NETWORK INNOVATION COMPETITION – ANGLE-DC PROJECT

HOLISTIC CIRCUIT CONDITION MONITORING SYSTEM REPORT

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EXECUTIVE SUMMARY

This report describes the characteristics the Angle-DC Holistic Cable Condition Monitoring system, installed in Q4 2016 and Q1 2017. The functionality, architecture and integration into the SP Energy Networks monitoring system are described.

Photos of the Holistic Cable Condition Monitoring system devices at Llanfair PG and Bangor sites are provided, as well as evidence of the data being recorded and the trend information being stored. Features of the formal service support contract are also detailed.

SECTION 1 PROJECT BACKGROUND

ANGLE-DC aims to demonstrate a novel network reinforcement technique by converting an existing 33kV AC circuit to DC operation. The existing distribution network is increasingly strained due to growing demand and a high penetration of distributed generation. The conventional AC network has limited controllability and flexibility, two fundamental attributes required as the network evolves and becomes increasingly complex. ANGLE-DC will utilise an existing 33kV AC circuit comprising cable and overhead line sections to establish a DC link. An AC/DC converter station will be installed at each end of the circuit and the condition of AC assets under DC stress will be monitored in real time using a Holistic Circuit Condition Monitoring System (HCCM).

The circuit condition monitoring forms an important learning outcome of this demonstrator project. The project will demonstrate on-line Partial Discharge (PD) monitoring systems. These are to be used to give an indication of PD based degradation and trend in time with other operating stresses which can influence PD including voltage ramp up/down, over voltages and ripple from power converters. Data will be analysed and benchmarked to inform SP Energy Networks and other DNOs about the way in which distribution circuits age. Pre and post-DC operation monitoring will allow for validation of theories about how DC impacts on cable ageing.

SECTION 2 INTRODUCTION

The impact of DC stress on the different types of cable, currently in use on the link, will be monitored to assess whether this induces Partial Discharge (PD) within the insulation. Partial Discharge is a time dependent phenomenon, occurring within voids in solid cable insulation. It is unclear what effect the application of a constant DC stress will have on voids within the cable insulation.

Initial testing of the cables was undertaken at a DC voltage of 38kV (40% above the design DC voltage) and minimal levels of PD were recorded. As part of the ANGLE-DC scheme, a HCCM system has been installed at each end of the link, as indicated in Figure 1. This will provide a real time view of the level of PD within the cables to assess whether the DC stress is causing any long term degradation. The DC PD data will be logged to allow benchmarking with the AC PD data; AC and DC PD trending of the cable insulation will then be compared.

The on-line monitoring facility can provide evidence of incipient faults in the cable allowing planned maintenance to be undertaken in advance of a fault occurrence, thus minimising down-time while cable repairs are undertaken.

The monitoring system continually logs partial discharge activity in the power cables, terminations and cable joints. PD levels are trended over time with alarms levels set to interface to the SCADA system if the condition worsens. In addition power quality is trended mainly by current harmonics on the system.

The monitoring system is made up of HVPD Kronos monitor nodes, which connect to sensors installed at the 33 kV power cable terminations at Bangor and Llanfair substations with a server housed at Bangor substation. An overview is shown in Figure 1.

Data is captured continuously from the sensors and processed with a data analysis PD event recognition algorithm to discriminate partial discharge and noise signals. A power quality module acquires and analyses power frequency and currents harmonics data.

A Partial Discharge Monitoring Server (PDMS) is located at Bangor substation; this collates the monitored data and continuously monitors the cable. Data trends are processed on the server and any activity of concern sends an alarm to a local SCADA interface in the substation that can be accessed by the 33 kV network central control room.

The server also hosts the customer Graphical User Interface (GUI) software; this can be accessed locally in the control room at Bangor Grid and also remotely. The user interface allows simple analysis of PD trends along with more detailed phase resolved PD pattern analysis. Reports can also be generated from the software. Software screenshots are shown in Figure 2.

