in the substation.





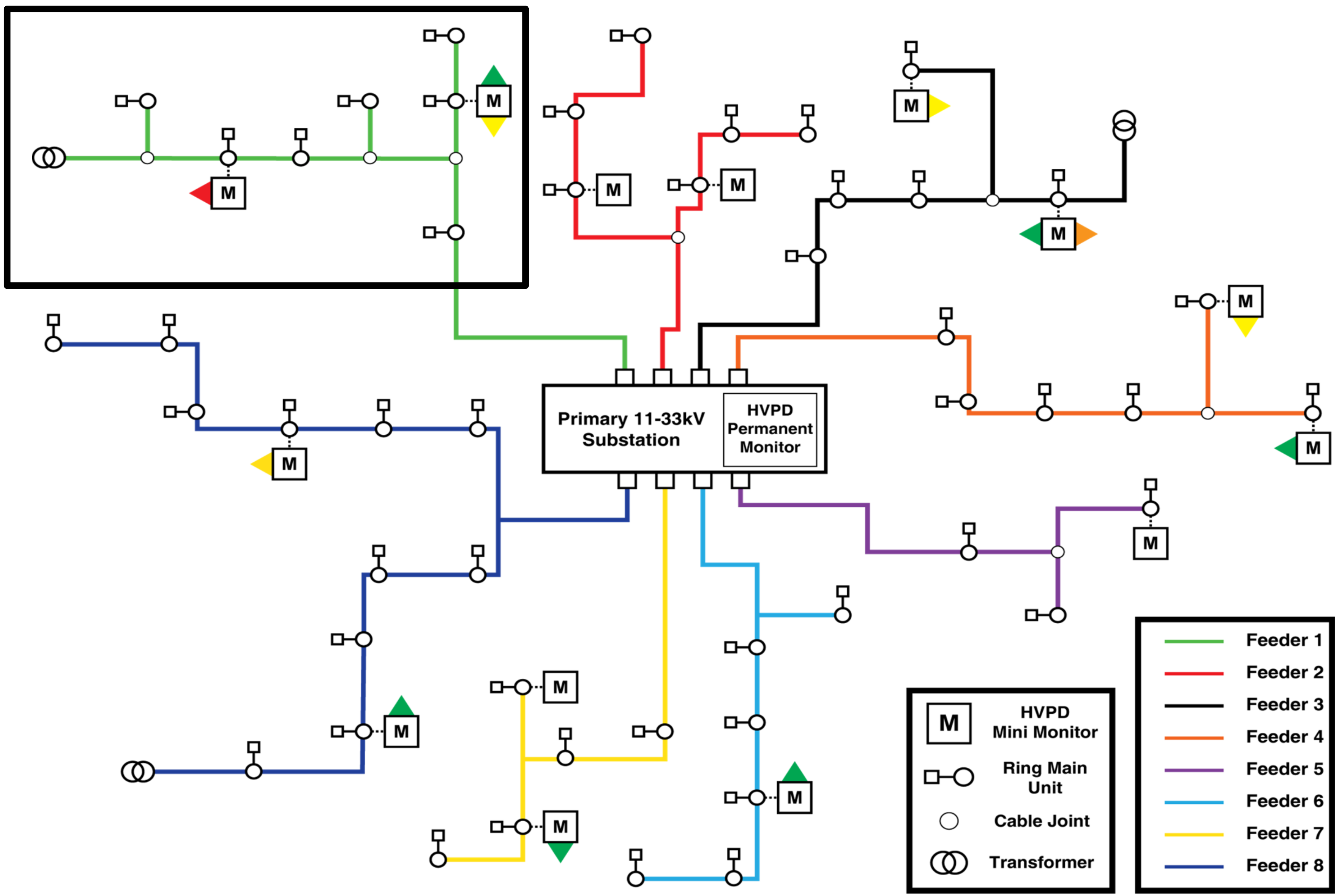
Combined OLPD Monitoring Solution

Primary Substation Monitor plus Distributed HVPD Mini™ Monitors

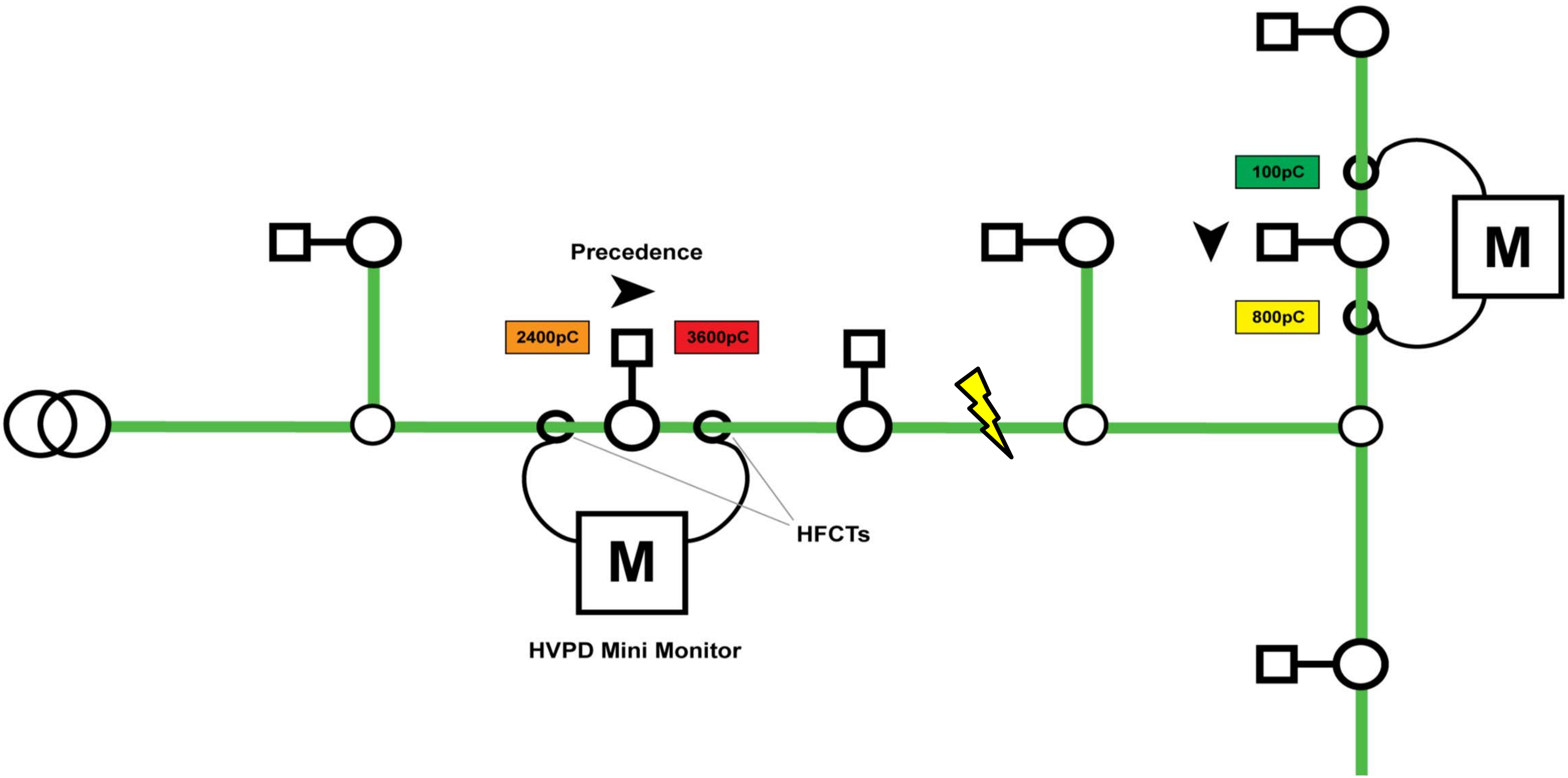


Combined OLPD Monitoring Solution

Primary Substation Monitor plus Distributed HVPD Mini™ Monitors



Precedence Detection using the HVPD Mini™ OLPD Monitor

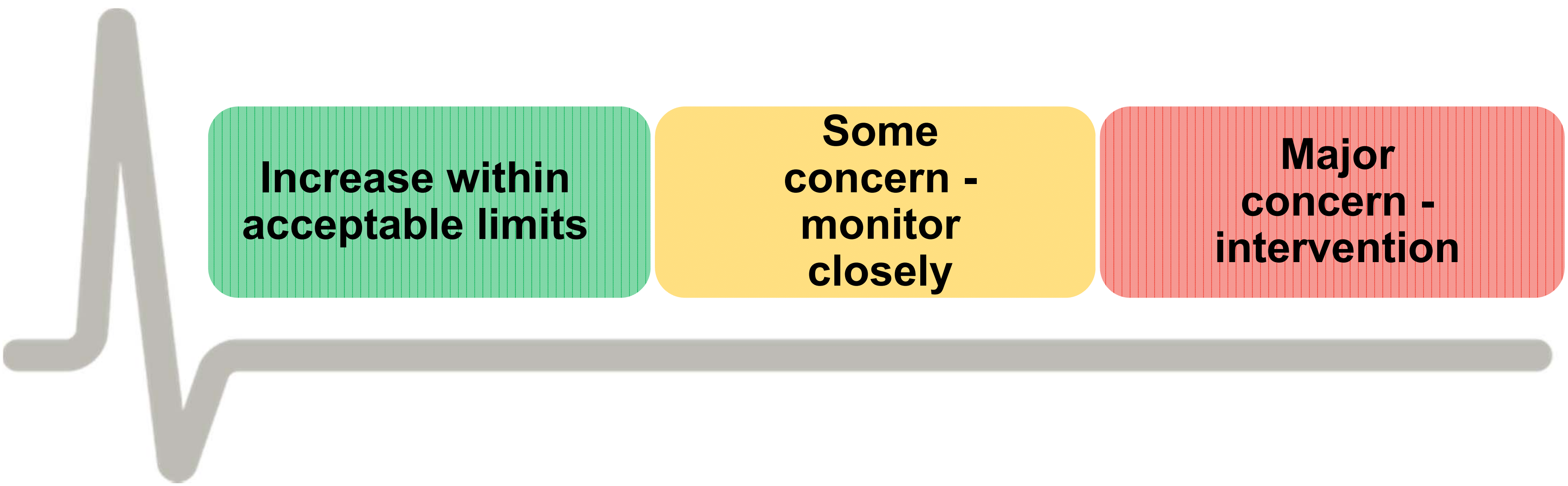


Phase 4 – Permanent Monitoring - HVPD Multi™ Permanent 16-Channel OLPD Monitor

- 24/7 monitoring of PD in switchgear, cables and rotating HV machines
- Non-intrusive, inductive sensors
