USER MANUAL

The PDSurveyor™

Universal, Hand-held On-line Partial Discharge (PD) Surveying Tool for Insulation Condition Testing of 3.3 kV to 45 kV Cables and Plant

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PDSurveyor™ User Manual
Version: 3.4
Date: 8th March 2011
Document Reference: PR0300PT-001-A

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1. General Information

The HVPD PDSurveyor™ and PD sensors have been designed for use only on the earthed, outer surfaces of metal-clad equipment and the earth/neutral connections of power cables.

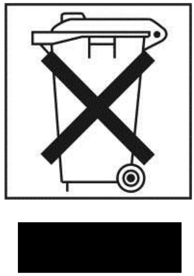
Under no circumstances should the HVPD PDSurveyor™ or PD sensors be allowed to contact the high voltage terminals of plant under test.

1.1. Safety Precautions

Before using the HVPD PDSurveyor™ and accessories in the substation or switchyard it is important that the user reads and understands the instruction manual and takes into account the following general safety information:

- The user should obey the plant owner's safety rules at all times.
- **Under no circumstances** should the HVPD PDSurveyor™ or PD sensors be allowed to contact the high voltage terminals of plant under test.
- Do not use the equipment if it is damaged.
- Inspect and test the signal cable for continuity.
- Always select the appropriate sensor and sensor connections for the application.
- Ensure all cabling is made in a tidy fashion and does not pose a trip hazard.
- It is advisable to test the equipment and instruments immediately before and after performing site tests to ensure that the site results have been correctly recorded.

1.2. Environmental Protection Announcement



This product contains general electronic components that may be environmentally harmful if improperly disposed. Please use correct disposal methods in accordance with local regulations.

Device can be returned to HVPD Ltd at the end of use for proper disposal.

1.3. Abbreviations

AA	Airborne Acoustic
BNC	Bayonet Neill-Concelman connector (RF cable termination)
EM	Electromagnetic
HFCT	High Frequency Current Transformer
HV	High Voltage
MV	Medium Voltage
PD	Partial Discharge
RMU	Ring Main Unit (also known as padmounts)
TEV	Transient Earth Voltage

2. Standard Scope of Supply

PDSurveyor™	
HFCT 100/50 Sensor	
100 kHz High Pass Filter	
2 metre BNC Cable	
User Manual	
Laminated Summary Usage Guide	
Certificate of Conformance	
Warranty Certificate	
Battery Charger (Region Specific)	
Soft Carry Case	

3. Specification

Hardware Details	
HFCT Sensor Input Connection Type	BNC
HFCT Input Internal Impedance	50 Ω
HFCT Accuracy	± 10%
HFCT Detection Frequency Range	100 kHz – 20 MHz
TEV Sensor	Built-in
TEV Accuracy	± 1 dB
TEV Detection Frequency Range	5 – 70 MHz
AA (Ultrasonic) Sensor	Built-in
AA Accuracy	± 1 dB
AA Detection Frequency Range	40 kHz ± 1 kHz
Onboard Interface	
LED Indicators	Power, 7 Level Peak PD Indicators per Sensor
Enclosure Details	
Dimensions (H x W x D)	220 x 120 x 110 mm
Weight	1.26 kg
Enclosure Material	Injection Moulded Plastic
Operating Environment	
Temperature Range	-10 to +55 °C
Relative Humidity	< 90% (non condensing)
Charging Humidity	20-85% (non-condensing)
Power	
Supply Type	Built-in Battery (Li-ion)
Low Battery Indicator	Flashing Power LED
Battery Charger Connection Type	2.1 mm Input Jack
Power Saving	Auto-off after 5 Minutes
Battery Charger (UK/EU)	
V_{in}	90-264 V AC 50/60 Hz
V_{out}	8.4 V DC
Dimensions (H x W x D)	33 x 90 x 45 mm
Weight	0.09 kg

4. HVPD PDSurveyor™ Introduction

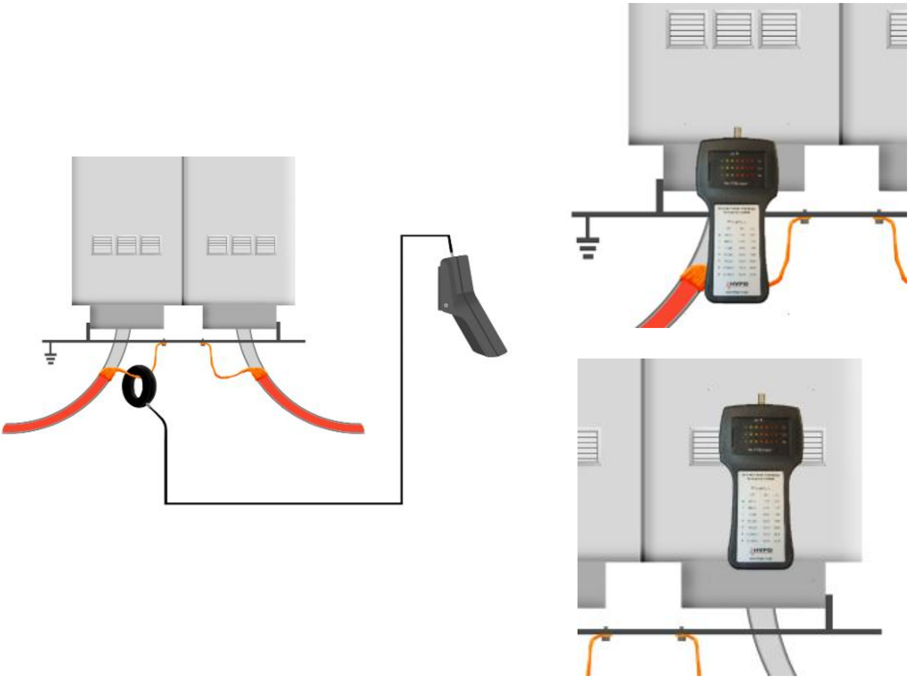


Figure 1: PDSurveyor™ use in a Substation

The PDSurveyor™ from HVPD Ltd is the world's first 3-sensor handheld on-line partial discharge detector for assessment of in-service medium voltage (3.3 to 45 kV) cables and metal-clad plant (switchgear, transformers, CTs / VTs, and rotating machines). It is a portable, hand-held device suitable for use by all operational staff in the substation, for safety screening and pre-qualification of PD levels before diagnostic testing is undertaken.

The HVPD PDSurveyor™ features internal Transient Earth Voltage (TEV) and Airborne Acoustic (AA) sensors to detect PDs from metal-clad equipment. There is an input for an external inductive High Frequency Current Transformer (HFCT) sensor for detection of PD in MV power cables.

PD signals are measured and processed by the PDSurveyor™ embedded hardware. The peak PD level is instantaneously displayed for each sensor on the seven PD level LED arrays.

4.1. Why use the PDSurveyor™?

1. **As a Safety Device** – The PDSurveyor™ provides an *immediate indication* to the user as to whether switchgear or other MV plant in the substation is safe to approach and to work in close proximity. This can be used by all operations staff to ensure their working area is safe from dangerous levels of PD activity which could produce catastrophic failure, explosion and personal injury.

2. **As a First-Line PD Screening Device** – PD measurements can be made relatively quickly and thus the PDSurveyor™ can be used to scan large numbers of MV cables and plant items for PD activity as a prelude to using diagnostic PD test and/or monitoring technology (such as the HVPD Longshot™ PD Test Unit from HVPD Ltd).

