ON-LINE PD SPOT TESTING AND CONTINUOUS MONITORING FOR IN SERVICE POWER CABLES – TECHNIQUES AND FIELD EXPERIENCES

Malcolm **SELTZER-GRANT** (1), Denis **DENISSOV** (2), Lee **RENFORTH** (1), Ross **MACKINLAY** (1) Hubert **SCHLAPP** (2), Frank **PETZOLD** (2)
1 - HVPD Ltd, Manchester (UK), malcolm@hvpd.co.uk, lee@hvpd.co.uk, ross@hvpd.co.uk
2 - SebaKMT, Baunach (Germany), denisov.d@sebakmt.com, schlapp.h@sebakmt.com, petzold.f@sebakmt.com

ABSTRACT

Applications of on-line PD spot testing and monitoring for in service power cables are presented. The motivation and advantages of the on-line approach to the cable insulation assessment are covered. The different aspects of PD testing are discussed: detection, location and continuous monitoring. The test techniques for different types of transmission and distribution cable circuit are shown with field examples. Integration of continuous monitoring with existing test techniques such as off-line testing and PD localisation is also shown.

KEYWORDS

On-line partial discharge PD monitoring medium high voltage power cables

INTRODUCTION

On-line partial discharge (PD) assessment is now widely deployed for detection of insulation defects in power cables and accessories when in-service for both new and service-aged circuits. In this paper the different aspects of on-line PD measurements are discussed including detection, location and continuous monitoring for different cable types and voltage classes.

The on-line PD detection approach often struggles with high electromagnetic interferences from the neighbouring equipment since a test object (power cable) is galvanically connected to the rest of network on both ends. A signal extraction technique based on the pulse shape analysis and the assessment of similarity to the pre-defined PD pulse shapes.

Continuous PD monitoring is discussed for routine assessment of 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. The described monitoring system presumes the sensor installation at just one end of the cable. Although localisation possibilities in this case are limited, the pulse shape recognition algorithm allows clear differentiation between cable and switchgear defects and their independent criticality assessment.

TEST APPROACHES

In order to PD test cables spot-testing and continuous monitoring methods can be used. Spot-testing has the advantages that it is reasonably quick to deploy with tests between 15 minutes and a few hours per circuit. Various advanced techniques can also be applied for noise discrimination, which is of particular use on transmission class cables where corona interferences can be more present [1]. Due to this spot testing is currently the most viable method for many transmission class circuits, especially those terminated into outdoor terminations.

Continuous PD monitoring is carried out to trend PD activities over time; for example in the case of distribution class paper cables where load varying PD trends are often observed; an example of this is shown in Figure 1. Continuous 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 [2].

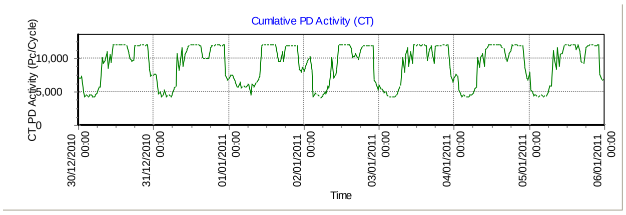

Fig. 1 Load varying PD activity in 10 kV paper insulated cable over one week

The continuous monitoring techniques have been mainly applied to distribution class networks with portable equipment, which is often more economical than permanent monitoring for assessment of many cables in an aged distribution network [3].

Subsequently the use of continuous PD monitoring has been combined with off-line PD diagnostics. This is as a means to focus existing routine off-line measurements and reduce the number of cables that are not PD effected being de-energised for measurement.

SENSING TECHNIQUES AND MEASUREMENT SYSTEMS

On-line Sensor Attachment

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 Attachment

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 2.

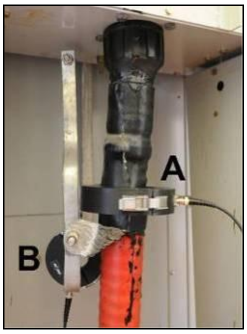

Fig. 2: HFCT sensors attached to a 3 core 11kV cable A: Cable with metallic sheath brought back through B: Cable sheath connection to ground

In many cases these sensors can be installed on the cables the outside of the switchgear. In air insulated switchgear/dry type cable boxes the sensor may be installed inside the plant but an outage is required to connect safely. Some examples of this are shown in Figure 3. In some cases the termination may be modified to make the earthing suitable. Permanent HFCT sensors also may also be installed inside of the cable box to ease future testing.

