Arc Aid

Final Learnings Report

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1. Contents

1. Executive Summary

Arc-Aid is a Network Innovation Allowance (NIA) project led by UKPN. As the project partner, National Grid Electricity Distribution (NGED) has trialled 20 sets of MetrySense 5000 advanced smart grid sensors on the 33kV Arc Suppression Coil (ASC) earthed network fed from St. Austell 132/33kV BSP in Cornwall, UK. The trial investigated whether the sensors could locate ASC earth faults more quickly and cost-effectively compared to traditional solutions such as network switching and line patrols.

The project is funded by Ofgem's Network Innovation Allowance (NIA) and was being delivered collaboratively between UKPN (lead partner) and NGED. The project began in February 2020 and the NGED scope associated with the project was completed in May 2022. The results from the NGED trial and UKPN's type testing, indicate that the MetrySense 5000 sensors can accurately detect and locate both transient and permanent earth faults on ASC networks.

The MetrySense 5000 sensors have also been found to provide a cost-effective solution for accurate measurement of various electrical parameters at remote locations on the distribution network. They have demonstrated greater insight into the complex power flows on the meshed 33kV network fed from St. Austell BSP.

The data from the 20 sets of sensors is continuing to be monitored and is now fully integrated into the NGED Network Management System (NMS). This has enabled NGED control engineers to observe the fault location information on their mimic screens in real-time. The sensors and the associated MetryView software platform are in a position to become a Business as Usual (BaU) tool for detecting and location earth faults on ASC earthed networks.

2. Project Background

Arc Suppression Coil (ASC) earthed systems are prevalent on the 33kV and 11kV distribution networks in National Grid Electricity Distribution's (NGED) South West licence area. They were developed early in the 20th century due to the difficulty in achieving low enough earth resistance to operate the incumbent protection systems for high-impedance earth faults. Although modern protective relaying has advanced, many of these networks remain in operation owing to the significant cost and complexity of conversion to conventional neutral earthing.

The ASC is an adjustable inductive reactance connected to the neutral of the transformers supplying the network. The ASC is 'tuned' so that the inductive impedance is close to resonance with the shunt capacitance of the connected network. This reduces the earth fault current that flows into the fault. Under earth fault conditions, the voltage across the ASC rises to approximately the nominal phase-to-earth voltage of the network allowing the presence of a fault to be detected.

A drawback of ASC systems is that they cannot identify the earth fault location or the specific faulty feeder. Consequently, network control engineers typically must carry out strategic network switching to isolate the faulted feeder, often disconnecting customers on healthy feeders in the process.

A joint Network Innovation Allowance (NIA) project 'Arc Aid' was created between UK Power Networks (UKPN) and NGED with the purpose of developing and trialling a novel advanced grid sensor, the MetrySense 5000, developed by Megger. The technology had been successfully installed in other countries for similar network configurations but had not been trialled in the UK prior to this project. The NIA project was led by UKPN and began in February 2020. The project is officially due to close in August 2022 (2 year and 7-month duration).

The low-cost sensors connect directly to the overhead line (OHL) conductors where they can measure a range of electrical parameters and communicate this information to our Network Management System (NMS) in real-time.

The project investigated whether the sensors could provide an accurate and cost-effective method for earth fault location on ASC networks, thereby reducing the number of Customer Interruptions (CIs) and Customer Minutes Lost (CMLs) that are experienced due to these types of faults. A fault indicator suitable for ASC arrangements also has the potential to help DNO line patrol teams locate and resolve a fault more quickly, reducing operational costs and improving safety, which will ultimately help us provide a better service to our customers.

3. Scope and Objectives

The NIA project scope and objectives are recorded in the NIA project registration document (PEA) and includes specific scope items related to the respective NGED and UKPN delivery activities. **Error! Reference source not found.** gives a description of the status of each of the project objectives that are related to the NGED project scope only.

Table 3-1: Status of project objectives

Objective	Status
Procure the equipment required for the testing at the PNDC and for the network trial	✓
Test the Metrysense 5000 fault indicator at the PNDC in conditions that replicate the network	✓
Analyse the results from the PNDC trial to assess if the technology is suitable	✓
Train staff in the installation of these units	✓
Install units in South West	✓
Integrate the sensors into NGED's control and SCADA systems	✓
Collect data in the trial area	✓
Analyse how reliable, robust and cost effective the new protection/monitoring system is	✓
Assess the safety improvement following the deployment of the units	✓
If the trial successfully confirms the expected benefits, the business case (i.e. Cost Benefit Analysis- CBA) will be updated based on the project findings and create a new standard and procedure for the implementation of the technology into the business	✓
Plan the adoption of this new type of fault indicator as Business as Usual (BaU) solution	✓

4. Success Criteria

Table 4-1: Status of project objectives

Success Criteria	Status
The units can be evaluated for fault location in 11kV and 33kV ASC networks	✓
An assessment of the real benefits delivered by MetrySense 5000 fault indicator when installed on the network has been carried out to provide the evidence required to decide whether the solution should be implemented more widely or not	✓

5. Details of the Work Carried Out

5.1. System Architecture

The scope of NGED's trial was to install 20 MetrySense 5000 sensor sets. Each set consists of three sensor units (corresponding to one unit per phase) and a pole-mounted gateway unit. The gateway unit uses low powered radio to communicate with the line mounted sensors. It provides additional computing and signal processing capabilities, and acts as a base station for data transfer back to NGED's NMS. Figure 5-1 shows one of the sensor sets we installed on a 33kV feeder supplying St. Blazey 33/11kV primary substation. Figure 5-2 shows an example of a pole mounted gateway that provides the telecoms connection to the NMS.

Figure 5-1 MetrySense 5000 sensor set on a feeder supplying St. Blazey 33/11kV substation

Figure 5-2: Example of a pole mounted gateway unit

Each discrete sensor unit contains an onboard battery pack charged directly from the OHL. The latest generation of sensors require a minimum 3A phase current on the line to ensure continued operation at full performance/functionality. The gateway is also supplied from an onboard battery charger supplied from a solar panel mounted on the cabinet. The system is therefore fully self-sufficient once installed.

The MetrySense sensors continually monitor their respective phase current and voltage waveforms. If a fault is detected, the three sensors immediately send waveform recordings and other data about the fault to the gateway. The gateway runs analysis algorithms on the complete 3-phase information to make a local decision about the fault. If a fault is confirmed, the fault data is communicated to central control either over the local cellular network, or over the Supervisory Control and Data Acquisition (SCADA) network. The project trialled both cellular and radio connected sensor sets to understand the merits of both systems. Figure 5-3 and Figure 5-4 show schematic diagrams of the two main system architectures used in this project.