4.2. PD Sensors

The HVPD PDSurveyor™ has three PD sensors for detection of different sources of PD activity in MV cables and plant as follows:

Sensor	Attachment Point	PD Detection
TEV (Transient Earth Voltage)	Metal-clad plant housing close to vents/seams/gaskets.	Electromagnetic radiation from PD sites in plant that is induced onto the plant metal housing.
AA (Airborne Acoustic)	Over vents in plant housing with line of site to PD source.	Airborne acoustic (ultrasonic) radiation through air from corona and surface discharges in the plant.
HFCT (High Frequency Current Transformer)	Power cable earth strap/drain wire or power cable with earth strap/drain wire brought back through sensor.	Current impulses from PD in cables, cable terminations and plant/switchgear cables are terminated into.

5. PDSurveyor™ – Key Features Summary

- Instant indication of PD activity in MV metal-clad switchgear, plant, and power cables whilst they are in service.
- Spot-tests efficiently to quickly find PD activity using PD level LEDs.
- Useful as a pre-cursor to more in depth diagnostic testing.
- Useful as a safety device prior to working in substations.

6. Product Description

7. Charging the Battery

Before first use, the PDSurveyor™ should be charged for at least 2 hours with the supplied charger. With normal use, the device should be fully charged at least once every week. The power LED flashing indicates a low battery.

Charger Connection

Note:	**Only use the supplied battery charger.** **It is not possible to use the PDSurveyor™ while under charge.**

When the battery charger is connected to a mains supply and the PDSurveyor™, its LED will change colour as follows:

Red: **Charging**
Green: **Charged**

PDSurveyor™ Charging

8. PD Guideline Levels

The colour coded PD levels are given as guidelines based on HVPD's experience of testing in service MV cables and plant.

In the event of moderate (Orange LEDs) or high PD activity (Red LEDs) being detected, diagnostic PD measurements are recommended to confirm and locate the PD source. Examples of such measurements with the HVPD Longshot™ PD Spot Test Unit are given in Appendix 2.

On-Line Partial Discharge Surveying System

PD Level Guide:

	CT	TEV	AA
● (green)	300pC	15dB	8dB
● (yellow)	600pC	22dB	12dB
● (yellow)	1200pC	26dB	15dB
● (orange)	3000pC	30dB	19dB
● (orange)	7800pC	35dB	22dB
● (red)	20000pC	38dB	26dB
● (red)	30000pC	45dB	30dB

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Recommended Action

- **LED 1** – Green (Plant OK – Retest within 12 months)
- **LED 2 & 3** – Yellow (Moderate PD – Retest regularly with the PDSurveyor™, monitoring recommended)
- **LED 4 & 5** – Orange (Moderate to high PD – Investigate source of PD using the HVPD Longshot™ Diagnostic Spot Test System)
- **LED 6 & 7** – Red (High PD – Test to determine cause, locate, and restrict access if necessary)

Note: PD levels and recommended actions are guideline levels only and are based on HVPD's experience in testing MV Plant.

What is Partial Discharge and why test for it?
Partial Discharge activity is localised electrical breakdown between two electrodes that does not completely bridge the gap between them. PD activity is indication of incipient faults in the insulation and is widely regarded as one of the best indicators of the deterioration of medium and high voltage insulation.

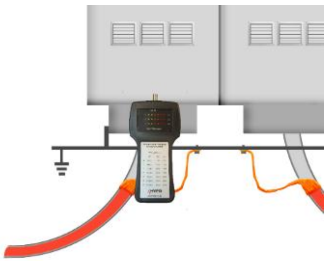
9. Performing Tests with Each Sensor

All sensors function independently and can display PD on each row of display LEDs simultaneously.

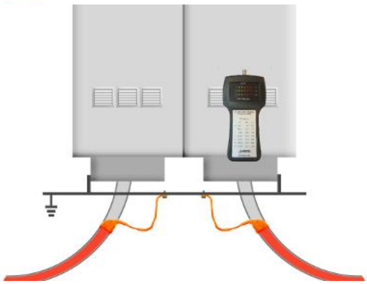
9.1. General Site Suitability and Precautions

- Ensure the PDSurveyor™ battery is charged before use.
- Ensure the test area is safe.
- The cable for the HFCT PD sensor should not be allowed to pose a trip hazard.

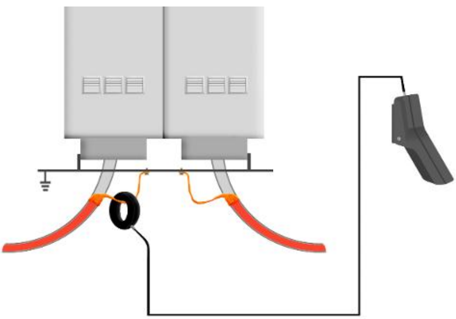
9.2. Schematic Guide for using each PDSurveyor™ Sensor



Testing using the Transient Earth Voltage (TEV) inbuilt sensor held directly against metal surface, close to vents / gaskets.



Testing using the Airborne Acoustic inbuilt sensor placed directly over air vents and other openings (line-of-sight detection).



Testing using the High Frequency Current Transformer attached to power cable earth strap.

10. Procedure for TEV PD Measurement

10.1. Background Noise Measurement

TEV measurements can be affected by background electrical noise in the substation. Sources include:

- Power electronic switching, e.g. from DC power supplies.
- Corona from outdoor switchyards.
- High frequency communication systems, e.g. two-way radios

To measure the background noise level, simply hold the PDSurveyor™ TEV sensor flat against metalwork where PD cannot occur e.g. Metal Doors or LV control panels.

Higher noise levels will desensitise measurement of real TEV PD signals.
For results to be acceptable, the background level should be less than 'Yellow'.

10.2. TEV Sensor Attachment Requirements

1. ***The switchgear must NOT have a double skin metal housing.***
2. ***There must be vents/openings in the metal housing for electromagnetic signals to emerge on outer surfaces.***

10.3. TEV PD Measurement

The TEV sensor should be placed flat against the metal-clad switchgear close to vents or gaskets or seams on the metal-clad housing. The LEDs will light to show the measured PD level. The user **MUST** hold the unit whilst in use.

It is recommended to place the TEV sensor at multiple points on the plant for example on the cable boxes and front and back of each switchgear panel.

10.4. TEV PD Measurement on Switchgear Bus

The recommended procedure for PD testing of a MV switchgear bus is to carry out an initial walk-by test with the PDSurveyor™ unit pressing the TEV on each panel on the front and back sides for a few seconds and noting the TEV PD levels.

It is normal for TEV signals to propagate between switchgear panels and thus one PD source can produce signals which are detected on multiple switchgear panels. The TEV signal amplitude will attenuate rapidly from the source and thus where the highest reading is measured gives a strong indication of the source. Diagnostic testing should be employed when a moderate-high TEV level (orange-red LED) is detected to obtain a more accurate PD location. See examples in Appendix 2.

11. Procedure for Acoustic (AA) PD Measurement

11.1. Background Noise Measurement

If any reading is made with the sensor flat on a surface (not over a vent or air gap) this can be discounted as background noise.

11.2. AA Sensor Attachment Requirements

1. ***There must be a clear air path (line of sight) from the sensor to the discharge source, i.e. a vent or hole in the plant housing.***
2. ***Fully enclosed air insulated switchgear with no grills, vents, air gaps etc, will not be suitable for Airborne Acoustic measurements.***

11.3. Airborne Acoustic (Ultrasonic) Sensor Attachment

The sensor should be placed over vents or air gaps in the switchgear housing as shown below. The LEDs will light to show the measured PD level.

As the acoustic sensor has a limited +/- 30° angle 'field of detection' it is possible, by moving the direction of the unit slightly, to locate the source of the air discharge, see Example 2, Appendix 2.

