ON-LINE CONTINUOUS PD MONITORING FOR IN SERVICE DISTRIBUTION CLASS CABLES AND SWITCHGEARS

Malcolm SELTZER-GRANT
HVPD Ltd – UK
malcolm@hvpd.co.uk

Denis DENISSOV
SebaKMT – Germany
denisov.d@sebakmt.com

Ross MACKINLAY
HVPD Ltd – UK
ross@hvpd.co.uk

Frank PETZOLD
SebaKMT – Germany
petzold.f@sebakmt.com

Lee RENFORTH
HVPD Ltd – UK
lee@hvpd.co.uk

Hubert SCHLAPP
SebaKMT – Germany
schlapp.h@sebakmt.com

ABSTRACT

The authors present a paper on the application of on-line continuous PD monitoring for in service distribution class cables and switchgears. Non-intrusive sensors are applied with a wide-band data capture unit. A signal extraction technique based on the pulse shape analysis and the assessment of similarity to the pre-defined PD pulse shapes is utilised to identify different PD sites and noises.

Such testing can be deployed temporarily or permanently with various strategies: to routinely assess cables (e.g. for several hours only), to trend PD activities vs. load cycle after defects found and to permanently monitor key circuits on the network. Case studies of different PD trends and integration of continuous monitoring with existing test techniques such as off-line testing and PD localisation is also shown.

INTRODUCTION

Partial discharge detection in power cables provides an indication of localised points of degradation in the insulation system. Detecting these weak points is of interest for condition based maintenance, asset replacement programmes and improving overall network reliability.

With on-line PD detection, tests can be done under normal working conditions with cables in-service. Continuous monitoring can also be achieved in which measurements are made over an extended period, generally in excess of 24 hours. This is advantageous in that time-varying PD trends can be observed and a more in depth diagnosis performed. Such measurements can also be performed in advance of more in depth on-line and off-line diagnostic and PD location tests. All types of cable can be PD affected including paper, XLPE and EPR cables, the detection method is similar for all cables. As cables are not isolated during on-line tests it is also possible to detect PD signals from the plant or switchgear into which the cable terminated.

This paper presents a new continuous PD monitor for power cables alongside case studies on its application to service-aged cables and in particular its use alongside existing off-line diagnostics.

MOTIVATION FOR CONTINUOUS ON-LINE PD MONITORING

Continuous PD monitoring is carried out to trend PD activities over time; for example in the case of paper cables where load varying PD trends are often observed (see Figure 1) or in cases where the PD activity is intermittent (see Figure 2) due to relations to ambient conditions. Monitoring also allows detection of PD level rises or other changes in the PD activity trend that have been observed to occur immediately before failure [1].

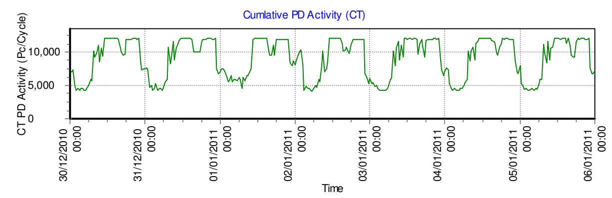

Figure 1 Load varying PD activity in 10 kV paper insulated cable over one week

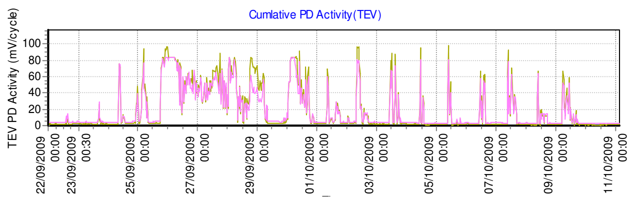

Figure 2 Intermittent bursts of PD activity in 11kV AIS over 2 weeks

PD monitoring can be carried out with either temporary or permanent equipment. In many cases it can be more economical to utilise temporary monitoring in an integrated program [2] due to the vast populations of aging cables on many electricity networks to be tested.

The deployment of continuous PD monitoring can also be combined with routine off-line PD diagnostics as a means to focus such measurements and reduce the number of cables that are not PD affected being de-energised for measurement.

PD DATA ANALYSIS

In the on-line test case the cables are not isolated from the substation and thus measurements are particularly susceptible to noise sources that are induced onto the cable under test.

For continuous noise sources such as radio broadcast signals filtering in both hardware and software is employed. For more stochastic impulsive noise sources, signals scan be rejected based on the pulse wave shape.