- Remotely accessible with GPRS/3G modem
- Onboard automatic analysis software provides differentiation of all PD pulses from noise
- Can monitor up to 4x rotating HV machines

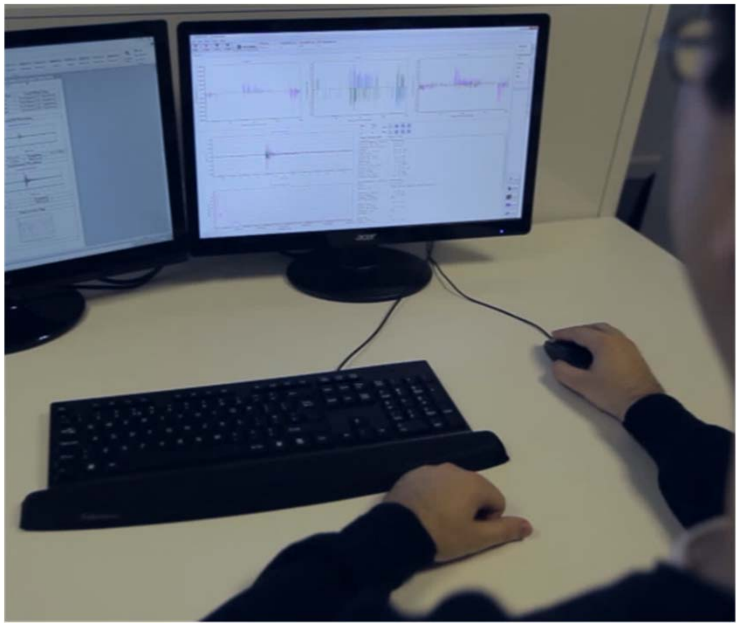
HVPD Multi™ Permanent Monitor

- The HVPD-Multi™ Monitor does not provide automated alarms but provide ‘*flags’* for further engineer investigation
- These ‘flags’ can signal an increase in either PD level or PD activity but can also be caused as a result of network switching
- Each ‘flag’ is investigated by HVPD engineers before a diagnostic decision is made regarding preventative maintenance interventions.