11.4. AA PD Measurement on Switchgear Bus

The recommended procedure for PD testing of a MV switchgear bus is to carry out an initial walk-by test with the PDSurveyor™ unit pressing airborne acoustic towards the vents openings on each switchgear panel and the PD levels noted.

The airborne acoustic detection is very directional and thus signals should only be detected on from the plant item is focussed on. Detection of signals radiated from adjacent switchgear panels or plant items should not occur.

11.5. AA and TEV PD Measurement

Airborne Acoustic is much more sensitive than TEV sensor discharges into air such as from corona and surface discharges. Hence it is possible for lower magnitude PD events, to detect the acoustic PD signals, and see no detectable TEV signals.

In general, the PD levels in switchgear must be above 100 pC before reliable TEV signals can be measured. The ultrasonic probe however, can easily make measurements at levels well below this, down to around 10 pC. This sensitivity is based on the proviso that there exists the continuous air path between the acoustic detector and the originating PD site and that the distance to the source of discharge is less than 1 metre.

12. Procedure for HFCT PD Measurement

12.1. Background Noise Measurement

HFCT measurements can be affected by background electrical noise sources inside and outside the substation. Sources include:

- Radio frequency interference from local radio transmission
- Corona from outdoor switchyards.

To measure the background noise level, attach the HFCT to the earthing conduit of a de-energised feeder, or a nearby LV earth.

For results to be acceptable, the background level should result in HFCT readings less than Yellow.

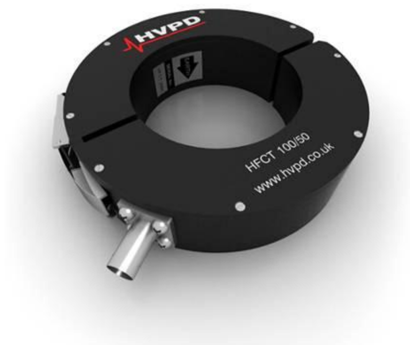
An in-line filter can be supplied if HFCT measurements are affected by excessive noise interference. Please contact HVPD for further details. Contact information on page 2 of this manual.

12.2. HFCT Sensor Attachment Requirements

1. ***There must be independent access to either the earth-straps or cores of the cables at the switchgear/transformers.***
2. ***There must be an insulated gland and washers between the cable earth and switchgear earth.***

12.3. HFCT Sensor Attachment

The HFCT sensor should be connected to the PDSurveyor™ using the supplied 50Ω BNC cable.



It must be ensured that the cable terminations are suitable for HFCT installation. HFCT sensors can be attached to single phase or three phase cables.

To measure the PD signals it is necessary to intercept the currents either in the conductor alone (i_+), or the earth strap / earth drain wire alone (i_-). If the HFCTs are installed so that both the conductor and screen pass through the middle of the coil, then the PD signals cancel each other out and no output is obtained from the HFCT. The correct and incorrect sensor attachments are shown in Figure 2.

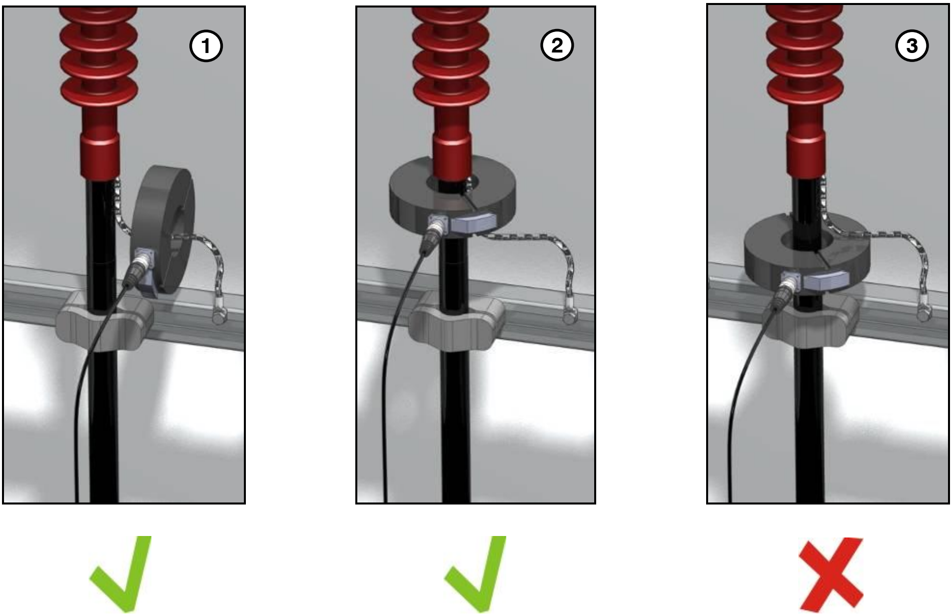


Figure 2: Cable Termination Options for HFCT Attachment

If possible the HFCT sensors should be attached to individual cable earth connections as opposed to common earth cables that are used to connect the sheaths of several cables to ground. Photographs of suitable and unsuitable cable terminations are shown in Appendix 1.

To attach an HVPD in-line filter, connect directly to the upper BNC port of the PDSurveyor™ unit, and the sensor cable to its other termination, leading towards the sensor.

12.4. Sensitivity to PDs in Cable Circuits

As PD signals travel down the power cable they will be attenuated as a general rule of thumb cables exceeding 1 km should be tested at both cable ends. If there are multiple RMUs in the circuit measurements should be made at every second or third RMU.

12.5. Measurement at Open Points in the Network

At open point RMUs on the network, the HFCT sensor may be attached to the closed-circuit feeder, providing there is still significant substation impedance seen by the closed circuit cable feeder; this is generally achieved if a distribution transformer is attached. It should be noted that when there is no other feeders attached the substation impedance will be much higher and thus the PD current magnitudes measured by the HFCT sensors will be less. If the distribution transformer is also disconnected then detection of any PD signal with HFCT sensors may not be possible.

12.6. 'Cross-Talk' of HFCT Signals in Substations

The effect of cable PD pulses and RF noise passing along common earth bars in substations can lead to 'cross-talk' between the different cable feeder circuits and can lead to confusion as to the source of any PD activity. Figure 3 below shows an example of where the PDSurveyor has been used to measure the PD activity at an 11 kV substation which is connected to 2x overhead lines. The results of the testing showed a continuous Orange 2 LED indication for all of the main feeders tested.

These results suggest that *the source of the signals was in fact AM radio interference* being picked-up from the overhead lines and radiated along the common earth bar to be picked-up at all points of attachment.

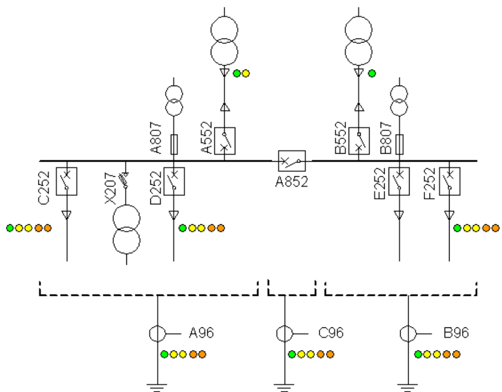


Figure 3: Example of PDSurveyor™ CT test results in a substation suffering with RF interference from AM radio pick-up on the common earth bar.

13. Maintenance

13.1. *Signal Cable*

The BNC cable should be tested routinely by injecting known signals and measuring with an oscilloscope. A good test signal is a 100 ns, 100 mV pulse, with a rise time <10 ns.

