On-line Partial Discharge (OLPD) Monitoring of Complete High Voltage (HV) Networks in the Oil & Gas Industry

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PROGRAMME

1. On-line Partial Discharge (OLPD) Testing and Monitoring of Rotating High Voltage (HV) Machines in the Oil & Gas Industry

2. ***On-line vs Off-line*** Partial Discharge Testing of Line-Fed HV Motors and Generators

3. Remote OLPD monitoring of ***Ex/ATEX*** **HV motors** using wideband HFCT sensors at the central switchboards

4. OLPD Testing and Monitoring of ***Variable Speed Drive (VSD)*** HV Motors

5. ***Case Studies*** from HVPD's recent OLPD Test and Monitoring Projects in the Worldwide Oil & Gas Industry

PRESENTATION I

On-line Partial Discharge (OLPD) Monitoring of Complete High Voltage (HV) Networks in the Oil & Gas Industry

PRESENTATION I - CONTENTS

- Introduction to HVPD Ltd
- Introduction to Partial Discharge (PD)
- On-line Partial Discharge (OLPD) sensors for rotating high voltage (HV) machines and complete HV networks
- Remote OLPD monitoring of line-fed Ex/ATEX HV motors and other plant from the central switchboards
- HV network OLPD monitoring database user interface options

- HVPD are experts in the field of on-line partial discharge (OLPD) technology and now have over 20 years of experience in the OLPD testing of in-service high voltage (HV) cables, switchgear, transformers and motors/generators.
- We supply portable and permanent OLPD diagnostic test and continuous OLPD monitoring solutions, and a complimentary range of on-site services, training and monitoring services.
- We have Five (5) main market sectors: Oil & Gas, Renewables, Transmission & Distribution, Shipping and Generation.

[redacted]

Oil & Gas

We specialise in onshore and offshore central remote on-line partial discharge monitoring and testing in Ex zones. Main projects include testing and monitoring of:

- Motors and generators
- Cables and cable accessories
- Switchgear
- Power Transformers

OEM:

SIEMENS

Schneider Electric

Operators:

bp

Chevron

ExxonMobil

DOLPHIN ENERGY دولفين للطاقة

[redacted]

Some of HVPD's Customers in 2013

VATTENFALL

Seadrill

SOHAR ALUMINIUM صحار ألمنيوم

Schneider Electric

الشركة السعودية للكهرباء
Saudi Electricity Company
طاقة مثمرة

ALSTOM

TATA

hongkong electric 港燈 HK Electric

Shell

Chevron

SCOTTISHPOWER

Stena Drilling
CARE, INNOVATION & PERFORMANCE

bp

DONG energy

RWE npower renewables

SIEMENS

DOLPHIN ENERGY دولفين للطاقة

HVPD

Some of HVPD's Oil & Gas Customers in 2013

SOHAR ALUMINIUM صحار ألمنيوم ALSTOM Schneider Electric Chevron SIEMENS

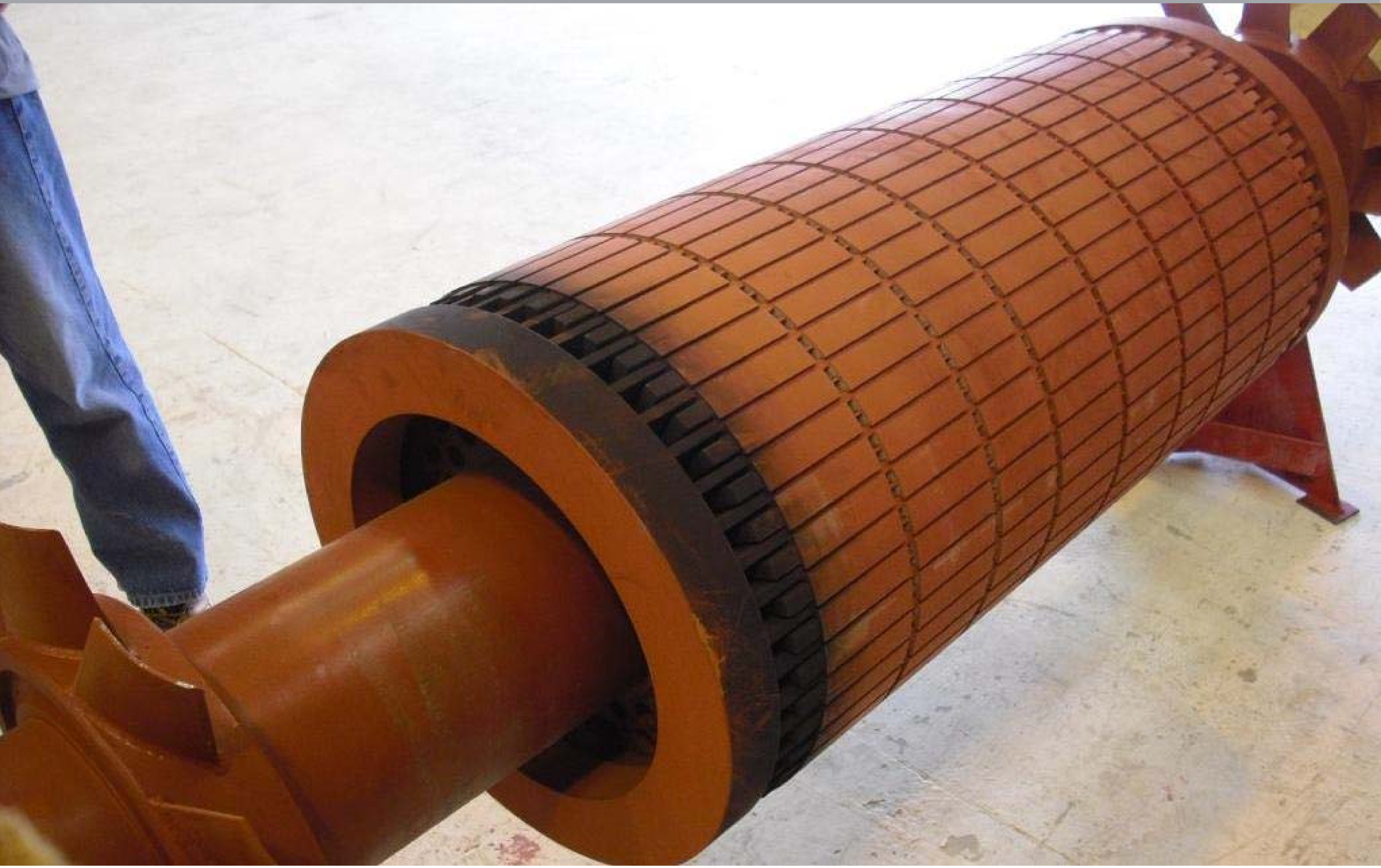
What is partial discharge?

"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

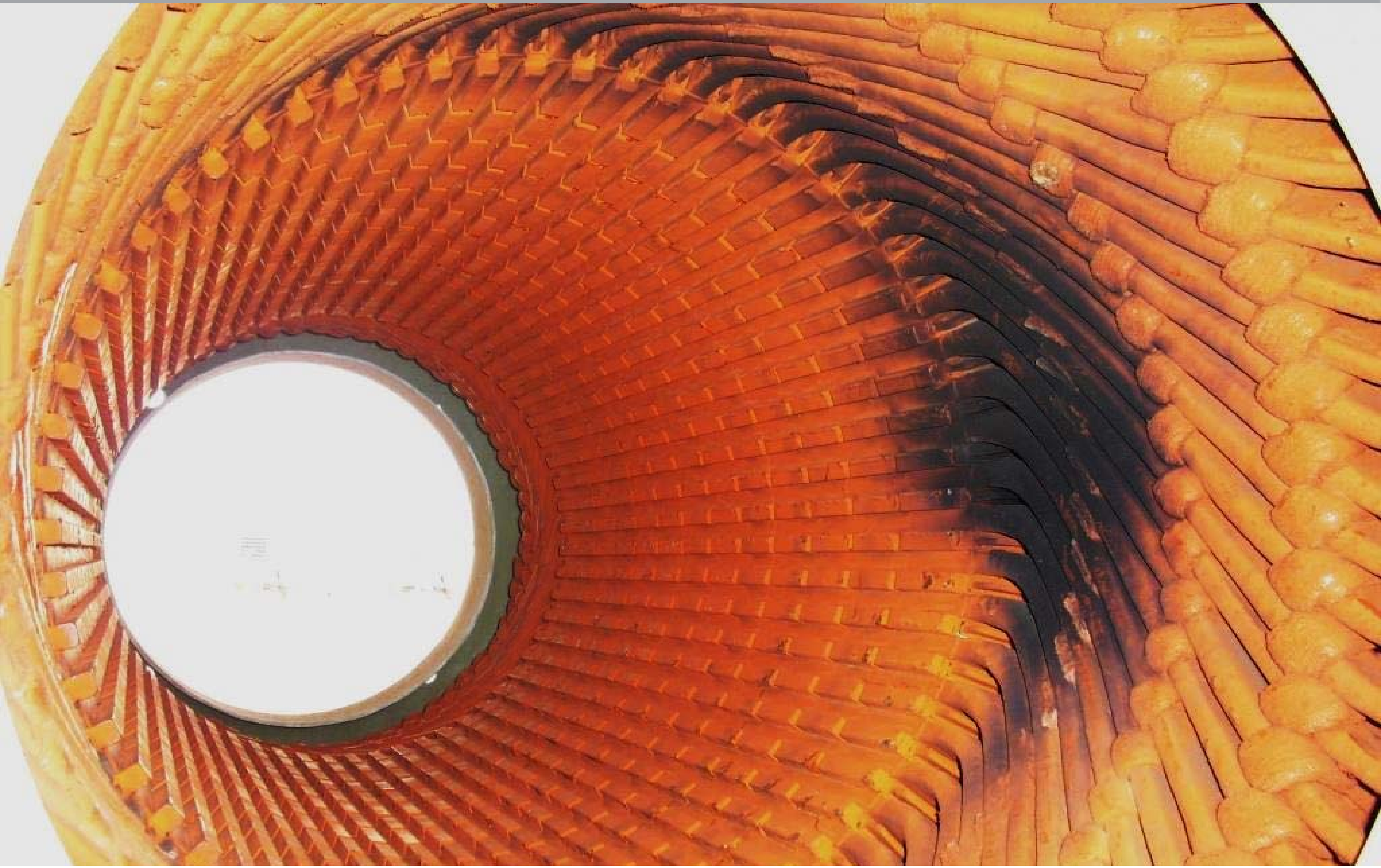
Why test for partial discharge?

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.

10 kV Amine Circulation Pump Rotor after an in-service failure of the stator



10 kV Amine Circulation Pump Stator
Stator HV Insulation failure occurred where the 'slot section' meets the 'end winding'

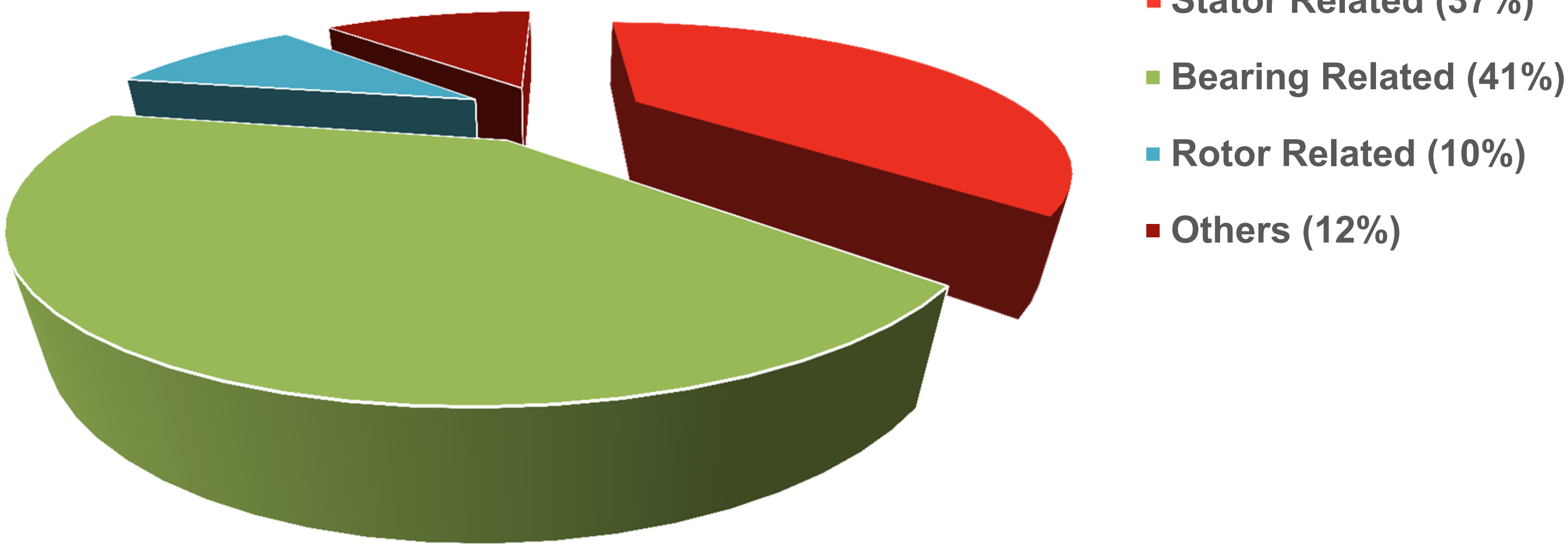


ON-LINE PARTIAL DISCHARGE

- OLPD testing refers to the testing of ***in-service*** high voltage (HV) cables and plant (including both static and rotating plant).
- The OLPD technique detects, locates and monitors partial discharge activity within the HV plant insulation, ***without the need to de-energise the plant.***
- The assessment of the health of HV network can thus be made with ***minimal disruption to operations and cost***.
- Equipment is tested under ***both normal (and abnormal) working conditions***, 24 hours per day, 365 days a year.
- OLPD diagnostics are an essential tool for the effective implementation of ***condition-based maintenance (CBM)*** techniques within HV power networks.

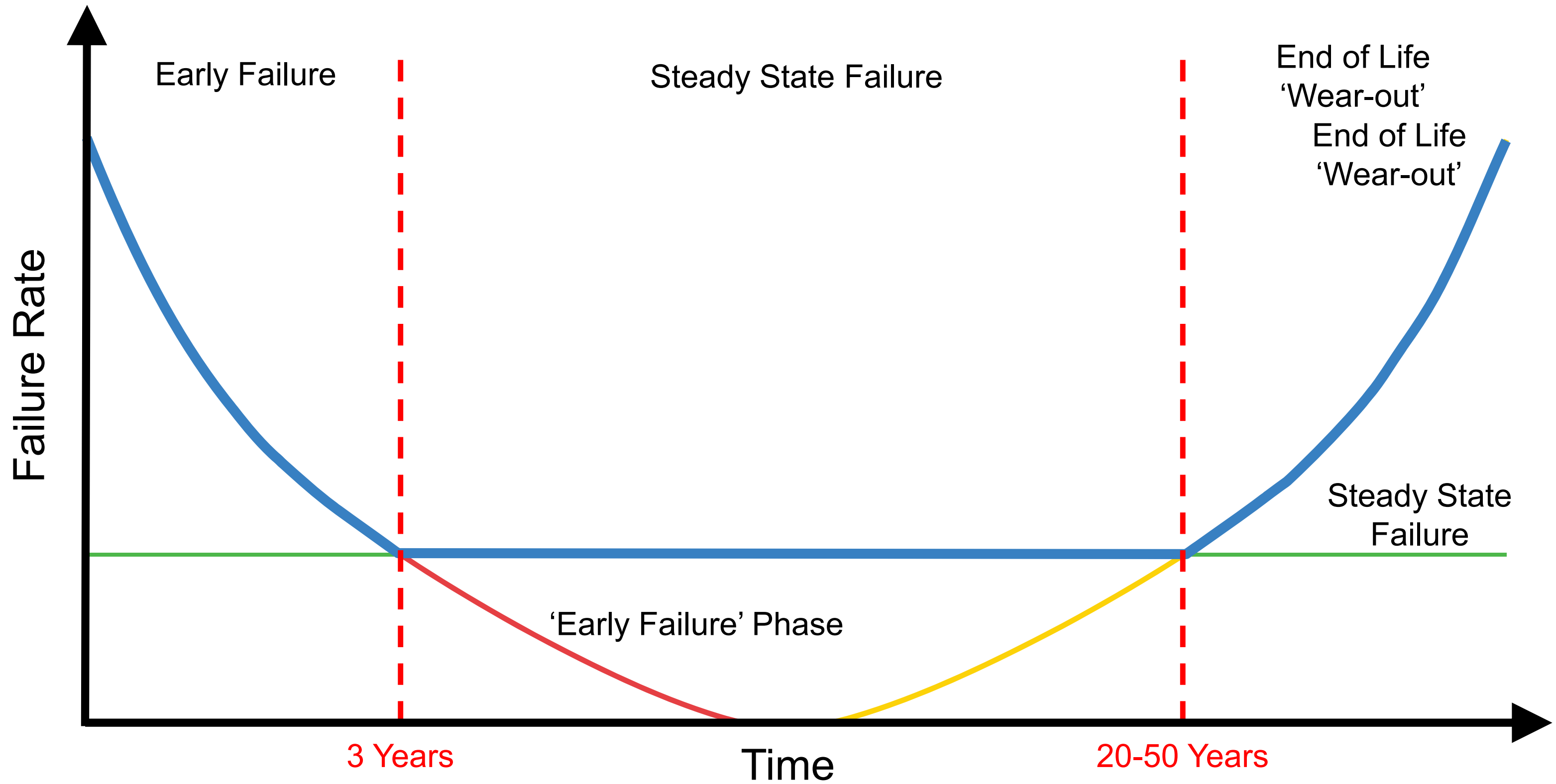
Cause of Failure Data for HV Rotating Machines
IEEE and EPRI Research Studies

IEEE EPRI ELECTRIC POWER RESEARCH INSTITUTE



- 41% of failures occur due to ***mechanical*** issues (vibration or bearings)
- ***37% of failures*** are electrical, from ***high voltage stator winding failures***
- 10% are ***rotor-related*** failures
- These three causes cover around ***90% of all HV motor failures***.
- ***On-line Partial Discharge (OLPD)*** techniques are used to detect ***electrical deterioration*** of the high voltage stator windings insulation prior to failure.

Reliability Centred Maintenance "Bathtub Curve"



Time-Based Maintenance and Replacement

- The oldest is in the worst condition?
- What is the rotating HV machines' historical service record, total hours of service and maintenance history?

Reactive Maintenance

- Assess similar/nearby plant only after a failure.

Condition-Based Maintenance (CBM)

- Assess the health of plant routinely and/or continuously and then perform maintenance only on plant in the worst condition (the 'worst 5%').

- ***High Voltage (HV) Ex/ATEX Motors***, like all other types of rotating HV machines, are prone to breakdowns and failures caused by ***both*** *electrical* ***and*** *mechanical 'wear and tear'.*

- Breakdowns and failures of the rotating HV machines are therefore inevitable with time in service, it is just a matter of time!

- Many of the breakdowns can be avoided through the implementation of ***Condition-Based Management (CBM)*** using ***condition monitoring (CM)*** technology to support preventative maintenance interventions.

- It is through the detection of ***'incipient' failure mechanisms*** and developing faults before they occur (using CM assessment and trending) that in-service failures and unplanned outages can be avoided.

- To provide a complete 'picture' of the health of a rotating HV machine it is therefore necessary to apply a ***combination of both electrical and mechanical CM technologies.***

The partial discharge (PD) insulation diagnostic techniques enable a ***continuous evaluation*** *of a* ***rotating HV machine's*** *dielectric integrity* ***throughout its service life***.

1. **Off-line Factory PD testing** should be carried out after manufacture, at the machine manufacturer's facility. Off-line PD testing should also be carried out ***at commissioning*** to provide 'baseline' PD measurements.

2. **Frequent OLPD testing** and/or continuous OLPD monitoring should be carried out throughout the critical, ***first 3 years of service*** – the '***infant mortality'*** or ***'bedding in'*** period of the machine.

3. **OLPD testing and monitoring** should be carried out ***after any repair*** and/or rewind is made to the machine – to ensure the repair has worked!

4. **Regular OLPD testing/monitoring** is required throughout the service life of the machine with particular focus on those machines that are reaching the ***end of their predicted 'design life'*** (typically of 20 years).

TEAM Stresses Affecting Rotating Machines

THERMAL

Loading / duty cycle thermo-mechanical effects and variations.

ELECTRICAL

Localised electrical stresses at the end windings and voids or delaminations in groundwall insulation.

AMBIENT

Temperature and relative humidity, surface discharges can occur with high humidity.

MECHANICAL

Wedge tightness, rotor alignment/concentricity, vibration effects, short-circuit fault forces.

To take into account these variable stresses, ***continuous* electrical and mechanical condition monitoring (CM)** of rotating HV machines is now becoming more widely applied in the worldwide oil and gas (O&G) industry.

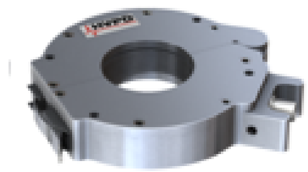
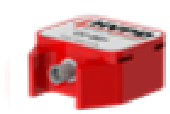
ON-LINE PARTIAL DISCHARGE (OLPD) SENSORS FOR ROTATING HIGH VOLTAGE (HV) MACHINES

OLPD Sensor Options Overview

There are three (3) main OLPD sensor options for rotating HV machines

High Voltage Coupling Capacitor (HVCC)	High Frequency Current Transformers (HFCT)	Rogowski Coil Sensors (RC)
• 80 pF / 500 pF / 1 nF rating • **High sensitivity** (when installed in the machine's cable terminal box). • The higher the capacitance, the better lower frequency response (to sub-10 MHz) to enable detection of PD deep into the HV windings.	• Available in a range of sizes to fit most confined spaces. • Ex/Atex-certified, saturation currents of up to 1000 A. • **High sensitivity at low frequencies** and capable of detecting PD in the machine **remotely** with the sensor installed at the switchgear.	• Does not saturate with high current (>5000 A). • Ex/Atex-certified (for use in hazardous gas zones). • **Very low sensitivity** and thus does not detect low levels of PD i.e. only significant PD activity can be detected.

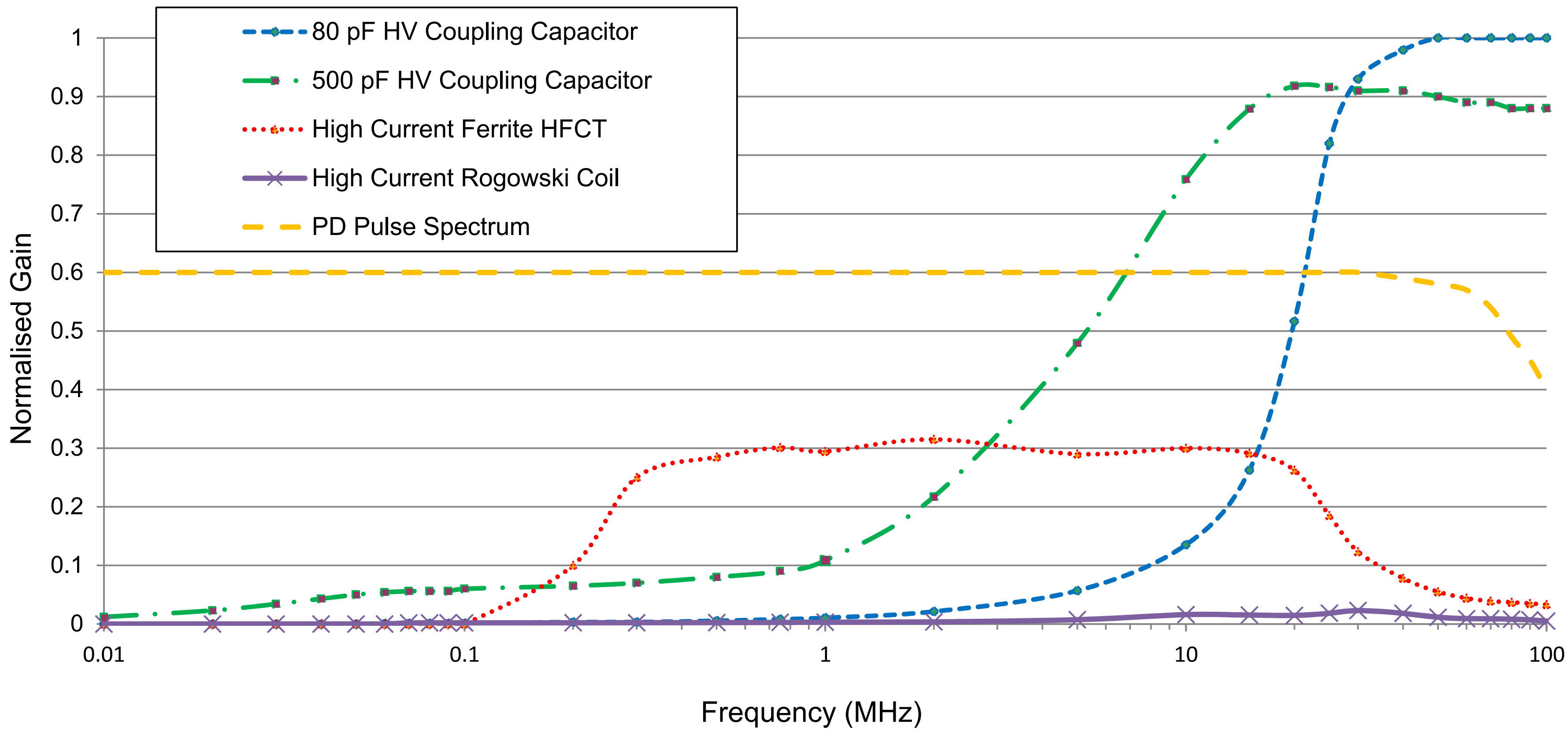
Rotating Machine OLPD Sensor Options (4) and Relative Sensitivity

Sensor	PD Sensor Options		
	Picture	Coupling Method	Relative Sensitivity at 10MHz
High Voltage Coupling Capacitor		Capacitive	100
Ferrite-cored High Frequency Current Transformer		Inductive	30
Transient Earth Voltage		Capacitive	5
Rogowski Coil		Inductive	1

Relative Sensitivity at 10 MHz of the 4 types of OLPD sensor

Rotating Machine OLPD Sensor Options (4)

Sensor Gain vs Frequency Response (10 kHz to 100 MHz)



The choice of PD sensor depends on:

- The rating of the machine
- The size of the cable box
- Whether it is bus-fed (HVCC) or cable fed (HFCT)

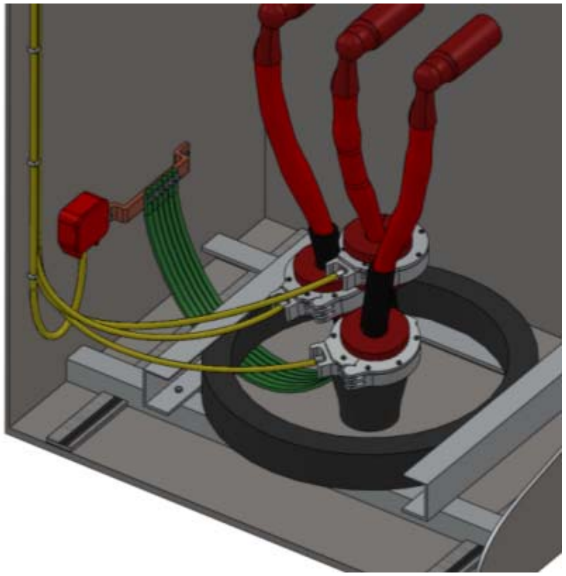
OLPD Sensors for Rotating HV Machines Installation Examples

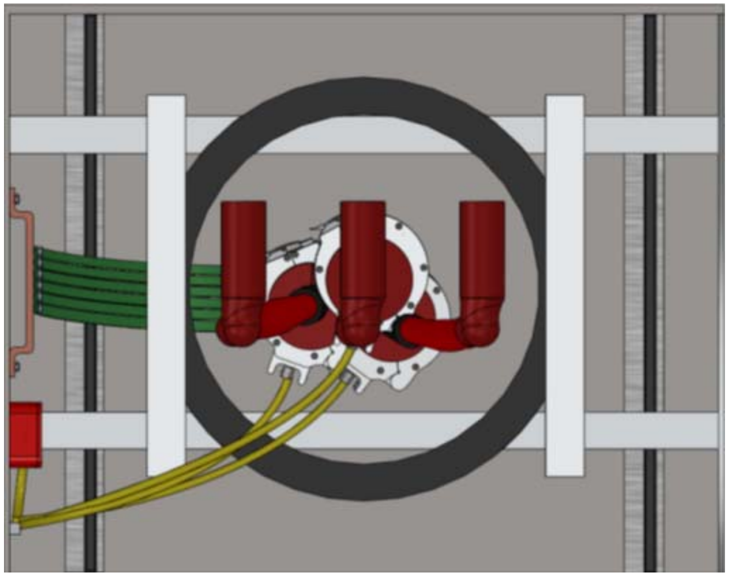
High Voltage Capacitive Couplers (HVCCs)

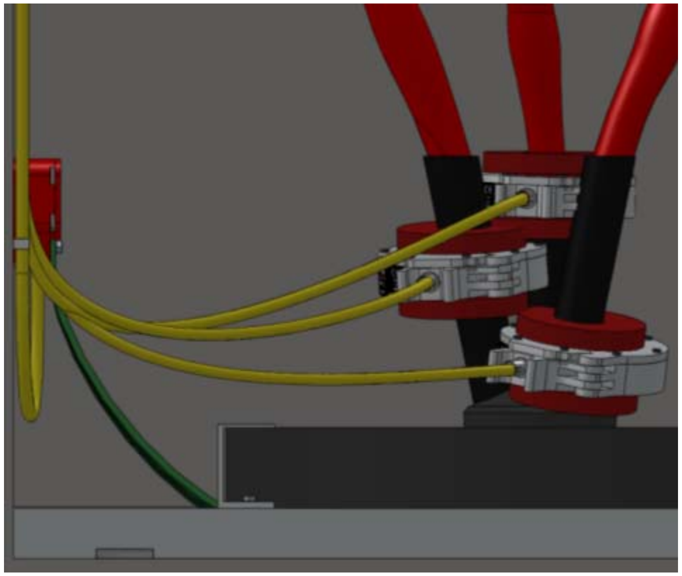
Permanent Rogowski Coil (RC) Sensors

HFCT Installation in an Ex/ATEX HV motor terminal box

HFCT Installation (3) + 1x TEV inside an HV switchgear box







Safety Note: For this installation the HFCT sensors must be installed on the correct silicone collars for the diameter of the cable tail, within the 'extended earth zone' i.e. on the black, semi-conductive tubing with all clearances maintained.

Each rotating machine cable feeder termination has the following sensors installed:

- ***1x TEV sensor*** (to measure *'Local'* PD in the switchgear/machine terminal box),
- ***3x HFCT sensors*** (one per phase) are used to measure PD in the HV cables ***and*** the remotely connected plant, whether this is a rotating HV machine or an HV transformer.

Permanent HFCT OLPD Sensors in Switchgear Cable Box

Points of Attachment

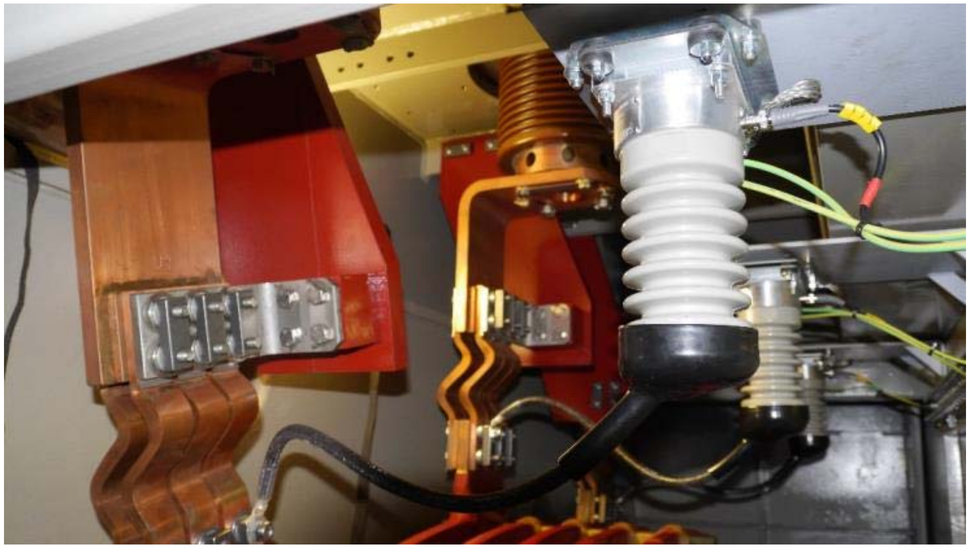
OLPD Testing of 13.8 kV 28.4 MW Gas Turbine Generator with temporary HFCT & TEV Sensors

OLPD Testing of 11 kV GT Generators (Offshore Drilling Vessel, Angola)

OLPD Testing of 6.6 kV Gas Turbine Generators (Cruise Ship, USA)

OLPD Testing of 10 kV Generators (Oil Processing Facility, Algeria)

OLPD Testing of 11 kV Hydro Generators (Power Generation Customer, Nepal)



Example of a 15kV HVCC Sensor Installation (Oil Refinery, UK)

PRESENTATION II

On-line and Off-line Partial Discharge Testing of Line-Fed HV Motors and Generators

Presented by:
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Managing Director
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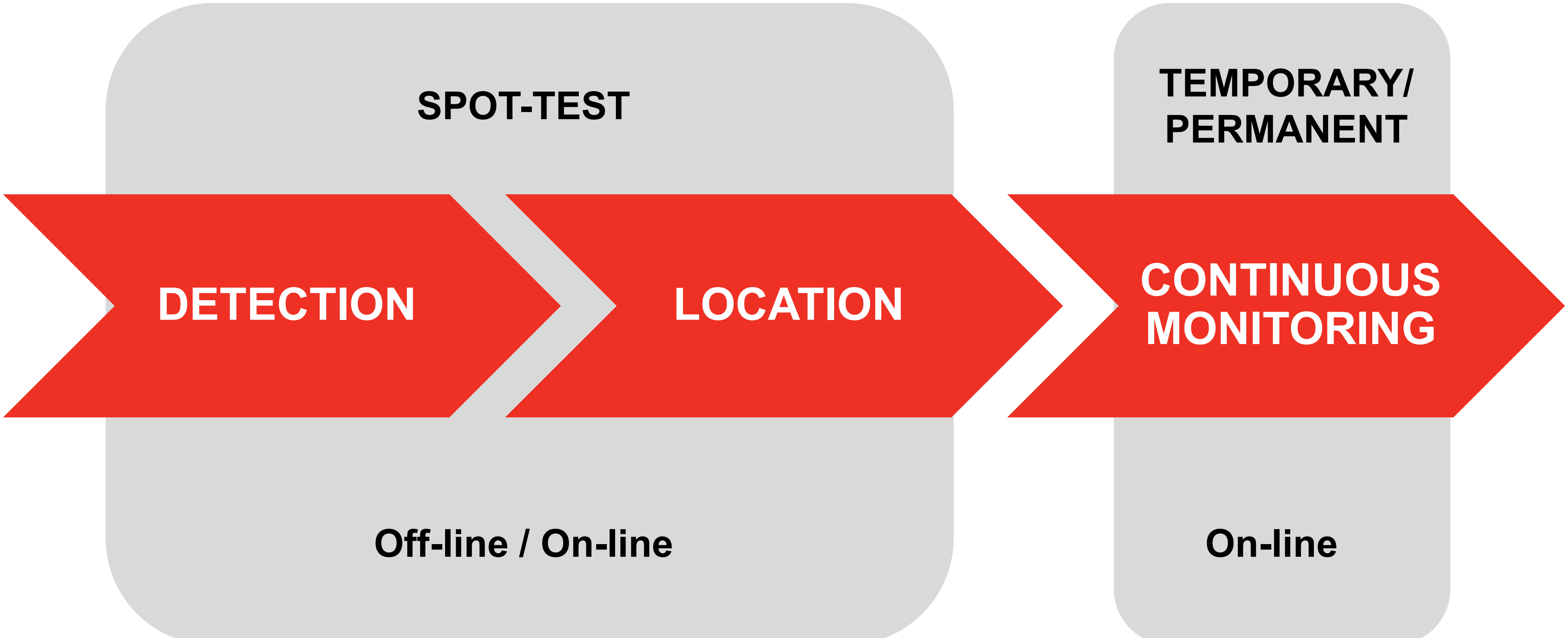
CONTENTS

- ***On-line*** (in-service) vs ***Off-line*** (out-of-service) PD testing
- Types of HV insulation defects in rotating HV machines
- PD pulse propagation analysis along HV feeder cables
- Phase Resolved Partial Discharge (PRPD) analysis

- **Case Study I** : On-line and Off-line PD testing and monitoring of 11kV generators on a drilling vessel.

- **Case Study II** : On-line and Off-line PD testing and monitoring of 6.6kV pump motors for a UK Power Generation client.

PD Testing Approach



HVPD

PD Test Methods

On-line

- In-service, under normal (and abnormal) working conditions
- Various sensor options are available

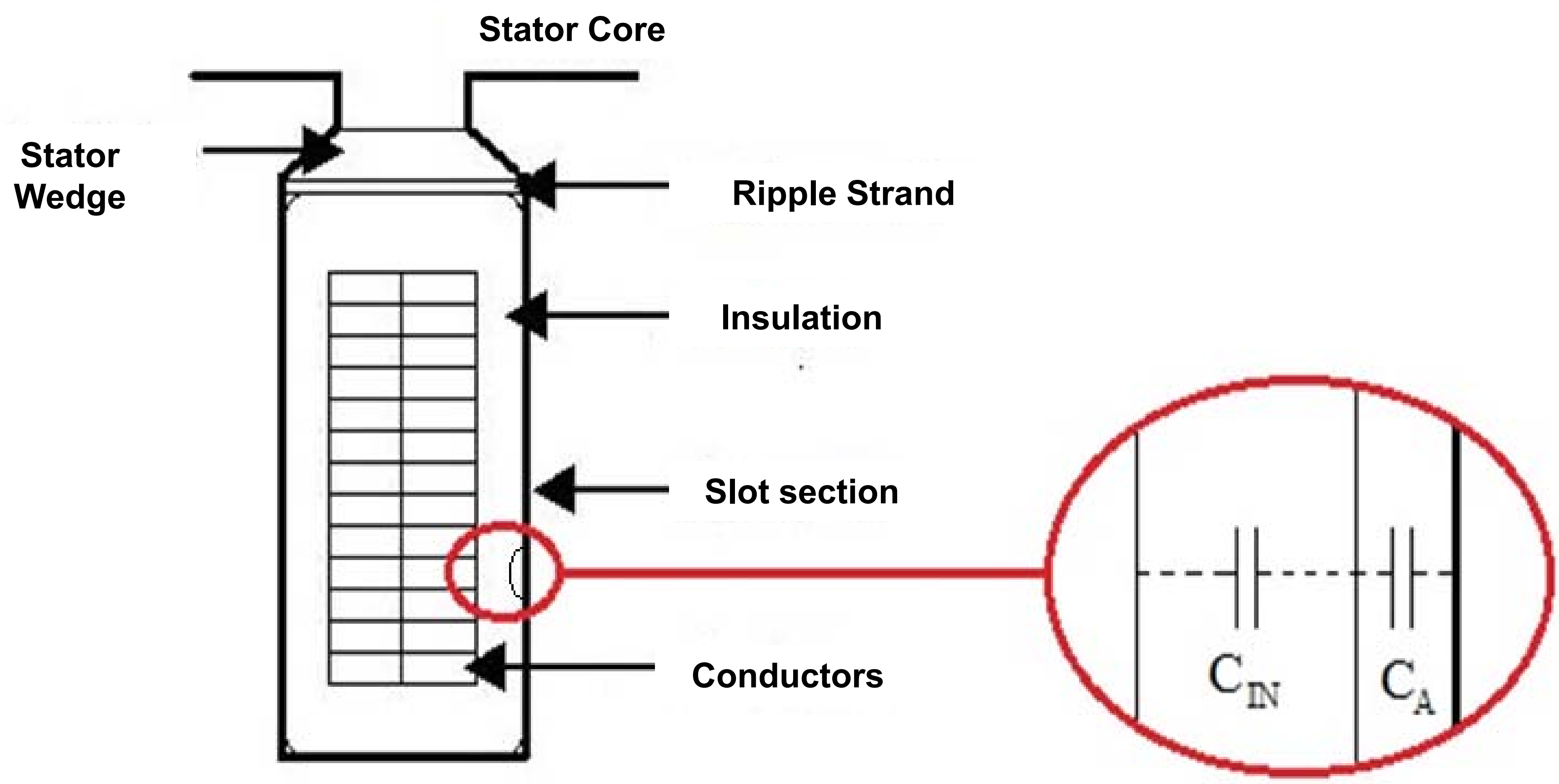
Off-line

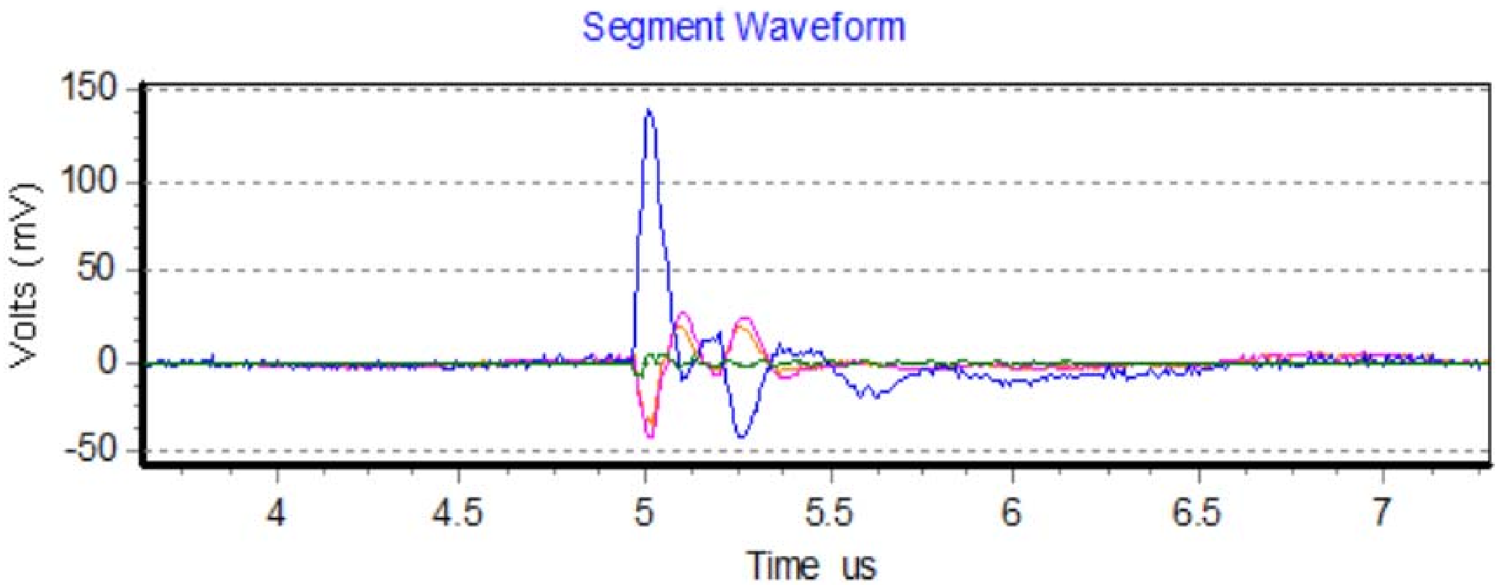
- Energised with external HV power source
- Usually a High Voltage Coupling Capacitor (HVCC) sensor is used

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

The **phase-to-earth** PD propagation path is formed by the capacitances of the air-gap/discontinuity and the insulation, and the phase winding of occurrence.



