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"Our Knowledge is Your Power"

PROPOSAL AND QUOTATION

Portable, 4-Channel HVPD Longshot™ Partial Discharge (PD) Test and Monitoring System suitable for on-line PD Testing of Switchgear, Cables, Joints, Terminations and Motors and Generators

for short-duration (10mins to 24 hour) PD testing & monitoring.

Date: 23.02.2010

Introduction to High Voltage Partial Discharge

HVPD hold substantial experience in the *On-line PD 'Spot' Testing and Cable PD Mapping (location) of 11kV & 33kV Cables and Switchgear*, with much of this experience in the UK having been developed from collaborative work with EDF Energy (formerly London Electricity) over the past 10 years. This work has focused on the PD testing and monitoring of older in-service, underground paper cables (PILC) and solid-insulated switchgear with a view to the reliable life-extension of these ageing assets beyond their 'design life'. By monitoring the condition of the insulation it is possible to provide *reliable life extension* of these assets, providing huge savings to utilities which would otherwise have to carry out wholesale cable & switchgear replacement programs at huge expense.

Over the course of the past 5 years the HVPD partners developed the portable, 4-Channel *HVPD Longshot™ PD Tester* which was brought to the market in 2003, with the v3.0 PDGold© Software. This test technology has since been upgraded through 2x Software upgrades (in 2005 and 2007) to the present v5.0 PDGold© software. Through PD testing and training contracts with our customers over the course of this period, HVPD have developed a wide range of *'PD Test Knowledge Rules'* for the On-line PD testing and monitoring of MV and HV Plant.

In recent years the partners have also applied the portable HVPD Longshot 'spot' test technology to the on-line PD testing of newer polymeric cables (up to 400kV) and air-insulated and gas-insulated switchgear through product supply and PD testing projects around the world (including Europe, North America, Middle-East, South East Asia and Australasia). As a result of this work we have been able to obtain first-hand marketing information which has shown an increasing interest in the application of On-line PD test and monitoring technologies, as electricity utilities and other hv plant owners become aware of the potential cost benefits which can arise from their application.

The PD diagnostic software and PD 'knowledge rules' which we have evolved from the projects described above will soon be combined into the new range of permanent and portable PD Monitor systems which we are presently developing. These include the SmoothSurvey ™ PD Monitor for primary substations and the HVPD-Mini™ PD Monitor for secondary substations.

Background

The following Proposal and Quotation is for the supply of the portable HVPD Longshot™ PD Test and Monitoring System (Figure 1).

Figure 1 HVPD Longshot™ 4-Ch PD Test and Monitoring Unit

The purpose of the PD testing and monitoring technology is to be able to measure and record any *internal PD activity* within the cables, cable sealing ends/terminations and other HV plant to which the sensors are attached. This is achieved via the *synchronous detection* (to less than 2ns) of signals on all 4x channels of the *HVPD Longshot™ unit*. By **synchronously recording** high resolution data on all 4x measurement channels at once and through analysis in the PDGold© v5.0 software with the automatic 'Event Recogniser©' module it is possible to achieve the following benefits when making measurements:

- The differentiation of PD signals from electrical 'noise'
- The location of the source of the PD can then be found using Time of Arrival (TOA) measurement techniques using distributed TEV and HFCT PD probes.
- Measurement of both Phase-to-Earth PD and Phase-to-Phase PD

There are three main reasons for carrying out the On-line PD Testing:

1. To get baseline readings for future condition assessment of the insulation condition and to find any 'incipient' insulation faults (i.e. faults yet to occur).
2. To provide an insulation quality check on the cables, terminations and other HV plant as part of the routine commissioning (e.g. IEC 24 hour 'soak' test).and/or maintenance checks
3. To locate PD activity as a pre-cursor to repair and/or replacement.

The testing method which will be employed is based on HVPD's prior knowledge of testing HV and EHV plant equipment. In order to get the highest resolution of PD test data it is necessary to monitor the HV plant under test for extended periods of time (typically from a minimum of 10 minutes up to 24 hours). The synchronous, *4-channel HVPD Longshot™ PD Test and Monitor* Unit from HVPD LTD is used with a combination of Transient Earth Voltage (TEV) probes, High Frequency Current Transformer (HFCT) sensor and 'shielding antennae' (for outdoor plant) with the simultaneous capture of the PD signals from all sensors.