INSTALLATION

DATA ANALYSIS



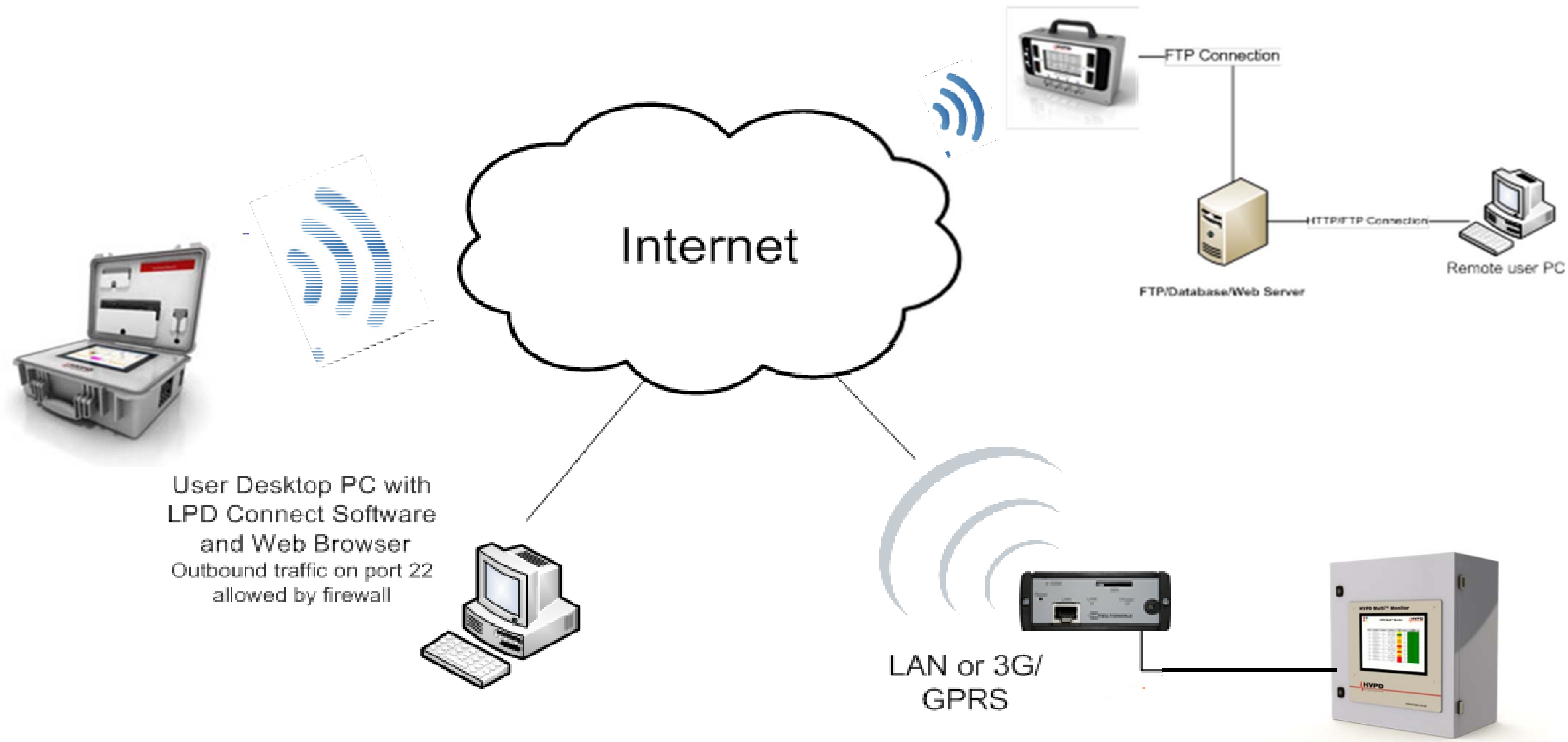
ADJUSTMENT

DAY 1

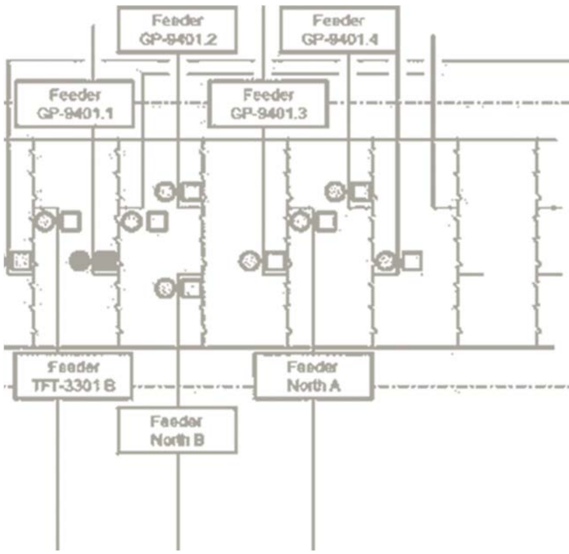
DAILY DATA ANALYSIS

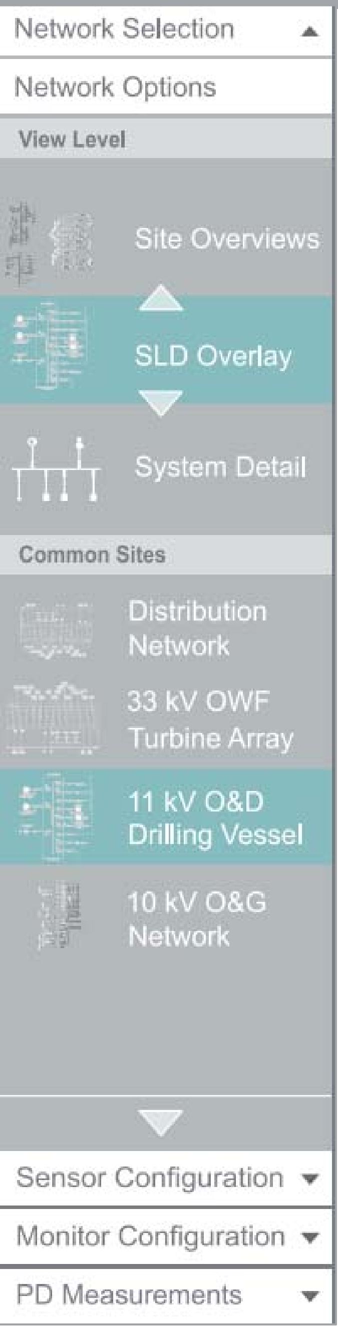
DAY 30

Phase 3 – Remote Access



EXAMPLE OF HV NETWORK OLPD MONITORING SYSTEM USER INTERFACE BASED ON THE CLIENT'S HV NETWORK SINGLE-LINE DIAGRAM (SLD)