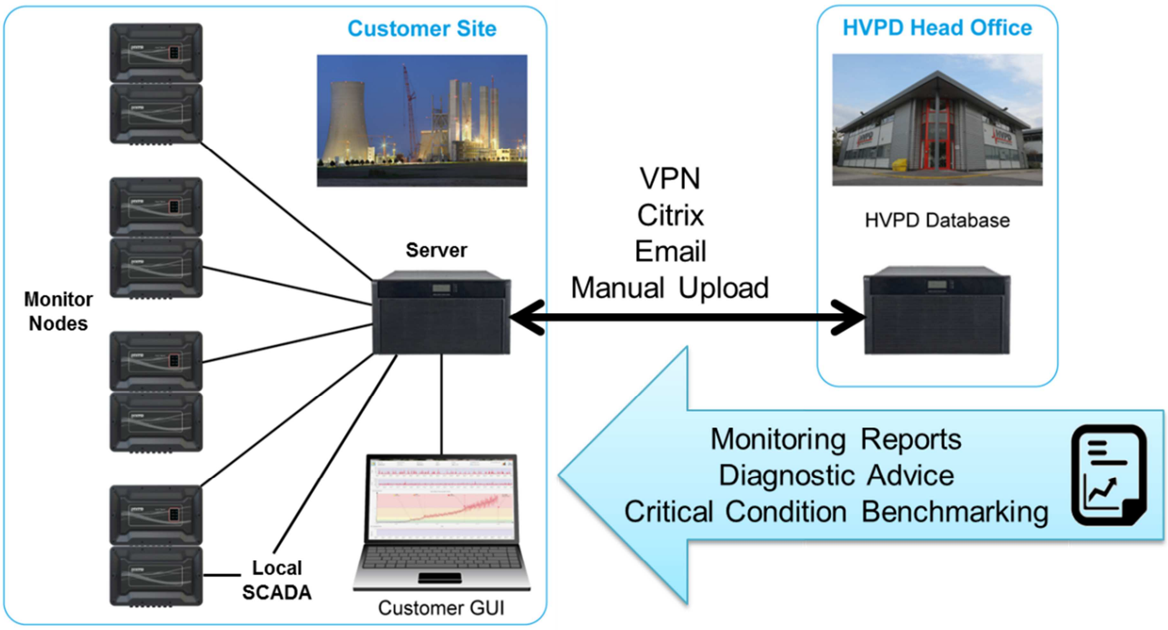


Figure 1. HCCM system overview.