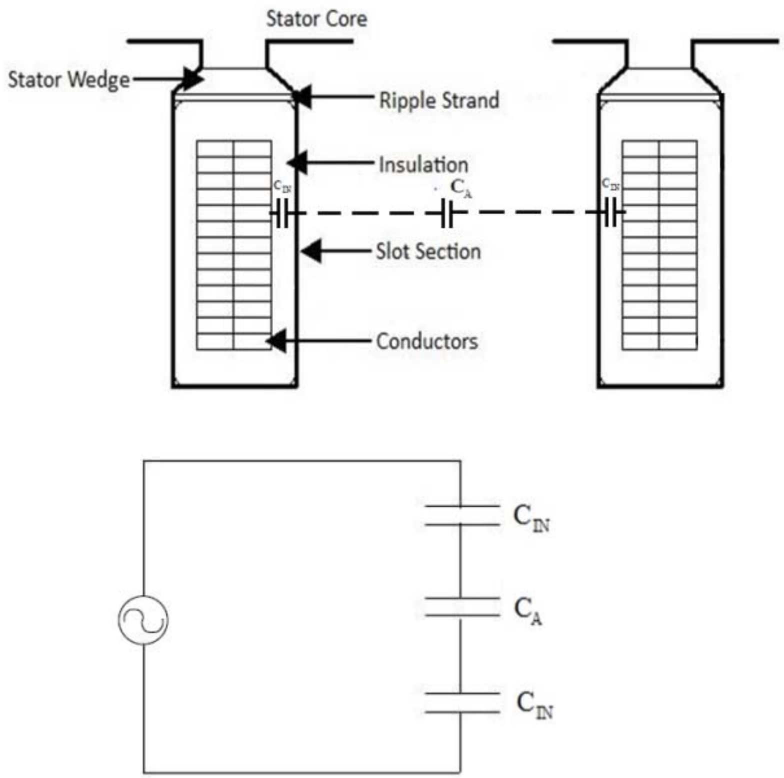


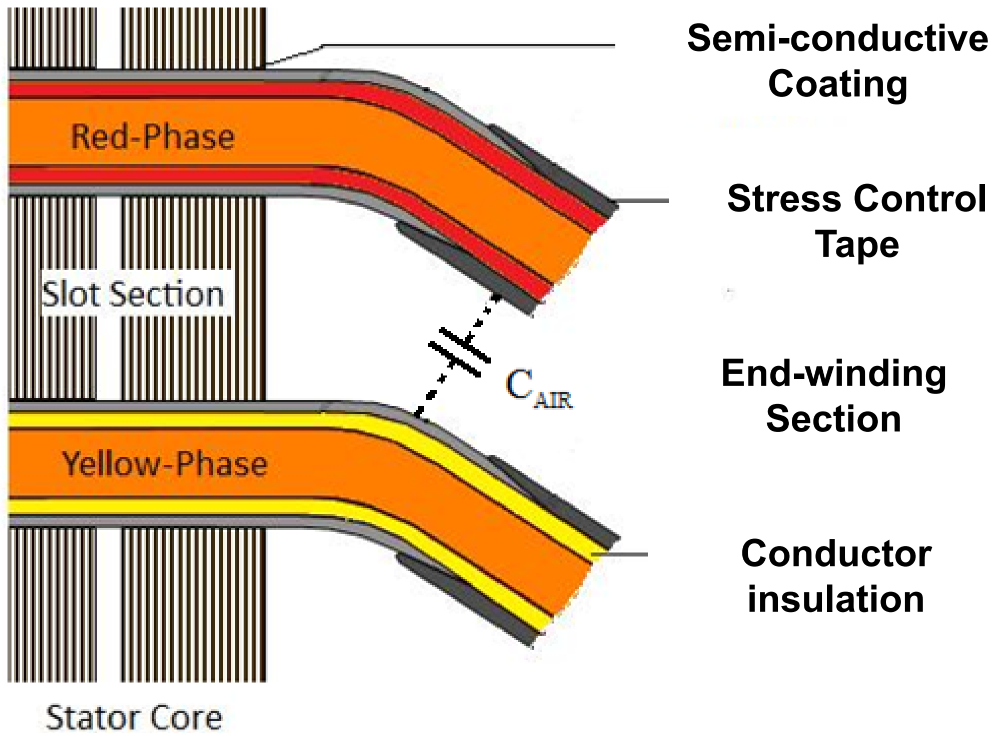
- These can be caused by surface discharges causing patches in the semi-conductive coating, delamination of the winding insulation and also vibration.

- The stator slot section PD produces a dominant pulse on one phase only (as shown above, in this case on the Blue Phase).

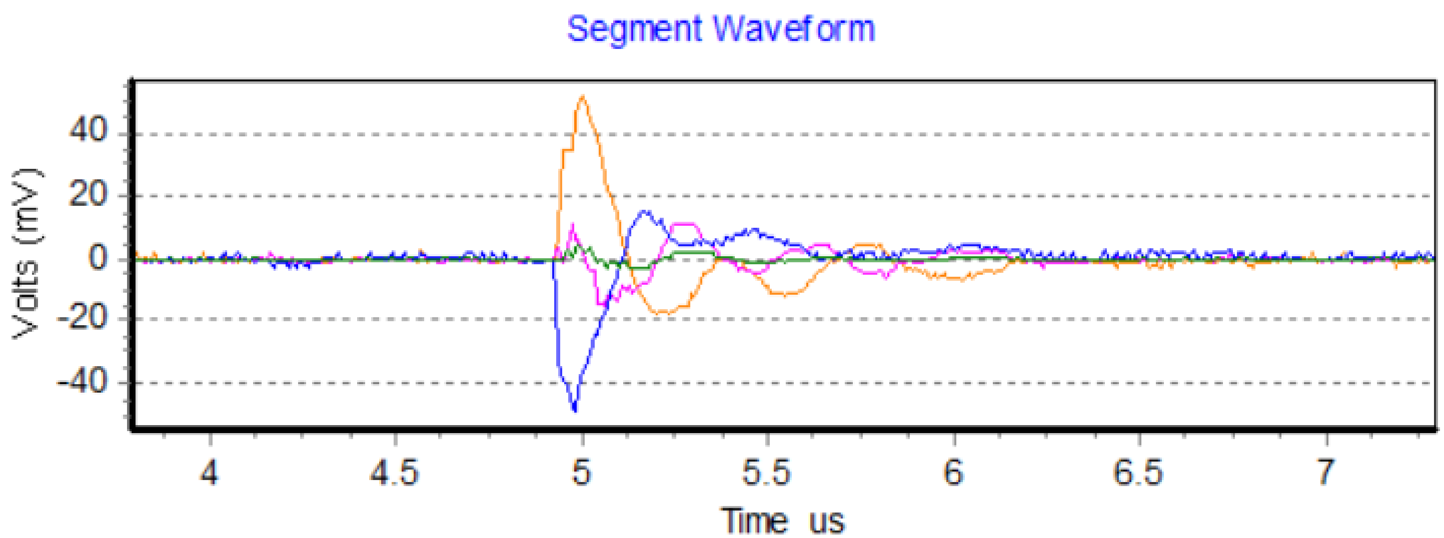
- Mutual coupling between phases often results in a very small, cross-coupled voltage pulse being seen on one or both of the other phases.

Stator End-Winding Region PD Activity





- Phase-to-phase PD mainly occurs at the end-winding region.
- These can be caused by inadequate stress-control, moisture ingress, contamination, in-sufficient clearances or excessive vibration.



- This can be caused by end turn insulation breakdown which is typically initiated by contamination, moisture ingress, high humidity and insufficient bar clearances and stress-control plus vibration.

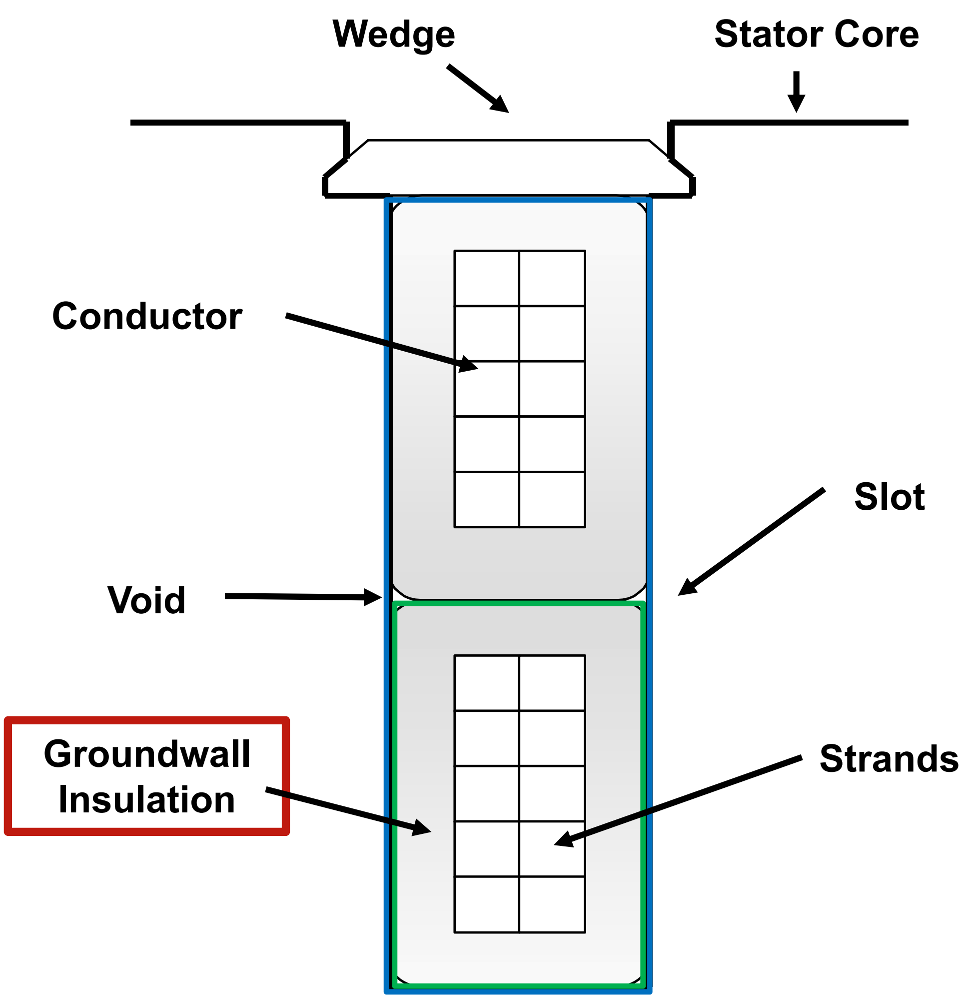
- The phase-to-phase PD propagation path is formed by the capacitances of the phase winding insulation and the air gap as well as the impedances of the phase windings the discharge occurs between.

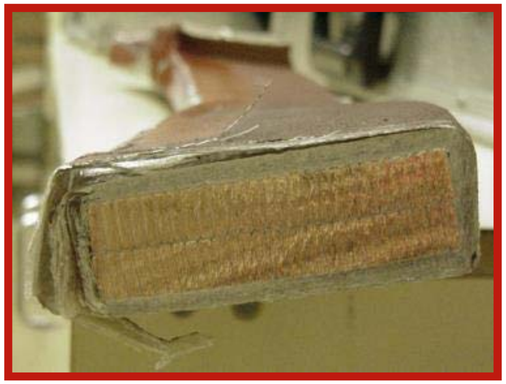
- An end winding phase-to-phase PD produces equal and opposite pulses on two phases (as shown above, in this case the discharge is between the Orange and Blue Phases).

TYPES OF DEFECTS IN ROTATING HV MACHINES

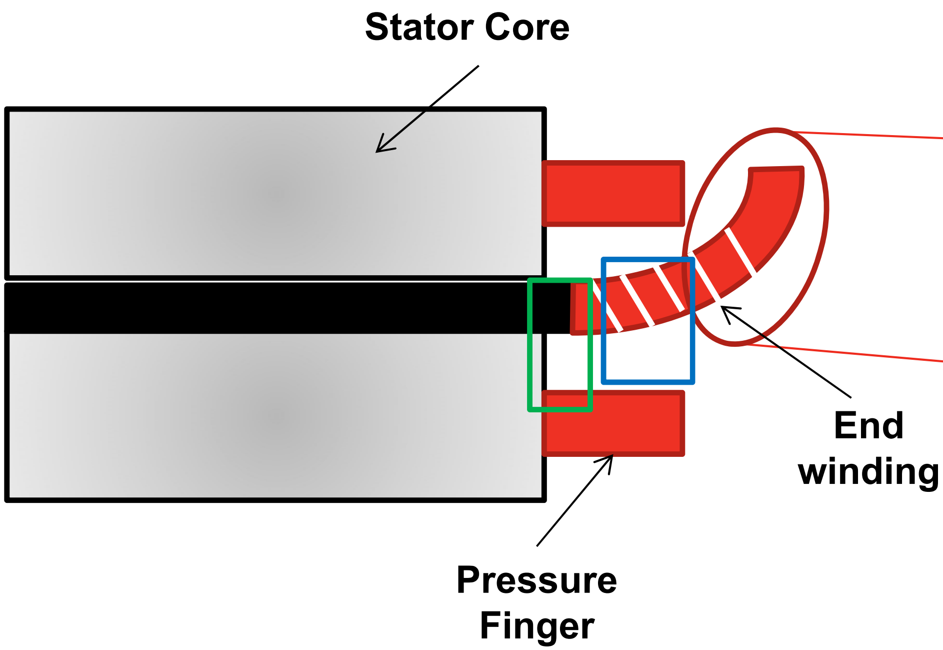
- Loose stator bar, stator bar vibration
- Phase-to-earth discharges in the slot section
- Damaged HV conductors
- Surface degradation (e.g. at the end windings)
- Corona ring stress relief degradation
- Phase-to-phase discharges at the end windings
- Delamination of mica-based insulation
- Voids in resin/VPI insulation
- PD in the accessories (e.g. CT / VT / cable terminations)

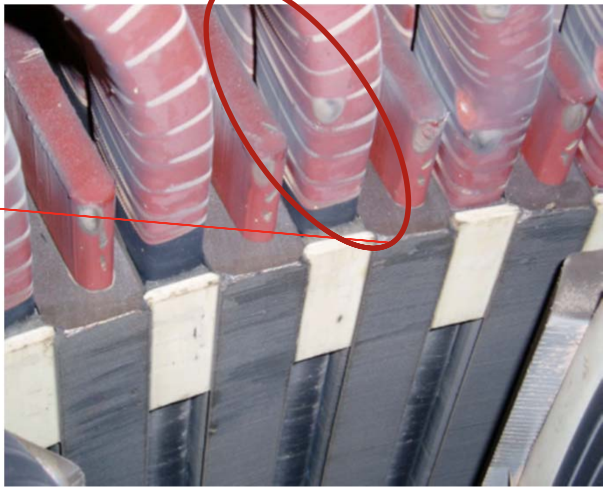
Internal Discharges in the Groundwall Stator Insulation





Surface Discharges on the End Windings of the Stator





Examples of Visual Inspection of HV Stator Windings

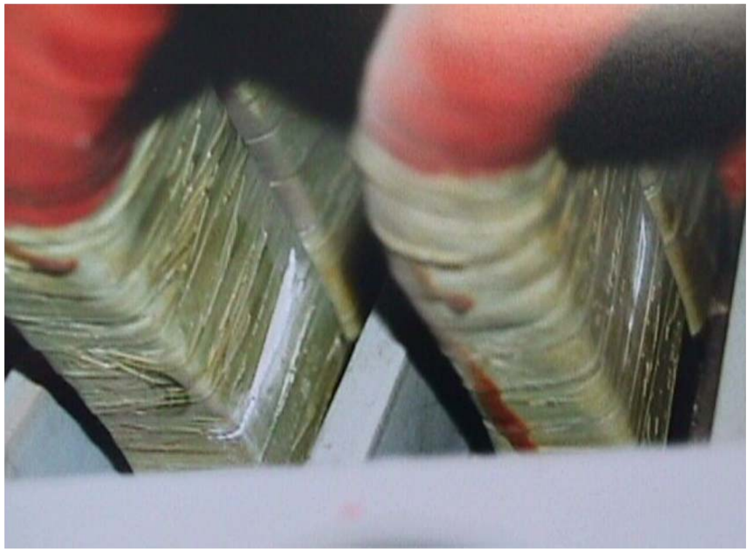
- This is very useful for identifying and confirming areas of surface degradation and tracking in the machine’s **end windings** (by removal of the machine’s end-caps).
- Requires de-energisation of the machine.
- It is **not** possible to view any degradation of the insulation in the slot section of the machine as this requires removal of the rotor (this is not a simple task and requires an extended outage).

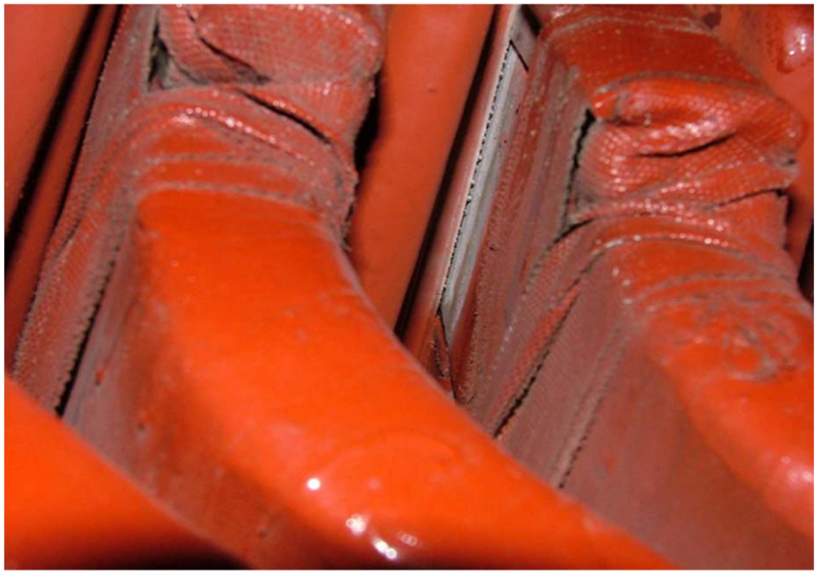
Examples of Insulation Deterioration in HV Connections

Surface Tracking &Treeing

Examples of Insulation Deterioration at Slot Exit Position

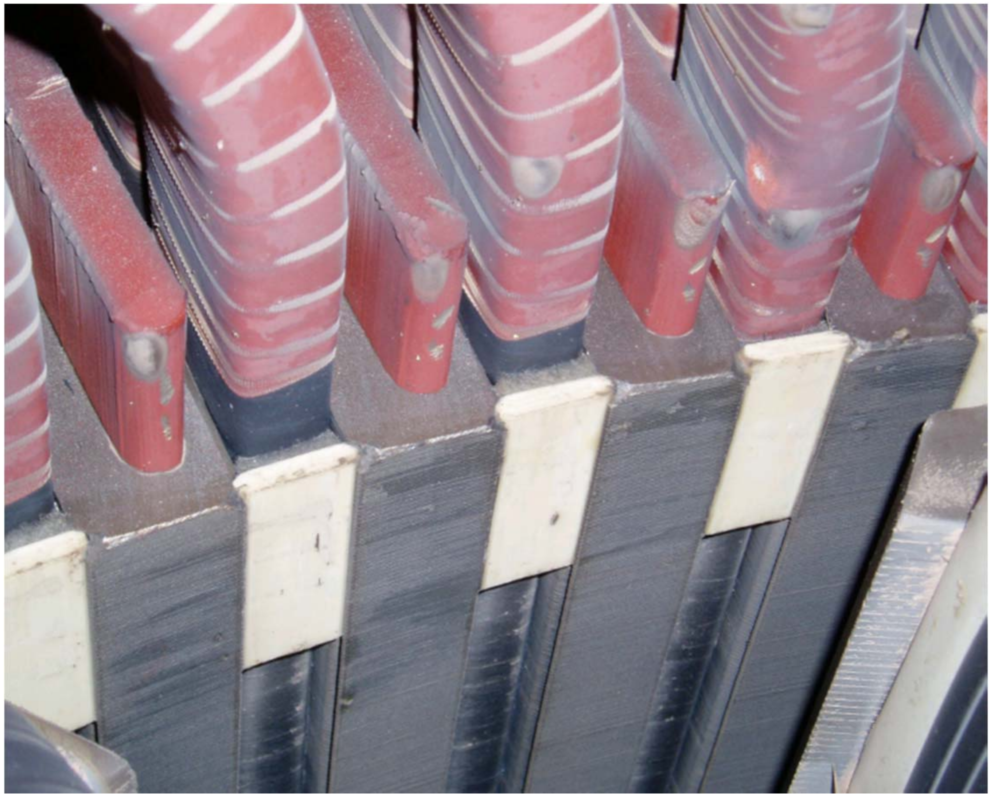
Corona Damage to Stress Relief





Examples of Insulation Deterioration

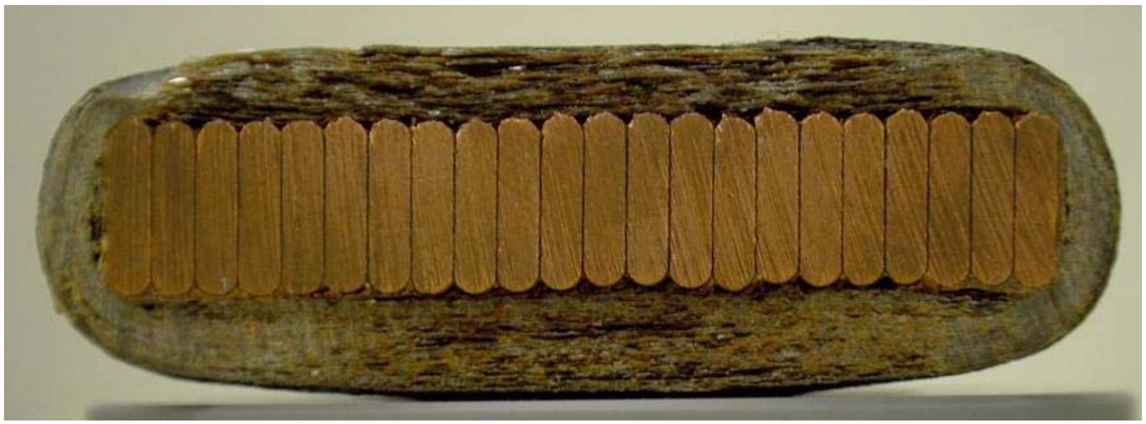
Poor Stress Control and Inadequate Clearance to Rotor

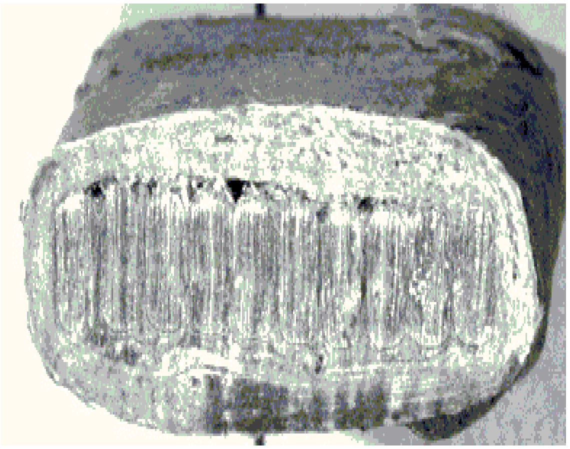


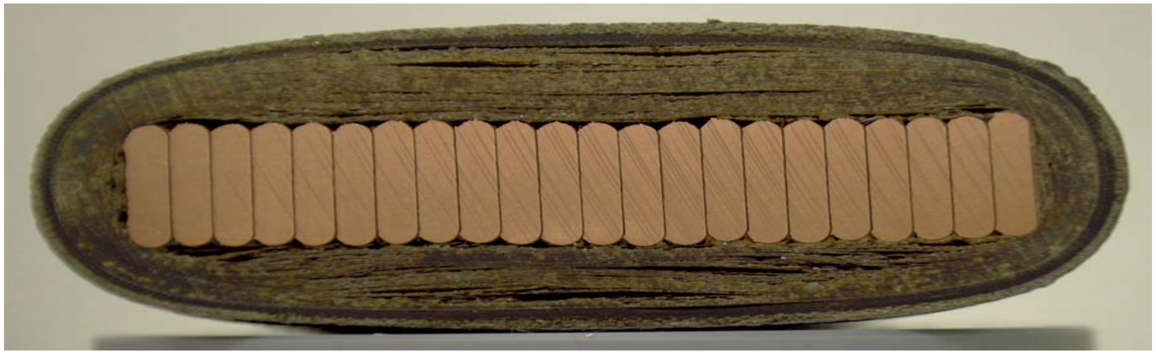
Examples of Insulation Deterioration
Damage from Slot Discharges

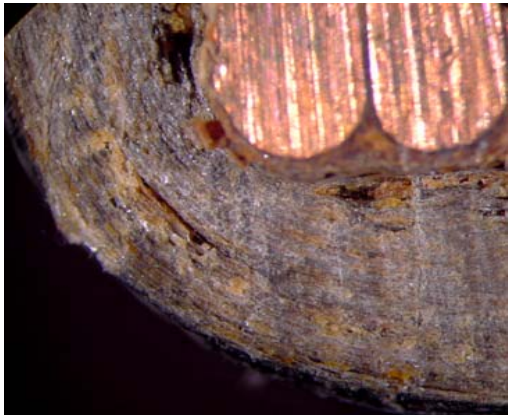
Examples of Insulation Deterioration

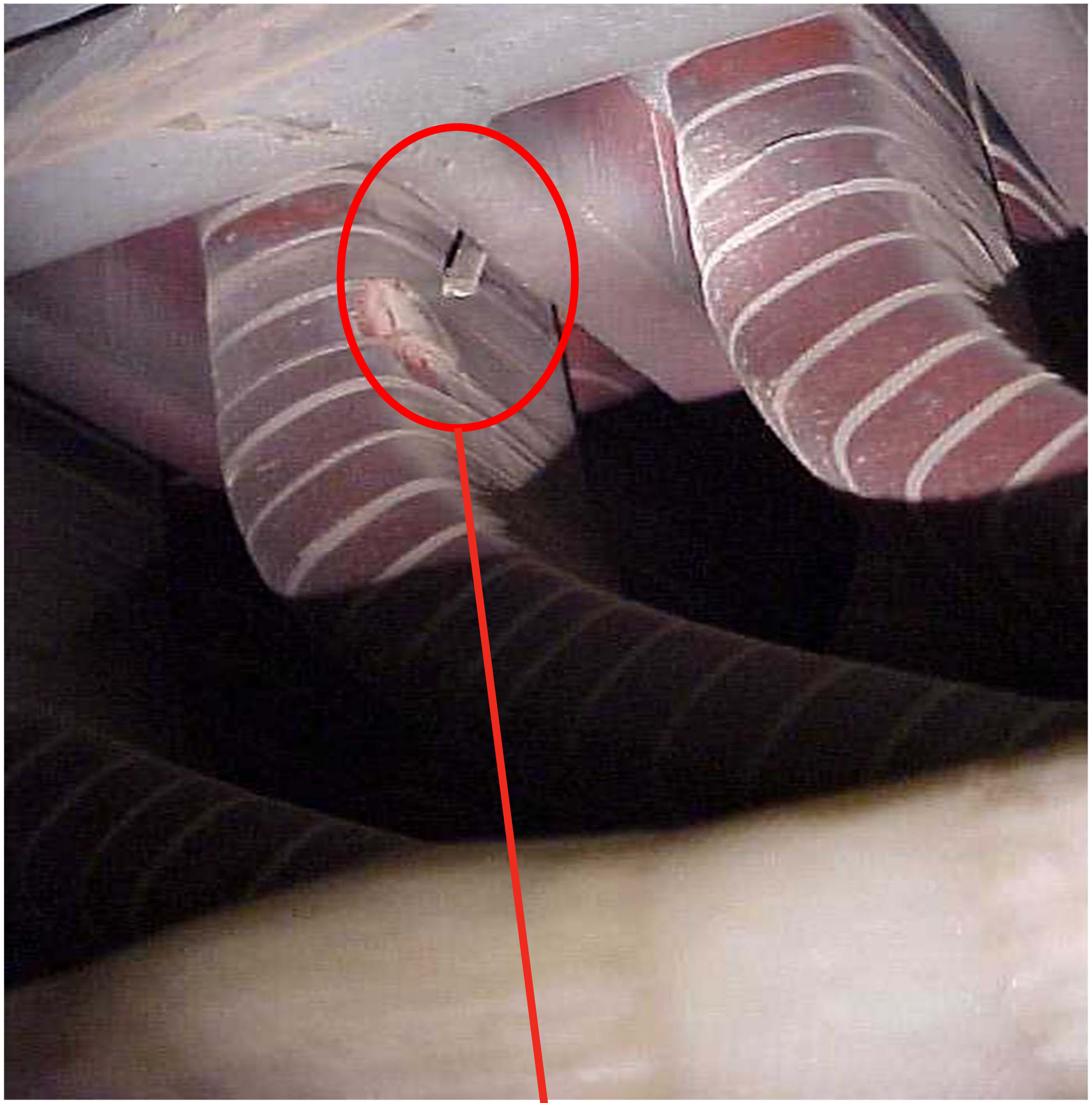
Delamination of Mica-Based Groundwall Insulation











Localised surface discharge due to a foreign object lodged between iron and coil

PRESENTATION III

Remote OLPD monitoring of ***Ex/ATEX*** **HV motors** using wideband HFCT PD sensors at the central switchboards

Hazardous Gas Locations 'Ex'/'ATEX' environment -
IEC 60079-0 Definition:

"An area in which an explosive atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of electrical apparatus."

- Common Types of Motor Protection: to "contain" an ignition (***Ex d – flameproof***), to exclude the gas (***Ex p – pressurised***), or does not present an ignition source (***Ex e*** *or* ***Ex n – increased safety or non-sparking***)
- Restrictions with plant design – e.g. for ventilation, either air circulating or heat-exchanger systems are used

Central HV Switchboard - an easier environment to monitor from

- No hazardous environment restrictions apply
- There is normally sufficient space and clearances within switchgear cubicles to install split-core, HFCT sensors
- Remote OLPD monitoring from the central switchboard is thus an attractive option when the motor to be monitored is in an Ex/ATEX hazardous gas zone

Remote OLPD Testing and Monitoring of HV Motors located in Ex/ATEX HazardouZone

- Central monitoring of PD activity in ***Ex/ATEX HV motor*** stator windings using wideband HFCT sensors at the switchboard was reported by HVPD in an ***IEEE-PCIC 2012*** conference paper in September 2012.
- HVPD published a second paper at the ***IEEE-PCIC 2013*** conference in September 2013 with asset management condition guidelines for assessing the condition of large populations of aged (20+ years) Ex/ATEX HV motors based on an ***'OLPD League Table'*** database.
- Copies of these IEEE-PCIC papers, co-written with Chevron and TCO (Tengizchevroil), are available from HVPD on request.

A NEW TECHNQUE FOR THE REMOTE PARTIAL DISCHARGE MONITORING OF THE STATOR INSULATION OF HIGH-VOLTAGE MOTORS LOCATED IN "Ex" (HAZARDOUS) LOCATIONS

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Paper No. PCIC 2012-067

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CONTINUOUS, REMOTE ON-LINE PARTIAL DISCHARGE (OLPD) MONITORING OF HV EX/ATEX MOTORS IN THE OIL AND GAS INDUSTRY

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Abstract — This paper presents results from the continued application of a new technique for the remote, on-line partial discharge (OLPD) testing and monitoring of in-service, high voltage (HV) Ex/Atex motors operating in hazardous gas zones. The technique employs high current, wideband, high frequency current transformer (HFCT) sensors located remotely from the motor under test, at the switchboard end of the HV feeder cable. Significant cost and operational benefits can be gained from this remote monitoring technique as the stator winding condition of these motors can be monitored without having to enter the hazardous gas (Ex/Atex) zone. The work described in this paper is a continuation of that carried out by the same authors, as reported at the IEEE-PCIC 2012 conference, and includes the development of proposed condition guidelines for assessing the condition of the stator winding insulation systems of large populations of aged HV motors, based on an on-line partial discharge (OLPD) 'league table' database. Two case studies are presented wherein the HV stator insulation condition and reliability of in-service motors, operating in a hazardous gas zones, and HV generators were assessed using both on-line and off-line partial discharge testing and monitoring techniques. The case studies emphasize the importance of carrying out extended, continuous on-line partial discharge monitoring of in-service rotating HV machines to detect underlying trends in partial discharge activity over time. The paper concludes with how condition monitoring data can support reliability centered maintenance and condition-based management regimes.

Index Terms – Partial Discharge, On-line Partial Discharge, Phase Resolved Partial Discharge, PD Diagnostics, Ex and ATEX Motors, Rotating HV Machines, Hazardous Gas Zones, Condition-Based Management.

I. INTRODUCTION

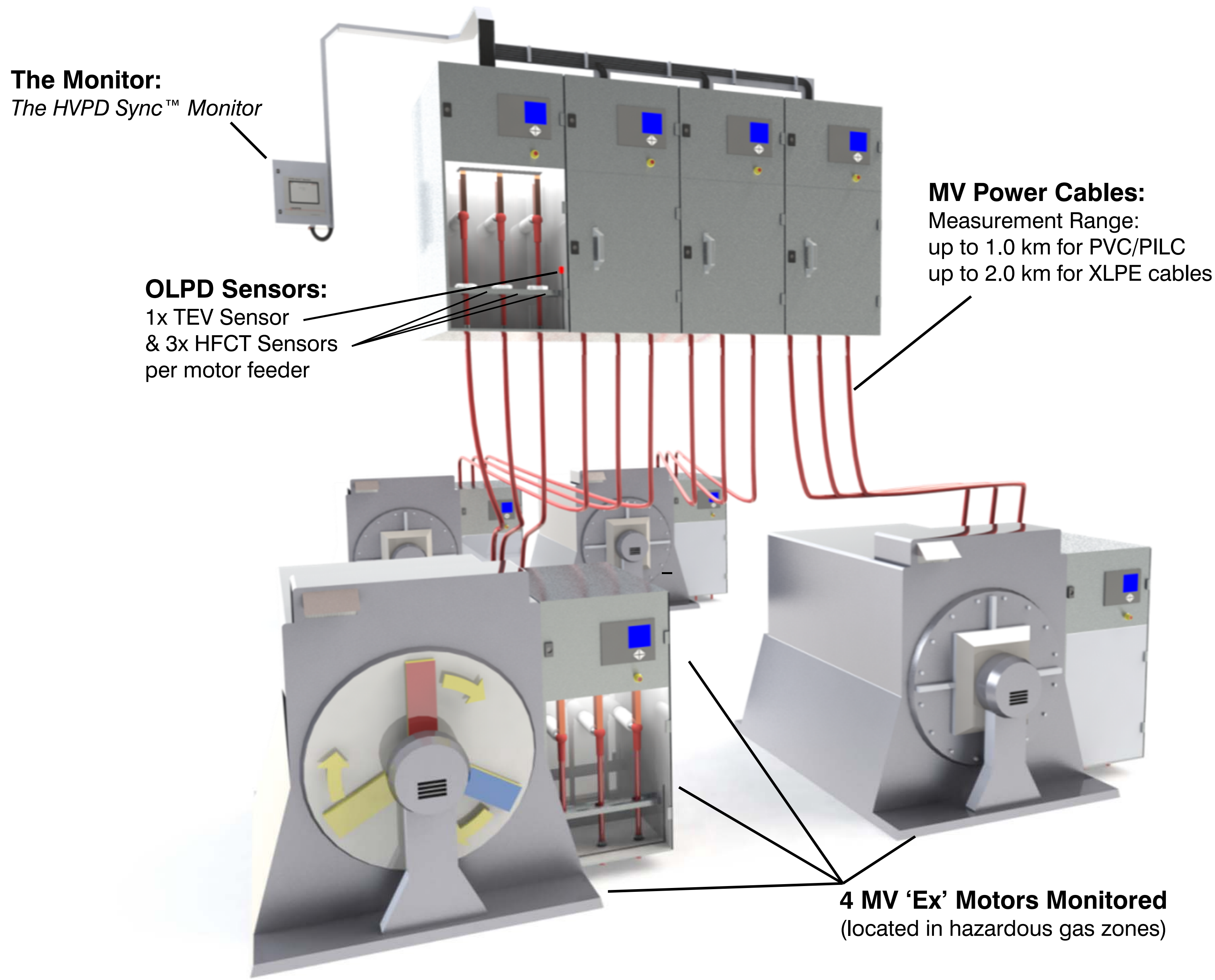
The term 'on-line' partial discharge (OLPD) monitoring refers to the diagnostic testing of the high voltage (HV) insulation of in-service cables and plant, in their normal operational mode. The technique can be applied to all types of HV plant including motors, generators, cables, switchgear and transformers. The technique is complementary to the use of out-of-service partial discharge testing of the stator windings (using a portable 50/60Hz HV power sources) that is often referred to as 'off-line' PD testing. The advantage of the OLPD testing of in-service rotating HV machines is that the HV stator winding condition is assessed with the machine operating under both normal working conditions and abnormal variations related to changes in the associated electrical, thermal and mechanical operational stresses.

Out-of-service, 'off-line' PD testing requires the motor to be de-energised and a portable HV power source used to energise each winding in turn with measurements normally made on a phase-by-phase basis. This technique is useful as the test engineer has control over the voltage and can therefore measure the partial discharge inception voltage (PDIV) during the test voltage ramp-up (typically to 2 Uo) and the partial discharge extinction voltage (PDEV)on voltage ramp-down. The techniques of on-line and off-line PD testing are considered by many people in the field of HV motor insulation diagnostics as complementary as the former can be used to pre-sort any machines that require an outage for off-line diagnostic testing, PD site(s) location and repair.