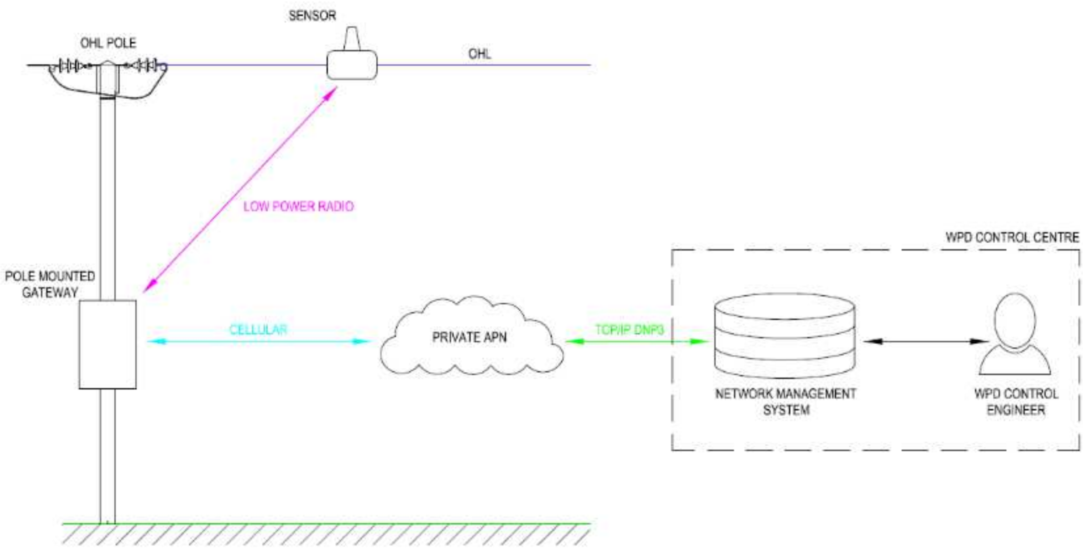


Figure 5-3 Cellular telecoms system architecture

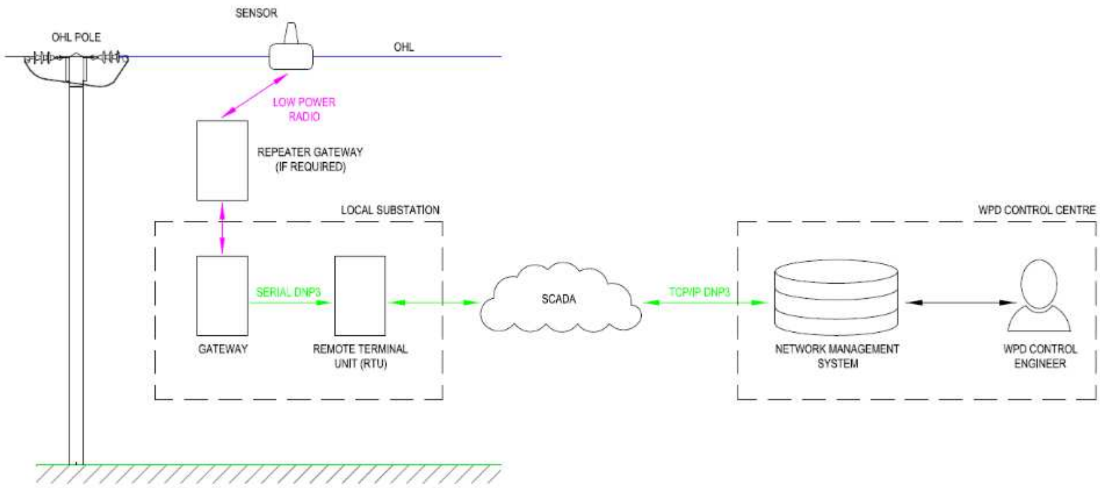


Figure 5-4 Radio telecoms system architecture

5.2. Trial Area Selection

The first stage of the project was to select an area of ASC earthed 33kV network suitable for the trial. A site selection methodology was developed, and after detailed analysis the meshed 33kV network fed from St. Austell 132/33kV Bulk Supply Point (BSP) was chosen as the project trial area. This area of network was selected primarily due to its relatively compact geographical footprint, allowing good sensor coverage. St. Austell also has high levels of Distributed Energy Resources (wind, solar, industrial CHP etc.) that can generate complex power flows under fault conditions. For these reasons it was identified that the network around St. Austell would benefit significantly from faster and more accurate earth fault location.

The majority of the MetrySense 5000 sets (16 out of the 20 in total) utilise cellular telecoms to communicate their measurements back to central control. The project team therefore carried out a study of the cellular signal strength of the main Mobile Network Operators (MNOs) across St. Austell. The study found that there was very good 3G/4G coverage from the main cellular carriers in the locations where the cellular sets were located.

Following the signal strength study, the sensor locations were strategically selected to optimise the area of 33kV network being monitored for fault detection. Typically, sensors were located at either end of a section of overhead line so that earth faults occurring along its span could be detected and located efficiently. An example of the selection methodology applied to an extract of the 33kV trial area can be seen in Figure 5-5.

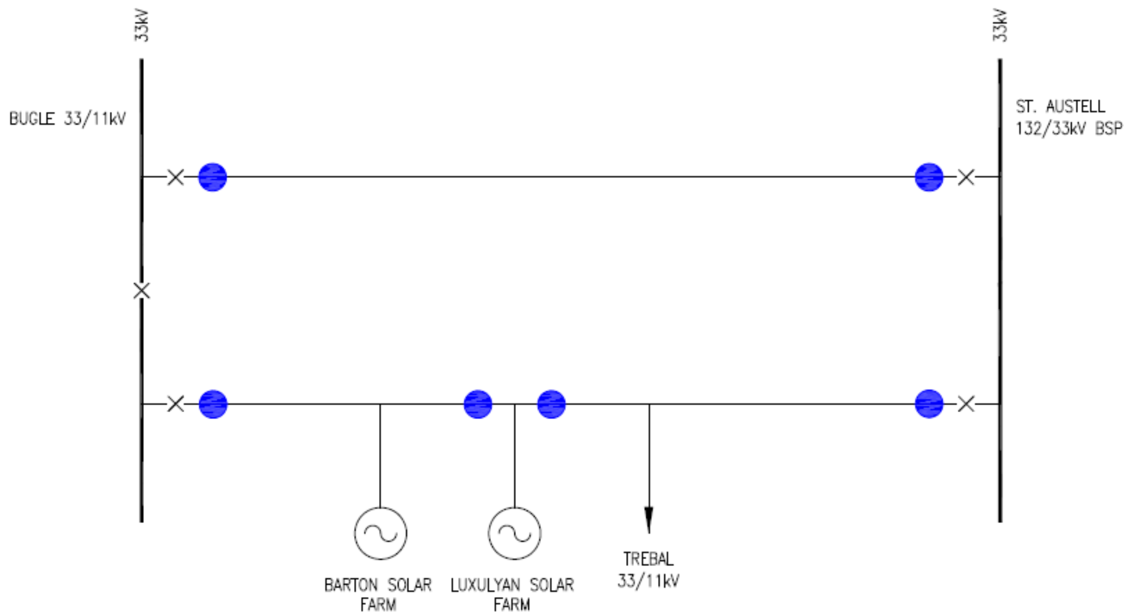


Figure 5-5 Example of sensor location selection (blue circle) on 33kV network fed from St. Austell 132/33kV BSP

5.3. Sensor installation

The MetrySense 5000 sets are capable of being installed directly on live 33kV conductors using standard live line techniques. However, the units were installed under outage conditions in the project trial as an approved live line installation policy was under development at the time. Outages can take considerable time to schedule, however, the project team was able to programme them effectively during the summer outage period, and no delays to the project programme were encountered. The live line policy was approved early in 2021 and subsequent installations proceeded with live line techniques to minimise time delays due to outage scheduling.

The MetrySense 5000 sensor body has a clamshell design allowing the unit to be placed over the OHL conductor as shown in **Figure 5-6**. The device has a main screw on the base that tightens and fixes the clamp to the conductor. A secondary smaller screw on the base is required to secure the housing to the line. The screw attachments are shown in **Figure 5-7**. The sensor can be installed with a hot stick attachment or on the live line using insulating gloves. The MetrySense

5000 units were found to be simple and quick to install by NGED site operatives using both the hot stick method and the insulated glove method.

Figure 5-6: MetrySense 5000 sensor clamping over the conductor

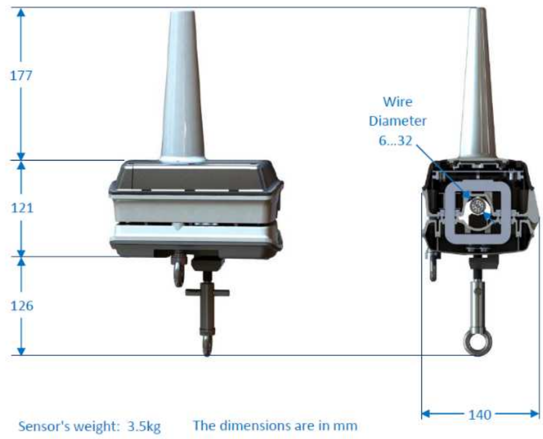


Figure 5-7: Profile view showing main and secondary screws

Each sensor in a set has a label indicating the assigned phase that it should be installed on (A, B or C). There is also an arrow next to the phase label that indicates the direction of positive power flow.

5.4. Information Technology Architecture

The data from the radio and cellular connected sensors interfaces with the MetryView software platform. This platform is Megger's proprietary system that analyses the data received from the remote sensor devices and allows visualisation of analysis results using a browser based Graphical User Interface (GUI) in real time. The MetryView system also provides the DNP3 data connectivity to the NMS in the control centre, so that fault detection signals can be displayed on control engineer mimic screens. **Figure 5-8** shows a screenshot of the MetryView GUI and corresponding Single Line Diagram (SLD) of the 33kV network fed from St. Austell.

