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Summary User Guide

The HVPD Mini™ Monitor

4-Channel, On-line Partial Discharge Portable Monitor

Continuous, Remote-Access Insulation Condition Monitoring
of 3.3 kV – 45 kV Cables & Switchgear

Summary User Guide 2010

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1. Introduction to this User Guide

This Summary User Guide gives an introduction to the new **HVPD Mini™ Monitor** from High Voltage Partial Discharge (HVPD) Ltd. The HVPD Mini™ Monitor is an *on-line* 4-channel, condition monitoring device suitable for the on-line 'spot-test' measurement and monitoring of *Partial Discharge (PD)* activity in medium voltage (3.3 kV to 45 kV) cables and switchgear, without outages of 50/60 Hz power grid supply. Partial Discharge activity is produced by incipient faults in medium voltage (MV) and high voltage (HV) insulation and is widely regarded as the best 'early warning' indicator of the deterioration of medium voltage and high voltage insulation.

The HVPD Mini™ Monitor unit has been designed as an entry-level, remote-access PD monitor for temporary or permanent PD monitoring. The unit is stand-alone, and is suitable for installation in electricity distribution substations for extended periods of time (24 hours to permanent) to log and trend PD data on the MV cables and switchgear to which the on-line PD sensors are attached.

The HVPD Mini™ Monitor is designed for use with non-invasive PD sensors (HFCT and TEV) that are attached to the earthing of live MV cables and switchgear to detect the electromagnetic radiation from PD sites. PD signals are measured by the sensors and processed by the HVPD Mini™ Monitor's embedded hardware. The system utilises synchronous capture of signals from the two HFCT channels and two TEV channels for signal precedence measurement that allow localisation of PD signals to cable feeders or switchgear panels.

An instantaneous display of the peak PD level is given for each channel on the seven level LED arrays. The LCD display shows the peak level and precedence for the past second and 24 hour period. The logged data is stored locally on the inbuilt flash memory for local downloaded to a PC with USB or regular upload data to a remote FTP server with the inbuilt GPRS modem. Data can be viewed on a PC with the HVPD MiniReader© software for Microsoft Windows.

The HVPD Mini™ Monitor and its key functions are shown below in Figure 1.

Figure 1: The HVPD Mini™ Monitor 4-Channel PD Logger

1.1 What Is Partial Discharge and Why Should We Test For It?

Partial Discharge (PD), as its name would suggest, 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 (both paper and polymeric), gas bubbles in liquid insulation or around an electrode in a gas (corona).

Partial Discharge activity can initiate under normal working conditions in high voltage (HV) and medium voltage (MV) equipment where the insulation condition has deteriorated with age and/or has been aged prematurely by thermal or electrical over-stressing. PD can also be observed, on occasion, with the commissioning of new equipment due to improper installation, poor design and/or workmanship (this is seen particularly in cable joints/splices and terminations which are made-up on site). After initiation, the PD can propagate and develop into electrical trees until the insulation is so weakened that it fails completely with breakdown to earth or between the phases of the 3-phase system.

Failure of High Voltage insulation is cited as the No. 1 cause of HV system failures with IEEE statistics indicating that electrical insulation deterioration causes up to 90% of electrical failures of certain high voltage equipment. On-line PD testing of HV plant gives advance warning of pending insulation failure thus allowing the plant owner to take remedial action during planned outages. Unlike off-line testing, on-line PD testing and monitoring gives an accurate picture of the plant's health and performance under service conditions.

1.2 MV Cables & Plant - Asset and Risk Management

If carried out carefully, the introduction of diagnostics (such as on-line PD testing) into the maintenance and operation of medium voltage (MV) distribution networks (cables, switchgear and other plant) can provide cost benefits through *more cost-effective asset management*. Through the collection and processing of diagnostic test data, it is possible for asset managers to better understand the condition of their assets using a condition-based 'Criticality' measurement. By understanding the 'Criticality' of a cable or plant item, and thus the consequential risks of failure, it is possible to implement more efficient and targeted replacement, repair and investment programs.

In a modern electricity distribution business, condition-based asset management is one of the essential tools to enable the *reliable, cost-effective life extension* of existing plant and cables to be achieved. Timely location and the targeted, *pinpointed* replacement of specific cable sections and accessories of unsatisfactory circuits enables the effective service life of the whole network to be economically extended.