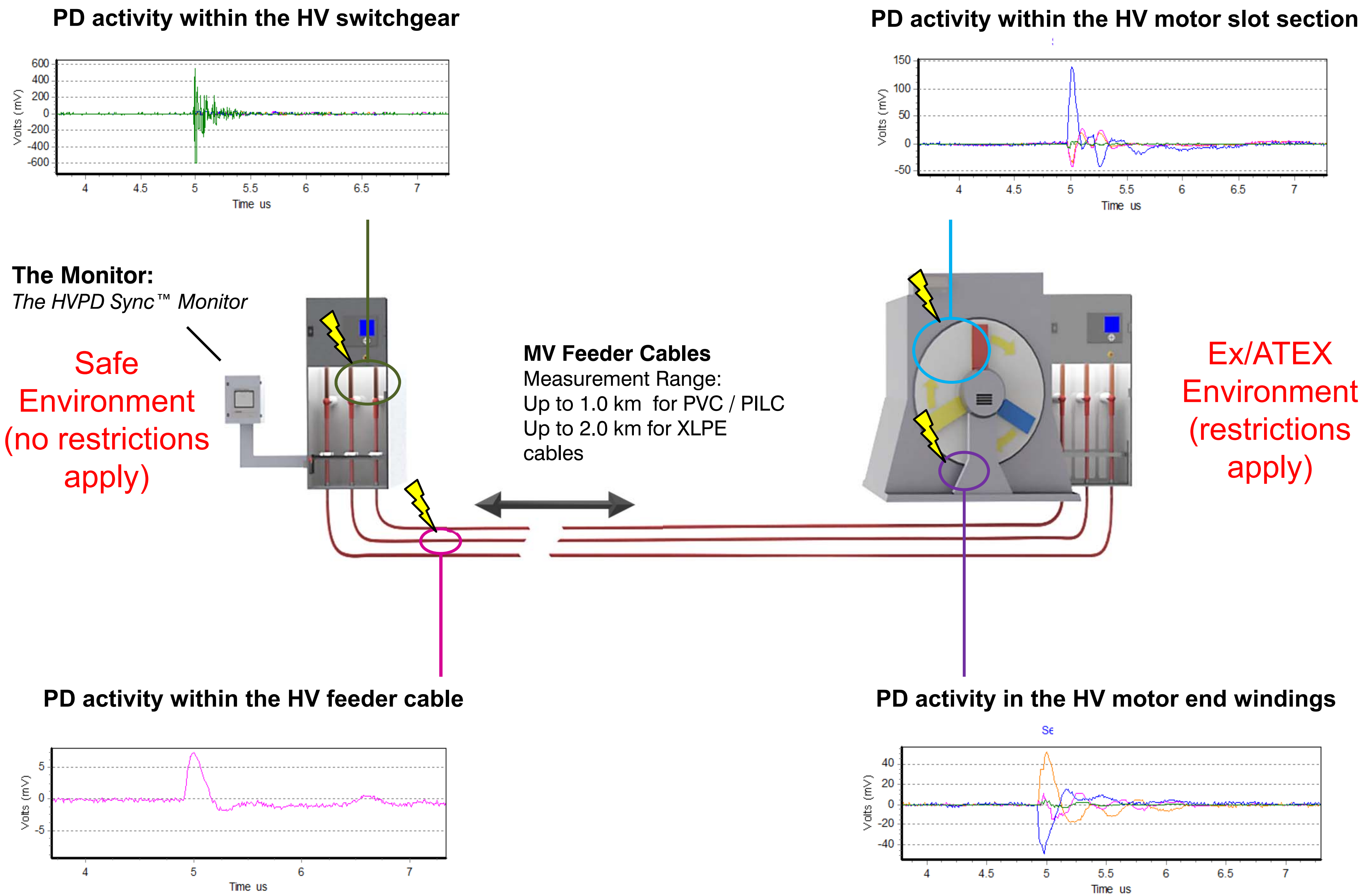
The OLPD insulation condition assessment of operational, in-service HV motors, generators, cables and switchgear is now becoming more widely accepted as a useful diagnostic aid in the worldwide petrochemcial industry. The application and uptake of the technology in the industry has increased significantly over the past five years as operators see the benefits that the technology brings, being capable of providing an 'early warning' against incipient HV insulation faults i.e. those faults yet to occur but which manifest themselves through high PD activity. It is estimated that OLPD electrical condition monitoring (CM) technology is presently applied in only around 10% of the HV motors and generators in the industry. It is interesting to compare this 10% estimate to the percentage of rotating HV machines in the industry that have mechanical (vibration and bearing wear) CM technology fitted (this is estimated at over 75%). This could possibly be due to the fact that historically it has been mechanical engineers who have been responsible for the design, build (and condition monitoring) of the motors and generators.

To illustrate the benefits of employing the OLPD electrical condition monitoring (CM) technology, it can be noted that two HV motor cause-of-failure analysis studies presented in [2] and [3] both reported that stator winding failure contributes to around 37% of the total HV motor failures reported. The data from these published studies is illustrated below in Fig. 1. With 37% of all failures due to HV stator winding failure, this would suggest that monitoring of the HV stator windings should be considered (in conjunction with the

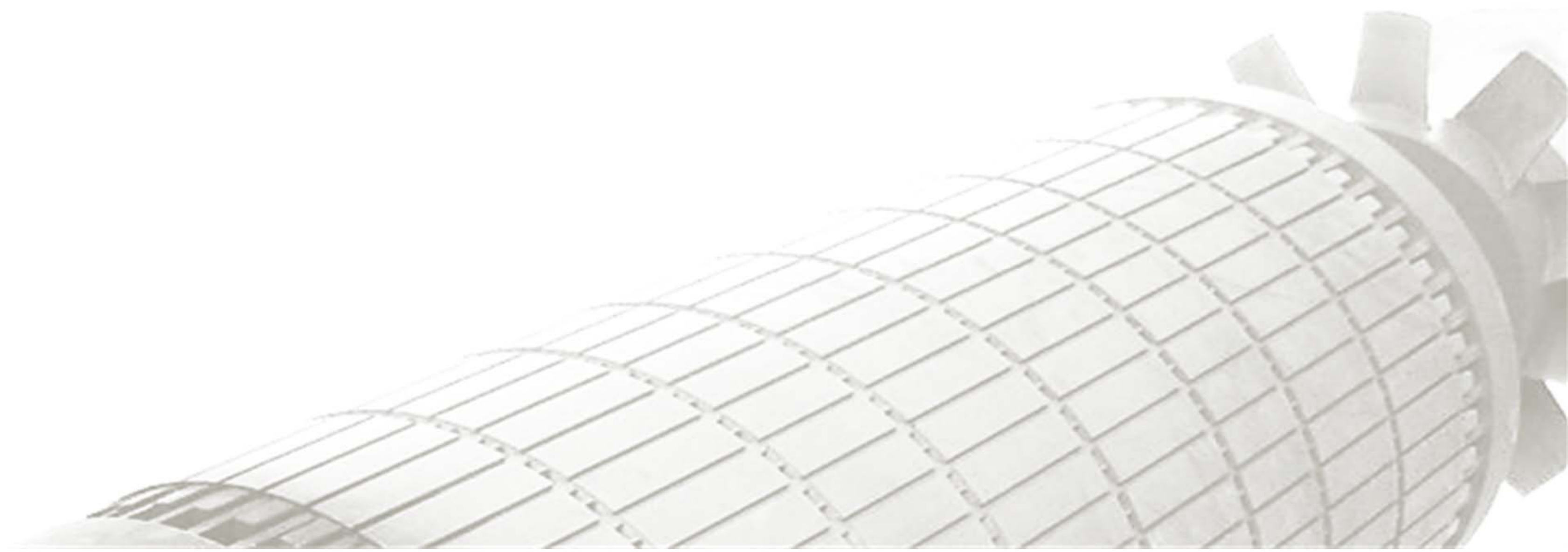
Remote OLPD Monitoring of HV Ex/ATEX Motors from the Switchboard



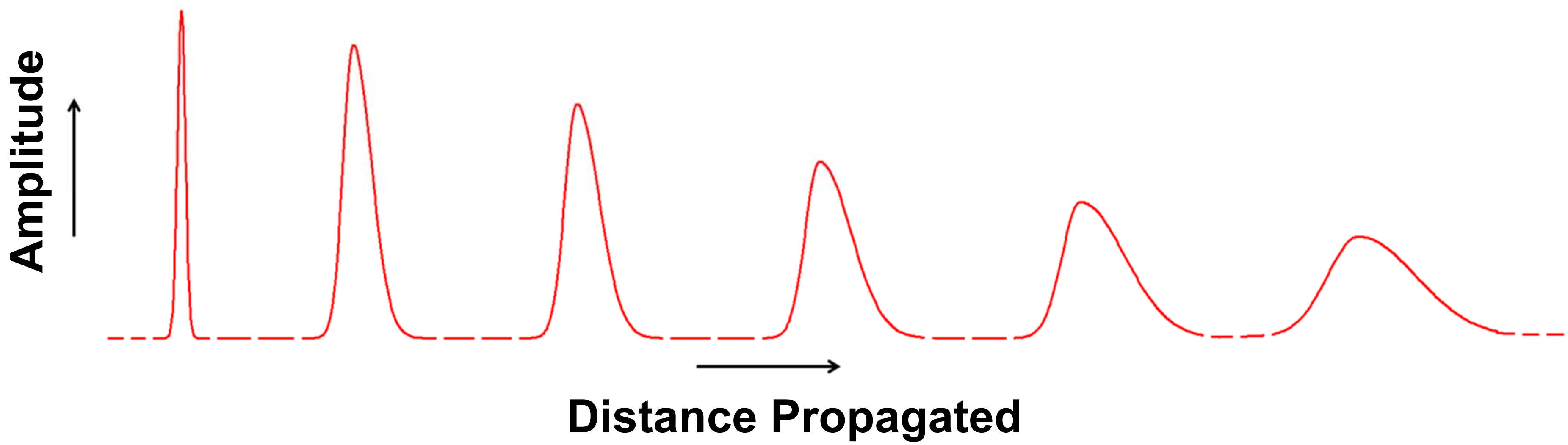
Remote OLPD Monitoring and Diagnostic Testing of Ex/ATEX HV Motors in Hazardous Gas Zones



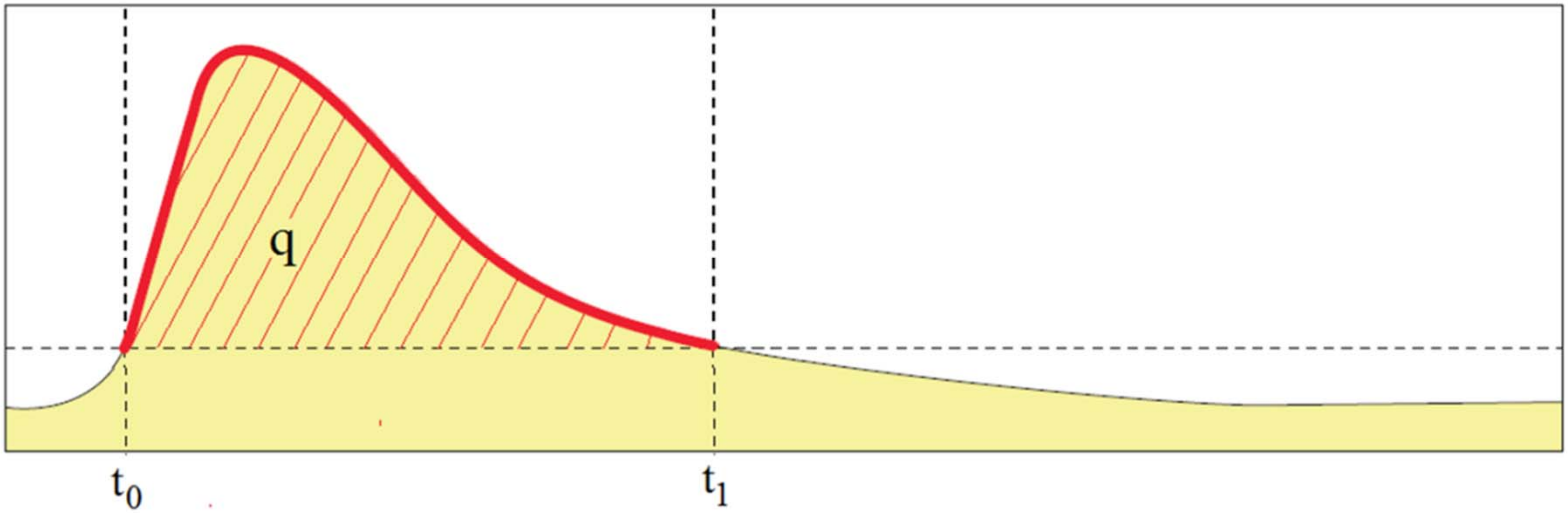
PARTIAL DISCHARGE PULSE PROPAGATION ALONG HV CABLE FEEDERS



- At the discharge source the PD pulse can be modelled by a Dirac-δ function, with a broad frequency spectrum and a very fast (< 1 ns) rise time.



- As a PD pulse propagates from its source (within the machines' stator winding) to the machine terminals and then along the feeder cable from the machine back to switchgear, **it changes shape (as shown above)**.
- These changes occur due to the effects of attenuation and dispersion as the cable/stator winding acts as a low-pass filter, stripping out the high frequency content of the pulse and developing into a '**Shark-Fin'** shape.



As the PD pulse travels down the HV feeder cable from its source in the rotating HV machine, it takes up a ***'Shark-fin'*** shape, as shown above.

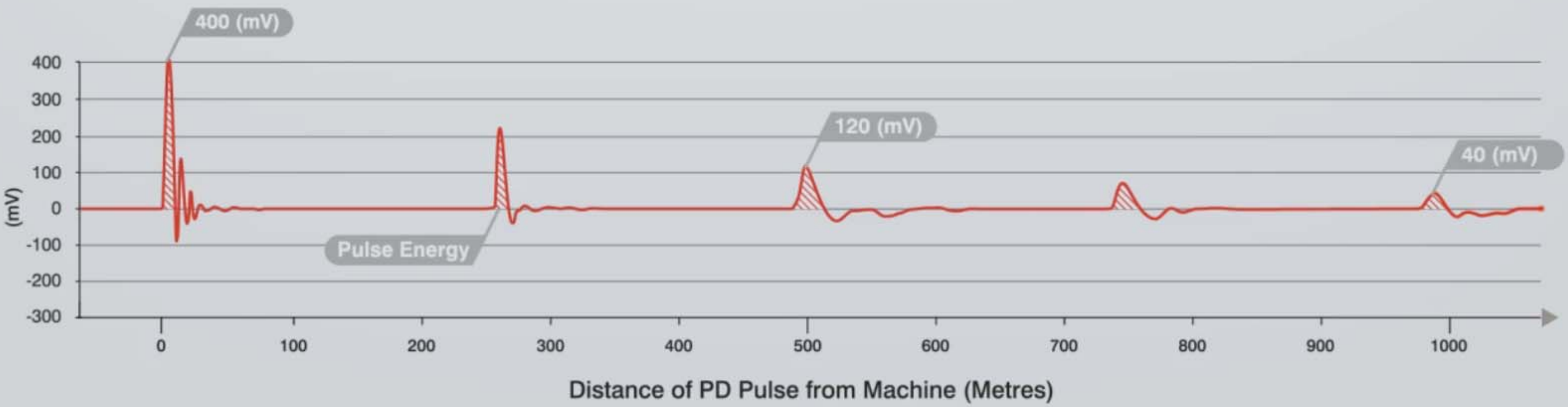
By measuring the 3 main parameters of the pulse: risetime (t_r); pulse width (*PW*); and falltime (t_f), it is possible to identify and discriminate the PD pulse from electromagnetic (E/M) 'noise'.

The Charge Content (q) of the pulse (in Coulombs) is calculated using the Transfer Impedance ($\mathrm{Z_{Tr}}$) of the HFCT sensor using the following equation:

$$q = \frac{1}{Z_{Tr}} \int_{t_0}^{t_1} V dt$$

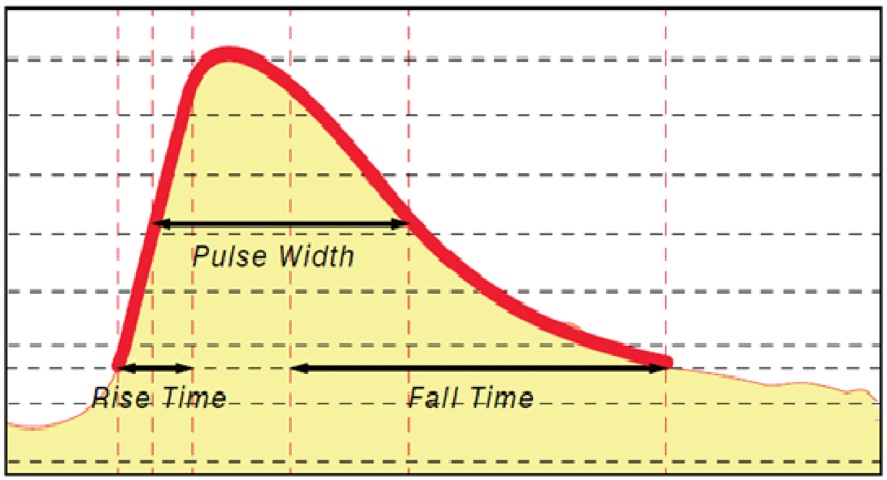
[redacted]

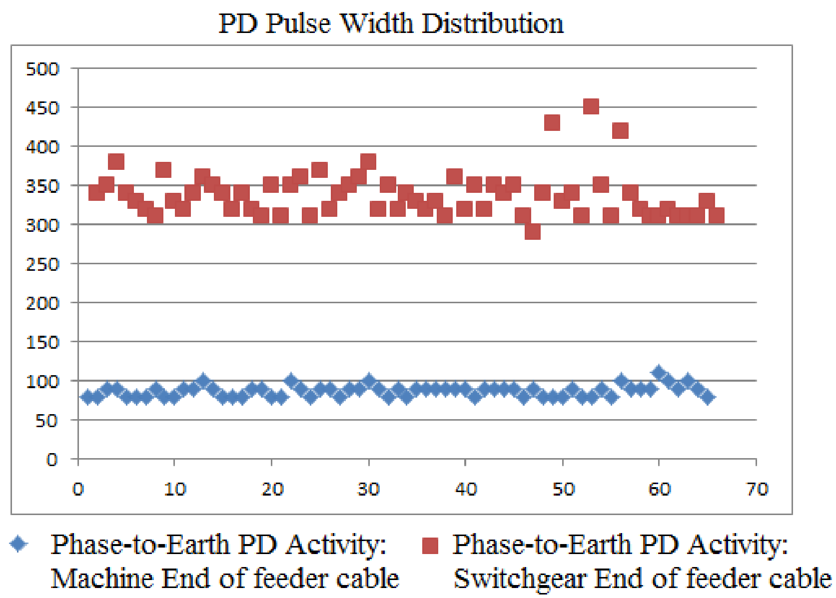
PD Pulse Propagation Analysis



Distribution of PD Pulse Widths at Motor and Switchgear

‘Clustering’ analysis of PD pulse widths shows how frequency dependent dispersion and attenuation increases the width of the PD pulses as they propagate along the cable from their source within the HV motors’ stator winding.

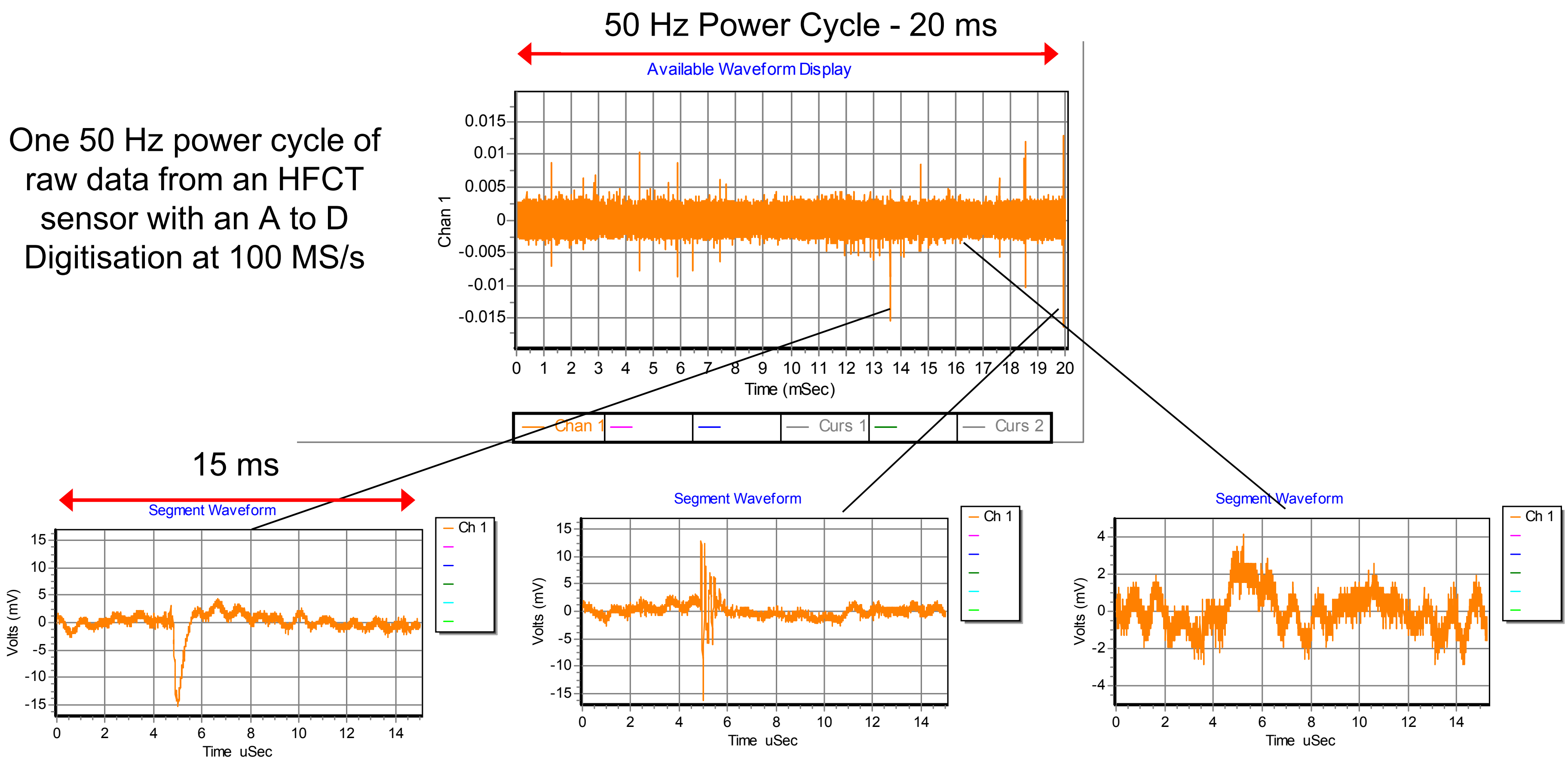




- The pulse widths for the ‘at HV motor’ measurements are in **blue (~90 ns),** and,
- The pulse widths for the same pulses detected at the switchgear cable end of the circuit (350 m away from the rotor) are in red **(~340 ns)**

Automatic PD Pulse Waveshape Analysis – sorting the PD from Noise

One 50 Hz power cycle of raw data from an HFCT sensor with an A to D Digitisation at 100 MS/s



Machine PD Pulse: 16 mV, 1160 pC

Switchgear PD Pulse: 15 mV, 24 dB

E/M Noise Pulse: 6 mV

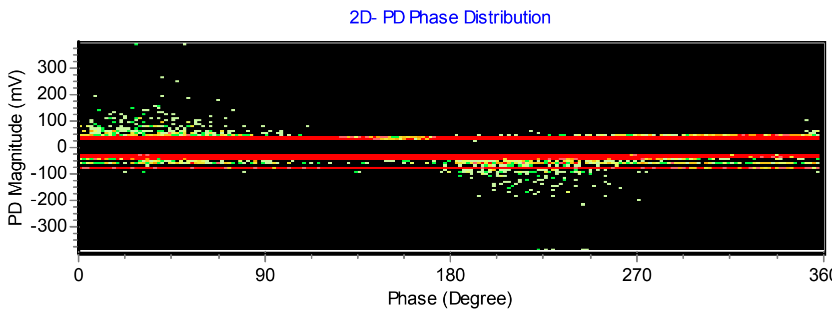
INSULATION CONDITION ASSESSMENT	ROTATING HIGH VOLTAGE (HV) MACHINES (3.3–15 kV)			
	PD Peak Level		PD Activity	
	High Frequency Current Transformer (HFCT) (nC)	High Voltage Coupling Capacitor (HVCC) (mV)	High Frequency Current Transformer (HFCT) (nC/Cycle)	High Voltage Coupling Capacitor (HVCC) (mV/Cycle)
Excellent	<2	< 20	<50	<500
Good	2–4	20–40	50–100	500–1000
Average	4–10	40–100	100–250	1000–2500
Still acceptable	10–15	100–250	250–500	2500–5000
Inspection recommended	15–25	250–600	500–1000	5000–10000
Unreliable	>25	>600	>1000	>10000

The analysis of OLPD test results is based on:

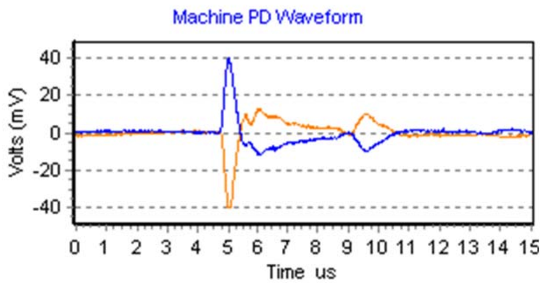
- PD level trends – e.g. the PD activity doubling in 12 months is a sign of severe insulation deterioration.

Jan 2009	June 2009	Jan 2010
8 nC	10 nC	17 nC

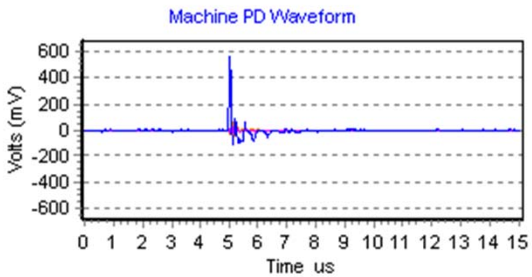
- Phase Resolved PD (PRPD) patterns – different defects have different phase patterns across the 50/60 Hz power cycle.



- PD pulse *'waveshape'* this can identify both phase-to-phase and phase-to-earth PDs and different PD sites within the machine's stator winding.



Phase-to-Phase PD



Phase-to-Earth PD

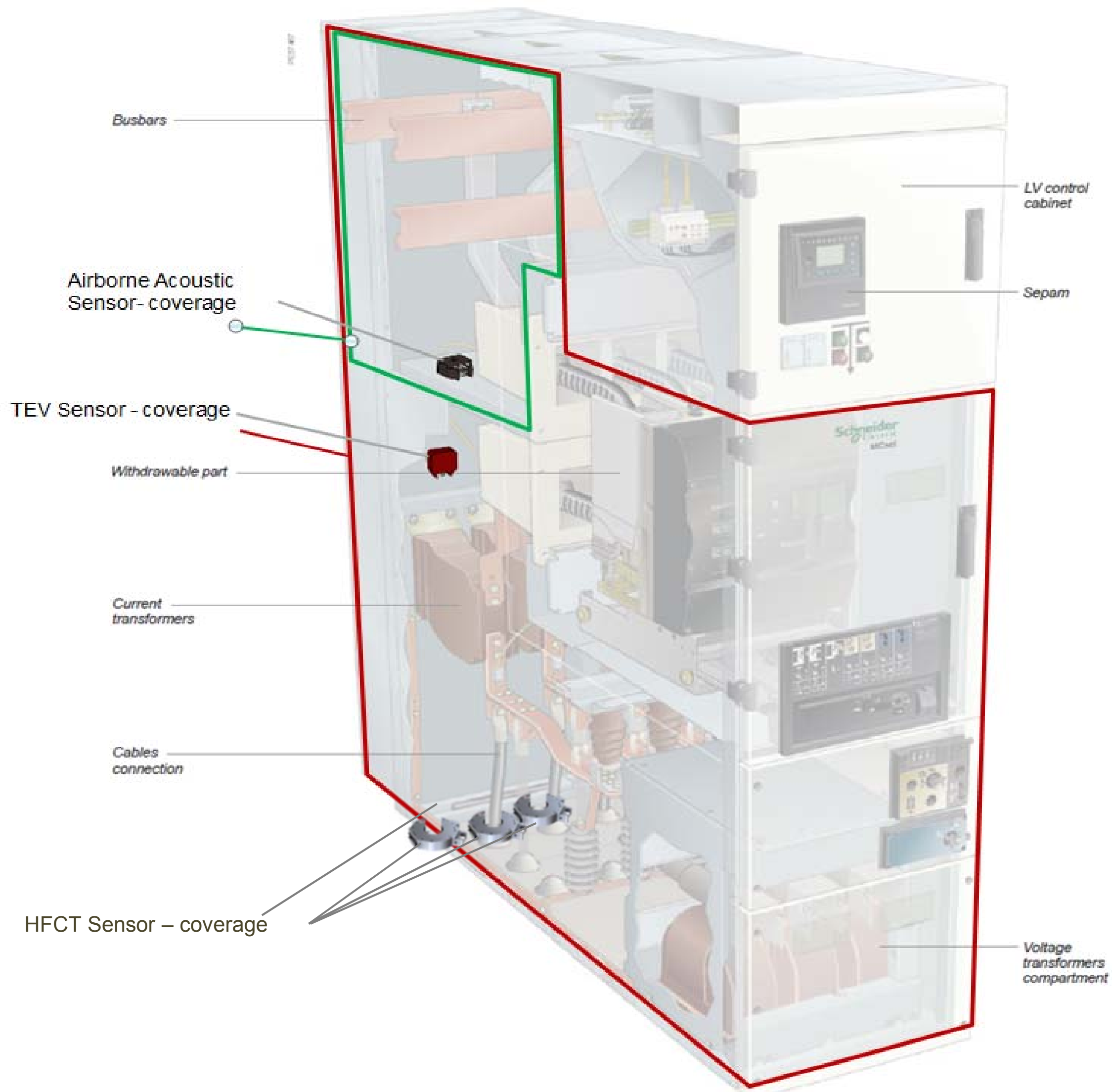
OLPD Sensors at the Switchgear Panel to Monitor the Complete HV Circuit

- HVPD recommend the use of a ***combination of three (3) OLPD sensors***, installed at the central switchboards, as follows:

- ***High Frequency Current Transformer (HFCT)*** sensors (one per phase) are used with to detect PD in the HV cables and the remotely connected plant (transformer or rotating machine)

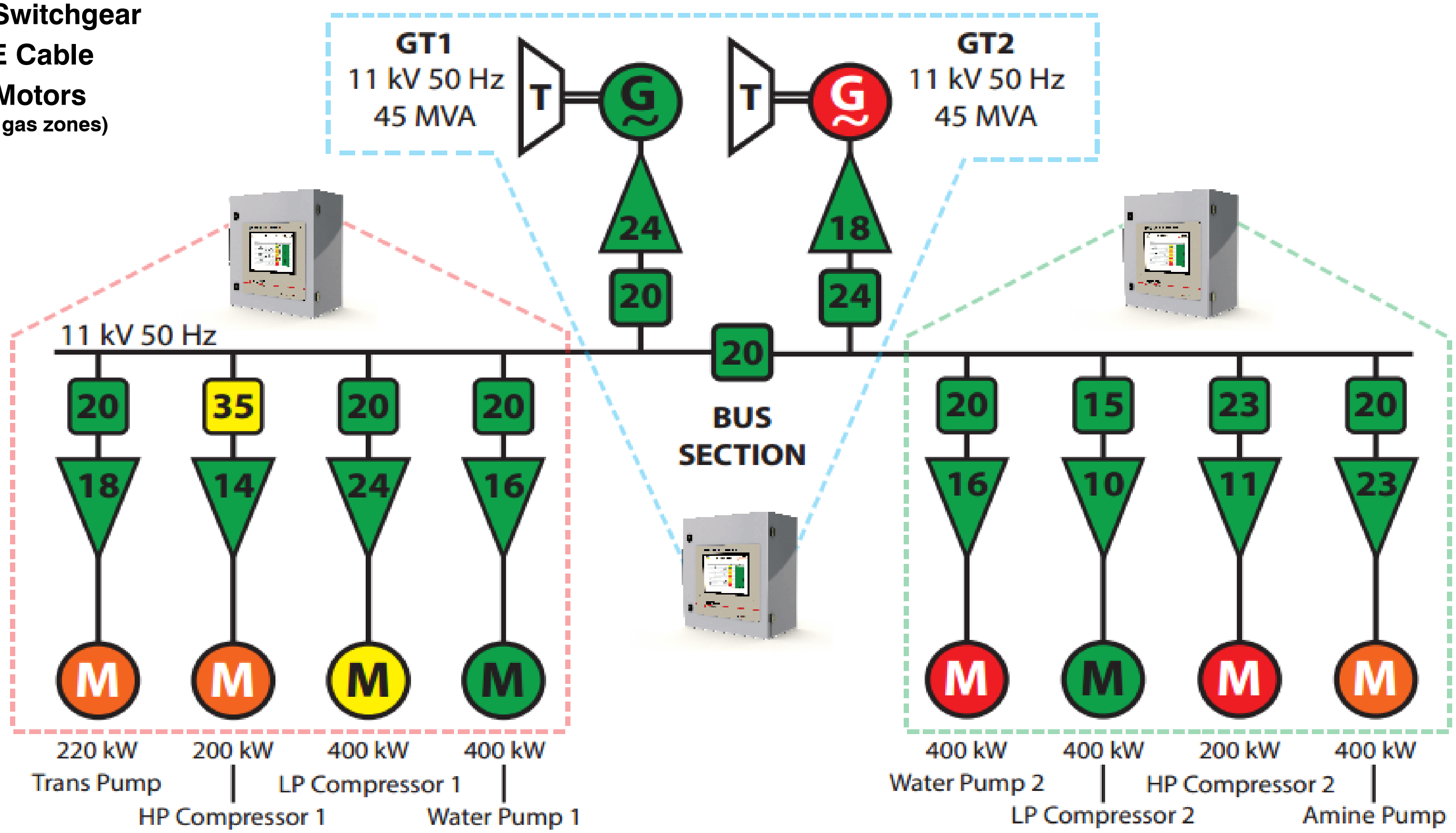
- ***Transient Earth Voltage (TEV)*** and ***Airborne Acoustic (AA)*** sensors are located inside the HV switchgear panels to monitor the sectionalised areas shown opposite.

- All co-axial signal cables are safely routed through to the LV section of the switchgear and then out of the switchboards to the HVPD-Sync monitor unit located in the substation.

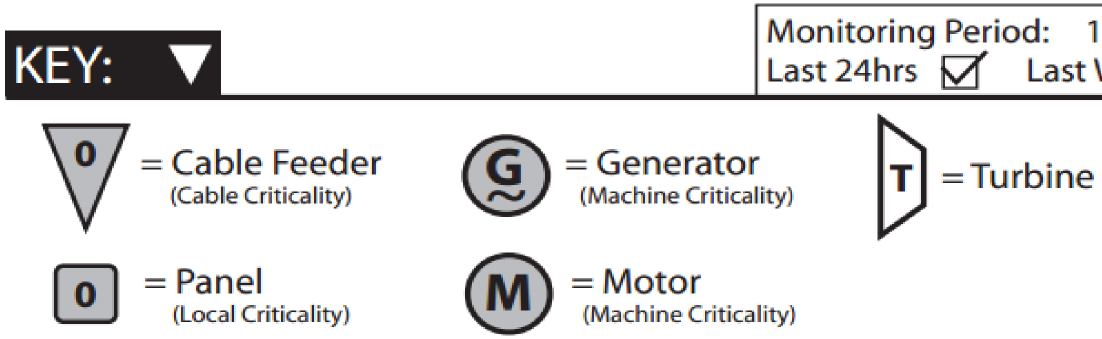


Complete 11 kV Oil & Gas Network Monitoring

11kV AIS Switchgear
11kV XLPE Cable
11kV 'Ex' Motors
(in hazardous gas zones)



Monitoring Period: 12/09/13 08:24 - 13/09/13 08:24
Last 24hrs ☑ Last Week ☐ Last Month ☐



On-line Partial Discharge 'OLPD League Table'

Reference	Comments	PD Monitor Trend	Condition
GT2	Slot/End-Winding PD Local Switchgear PD	Increasing PD	Unreliable
WATER INJECTION PUMP 2	End-Winding PD	Increasing PD	Unreliable
HP COMPRESSOR 2	End-Winding PD Local Switchgear PD	Increasing PD	Unreliable
AMINE PUMP	Slot Section PD	Increasing PD	Probable Inspection
HP COMPRESSOR 1	Slot/End-Winding PD	Increasing PD	Probable Inspection
TRANSFER PUMP	Slot/End-Winding PD	Stable PD	Probable Inspection
LP COMPRESSOR 1	Slot Section PD	Stable PD	Acceptable
GT1	Slot/End-Winding PD	Increasing PD	Good
WATER INJECTION PUMP 1	Slot/End-Winding PD	Stable PD	Excellent
LP COMPRESSOR 2	Slot/End-Winding PD	Stable PD	Excellent

COMPLETE HIGH VOLTAGE (HV) NETWORK OLPD MONITORING

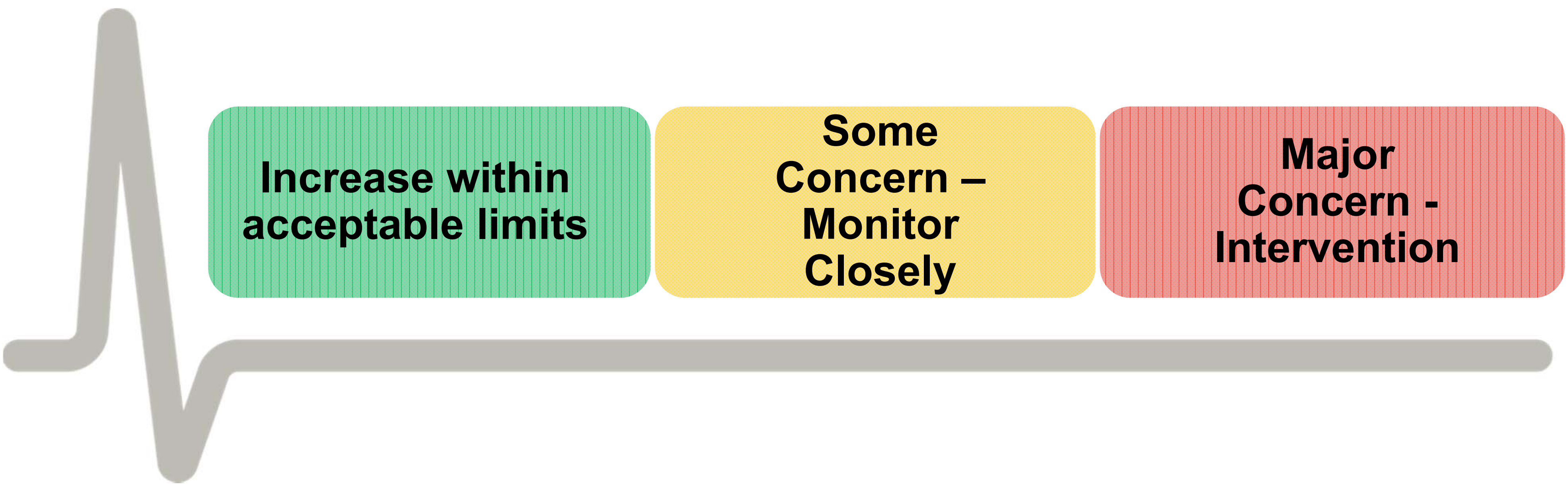
- Comprehensive OLPD monitoring coverage of entire HV networks, including ***generators/motors, switchgear, cable and transformers***.
- Real-time pooling of insulation Condition Monitoring (CM) data from multiple sensors / monitoring units across the network.
- Networking of this data is made to the remote ***Decision Support Centre (DSC)*** at HVPD for logging, comparison and trending.
- The condition of individual plant items is displayed on a user interface that contains the network's ***single line diagram*** with superimposed colour-coded plant condition indicators.
- The CM data allows the network operator to identify any plant with a significant risk of insulation failure and ***schedule preventative maintenance interventions*** to avoid outages.