To identify internal discharges in outdoor HV Plant under On-line PD testing conditions it is necessary to differentiate the very dangerous *internal* PD signals in the HV plant to those signals from the more benign, external surface discharges and corona (neither of which are harmful to outdoor HV plant). The test system must also be able to differentiate between the PD activity and any electrical 'noise' on the site, such as that from RF interference etc. Both of these functionalities is achieved in the *HVPD Longshot™ PD Test Unit* using the HVPD LTD PDGold© v5.0 software which includes both the *'Event Recogniser©' Wave*form analysis software module and the *'Precedence Detector©'* time-of-flight software module.

The HVPD Longshot™ Test Unit and PDGold© Software

The 4-Channel HVPD Longshot™ PD Tester provides *an 'early warning system' of incipient insulation faults* by the measurement of Partial Discharge (PD) activity in cable circuits and the corresponding switchgear panels or other HV plant to which the PD sensors are attached. The Spot-Testing process includes capturing the waveforms of electrical activity using the unit's very high speed data acquisition capability (2 to 10 Million points per 50Hz power cycle) and then applies the unique *'Event Recogniser©'* and '*Precedence Detection©'* software modules *to differentiate between PD activity in the cable, the switchgear and any electrical 'noise'* such as motor exciter pulses, thyristor switching, RF interference etc. This analysis is made using an automatic, detailed analysis of pulse frequency, waveshape and other pulse characteristics.

The PD spot tests utilise the PDGold© software plus the ScopeControl© and PDMap© packages to provide on-the-spot assessment of HV insulation condition including source and magnitude of PD, thereby providing effective insulation condition analysis whilst filtering out noise from other sources.

On-Line PD Test Set-up and Methodology

In order to make On-line PD Tests of the cables then access to either the earth-straps or cores of the cables at the cable terminations is required. HVPD recommend that for the best results, *1x HFCT sensor is connected around either the core or the earth cable/strap of each phase.* 1x TEV attached to either the outside of the switchgear panel or the termination of the central phase. This allows for the measurement of both Phase-to-Phase and Phase-to-Earth PD activity in the cables and terminations through measurement of the PD current in the conductor, i_+ (Figure 2 below shows the HFCT sensors connected around the cores of the cables). The TEV sensor is used in conjunction with HFCT sensors to detect 'local' PD in either the switchgear panel or the termination. The recommended test set-up is illustrated below in Figure 2.

