ADVANCED EARTH FAULT DETECTION ON ARC SUPPRESSION COIL EARTHED NETWORKS

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Keywords: ADVANCED, EARTH, FAULT, DETECTION, SENSOR

Abstract

The Arc-Aid project is trialling 20 sets of MetrySense 5000 advanced Smart Grid Sensors on the 33 kV Arc Suppression Coil (ASC) earthed network fed from St. Austell 132/33 kV BSP in Cornwall, UK. The trial is investigating whether the sensors can 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 is being delivered collaboratively between UKPN (lead partner) and WPD. The project began in Feb 2020 and is due for completion in Dec 2021. Early results from the trial and type testing indicate that the MetrySense 5000 advanced Smart Grid Sensors can accurately detect and locate earth faults. However, there have been no permanent earth faults observed on the 33 kV network during the trial, and therefore further trial data is required before a full appraisal of the sensors can be made with respect to the primary aim of this trial.

1. Introduction

Arc Suppression Coil (ASC) earthed systems are prevalent on the 33 kV distribution network in Western Power Distribution's (WPD) South West licence area, UK. They were developed in the 20th century due to the difficulty in achieving low enough earth resistance to operate 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 fault to be detected.

A drawback of ASC systems is that they cannot identify the earth fault location or the specific faulted 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 WPD with the purpose of developing and trialling Metrycom's MetrySense 5000 sensors. The NIA project began in February 2020 and is due for completion December 2021.

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 control engineers in real-time.

The project will determine if the sensors are an accurate and cost-effective way of providing earth fault location data, thereby reducing the number of customer interruptions, and assisting line patrol teams. This paper will give an overview of the project, the methods and solutions that are being trialled and the learning generated from the project to date.

2. Methodology

2.1. System architecture

The scope of WPD'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 central control. Fig. 1(a) shows a typical installation of a MetrySense sensor set on a 33kV overhead line. Fig. 1(b)**Error! Reference source not found.** shows the pole-mounted gateway unit beneath a sensor set.

Fig. 1 (a) MetrySense 5000 sensors on an OHL (left) (b) Gateway unit installed on OHL pole (right)

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 [1].

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 existing Supervisory Control and Data Acquisition (SCADA) network. The project is trialling both cellular and radio connected sensor sets to understand the merits of both systems. Fig. 2. And Fig. 3 show schematic diagrams of the two main system architectures used in this project.

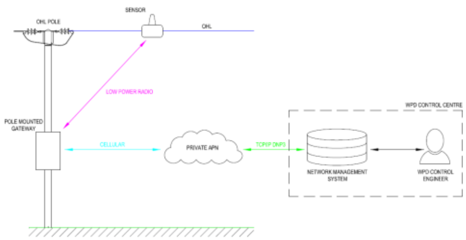

Fig. 2 Cellular telecoms system architecture

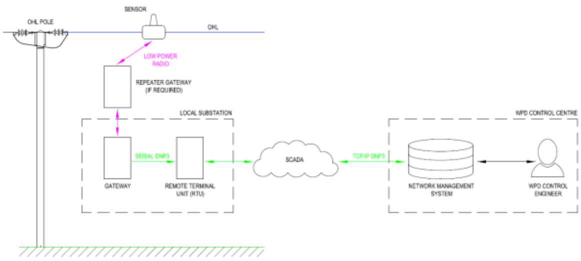

Fig. 3 Radio telecoms system architecture

The first stage of the project was to select an area of ASC earthed 33 kV network suitable for the trial. A site selection methodology was developed, and after detailed analysis the meshed 33 kV network fed from St. Austell 132/33 kV 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 (Cornwall, UK) 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.

2.2. Cellular signal strength study

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.