13.2. *Calibration*

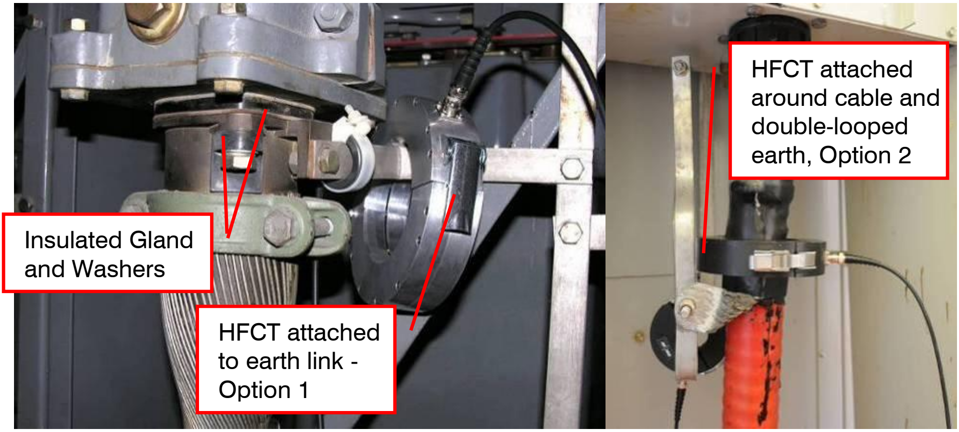
It is recommended that the PDSurveyor™ and sensors are recalibrated every 12 months to ensure readings remain accurate. Please contact HVPD Ltd to arrange; contact details are on the front of this manual.

13.3. *Packing and Transport*

The provided soft-carry case should be used to protect the PDSurveyor™ between tests.

Appendix 1: Photographs of Cable Terminations Suitable and Unsuitable for HFCT Attachment

Suitable Cable Terminations



Unsuitable Cable Terminations

Appendix 2: Example Test Projects

Example 1: PD Testing of 11 kV Air-Insulated Switchgear

Introduction

The purpose of the testing was to evaluate the condition of the 3x 11 kV GEC VMX switchgear panels. This type of switchgear has a history of PD problems, mainly associated with the VT and the cast resin parts of the circuit breaker spouts. The PD activity detected has been associated with discharges in air and surface tracking (in contrast with internal) PD activity in voids in the insulation. The PD activity in air can lead to long term damage to the insulating surfaces of the switchgear, and this damage can result in reduced hydrophobicity of the insulating surfaces. In this condition, tracking and discharge related erosion are then both possible which can then lead to failure in service, which is why this type of switchgear must be kept free of PD activity.

It should be noted that this type of PD activity in air and on the surfaces of the switchgear insulation can be dependent on the humidity and temperature of the surrounding air and it is entirely possible to measure PD levels on a warm and dry day, and find no activity at all. This does not mean that in colder and more humid circumstances, the potential PD activity cannot appear at some later time as this type of PD is known to be intermittent in nature (i.e. ‘it comes and goes’). The 3-panel switchgear panels tested are shown below in Figure 4.

Figure 4: Front View of GEC VMX AIS Panels No.1, No.2 & No.3 (from left to right)

Results

Initial PD Screening was carried out in the substation on the 3x GEC VMX switchgear panels with the PDSurveyor™ unit using the TEV Sensor held up against the switchgear panels. All readings are given in dB (decibels) which is the convention for TEV (Transient Earth Voltage) signals as per these measurements (refer to Table A1 (below) for PD Guideline Levels).

Test 1: PD Screening (TEV Sensor) of 11 kV GEC VMX AIS – *Panel No.1*
PD Screening tests with the TEV sensor on the PDSurveyor™ unit showed the front of Panel No.1 to contain some PD signals. PD levels were detected at a level of 3 LEDs (YELLOW 2) which equates to *28 dB* of TEV partial discharge. Further testing at the side and back of the No.1 panel showed an intermittent LED (GREEN 1) which equates to a low level of TEV PD of *15 dB*.

Test 2: PD Screening (TEV and AA Sensors) of 11 kV GEC VMX AIS – *Panel No.2*
The same test was repeated on the front of Panel 2. PD levels were detected with 6 LEDs (RED 1) which equates to *44 dB* of TEV partial discharge which is a *very high level for this type of switchgear*. Further testing at the sides and back of the housing showed an intermittent LED (GREEN 1) as per Test 1 (low level of PD).

Test 3: PD Screening (TEV and AA Sensors) of 11 kV GEC VMX AIS – 3rd Panel
The same test was repeated on the front of Panel 3. The result of the test was the same as per the test on Panel 1 i.e. a level of **3 LEDs (YELLOW 2)**, equating to **28 dB** of partial discharge. Further testing at the sides and back of the housing showed an intermittent LED (GREEN 1) as per Tests 1 and 2.

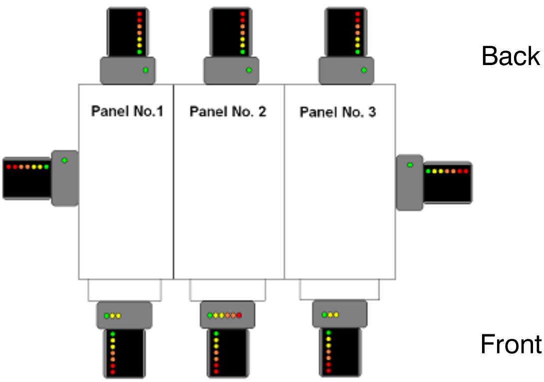


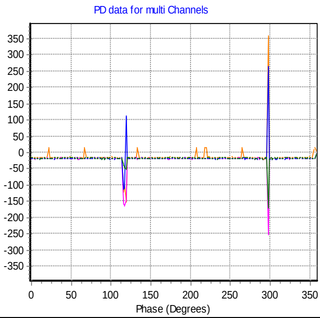
Figure 5: Illustration of PD Surveyor™ test positions and PD measurement results (highest signal on the Front of Panel No.2)

Figure 6: Panel 2 – PDSurveyor™ Display (RED 1 Level = 44 dB)

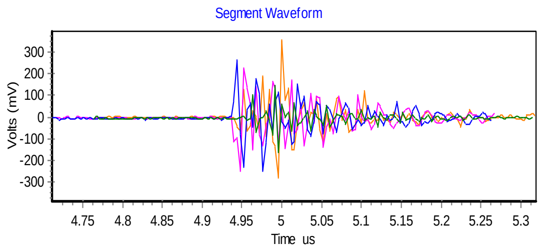
Figure 7: Panel 3 – PDSurveyor™ Display (YELLOW 2 Level = 28 dB)

HVPD Longshot™ Diagnostic Spot-Test Results

20 ms Power Cycle



PD Event



Panel 1 Front	Panel 2 Front	Panel 3 Front	Panel 2 Rear

Signals arrive first at Panel 2 front, closely followed by Panel 3 front.

Conclusions

It can be seen from the PD Surveyor tests (Tests 1 - 3) that a substantial amount of partial discharge was detected at the front of ***Panel No.2*** with ***PD levels of 6 LEDs (RED 1) equating to 44 dB of partial discharge which is diagnosed as high level***. The other two panels measured moderate PD levels of 2 LEDs (Yellow 2) 28 dB and it was likely that this partial discharge being detected in Panels No.1 and Panel No.3 are remnants of the signals originating from the source in Panel No.2.

Further testing with the HVPD Longshot™ unit confirmed the very high levels of partial discharge activity (of up to 51 dB) originating from Panel No.2. The HVPD Longshot™ unit was also used to carry out time-of-arrival measurements using distributed TEV sensors made. This test confirmed that the source of the PD was from the *front right portion of the No.2 Panel.* This appears to be near, but not necessarily in, the truck section of the panel. It is also possible that the site of discharge is in the right phase 'spout' of the main housing. Alignment issues with the truck in the No.2 Panel may also be a factor as to why the discharges initiated in the first place.