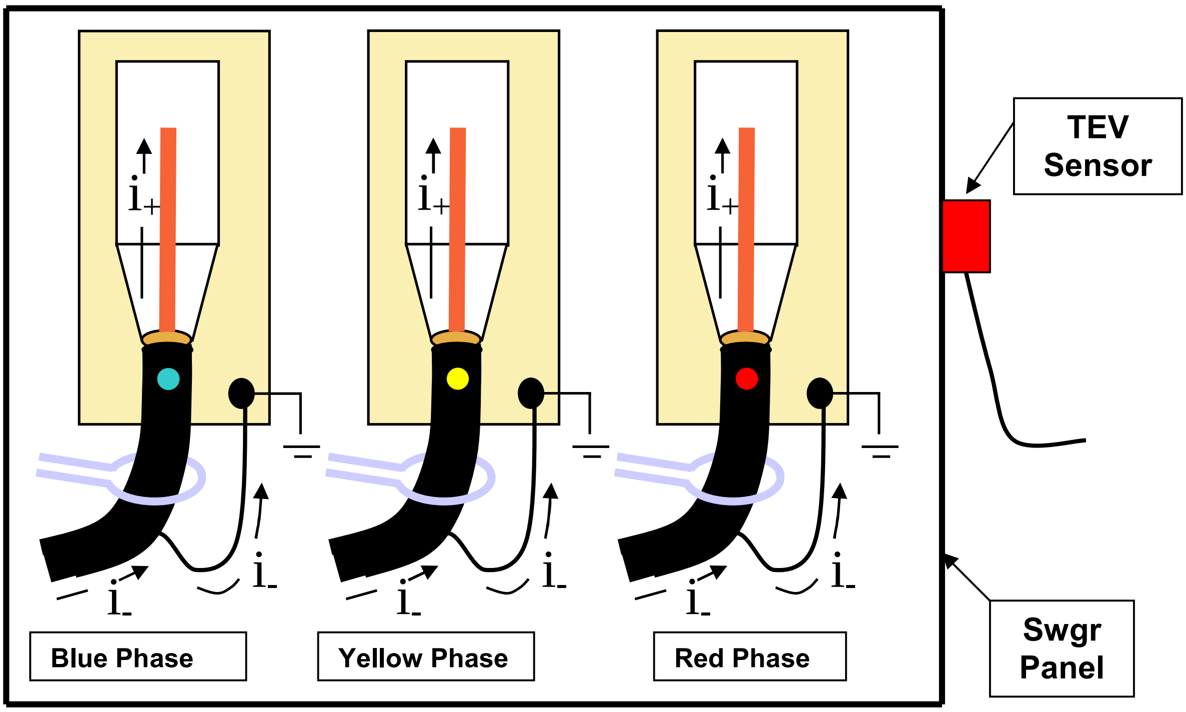


Figure 2: Recommended Test Set-up for On-line PD Testing of HV Cables

The **'Event Recogniser©'** software module *is used differentiate between PD activity in the cable, the switchgear and any electrical 'noise'* such as RF interference etc. This analysis is made using an automatic, detailed analysis of pulse frequency, waveshape and other pulse characteristics.

The **'Precedence Detector©'** software module is used to time *'which pulse came first'* between the 4 channels of the unit thereby automatically differentiating between internal PD activity in the cable sealing ends and external noise.

These software modules are described below.

PD Type Waveshapes and Their Recognition

PD activity from cables and switchgear/local equipment have different frequency content and waveshapes which depend on the source of the discharge. It is through measuring the PD pulse characteristics that the PD Monitor's 'Event Recogniser' software module is able to differentiate between these different types of discharge, as described below:

Cable PD Waveshapes

Cable PD's are normally in the frequency range of 200kHz (if the pd site is 'far away' idown the cable) up to around 4MHz (if the cable pd site is 'nearby' i.e. a few metres to a few 10's of metres away). When viewed at the standard timebase resolution used by the PD Monitor system (15□sec across screen) these pulses have a distinctive monopolar shape which is similar to a 'sharks fin' with a typical risetime, fall-time and pulse width within a set range. An example of a (negative) cable PD pulse is shown below in Figure 3.

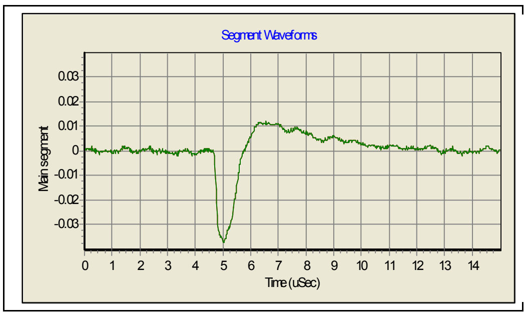


Figure 3: Example of Typical Monopolar Cable PD Pulse (-ve pulse)

Switchgear/Local Equipment Waveshapes

Switchgear or 'Local Equipment' PD (such as in the cable termination) has a very different waveshape and frequency content than the cable PD's shown above in Figure 8. These pulses are of higher frequency (typically from 4MHz to over 100MHz) and have a different waveshape to the cable pulses. These local PD's are typically oscillatory in shape due to the original pulse producing multiple reflections within the local plant. An example of a switchgear/Local PD pulse is shown below in Figure 4.