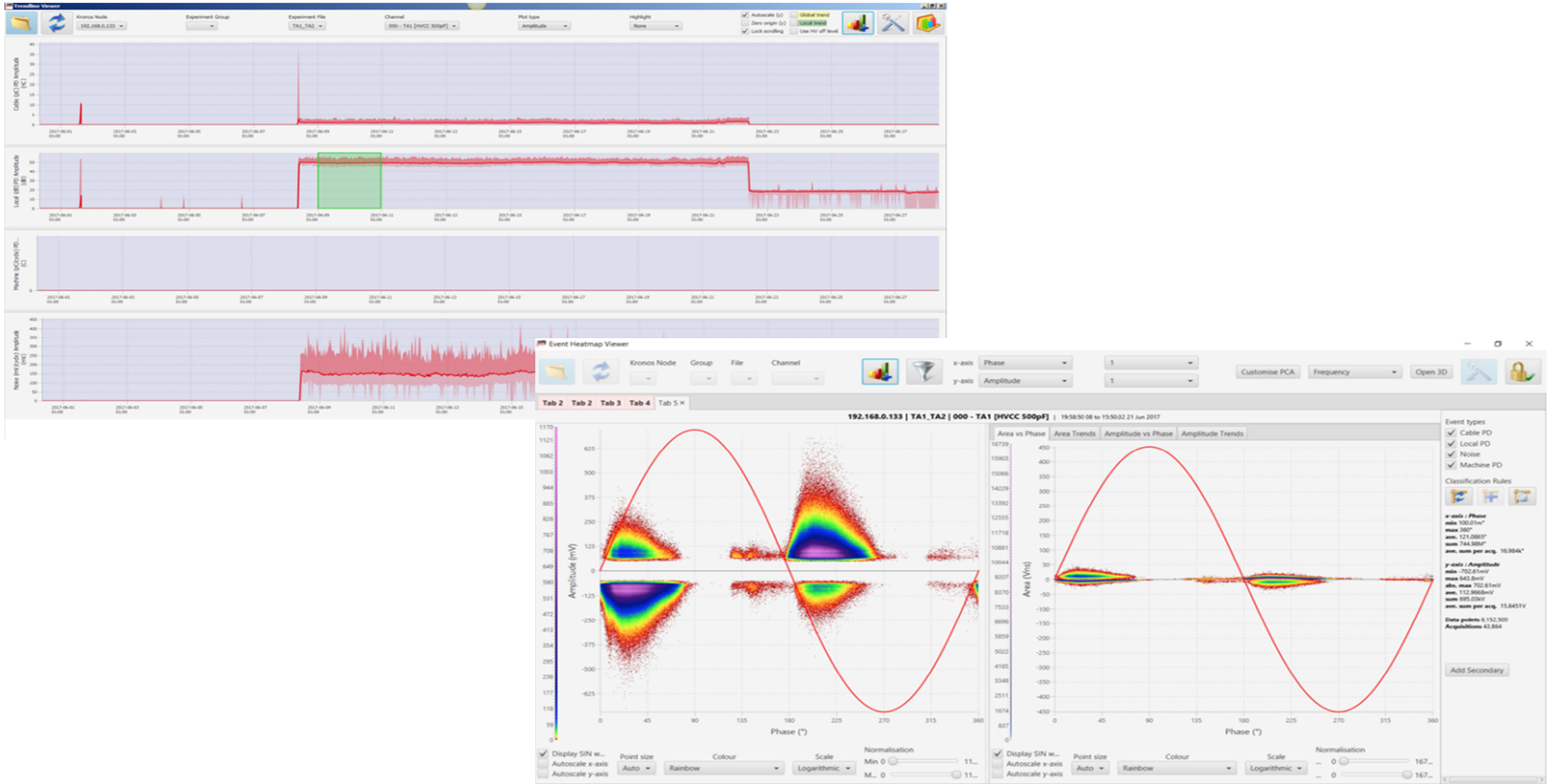


Figure 2. Software screenshots showing time series pulses captured by the HCCM sensors (top) and filtered data showing PD on a phase resolved plot (bottom).

SECTION 3 CHARACTERISTICS OF INSTALLED EQUIPMENT

3.1. Installed Equipment

3.1.1 Permanent Monitor

A HVPD Kronos® Permanent Monitor has been installed within a free standing enclosure at each substation. The monitors are On-line Partial Discharge (OLPD) Insulation Condition Monitoring (ICM) systems suitable for the long-term, continuous monitoring of medium voltage networks. The monitors have a 24-channel input, which capture up to six signal channels synchronously using a multiplexer; this will provide information to help SP Energy Networks avoid unplanned outages on the (Medium Voltage Direct Current) MVDC link.

The HVPD Kronos Monitors communicate back to a local PDMS for coordination and organisation of data. The insulation condition data is then uploaded to a central database for logging, benchmarking and trending by HVPD.

3.1.2 Transient Earth Voltage Sensor

The Transient Earth Voltage (TEV) sensor is a capacitive probe designed to detect local, high-frequency PD pulses in switchgear, cable sealing ends, machine cable boxes, transformers and other plant. The sensors were installed on the cable ceiling ends at Bangor and Llanfair PG.

The sensor has a wideband frequency response to detect 'local' PD pulses in the range of 1 MHz to 100 MHz. When local PD occurs within plant, high frequency RF energy is emitted from the PD location. When the PD is within metal-clad switchgear or cable boxes, the RF radiation is induced onto the inner metal surfaces of the switchgear housing, this energy will emerge onto the outer of the metal-clad housing where there are gaps (e.g. joints, seams, gaskets, vents etc.). These generally oscillatory signals are known as transient earth voltages and are a good indicator of 'local' PD at the substation.

3.1.3 High Frequency Current Transformer

Wideband, high-current, High Frequency Current Transformer (HFCT) sensors have been installed on the cable ceiling ends and are being used to measure partial discharge in power cables and in remotely connected HV plant such as the MVDC link transformers. The sensors are attached around each phase of the circuit cables at each end of the link. The sensors are designed for applications such as the Angle DC circuit where high conductor currents are present. Specifically designed for the application of OLPD monitoring, the high-current HFCT sensors are suitable for the measurement of PD in cables rated up to 20 MVA and above.

3.1.4 Power Quality Current Transformer

The sensor operates in a lower frequency band than the HFCT for detection of power frequency (50/60 Hz) and power quality (PQ) currents up to 200kHz.

3.2. Functionality

As is common in PD measurements, data is acquired synchronously to the power cycle of the high voltage. This allows for Phase Resolved PD (PRPD) patterns to be observed as means to identify different types of PD and can also aid in identification of noise interferences. However, it should be noted this may not be relevant under DC conditions; the system software will be changed at this point which can synchronise the data acquisition in different ways i.e. the expected DC ripple frequency.

Data is acquired at a high sampling rate (100 M Samples/Second), which allows the PD waveforms to be digitised and the data to be clustered based on pulse shape parameters and PD event recognition algorithms applied to aid separation of different PD sources and segregating noise interference. This is shown in Figure 3 which has been acquired from a previous test, at a different site. Figure 4 shows a raw data phase resolved PD (PRPD) pattern, each data point represents an impulsive signal with durations varying from a few nanoseconds to hundreds of microseconds.