2.3. Sensor location selection

Following the signal strength study, the sensor locations were strategically selected to optimise the area of 33 kV 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 33 kV trial area can be seen in Fig. 4

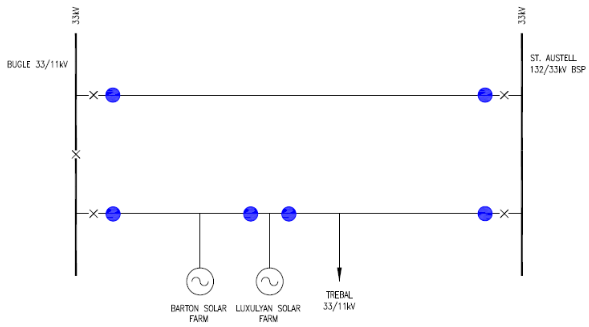

Fig. 4 Example of sensor location selection (blue circle) on 33kV network fed from St. Austell 132/33kV BSP

2.4. Sensor installation

The MetrySense 5000 sets are capable of being installed directly on live 33 kV 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 and no delays were encountered. The live line policy was approved early in 2021 and subsequent installations will proceed 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 Fig. 5 (a). 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 Fig. 5 (b). The sensor can be installed with a hot stick attachment as shown in Fig. 6 or on the live line using insulating gloves.

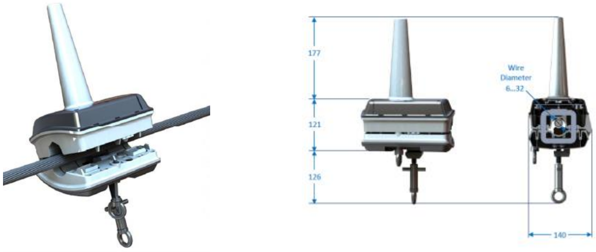

Fig. 5 (a) Sensor clamping over the conductor (left) (b) Profile view showing main and secondary screws (right)

Fig. 6 Sensor installed using Grip-All hot stick

The MetrySense 5000 units were found to be simple and quick to install by WPD site operatives using the hot stick method. The insulated glove method will be trialled on the remaining four sensor installations.

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. 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 33 kV network is meshed with several 33 kV rings. The orientation of the sensors on the network was aligned with the policy requirements for substation measurement transducers on the Network Management System (NMS), which always has positive power flows shown as flowing out of the substation busbar.

2.5. MetryView software platform

The data from the radio and cellular connected sensors interfaces with the MetryView software platform. This platform is Metrycom'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 central control centre, so that fault detection signals can be displayed on control engineer mimic screens. Fig. 7 shows a screenshot of the MetryView GUI and corresponding Single Line Diagram (SLD) of the 33 kV network fed from St. Austell.

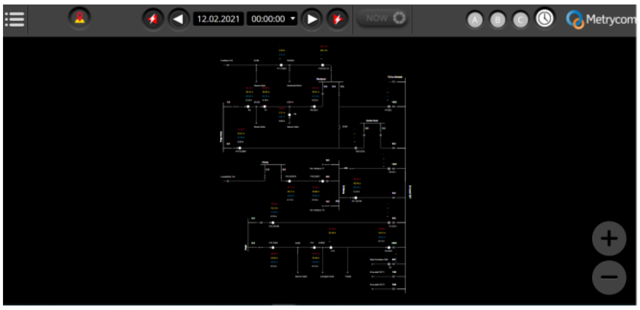

Fig. 7 Web-based MetryView GUI and SLD representation

2.6. Information technology architecture and staging

In its final design configuration, the MetryView software is hosted on a purpose-built server for the project trial, located behind the WPD 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 Metrycom in Israel to allow the trial to proceed. This Stage 1 work is shown diagrammatically in Fig. 8. The WPD server is now fully constructed and the Stage 2 work is to migrate the sensor sets across to the new server by replacing the cellular SIM cards with WPD units capable of communicating to the WPD private Access Point Name (APN). This is shown diagrammatically in Fig. 9. The sensor data can then be integrated with the WPD NMS to allow control engineers visibility of fault detection and location information.