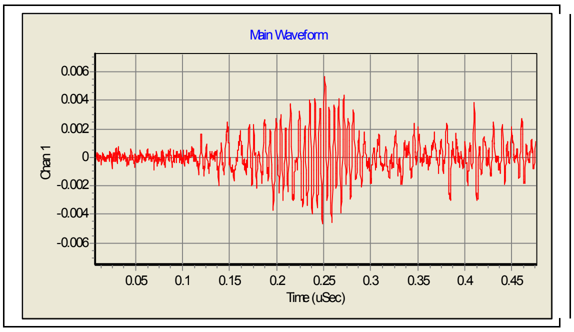


Figure 4: Example of Typical High Frequency,Oscillatory Switchgear PD Pulse

Examples of Noise Pulse Waveshapes

Noise pulses are typically of three forms, switching noise/generator exciter pulses (typically in the frequency range of 30-100kHz), RF noise from AM radio broadcasts (in frequency range 500kHz to 1.2MHz) or from signalling schemes (Power Line Carrier - PLC signals) used for signal communications along the overhead lines between substations. The 'EventRecogniser©' software identifies these noise pulses via frequency analysis in the case of switching noise (this being of too low frequency for PD) and through waveshape analysis in the case of RF and PLC Noise (the sinusoidal nature of these signals is rejected by the software as being from a PD source). Two examples of a switching noise and RF noise are shown below in Figure 5 (these would be automatically characterised as noise by the HVPD Longshot^{TM} PD Monitor software).

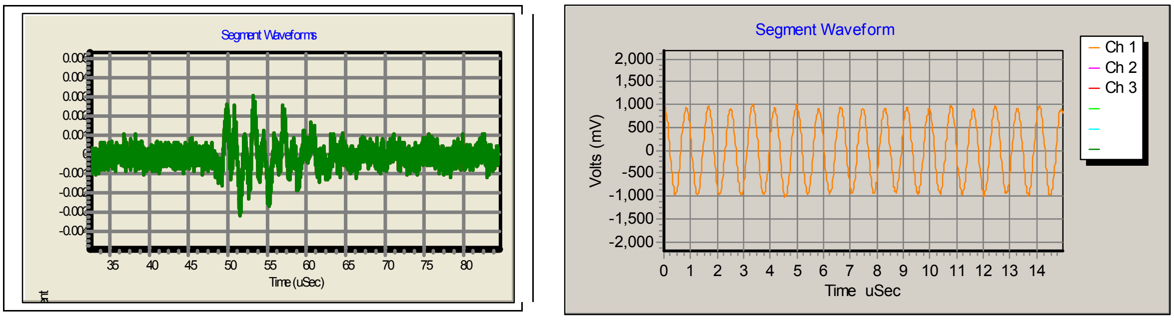


Figure 5: Examples of Typical Noise Pulses
(left: Switching noise at 40KHz, right: RF noise at 600KHz)

By automatically identifying the various waveshapes shown above in Figures 3 to 5, the HVPD Longshot^{TM} PD Monitor software provides an instant diagnostic as to the presence and magnitude of any PD activity present whilst automatically removing the noise pulses. Unlike other commercially-available systems, the HVPD Longshot^{TM} PD Monitor will collect and analyse the noise pulses and display them to the user so that they can be viewed manually if required. It should be noted that other systems use hardware filters to block-out bands of frequencies to try to reduce noise, which whilst they can work also block-out real PD pulses). The software is thus very transparent and also very easy and quick to use, allowing large numbers of HV plant items to be scanned for PD.

HVPD Longshot^{TM} PD Monitor *'EventRecogniser©'* Software Module

A screenshot of the *'EventRecogniser©'* data analysis page is shown overleaf in Figure 6. This example shows a combination of Cable PDs up to 2,500pC (bottom left graph) and noise pulses of up to 17mV (bottom right graph). The 'Segment Waveform' box in the top left-hand corner of the screen shows the 'Waveform' of one of the cable PD pulses measured in this test. This pulse has been identified by the software as a cable PD due to it having the right waveshape (similar to a sharks fin) with a risetime, fall-time and pulse width in the correct range and the correct frequency (0.625MHz) for a cable PD.