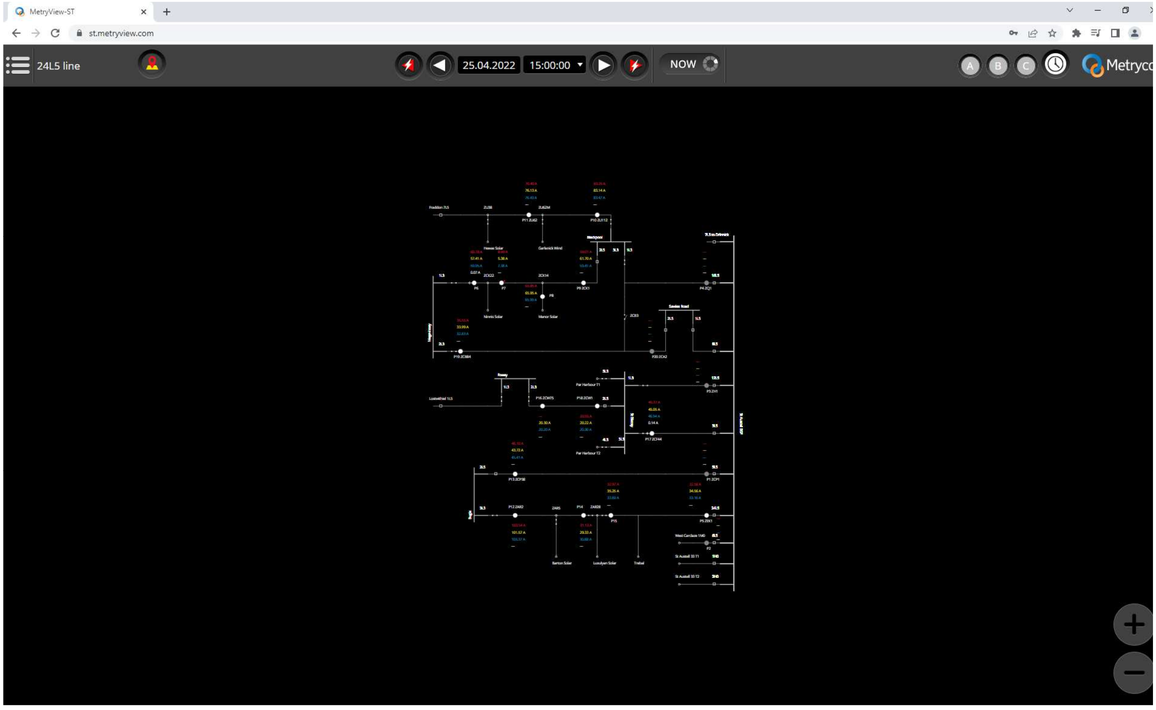


Figure 5-8 Web-based MetryView GUI and SLD representation

In its final design configuration, the MetryView software was hosted on a purpose-built server for the project trial, located behind the NGED firewall. The server was not available during the installation of the sensor sets at the start of the project, so sensor data was temporarily relayed directly to servers hosted by Megger to allow the trial to proceed. This Stage 1 work is shown diagrammatically in **Figure 5-9**. The NGED server is now fully constructed, and the cellular SIM cards have been replaced with NGED units capable of communicating to the NGED private Access Point Name (APN). This is shown diagrammatically in **Figure 5-10**. The sensor data has now been fully integrated with the NGED NMS to allow control engineers visibility of fault detection and location information.

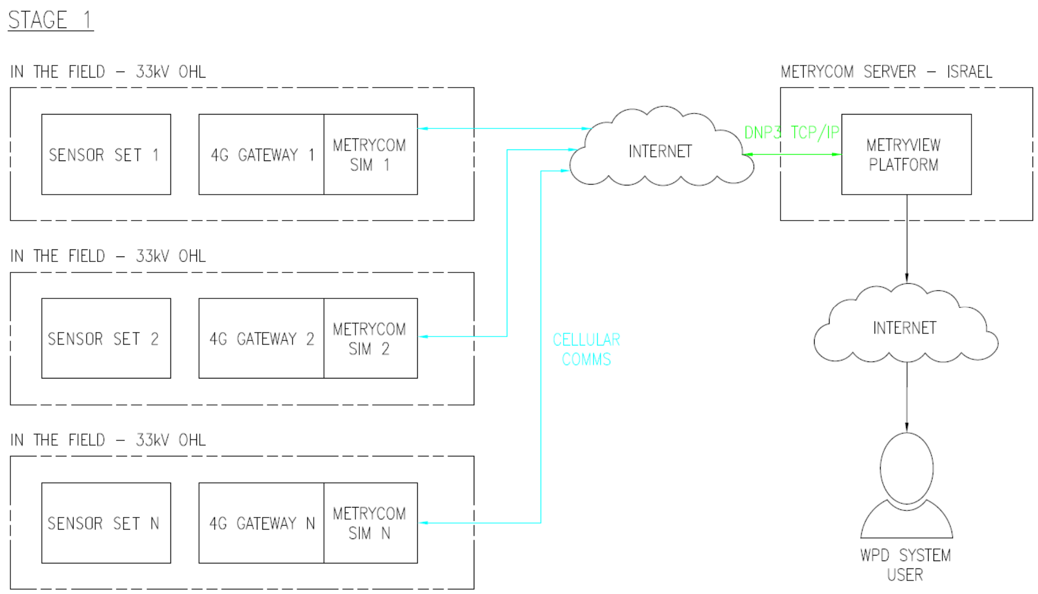


Figure 5-9 Stage 1 works - cellular sensor data relayed to Megger server while local server is built

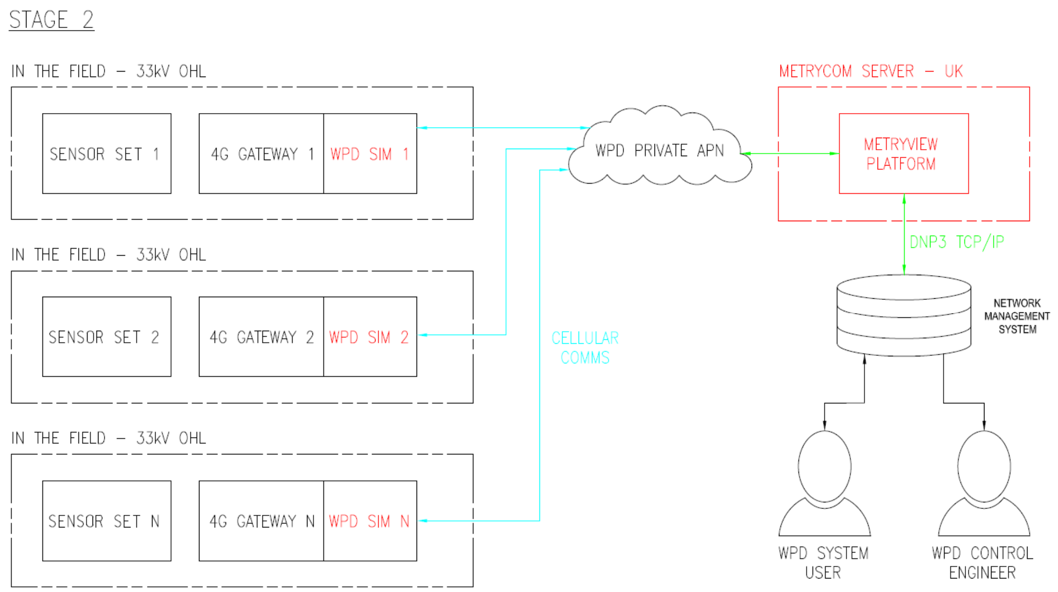


Figure 5-10 Stage 2 works - cellular sensors migrated to Megger server after completion of build

5.5. Cyber security

The MetryView software platform interfaces with NGED's NMS and therefore the cyber security performance of the platform was a key consideration of the project. A cyber security penetration test was performed on the MetryView system to identify and record non-compliances to NGED standards. Several minor improvements were identified and reported to the manufacturer to address and fix in the proceeding software release.

5.6. MetryView/NMS Interface

A key project requirement was the ability for the NGED control engineers to easily locate an earth fault on their Human Machine Interface (HMI) from the real-time sensor data. This was facilitated by a DNP3 telecommunications channel between MetryView and the NMS indicated by the green arrow in **Figure 5-11**. The critical DNP3 data signals from the sensors were identified and mapped to the NMS. In addition, a mimic symbol for the sensor sets was developed in the NMS so that the control engineer could easily interpret the earth fault detection and direction of the fault current on the NMS mimic screens. **Figure 5-11** shows a screenshot of the mimic symbol (grey diamond) for a sensor set.

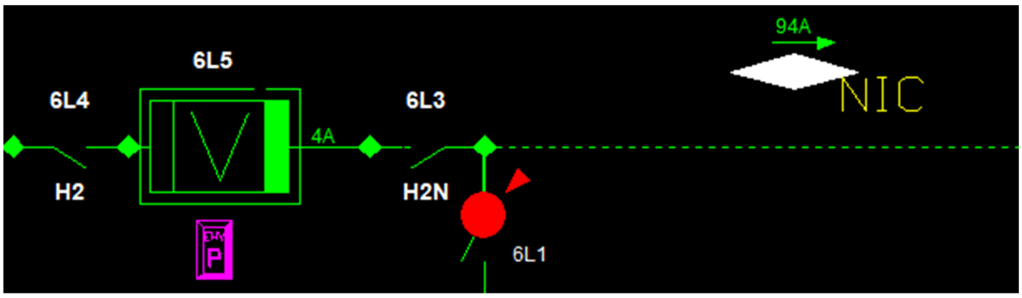
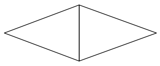
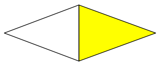
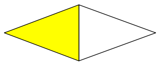
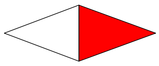
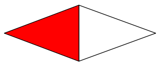


Figure 5-11 Sensor mimic symbol (grey diamond) on the NMS

The diamond symbol represents a simple way of visualising real time current flow and fault data from the sensors, which enables the control engineer to clearly interpret the information on their HMI. The real time current magnitude and direction is shown by the green arrow above the diamond. The current magnitude is taken from the L2 phase sensor set and the direction is taken from a calculation of the average power factor from each sensor unit in the set. Table 5-1 summarises the different mimic symbol indications. A detailed description of the NMS interface for the sensors can be found in the "Alarms in Power ON v8" design document.