Fig. 3: HFCT sensor attachment inside of switchgear

Sensors at Cable Mid-points

In addition to the installation of sensors at the cable terminations, attachment at cross-bond points is also necessary when such earth-sheath bonding is used. This is to combat the issue with signals distortion/attenuation at the cross-bond point [4] and also maintain the highest sensitivity to PD in the joints.

On-line Signal Measurements

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 4 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 6. 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.

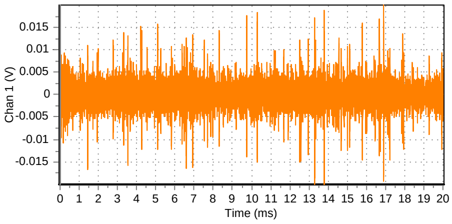

Fig. 4: Power cycle of data captured on 6.3kV EPR cable

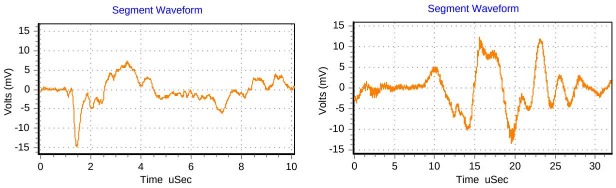

Fig. 5: PD event (left) and noise event (right)

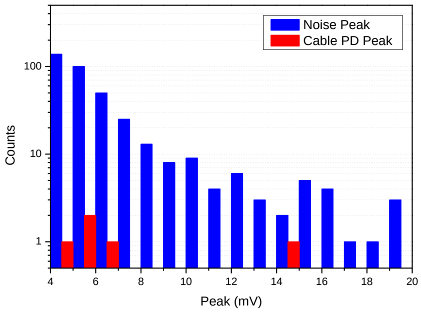

Fig. 6: Normal distribution of impulsive event types

On-line PD Spot Test System

Spot test measurements are made with an oscilloscope-based system with four channels and sampling rate set at 100-500 MS/s. Data traces of one 50/60 Hz power cycle in length (20/16.67 ms) are captured synchronously on all channels and processed with the measurement software. Multiple sensor synchronous capture allows discrimination of interferences to made using signal time of arrival comparison between sensors [1]. An example measurement set-up at an outdoor cable termination is shown in Figure 7.

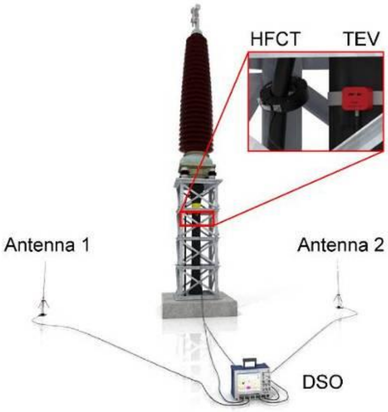

Fig. 7 On-line PD spot test system at HV cable

On-line PD Monitoring System

The PD Monitoring 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. The unit has an onboard web interface which can be accessed on the unit or remotely via LAN or a GPRS/HSDPA modem.

As with spot measurements, data is captured power cycle duration blocks. After 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 is getting bigger and increases in PD count indicate defects discharging more rapidly.

The system installation with PD sensors is shown in Figure 8.

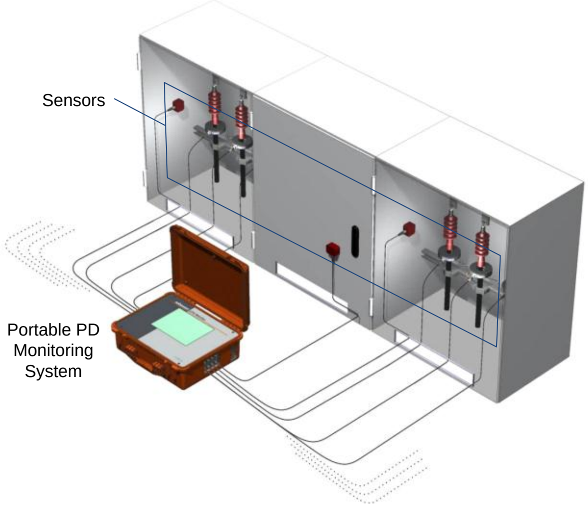

Fig. 8: On-line PD monitoring system installation

The system is mainly for installation at indoor primary distribution 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.