Figure 3 shows a single power cycle of data captured from a 6.3kV EPR cables. All of the short duration impulsive events were analysed and classified as PD and noise using a wave shape knowledge rule set, examples of these waveforms extracted from the power cycle trace are shown in Figure 5. The normal distribution of the impulsive events can be seen in Figure 4. It is clear that the majority of the activity is in fact from noise sources. However by processing all events PD data can be extracted below the noise peaks.

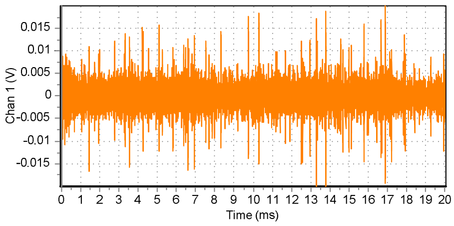

Figure 3 Power cycle of data captured on 6.3kV EPR cable

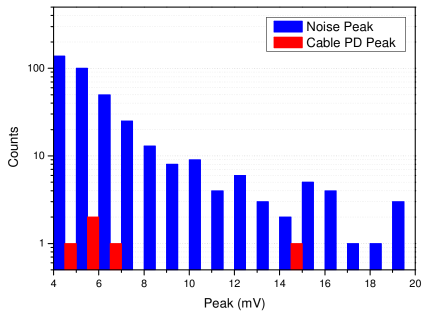

Figure 4 Normal distribution of impulsive event types

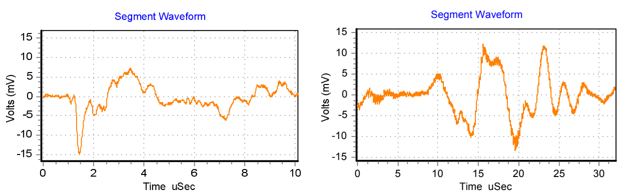

Figure 5 PD event (left) and noise event (right)

ON-LINE PD MONITORING SYSTEM

The PD monitoring system comprises an acquisition unit and passive, non-intrusive sensors. Depending on the cable termination type, between one and four sensors are used per circuit under test. The system installation is shown in Figure 6. Sensors may be attached inside or outside of the switchgear as will be described in the following sections.

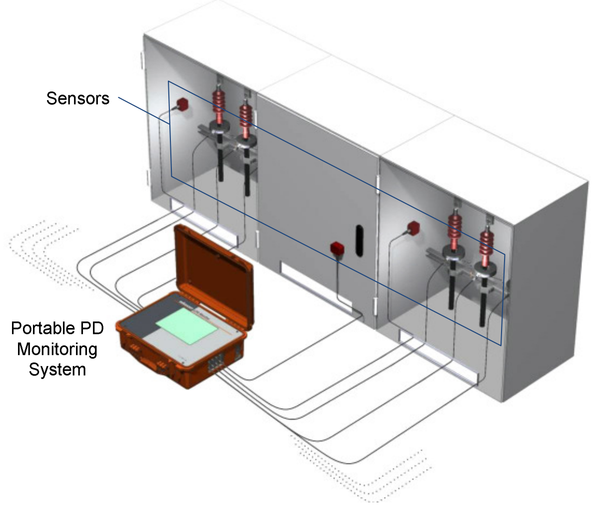

Figure 6 On-line PD monitoring system installation

The system is mainly for installation at primary substations where many cables can be monitored in a single session. Due to attenuation of PD signals in the cable, generally lengths up to around 2.5km will be tested from one end. For longer cables, measurements are also made at the other end or at ring main units in the circuit.

Sensor Connections

In order to detect PD activity on-line, non-intrusive sensors must be utilised. The sensors used for on-line PD detection are the high frequency current transformer (HFCT) for detection of the current impulses from PD in the cables and switchgear and transient earth voltage sensors (TEV) for detection of electromagnetic radiation from local PD activity from sources nearby to the sensor attachment point for example in the cable termination or switchgear. By using a combination of sensors, sensitivity to different types of PD can be obtained and the measurements from different sensors correlated to aid in the diagnosis.

HFCT Sensors

HFCT sensors may be attached onto the cable sheath or cable with the metallic sheath brought back through. A key requirement is the cable metallic sheath has a single connection to ground. Both positions are illustrated in the picture in Figure 7.

In many cases these sensors can be installed on the cables the outside of the switchgear. If this is not possible the sensors may be installed inside of the switchgear or cable box (depending on design) but an outage is required to connect safely. Some examples of this are shown in Figure 8. In some cases the termination may be modified to bring the metallic sheath ground connection outside of the switchgear.