HVPD

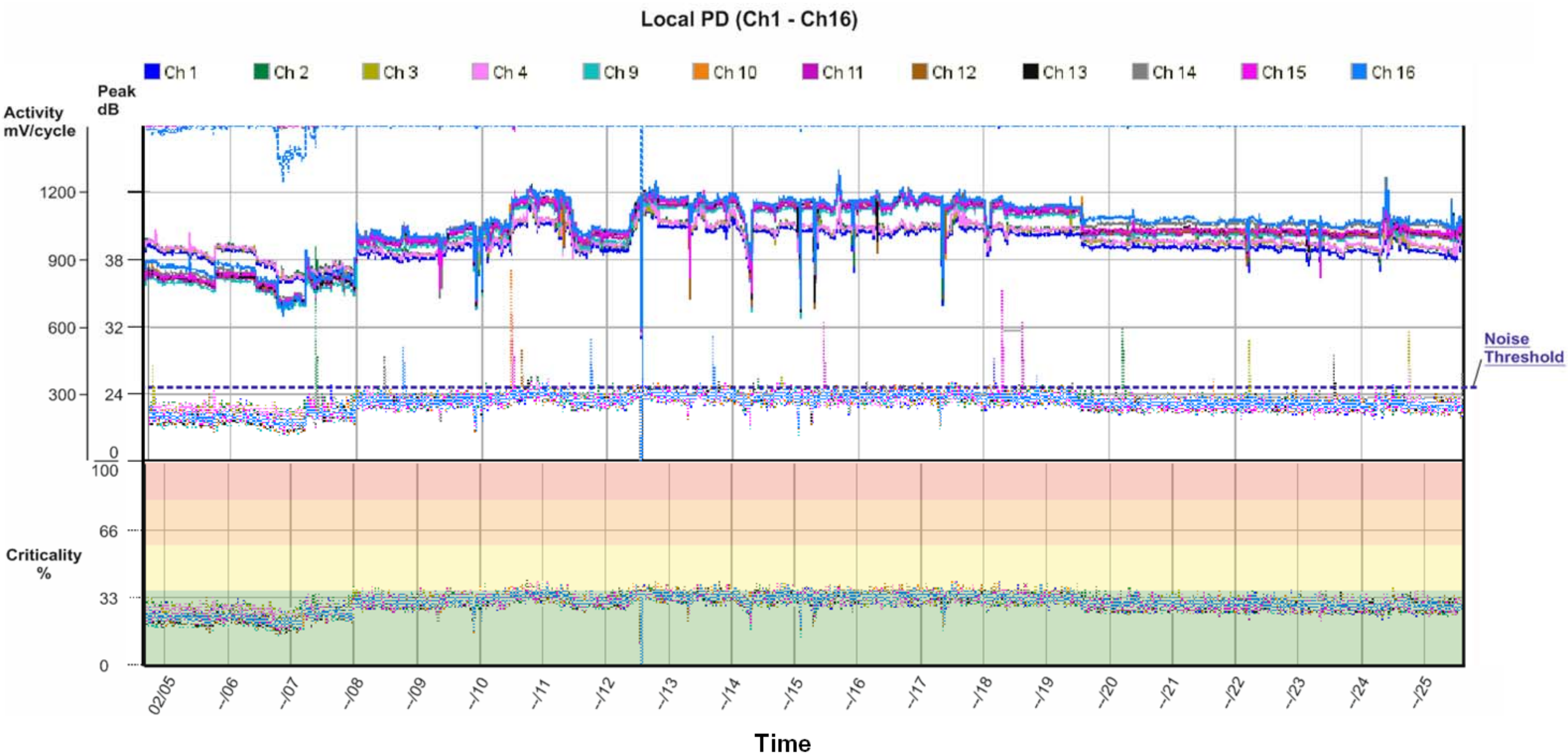
HVPD Complete HV Network OLPD Monitoring

HVPD-Multi™ Monitor
Automated alarms vs flags

- 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.



OLPD trend data after post-processing with HVPD Smoothing Algorithm™



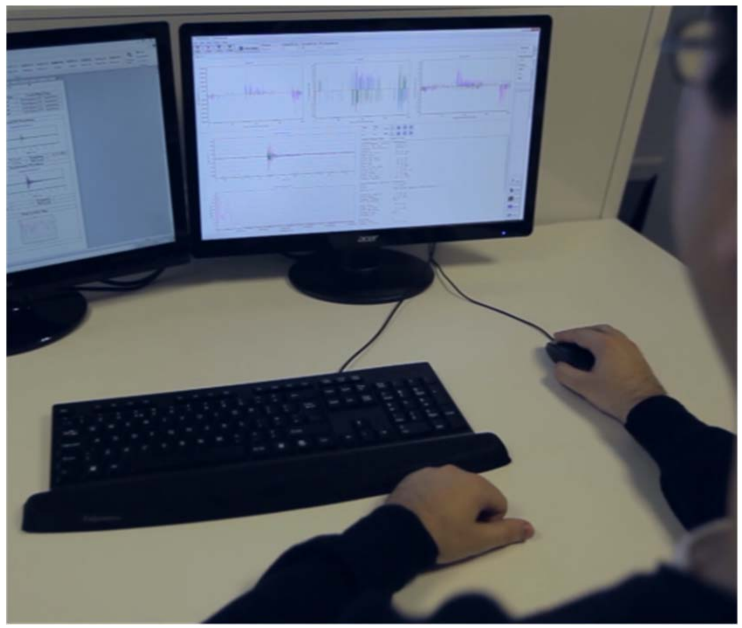
- The intermittent noise spikes (top) were removed to give % criticality values.
- After removal of the noise spikes by the software the PD levels for this HV motor showed low levels of PD with OLPD criticality levels of 22–36%.

HVPD Multi™ Monitor

30 day monitoring 'training' period

INSTALLATION

DATA ANALYSIS

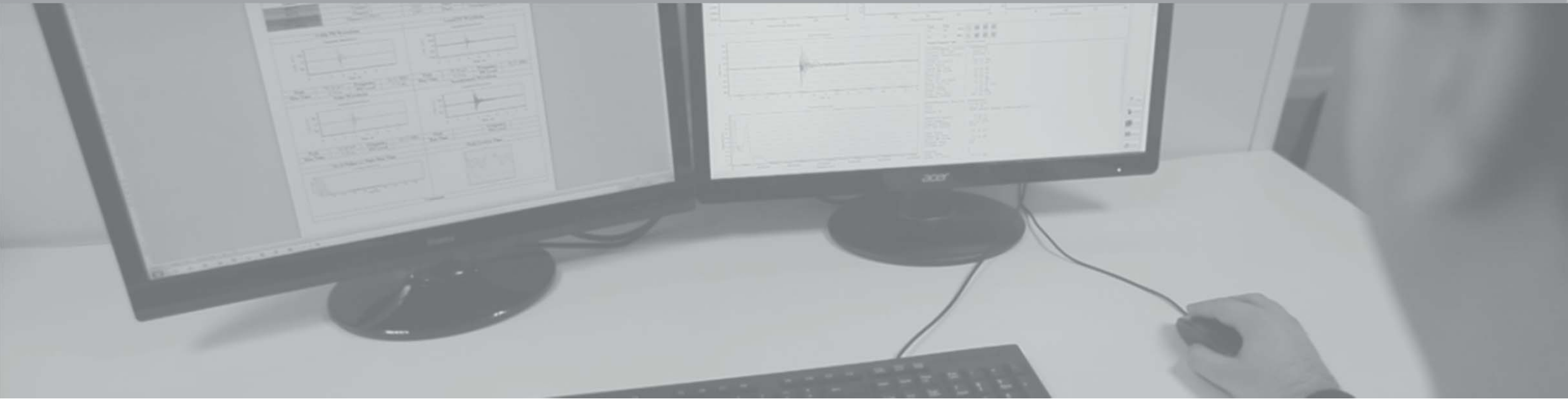


ADJUSTMENT

DAY 1

DAILY DATA ANALYSIS

DAY 30



- The data is analysed on a daily basis with the previous 24 hours of data compared against the present 24 hours of date
- At the end of the training period, the background noise level thresholds and software filter settings are adjusted
- This approach helps to avoid ‘false alarms’ being accidentally triggered by noise spikes and HV network switching

EXAMPLE OF HV NETWORK OLPD MONITORING SYSTEM USER INTERFACE FOR A CLIENT'S LARGE OIL REFINERY HV NETWORK SINGLE-LINE DIAGRAM (SLD)

HV Network OLPD Monitoring System User Interface linked to Oil & Gas Customer's SLD

HVPD TCO Monitoring Database

Analysis / Reports | Substations / Network Selection

Local Area Network Criticality League Table

Networks	Criticality (0-100) Cable	Criticality (0-100) 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

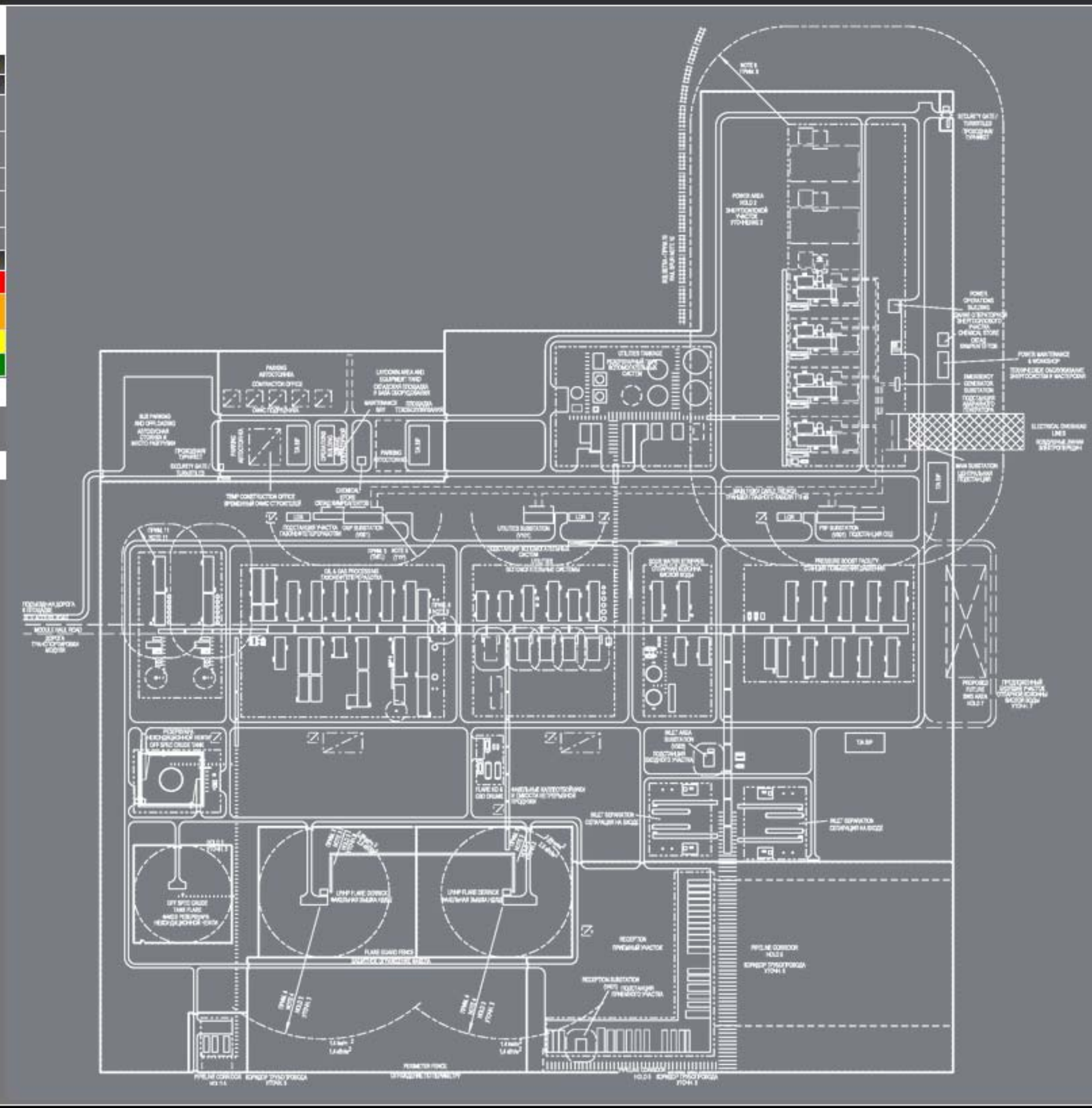
Condition/Action Guideline	Criticality (0-100)
High PD / Diagnostic	76-100
Moderate to High PD / Investigate	51-75
Moderate PD / Monitor	26-50
Plant OK / No Action	0-25

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

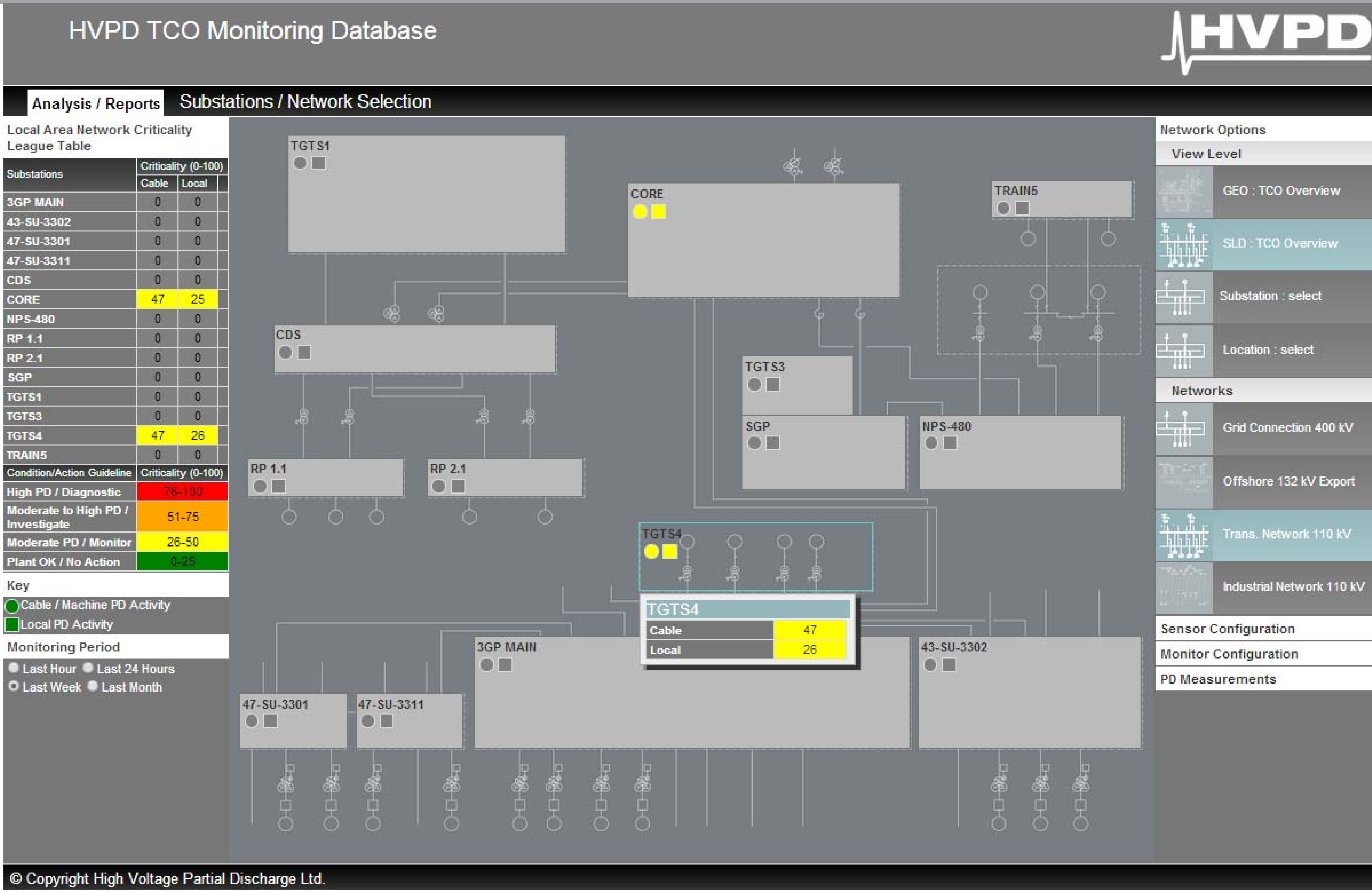
- Grid Connection 400 kV
- Offshore 132 kV Export
- Trans. Network 110 kV
- Industrial Network 110 kV

Sensor Configuration

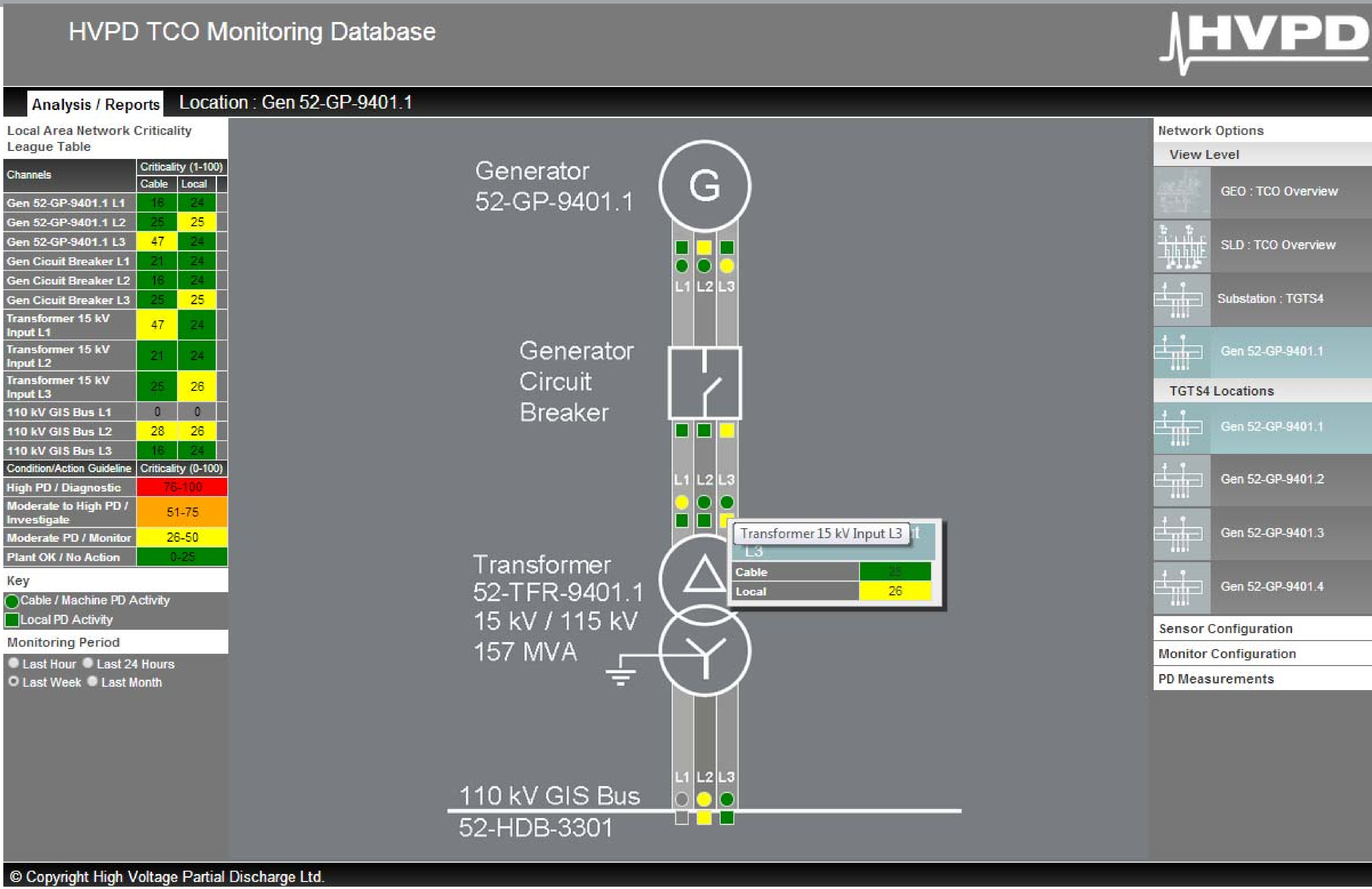
Monitor Configuration

PD Measurements

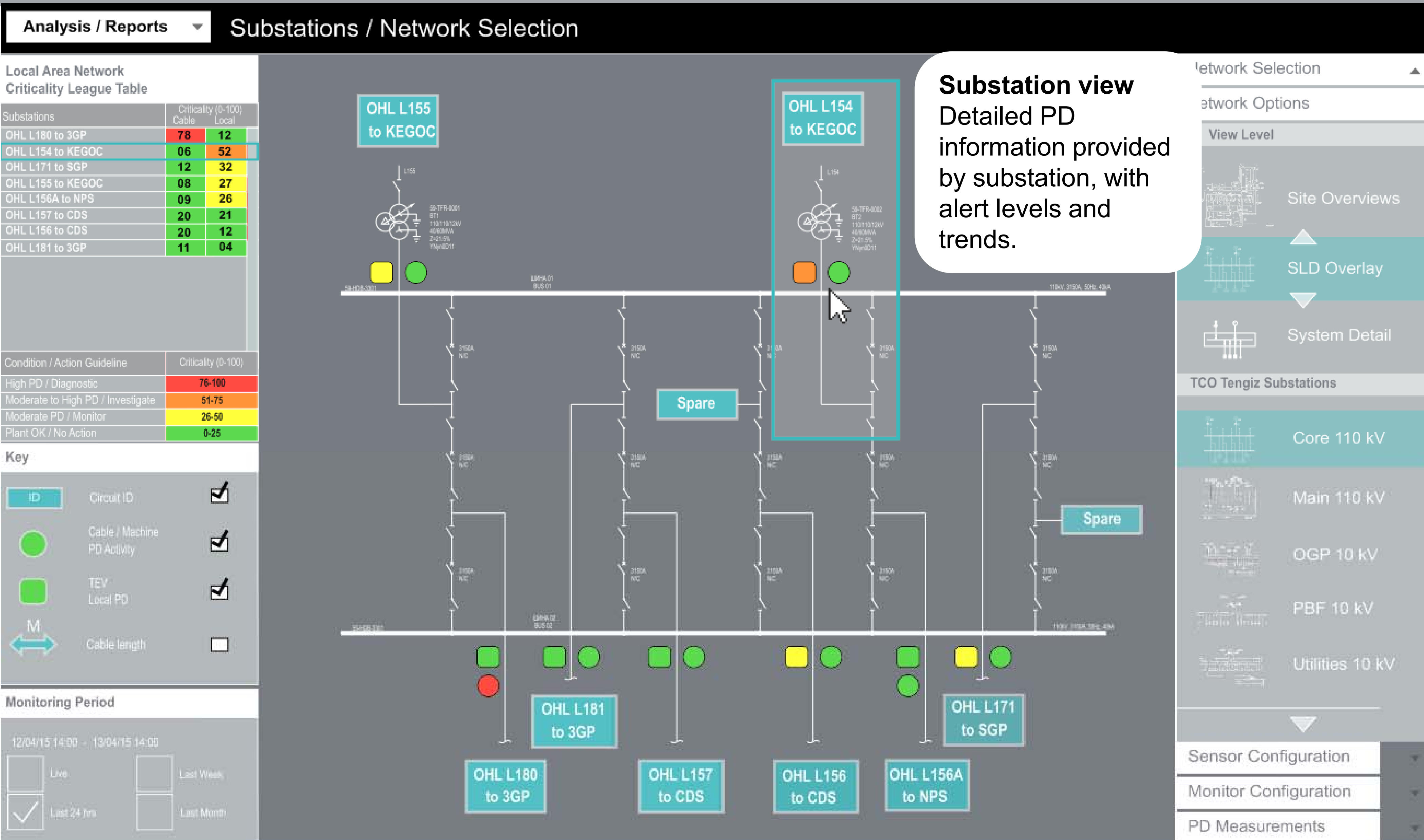
HV Network OLPD Monitoring System User Interface linked to Oil & Gas Customer's SLD



HV Network OLPD Monitoring System User Interface linked to Oil & Gas Customer's SLD



HV Network OLPD Monitoring System User Interface linked to Oil & Gas Customer's SLD



Substation view
Detailed PD information provided by substation, with alert levels and trends.

HVPD Monitoring Database

- Alongside the monitoring technology, HVPD also offer our clients an ongoing data monitoring and support service
- Technical support from HVPD engineers (via email/phone)
- Emergency response by phone on any identified incidents
- Monthly condition monitoring (CM) reports
- Diagnostic recommendations from the OLPD monitoring data, HVPD act as an external ***Decision Support Centre (DSC)***
- Comparison and benchmarking of the OLPD activity in the HV network to the ***HVPD OLPD Measurements Database©***
- Annual software upgrades and updates to the latest version of the HVPD OLPD Measurements Database©

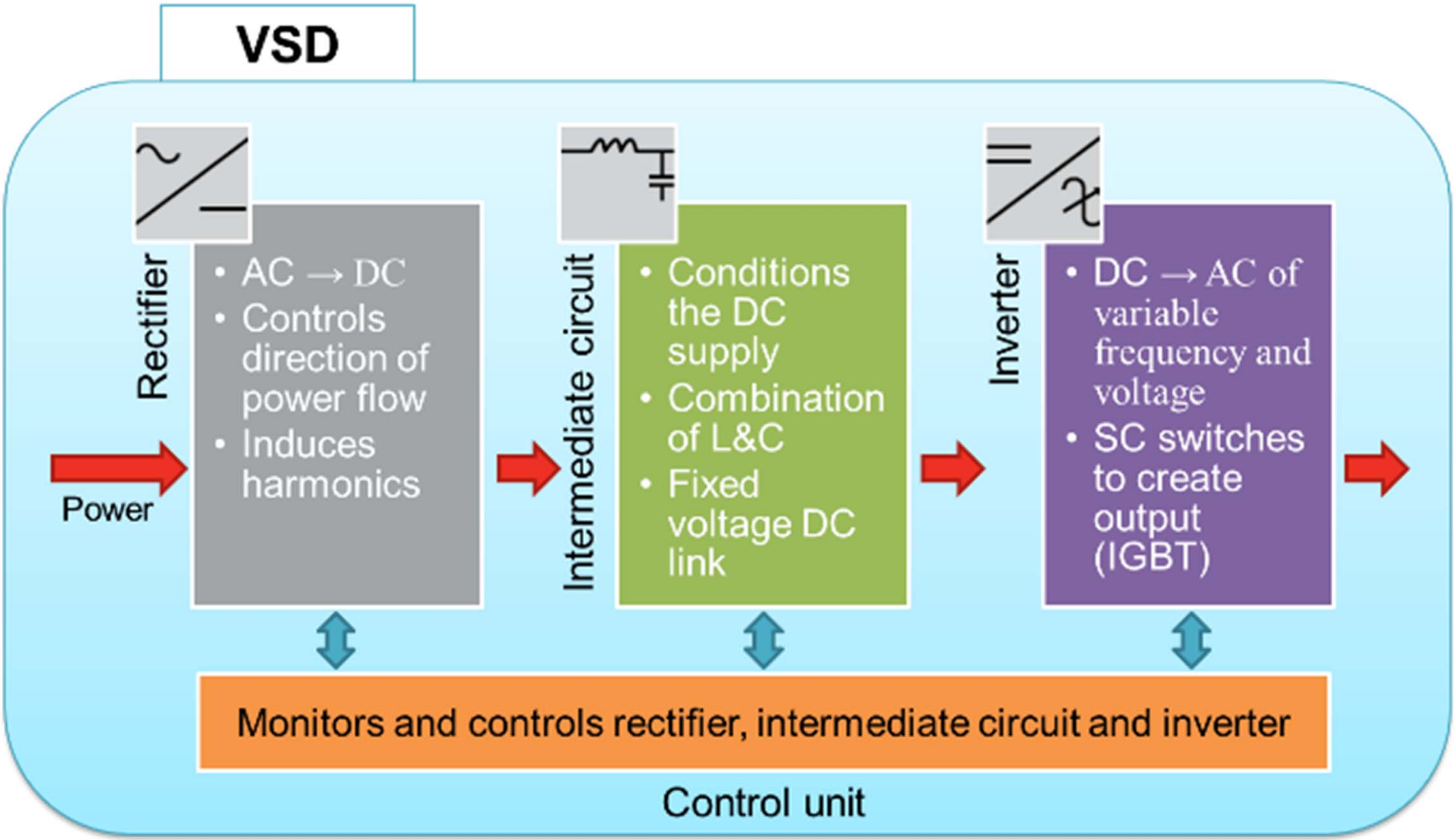
HVPD

PRESENTATION IV

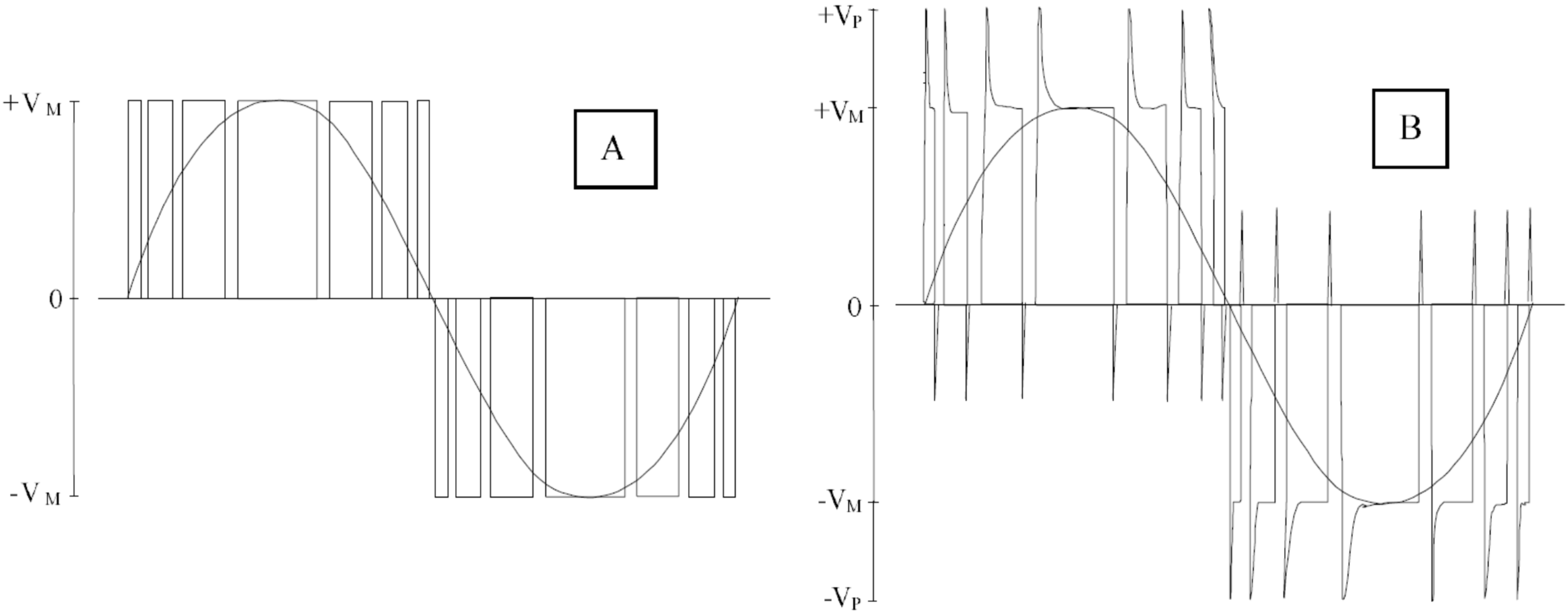
On line Partial Discharge (OLPD) Testing and Monitoring of Variable Speed Drive (VSD) HV Motors

Six Noise Reduction Methods for VSD HV Motors and HV Generators
Advantages & Disadvantages

NOISE REDUCTION METHOD	ADVANTAGE	DISADVANTAGE	NOTES
1. Use a ‘***Twin-Coupler’ HVCC installation*** (2x HVCC sensors per phase) at the machine terminals	• Can clearly distinguish interference from outside of the machine using Time-of-Flight (TOF) measurements ***with sensors separation down to 1.5m.*** • The HVCC allows for a good reference signal of power frequency	• Compact termination boxes may not have space for the two HVCC’s separated by a minimum of 1.5 m • May still be hard to distinguish PD from VSD noise if the interference is large	• High sampling rate digitiser (>250 MS/s) is required to distinguish pulses with the correct accuracy. • It is recommended that the 2x HVCC sensors are installed at the motor terminal box separated by a minimum of 1.5m
2. Use a ***‘Twin-HFCT’ installation*** (with 2x HFCT sensors per phase) at the machine terminal box or one at the machine terminal and the other at the VSD drive.	• Can clearly distinguish interference from outside of the machine using Time-of-Flight (TOF) measurements ***with sensors separation down to 3m.***	• Cable termination may not have space for two HFCTs, separated by 1.5 m • Pulses don’t have as sharp rise times on the HFCT sensor as they do on the HVCC sensors so distinguishing pulse start times is harder	• High sampling rate digitiser (>250 MS/s) likely required to distinguish pulses • Higher bandwidth HFCT required to detect any fast rise times (of <10 ns) • It is recommended where possible that the 2x HFCT sensors are installed at the motor terminal with a minimum separation of 3m
3. HFCT/HVCC with other ‘gating ‘sensor	• Assists in the cases where terminal boxes have only room for one HVCC coupler or HFCT sensor	• Gate sensor may be subject to more interference than machine windings	• Install position and type of gating sensor to be determined, RF antenna or HFCT on ground could be options
4. Hardware Filtering	• Filter can be selected for the VSD interference pulses bandwidth • Dynamic range of digitised maintained.	• Each VSD needs to be characterised for the best filter solution • PD pulse shapes can be distorted by filters if they are not chosen carefully	
5. Software Filtering	• Software Filters can be selected for the VSD interference pulses bandwidth • Easier to adjust filter design pose installation than with hardware.	• Possible loss of dynamic range on digitiser over hardware options • Each VSD needs to be characterised for each filter – some ‘training’ required • PD pulse shapes distorted by filter	
6. Event recognition	• VSD pulses can be characterised and discounted based on waveshape • PD pulses can be characterised and identified based on waveshape	• Overlap of VSD and PD pulses not taken into account. • Large magnitude/quantities of VSD pulses may make PD identification hard	• VSD/PD pulse overlap is of particular concern where machine windings are subject to very fast rise time VSD pulses that can degrade insulation.

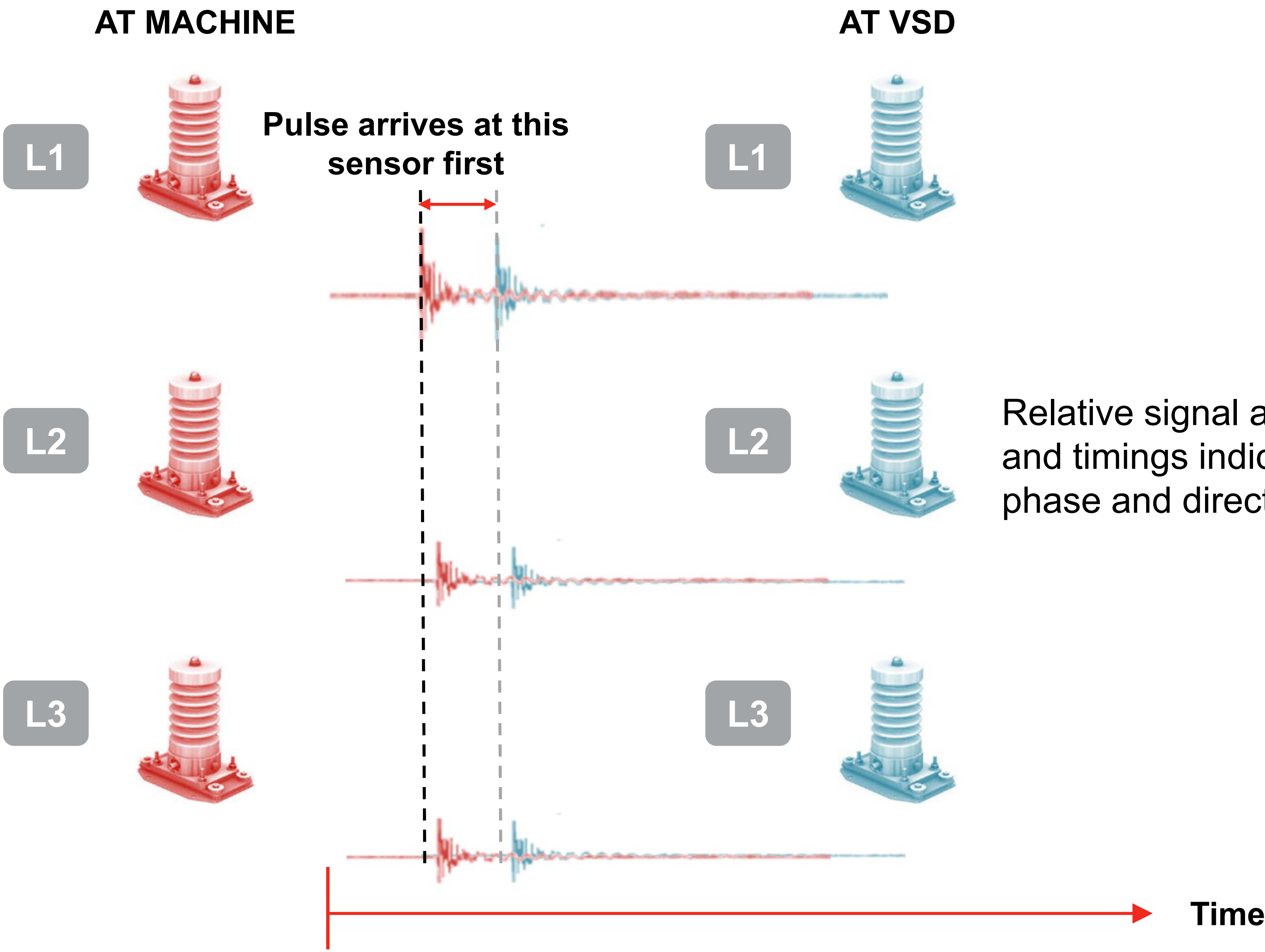

VSD
Rectifier
• AC → DC
• Controls direction of power flow
• Induces harmonics
Power
Intermediate circuit
• Conditions the DC supply
• Combination of L&C
• Fixed voltage DC link
Inverter
• DC → AC of variable frequency and voltage
• SC switches to create output (IGBT)
Monitors and controls rectifier, intermediate circuit and inverter
Control unit

Comparison of voltage pulses at the output of the VSD (A) and at the input of the motor (B)



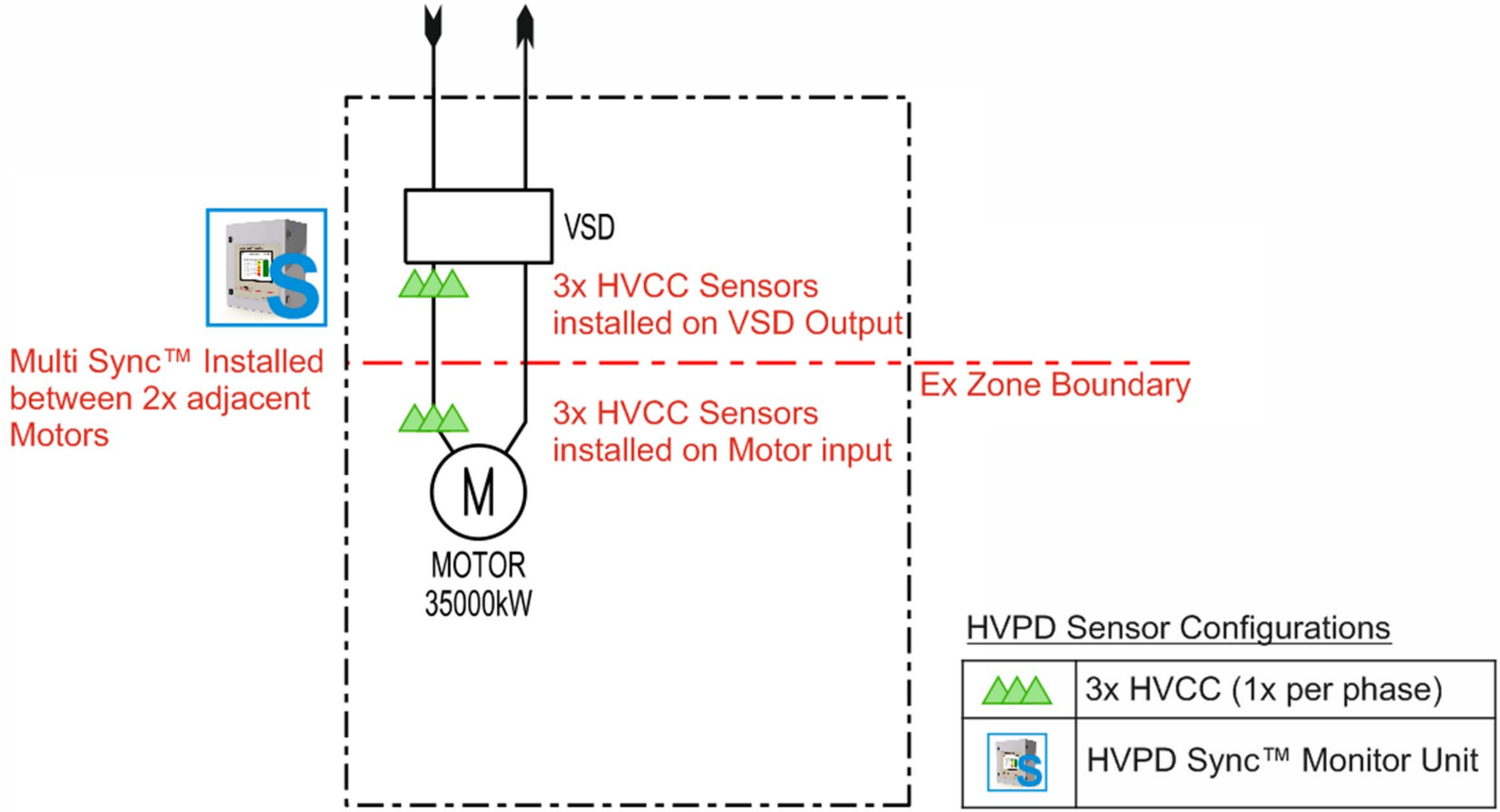
- HVPD's have experience with inverter-fed rotating machines from over 10 years of OLPD testing of in-service rotating HV machines.
- Designed to reliably measure partial discharge (PD) in the HV stator winding of VSD/ASD-fed machines, whilst discounting any high-frequency electromagnetic (E/M) 'noise' signals from the VSD switching electronics.
- The HVPD Sync™ OLPD Monitor, and a combination of hardware and software noise reduction techniques, including the use of a 'twin-sensor' monitoring approach with two sensors installed per phase to carry out 'precedence' pulse arrival measurements to discount VSD/ASD 'noise' from PD in the motor HV stator windings.