Table 5-1 Summary of sensor mimic symbol indications

State	Indication Display	Triggering Algorithm
No faults detected		N/A
Earth fault forward		Transient Analysis + Fifth Harmonic (H5)
Earth fault reverse		Transient Analysis + Fifth Harmonic (H5)
Phase-to-phase fault forward		Transient Analysis
Phase-to-phase fault reverse		Transient Analysis

5.7. DNP3 Integration Testing

It was important to ensure the data flowing across the MetryView/NMS interface was aligned with the design specification and the correct indications were present on the control engineer screens for each fault scenario. The DNP3 integration testing was the key process used to validate the data flows. A DNP3 integration test plan was produced to allow the project team to logically step through each DNP3 signal from the sensor sets and verify the correct corresponding behaviour on the NMS.

There were some analogue and binary data points that could only be triggered by simulating input conditions either by manually changing values in the MetryView database, or by automatically simulating waveform data and applying this directly to the sensor set under test. To efficiently achieve this, Megger were able to create a simulation tool to carry out the automatic generation of input parameters. A screenshot of the simulation tool is provided in Figure 5-12.

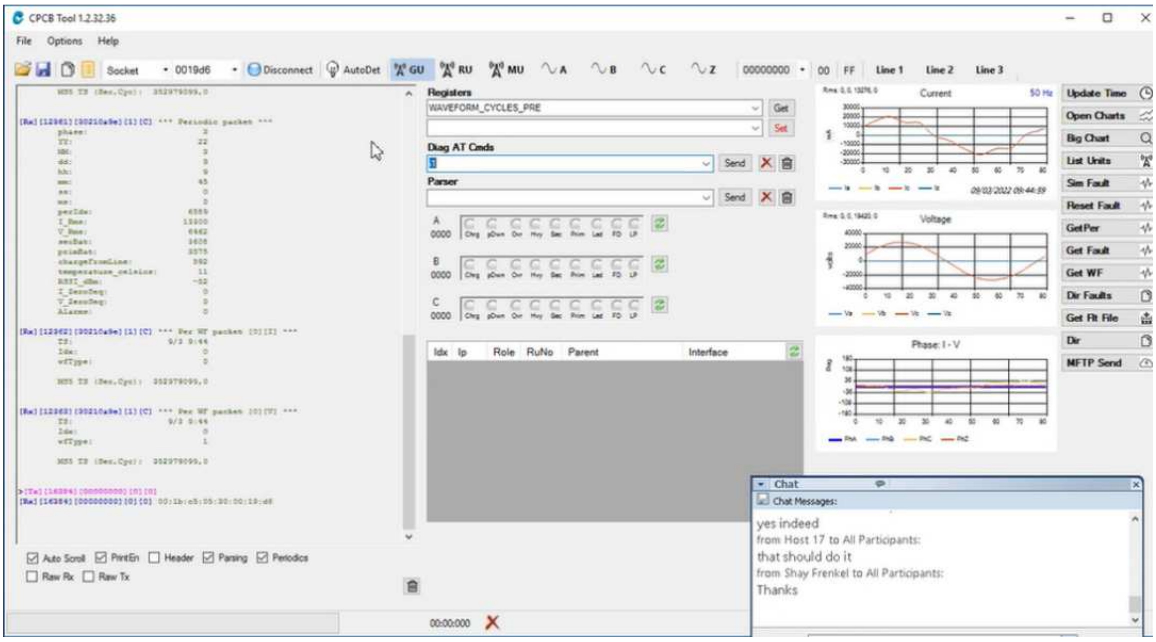


Figure 5-12 Screenshot of the Megger simulation tool used for the DNP3 integration testing

The DNP3 integration testing was successfully completed on 13 April 2022, and this then allowed the sensor mimic symbol and associated configuration to be copied to all remaining sensor sets locations on the NMS.

6. Performance Compared to Original Aims, Objectives and Success Criteria

6.1. General

The MetrySense 5000 sensor sets successfully met the original aims and objectives of the project. Unfortunately, there was no permanent ASC faults on the 33kV network fed from the St. Austell BSP throughout the duration of the trial. However, the sensors were able to detect and log multiple transient earth fault disturbances and this provided sufficient data for the project team to identify the location of the associated earth fault on the network.

Separately, and in parallel with the Arc-Aid project, a small number of additional MetrySense 5000 sensors were installed on the 11kV network fed from Davidstow 33/11kV primary substation. The 11kV network in this vicinity was experienced considerably more earth fault events in comparison with 33kV trial area. This was expected as the 11kV system is typically more susceptible to transient disturbances when compared to the 33kV network.

The following sections describe the performance of the sensors on the 33kV and 11kV installations in more detail by exploring an example of a real-world earth fault event recorded by the MetrySense 5000 units during the project trials.

6.2. 33kV – Blackpool 2L5

At 11:59:10 14 June 2021 a transient earth fault was detected on the Blackpool 2L5 to Mevagissey 1L3 feeder, which also supplies Ninnis & Manor Solar Farms. Figure 6-13 shows the MetryView SLD for the fault event that was recorded by the system. Each circle on the diagram represents a discrete sensor set. The yellow circles correspond to the sensor sets that have detected the transient earth fault and their associated arrows show the direction of the fault current. The yellow colour also tells the user that the feeder remained energised and did not power down due to the fault.

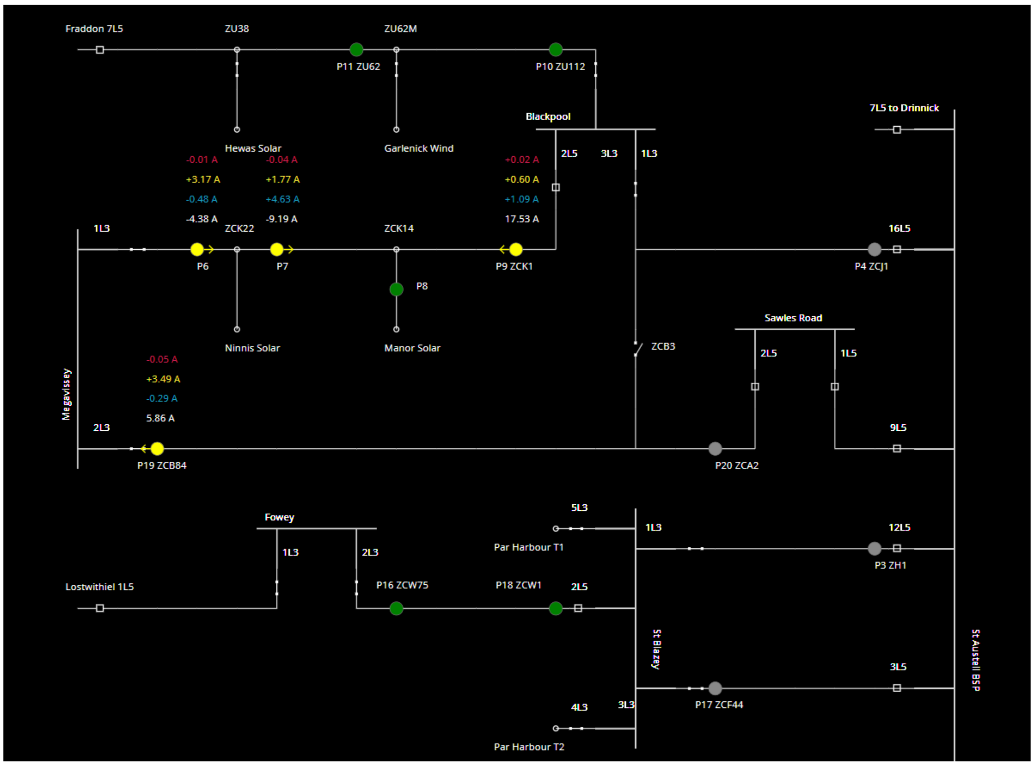


Figure 6-13 MetryView screenshot showing transient earth fault on Blackpool 2L5

On closer inspection in MetryView, it was apparent that Phase C had experienced a very short transient earth fault between P7 and P9 sensor sets, with fault currents flowing in from Mevagissey and Blackpool substation. **Figure 6-*14*** shows the data recorded by sensor set P9, which indicates that the fault occurred on Phase C with a 17.5A zero-sequence current flow. The Manor Solar Farm also discharged some current into the fault, but this was small in comparison. The fault was extinguished by the ASC and the feeder remained energised with no customer interruptions.

P9 ZCK1			Fault event data
	Phase A	Phase B	Phase C
Fault data			
Fault phase (local decision)	● (green)	● (green)	● (yellow)
Power down (immediately after fault)	○	○	○
Local fault type	Voltage Change	Voltage Change	Self-Extinguishing GND Fault
Current before fault	53.11A	55.50A	52.85A
Current rise (Fault current)	0.02A	0.60A	1.09A
Waveform graphs			
Fault zero sequence data			
Fault Direction		Forward	
Zero-Seq Active Fault Current (x3)		17.529A	
Zero-Seq Current rise (x3)		34.68A	
Zero-Seq Voltage rise (x3)		11.844kV	
Zero-Seq -I/V angle after fault		-106°	
Sensors' Direction in the Diagram		Left	

Figure 6-14 MetryView screenshot of sensor set P9 transient earth fault on Phase C (yellow indication)

The fault waveform data shown in **Figure 6-*15*** shows the transient current during the fault on Phase C (blue trace) before being rapidly extinguished by the ASC. **Figure 6-*16*** and **Figure 6-*17*** show the waveform of zero-sequence active fault current at P9 and P7 respectively. Comparing the two waveforms clearly shows the transient current disturbances are 180° out of phase indicating that the transient fault occurred on the OHL between P7 and P9 sensor sets.