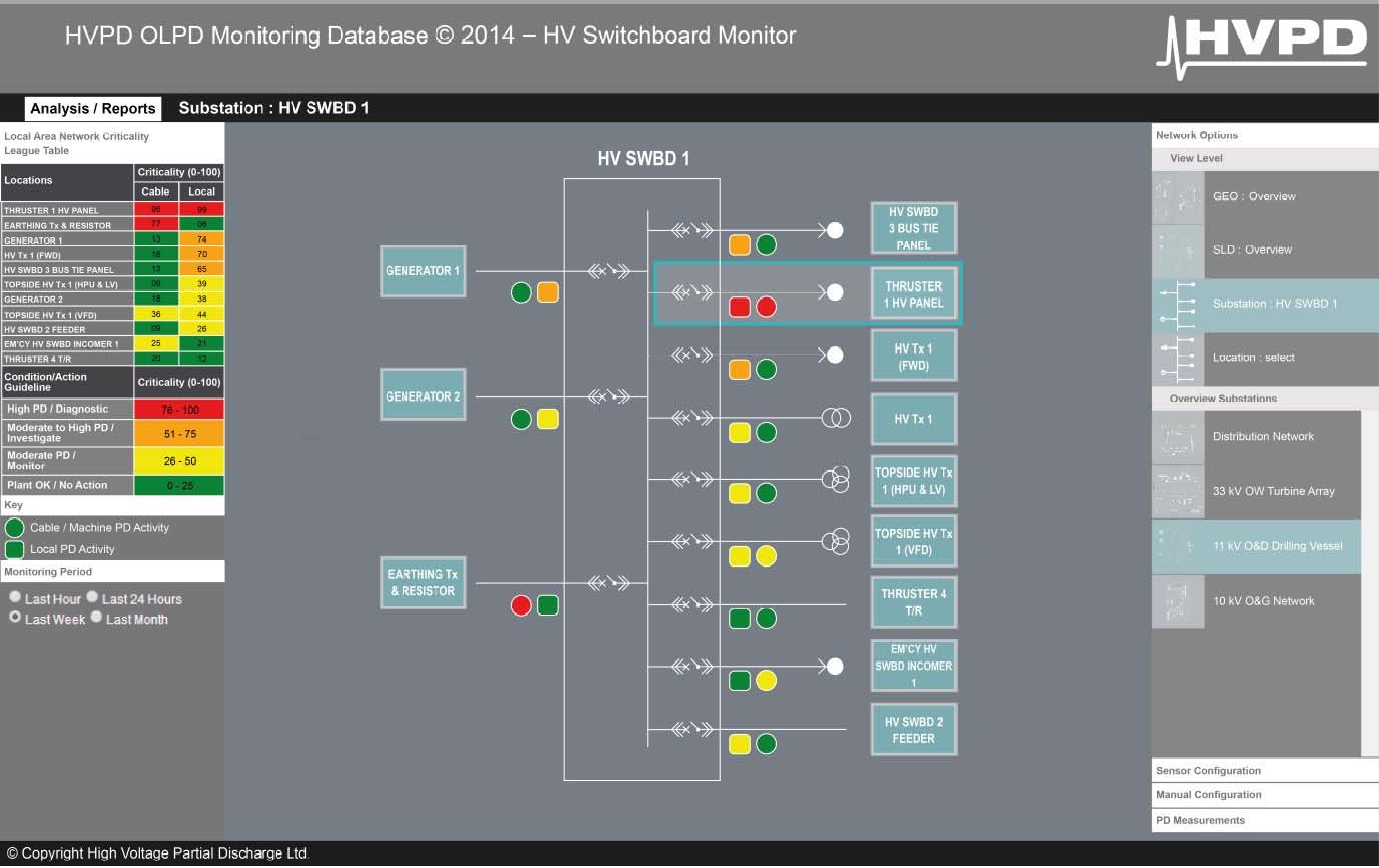


Presents data hierarchically using a 3-level interface:

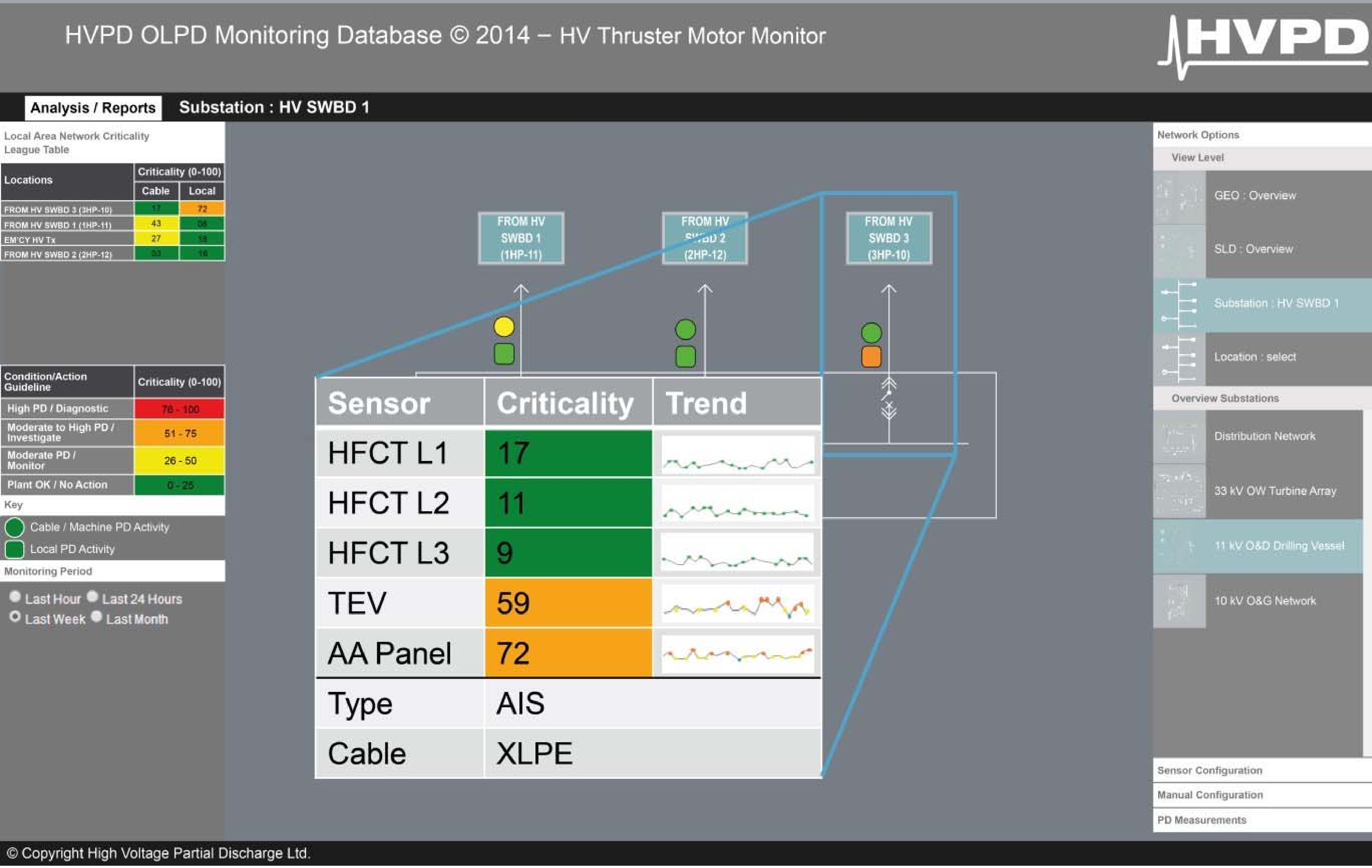
- 1^{st} level: all sites/vessels
- 2^{nd} level: one site/vessel (entire SLD)
- 3^{rd} level: one switchroom