- Used to conduct pulse precedence measurements
- Compares the pulse’s arrival times to the first and the second sensor (on the same phase).
- Locates the source of the PD to a particular item of plant item in the network (in this case the rotating HV machine’s stator winding)
- Discounts the external E/M ‘noise’ (in this case from the inverter switching pulses from the VSD/ASD drive).

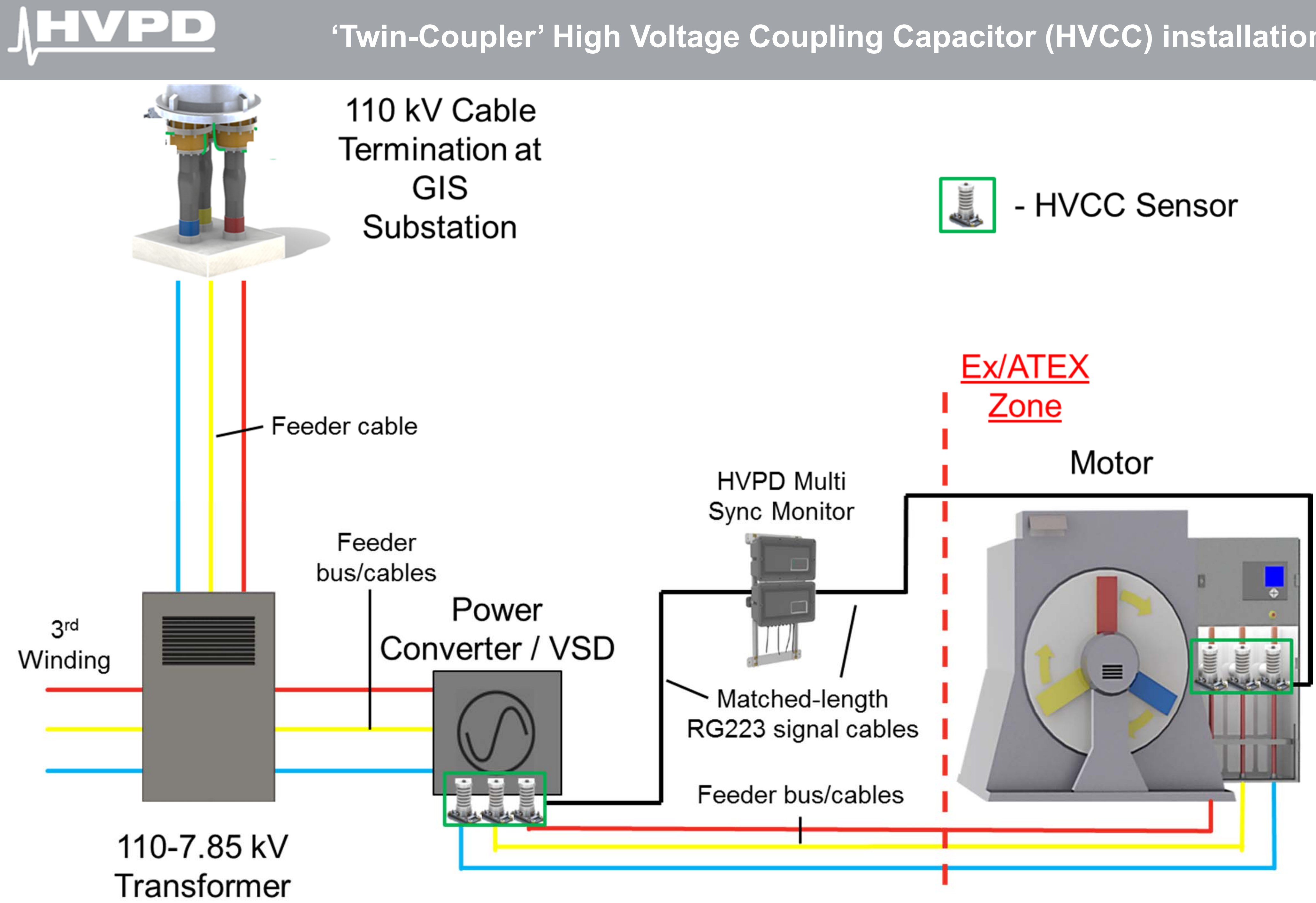


Relative signal arrival times and timings indicate source phase and direction

Example of an ASD/VSD Motor OLPD Monitoring Solution with HVCC Twin Couplers

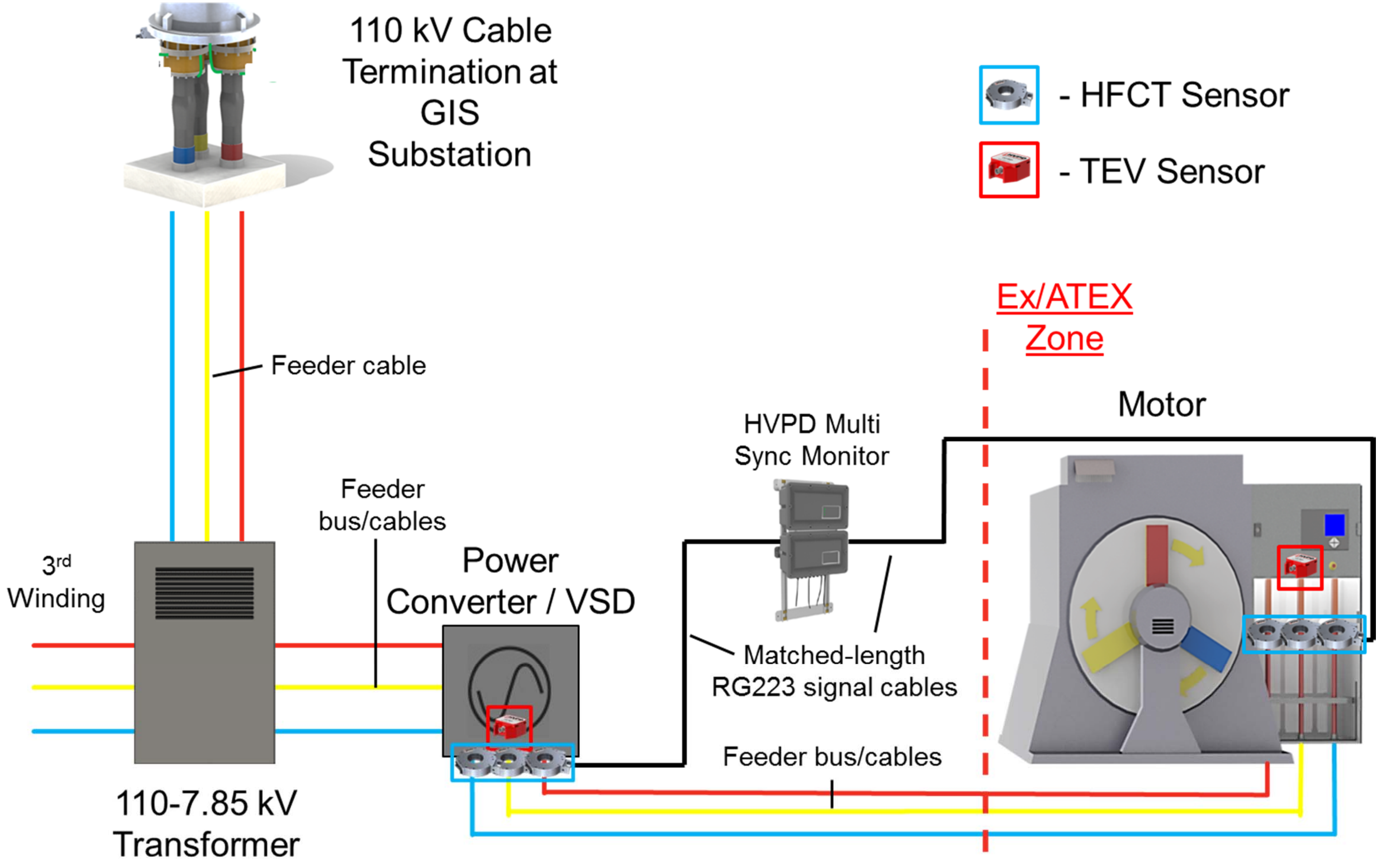


‘Twin-Coupler’ High Voltage Coupling Capacitor (HVCC) installation



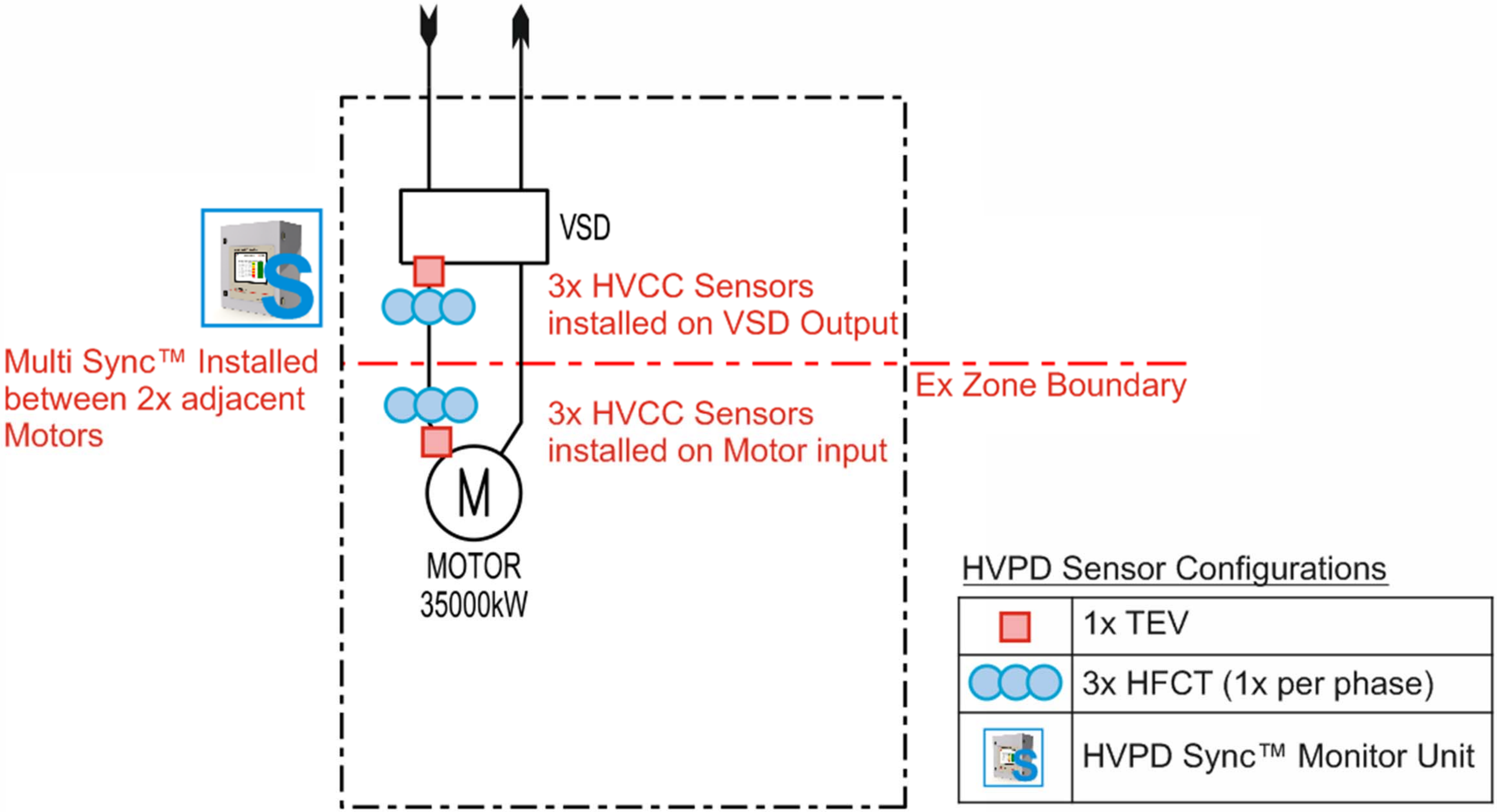
- The matched-length sensor coaxial signal cables are routed back to the HVPD Remote Terminal Unit (RTU) or HVPD Sync™ monitor.
- The monitor is located equidistant between the VSD drive and the motor.
- The direction of the origin of any pulse detected can be identified
- Any pulses detected first on the HVCC/HFCT sensors nearest to the VSD are discarded.
- Simultaneously, pulses arriving from the other direction, i.e. from the stator winding of the HV motor, can be captured and analysed by the HVPD Sync™ OLPD Monitor.

'Twin-HFCT' Sensor Installation



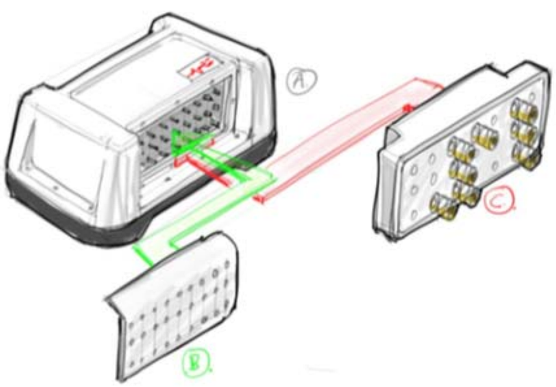
HVPD

Example of an ASD/VSD Motor OLPD Monitoring Solution with ‘twin-HFCT’ sensors plus 1xTEV



HVPD-Sync™ Permanent OLPD Monitor

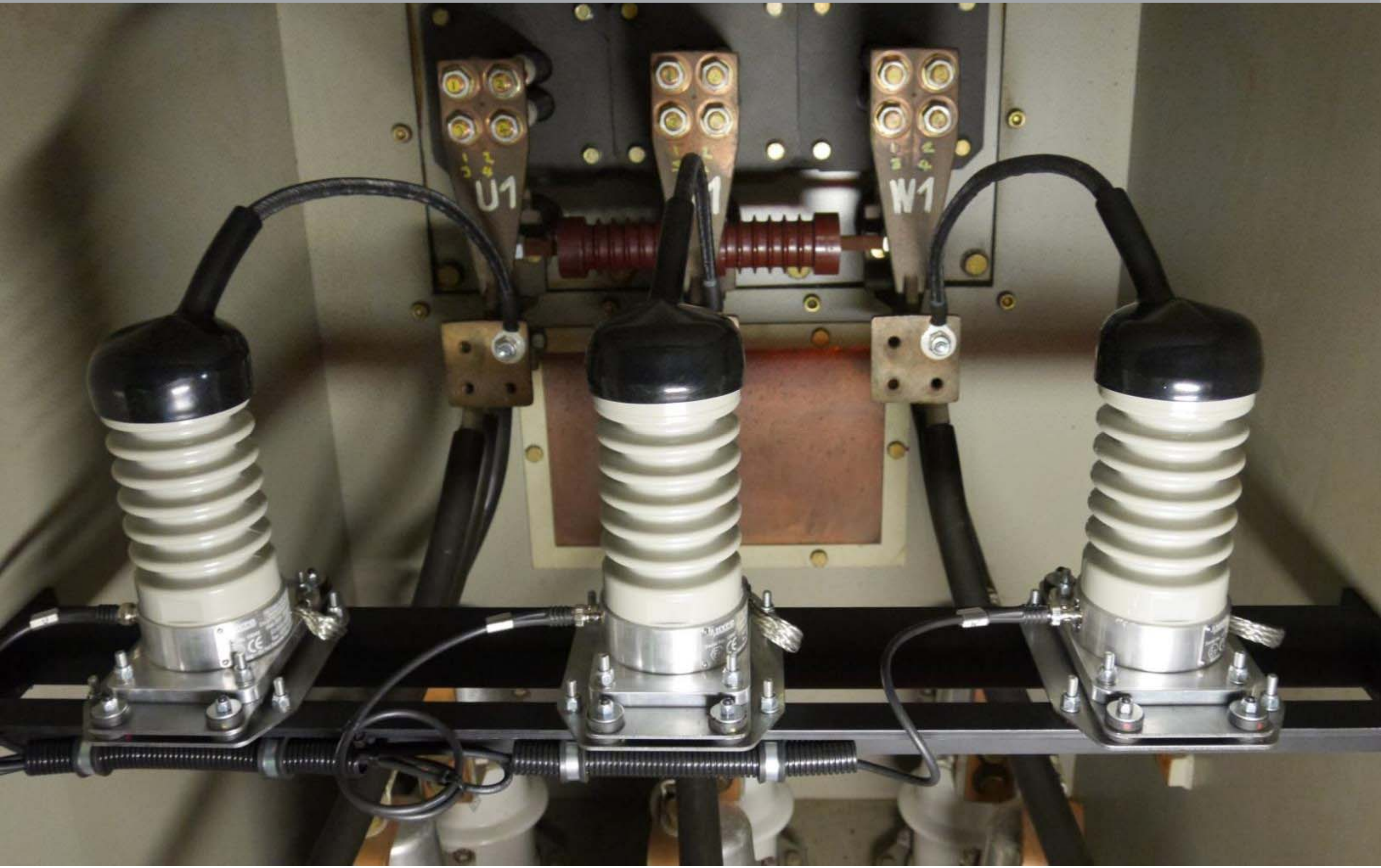
Can Monitor up to 4x HV Circuits Simultaneously



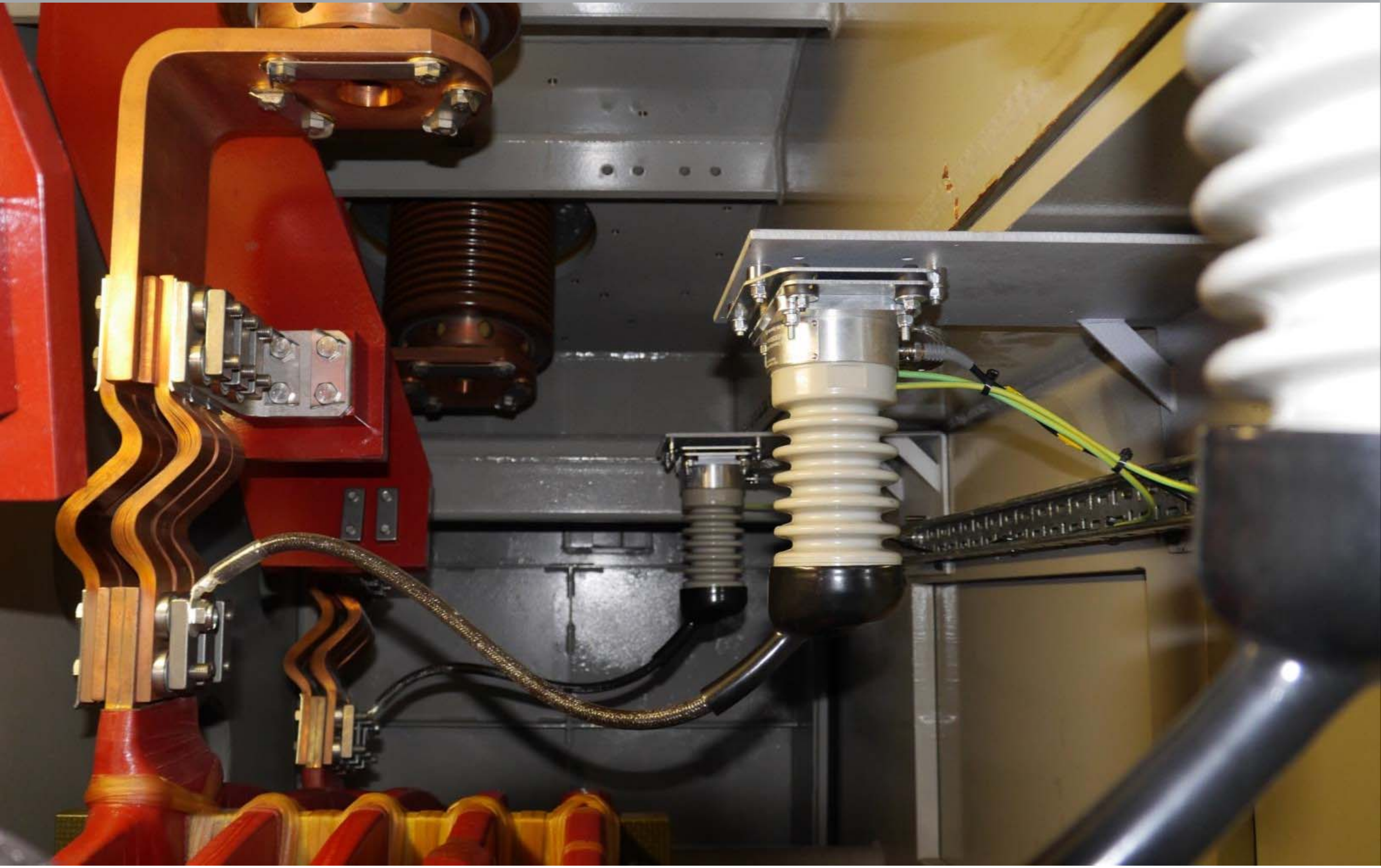
- Continuous, centralised, remote OLPD monitoring of PD in switchgear, cables and rotating HV machines.
- 4x complete HV feeders (including the remotely connected HV plant) can be monitored by one monitor.
- Compatible with all types of OLPD sensors.
- IP65 Rated (Outdoor UBS shell), suitable for a wide range of applications and environments.
- Remotely accessible via Modbus TCP-IP, RS485, GPRS/3G modem or manual data download.
- Onboard automatic waveshape pulse analysis software provides differentiation of all PD pulses from ‘noise’
- The system generates a ‘PD Criticality’ number from 0–100% through ***comparison and benchmarking*** with the ***HVPD OLPD Measurements Database***©.

- 6-channel, synchronous data acquisition capability
- Measurements on all 6 channels can be made to within 5 ns of each other on all channels)
- Specifically designed for use with the HVCC ‘Twin Coupler’ or ‘Twin HFCT’ sets of sensors installed in the VSD drive and motor terminal boxes.
- Characterises and discards VSD pulses based on their wave shape while simultaneously characterising and identifying PD pulses.

Permanent On-line HVCC Installation in 11 kV Generator Terminal Box



Permanent On-line HVCC Installation in 11 kV Generator Compartment



Permanent HFCT OLPD Sensors in Ex/ATEX Motor Cable Box

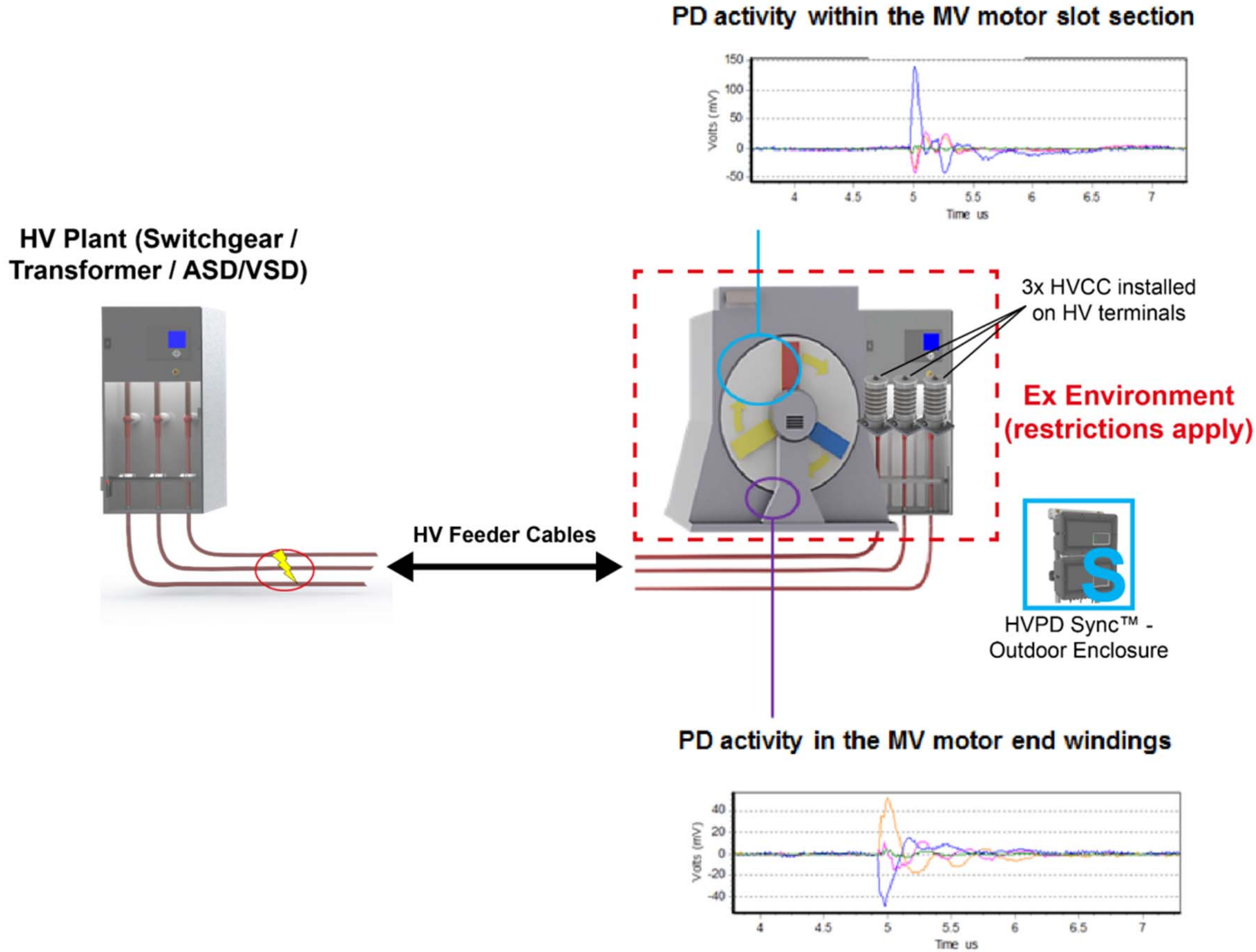
- The sensors and monitor arrangement shown can be used for HV cable lengths (from the VSD drive to the motor) of up to 100 m.
- The two RG223 co-axial signal cables from the VSD sensors and the motor cable box sensors would both be 50 m in length, this being the maximum length possible.
- The minimum separation between the ‘twin-HVCC’ sensors is a minimum separation of 2 m from each other
- The HFCT sensors require a minimum separation of 2.5 m (due to having a lower frequency response than the HVCC sensors).
- These separations refer to the minimum required distances in the case where both sets of twin sensors are being installed in a single, large cable boxes (such as on a large generator).

- The OLPD measurements made by the sensors are conditioned by a number of hardware and software filter modules that are selected according to the bandwidth of the VSD interference.
- Hardware filters cannot distort the shape of the PD pulses and/or completely remove the PD pulses themselves.
- The HVPD Sync™ OLPD Monitor also uses a number of software filters that are both flexible and adaptive since their cut-off, notch or band-pass frequencies can be adjusted after installation through remote communications and software upgrades.
- HVPD strongly recommend that a preliminary *desktop engineering study* is made of the details of the VSD-driven motor, including cable box drawings, details of the VSD system, etc.
- Baseline measurements of the E/M noise present in the circuit should also be carried out during the commissioning of the monitor in order to select the correct hardware filters. The monitor then undergoes a 30–60 day ‘training period’ where remotely-programmed, adaptive software filters are adjusted to remove any E/M noise sources on the network *whilst preserving the PD pulses*.

- Ex/ATEX-rated OLPD sensors termination boxes and suitable cable glands must be used.
- HVPD supply Ex/ATEX rated versions of HVCC sensors and HFCT sensors.
- These sensors are permanently installed inside the VSD and motor HV cable / bus compartment (one per phase)
- BNC signal connections are brought out to an external sensor connection box on the side of the motor and then outside of the Ex/ATEX zone through suitable Ex/ATEX signal cable glanding, as specified by the client.

HVCC PD Coupler Sensor Termination Boxes

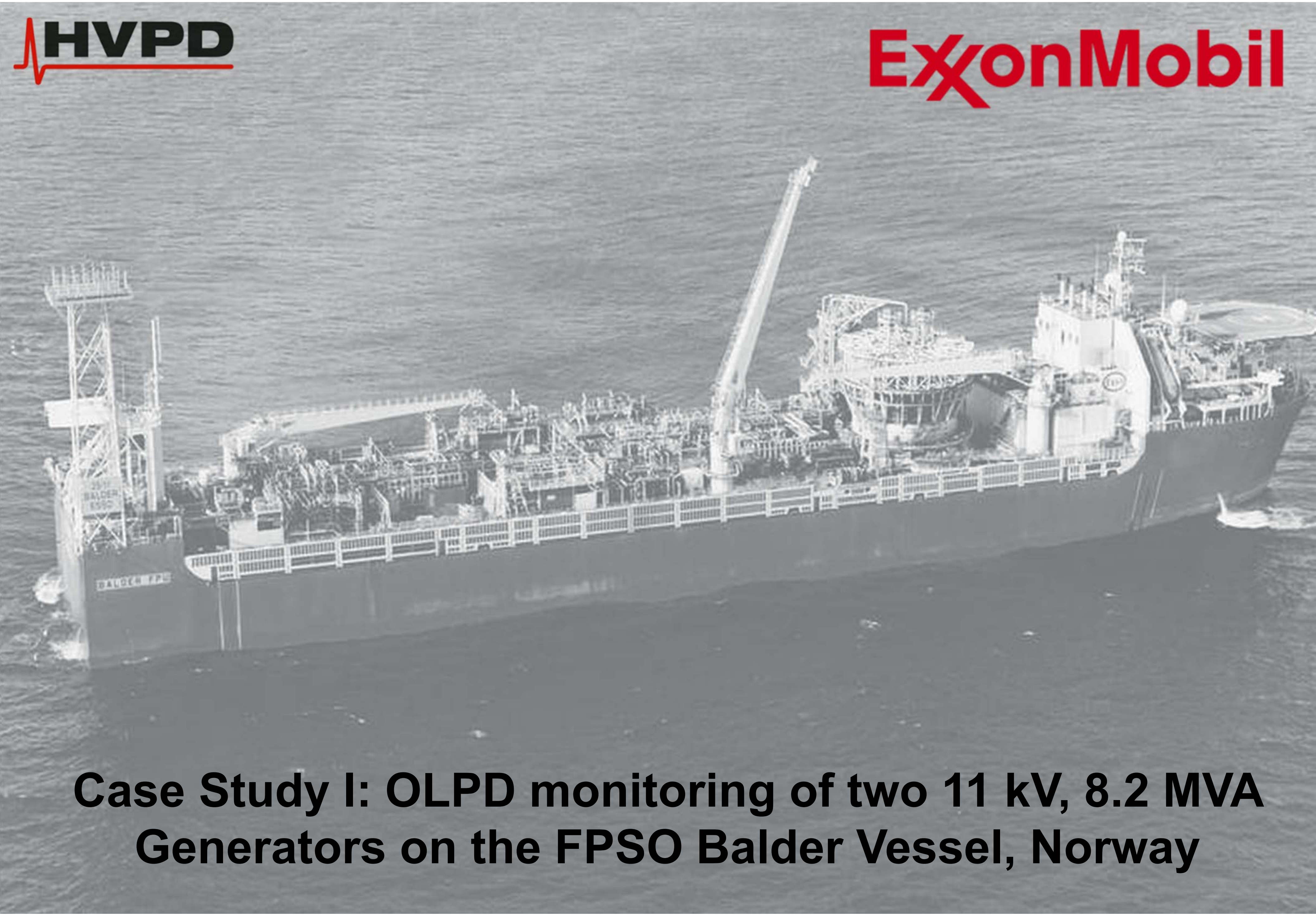
Direct OLPD monitoring of HV Motors located in Ex/ATEX zone



- Reliably measure PD in the HV stator winding of VSD machines
  - System discounts high-frequency, EM signals from the VSD switching electronics.
  - Achieved by a combination of hardware and software VSD noise reduction techniques,
- HVPD's solution employs *'Twin-Coupler' HVCC* sensors installed at the *minimum distance of 1.5 m from each other* in the machine's cable box. Alternatively, *'Twin-HFCT'* sensors can be used although these must be installed at a *minimum distance of 3 m from each other*.
- Hardware and software noise filters, combined with pulse 'precedence' measurements from the twin sensors to provide a robust system to discount any pulses that are received on the HVCC nearest to the VSD whilst preserving the PD pulses from the machine's stator winding that arrive first on this sensor.

PRESENTATION V

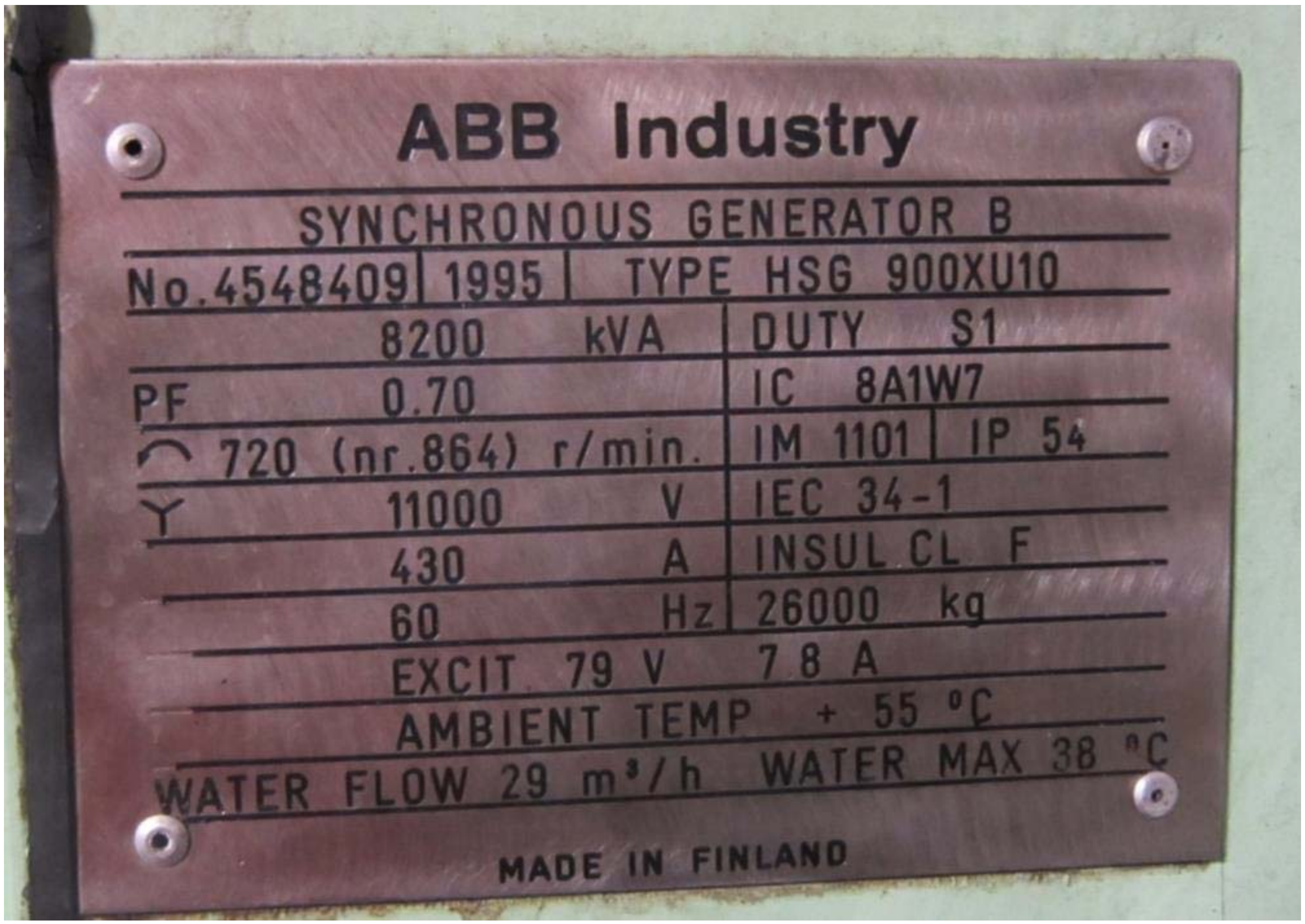
Case Studies from HVPD's recent OLPD Test and Monitoring Projects in the Worldwide Oil & Gas Industry



Case Study I: OLPD monitoring of two 11 kV, 8.2 MVA Generators on the FPSO Balder Vessel, Norway

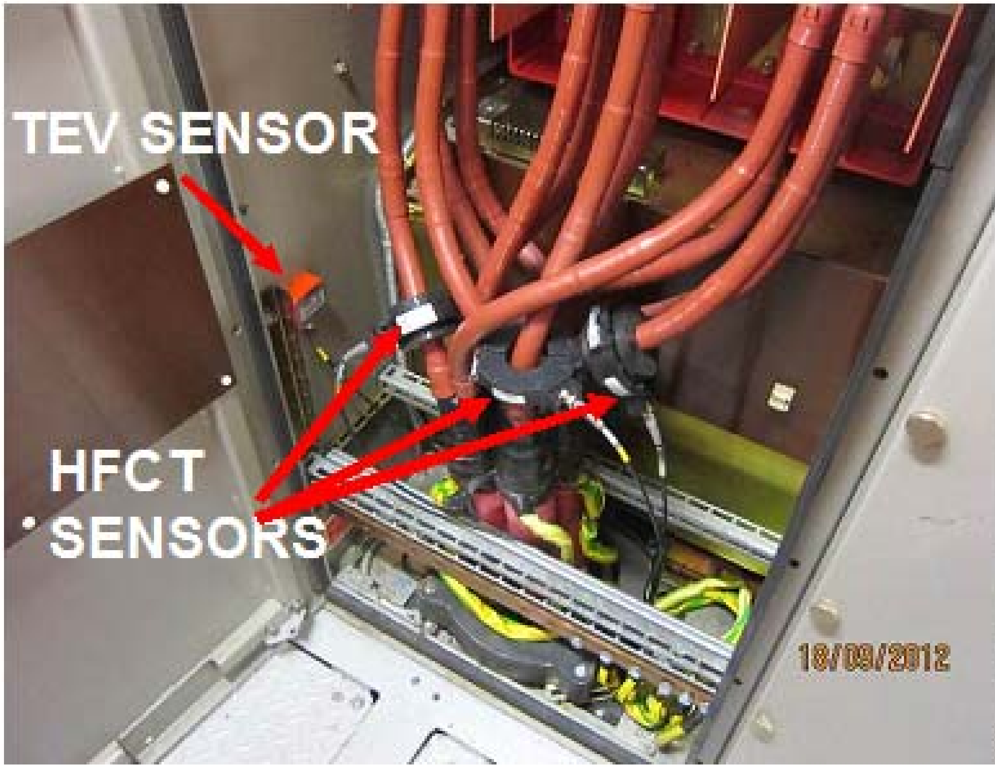
Nameplate of 11kV Generator B (FPSO Balder)