Due to the very high level of partial discharge activity in Panel No.2, the plant owner was advised to carry out a visual inspection and instigate any remedial action to rectify the problem. Further advice included that after the remedial work was completed the 3x panels should be retested and, due to the intermittent nature of this type of PD activity, possibly monitored over an extended period of time to check that the problem of the PD activity has been rectified.

Example 2: PD Survey of 30 kV AIS with the Airborne Acoustic Sensor

Introduction

A quick survey (<1 minute per bay) was carried out of all bays of open-frame, AIS switchgear on the three 30 kV bus sections at the substation. The survey utilised the PDSurveyor Airborne Acoustic (AA) sensor shown in operation in Figure 8.

Figure 8: Survey of Air Insulated Switchgear with the PDSurveyor™ Airborne Acoustic Sensor

Results

The results of these tests are summarised in the table below:

T42 30 kV Switchgear Bay No	AA pointed at Bushing PD Level (dB)	AA pointed at Breaker PD Level (dB)
1	<12	<12
2	20	<12
3	<12	<12
4	<12	<12
5	<12	<12
6	<12	<12
7	<12	<12
8	<12	<12
9	<12	<12
10	12	<12

11	<12	<12
13	<12	<12
14	<12	<12
15	<12	<12
16	<12	<12
17	<12	<12
18	<12	<12
19	<12	<12
20	<12	12

Conclusions

Only bay 2 showed acoustic PD activity, which showed 20 dB originating on the bushing. On closer inspection of the cable termination and bushings, water damage was visible on the ceiling, as shown in Figure 9. It is highly likely that this is the source of the discharge activity detected using the PDSurveyor™.

the advice to the plant owner here was to re-test this switchgear regularly (at a minimum of every 3 – months) and to also consider the monitoring of the PD activity over an extended period of time to check that the levels of PD activity do not increase.

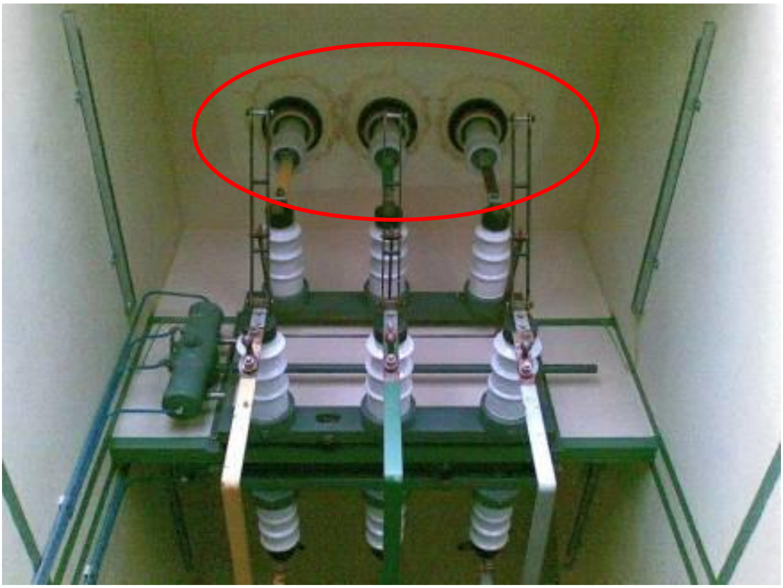


Figure 9: Water Damage on T42 30 kV Bay 2 Bushings

Example 3: On-line PD Screening of 10 kV Cables, Switchgear and MV Motors

Introduction

The purpose of the testing was to carry out on-line PD screening of 10 kV Cables, Switchgear and an in-service 10 kV N2 Compressor Motor at the customers industrial gas factory using the PDSurveyor™ handheld PD screening device.

Results

Test 1: PD Screening (TEV and AA Sensors) of 10 kV AIS

PD Screening tests with the TEV sensor on the PDSurveyor™ unit showed the 10 kV AIS in the customers main substation to be discharge-free.

Test 2: PD Screening (HFCT Sensor) of 10 kV XLPE Cables

The 150 metre long cables supplying the MV motors in the factory were connected at the main substation by earth straps to a common earth bar. PD Screening tests were made at the main substation end of the cable with the HFCT sensor clipped around the individual earth straps of each of the cables in turn to measure the PD levels on the cables. The PDSurveyor™ results showed very high 'Cable' PD levels of up to 6 LEDs (RED 1- *20,000 pC+)* on the *N2 Compressor Motor Cable* (see Figure 10 below). PD levels of up to 3,300 pC+ and were also detected on the earth straps of the cable feeders on each side of the N2 Compressor Motor Feeder which shared the common earth bar.

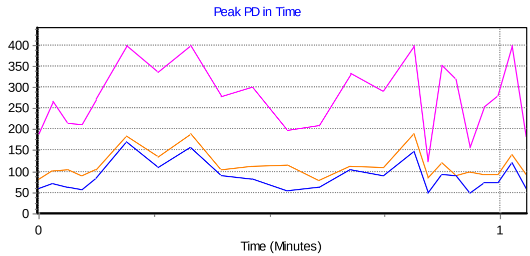
Figure 10: PDSurveyor™ with HFCT on earth strap of N2 Motor Compressor Cable showing 6x LEDs (RED 1 lit) on HFCT (20,000 pC)

It appeared from the survey that *the source of the PD was from the N2 Compressor Motor cable feeder* as this showed the highest levels of PD (at 20,000 pC+) compared to its nearest 2x cables (to the Transformer and the Air Compressor at 9,000 pC and 3300 pC+ respectively). The next stage of the investigation was to carry out Diagnostic Testing with the HVPD Longshot™ PD Spot Tester and Monitor to further confirm and then locate the source of the very high PD pulses.

Test 3: HVPD Longshot™ PD Test of 3x HFCTs at Cable Joint

HFCT Sensors were attached to the earth straps of the following 3x 10 kV Cable Feeders. These earth straps shared the same common earth bar.

Ch 1 – Orange Colour – Transformer Cable
Ch 2 – Pink Colour – N2 Compressor Motor Cable
Ch 3 – Blue Colour – Air Compressor Motor Cable



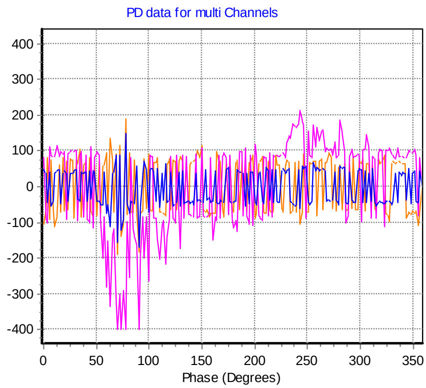


Figure 11: PD Test Data across 50Hz Power Cycle – HFCTs attached to Earth Strap Ch 1 (Orange) – Cable to Transformer, Ch 2 – N2 Compressor, Ch3 – Air Compressor

The PDGold© Event Recogniser Software with 'Event Recogniser' module was used to carry out further Diagnostic Analysis of the HVPD Longshot™ PD Data shown above in Figure 11. Some of the results from this analysis are shown below in Figure 12.

PDGold© 'Event Recogniser' Software Analysis.