Figure 4 shows the same data set plotted with pulse Amplitude against peak in the frequency spectrum. From this plot, three clusters of activity have been identified with the corresponding PRPD patterns and pulse waveforms shown. The lower two cluster's PRPD patterns are indicative of PD activity from different sources in the insulation system, whilst the top cluster is from noise interference. It can be noted in this case the PD patterns are not visible in the raw data in Figure 3 and it is only through detailed evaluation of the data in the different PD sites can be identified.

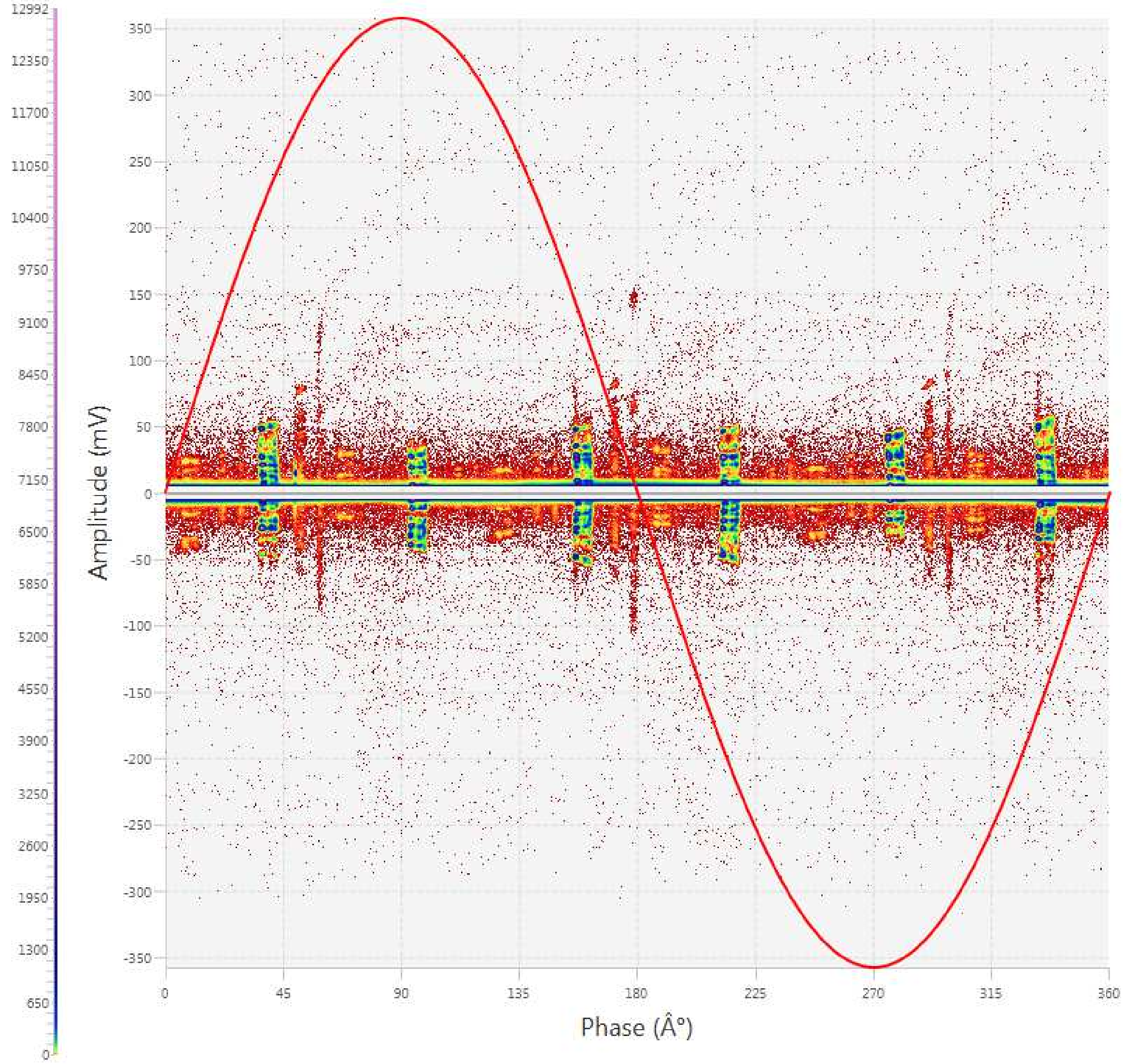
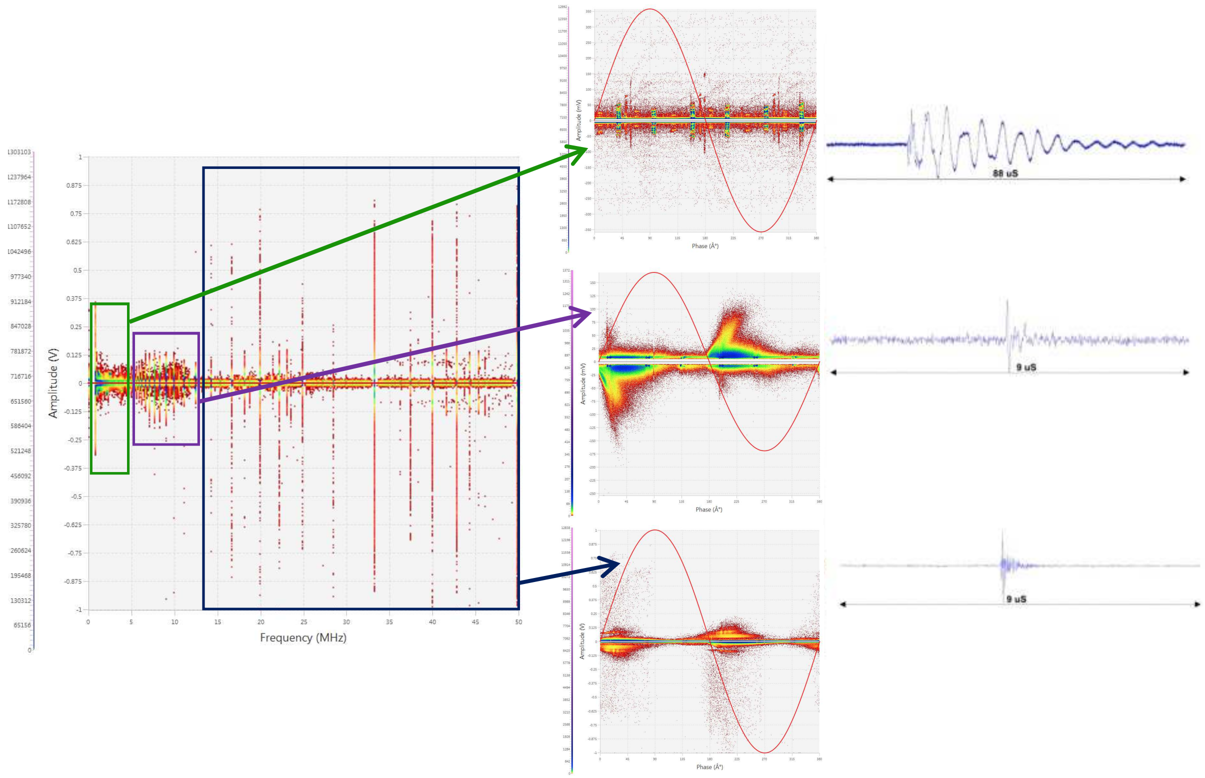