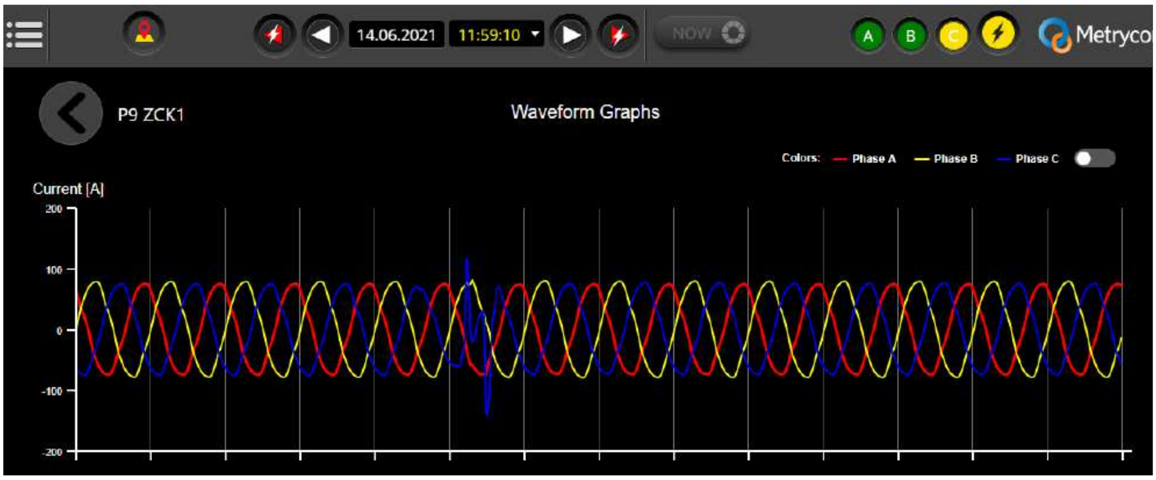


Figure 6-15 MetryView screenshot of sensor set P9 transient earth fault on Phase C (blue trace)

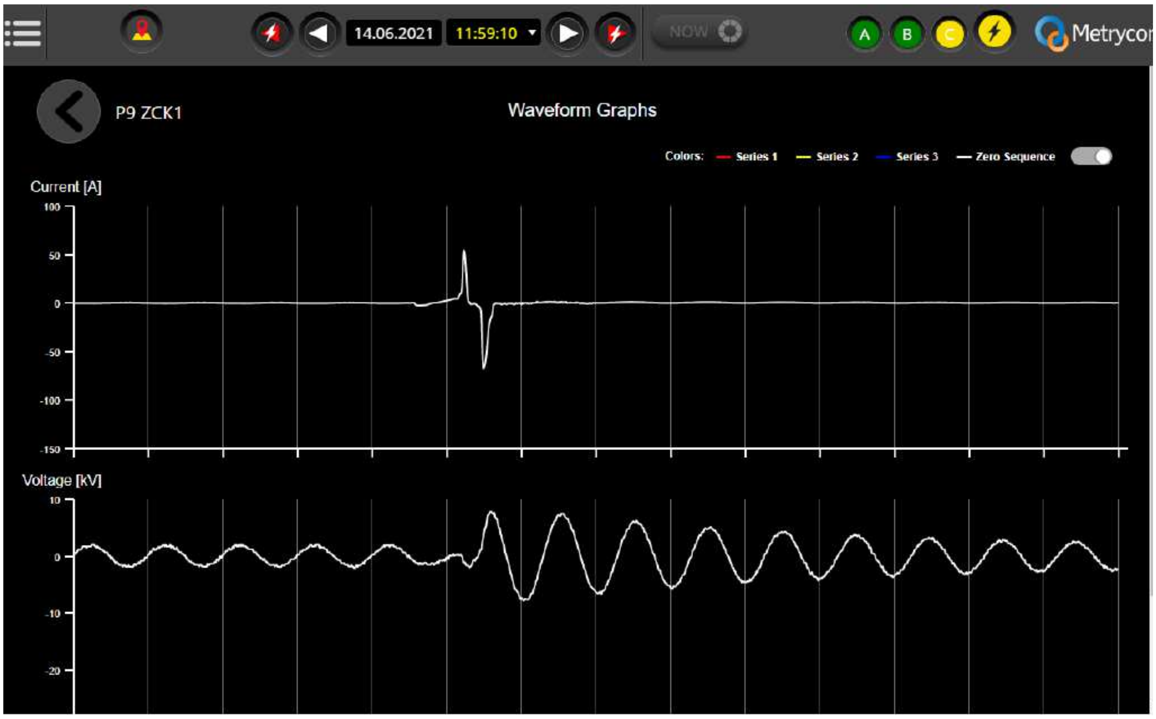


Figure 6-16 MetryView screenshot of sensor set P9 zero sequence current and voltage during transient earth fault

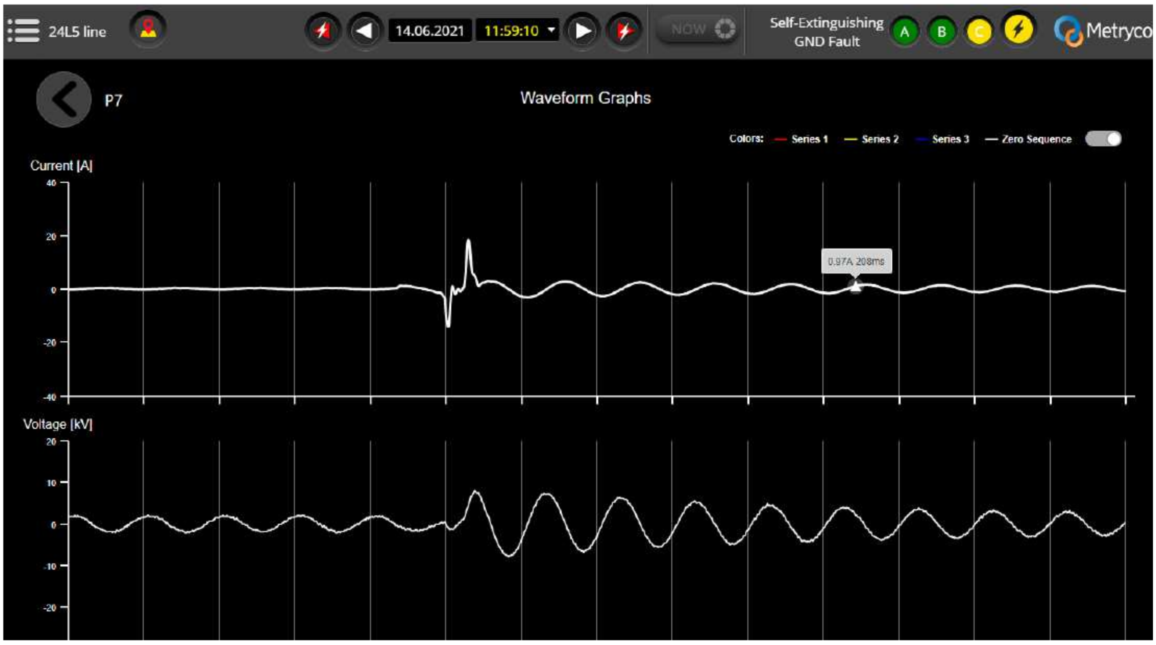


Figure 6-17 MetryView screenshot of sensor set P7 zero sequence current and voltage during transient earth fault

6.3. 33kV – West Carclaze 6L5 to 1M0

At 04:51:59 14 March 2022 the system detected a large phase-to-earth fault downstream of P2 fed from 6L5 West Carclaze at St. Austell 33kV. Figure 6 6 shows the MetryView SLD for the fault event that was recorded by the system. This feeder supplies the West Carclaze 33kV Solar Park and the fault was confirmed to be linked to a 33kV cable joint failure on this cable section. NGED control engineers identified that the St. Austell BSP ASC had detected an earth fault, however, the local customer circuit breaker tripped and isolated the fault from the 33kV system.

The waveforms shown from the P5 sensor set in Figure 6 7 indicate a large fault on the Phase A (red trace). The arc is extinguished by the ASC and does not transition to a permanent fault. The zero-sequence waveforms are shown in Figure 6 8. These show that the initial transient current and voltage peaks are in the same direction, indicating that the fault current is in the backward direction relative to the sensor i.e., current flow is toward the St. Austell 33kV busbar. This was confirmed as the correct direction based on the cable fault location.