FIELD CASES

Case 1: 6,6 kV PVC cable

The PD activity in a belted 3 km long 6 kV cable at industrial site was analysed. Initially Figure 9a 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 9c.

Critical PD level was verified to be 6000 pC (peak) with an off-line damped AC test (OWTS) at rated voltage Uo (see Figure 9b). The level increased to 50 nC if phase-to-phase voltage 1.7Uo was applied to the cable. In both cases however the mapping could not be achieved, due to presence of multiple defects distributed over the whole length of the cable. This often occurs with PVC insulations, thus visual identification of the reflected pulse was nearly impossible.

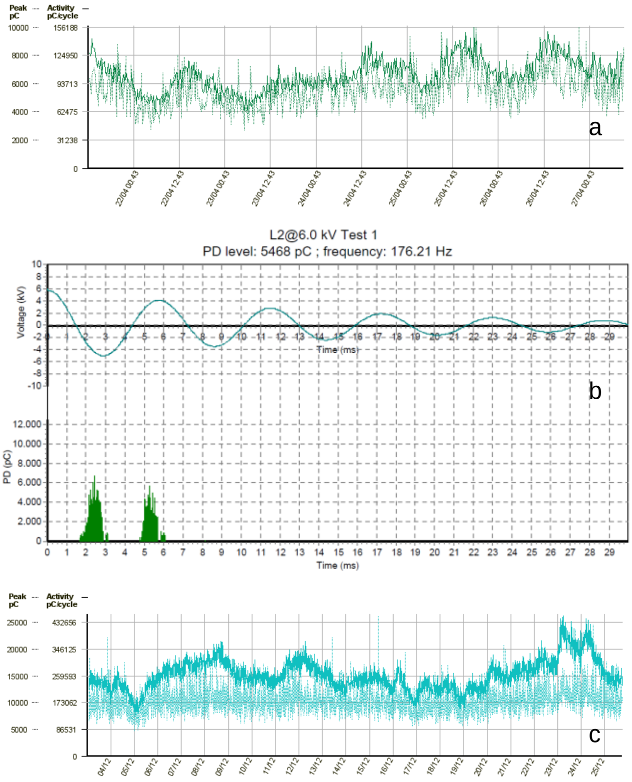

Fig. 9: PD in 6 kV PVC cable at industrial site measured online in Apr. (a) and Dec. (c) 2010 and offline DAC verification in Jun. 2010 (b)

Case 2: 10 kV PILC cable

Figure 10 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 10a presents a one week long load pattern distributed via 4 parallel 1,5 km PILC cables. Figure 10b is an aligned intermittent PD activity occurring in 2 different cables. It can be easily seen that one defect (blue) appears at low load intervals; and the other one on the contrary appears at peak load intervals (brown). Again an off-line DAC measurement revealed several defect on the cable.