The new generation of condition-based, asset management tools is aimed at directing limited investment to those networks with the poorest performance, the highest operational costs and the largest potential gains in terms of customer satisfaction. Condition-based maintenance techniques are, in fact, the *only* real alternative to wholesale renewal of aged underground cable networks. With replacement rates of in-service cables in UK and other European utilities remaining at very low levels (typically less than 0.5% per annum in many cases) the need for an alternative asset management solution is very clear to see!

1.3 Diagnostics and System Economics

The timely location and targeted replacement of specific, discharging sections of unsatisfactory circuits enables the service life of the whole circuit to be economically extended. The new generation of condition-based, asset management tools (such as the HVPD Mini™ Monitor) are thus focused on enabling increasingly limited capital investment to be directed at those circuits with the poorest performance, highest costs or the largest potential gains in terms of customer satisfaction and customer minutes lost (CML).

Projects carried out to date by HVPD have ranged from PD testing of large, public electricity utility networks through to small industrial customer networks. A large part of the asset management strategy for a cable network comes from the owner's cable replacement policy, which is normally linked to the failure rate, customer interruptions and customer minutes lost. For example, the utility cable owner with severely failing assets due to an ageing population has a different problem to the industrial owner with a large, new cable network, but no failures to date. Prediction of failure rates into the future can give an estimate of the likely future costs and it is recommended that all asset owners should do this. For large networks, the failure rates are not too difficult to predict in the short and medium term based on historical data and trends. All the costs can then be estimated, and a decision made about diagnostics, replacement and priorities.

1.4 Cost Drivers for both Large and Small MV Network Asset Management

For large utility MV networks, the largest savings are to be made in *deferring and/or targeting capital replacement programmes* of the cable and switchgear population. This is simply due to the capital cost of replacement being so large when compared to the other costs. For example, in many utilities, the cost of an interruption is perceived as merely the cost of the repair, particularly when automatic re-configuration of the network is available. Potentially the largest cost saving to be made here is to be able to pinpoint any weak, discharging points on a circuit (typically at cable accessories) on badly performing circuits. By repairing only the localised problem, instead of replacing the entire cable, as is present practice in many utilities, it is possible to maintain good levels of cable reliability at the fraction of the cost of complete cable replacement.

Similar HVPD studies on smaller *industrial and commercial customer networks* show that the cable/switchgear replacement costs do not dictate the asset management policy as per the utility example. The costs of any interruption can in some cases completely outweigh the capital cost of cable/plant replacement. Oil platforms, industrial processes, nuclear reactors and other high profile power supplies can have a very large cost of interruption (running into Millions of Euros). Such customers have less difficulty in justifying the cost of diagnostic measurements, or complete system monitoring. As a general 'rule of thumb', if the cost of an outage in terms of lost production is greater than say €200k/day, such asset owners tend to be very focused on the condition of their cables and plant!

1.5 The Benefits of *On-line* Partial Discharge Field Measurements:

- PD testing and monitoring are truly predictive tests, indicating insulation degradation in advance of failure through 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 require any over-voltages, thereby not exposing the tested equipment to higher stresses than those encountered under normal operating conditions.
- Trending can be accomplished by storing test and monitoring data in a spreadsheet or database to compare with future tests.
- In many instances the site of the partial PD occurrence can be located within the cable or plant (with TDR measurements), so the localised problem can be repaired.
- The cost to perform an *on-line* PD survey is relatively inexpensive compared with off-line PD testing, allowing annual survey and short-term monitoring (typically 1 week at a time) to be performed economically at most facilities.

1.1 HVPD Mini Monitor™ – Key Features

- Continuous 24/7 monitoring of PD activity in MV metal-clad switchgear & cable feeders
- Precedence detection for both cable PD (HFCT) and local PD (TEV) signals to show 'which pulse came first' and determine the cable feeder or switchgear panel that is the source.
- Four input channels: Two HFCT channels for cable PD measurement and two TEV channels for local PD (cable terminations, switchgear) detection.
- Suitable for installation at primary substation or secondary substations/ring main units
- Detects load varying and intermittent PD activity.
- Compact and portable enclosure with carry handle for permanent or temporary installation.
- Installation and monitoring without outage.
- PD spot-test function to quickly find circuits with cable/local PD activity using PD level LEDs.
- Measures and logs PD magnitude (pico-coulombs on HFCT, dB on TEV) and PD count (number of pulses) to provide a measure of the cumulative PD activity in each measurement period.
- Stores up to 12 months of 4-channel PD monitoring data on local flash memory.
- Unit data upload via GPRS 3G to HVPD remote server, and user local download via FTP.
- Alternative local user download via USB for conditions where GPRS upload is not possible.
- Remote access to data via FTP/web interface.