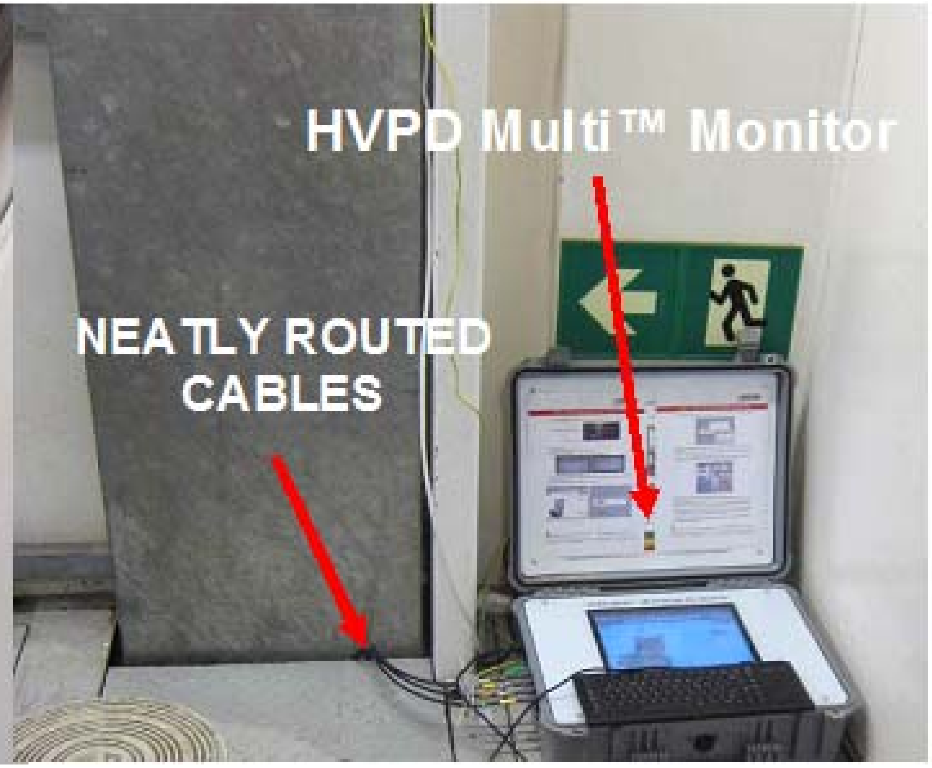
Generator	Reference	Manufacturer	Type	Rating (MW)	Voltage (kV)	Load I (A) *(From Name Plate)*	Year of Manufacture
Generator B	651-EG-01B	ABB	HSG 900XU10	8.2	11	430	1995
Generator C	651-EG-01C	ABB	HSG 900XU10	8.2	11	430	1995



HVPD Longshot™ OLPD Test System
at the 11 kV Switchboard

Portable HVPD Multi™ OLPD Monitor
at the 11 kV Switchboard


TEV SENSOR
HFCT
SENSORS
18/09/2012


HVPD Multi™ Monitor
NEATLY ROUTED
CABLES

HVPD

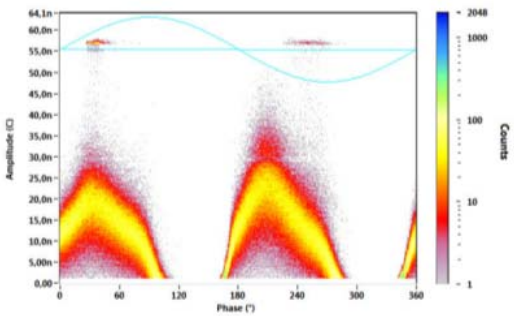
Temporary HFCT and TEV Sensor Attachments on 11 kV Generator B Cable *at the switchgear end of the circuit*

DC Test and Off-line Partial Discharge Test Data from Generator B &C

Recommended IR and PI Values at 40°C (According to NEK410)	
IR	> 3,6 MΩ
PI	> 2,0

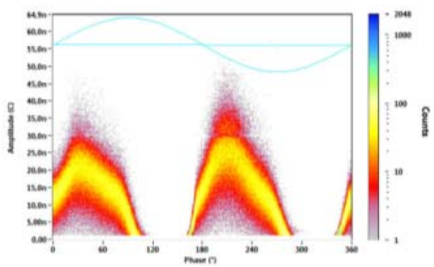
Plant / Reference	Phase	Q_m (Peak PD) (nC)	Q_{app} (Avg. PD) (nC)
Generator B 651-EG-01B	U	55.7	55.7
	V	32.3	32.3
	W	30.2	30.2
Generator C 651-EG-01C	U	30.2	30.6
	V	34	34
	W	33.8	33.8

Spenning	Q_m	Q_{app}	*Frekvens*	*LLD*	*Num gain*	*HWgain*	*Acq time*
[kV]	*[nC]*	*[nC]*	*[Hz]*	*[%]*			*[s]*
6,4	55,7	55,7	61	2	1	1	30



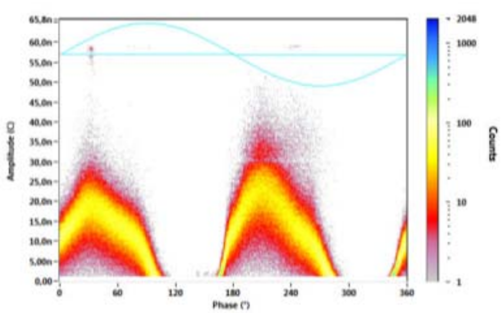
Phase U1: ***High PD Levels*** (up to 55.7nC)

Spenning	Q_m	Q_{app}	*Frekvens*	*LLD*	*Num gain*	*HWgain*	*Acq time*
[kV]	*[nC]*	*[nC]*	*[Hz]*	*[%]*			*[s]*
6,4	32,3	32,3	60	2	1	1	30



Phase V1: ***Medium-High PD Levels*** (up to 32.3nC)

Spenning	Q_m	Q_{app}	*Frekvens*	*LLD*	*Num gain*	*HWgain*	*Acq time*
[kV]	*[nC]*	*[nC]*	*[Hz]*	*[%]*			*[s]*
6,4	30,2	30,2	60	2	1	1	30



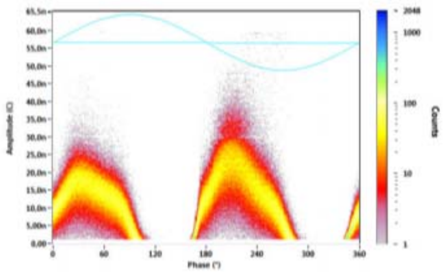
Phase W1: ***Medium-High PD Levels*** (up to 30.2nC)

Conclusion: *Generator B showed medium-high levels of PD activity (30.2 - 32.3nC) on* two phases and ***High PD levels (55.7nC) on Phase U1*** *during the off-line PD tests.* ***Recommendation:*** *carry out stator insulation repair, with particular focus on Phase U1.*

Karsten Moholt - Off-line PD Measurements

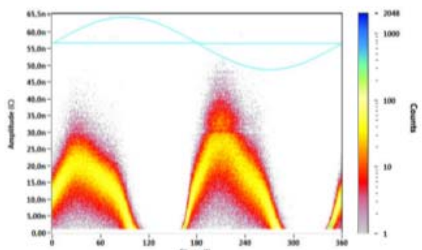
Detailed Test Results: Phase U1, V1 and W1 ***Generator C****, August 2012*

Spenning	Q_m	Q_{app}	Frekvens	LLD	Num gain	HWgain	Acq time
[kV]	[nC]	[nC]	[Hz]	[%]			[s]
6,4	30,2	30,6	60	2	1	1	30



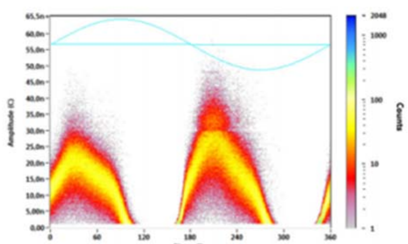
Phase U1: ***Medium-High PD Levels*** (up to 30.2nC)

Spenning	Q_m	Q_{app}	Frekvens	LLD	Num gain	HWgain	Acq time
[kV]	[nC]	[nC]	[Hz]	[%]			[s]
6,4	34	34	60	2	1	1	30



Phase V1: ***Medium-High PD Levels*** (up to 34.0nC)

Spenning	Q_m	Q_{app}	Frekvens	LLD	Num gain	HWgain	Acq time
[kV]	[nC]	[nC]	[Hz]	[%]			[s]
6,4	33,8	33,8	60	2	1	1	30

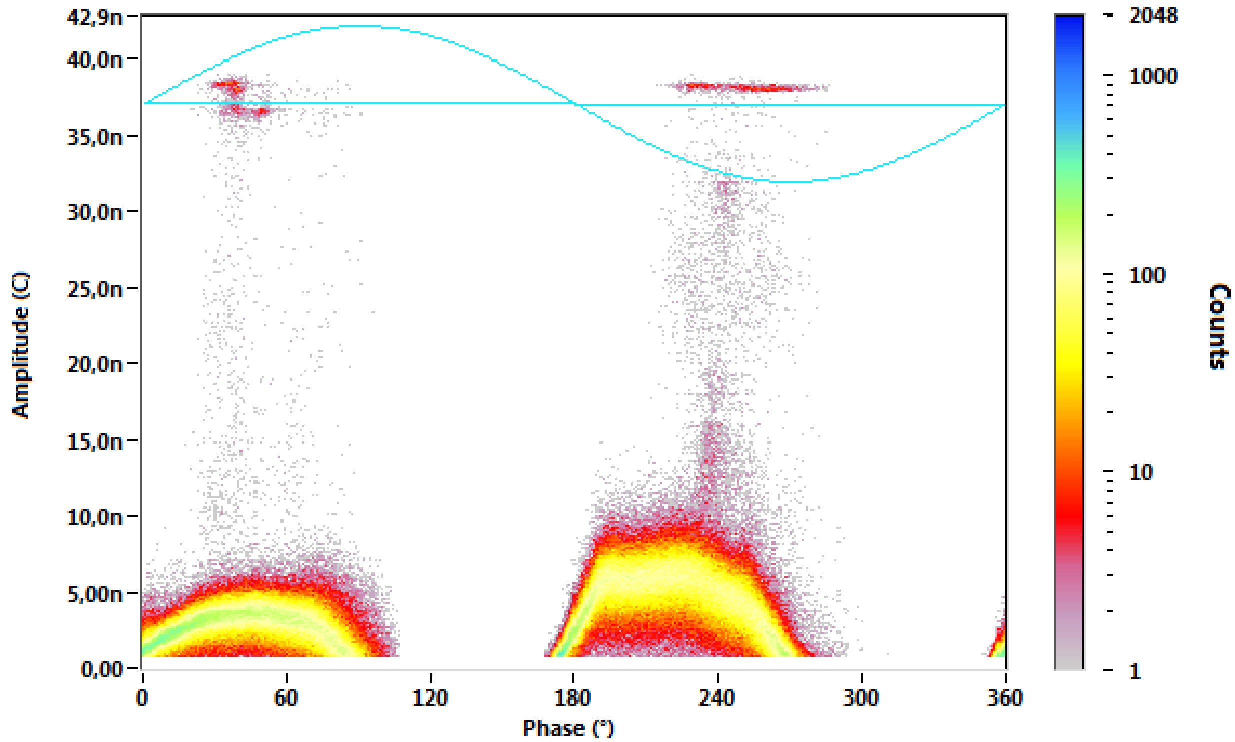


Phase W1: ***Medium-High PD Levels*** (up to 33.8nC)

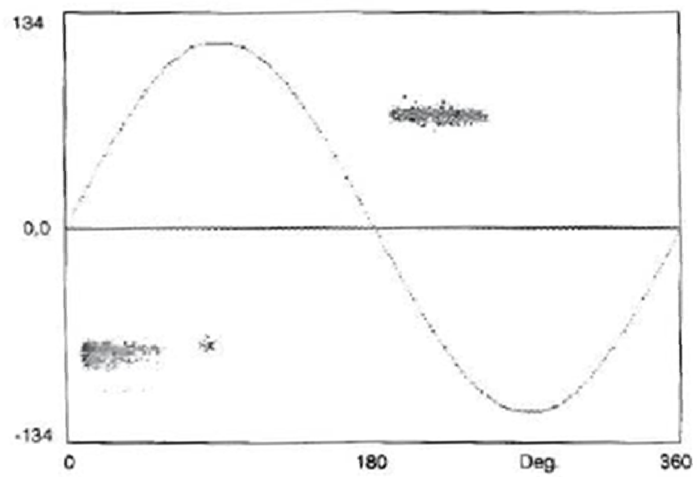
Conclusion: *Generator C showed medium-high levels of PD activity (30.2 - 34.7nC) on* ***all three phases*** *during the off-line PD tests.* ***Recommendation:*** *carry out stator insulation repair .*

Karsten Moholt OLPD Measurement Result against Guideline Levels

Generator B

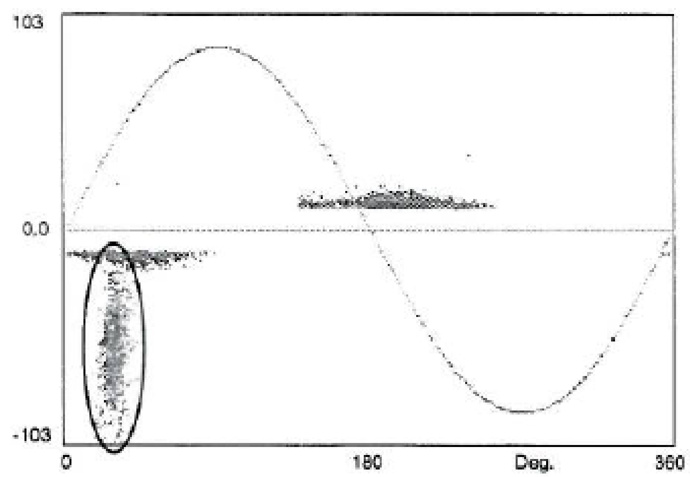


Guideline OLPD Levels for Rotating HV Machines (3.3 kV to 15 kV) – 31.12.2013		© HVPD Ltd 2013 all rights reserved
Condition Assessment	**PD Peak Level (nC)**	**PD Activity (nC/cycle)**
New/Excellent	*<2.0 nC*	*<50*
Good	*2.0 – 5.0 nC*	*50 – 200*
Average	*5.0 – 10.0 nC*	*200 – 450*
Still Acceptable - Monitor	*10.0 – 20.0 nC*	*450 – 750*
Probable Inspection	*20.0 – 35.0 nC*	*750 – 1250*
Problem / Unreliable	*>35.0 nC*	*>1250*



End-winding Partial Discharge - Type I

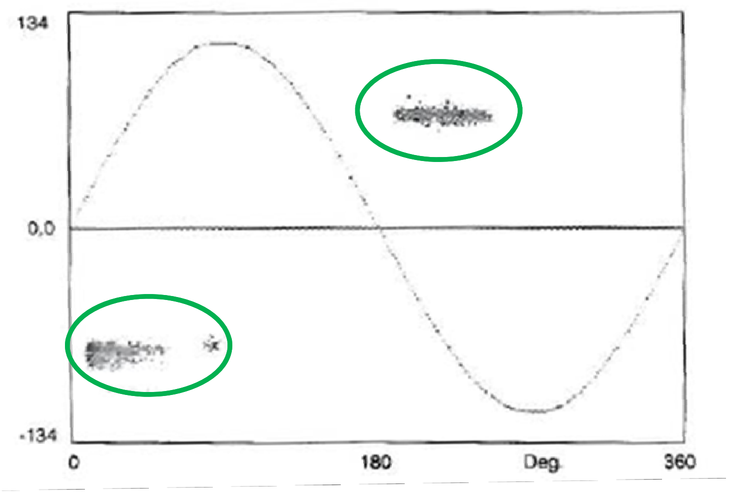
Gas type discharges between bars in the winding overhang or between a bar and the press finger of the core



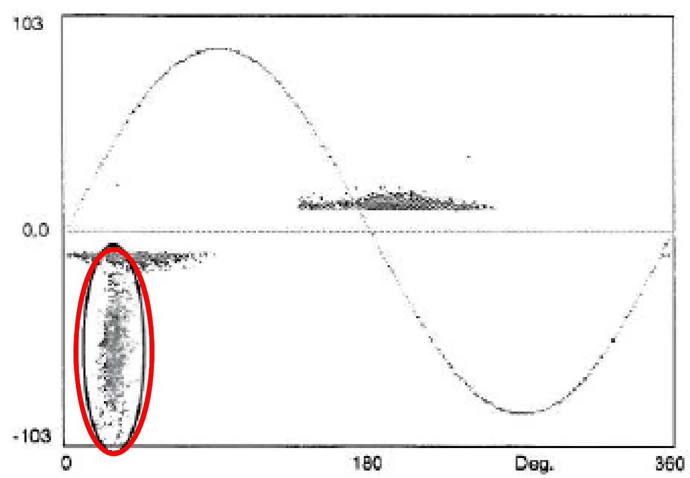
End-winding Partial Discharge - Type II

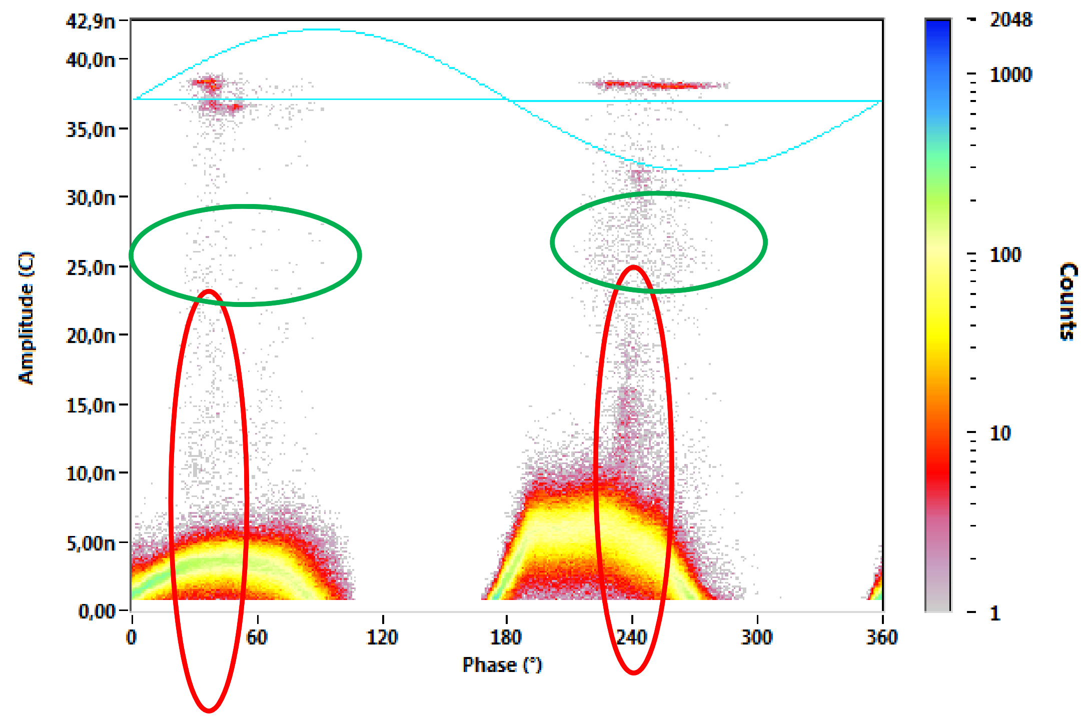
Surface discharges / tracking along the winding overhang due to contamination or poor stress control grading at the air / insulation interface

End-winding discharges



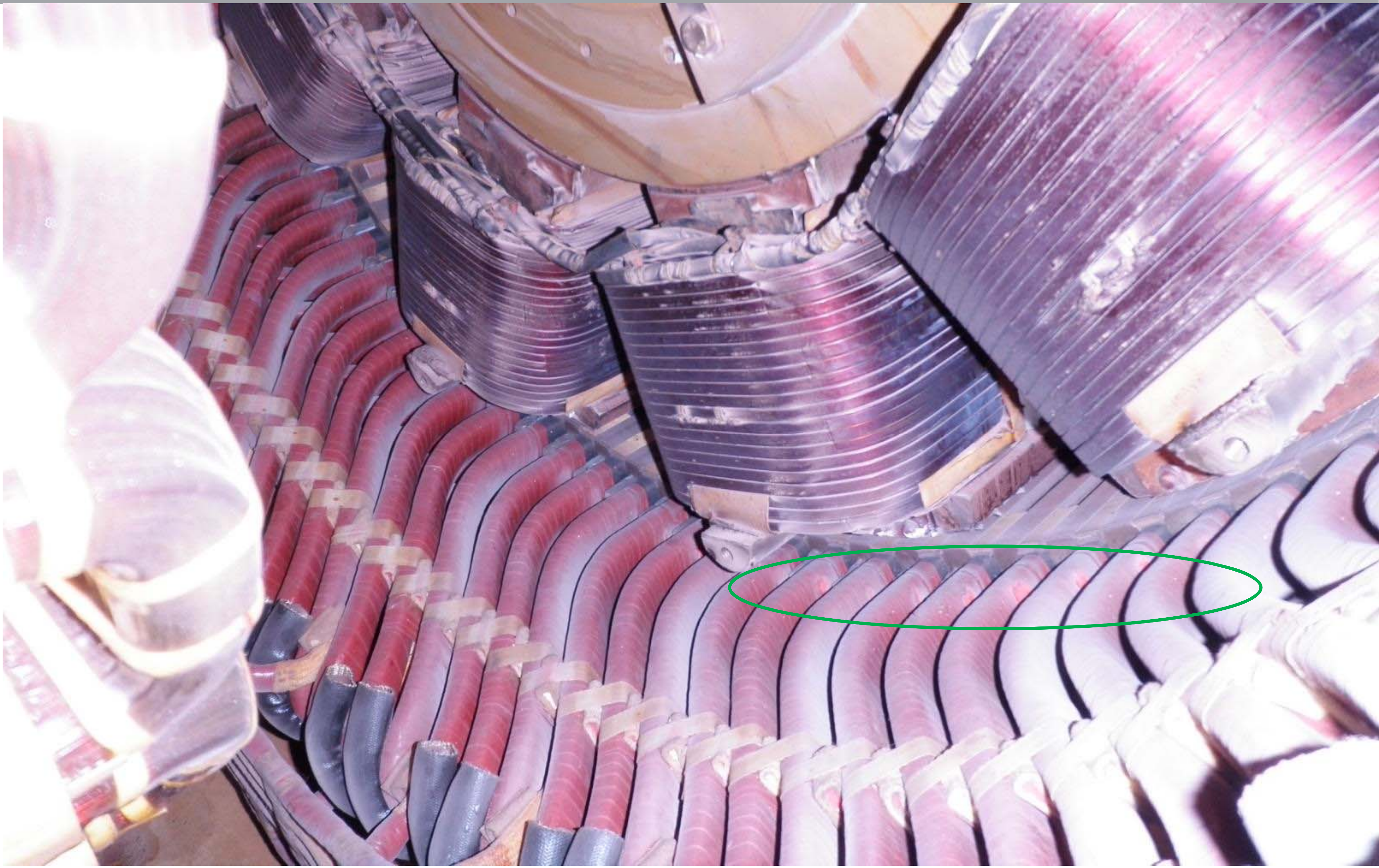
End-winding discharges



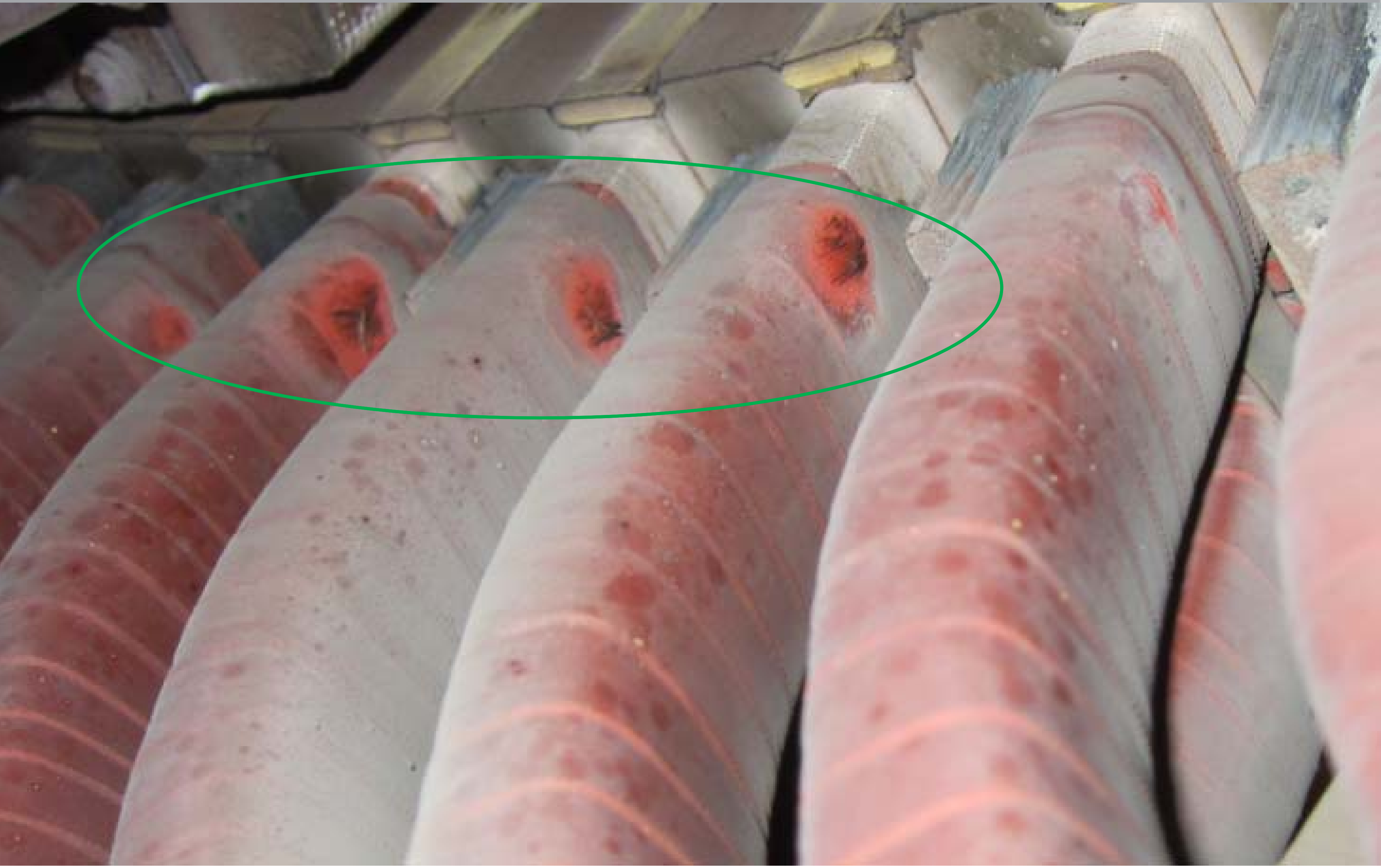


Conclusion: *Generator B showed PRPD patterns for* **both Type I and Type II end winding discharges** *during the off-line PD tests.*
Recommendation: *carry out stator insulation repair with focus on the end windings.*

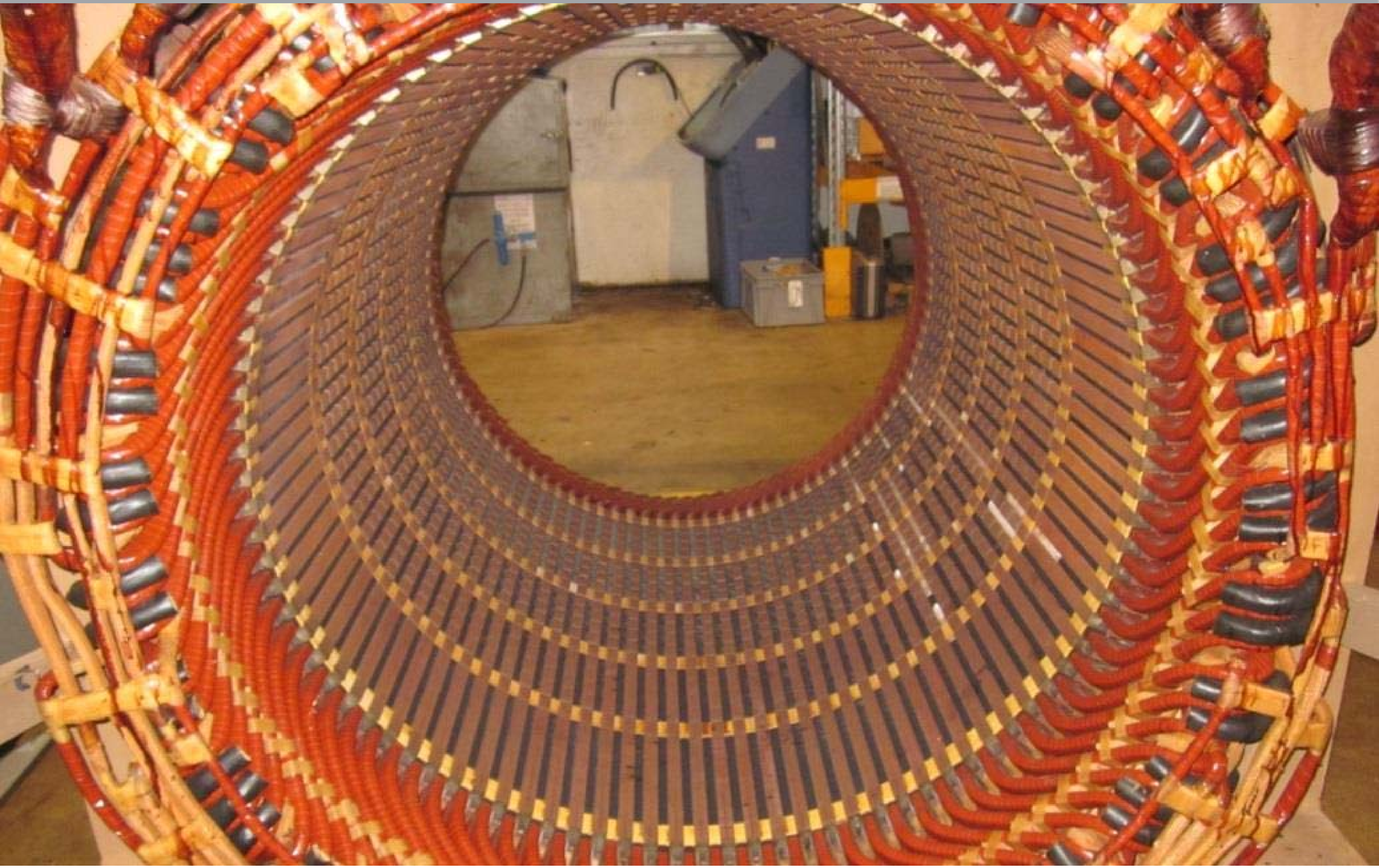
Evidence of Corona Discharges



Corona Discharge - Surface Insulation Degradation



Disassembled Stator



Disassembled Stator showing evidence of slot discharge erosion

Summary of HVPD's On-Line Partial Discharge (OLPD) Test Results

(September 2012)

Plant / Reference	Phase	Peak (nC)	Activity (nC/Cycle)	Local (dB)	Overall Condition	Comments
Generator Load : 20%				**Winding Temperature at the start of tests: 60-68°C**		
Generator B 651-EG-01B	U	36.50	1220	0	Problem, Unreliable	Internal or Slot Discharges Monitor PD Levels Closely
	V	35.74	1025			
	W	26.33	969			
Generator C 651-EG-01C	U	19.51	570	0	Probable Inspection	Internal or Slot Discharges Monitor PD Levels Closely
	V	22.26	617			
	W	24.33	842			
Generator Load : 40%				**Winding Temperature at the start of tests: 75-85°C**		
Generator B 651-EG-01B	U	34.05	913	0	Problem, Unreliable	Internal or Slot Discharges Monitor PD Levels Closely
	V	28.20	917			
	W	52.91	936			
Generator C 651-EG-01C	U	22.06	393	0	Probable Inspection	Internal or Slot Discharges Monitor PD Levels Closely
	V	23.46	465			
	W	31.63	481			
Generator Load : 80%				**Winding Temperature at the start of tests: 100 -110°C**		
Generator B 651-EG-01B	U	39.03	1280	0	Problem, Unreliable	Internal or Slot Discharges Monitor PD Levels Closely
	V	42.26	1103			
	W	55.40	1077			
Generator C 651-EG-01C	U	24.52	787	0	Problem, Unreliable	Internal or Slot Discharges Monitor PD Levels Closely
	V	23.13	757			
	W	33.80	1110			

Comparison of On-line and Off-line PD Results for Generators B & C

Plant Reference	Phase	On-Line PD Test Level (nC) 20% Gen. Load	40% Gen. Load	80% Gen. Load	Off-line PD Test Level (nC) Q_m (Peak PD)	Q_{app} (Avg. PD)
Generator B 651-EG-01B	U	36.50	34.05	39.0	55.7	55.7
	V	35.74	28.20	42.3	32.3	32.3
	W	26.33	52.91	55.4	30.2	30.2
Generator C 651-EG-01C	U	19.51	22.06	24.5	30.2	30.6
	V	22.26	23.46	23.1	34.0	34.0
	W	24.33	31.63	33.8	33.8	33.8

Discussion: The results from the OLPD tests carried out by HVPD (of the in-service 11kV generators) concurs closely with the PD test data from the Karsten Moholt off-line PD tests.

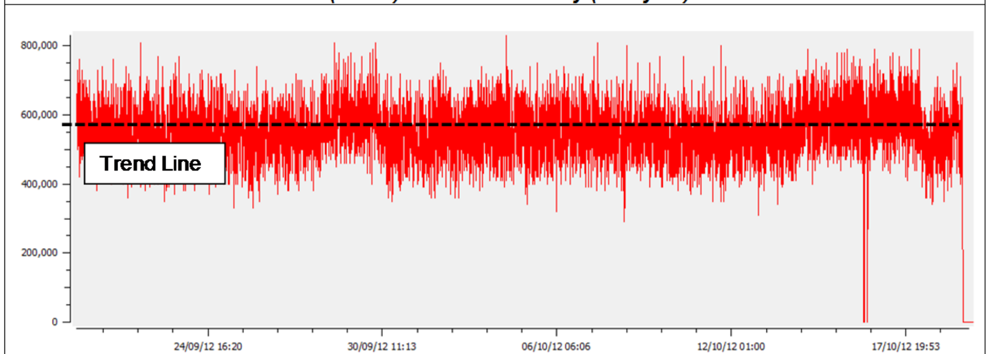
Generator B is in the '***Problem/Unreliable' RED condition category*** and ***Generator C*** is in the ***'Probable Inspection' ORANGE condition category***.

- Following these measurements of high PD levels on Generator B from both the off-line and on-line PD tests, ***Generator B was removed from service*** on 19th October 2012 and sent to the repair factory to be re-wound.
- A ***previously repaired generator*** (of the same manufacturer and Type: HSG 900XU10 (*ABB, 11 kV, 8.2 MVA*) was installed in place of Generator B and went into service on 15th November 2012.
- It was found that the ***replacement Generator B*** had low and decreasing levels of PD when compared to the previous generator that was removed from service.
- This replacement generator had a stator winding insulation condition in the ***'New/Excellent'*** condition category.

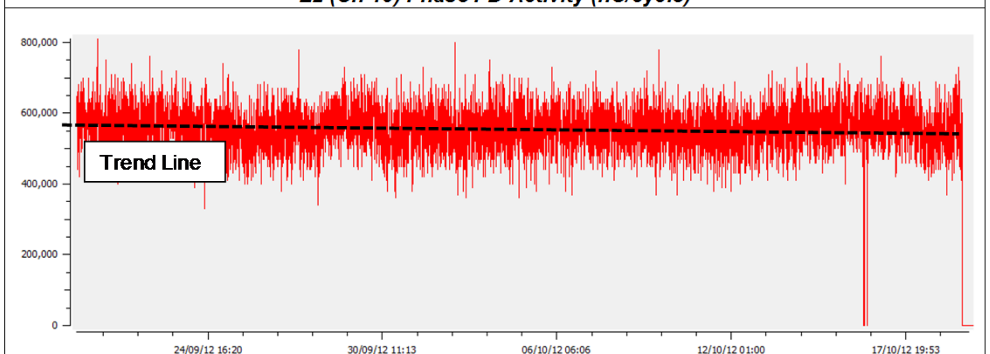
HVPD's Continuous OLPD Monitoring Data for Generator B
Pre-Replacement (20.09–19.10.2012)

HV Asset	*Phase*	*OLPD Activity (nC/Cycle)*	*Standard Deviation (nC/Cycle)*	*OLPD Activity change rate (nC/Cycle)/(Month)*	*Avg PD Activity Increase Rate (%/Month)*
Generator B	L1 (W)	790	78.03	8.81	1.59
	L2 (V)	760	60.16	-0.24	-0.04
	L3 (U)	400	51.87	33.81	32.00

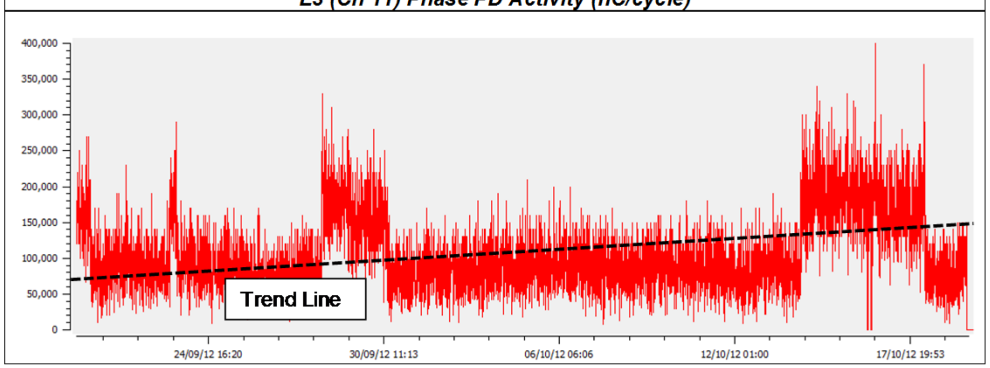
L1 (Ch 09) Phase PD Activity (nC/cycle)



L2 (Ch 10) Phase PD Activity (nC/cycle)



L3 (Ch 11) Phase PD Activity (nC/cycle)

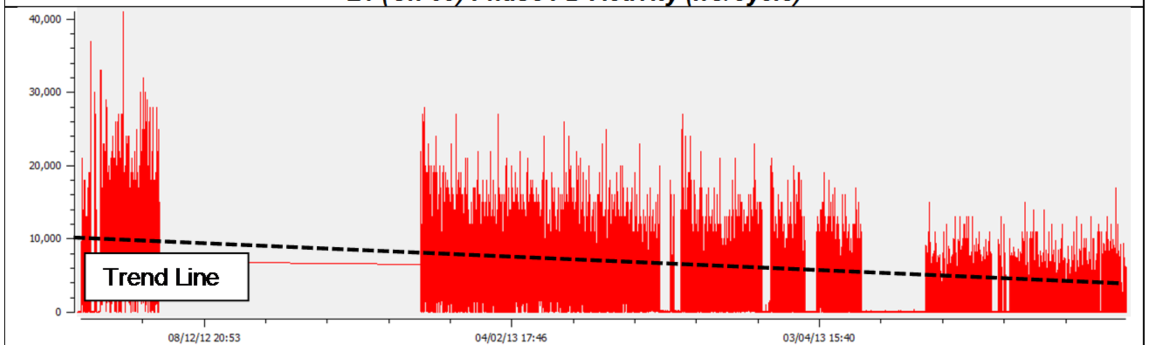


Note: *rising OLPD Activity trend line on Phase L3 (U) of 32% per month.* ***Recommendation:*** *carry out stator insulation repair with focus on the end windings.*

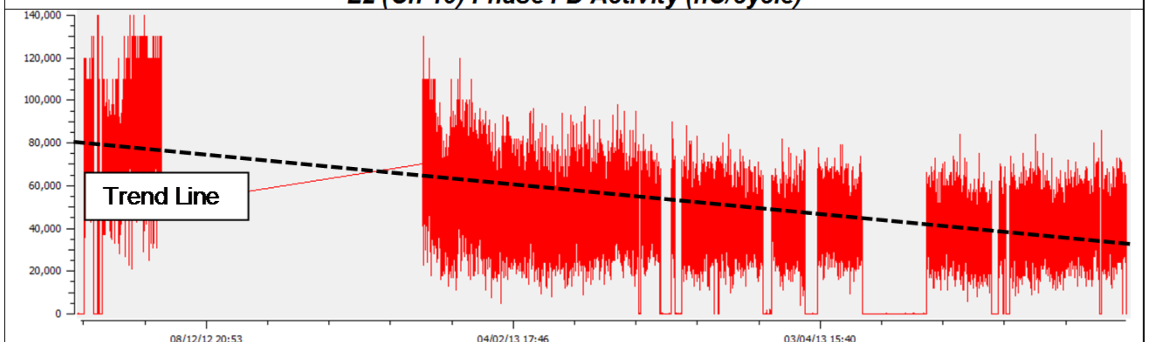
HVPD's Continuous OLPD Monitoring Data for Generator B *Post-Replacement* (15.11.2012–30.05.2013)

HV Asset	Phase	OLPD Activity (nC/Cycle)	Standard Deviation (nC/Cycle)	OLPD Activity change rate (nC/Cycle)/(Month)	Avg PD Activity Increase Rate (%/Month)
Generator B	L1 (W)	5.72	4.12	-1.08	-18.89
	L2 (V)	49.06	19.70	-6.57	-13.38
	L3 (U)	4.58	4.20	-0.80	-17.43