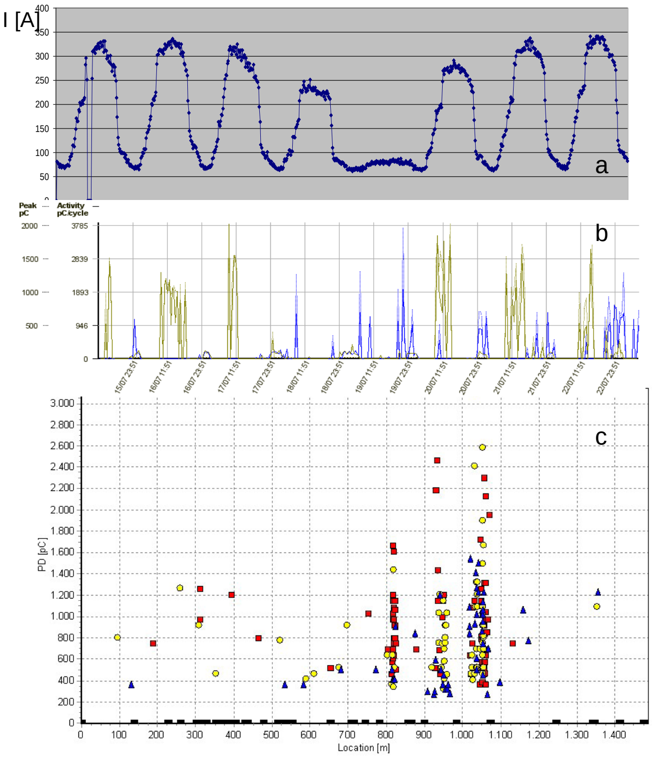

Fig. 10: PD activity in 10 kV PILC cable: a) load current in A, b) intermittent PD defects burning in "cold" (blue) and "hot" cable (brown), c) offline mapping at Uo

Case 3: 30 kV XLPE cable

PD defects in XLPE cable typically show a load cycle independent PD activity as in Figure 11. The PD was verified by off-line tests and localised in a joint at 1100m from the measurement point.

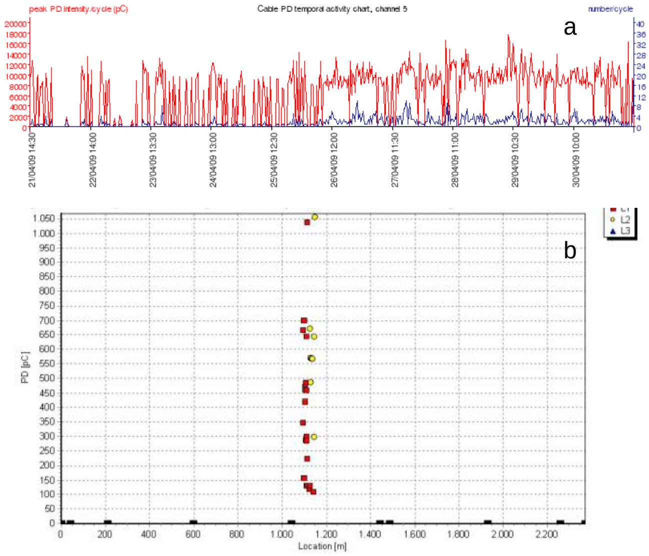

Fig. 11: Online PD trend (a) in 30 kV XLPE cable at industrial site and offline DAC mapping at Uo (b)

Case 4: 10 kV PILC cable

An interesting case of constant peak PD level and highly variable number of PD pulses is shown in Figure 12. A 10 day trend with relatively constant peak PD of 1,8 nC is affected by variable number of PD pulses in the range of 12-60 cable PD pulses per period. Thus the cumulative PD activity results in the range of 10-50 nC/cycle. An off-line DAC test successfully verified the peak PD level at Uo and helped to localise the defect spot on L3 (blue triangle).

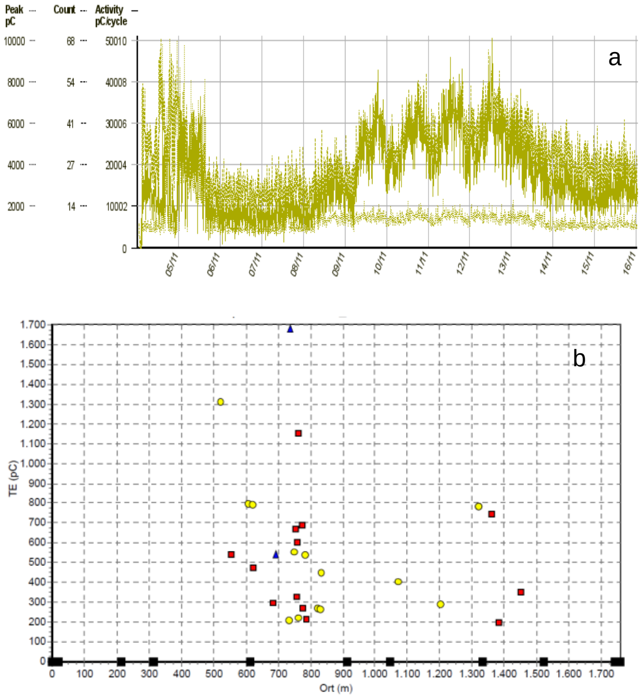

Fig. 12: Online PD trend (a) in 10 kV PILC L3 cable and offline DAC mapping at Uo (b)

Case 5: 110kV XLPE cable termination

An on-line spot test on a 110 kV transformer cable termination revealed a suspect PD signature on the L2 phase (no PD on other phases). The extracted phase patterns of the PD and noise data and characteristic pulses are shown in Figure 13 and Figure 14 respectively.