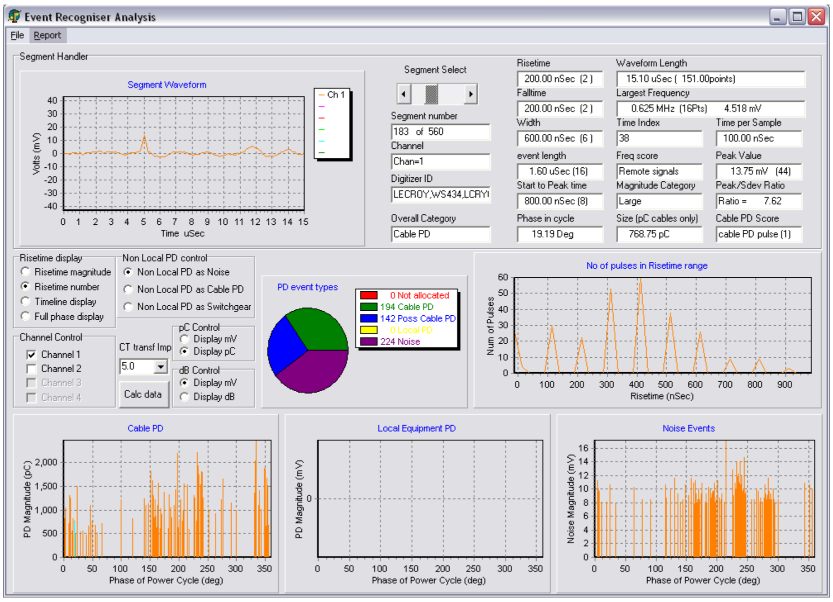


Figure 6: HVPD Longshot^{TM} PD Monitor Event Recogniser Page showing Cable PD's

Switchgear or 'Local Equipment' PD (such as in the cable termination) has a very different waveshape and frequency content than the cable PD's shown above in Figure 6. A Screenshot from the Event Recogniser software showing an example of a Switchgear/Local Equipment PD pulse is given below in Figure 7. This result shows Switchgear/Local Equipment PDs of up to 10mV (bottom middle graph) with a few noise pulses (bottom right graph). The 'Segment Waveform' box in the top left-hand corner of the screen shows the 'Waveform' of one of the Switchgear/Local Equipment PD pulses measured in this test. This pulse has been identified by the software as a 'Local' PD due to it having the right waveshape (high frequency, 'ringing' pulse) with a risetime, fall-time and pulse width in the correct range and the much higher frequency (22.5MHz) than would be seen for a cable PD.

Figure 7: Event Recogniser Software Page showing 'Local/Swgr' PD's

‘PrecedenceDetector©’ Software Module

In order to test EHV cables and cable sealing ends it is necessary to have synchronous detection of PD signals (within 2ns of each other). This is achieved in the HVPD Longshot^{TM} PD Test Unit hardware which collects and stores the highly digitised data which is then analysed in software module carries out automatic analysis of ‘which pulse came first’ and is used in conjunction with distributed probes as shown in Figure 7 above. This module discriminates between ‘external signals’ which come from outside the shielded area (outside the Shielding Antennae) from ‘local signals’ (originating from inside the shielded area). An example of the Precedence Detector Module output from a previous test on a HV cable sealing end is shown overleaf in Figure 8.