Figure 3. Typical raw phase resovled data from HCCM PD sensors (PD and noise). The color indicates the number of mV pulses that occured at the recorded phase relative to the 50 Hz power cycle.



(a) *(b)* *(c)*

Figure 4 This shows how the PD and noise data is separated using pulse amplitude and frequency. (a) A frequency domain plot showing the number of mV pulses (represented by colour); three distinct patterns are evident. (b) Phase resolved plots separated by the three frequency bands identified in (a). Top plot shows noise and the bottom two plots show PD activity. (c) Partial discharge pulses derived from seperated data.

3.3. Architecture

Monitoring hardware has been installed at Bangor Grid and Llanfair substations. A server is installed at the Bangor Grid control room with HMI and SCADA interface. Modem routers are installed at both sites for communications between the sites and remote access.

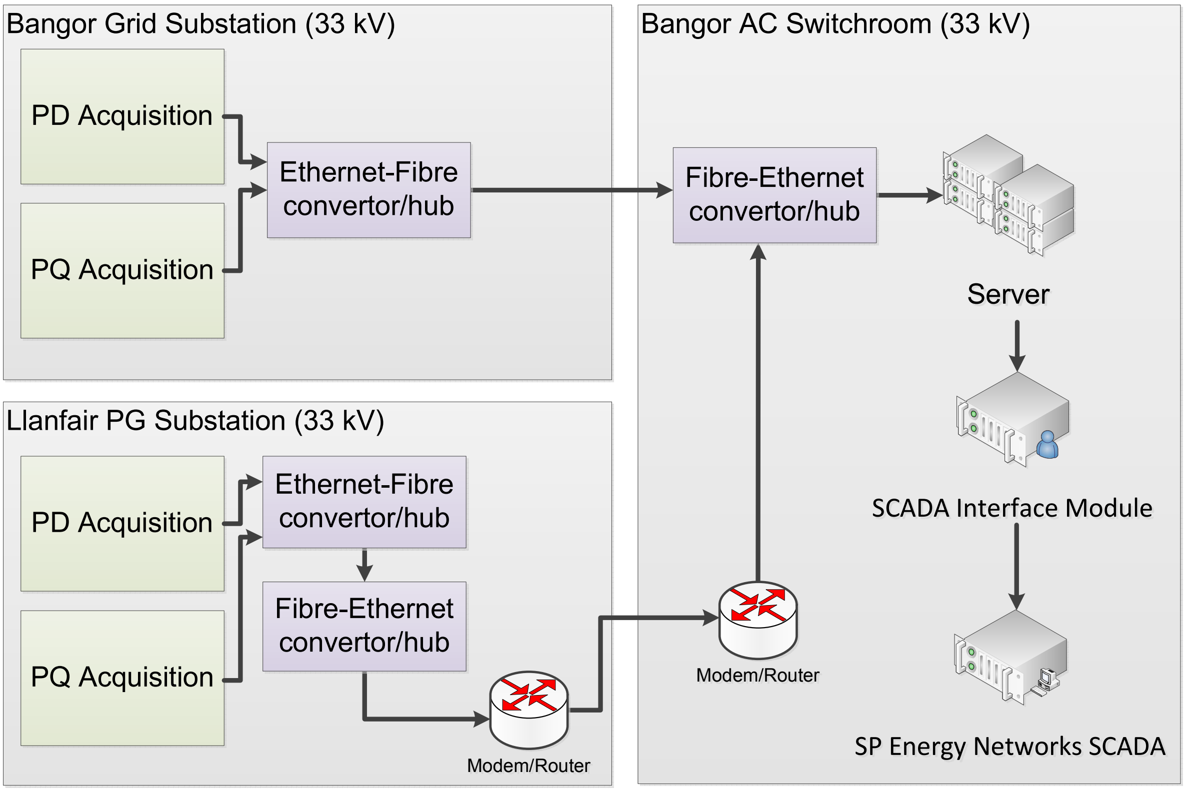


Figure 5. HCCM system architecture.

3.4. Integration into SPEN Monitoring System

The HCCM system provides real time monitoring to the Network Control Centre via the existing SCADA system. This is in the form of alarms which provide two stages of warning to Network Control Engineers of increasing PD levels. The first level is a warning of higher than normal level of PD has been detected and consideration of removing the circuit from service can be made dependent upon network integrity and the criticality of the circuit. The second level alarm is when excessive PD has been detected and immediate action to de-energise the circuit will be taken.

SECTION 4 SITE INSTALLATIONS

Figure 6. Cable terminations with HCCM sensors fitted.

The installation of the HCCM equipment at both sites required sensors and current transformers (CTs) to be installed on the cable terminations. These included the TEV sensor, HFCT and the WBCT. The CT's were of the split type which meant they could be fitted around the existing cable cores.

Frames were made to support the CT's concentrically around the cable cores. The TEV sensors are simply attached to the cable cores.

The CT and sensors are wired into a local connection box which is mounted within a reasonable 'lead length'. At Llanfair PG the connection boxes are mounted on the termination poles and at Bangor it is mounted on the cable terminal concrete supports.

Figure 7. Local connection box mounted on termination poles.

Figure 8. Kronos cabinet containing local data storage and power qulity equipment.

From the KRONOS cabinets the data output is transmitted to a local server via a fibre optic link. This server also communicates to the KRONOS monitor at the Llanfair PG end of the circuit to collect the data before transmitting it to HVPD's facility for analysis.

The CT and sensor outputs are then multicore wired into the KRONOS cabinets where the signals are processed into data for recording and onward transmission. The KRONOS cabinets were mounted on a moveable frame due to the future changes taking place to the circuit when it is transferred over to the DC converter station output.

Figure 9. Kronos cabinet showing internal equipment..

4.1. Initial Results

This section provides preliminary data collected by the Angle-DC HCCM system during its first 6-months of operation. The intention is to provide evidence of the system's live operation rather than a report on the trend of AC PD on the Angle-DC double circuit phases. A full report on the 1st year of monitoring results shall be produce in H1 2018. Initial findings indicate PD has been detected at both ends. The Bangor data shows more intermittent PD, which may be more likely down to external corona/surface discharges.