2. Standard Scope of Supply and Supply Options

The HVPD Mini™ Monitor is supplied with PD Sensors and BNC signal cables and GPRS antenna for remote download of the PD monitoring data using its inbuilt GPRS modem; a high gain antenna can also be supplied for areas of poor GPRS signal reception.

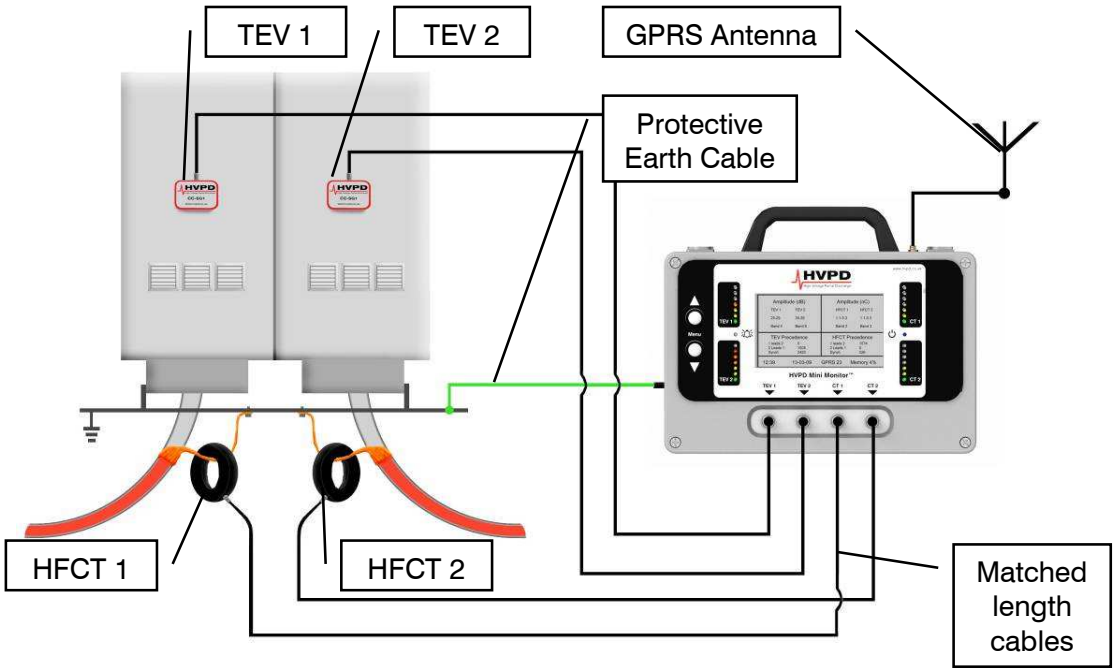
HVPD MiniReader© software for Microsoft Windows is supplied for setting up test data using a USB-connected PC, downloading of data locally via USB or remotely via FTP and viewing of collected data after download.

The customer has the option to install their own telecom service-provider's GPRS simcards or alternatively HVPD can supply the customer with a complete solution including: simcard rental, data hosting, databasing, data analysis and reporting.

HVPD Mini™ Monitor	
2x HFCT 100/50 Sensors	
2x CC-SG1 TEV Sensors	
4x 10 m BNC Cables	
1 dB Antenna with 3 m Cable	
HVPD MiniReader© Software for Microsoft® Windows®	
USB A-B Cable	
AC/DC Power Supply	
5 m Protective Earth Cable	

Table 1: HVPD Mini Monitor™ - Standard Scope of Supply

3. Installation Diagram



The HVPD Mini™ Monitor can be installed at primary substations, secondary substations or ring main units/padmounts. Set-up is straightforward; HFCT sensors are attached to two adjacent cable feeders and TEV sensors attached to two adjacent switchgear panels. With this set-up two power cables and two switchgear panels can be monitored for PD. The HVPD Mini™ Monitor precedence detection circuits are then used to determine the origin of the PD.