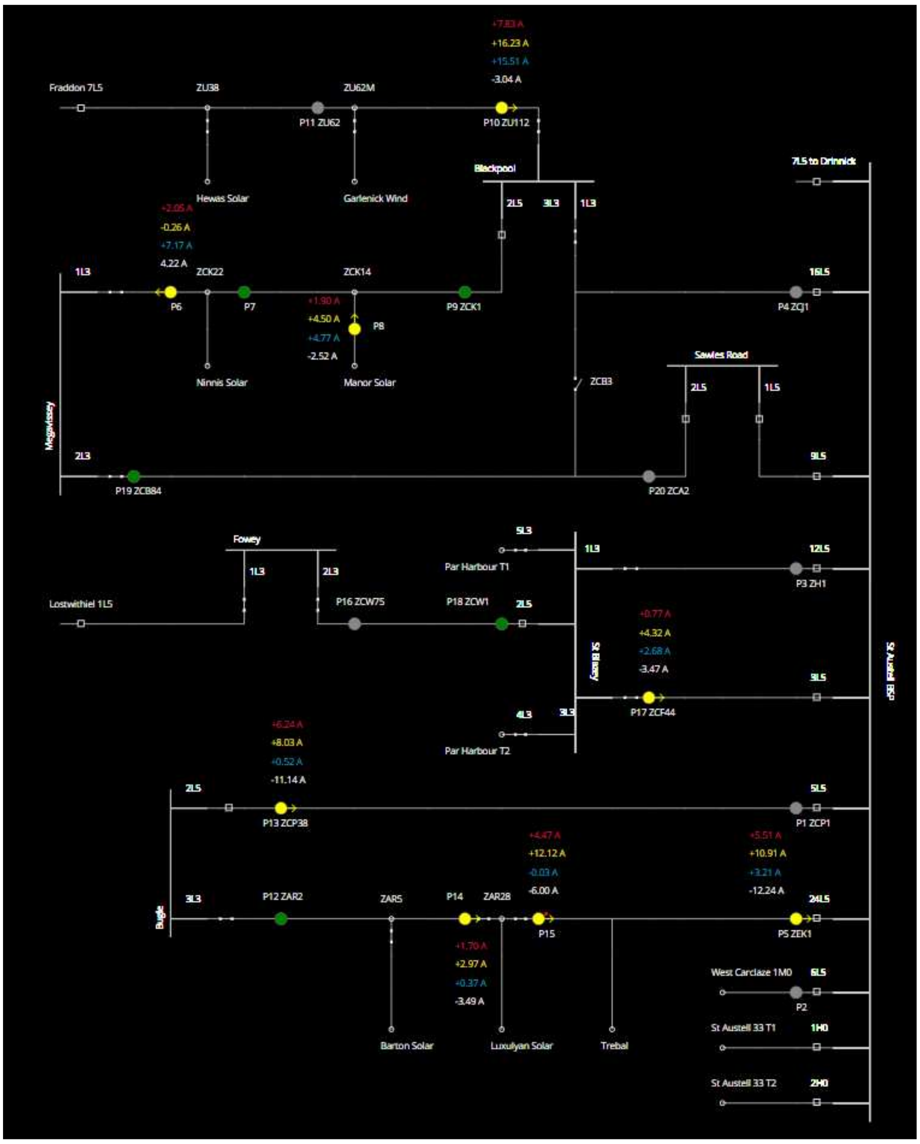


Figure 6- MetryView screenshot showing transient earth fault detected downstream of West Carclaze 1M0

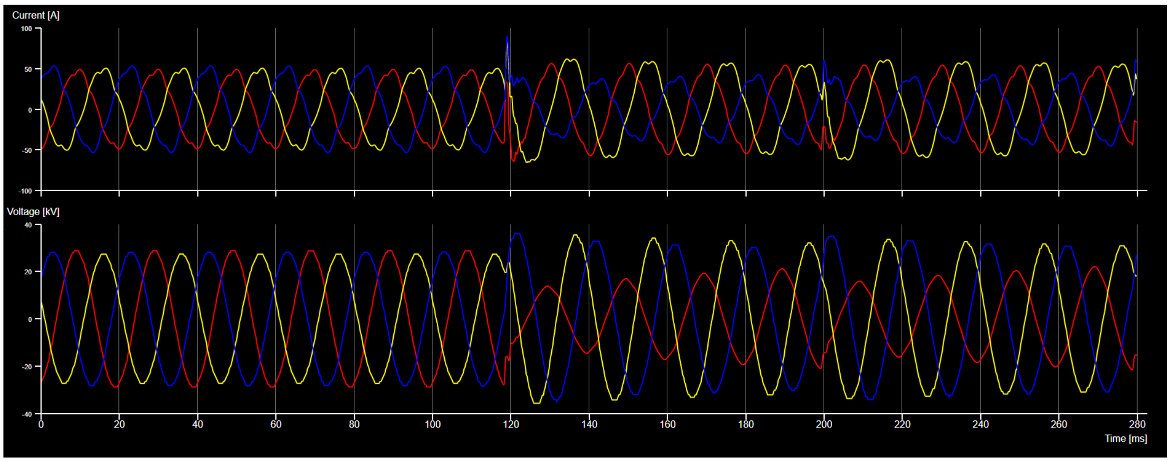


Figure 6- MetryView screenshot showing voltage and current waveforms from sensor set P5

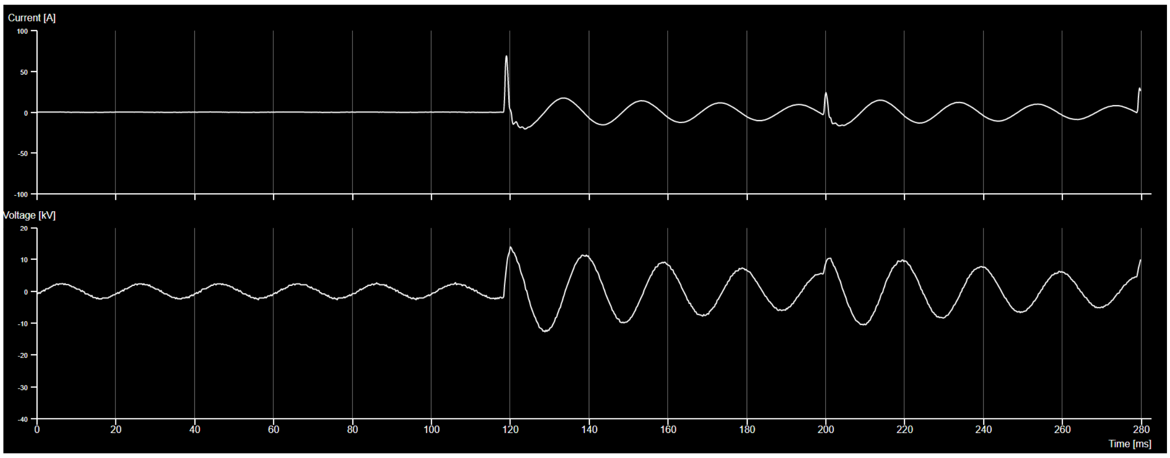


Figure 6- MetryView screenshot showing zero sequence voltage and current waveforms from sensor set P5

6.4. 11kV – Davidstow CB42

At 22:47 27 November 2021 sensor set 43K83 detected a persistent earth fault was on the Davidstow 11kV CB42. Metryview showed immediately that Phase A (red trace) had experienced a transient fault in the forward direction i.e. outwards from the 11kV busbar. Smaller reverse capacitive discharges were also shown on the sensors 43M2 and 43L225 confirming the direction of the fault. **Figure 6-** shows the transient fault directions recorded for all three sensor sets installed at Davidstow.

Figure 6- MetryView screenshot showing transient fault directions for the fault downstream of CB42

Interrogating the 43K83 sensor data in more detail showed that the active fault current was 1.14A. In addition, the fifth harmonic algorithm was also triggered. This is shown by the orange signal indication in **Error! Reference source not found.**. The fault was not cleared by the ASC and therefore developed into a permanent or persistent earth fault. This is shown in **Figure 6-19**.

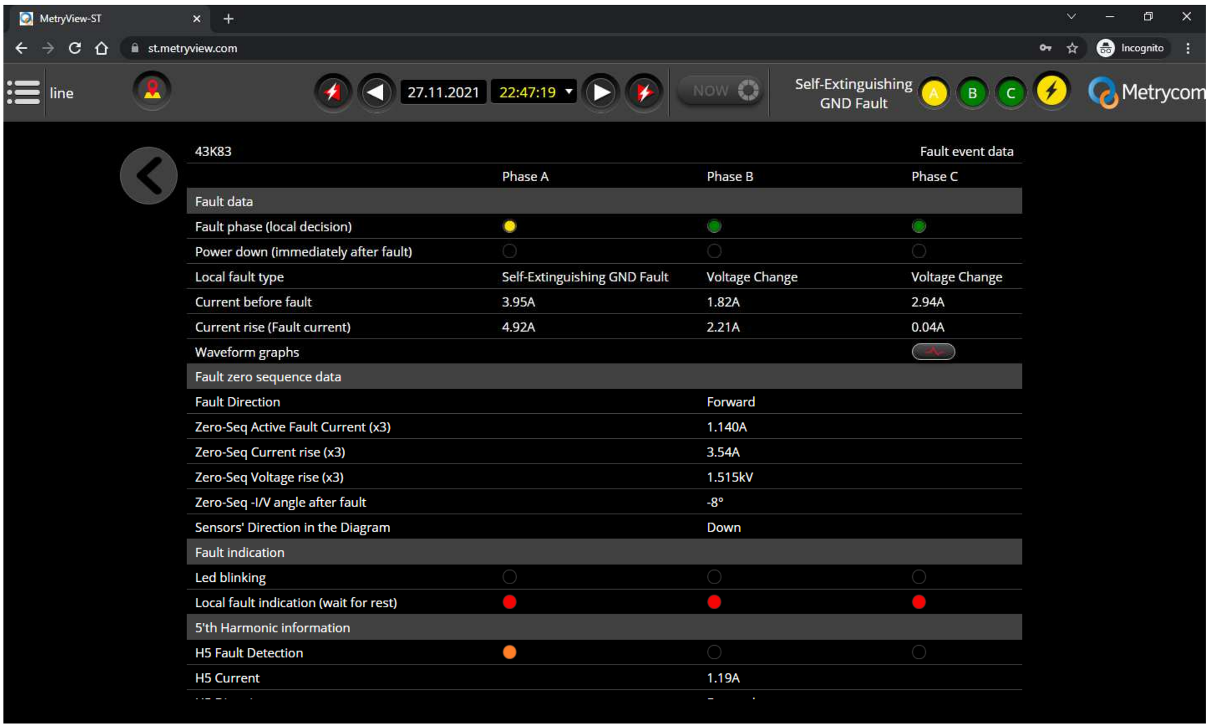


Figure 6- MetryView screenshot showing sensor set 43K83 fault data for the fault downstream of CB42