Complete Network Monitoring Database Interface

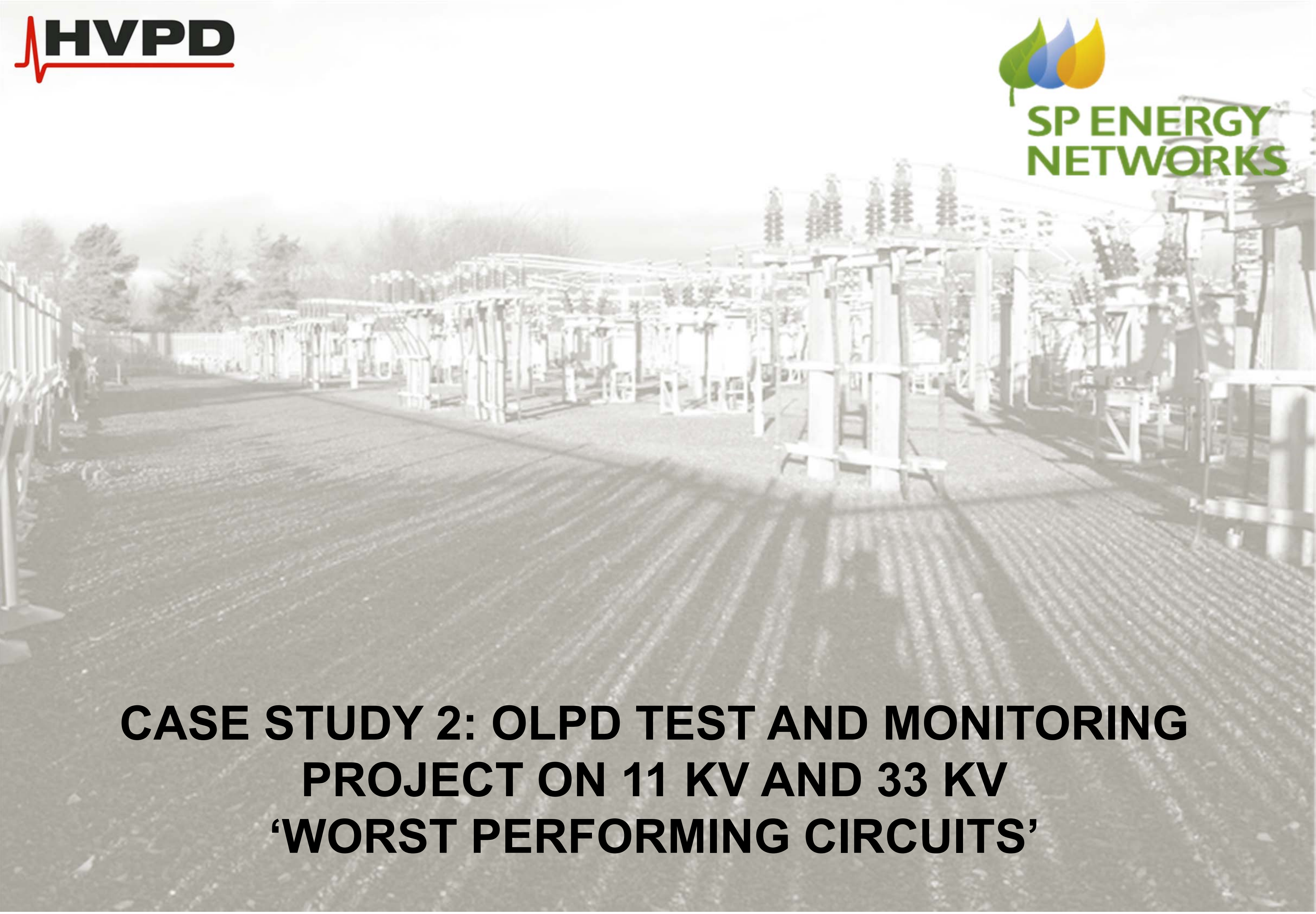
Complete Network Monitoring Database Interface



Complete Network Monitoring Database Interface



EXAMPLES OF DEPLOYMENT OF PD TESTING IN ASSET MANAGEMENT SYSTEMS



CASE STUDY 2: OLPD TEST AND MONITORING PROJECT ON 11 KV AND 33 KV 'WORST PERFORMING CIRCUITS'

Case Study: Introduction

- ‘Worst Performing Circuits List’ focuses on replacing cable sections with the highest number of faults.
- Due to budget, it is only possible to replace a small percentage of circuits a year.
- Limited monitoring budgets need to be used on circuits with the highest risk of failure.