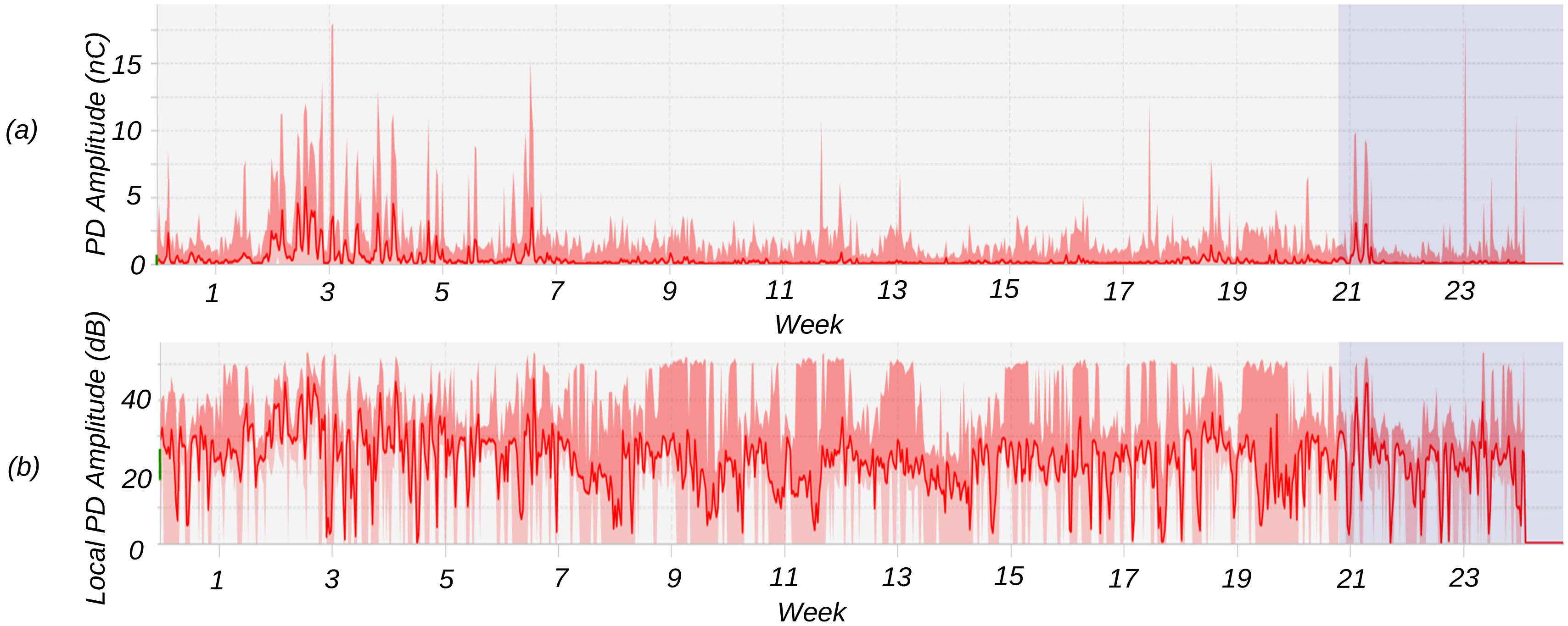


Figure 10. Raw time series sensor data showing PD amplitude from HFCTs and TEV sensors over a 21 week period (09/02/2017 – 13/07/2017).