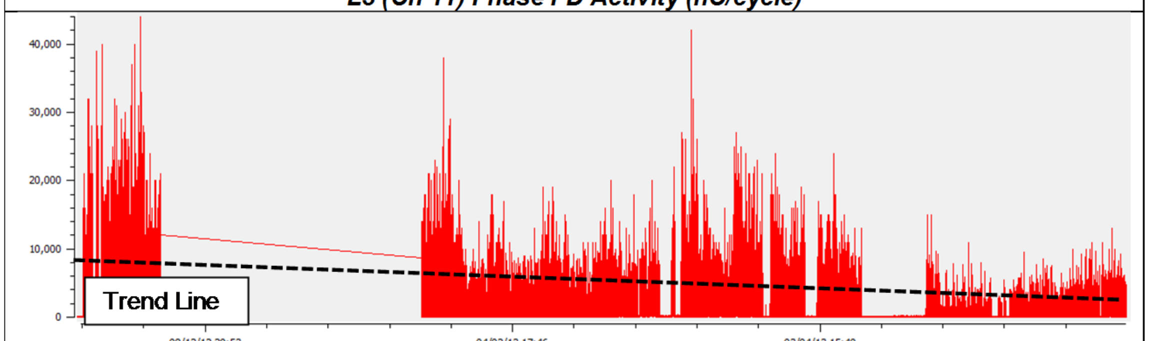
L1 (Ch 09) Phase PD Activity (nC/cycle)



L2 (Ch 10) Phase PD Activity (nC/cycle)



L3 (Ch 11) Phase PD Activity (nC/cycle)



Note: *Very low levels of OLPD Activity (<50nC) with a decreasing trend line seen on all phases.*

Conclusion: *the stator winding condition of the replacement Generator B is in the* **'Excellent'** *condition category.*

HVPD's OLPD Monitoring of Generators B & C

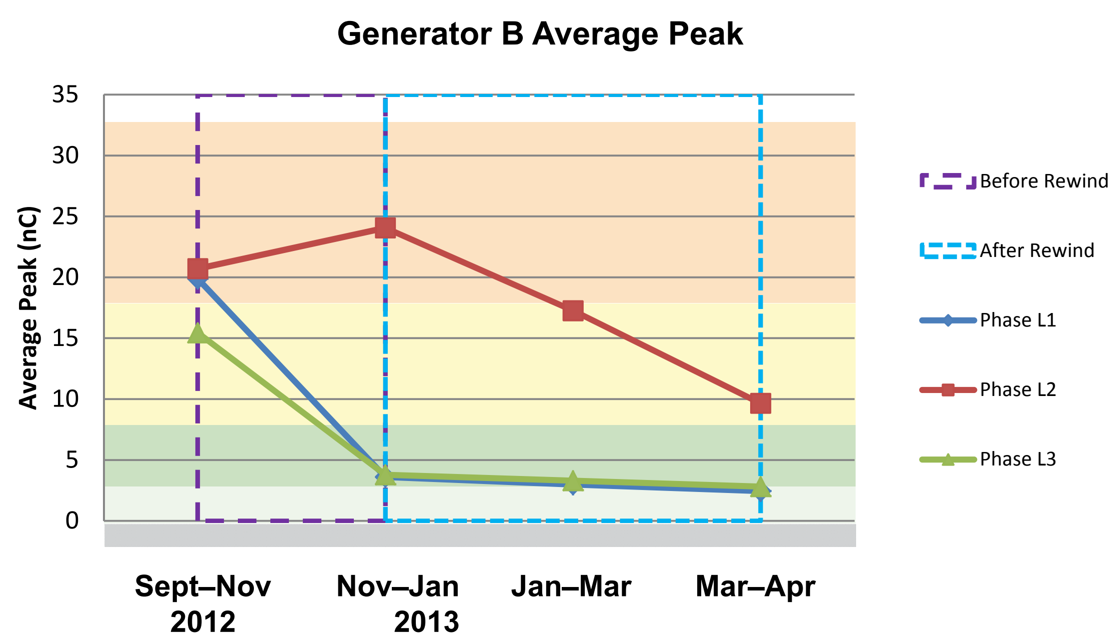
PD trending data for the 8-month monitoring period (20.09.2012–30.05.2013)

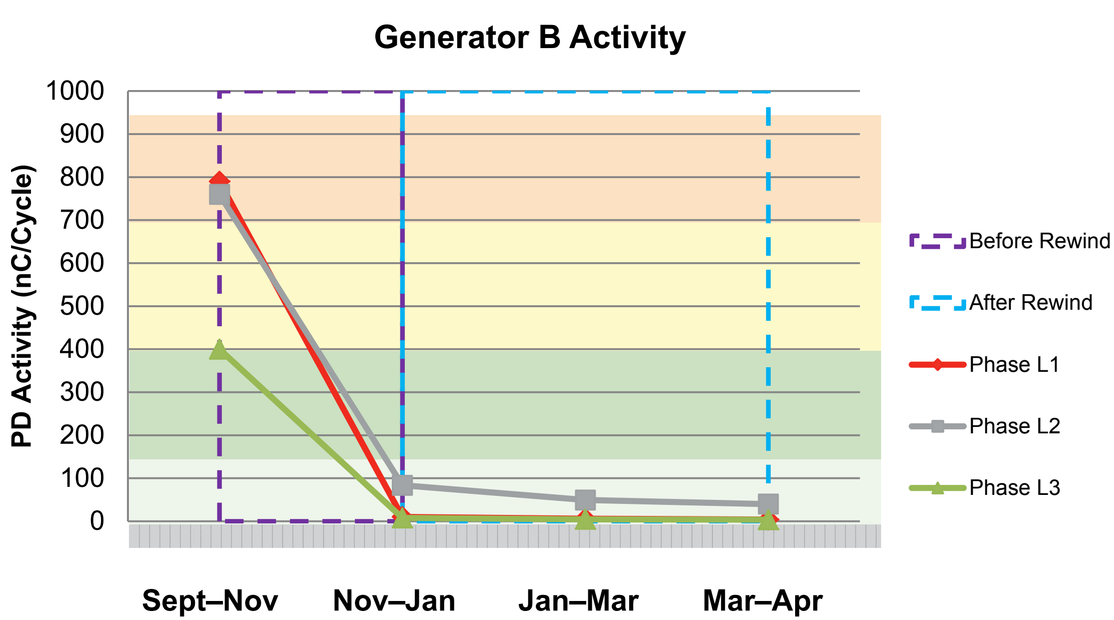
HV Asset	Phase	Average Activity (nC/Cycle)	Standard Deviation (nC/Cycle)	PD Activity change rate (nC/Cycle)/(Month)	Avg. PD Activity Change Rate (%)/(Month) (%/Month)	HVPD Multi Monitor PD Trend	Condition
Generator B – *Before Replace*	U (Channel 11)	400	51.8	8.81	1.59	Increasing	Average
	V (Channel 10)	760	60.1	-0.24	-0.04	Stable	Probable Inspection
	W (Channel 09)	790	78.0	33.81	32.00	Increasing	Probable Inspection
Generator B – *After Replace*	U (Channel 11)	5	4.2	-0.80	-17.43	Decreasing	New/Excellent
	V (Channel 10)	49	19.7	-6.57	-13.38	Decreasing	New/Excellent
	W (Channel 09)	6	4.1	-1.08	-18.89	Decreasing	New/Excellent
Generator C – *Before Replace*	U (Channel 11)	964	117.3	16.12	1.67	Increasing	Probable Inspection
	V (Channel 10)	1244	157.8	27.41	2.21	Increasing	Problem / Unreliable
	W (Channel 09)	1418	188.7	37.14	2.62	Increasing	Problem / Unreliable
Generator C – *After Replace*	U (Channel 11)	*TBC*	*TBC*	*TBC*	*TBC*	*TBC*	*TBC*
	V (Channel 10)	*TBC*	*TBC*	*TBC*	*TBC*	*TBC*	*TBC*
	W (Channel 09)	*TBC*	*TBC*	*TBC*	*TBC*	*TBC*	*TBC*

- Note the PD Activity before (790nC/cycle) and after (49nC/cycle) ***replacement of Generator B***.
- The replacement Generator B had a stator winding insulation condition in the ***'New/Excellent'*** condition category.

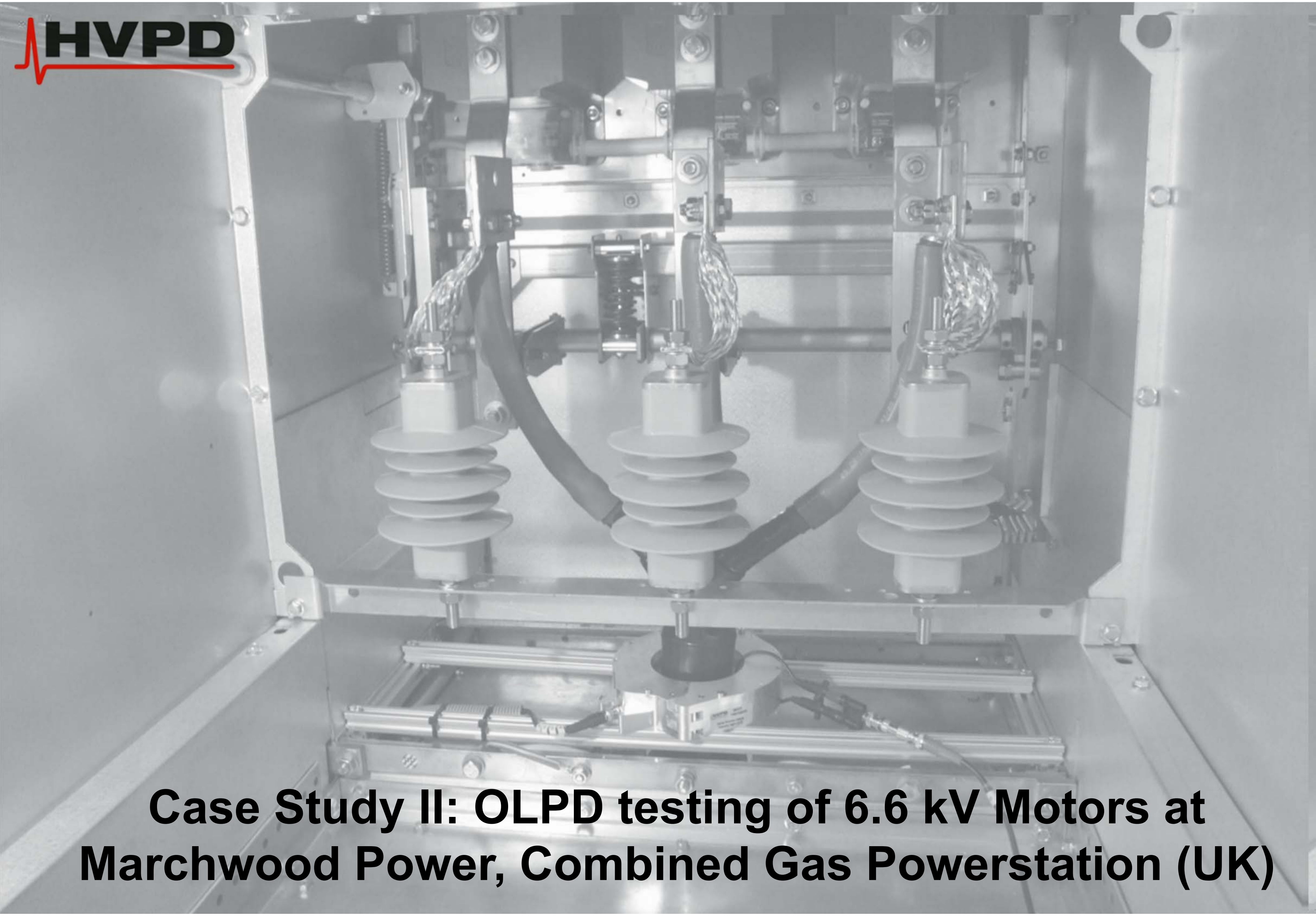
HVPD's Continuous OLPD Monitoring of Generator B

Average peak and activity levels change before and after replacement



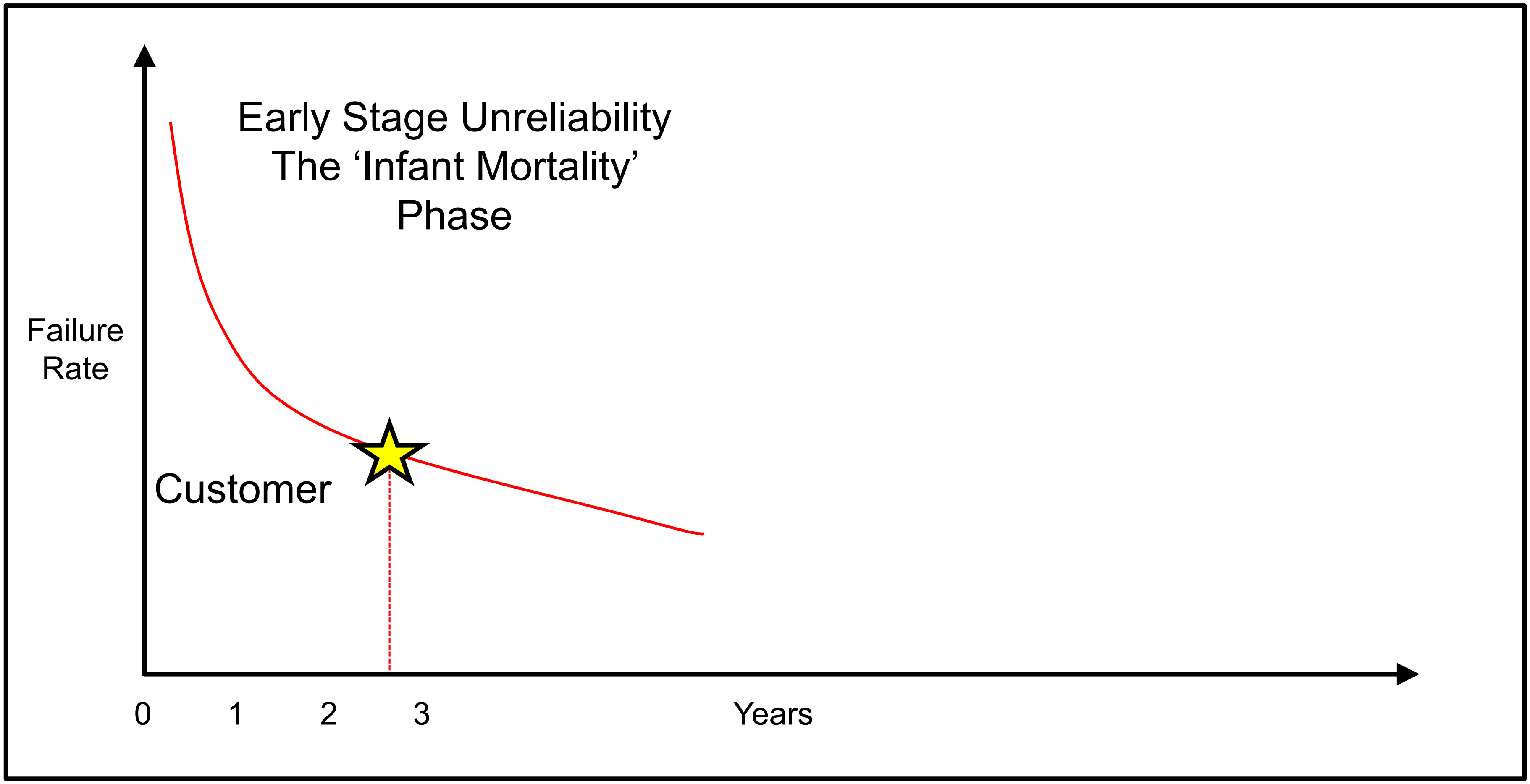


HVPD



Case Study II: OLPD testing of 6.6 kV Motors at Marchwood Power, Combined Gas Powerstation (UK)

The HV motors were under a 3-year warranty and had been in-service for just over 2-years at the time of the test and monitoring project.



Off-line PD Test Results For Manufacturer B's HV Motors

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 B1	10,530	30,260	12,870	24,960	7,865	4,846	17,180	44,040
Motor B2	14,920	30,620	17,730	27,070	15,640	22,100	26,390	42,520
Motor B3	15,140	30,890	16,920	31,040	16,530	24,410	26,780	44,370

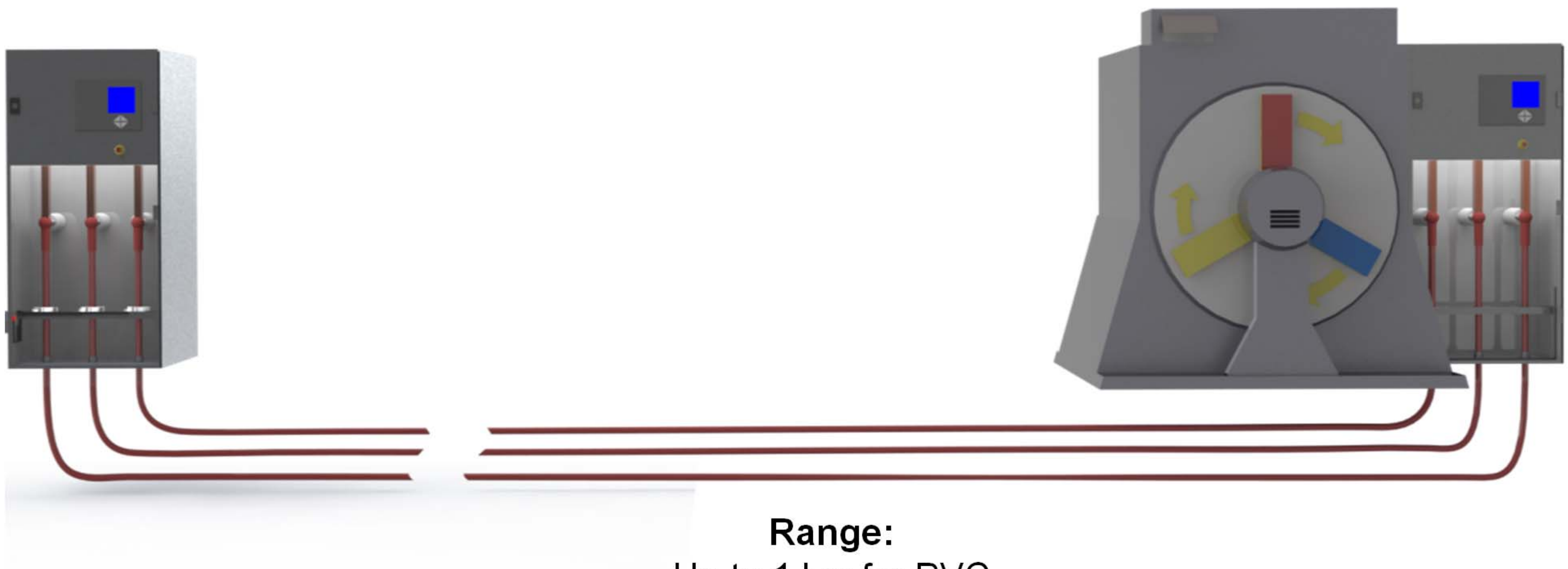
Off-line PD measurements (carried out by Siemens UK) for motors B1, B2 and B3 showed an increasing trend from the 2010 tests to the 2011 tests with an average increase in PD levels across all 3 motors of around 100%.

The PD levels **had doubled (in average) over the 12 months between these tests in 2010 and 2011**.

OLPD Permanent Sensor Installation

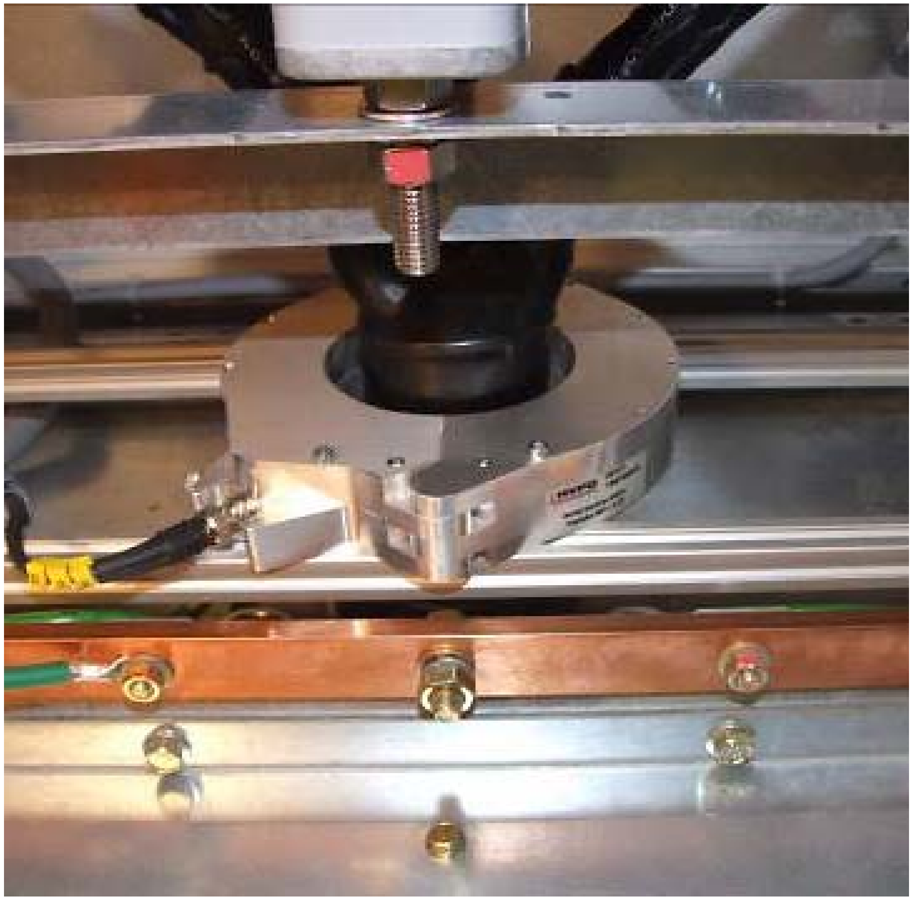
HFCT Sensors located at
HV Switchboard Cable End

Rotating HV Machine End



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

6.6 kV Motors, OLPD Sensor Installation at the Switchgear



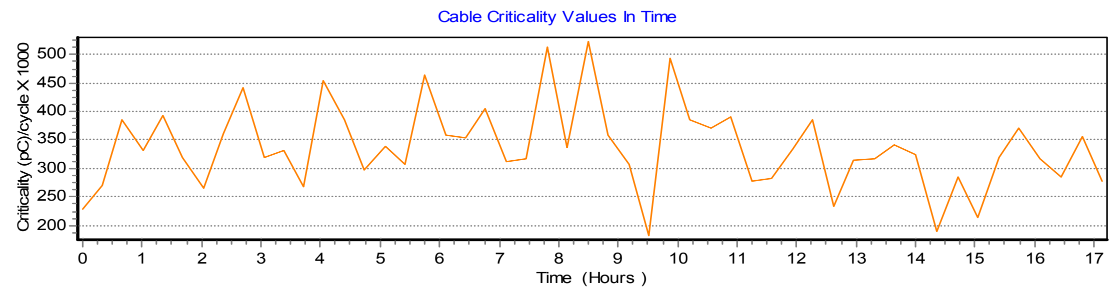
Summary of HVPD's Initial OLPD Test Results

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

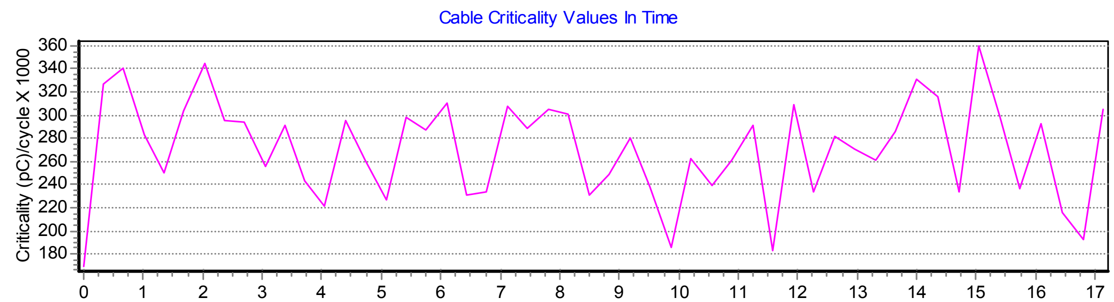
- Manufacturer A's feedwater pump HV motors (Ref: A1, A2 & A3) all had ***Good to Average*** PD levels with the stator insulation in the Green Condition Category - satisfactory condition.
- However, Manufacturer B's circulating water pump HV motors (Ref: B1, B2 & B3) all showed ***Very High*** PD activity levels (up to from 33,000 pC to 68,000 pC), ***Red Condition Level – Problem/Unreliable***.

Graphs of HVPD Extended OLPD Monitoring Data (Over 24 hours with the HVPD-Longshot™)

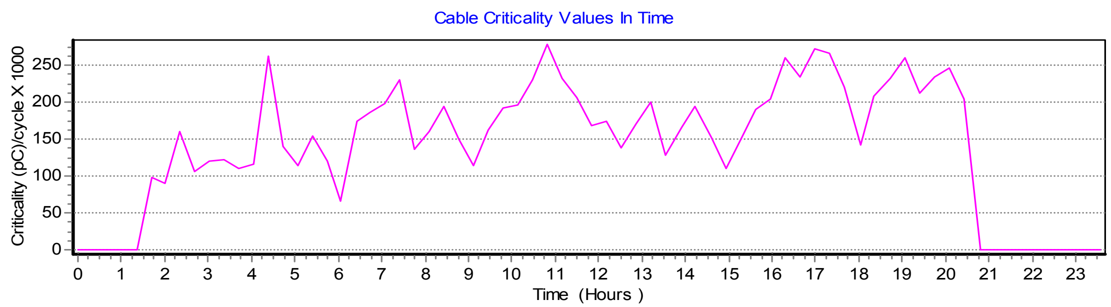
B1



B2



B3



- A full visual internal investigation and OLPD monitoring of the B1, B2 & B3 motors was recommended to find the cause of the high PD on these 2-year old motors.
- All ‘remote’ HVPD results used a calculated ***PPRF (PD Pulse Retention Factor)*** which accounts for the signal attenuation along the 780m long XLPE feeder cables (PPRF for this cable = 0.79 i.e. 79% of the PD signal was retained after travelling along the cable from motor to switchgear).

Off-line Motor Visual Inspection of Motor by Siemens UK after Off-line PD Tests

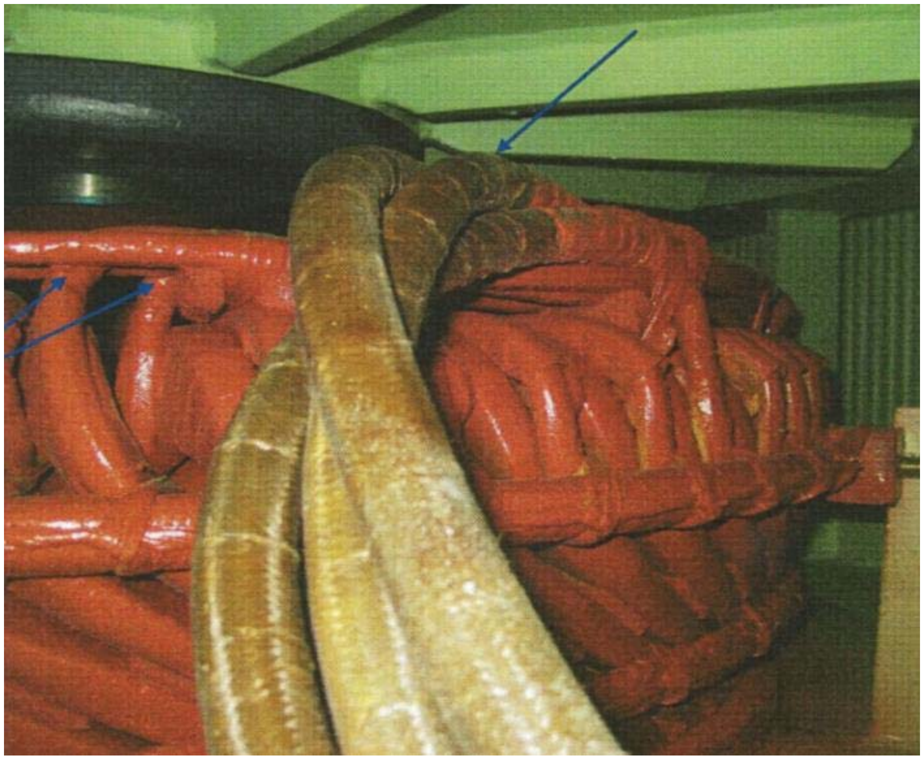


Image of Neutral Terminal Box. The Glass Cover (arrowed) was removed to inspect the windings

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

Off-line Motor Visual Inspection of Motor by Siemens UK after Off-line PD Tests

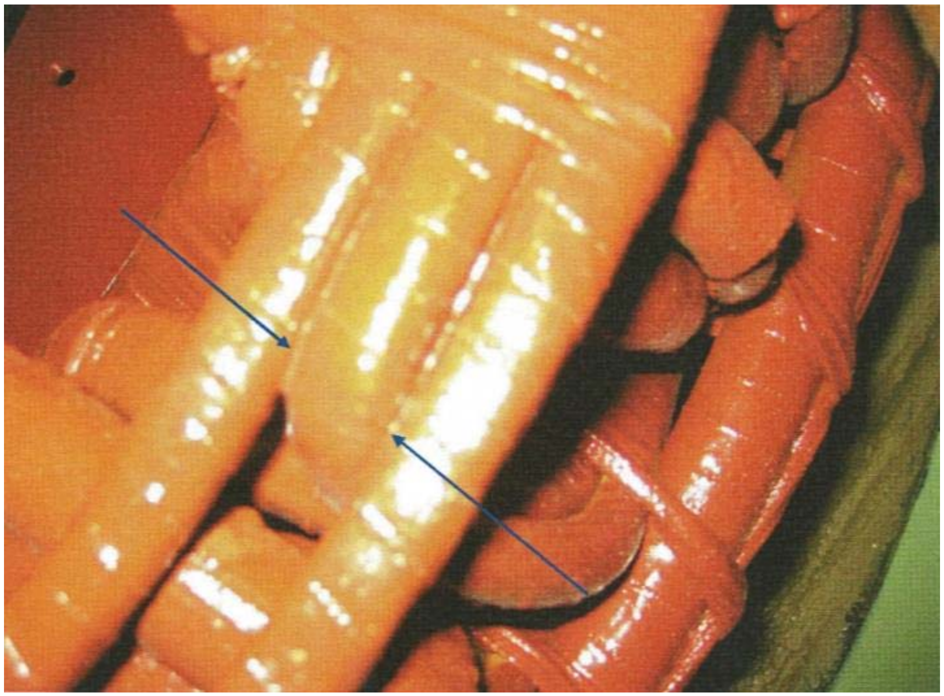


Image of connections not adequately spaced (arrowed) = design issue

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

Conclusions

Warranty Claim with 6.6kV Motor Manufacturer

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

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

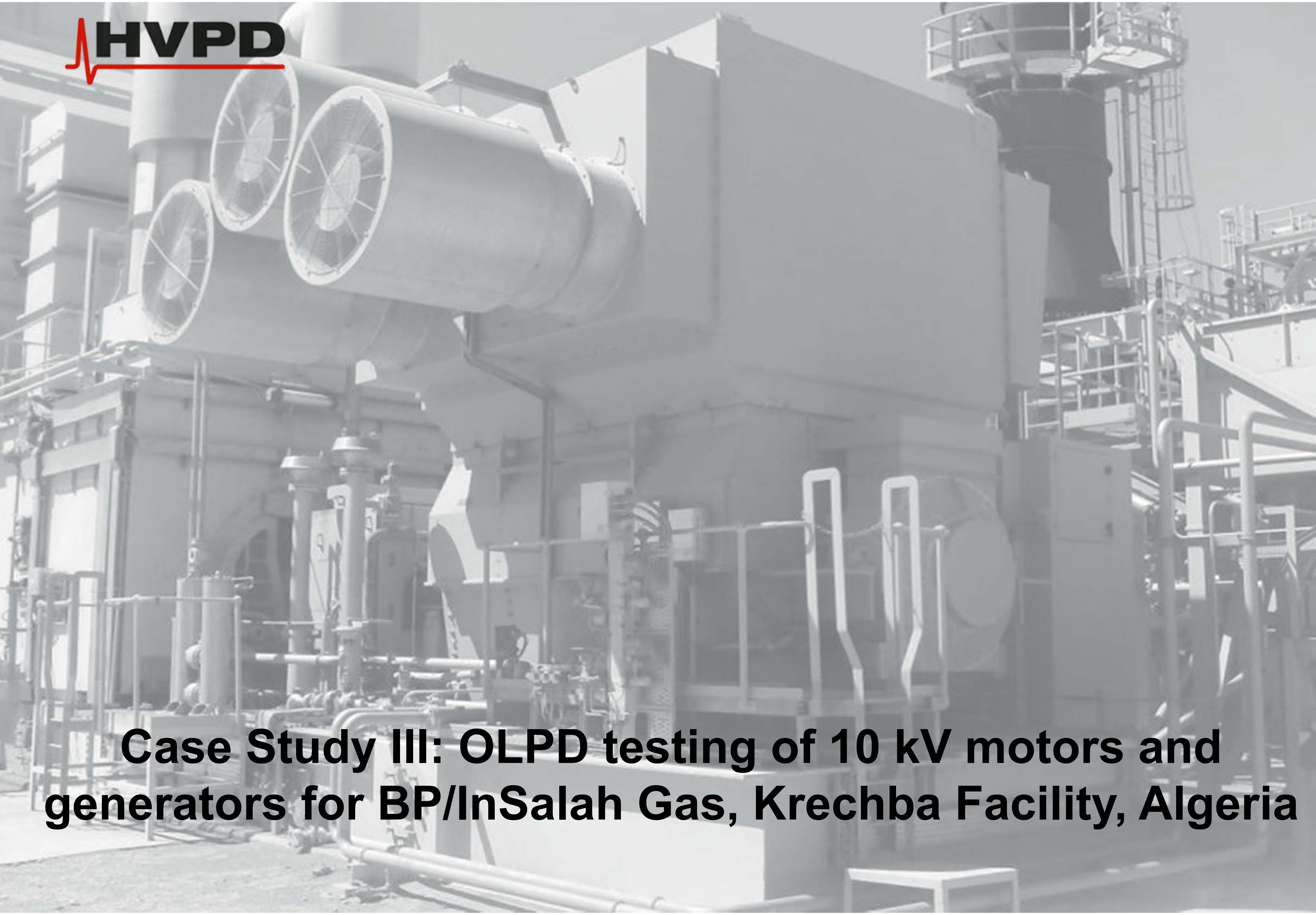
The motors were rewound and repaired under warranty!

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 manufacturing defect, which with PD was always going to be a difficult one to secure."

Example of Criticality 'OLPD League Table' for HV Motor Circuits from 12 Months of OLPD Monitoring Data (*May 2012–May 2013*)

Project Reference	***Peak PD (nC)***	***Local PD (dB)***	***PD Activity (nC/Cycle)***	***Comments***	***PD Monitor***	***HVPD Multi™ Monitor PD Trend***	***Condition***
001	140	<10	3899	Stator Slot & End-Winding Discharges	**3 months**	Stable	Problem / Unreliable
002	159	<10	3781	Stator Slot & End-Winding Discharges	**12 months**	Stable	Problem / Unreliable
003	57	<10	3543	Stator Slot & End-Winding Discharges	Not Installed	None – ***monitor required asap***	Problem / Unreliable
004	44	<10	1427	End-Winding Discharges	***New Installation***	TBC - New	Problem / Unreliable
005	78	<10	1106	Stator Slot & End-Winding Discharges	**3 months**	Increasing	Problem / Unreliable
006	35	<10	1086	End-Winding Discharges	***New Installation***	TBC - New	Problem / Unreliable
007	55	<10	990	Stator Slot & End-Winding Discharges	**7 months**	TBC – Intermittent Use	Probable Inspection
008	13	<10	935	Stator Slot & End-Winding Discharges	***New Installation***	TBC - New	TBC – Requires monitor data
009	26	<10	847	End-Winding Discharges	***New Installation***	TBC- New	TBC – Requires monitor data
010	29	<10	570	Stator Slot & End-Winding Discharges	**12 months**	Decreasing	Still Acceptable
011	16	<10	262	Stator Slot Discharges	Not Installed	None **–** ***monitor required***	TBC – *Requires monitor install*
012	21	<10	258	Stator Slot & End-Winding Discharges	**3 months**	Increasing	Still Acceptable
013	36	<10	102	Stator Slot & End-Winding Discharges	Not Installed	None **–** ***monitor required***	TBC – *Requires monitor install*
014	*No Data Available – HV Motor Not Energised*				***New Installation***	TBC - New	TBC – Requires monitor data



Case Study III: OLPD testing of 10 kV motors and generators for BP/InSalah Gas, Krechba Facility, Algeria

- HVPD Engineers performed OLPD PD Testing on selection of ABB 10kV gas turbine generators and motors at BP/In Salah Gas, Krechba facility in Algeria in September 2010.

- Previous OLPD testing had been carried out 4 years earlier by HVPD (October 2006) after commissioning of the rotating machines ***when no PD activity was detected*** on any of the machines tested .

The OLPD testing in September 2010 was requested by BP after they suffered an ***in-service failure of the stator insulation on a 10 kV amine circulation pump***, causing operational disruption and loss of revenue.

HVPD

Summary of OLPD Test Results

2006

Site	Voltage (kV)	Plant	Circuit Reference	PD Level (pC)
Krechba	10	Gas Turbine “A”	***A***	No PD detected
Krechba	10	Gas Turbine “B”	***B***	No PD detected
Krechba	10	Amine Pump	***C***	No PD detected
Krechba	10	Amine Pump	***D***	No PD detected
Krechba	10	Amine Pump	***E***	No PD detected
Krechba	10	CO2 Compressor	***F***	No PD detected

2010

Site	Voltage (kV)	Plant	Circuit Reference	PD Level (pC)
Krechba	10	Gas Turbine “A”	***A***	13180
Krechba	10	Gas Turbine “B”	***B***	20450
Krechba	10	Amine Pump	***C***	11700
Krechba	10	Amine Pump	***D***	10600
Krechba	10	Amine Pump	***E***	12100
Krechba	10	CO_2 Compressor	***F***	No PD detected

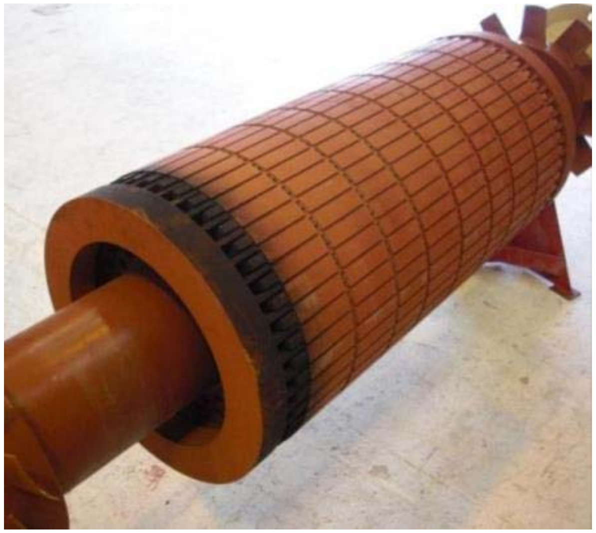
HVPD

In-service Failure of 10 kV Pump Motor Stator Winding

- The stator insulation failed at the location where the slot section meets the end winding

- This is a typical ‘weak point’ in the HV stator insulation system

- The failure was likely caused by condensation forming at this point, combined with a combination of high mechanical and electrical stresses at this location



- The failed Amine Pump Motor had been previously tested 4 years prior to failure (in 2006) when ***no PD was detected***.
- The conclusion to this was: **4 years between tests is too long a time period!**
- HVPD's recommendations to the client included that in order to provide an effective 'early warning' system to avoid future in-service failures such as this that ***permanent OLPD sensors*** and a ***continuous OLPD monitoring system*** is installed to provide continuous 24/7 monitoring.