Case Study: Average Number of Faults per 100 km per Annum

- Network A 11 kV: 6.91 faults per 100 km per annum
- Network B 11 kV: 13.66 faults per 100 km per annum
- Network A & Network B 33 kV: 11.5 faults per 100 km per annum

Summary Data of 11 kV Worst Performing Circuits in Networks A & B (2004-2008)

No. of Circuits	Total Length	Average Circuit Length	Average faults per annum (Av. 5 years 2004 to 2008)	Faults per 100 km p.a.
Network B - 86	530 km	6.160 km	72.4	13.66
Network A -122	970 km	7.950 km	67.0	6.91
Total - 208	***1500 km***	***7.210 km***	***139.4***	***9.30***

Summary Data of 33 kV Worst Performing Circuits in Networks A & B (2002-2008)

No. of Circuits	Total Length (est.)	Average Circuit Length (est.)	Average faults per annum (Av. 7 years 2002 to 2008)	Faults per 100 km p.a.
Network B– 51	357 km	7.000 km	42.1	11.80
Network A – 62	434 km	7.000 km	48.6	11.19
Total – 113	***791 km***	***7.000 km***	***90.7***	***11.47***

Case Study: Suitability of Cable Terminations for OLPD Testing

- The suitability of cable terminations for the attachment of the HFCT sensors is the main restriction on the widespread application of the OLPD technology.
- Only around 40% of the terminations on the customer's networks can be considered as 'suitable'.
- For future testing, it has been suggested that the customer modify solidly bonded terminations.

Case Study: Test Locations and Methodology

- OLPD tests were carried out at substations with worst historical failure rates.
- HVPD Mini™ Portable was installed at a number of substations.
- The spot testing was carried out using HVPD's OLPD test technology.

10% of all of 39x 33kV cable circuits tested are the **Red Condition Category**.

No. of Circuits	Condition	%
26	Discharge within acceptable limits	66
7	Some concern, monitoring recommended	18
2	Some concern, regular monitoring recommended	5
4	Major concern, locate PD and then repair or replace	10

4% of all 25x 11kV circuits tested in this project are in the **Red Condition Category**.

No. of Circuits	Condition	%
18	Discharge within acceptable limits	72
4	Some concern, monitoring recommended	16
2	Some concern, regular monitoring recommended	8
1	Major concern, locate PD and then repair or replace	4

Case Study: Worst Performing Circuits

Criticality Number	Circuit	Comments	Peak PD Value	Cumulative PD Level	OLPD Criticality (%)	Maintenance Action
1.	Circuit 18	Large PD on this circuit	3600pC	195 nC/Cycle	83.2	Major concern, locate PD and then repair or replace.
2.	Circuit 62	Large cable PD	4000pC Cable Box PD	62nC/Cycle 1.2V/Cycle	79.7	
3.	Circuit 28	No cable PD Local PD is 36dB	36dB	1.1 V/Cycle	78.3	
4.	Circuit 26	No cable PD Local PD 35dB	35dB	1.4 V/Cycle	76.4	
5.	Circuit 14	Some outdoor PD	25dB Local PD	24.6 V/Cycle	*Outdoor Survey*	
6.	Circuit 32	No Cable PD Local 34dB	34dB	1.0 V/Cycle	73.3	Some concern, repeat test and regular monitoring recommended.
7.	Circuit 50	Cable box PD TEV levels at 35dB	1600pC & 35dB	4.2 nC/Cycle 0.7 V/Cycle	70.1	
8.	Circuit 63	Cable PD & Cable Box, 30dB	1200pC 30dB Cable Box	<10 nC/Cycle 1.5V/Cycle	62.2	
9.	Circuit 36	No Cable PD Local 27dB	27dB	1.6 V/Cycle	57.7	
10.	Circuit 21	Large PD on this circuit	3800pC	21 nC/Cycle	56.3	Some concern, re-test within 6 months.
11.	Circuit 61	Low-Medium Level Cable PD	1600pC	52nC/cycle	55.8	
12.	Circuit 40	Medium-High Cable PD	4000pC	<10 nC/Cycle	55.5	
13.	Circuit 37	No Cable PD Local 23dB	23dB	1.1 V/Cycle	46.6	
14.	Circuit 31	No Cable PD Local 25dB	25dB	0.6 V/Cycle	45.7	
15.	Circuit 46	Medium Cable PD	2500pC	<10 nC/Cycle	38.2	
16.	Circuit 27	No cable PD Local PD 20dB	20dB	0.8 V/Cycle	37.4	
17.	Circuit 43	Medium-High Cable PD	3500pC	<10 nC/Cycle	37.1	
18.	Circuit 12	Incipient PDof 2000pC measured at Circuit 12	2000pC	<10 nC/Cycle	29.1	
19.	Circuit 11	PD on circuit, no location	1000pC	40.4 nC/Cycle	28.0	
20.	Circuit 23	Red phase is the source	1400pC	<10 nC/Cycle	25.2	

- Continuous OLPD monitoring of the medium and high PD sites (the highest risk of failure).
- Retesting of all of the ‘TOP 20’ circuits within the next 3-6 months.
- Deploy monitoring units at the worst performing substations over an initial 3-month monitoring period.
- For the 44x circuits which have lower, a repeat ‘spot’ test within 12 months would be prudent.
- A larger survey of a minimum 100x 11 kV and 100x 33 kV feeders should be carried out to provide a more statistically valid data set.

HVPD

RTA

هيئة الطرق والمواصلات
ROADS & TRANSPORT AUTHORITY

CASE STUDY 3: OLPD TESTING AND CABLE MAPPING OF 33 KV XLPE CABLES IN THE DUBAI METRO NETWORK

Case Study: Introduction

- OLPD testing was carried out in response to a number recent faults* of 33 kV cable joints within the customer’s network.
- The faults led to disruption of the power supply to the Metropolitan rail system.
- The purpose of the testing was to measure and locate any PD activity within the cables with particular focus on the cable joints.