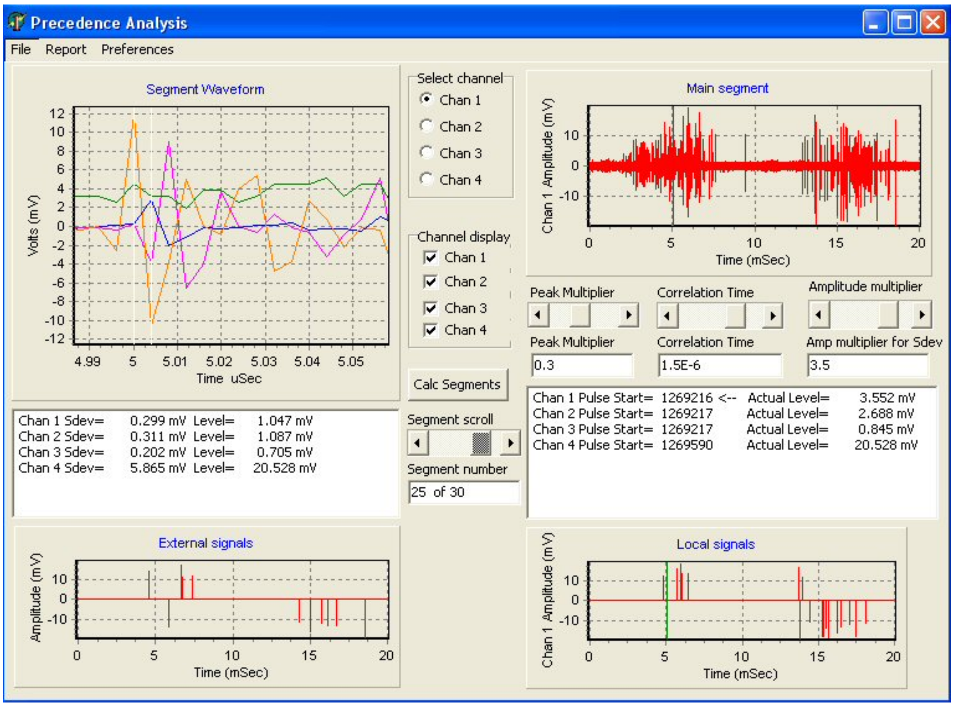
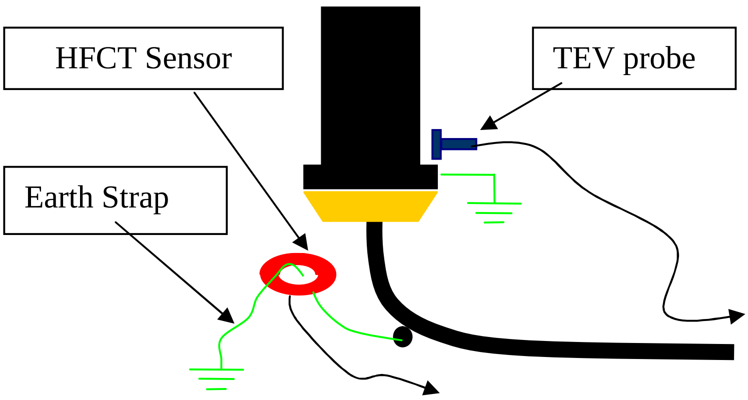
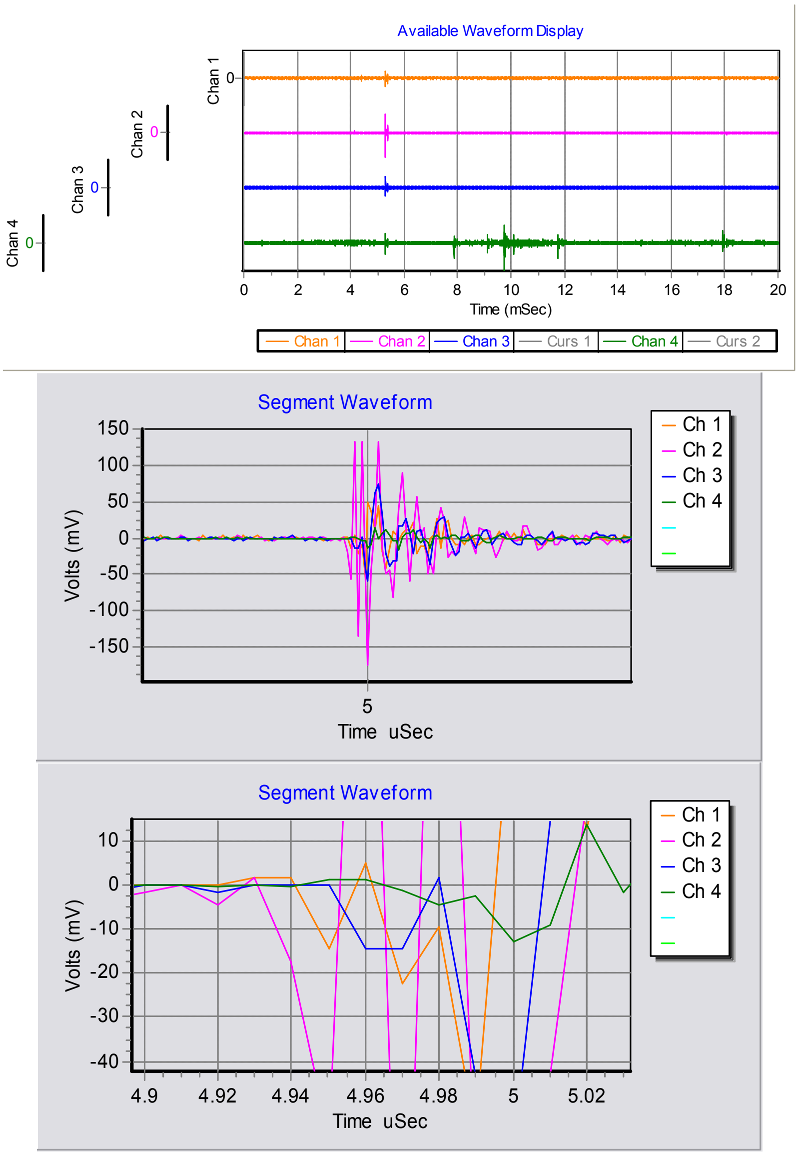