HVPD

Case Study IV: OLPD testing and monitoring of a complete 11kV network on a Stena Drilling Vessel

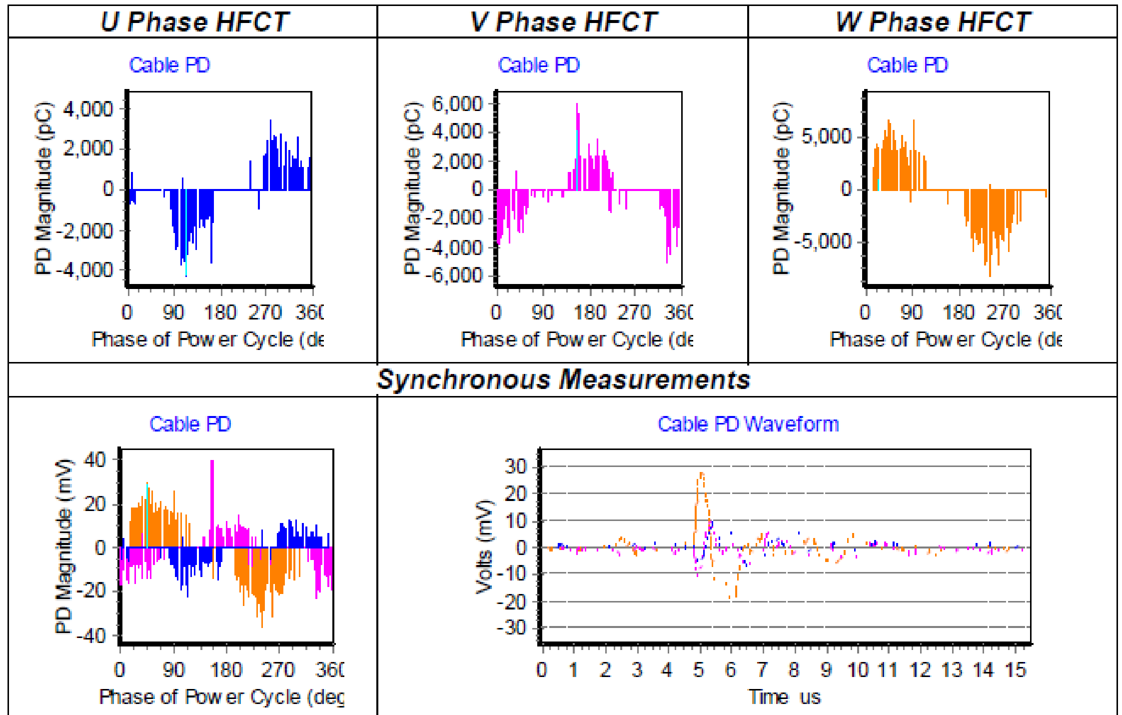
11 kV Main Switchboard

11kV Generators

Generator No.4 Tested Using HFCT Sensors at the Central Switchboard

- ‘Slot Section’ PD activity within generator easily measured at the switchboard end of the cable

- Conclusion: It is possible to monitor PD levels within generators on vessel with an HFCT sensor around each cable phase at the central switchboard



	U Phase	*V Phase*	*W Phase*
Peak (pC)	4267	6045	8411
Average (pC)	1420	1685	2904
Activity (nC/Cycle)	21.9	21.2	71.9
Condition	‘Average’	‘Average’	‘Average’

Port Switchboard (11kV)							
Unit No	***Description***	***No Cables***	***No HFCT's***	***Type***	***No TEV's***	***Total***	***Total Channels***
1	Bus Tie (HV SWB 3)	4	1	140-100HC	1	2	26 (2 Multi Units)
2	Thruster 1 HV Panel	2	1	140-100	1	2	
3	HV Transformer 1 FWD	1	1	140-100	1	2	
4	HV Transformer 1	1	1	140-100	1	2	
5	Topside HV Transformer 1 (HPU & LV)	2	1	140-100	1	2	
6	Generator 1	2	3	100-50HC	1	4	
7	Generator 2	2	3	100-50HC	1	4	
8	Busbar Measurement			N/A			
9	Topside HV Transformer 1 (VSD)	1	1	140-100	1	2	
10	Thruster 4 Transformer	2	1	140-100	1	2	
11	Emergency SWB (Incomer 1)	1	1	140-100	1	2	
12	Bus Tie (HV SWB 2)	4	1	140-100	1	2	

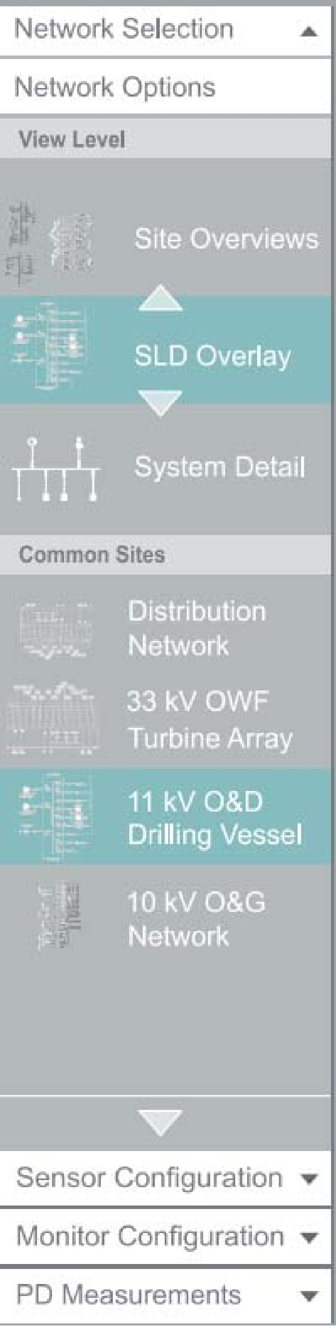
Central Switchboard (11kV)							
Unit No	***Description***	***No Cables***	***No HFCT's***	***Type***	***No TEV's***	***Total***	***Total Channels***
1	Bus Tie (HV SWB 1)	4	1	140-100	1	2	28 (2 Multi Units)
2	Thruster 3 HV Panel	2	1	140-100	1	2	
3	HV Transformer 2 FWD	1	1	140-100	1	2	
4	HV Transformer 2	1	1	140-100	1	2	
5	Topside HV Transformer 2 (HPU & LV)	2	1	140-100	1	2	
6	Generator 3	2	3	100-50	1	4	
7	Generator 4	2	3	100-50	1	4	
8	Busbar Measurement			N/A			
9	Topside HV Transformer 2 (VSD)	1	1	140-100	1	2	
10	Thruster 6 Transformer	2	1	140-100	1	2	
11	AFT Fire Pump	1	1	140-100	1	2	
12	Emergency SWB (Incomer 2)	1	1	140-100	1	2	
13	Bus Tie (HV SWB 3)	4	1	140-100	1	2	

Permanently Mounted OLPD Sensors for the 11 kV Circuits (Option 1 – HFCT on combined cable earth)

Permanently Mounted OLPD Sensors for the Generator Circuits Using Option 2 (Around all 3x phases and cancelled earth)

Permanent OLPD Monitor Installation

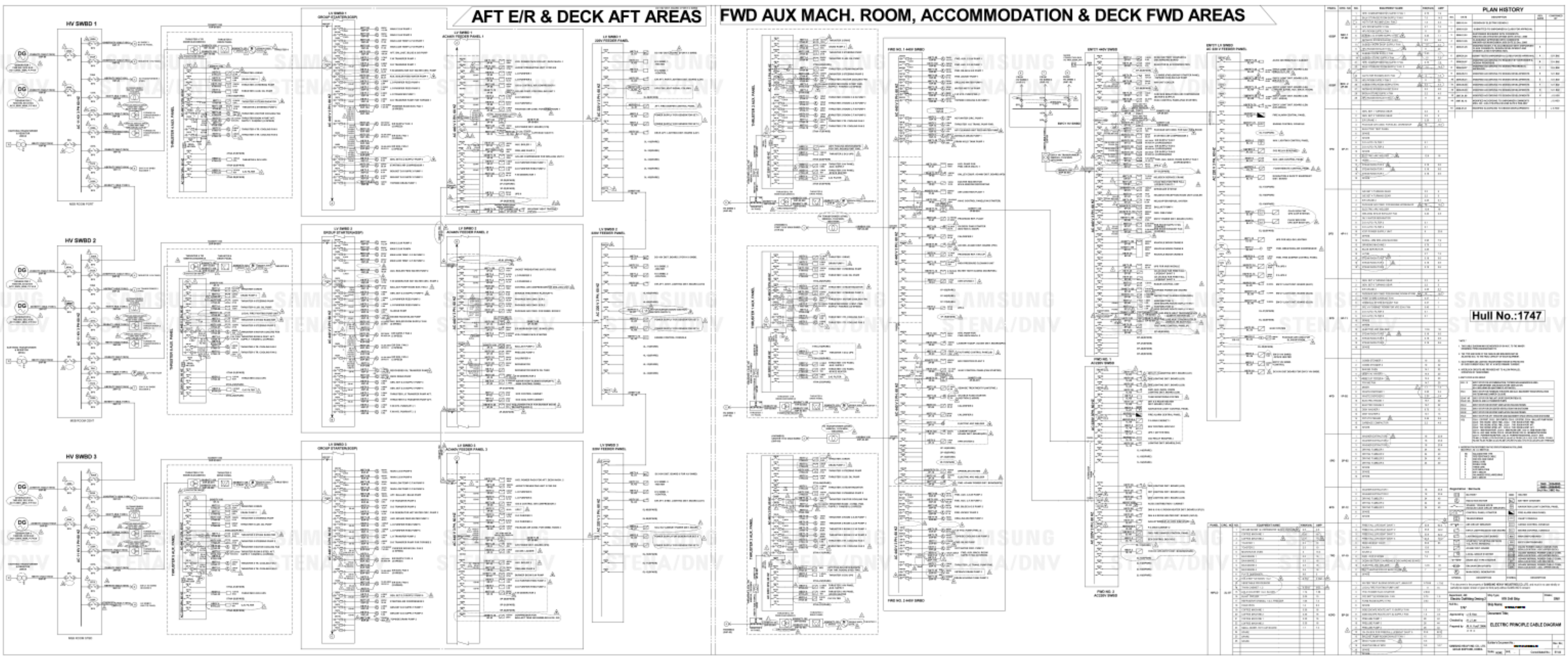
Permanent OLPD Monitor Installation



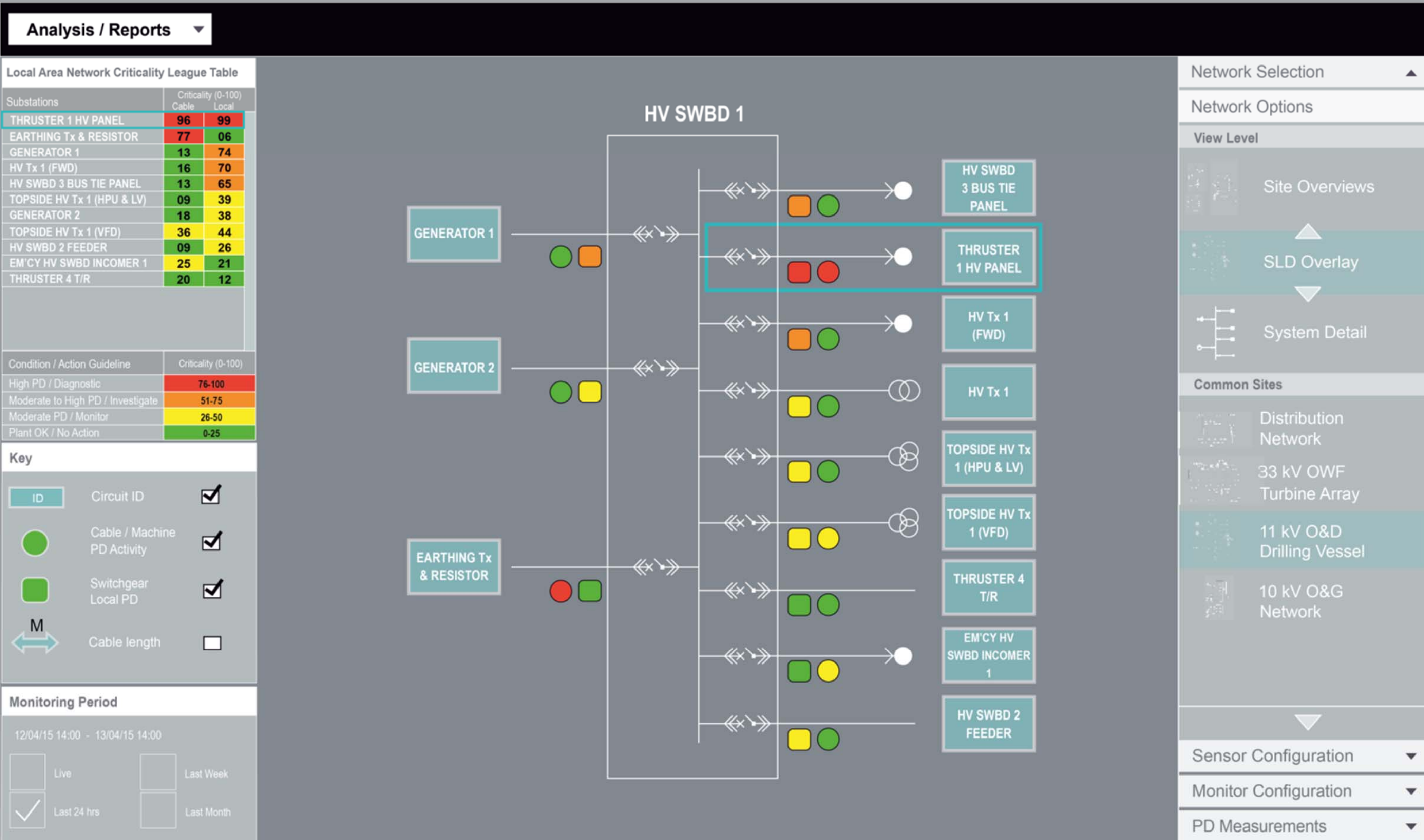
Presents data hierarchically using a 3-level interface:

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

Based on the network's single-line diagram (SLD)

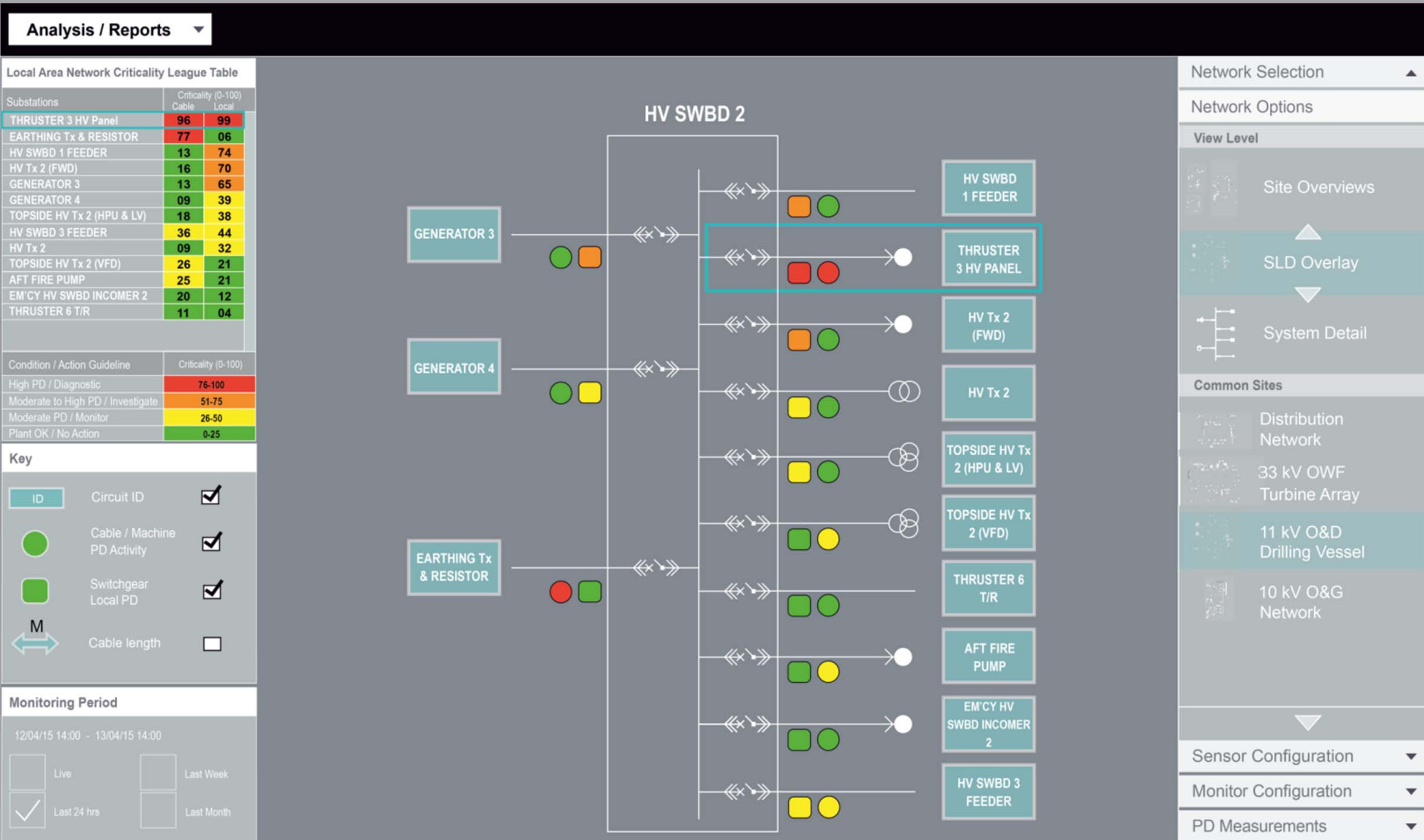


Features



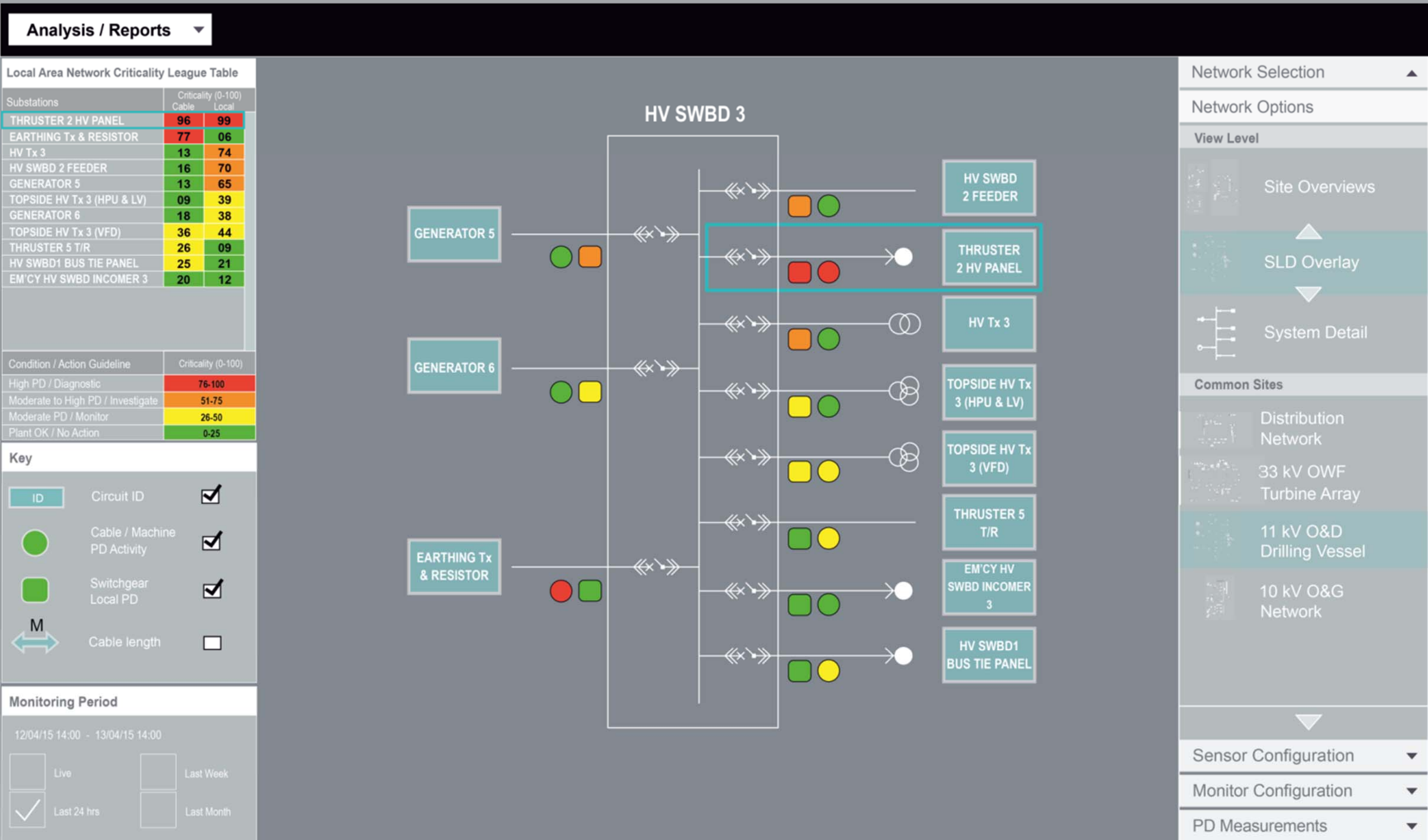
Analysis / Reports
Local Area Network Criticality League Table
Substations
Criticality (0-100)
Cable
Local
THRUSTER 1 HV PANEL 96 99
EARTHING Tx & RESISTOR 77 06
GENERATOR 1 13 74
HV Tx 1 (FWD) 16 70
HV SWBD 3 BUS TIE PANEL 13 65
TOPSIDE HV Tx 1 (HPU & LV) 09 39
GENERATOR 2 18 38
TOPSIDE HV Tx 1 (VFD) 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

Features



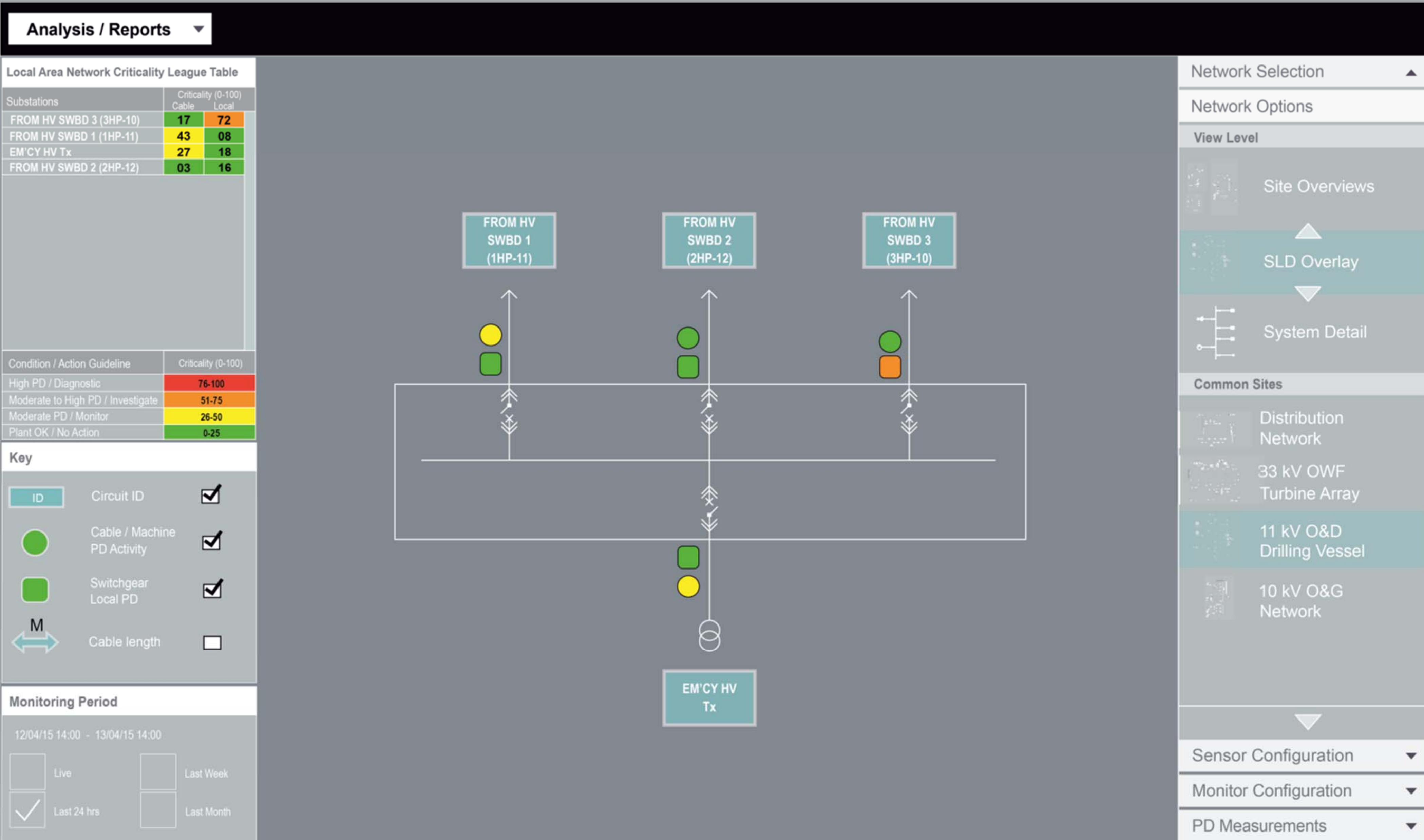
Analysis / Reports
Local Area Network Criticality League Table
Substations
Criticality (0-100)
Cable
Local
THRUSTER 3 HV Panel 96 99
EARTHING Tx & RESISTOR 77 06
HV SWBD 1 FEEDER 13 74
HV Tx 2 (FWD) 16 70
GENERATOR 3 13 65
GENERATOR 4 09 39
TOPSIDE HV Tx 2 (HPU & LV) 18 38
HV SWBD 3 FEEDER 36 44
HV Tx 2 09 32
TOPSIDE HV Tx 2 (VFD) 26 21
AFT FIRE PUMP 25 21
EM'CY HV SWBD INCOMER 2 20 12
THRUSTER 6 T/R 11 04
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 2
GENERATOR 3
GENERATOR 4
EARTHING Tx & RESISTOR
HV SWBD 1 FEEDER
THRUSTER 3 HV PANEL
HV Tx 2 (FWD)
HV Tx 2
TOPSIDE HV Tx 2 (HPU & LV)
TOPSIDE HV Tx 2 (VFD)
THRUSTER 6 T/R
AFT FIRE PUMP
EM'CY HV SWBD INCOMER 2
HV SWBD 3 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

Features



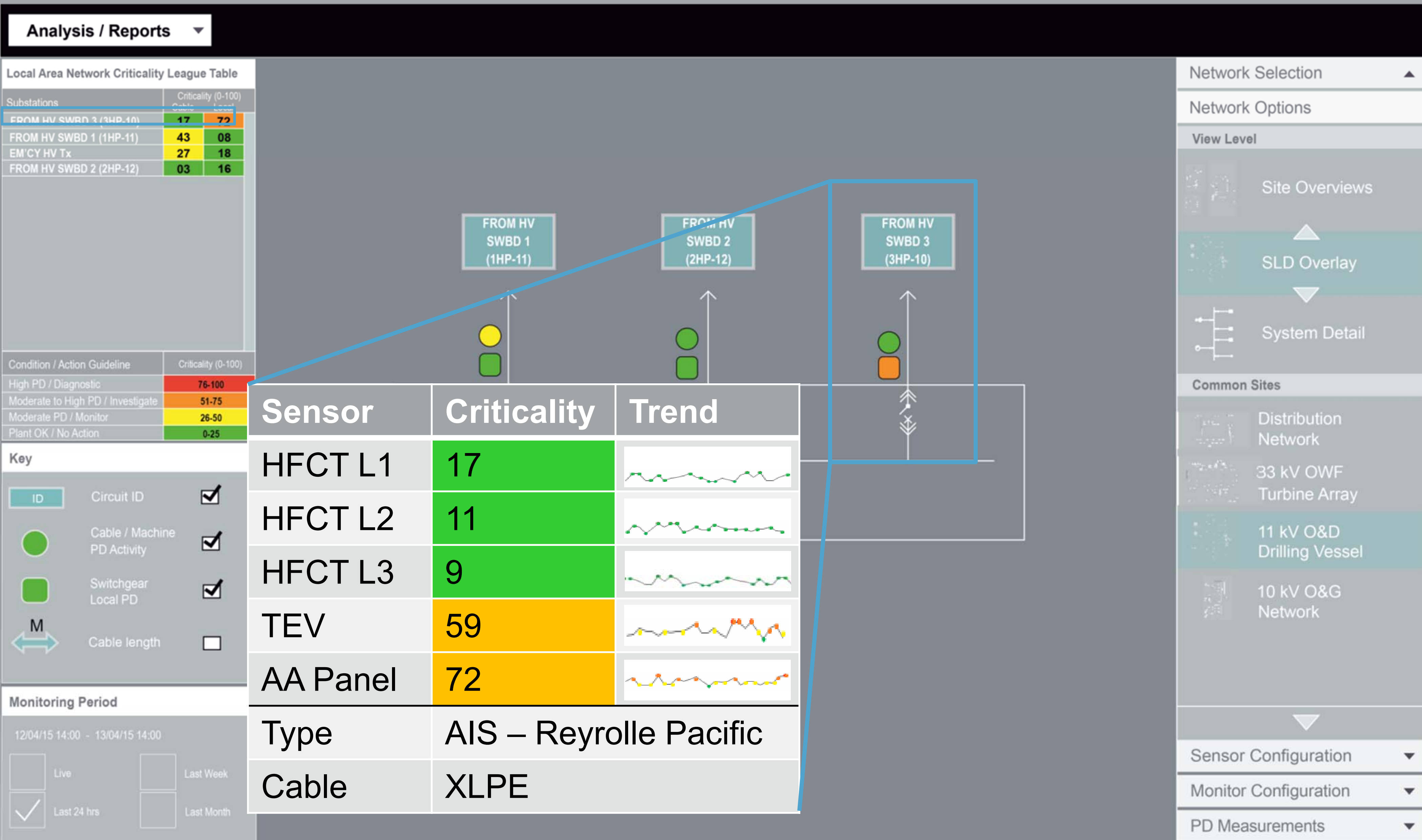
Analysis / Reports
Local Area Network Criticality League Table
Substations
Criticality (0-100)
Cable
Local
THRUSTER 2 HV PANEL 96 99
EARTHING Tx & RESISTOR 77 06
HV Tx 3 13 74
HV SWBD 2 FEEDER 16 70
GENERATOR 5 13 65
TOPSIDE HV Tx 3 (HPU & LV) 09 39
GENERATOR 6 18 38
TOPSIDE HV Tx 3 (VFD) 36 44
THRUSTER 5 T/R 26 09
HV SWBD1 BUS TIE PANEL 25 21
EM'CY HV SWBD INCOMER 3 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 3
GENERATOR 5
GENERATOR 6
EARTHING Tx & RESISTOR
HV SWBD 2 FEEDER
THRUSTER 2 HV PANEL
HV Tx 3
TOPSIDE HV Tx 3 (HPU & LV)
TOPSIDE HV Tx 3 (VFD)
THRUSTER 5 T/R
EM'CY HV SWBD INCOMER 3
HV SWBD1 BUS TIE PANEL
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

Features



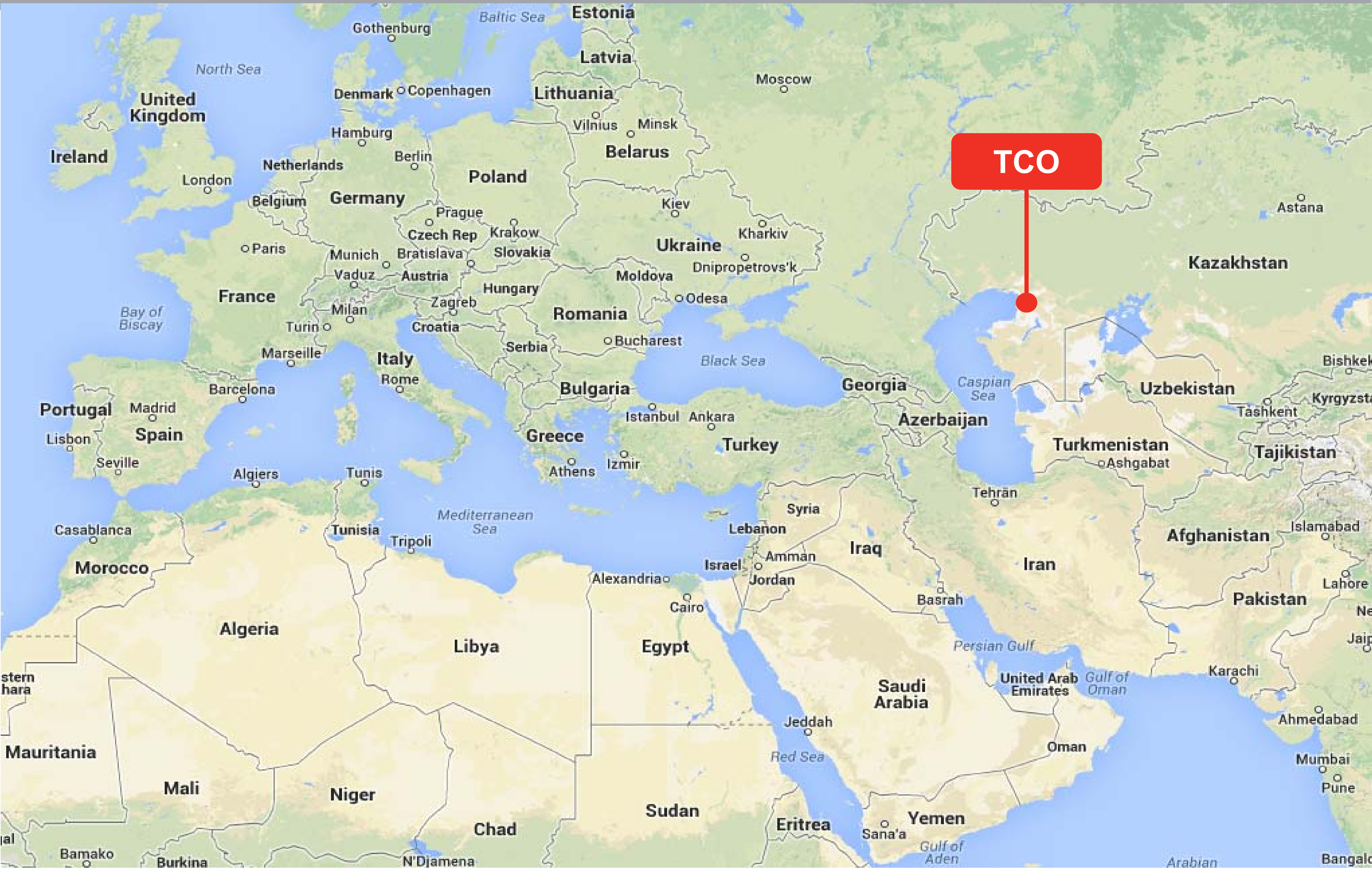
Analysis / Reports
Local Area Network Criticality League Table
Substations
Criticality (0-100)
Cable
Local
FROM HV SWBD 3 (3HP-10) 17 72
FROM HV SWBD 1 (1HP-11) 43 08
EM'CY HV Tx 27 18
FROM HV SWBD 2 (2HP-12) 03 16
Condition / Action Guideline
Criticality (0-100)
High PD / Diagnostic 76-100
Moderate 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
FROM HV SWBD 1 (1HP-11)
FROM HV SWBD 2 (2HP-12)
FROM HV SWBD 3 (3HP-10)
EM'CY HV Tx
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

Features – System Highlight



Case Study V: Ex/ATEX 10 kV Motor OLPD test & monitoring project (Tengizchevroil (TCO), Kazakhstan, 2011–2014)

TCO - Location



About Tengizchevroil (TCO)

- Tengizchevroil LLP (TCO) was formed between the Republic of Kazakhstan and Chevron Corporation of the USA.
- The Tengiz field has a net daily production of 218,000 barrels of crude oil, 301 million cubic feet of natural gas and 18,000 barrels of LNG.
- 50% of the 100x in-service 10 kV Ex/ATEX motors at the facility had reached the ‘design-life’ of 20 years.
- TCO wanted to apply condition monitoring (CM) technology to provide ***reliable life extension*** of the assets.

100	**Ex/ATEX HV motors in operation**
50	**These motors have now been in-service for 20 years**
-40C – +40C	**There is a wide range of ambient air temperatures at the site**

- The 10kV HV motors at the facility are critical to production operations with only limited spares maintained at the site.
- Almost all of the HV motors at the facility are ***Ex/ATEX rated***.
- A conventional partial discharge monitoring approach (using *High Voltage Coupling Capacitor* sensors) has been applied for the ***10 kV gas turbine generators*** at the facility (these are located in a non-Ex/ATEX location).
- The client required a solution for OLPD monitoring of their Ex/ATEX HV motors ***without having to enter the Ex/ATEX hazardous gas zone***.

10 kV, 800 kW Amine Pump

10 kV, 2400 kW Air Blower

HVPD provide the following services for TCO:

- An ongoing installation of permanent HFCT sensors (located at the central HV switchboards) and HVPD Multi™ Monitors on HV motor circuits.
- Periodical and baseline *diagnostic* OLPD spot-testing using the HVPD Longshot™ OLPD test unit.
- Further integration of HVPD OLPD monitor technology interface to the TCO IT network through MODBUS and OPC protocols.

2011

September - Pilot Project – OLPD Test & Trial Monitoring

2012

January – TCO Purchase 31x HVPD Multi™ Permanent Monitors to monitor 100x HV Motors

May – OLPD Test and Monitor Installation started

August – OLPD Test, Monitor Installation & Monitoring Data Analysis

2013

May/June - OLPD Test, Monitor Installation, Monitoring Data Analysis and Further Integration of HVPD Monitors into TCO IT Infrastructure

DATA HANDLING, HOSTING, ANALYSIS AND SUPPORT

2012 → 2017

- The monitoring technology applies knowledge held in ***HVPD's OLPD Measurements Database©*** that has a large population of measurement data on cables, switchgear, transformers, motors and generators.
- Identifies a HV network's ***'worst 1%, 2% and 5%'*** of assets and identifies any cables/plant/machines/transformers with a high risk of failure.
- All monitoring data is sent to the ***"HVPD Decision Support Centre"*** in Manchester, UK and HVPD's OLPD monitoring engineers provide data analysis and provide insulation condition status of the HV network.
- Condition Criticality Data is integrated in the facility's ***Electrical Control System (ECS)*** to raise 'flags' and/or alarms.
- The user interface screen includes the condition criticality data superimposed onto a 'mimic' of the network's ***single-line diagram (SLD).***

Example of Criticality 'OLPD League Table' for HV Motor Circuits from 12 Months of OLPD Monitoring Data (*May 2012–May 2013*)

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003	57	<10	3543	Stator Slot & End-Winding Discharges	Not Installed	None – ***monitor required asap***	Problem / Unreliable
004	44	<10	1427	End-Winding Discharges	***New Installation***	TBC - New	Problem / Unreliable
005	78	<10	1106	Stator Slot & End-Winding Discharges	**3 months**	Increasing	Problem / Unreliable
006	35	<10	1086	End-Winding Discharges	***New Installation***	TBC - New	Problem / Unreliable
007	55	<10	990	Stator Slot & End-Winding Discharges	**7 months**	TBC – Intermittent Use	Probable Inspection
008	13	<10	935	Stator Slot & End-Winding Discharges	***New Installation***	TBC - New	TBC – Requires monitor data
009	26	<10	847	End-Winding Discharges	***New Installation***	TBC- New	TBC – Requires monitor data
010	29	<10	570	Stator Slot & End-Winding Discharges	**12 months**	Decreasing	Still Acceptable
011	16	<10	262	Stator Slot Discharges	Not Installed	None **–** ***monitor required***	TBC – *Requires monitor install*
012	21	<10	258	Stator Slot & End-Winding Discharges	**3 months**	Increasing	Still Acceptable
013	36	<10	102	Stator Slot & End-Winding Discharges	Not Installed	None **–** ***monitor required***	TBC – *Requires monitor install*
014	*No Data Available – HV Motor Not Energised*				***New Installation***	TBC - New	TBC – Requires monitor data

- OLPD testing and monitoring of rotating HV machines, is a simple, non-invasive and effective way to assess the insulation condition of the machine's HV stator winding.

- There are a range of suitable OLPD sensors for this application with the best choice depending on the size and location of the rotating HV machine

- Such OLPD condition monitoring (CM) technology can be used to support Condition-Based Management (CBM) of rotating HV machines by identifying those machines in need to preventative maintenance to avoid unplanned outages.

- Increasing levels of PD activity provides an 'early warning' against insulation failure by detecting 'incipient' and developing HV insulation faults.

- Diagnostic condition assessment should be made using a combination of PD levels, PD activity and, most importantly, PD trend.

- All measurements are compared and benchmarked against HVPD's ***Rotating HV Machine Measurements Database©*** to help assess the risk of HV stator winding insulation failure.

- HVPD have supplied condition-based assessment technology for the testing and monitoring of high voltage (HV) networks for over 20 years.

- We provide diagnostic and testing services, consultancy services, training and continuous ***On-line Partial Discharge (OLPD)*** monitoring systems.

- In 2011, HVPD developed a ***remote OLPD monitoring technique*** *(in conjunction with Chevron, TCO and BP)* for the monitoring of ***complete Ex/ATEX HV motor feeder cable circuits***, from the switchgear to the stator windings of the HV motor.

- This technique uses a combination of (3) wideband, **high frequency current transformer (HFCT) sensors** and (1) ***Transient Earth Voltage (TEV) sensor***, installed at the central HV switchboards.

- The technique is suitable for OLPD monitoring ***all types of rotating HV machines***, including motors and generators and can also be used to monitor the HV windings of remote transformers (although secondary monitoring systems are required to monitor ‘beyond the transformer’ such as VSD motors, as described in Presentation III).

- For the OLPD monitoring of large HV generators (>20MVA) HVPD use permanent ***high voltage coupling capacitor (HVCC)*** sensors located inside the generator cable box.