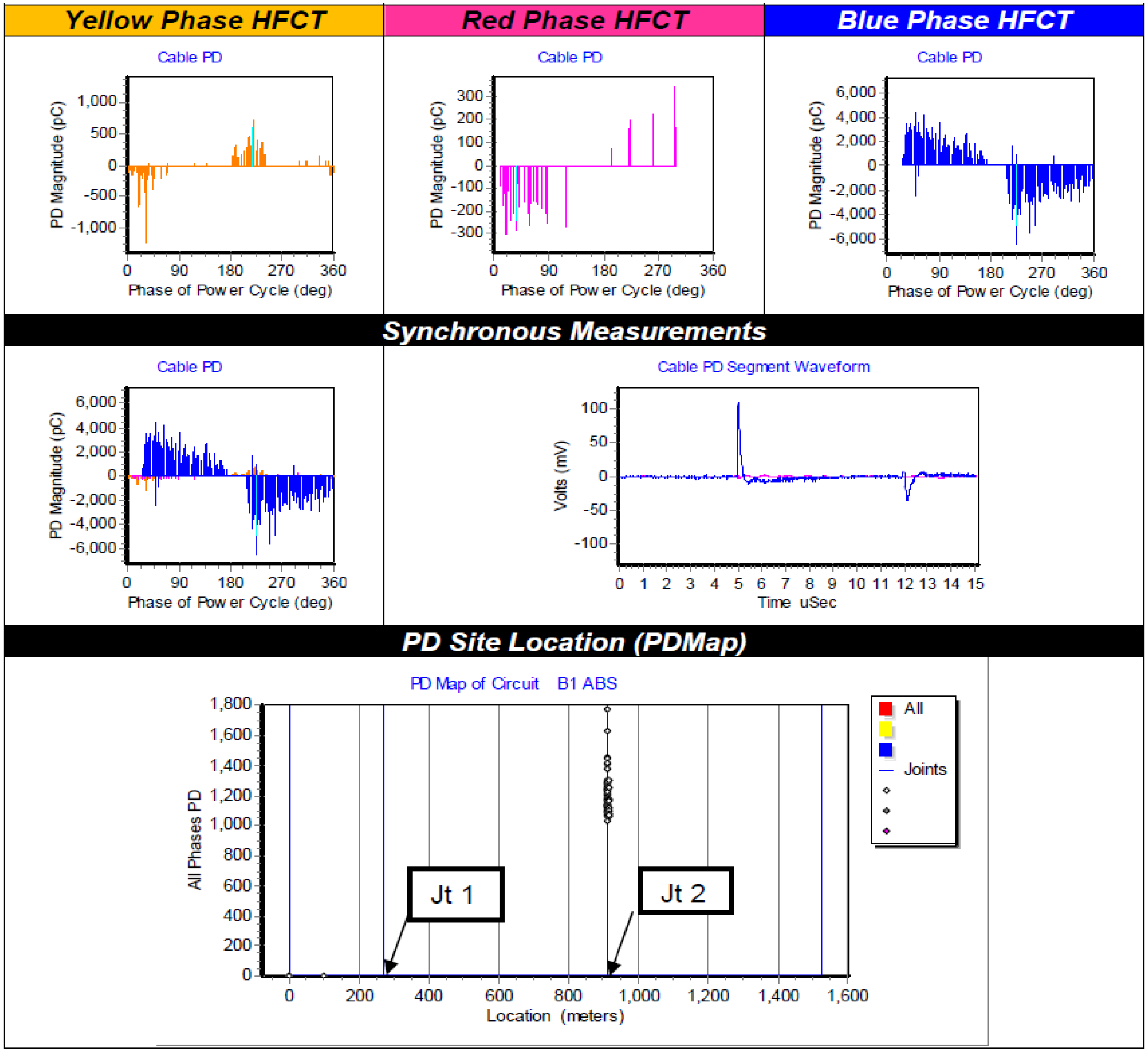
** It should be noted that this was a newly installed cable system that had been in-service for just over 12 months before the faults started to occur.*

Case Study : OLPD Testing Equipment and Methodology

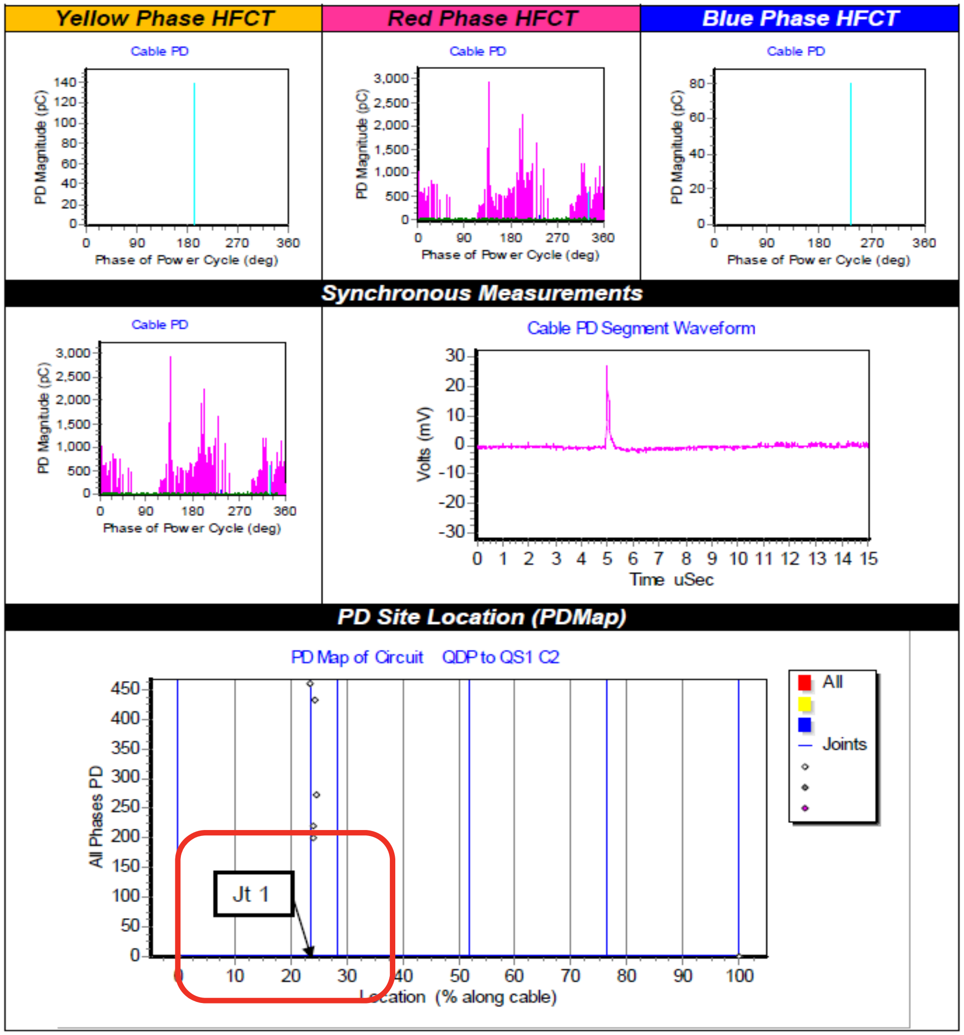
- On-line Cable PD Mapping using the HVPD Longshot™ test unit and Portable transponder.
- Tests started with calibration testing with pulse injection HFCTs.