It is recommended to carry out an on-line spot-test prior to commissioning an HVPD Mini™ Monitor using an advanced on-line PD diagnostic device such as the HVPD Longshot™ unit to pre-qualify the origin of local signals and differentiate PD from noise.

4. PD Signal Acquisition Hardware

The system records and stores the *PD Peak Magnitude* (8x PD levels) for both HFCT measurements (PD measurements in picocoulombs, pC) and TEV Measurements (in decibels, dB). The PD Magnitude levels for the v1.0 HVPD Mini™ Monitor for both of these measurements are given in Table 2 below.

Band Reference	LED Reference	LED 'On' Signal Level		
		LED Colour Code	HFCT (pC)	TEV (dB)
0	No LED	**N/A**	<300	<6
1	Green 1		300	6
2	Yellow 1		600	12
3	Yellow 2		1100	17
4	Orange 1		2600	25
5	Orange 2		8500	30
6	Red 1		17000	35
7	Red 2		25000	40

Table 2: HVPD Mini™ Monitor - PD Signal LED Levels

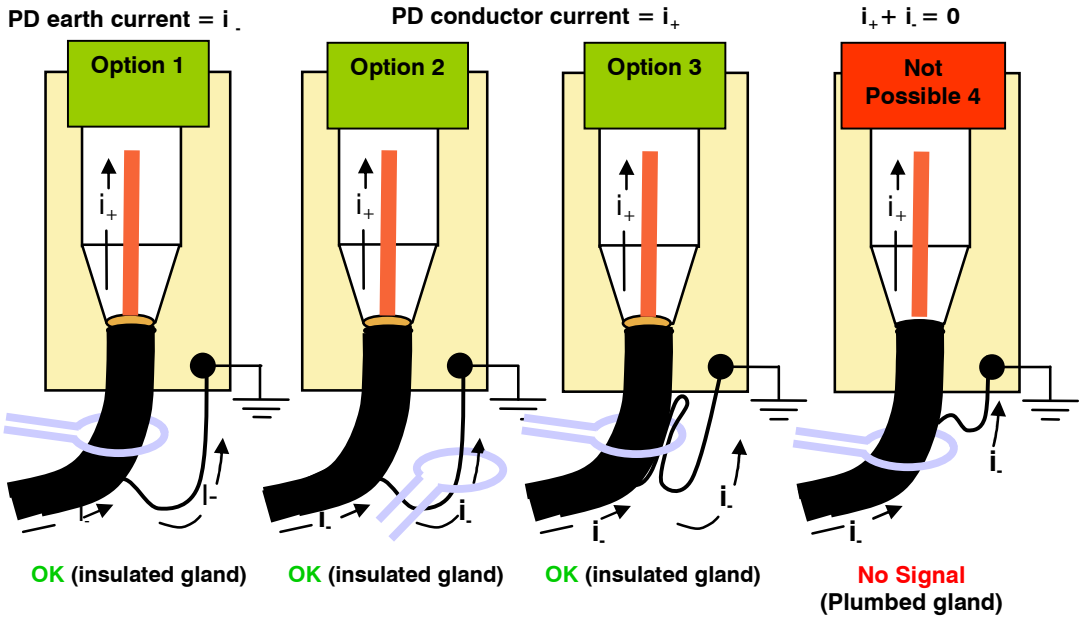
1.6 On-line PD Sensors

When a PD occurs in a cable there will be a high frequency electrical impulse that propagates away from the PD site in both directions down the cable. At the cable terminations it is possible to measure these pulses with split-core High Frequency Current Transformers (HFCT), provided the terminations are suitable:

HVPD HFCT 100/50 High Frequency Current Transformer

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

If these conditions are not met it may be possible to install permanent sensors inside of the cable box or switchgear, please contact HVPD Ltd for further information.