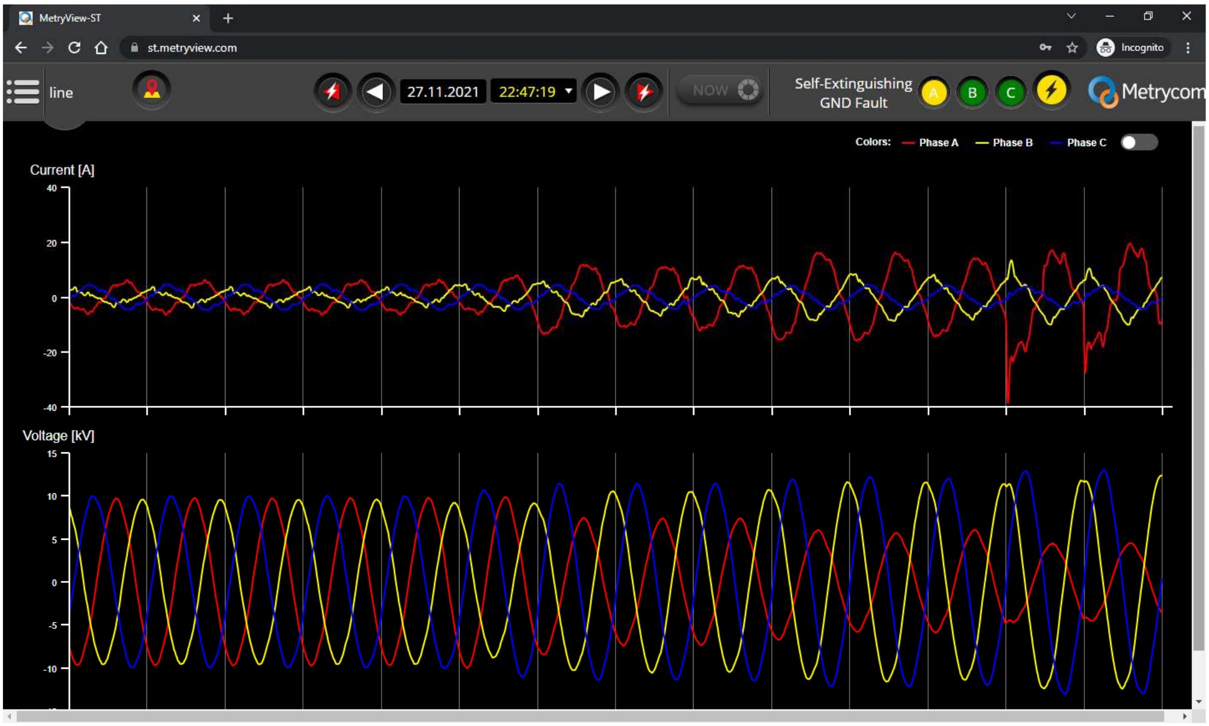


Figure 6-18: MetryView screenshot showing persistent earth fault current and voltage waveforms for sensor set 43K83

The fault detected by 43K83 was critical to the validation of the fifth harmonic algorithm as there was no persistent earth faults during the trial on the 33kV network. The fifth harmonic algorithm triggered and correctly indicated the direction of the real-time earth fault current. This is shown diagrammatically in **Figure 6-** where the fifth harmonic current flow is shown by the orange arrows.

Figure 6- MetryView screenshot showing fifth harmonic earth fault direction for the fault downstream of CB42

7. Required Modifications to the Planned Approach during the Course of the Project

There were no major changes to the NGED planned approach. UKPN did modify the project direction to increase the budget and duration of the project on two occasions, however, this is beyond the scope of this document. The UKPN project closedown report will detail the general modifications to the planned approach that were captured in the updated project direction documentation.

As part of the first modification proposed by UKPN we requested to increase our budget to cater for some unforeseen costs associated with the IT integration of the sensor technology, and to cover the additional project management time required for the overall increase in project duration. This amounted to an additional £40k in the NGED project budget

8. Project Costs

Table 8-1: Overall Project Spend

Activity	Budget	Actual	Variance (%)
Contractors	£185,000	£157,742	-14.7
WPD Network Services Costs	£30,000	£24,159	-19.5
Totals	**£215,000**	**£187,816**	**-12.6**

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9. Lessons Learnt for Future Projects and outcomes

The learning from the project has been captured regularly in a learning log. A summary of the main learning points is provided in Table 9 1 below.

Table 9 1: Project learning summary

Area	Learning Detail	Comment
Design	The MetrySense 5000 sensors switch into low power mode if there is less than 5A (3A on the new models) average phase current over a 24-hour period. The low power mode has a reduced sampling rate and therefore the fault waveforms cannot be generated. This means that the sensors will not be able to indicate the direction of an earth fault. However, the sensor can still detect that a fault is present on the system.	The sensors go into a low power mode to avoid complete discharge of their onboard battery systems. A key learning point is to ensure that the sensor sets are not installed on circuits with persistently low load.
Design	The MetrySense sensor software can be updated via a laptop connected to the gateway via USB. The cellular sensors are capable of being updated remotely over the cellular network although this is only the case if a non-WPD SIM card is installed.	During the project, the sensor firmware was updated to incorporate improvements and fixes. The project demonstrated that this could be done remotely for the cellular units with a Megger SIM and it is also possible to upload new firmware to sensors with WPD APN’s when it is done via the WPD server.
Installation	The pole-mounted gateway devices can be left isolated from HV earth provided they are	It was important to ensure that the sensor sets, and associated gateways were installed safely on

	installed a minimum of 3.7m above ground level. The gateway steel case is to be tied into the existing HV earth connection should this exist on the pole.	the network. The project team liaised closely with our policy team to ensure that the correct guidelines were followed and communicated to the installation team.
Testing	The MetrySense sensor sets will require a full cyber security penetration test on all MetrySense sub-system and system elements to ensure that they meet cyber security standards.	Due to cost and timescale considerations an internal penetration test was carried out by our cyber security team only on the MetryView web interface. This was on the proviso that a more detailed set of tests will be carried out if they move to BaU.
Installation	It was found that the original gateway fixing bracket, which allowed movement in the vertical plane and meant that the gateway was susceptible to movement in high winds.	The original fixing bracket for the gateway was kept for the trial, but an alternative design should be sought if a BaU roll-out of the gateways is carried out.
Design	The MetryView GUI does not have a “connected” indication from the sensor sets to indicate that the sensors are connected to the gateway correctly. This made it difficult to proceed to install the Phase C unit during the P17 installation.	This is not a necessary change for future software revisions; however, it could help to improve the user friendliness of the connection process. The communication status of the sensor was included in the DNP3 datapoints and this is available for use.
Design	The MetrySense sensor units have a press button that is used to connect the device to the gateway and awake it from sleep mode. There is an LED that blinks to indicate the connectivity status of the unit depending on the	A future change to improve the ability of site engineers to interpret these messages more easily could help to improve the user friendliness of the sensor installation process.

	length of time the button is pressed. There are several different LED blink messages that can be difficult to interpret at site.	
Design	After reviewing the DNP3 Signal List the PowerON team noticed that the point ranges were beyond the maximum addressable ranges (0-351 for analogue I/O, 0-512 for digital I/O).	The learning for this point is to ensure that the addressable ranges are communicated to the manufacturer at an early stage in the design.
Installation	A key learning outcome from the installation phase of the project is to determine a consistent sign convention for power flow prior to the sensor installations. This is relatively straightforward for networks with radial feeders; however, the St. Austell 33kV network is meshed with several 33kV rings. The orientation of the sensors on the network was aligned with the policy requirements for substation measurement transducers, which always has positive power flows shown as flowing out of the substation busbar.	Standard procedure for Primary Network transducers was implemented.
Trial	An issue was identified with the 4G modem in set P18 gateway causing loss of comms to the sensors on the OHL. Megger were able to tether the P18 sensors onto the adjacent P17 gateway. The software to allow fault detection capability for the two sets of sensors on the P17 gateway was successfully uploaded remotely by Megger.	The functionality to shift sensor sets onto an adjacent gateway unit could reduce sensor downtime due to a gateway fault. This was successfully demonstrated in this learning point.