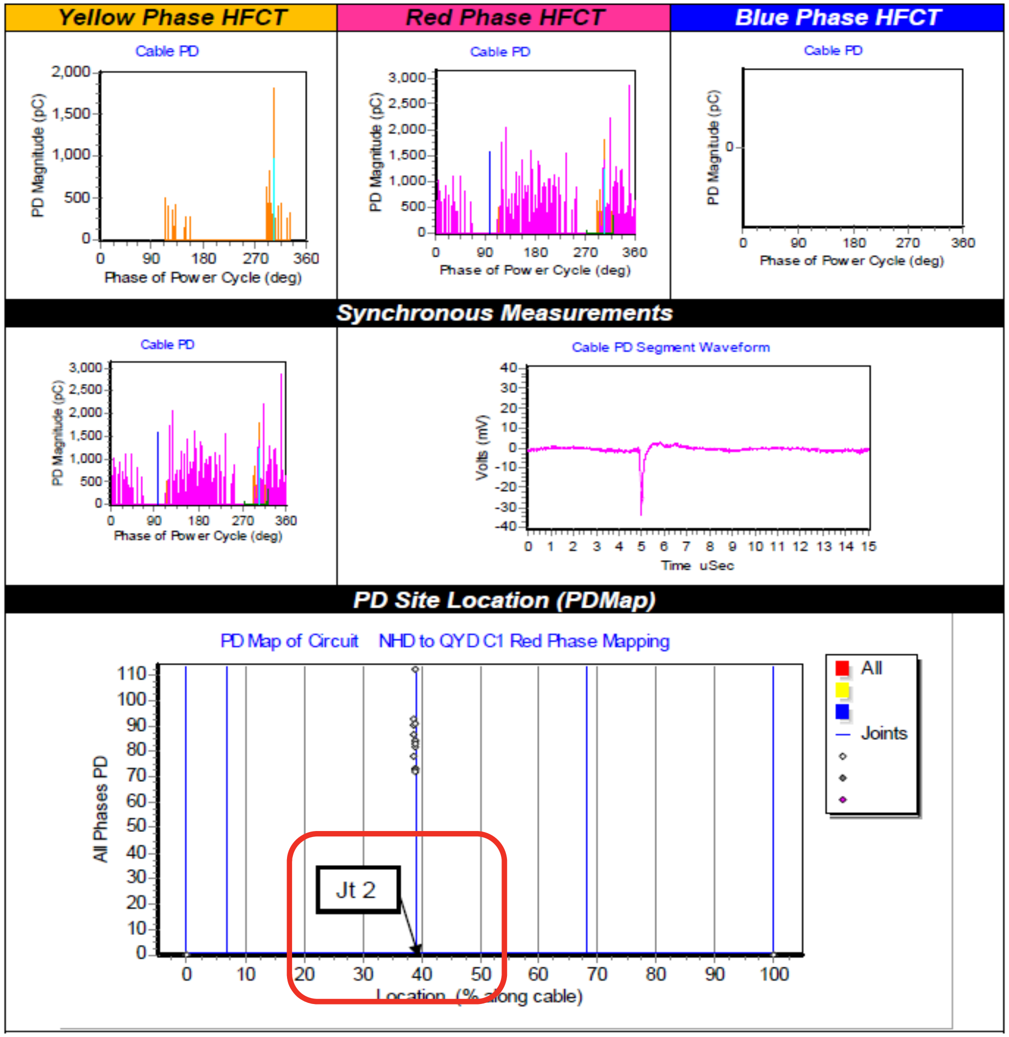
Case Study: Test Results

- Cable PD signals have been detected on Blue Phase with cross-talk (lower magnitude) on Red and Yellow phases.
- The source of PD was located to Joint Number 2 (Jt2) using the on-line PD mapping technique.
- The faulty joint on this cable was replaced and re-tested using the HVPD Longshot™ test unit to verify the repair was good



Case Study: Test Results





PD located to joints on Red Phase

Case Study: Top 20 'Worst Performing Circuits'

- Out of the 50+ circuits tested, Major PD was detected within cable accessories on the three of the circuits (6%) as shown in RED in the Table below.
- The levels of discharges detected put these 33 kV cables into RED category, "Major concern, locate PD and then repair or replace".

Criticality Number	Circuit	Comments	Peak Cable PD Level (pC)	Local PD Level (dB)	Cumulative Cable PD Level (nC/cycle)	OLPD Criticality (%)	Maintenance Action
1.	DUB to MPS1 C2	B Phase	25888	<10	247	97.4	**Major concern, locate PD and then repair or replace.**
2.	ABS to AH C2	B / Y Phase	9729	<10	120	90.3	
3.	BUR to HCC C2	B / Y Phase	3781	<10	12.3	78.7	
4.	BUR to HCC C1	B / Y Phase	3245	<10	7.9	78.1	
5.	ABS to AH C1	B / Y Phase	2920	<10	14.4	77.4	
6.	NHD to QYD C2	R Phase	2849	<10	15.0	76.2	
7.	ALQ to AHS C2	B Phase	1733	<10	4.6	70.6	**Some concern, repeat test and regular monitoring recommended.**
8.	MPS3 to BNS C2	R / B Phase	1337	<10	6.4	65.5	
9.	NHD to QYD C1	R Phase	887	<10	8.8	47.8	
10.	HCC to CRK C1	Y / B Phase	759	<10	2.5	39.2	
11.	AHS to SLD	Y / R Phase	705	<10	3.1	38.5	
12.	STD to ABH	Y Phase	238	<10	1.0	24.1	**Re-test in 12 months.**
13.	ALR to BNS C1	B Phase	184	<10	0.9	18.6	
14.	ALR to BRJ	No PD detected	0	<10	0	0	
15.	ALG to PMD	No PD detected	0	<10	0	0	
16.	ALG to KBW	No PD detected	0	<10	0	0	
17.	AQD to AQ2	No PD detected	0	<10	0	0	
18.	JDD to CRK	No PD detected	0	<10	0	0	
19.	ODM to JDF C1	No PD detected	0	<10	0	0	
20.	ODM to JDF C2	No PD detected	0	<10	0	0	

CONCLUSIONS

- A combination of both on-line and off-line partial discharge testing and OLPD monitoring systems for in-service plant helps produce 'risk-of-failure' indices that support condition-based asset management decisions

- By replacing or repairing cables or plant that has high levels of OLPD activity (and therefore a higher risk of failure) the MV and HV plant owner can target their maintenance budgets to those assets in most need whilst simultaneously reducing the risk of HV insulation faults on their network

- With the advent of recent developments in wideband OLPD monitoring, such as with the HVPD Complete HV Network Monitoring Solution, the entire installed HV network, including switchgear, cables and remotely connected HV plant can be assessed under normal working conditions, without the need for an outage

- Real-time condition monitoring (CM) such as this, combined with a proactive, preventative maintenance intervention strategy can help reduce the risk of unplanned outages caused by HV insulation failure

End of Presentation

Thank you for your time

Q&A?