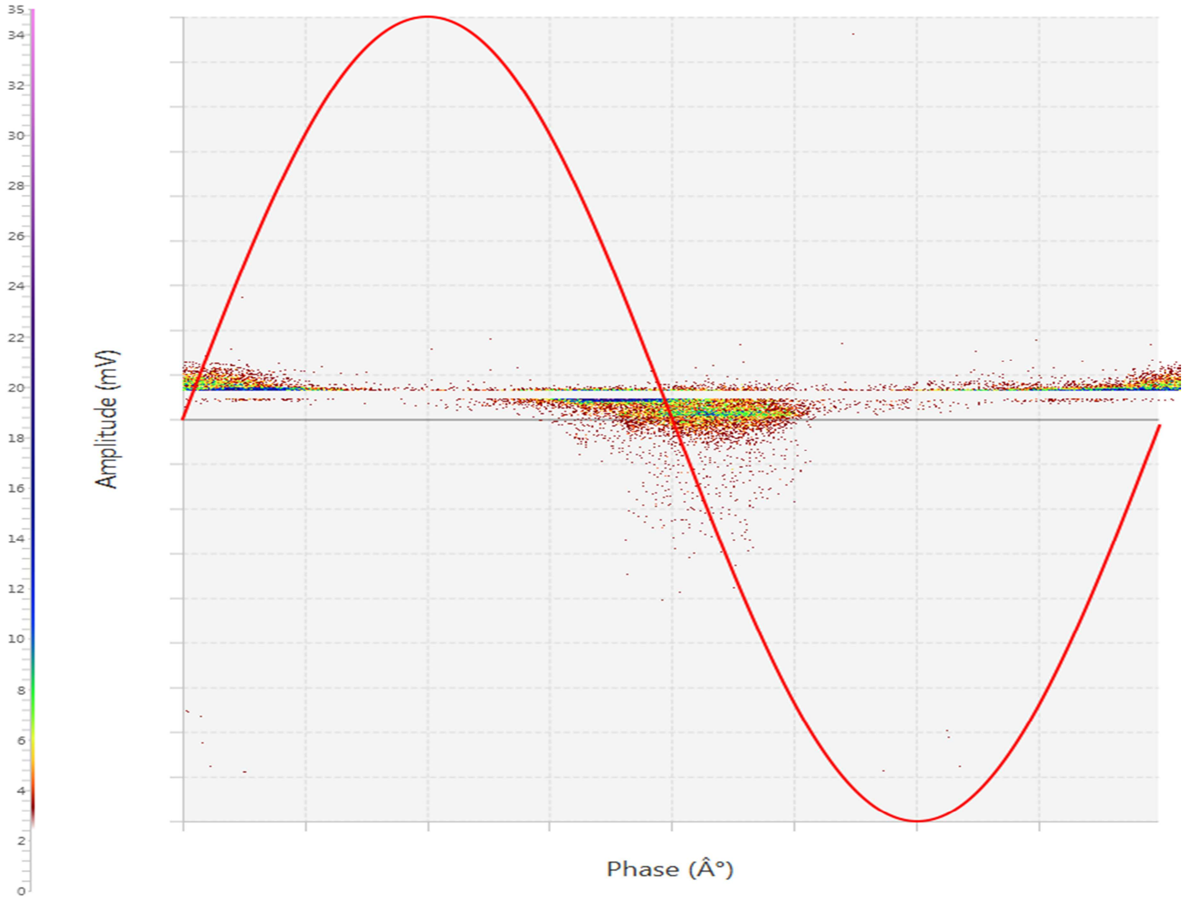


Figure 11. Phase resovled data from HCCM PD sensors, showing low levels of PD activity. The color indicates the number of mV pulses that occured at the recorded phase relative to the 50 Hz power cycle.

SECTION 5 SERVICE SUPPORT CONTRACT

Below is an extract from the procurement contract which was entered into with HVPD Ltd for the Angle-DC project.

Table 1. Project Cost (Option 2 – Bangor Treborth Substation & Llanfair PG Substation).

Item	Description	Price
C.2	HMS Hardware (Bangor Treborth)	[redacted]
	HMS Hardware (Llanfair PG)	
C.3	Installation (Bangor Treborth)	
	Installation (Llanfair PG)	
	Installation & Commissioning Report (Bangor Treborth)	
	Installation & Commissioning Report (Llanfair PG)	
C.4 & C.5	Lifetime Software Updates and Service Support (Bangor Treborth) – 3 Years	
	Lifetime Software Updates and Service Support (Llanfair PG) – 3 Years	

Table 2. Features of the HVPD services contract.

HVPD Service Contract
Comparison and benchmarking of OLPD activity in the network across the assets to the HVPD OLPD Measurements Database© which holds data from all types of HV assets derived from over 20 years' experience
Database user interface with all condition data superimposed onto a bespoke single-line diagram (SLD) of the network
4 condition monitoring reports* (two reports in year one and two reports in year three – reports to be submitted at 6-monthly intervals) including updating of data to the latest HVPD OLPD Measurements Database© (* *amended*)
Annual software upgrades, including updates in line with the HVPD OLPD Measurements Database©
Diagnostic recommendations and maintenance intervention advice
Extended hardware warranty

SECTION 6 ACCURACY ASSURANCE STATEMENT

The Project Manager and Director responsible for the ‘NIC – Angle-DC Project’ confirm they are satisfied that the processes and steps in place for the preparation of this Project Progress Report are sufficiently robust and that the information provided is accurate and complete.

Signature (1): James Yu – Future Networks Manager

Signature (2): Colin Taylor – Engineering Services Director