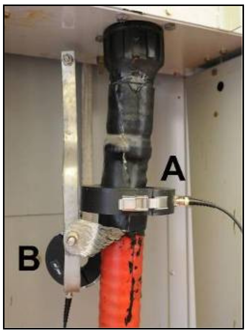

Figure 7 HFCT sensors attached to a 3 core 11kV cable
A: Cable with metallic sheath brought back through
B: Cable sheath connection to ground


Figure 8 HFCT sensor attachment inside of switchgear

Permanent HFCT sensors also may also be installed inside of the cable box as shown in Figure 9 to ease future testing.

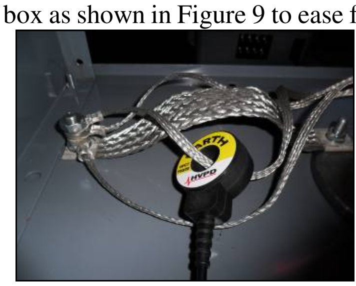

Figure 9 Permanent HFCT inside of cable box.

TEV Sensors

In order to test medium voltage, metal-clad solid-insulated switchgear (SIS) and air-insulated switchgear (AIS) for PD, TEV sensors are utilised. The occurrence of PD within the equipment induces a voltage on the inner surface of the earthed housing. The pulse will emerge on the outer surface through breaks in housing such as vets, joints or seams. The TEV sensors are attached to the inside or outside of the switchgear panel to capacitively couple these signals.

DATA ACQUISITION UNIT

The acquisition unit houses a computer, user display, signal digitiser and 16 channel multiplexers. Multiplexing is utilised in order to maximise the number of cables which may be tested in a single monitoring session and keep acquisition hardware costs down. Remote access to the unit is achieved via LAN or a GPRS/HSDPA modem.

Software

The software topology consists of a web interface, automated data acquisition and processing software and database to store the recorded data.
All control of the unit for system set-up, data viewing and report generation is made via the onboard web-interface. The web-based interface allows the same interface to be viewed locally or remotely from a desktop computer or laptop using a web browser. A screenshot of the interface can be seen in Figure 10.

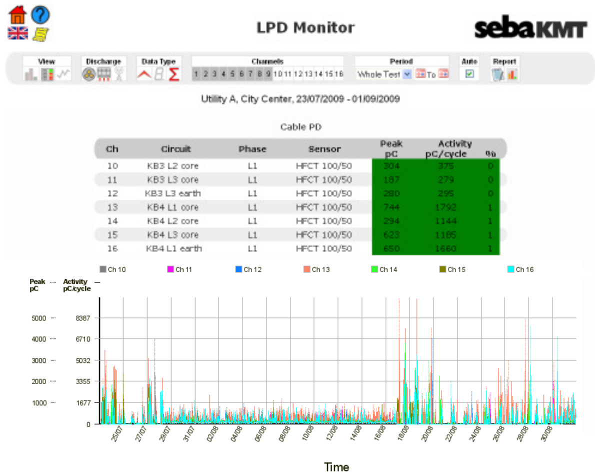

Figure 10 Web-based user interface

The data acquisition and processing software works by capturing 50/60 Hz power cycle duration traces from the PD sensors at a high sample rate (100MS/s). PD event recognition carried out to extract all the impulsive events in the power cycle and classify them as from PD or noise sources based on a pulse wave shape knowledge rule set as shown in the previous section. As the data is sampled at a high capture rate the wave shapes of different PD sources can also be detected, for example PD activity in the cable and local PD from the cable termination and switchgear. The PD event recognition process is shown diagrammatically in Figure 11.

After the processing of the data summary statistics are generated and saved. Notably the peak: magnitude of largest pulse detected (pC for cable PD, dB/mV for local PD/noise); count: number of pulses of each category detected and activity: integrated sum of all pulses of that category (pC/cycle for cable PD, mV/cycle for local PD/noise).
By trending this summary data, changes in the PD activity during the monitoring session can be observed. For example increases in PD peak indicate the defect are getting bigger and increases in PD count indicates defects discharging more rapidly.

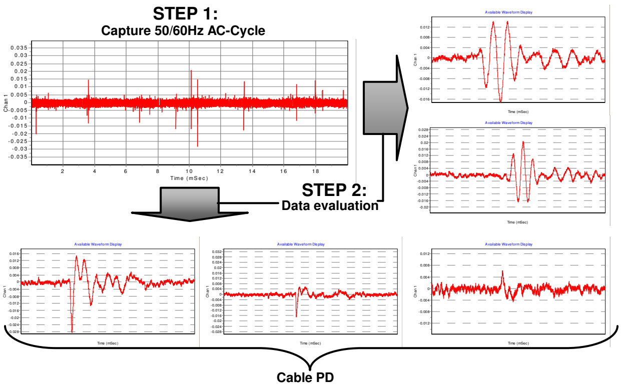

Figure 11 Example of extraction of PD and noise events from power cycle trace

CASE STUDIES

The system has been deployed for measurements in around 100 substations. In some cases follow on diagnostic tests have been performed using off-line OWTS PD testing.