HFCT Sensor Connection Options for MV Cable PD Testing

To measure the PD signals it is necessary to intercept the currents either in the conductor alone (i+), (option 1) or the screen / earth drain alone (i-) (option 2). The HFCT can also be connected around the core of the cable with the earth braid or cable passed back through the centre of the HFCT (option 3). In this case two earth currents passing through the sensor in opposite directions and thus cancel each other out leaving the conductor PD current, $\mathbf{i}_+$. This technique also cancels out a lot of the ground loop noise and improves the signal-to-noise measurement of $\mathbf{i}_+$. 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 PD signal is measured by the HFCT.

Local high frequency discharges signals are generally oscillatory in shape and can be detected with TEV sensors placed onto the outer metal-clad surfaces, close to the vents or gaskets. The 2x HVPD CC-SG1 TEV sensors supplied with unit (left) are magnetically latched onto the outside of the metal-clad switchgear housing. In order to measure any local PD signals the switchgear must be suitable:

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

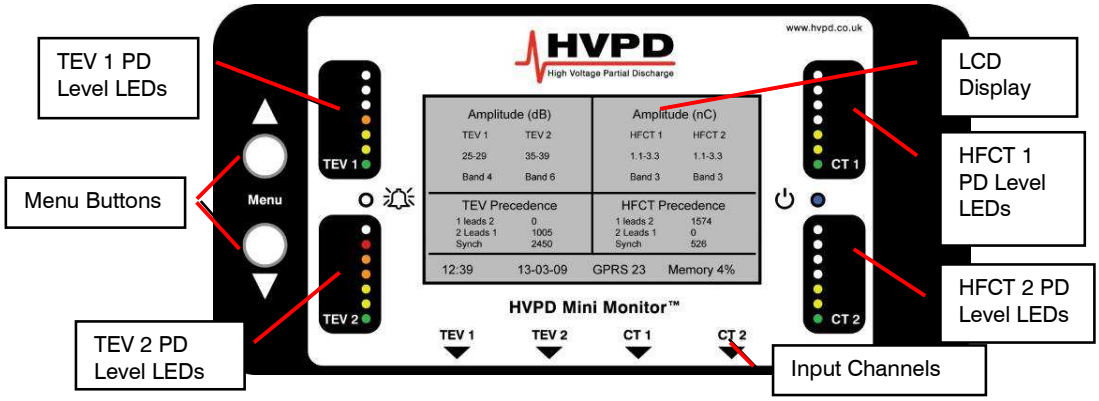
HVPD CC-SG1 Transient Earth Voltage (TEV) Probe

If these conditions are not met it may be possible to install permanent sensors on the inside of the switchgear, please contact HVPD Ltd for further information.
The peak of the local PD TEV signals is measured in decibels (sensor output voltage referred to 1mV) by the HVPD Mini™ Monitor.
When the signals emerge on the outer surface from a switchgear panel they will likely also be detected on the switchgear panels adjacent to the source. As with the HFCT sensors the HVPD Mini™ Monitor captures pulses synchronously on two TEV sensors and calculates the pulse precedence between them to determine the source.

1.7 Onboard User Interface

The HVPD Mini™ Monitor onboard user interface panel has 4x colour-coded PD Level LED arrays for the TEV1, TEV2, CT1 and CT2 channels and a 5" monochrome LCD display.

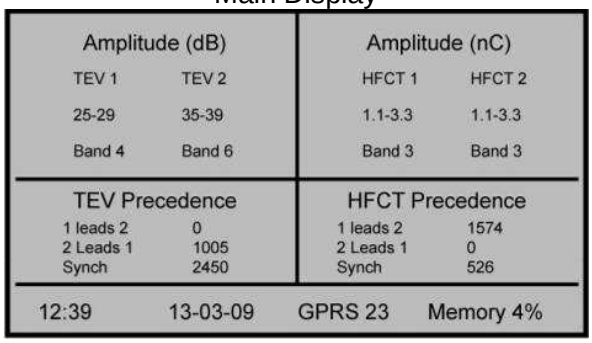
The 7-level LED arrays provide an instant measure (six times per second) of PD level-band in the cables and plant to which the sensors are attached. The LCD display is scrollable using the menu buttons to give instantaneous display for the PD level band and precedence and 24 hour logs of the PD level bands and precedence.