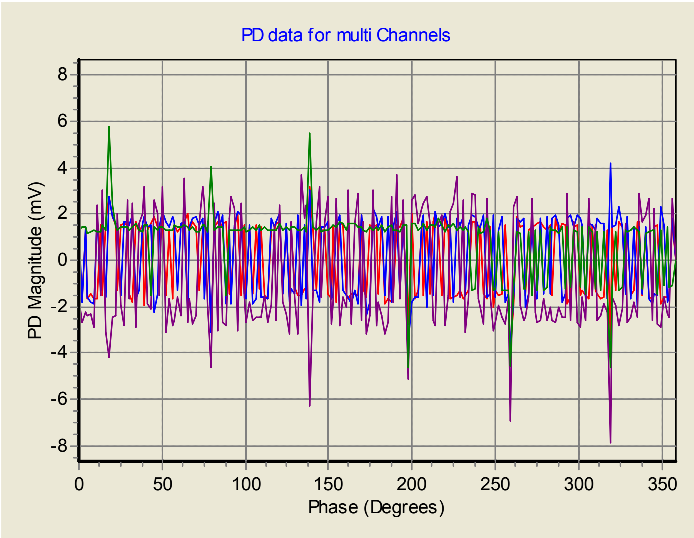
Figure 8: Precedence Detector Software Page showing External and Local PD’s