Area	Learning Detail	Comment
Testing	The MetrySense-5000 units passed the performance tests organised by UKPN. The tests took place at the PNDC laboratory w/c 19 Oct 2020	This was a significant milestone in the project and validated the fault detection capability of the MetrySense 5000 units.
Testing	The MetryView system underwent internal penetration testing by the WPD Cyber Security team on 28 October 2020. The system passed the testing with some recommendations for improvements.	There were only some minor recommendations and improvements from the testing and these were promptly addressed by Megger
Installation	Megger discovered a bug in their gateway firmware during the SIM connectivity tests. The username and password were inverted, and this was the source of difficulty in connecting the units to the WPD APN	This issue was resolved in a software update and is to be noted as a test in future projects.
Installation	The WPD Telecoms Team was asked to investigate why the cellular data was not reaching the MetryView server behind the WPD firewall. An investigation led to the discovery that the firewall was misconfigured and was blocking the data. A simple fix was applied, and the communications issue was resolved.	This issue was resolved with a minor firewall configuration update and is to be noted as a test in future projects.
Design	A design meeting was held on 29 April 2021 to discuss the interpretation of the fault location signals on PowerON. It was found that Megger’s transient algorithm will only detect an initial ASC earth fault and will not pick-up any subsequent fault direction changes due to	The 5th harmonic algorithm is critical to the ability of the system to locate persistent earth faults on the network. It allows a real-time direction to be given even if the fault current changes direction under network reconfiguration. An

	network switching. Instead, a new 5th harmonic algorithm has been developed to achieve this dynamic response.	important note is that the 5^{th} harmonic only picks-up when there is sufficient 5th harmonic content above the trigger level setting.
Installation	A meeting with WPD telecoms was held on 7 September 2021 to discuss the radio set installations. It was noted that the GE iBox RTU has three standard template configurations that limit the number of analogue points to a maximum of 20 points per DNP3 device.	The limitation on DNP3 analogue points on the new RTU meant that the DNP3 Signal List had to be rationalised so that only the most critical analogues were integrated with PowerON.
Installation	There was an issue during the commissioning of the radio sensor sets at St. Austell BSP to PowerON. The current values and directions from the sensors were not aligning with the associated feeder circuit breaker transducers. After an investigation, it was observed that the order of the sensor set installations was changed from the original plan, and therefore they had been assigned to the wrong feeder in PowerON. In addition, the current direction arrows were being derived from the yellow current analogue measurement instead of the average power factor calculated by the sensors. Both issues were corrected in PowerON and the system was then working as anticipated.	This point shows that a clear and robust test plan identifies integration discrepancies and ensures they are remedied in a timely manner.
Trial	During the trial it was noted that both the cellular and radio sets refresh	This learning was documented and communicated to the

	their current and voltage measurements every 5 minutes, which is considerably slower than existing feeder circuit breaker transducers. For the sensors that are located close to the feeder breakers, this can lead to a mismatch between the reported current magnitude and direction values in PowerON while the sensors refresh their data. The resolution can be improved to 30-40s for the radio sets and 15s for the cellular sets, however, this increases the data flows and may impact sensor battery life. The trial continued with the default 5-minute refresh rate.	project team. For future installations, the duration of the data refresh should be investigated.
Testing	The DNP3 integration testing was a point-to-point test between MetryView and PowerON to validate that the PowerON interface was displaying all the correct analogues and binaries at the interface. The testing picked up several discrepancies that are summarised as: • The PowerFactorAv analogue did not have the correct factor applied to the raw value in PowerON. • The FaultCurrent Analogue value in PowerON was not matching the phase-to-phase fault current that was simulated (simulated 102.25A – displayed 36.7A). The FaultForward and FaultBackward binaries were shown as 'bad scan' on PowerON and	The outcome of this learning point has shown that it is important to carry out integration testing for all projects of this nature as it cannot be assumed that all data points are correctly configured in the build.

	therefore we were not able to test the symbol direction/colour parameters. The discrepancies were quickly fixed and the integration testing completed successfully.

10. The Outcomes of the Project

In summary the outcomes of the project are:

- The selection of St. Austell BSP and downstream 33kV network as the trial area for the MetrySense 5000 sensor units.
- The successful installation and integration of 16 cellular MetrySense 5000 sensor sets on the 33kV network fed from St. Austell BSP, Cornwall.
- The successful installation and integration of 4 radio MetrySense 5000 sensor sets on the 33kV network fed from St. Austell BSP, Cornwall.
- Integration of both cellular and radio sensor units into PowerON and the creation of a bespoke symbol to allow control engineers to visualise fault detection and location information on their mimic screens.
- The successful trial of the installed MetrySense 5000 sensors including gathering and analysis of several transient and persistent earth fault events. This data was used to validate and improve the sensor performance.
- The production of a technical paper "Advanced Earth Fault Detection on Arc Suppression Coil Earthed Networks" presented at the CIRED 2021 international conference.

The following Table 4 2 provides a list of the main design documents and reports associated with the MetrySense 5000 sensors and network integration work. These documents are listed here for reference for internal WPD staff only and are not to be shared with third parties.

Table 4 2: Summary list of main design documents and reports

B	Description
MetrySense DNP3 data points V1.12	The complete list of DNP3 data points and associated addresses that can be brought back from the sensor sets
St Austell scheme_V2	Drawing showing the locations of all 20 sensor sets installed as part of the trial
20200331 - Cellular Architecture and Staging Plan - Stage 1-4 - V1	A set of drawings indicating the staging works required to integrate the cellular sensor sets into the WPD environment
MetrySense-5000 Analysis of Operation in the UK using Solar Power	A report to quantify the available solar power in the UK to power the sensor gateway electronics

MetryView Server requirements for WPD	A specification document that states the server requirements to run the MetryView software in WPD’s environment
MetrySense 5000 - Installation Guide - v2.10	The installation guide for the MetrySense 5000 sensor units
DNP3 Controller User Guide 1.0	The user guide for the DNP3 Controller. This device is required to interface the radio sensor sets with the local substation RTU
Metryview Pen Test v1.0	The penetration test report produced by WPD’s Cyber Security testing team. The penetration test covered the MetryView software web interface
Alarms in Power On v8	A document specifying how the fault detection and direction indications are processed and displayed on the PowerON screens
ARK-1550-S9A1E	Technical datasheet for the DNP3 Controller

11. Data Access Details

Reference is made to our Energy Data Hub, which is our central data store for easy access to all of the existing data that WPD currently share with the industry, regulator and customers.

Detailed network plans are also available via our Data Portal.

12. Foreground IPR

Default IPR arrangements apply to the project. There has been no foreground IPR created in this project

13. Planned Implementation

The MetrySense 5000 sensor sets have been able to accurately locate both transient earth faults on live 33kV network and both transient and permanent earth faults on the 11kV ASC distribution network in our South West license area. In addition, the MetrySense 5000 sensors have been successfully type tested by UKPN at the PNDC in Glasgow, UK. The tests showed that that the advanced sensor units were able to successfully detect and locate all applied faults. The sensors also successfully detected all high impedance faults including a 10 kΩ phase-to-earth fault impedance with a fault current of less than 400 mA.

The MetrySense 5000 sensors also provide a cost-effective solution for accurate measurement of various electrical parameters at remote locations on the distribution network. The project team has also learnt that the devices can be installed easily on the overhead lines, both under outage and under live line conditions.

All 20 MetrySense 5000 sensor sets have been successfully installed and the data from these is continuing to be monitored and is now fully integrated into our PowerON NMS. This has enabled our control engineers to observe the fault location information on their mimic screens in real-time. The sensors and the associated MetryView software platform are now a BaU tool for detecting and locating earth faults on ASC earthed networks.

In terms of a further wider roll-out of the sensors across WPD's network, it is recommended that a full cyber security penetration test is carried out by a third-party specialist. This will ensure that any security vulnerabilities at the hardware and software levels are captured and addressed appropriately by the manufacturer.

14. Contact

Further details on this project can be made available from the following points of contact:

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Glossary

Abbreviation	Term
APN	Access Point Name
ASC	Arc Suppression Coil
BSP	Bulk Supply Point
CBA	Cost Benefit Analysis
CHP	Combined Heat and Power
CIRED	International Conference on Electricity Distribution
DNO	Distribution Network Operator
GE	General Electric
GUI	Graphical User Interface
HMI	Human Machine Interface
HV	High Voltage
IPR	Intellectual Property Rights
LED	Light Emitting Diode
NIA	Network Innovation Allowance
NMS	Network Management System
OHL	Overhead Line
PEA	Project Eligibility Assessment
PNDC	Power Networks Demonstration Centre
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SIM	Subscriber Identity Module
SLD	Single Line Diagram
UKPN	UK Power Networks
USB	Universal Serial Bus
WPD	Western Power Distribution