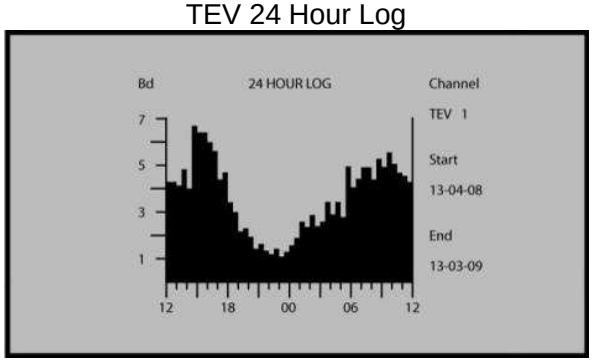
LCD Display Main Page

The onboard LCD display is scrollable with seven screens as follows: Main page (shows instantaneous TEV/HFCT PD Level and precedence, date/time, GPRS signal strength), TEV 1 24 hour log, TEV 2 24 hour log, HFCT 1 24 hour log, HFCT 2 24 hour log, TEV 1&2 precedence, HFCT 1&2 precedence.

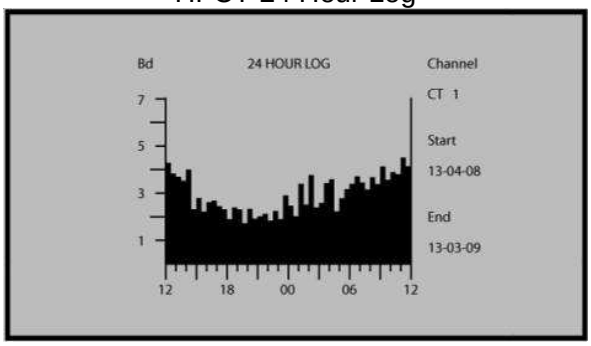
Main Display



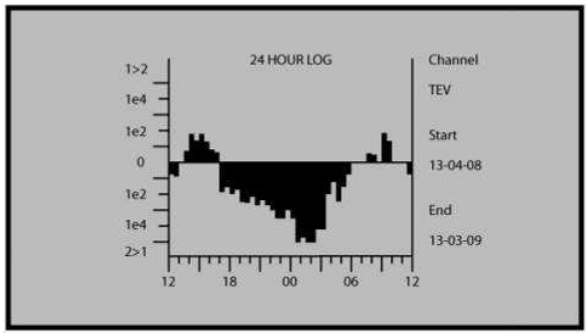
TEV 24 Hour Log



HFCT 24 Hour Log



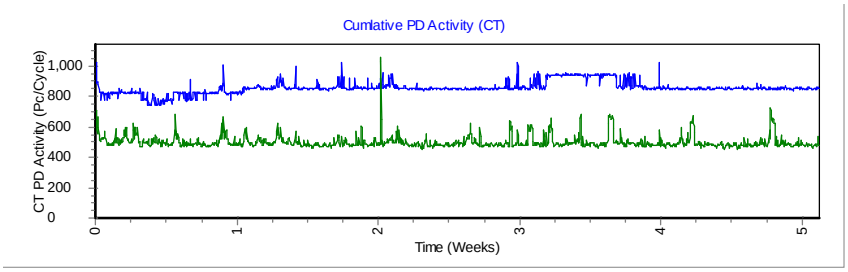
TEV Precedence



5. Example Results from MiniReader© Software

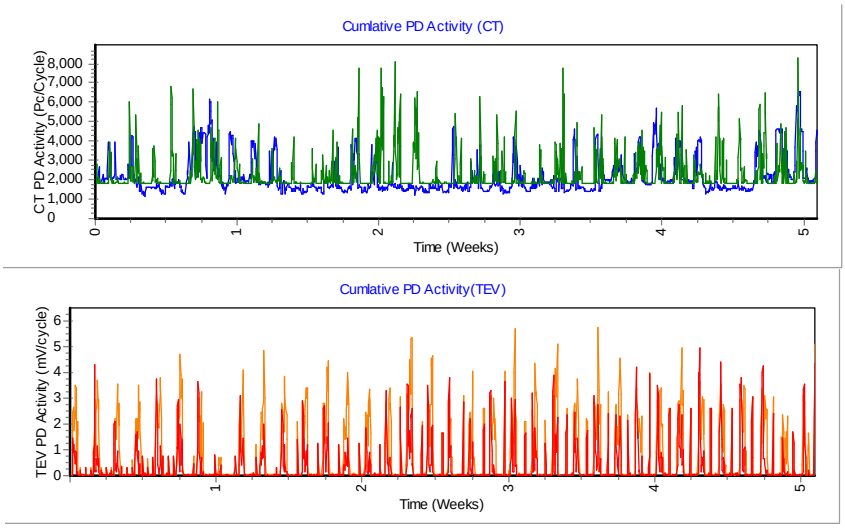
The following shows some examples of data recorded with the HVPD Mini™ Monitor of PD activity in live medium voltage equipment. The graphs displayed are from the MiniReader© software. Typical events that can be observed are load-related events influencing activity. PD trends before and after switching operations or faults on the system, rising PD levels.