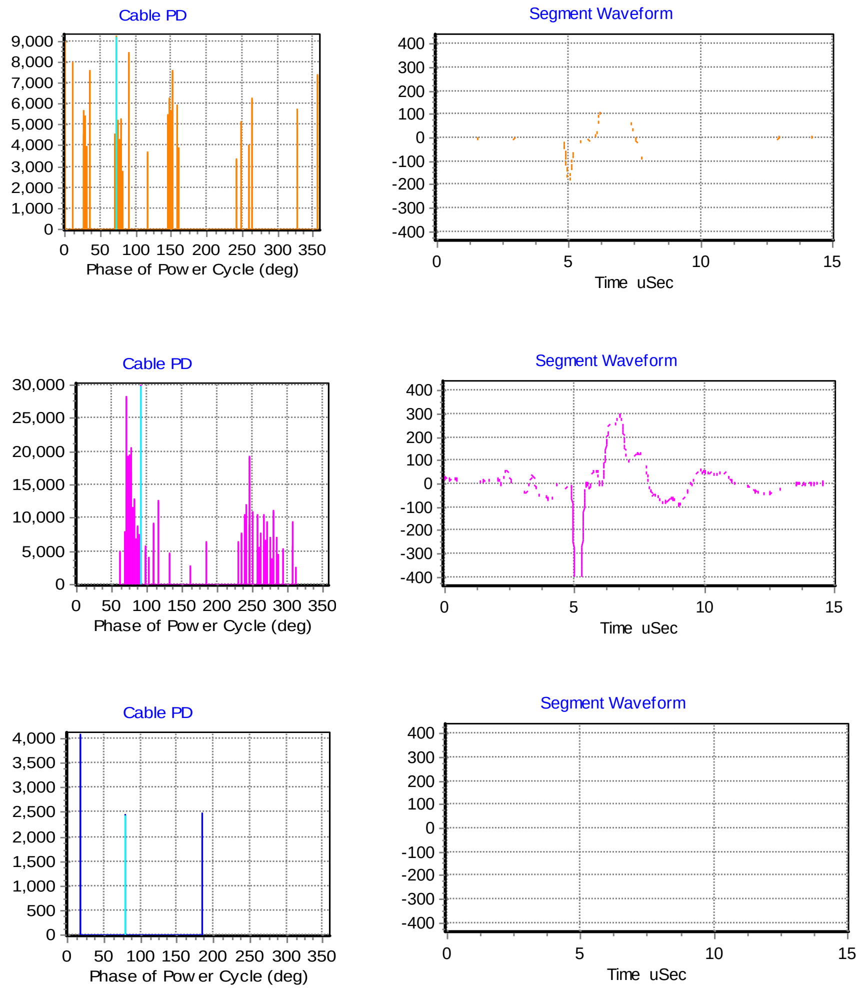


Figure 12: 'Cable' PD Data measurements in picocoulombs (pC)
Ch 1 – Orange – Transformer Cable (up to 9,000 pC)
Ch 2 – Pink – N2 Compressor Motor Cable (up to 30,000 pC)
Ch 3 – Blue – Air Compressor Motor Cable (up to 4,000 pC)

Conclusions

The result from the PDGold© test confirmed that *the source of the large PD pulses was from the N2 Compressor Motor 10 kV cable feeder* as this showed the highest levels of PD (30,000 pC+) and also as the Time-of-Flight (TOF) measurements made on the cable earths (which shared a common earth bar) showed that the PD pulses always arrived first on the HFCT connected to the N2 Compressor Motor cable. The other signals seen in Ch1 and Ch3 are the remnants of the Ch2 pulse which is picked-up from the common earth bar.


Figure 13: On-line PD Testing
Left: Testing with the HVPD Longshot™ PD Spot Test Unit
Right: The N2 Compressor Motor – 3 MVA, 10 kV, 300 A Type: TECO-Westinghouse

The very large PD pulses detected (of 30,000 pC+) from the N2 Compressor Motor are a cause for concern as these levels are above the "acceptable" PD level guidelines for rotating MV machines shown below in Table D1.

For the case of 3.3 - 13.8 kV rotating machines (motors & generators), there is a generally accepted view (taken from Research studies around the world) that the **Guideline PD Levels vs. Condition given in Table D1** can be applied to the stator windings.

There are two cases in a stator winding for measurement of PD activity, as follows:

PD activity in the Slot Sections. These are Phase-to-Earth discharges, which can 'eat away' at the insulation in the slot over time.

PD activity in the End Winding. These are Phase-to-Phase discharges and normally occur when the end of the slot section meets the end windings.

Assessment	Colour Code	PD in Slot Section	PD in End Windings
New/Excellent		<2000 pC	<2000 pC
Good		2000 – 4000 pC	2000 – 4000 pC
Average		4000 – 10000 pC	4000 – 10000 pC
Still Acceptable		10000 – 15000 pC	10000 – 15000 pC
Probable Inspection		15000 – 20000 pC	15000 – 30000 pC
Problem/Unreliability		>20000 pC	30000 pC

Table D1: PD Levels vs. Condition for 3.3 – 13.8 kV Machines

Conclusions

The PD levels in the stator winding of the N2 Compressor Motor (10 kV, 3 MVA Induction Motor) are *very high at 30,000 pC*. As these PD pulses were measured at the substation end of the 150 m long cable to the motor (i.e. 150 m from the motor) it is likely that the PD levels in the motor stator winding will in fact be higher than this, bearing in mind some signal attenuation of the PDs as they pass along the cable.

The very high PD levels require the following actions to be taken by the plant owner:

Continue to monitor the condition of the stator insulation using regular (3-monthly) Online PD Spot Tests with the HVPD Longshot™ PD Spot Tester as described herein. These Spot-Tests should also be combined with extended PD monitoring for periods of 24 hours at a time (using the HVPD Longshot ™ unit in monitor mode).

It is very important with the measurement of PD on rotating machines to develop *PD Trend data over time* to ensure PD levels do not worsen in time. For example, if a machine has a high PD level at new (at commissioning) but then this PD level does not change during service, then this will probably be more reliable than a machine which starts off at a lower initial PD level, but deteriorates in service. Hence, if the PD data can be obtained over time, by PD testing every few months then this is also a very valuable diagnostic.

Plans should be put in place to carry out a full inspection of the motor at the next maintenance outage. It may also be advisable for the company to enquire with the motor manufacturer about what options are available to them for the rewinding and/or ‘patching’ of the motor’s stator winding insulation.

Example 4: 11 kV Switchgear TEV PD Location

Introduction

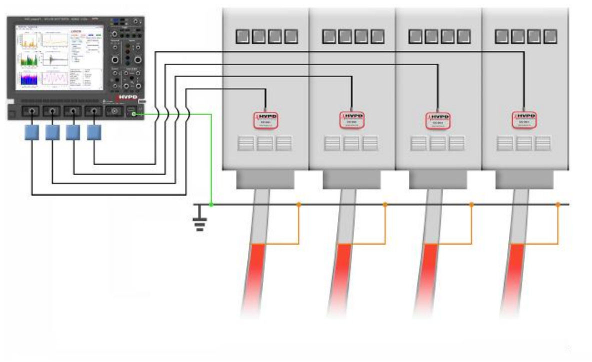
Maintenance Engineers could hear 'popping' sounds emanating from within the switchgear. HVPD conducted tests using the HVPD PDSurveyor™ and HVPD Longshot™ PD Diagnostic Spot Tester.