Case 1: 6,6 kV PVC cable

Initially Figure 12a shows PD levels of 6000 pC peak and 130 nC/cycle cumulative PD activity measured for 1 week in April 2010. 8 months later the cumulative activity has doubled during repeated test for 3 weeks, although the peak increased just for about 20% as shown in Figure 12b.

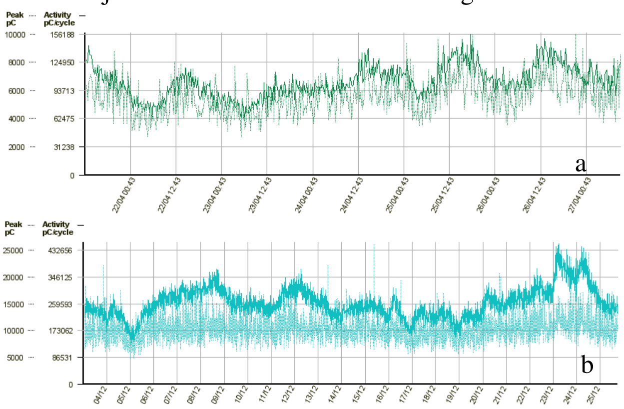

Figure 12 PD in 6 kV PVC cable at industrial site measured in April (a) and December (b) 2010

Critical PD level was verified to be 7000 pC (peak) with the offline damped AC test (OWTS) at rated voltage Uo. The level increased to 50 nC if phase-to-phase voltage 1.7Uo was applied to the cable.

Case 2: 10 kV PILC cable

Figure 13 shows an example of intermittent PD activity that appears at certain moments of load cycle. This behaviour is typical for fluid insulated cables and is a result of thermal expansion of dielectrics.

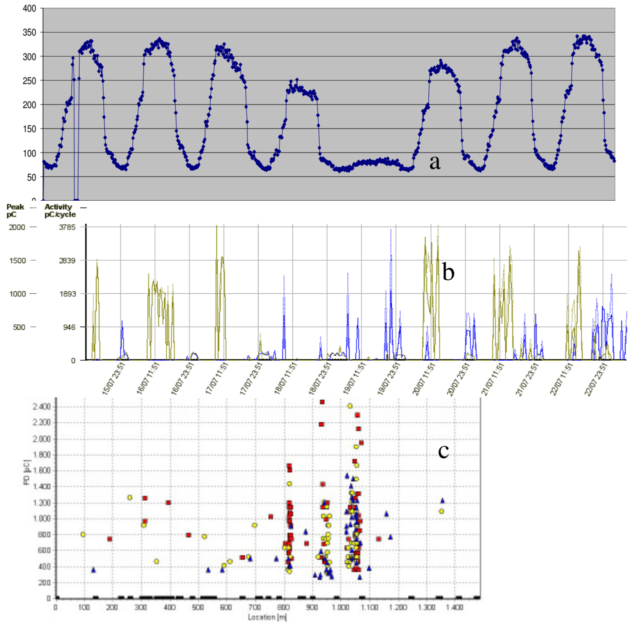

Figure 13 PD activity in 10 kV PILC cable: a) applied phase current in A, b) intermittent PD defects measured on different phases burning in a “cold” cable (blue) and in a “hot” cable (brown), c) offline mapping at Uo

Case 3: 30 kV XLPE cable

PD defects in XLPE cable typically show a load cycle independent PD activity as in Figure 14. The PD was verified by offline tests and localised in a joint at 1100m from the measurement point.

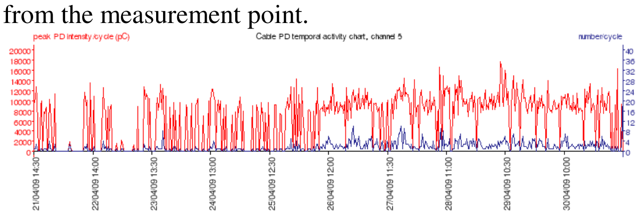

Figure 14 PD in 30 kV XLPE cable at industrial site

CONCLUSIONS

The elements of a continuous PD monitoring system have been shown. Suitability of cable terminations for the non-intrusive sensors has been discussed along with options for installation in-side of the cable box.

The system may be effectively deployed both as a tool for trending PD activities and for focussing off-line and on-line diagnostic and PD location measurements.

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