5.1 Steady PD Activity



Very little variation in the traces over the monitoring period, and it is of a generally low level.

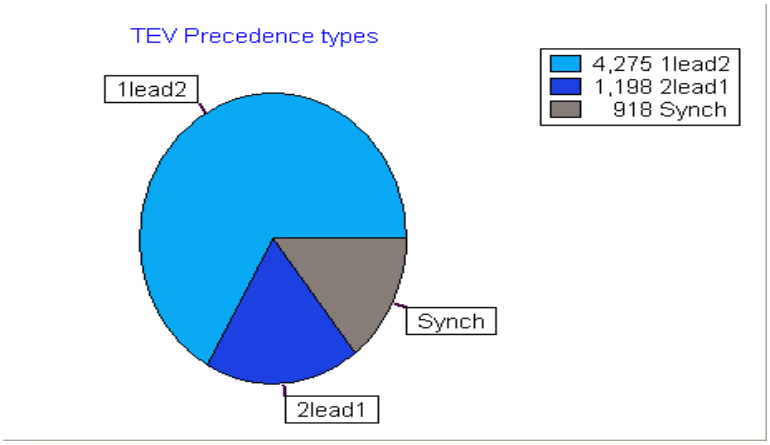
5.2 Load Related PD activity



HFCT & TEV cumulative PD activity charts showing sporadic and unpredictable activity patterns.

- PD levels rise and fall with load on cables and switchgear, particularly in PILC cables the wax/oil-impregnated paper sheathing can harden and allow voids to form permitting PDs to be ignited. Increase in surface discharges in switchgear can be observed to follow humidity and the late-evening 'dew point'
- Consequences of switching circuits in and out may also be observed, due to changes of load upon connected feeders, this can result in an increase of PD even when load is reduced, for in PILC cables,

5.3 Precedence Detection

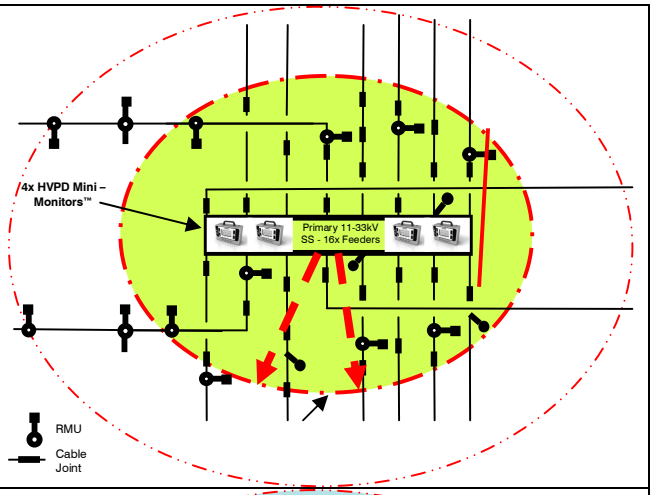
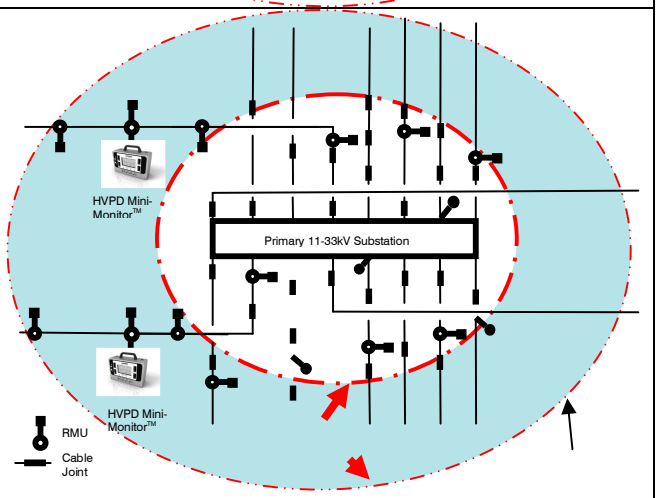
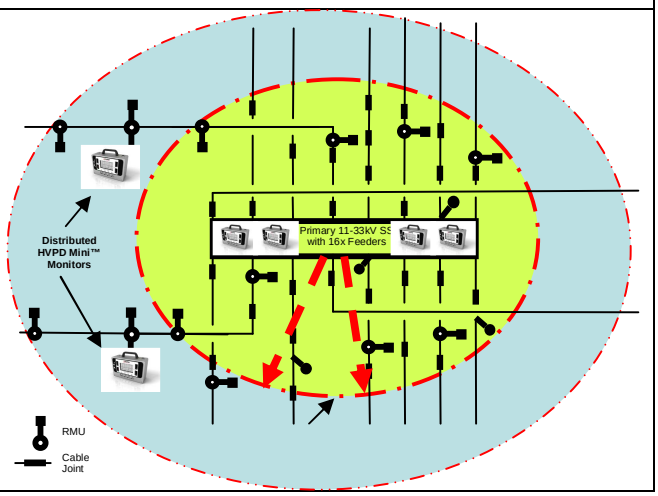