Results

Secondary Substation

PDSurveyor™ Results

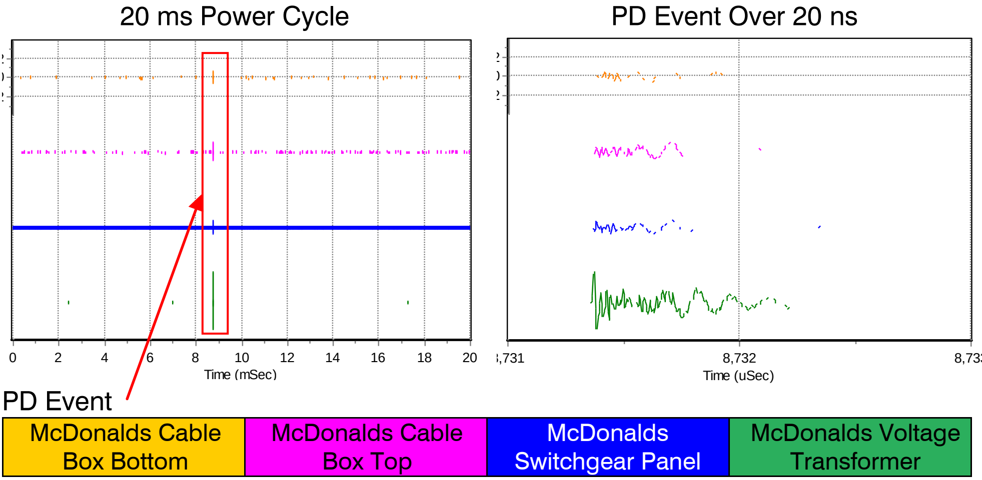
Panel	Name	TEV PD Level
1	Transformer	🟢🟡🟡🟠
2	Balhousie St	🟢🟡🟡🟠
3	Harley Place	🟢🟡🟡🟠🟠
4	McDonalds	🟢🟡🟡🟠🟠🔴🔴



HVPD Longshot™ PD Diagnostic Test Set-up

Synchronous capture was employed with multiple TEV sensors to locate PD site, detected most strongly on the McDonalds feeder.

HVPD Longshot™ Results



Conclusions

The HVPD Longshot™ waveforms show a significant Local PD (600 mV / 56 dB) (CH4) (Green – McDonalds Voltage Transformer). This confirmed the original diagnosis of the PDSurveyor™ and allowed further and more detailed diagnosis of the type and severity of the discharge.

Example 5: PD Location on Outdoor Cable Terminations

Introduction

Field Engineers measured high TEV activity during routine maintenance, and HVPD were requested to perform testing using the PDSurveyor™ and HVPD Longshot™ PD Diagnostic Spot Test Unit.

11 kV Switchgear

Outside the Substation

Results

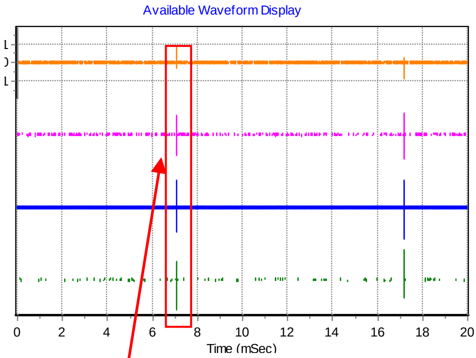
PDSurveyor Results

Panel No	Name	Local PD - TEV (dB)
1	Craig view Mills Housing (003)	30
2	Knox Hill (004)	30
3	TR1	30
3	TR1 VT	35
4	Bus Section Adaptor	30
5	Bus Section 1/2BB1	30
6	TR2	35
6	TR2 VT	38
7	(008)	35
8	Inverbervie Mill (009)	35

High TEV readings were measured across the switchgear, and were highest close to TR2 VT

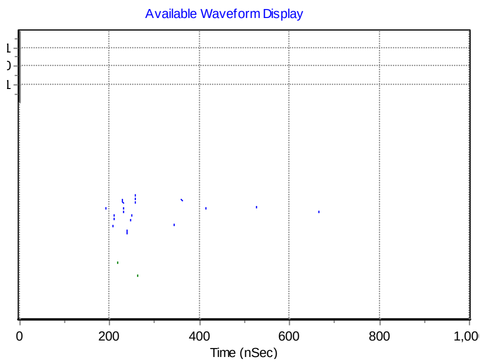
HVPD Longshot Results

20 ms Power Cycle



PD Event

PD Event Over 20 ns

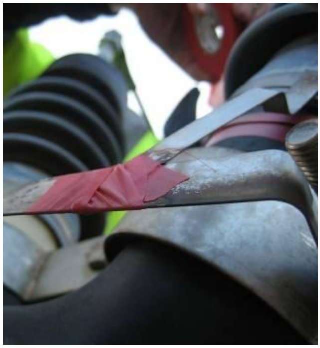


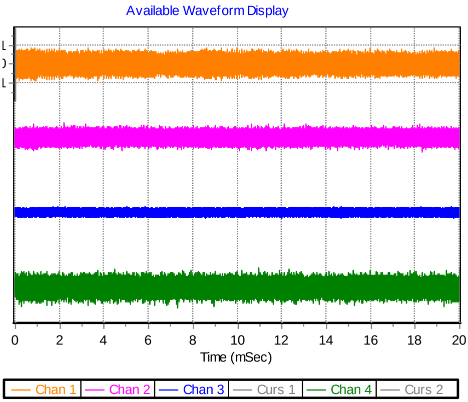
TR2 HFCT (Inside)	TR2 VT TEV	TR2 TEV (Outside)	TR2 HFCT (Outside)

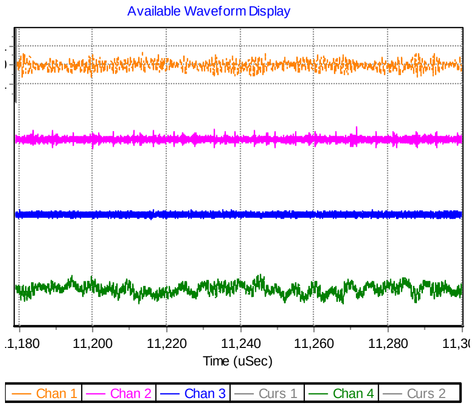
The signal timing indicates the PD source to be outside (CH3/CH4)

Visual Inspection and Remedial Actions

Visual inspection of outdoor termination found floating metalwork at the cable termination – and a satisfactory temporary repair was emplaced until permanent repair performed.







TR2 HFCT (Inside)	TR2 VT TEV	TR2 TEV (Outside)	TR2 HFCT (Outside)

No detectable PD was observed after the loose metalwork was reattached.

Conclusions

Panel No	Name	Local PD - TEV (dB)
1	Craig View Mills Housing (003)	<15
2	Knox Hill (004)	<15
3	TR1	<15
3	TR1 VT	<15
4	Bus Section Adaptor	<15
5	Bus Section 1/2BB1	<15
6	TR2	<15
6	TR2 VT	<15
7	(008)	<15
8	Inverbervie Mill (009)	<15

After rectification, the PDSurveyor™ results were all significantly reduced, and no PD was observed above the local low-level background noise.

No Corona activity detected acoustically


Low-Moderate TEV Activity as a result of Corona activity at termination

Appendix 3: Overview of Partial Discharge Testing

Partial discharge (PD) is an electrical discharge that occurs across a *portion* of the insulation between two conducting electrodes, without completely bridging the gap. Partial discharges can occur in:

- Voids in solid insulation (paper, polymer etc)
- Gas bubbles in liquid insulation
- Around an electrode in a gas (corona)

IEEE statistics indicate electrical insulation deterioration by age or thermal stressing causes up to 90% of electrical failures of certain high voltage equipment, caused by improper installation or design. Unlike off-line testing, on-line PD testing and monitoring gives an accurate picture of the plant's health and performance under service conditions. It is known that some discharges can be extremely dangerous to the health of the insulation system, and determining this accurately is a key reason why many industrial and utility operators perform regular PD testing. Dangerous PD includes internal discharges within polymeric cables and accessories or surface tracking in air-insulated switchgear). Other types can be relatively benign (e.g. corona into air from HV conductors and surface discharges on outdoor porcelain insulators). The various types of PD activity are shown in Figure 14 (below).