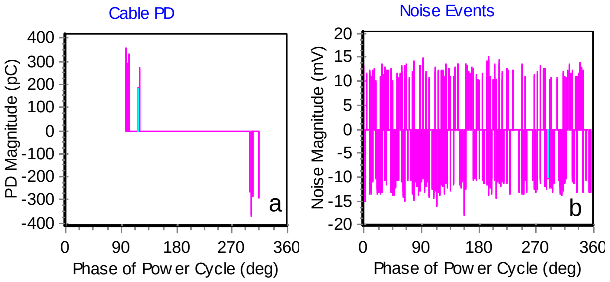

Fig. 13: Phase pattern for segregated PD (a) and noise (b)

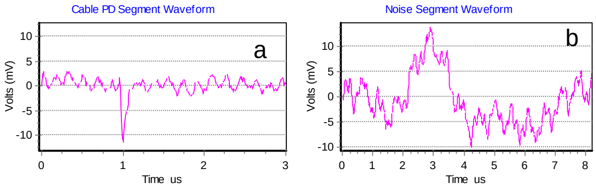

Fig. 14: Typical PD (a) and noise (b) waveforms

Due to the criticality of the cable to the network and the experience of a failure experience of similar cable termination of the same vintage, remedial action was deemed necessary. The suspect termination was subsequently removed from service.

Photographs of the PD damage are shown in Figure 15. It can be seen that the termination is severely degraded – thought to be due to incorrect installation of the stress cone – and from the extent of the damage is very close to failure. It should also be noted that the termination was not in fact removed from service until fourteen months after the initial PD measurement. It is expected the magnitude and recurrence of the PD immediately before removal of the termination would have been very much higher than at the time of spot test.

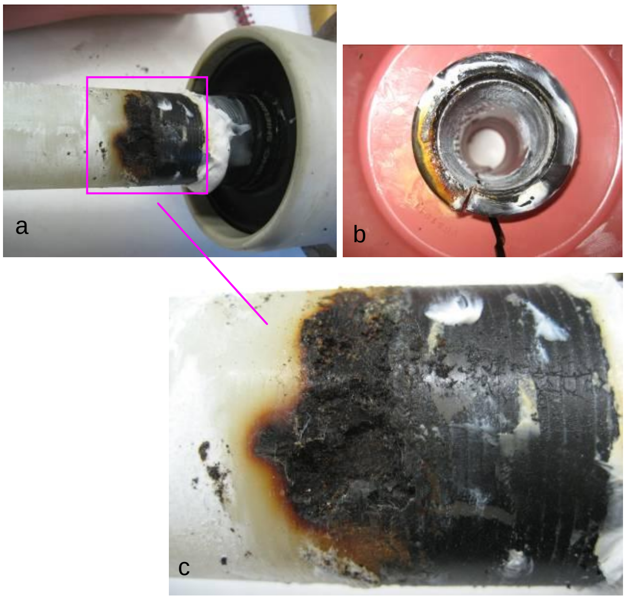

Fig. 15: Degradation to 110kV termination with stress cone removed (a). Detail of damage (b). Inside of stress cone (c)

CONCLUSIONS

The application of on-line PD spot-test and continuous monitoring have been shown as effective techniques for distribution class and transmission class cable insulation assessment.

Suitability of cable terminations for the non-intrusive HFCT sensors remains key to the technology's use. The combined use of the on-line technology with off-line measurements for distribution class circuits has been shown in several cases. The detection of continuous, intermittent and load dependent PD activity with on-line monitoring can also add more depth to final diagnostic on the cable.

Whilst at distribution class, some PD can be tolerated; this is not the case for transmission class cables and on-line spot test has been shown as an effective warning of incipient faults in these cables.

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