Proportion of Precedence Readings (TEV sensors)

A pie chart is produced for the HFCT and TEV precedence measurements to show the distribution of PD events arriving first at the two HFCT and two TEV sensors

5.4 Applications and Strategic Deployment on Distribution Networks

There are a number of applications which have been identified for the HVPD Mini™ Monitor on electricity networks. As the system allows for PD monitoring of primary substations, PD RMU's and other secondary substations and the combination of the two to provide *Wide-Area Network PD Monitoring* as follows:

Application 1: PD Monitoring at *Primary MV Substations* - to monitor PD in both the cables and primary switchgear. Only 2.5 km or 3 RMUs distance can be monitored (thick red dashed-line). More HVPD Mini™ Monitors are required for wider area monitoring.	
Application 2: PD Monitoring at *Ring Main Units* (RMU's), Padmounts and other Secondary Switchgear - to monitor PD activity in both the cables and the RMU or other secondary switchgear. (Range extended up to dotted red ring, indicated by arrows). Further extension of PD monitoring into the network, beyond the 'reach, of any PD monitors installed at primary substations is achieved by using portable, secondary PD monitors situated at Ring Main Units and other secondary switchgear. They can then monitor precedence together, locating faults to a higher precision.	
Application 3: *Wide Area Medium Voltage Network PD Monitoring* using multiple HVPD Mini™ Monitor units – the blue ring shows the combined range of detection for primary and secondary HVPD Mini™ Monitors: range up to 5 km or up to 6x RMUs. This wide-area network monitoring solution allows cables of up to 5 km in length or four in-line RMUs/switches to be monitored.	

6. Future Developments and Databasing of PD Monitoring Data

HVPD are presently developing a combined, 'holistic' customer service and data management package to complement the HVPD Mini™ Monitor technology, as follows:

New HVPD Mini Monitor iHost Database Application

This will include data hosting, databasing and automatic reporting of PD activity to customers who have purchased multiple HVPD Mini™ Monitor units. This data will be made available on the HVPD FTP server from a new iHost database application. This development is expected to be completed in Q4 2009 when it will be used as part of the new HVPD data management service offering.

HVPD On-site PD Testing and Monitoring Service Package

In order to get the most out of the portable HVPD Mini™ Monitor it is advised that the unit is moved around the network at intervals of around 1-2 weeks per substation to collect PD monitoring data from wide-area networks. In these cases there is a requirement for test technicians to travel to the substations to set-up and de-commission the units and to set-up the GPRS communication link. HVPD can offer test technician services on a time and materials basis in such a cases.

For further details on the HVPD Mini™ Monitor, its PD monitoring applications and pricing please contact HVPD Ltd on +44 (0) 161 877 6142 or by e-mail at info@hvpd.co.uk.