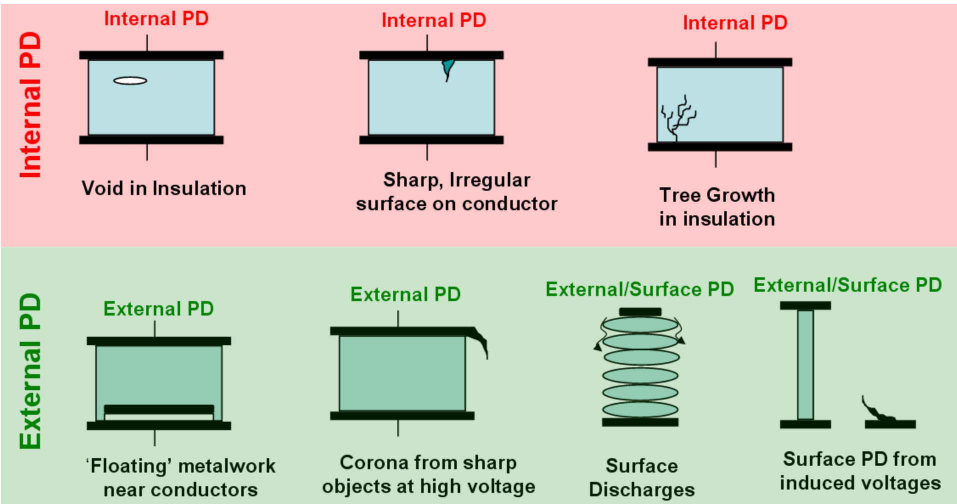


Figure 14: The Seven Main Types of PD Activity (inc. internal and external PD)

Rationale behind On-Line PD Testing

The Benefits of On-line Partial Discharge Field Measurement:

- It is truly a predictive test, indicating insulation degradation in advance of the failure (the detection of 'incipient' faults).
- It is a non-intrusive test, requiring no interruption of service and is performed under normal operating voltage and load.
- It is a non-destructive test i.e. it does not test to failure or adversely affect the equipment under test.
- It does not use any over-voltages and thereby avoids exposing the tested equipment to higher voltage stresses than those encountered under normal operating conditions.

Trending can be accomplished by storing results to allow comparison with future tests.

The PDSurveyor™ PD Test Unit provides an 'early warning system' of incipient insulation faults by the measurement of PD activity in the MV plant to which its sensors are attached. Partial Discharge (PD) activity is produced by incipient insulation faults in high voltage insulation and is widely regarded as the best indicator of insulation condition, providing an early warning against insulation faults ahead of their occurrence, thus enabling the high voltage plant owner to take corrective action before catastrophic insulation failure/explosion occurs.

PD testing is particularly important where MV plant has a high 'Criticality'. This may be due to its age, historical failures or the consequences of its failure (position in the distribution network). Identification of the 'critical plant' within the plant owner's MV network can be achieved quickly and easily using High Voltage Partial Discharge's on-line PD testing technology to provide an 'early warning system' for incipient faults.

Regular on-line PD 'spot-testing' and longer term PD monitoring allows for analysis trends in PD activity to be observed over time. This may reveal correlation with environmental (temperature, humidity etc) or service conditions (changes in load etc). As PD activity is often present well in advance of insulation failure it is possible by observing its development that strategic decisions can be made about refurbishment and renewal programmes.

The PDSurveyor™ and the HVPD 4-Phase PD Test & Monitoring Approach

Over the past decade HVPD have worked in close collaboration with a number of electricity transmission and distribution utilities around the world (including close collaboration with EDF Energy, Scottish Power Systems and Scottish & Southern in the UK) on the development of a range of on-line PD surveying, Diagnostic 'spot-testing' and PD monitoring technologies. These developments have included the handheld *PDSurveyor™ PD Surveying Tool* and the *HVPD Longshot™ Diagnostic PD Spot Tester*, both of which have been used as portable units in the field for a number of years.

The PDSurveyor™ has been developed to meet the market demand for a simple, low-cost PD surveying unit which can be used as a 'first-line' PD test and screening device by all operational staff.

HVPD and others have proposed for many years that for the cost-effective, long-term condition-based management of medium voltage cables and plant, a 4-Phase PD Test and Asset Management Solution should be applied. This is as an alternative to the wholesale installation of permanent PD monitoring solutions which is presently not economically viable due to the very high cost. The 4-phase, HVPD test and monitoring approach illustrated below in Figure 15 has been has now been presented at a number of International Conferences on MV and HV Plant Monitoring in the past 10 years, to widespread acclaim. The management approach provides for a *systematic and cost effective methodology* which can identify, locate, and monitor PD activity within the customer's network.

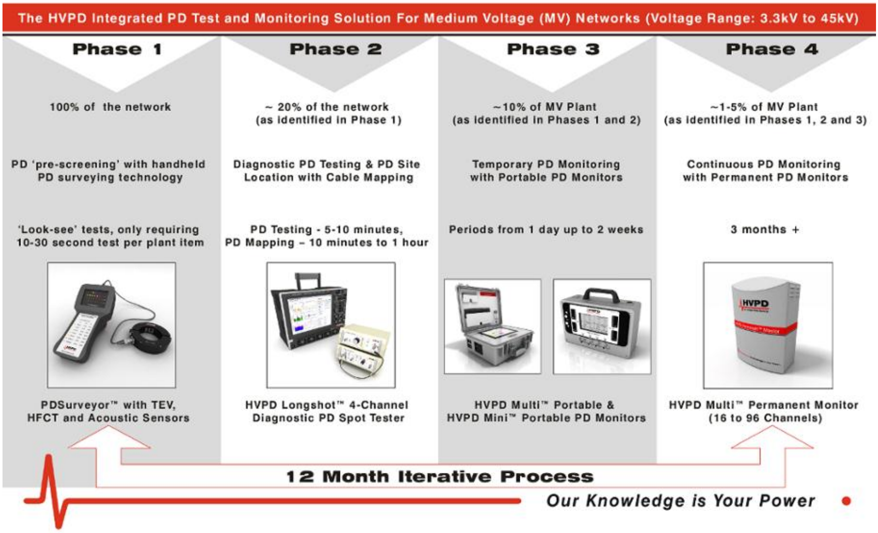


Figure 15: HVPD 4-Phase Asset Management Approach for the On-line PD Testing and Monitoring of MV Networks

The main benefit of this 4-phase solution is to provide the framework for a *more cost-effective* approach to PD testing and monitoring *as an alternative to the large-scale installation of permanent PD monitoring systems*. The approach is based on the on-line PD test and monitoring experience of the company's Directors and Senior Engineers which has been attained over the past 11 years and is based on the fact that only between *5 to 20%* of MV assets in a network will have *significant levels of PD activity*. The key to any approach here is to ensure that any test and monitoring resources are directed to this small percentage of the network.

Through the pre-screening of all assets for PD quickly and cheaply in Phase 1 it is possible for the MV plant owners to identify those assets as having some cause for concern with these assets then taken onto the next stage of the asset management solution, Phase 2; comprehensive diagnostic PD testing and onwards to PD location (Phase 3) and then PD monitoring (Phase 4) followed eventually by remedial action and repair (if PD levels increase beyond acceptable PD activity guidelines.

For further information or applications advice please contact HVPD Ltd:

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