Sensor Attachments

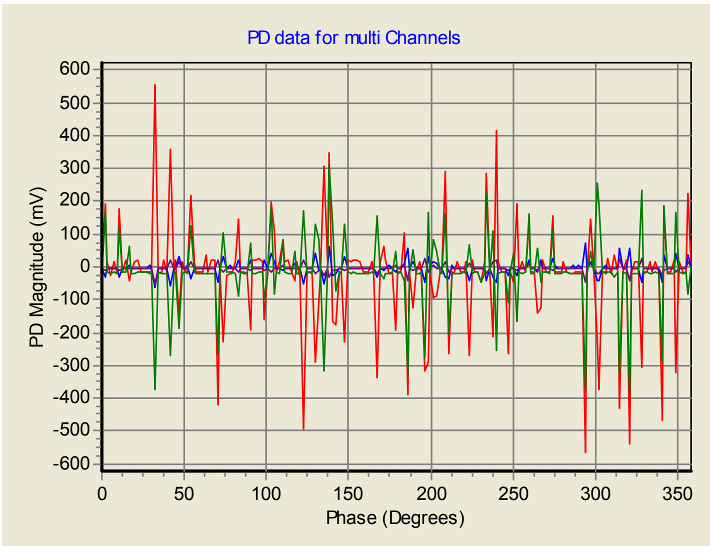


PD Test Results - Large Discharge Pulse (≈180mV) on Red Phase Sealing End



Peak PD activity across the phase at 25% excitation

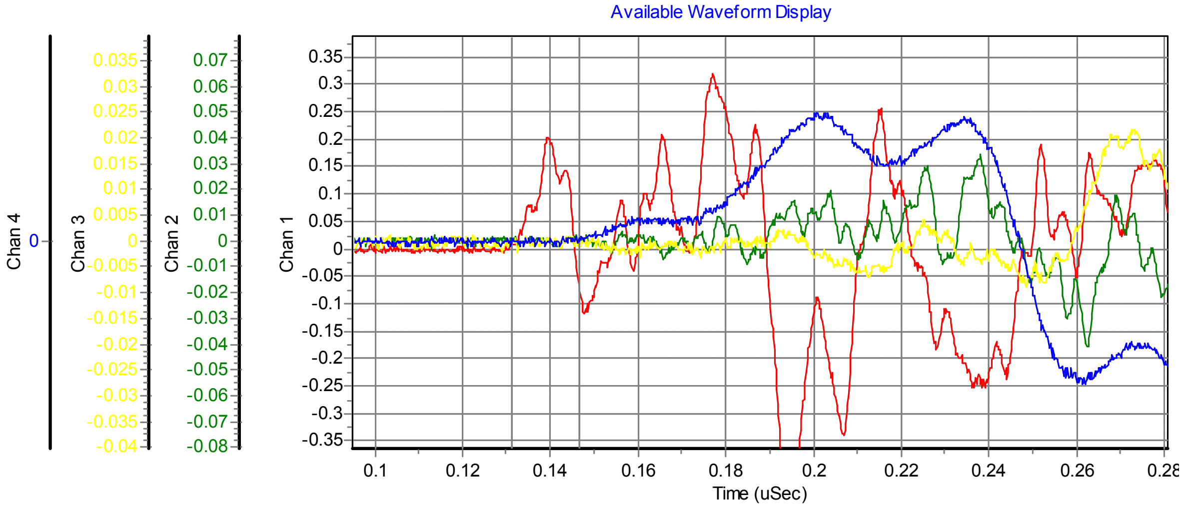
HV Side - Blue Phase TEV=red colour,
HV Side - Yellow Phase TEV =blue colour,
HV Side - Yellow Phase CT =green colour
LV side TEV =purple colour
Peak Activity = 8mV (6x exciter pulses)



Peak PD activity across the phase at 60% excitation

HV Side - Blue Phase TEV=red colour,
HV Side - Yellow Phase TEV =blue colour,
HV Side - Yellow Phase CT =green colour
LV side TEV =purple colour

Peak Activity = 550mV with large PD events observed from the blue phase on the HV side of the transformer.



Time Of Flight Measurements for PD Location

HV Blue Phase PD pulses at 60% excitation
Blue Phase TEV Signal First - timed difference in cursors is 15nSec.
HV Blue Phase CT=blue colour, HV Yellow Phase TEV =green colour,
HV Blue Phase TEV =red colour, LV side TEV=yellow colour

To ascertain the location of the PD event, the signals were timed coming from the various sensors. The results shows that the Blue Phase TEV signal (red colour) on the HV side leads the Blue Phase CT (blue colour) signal by about 15nSec.
This represents a distance of 5m travelling at the speed of light in air.
All other signals trailed the Blue Phase TEV in time, showing that the signals could not originate in the other phases. The TEV probe on the LV side of the transformer also showed that it could not originate on the LV side of the system. The timings show clearly that this was a PD event originating in the HV side of the blue phase cable sealing end.

The PD was located at the support insulators on the blue phase connecting link between the HV cable sealing end and the transformer output bushing as shown below.
The support insulators were removed and then renewed which resulted in a discharge free operation for the HV side of the blue phase.

Site of PD Activity