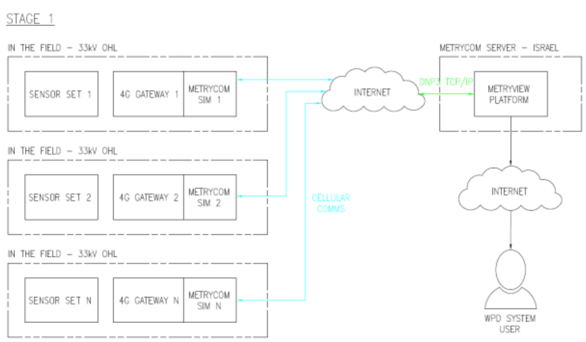

Fig. 8 Stage 1 works - cellular sensors relayed to Metrycom server in Israel while local server is built in UK

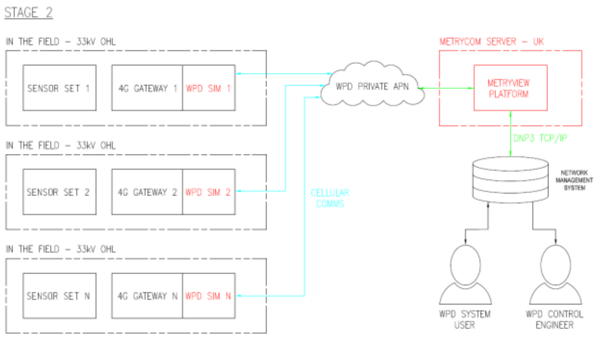

Fig. 9 Stage 2 works - cellular sensors migrated to Metrycom server in UK after completion of build

2.7. *Cyber security considerations*

The MetryView software platform interfaces with WPD'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 WPD standards. Several minor improvements were identified and reported to the manufacturer for address and fix in the software release.

3. Results

The trial is currently under way with 16 cellular sets installed out of a total of 20 sets. The remaining four sets are radio connected and will connect to the existing SCADA system via the RTU at St. Austell BSP.

3.1. *Permanent and transient earth faults*

Unfortunately, there have been no permanent earth faults recorded on the sections of 33 kV network monitored by the installed sensor sets. There have however, been several transient earth fault events that have been recorded and analysed by the Metrycom technical team. These events have provided useful data for the engineers to tune and configure the fault detection and processing algorithms in MetryView.

Fig. 10 shows a screenshot of a transient disturbance detected by the P15 sensor on the 24L5 33 kV feeder from St. Austell BSP to Bugle 33/11 kV primary substation. The sensor detected the fault on Phase B (yellow trace).

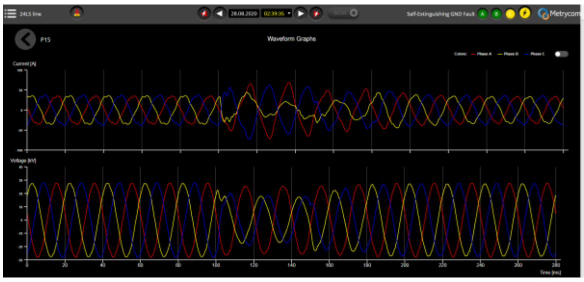

Fig. 10 Transient earth fault detected on St. Austell 33 kV network on 28 August 2020

The detection and logging of multiple transient disturbances has give the project team confidence that the devices will be able to detect and locate permanent faults, however, this functionality cannot be validated until a permanent ASC fault occurs on the 33 kV network.

3.2. *Type tests*

UKPN have separately type tested the MetrySense 5000 sensors at the Power Networks Demonstration Centre (PNDC) external laboratory in Glasgow, UK. The tests were carried out using a Hardware in the Loop (HIL) configuration. UKPN's Benhall 33/11 kV primary substation was modelled in software and current and voltage outputs from the HIL system were amplified to simulate real-world signals. These amplified signals were then used as inputs to two sets of MetrySense 5000 sensors. The diagram in Fig. 11 gives a high-level description of the HIL process used in the type test. The SLD in

Fig. 12 shows the sensor and simulated fault locations at Benhall 33/11 kV substation.

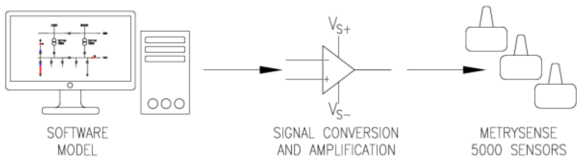

Fig. 11 HIL signal simulation for MetrySense type test at PNDC

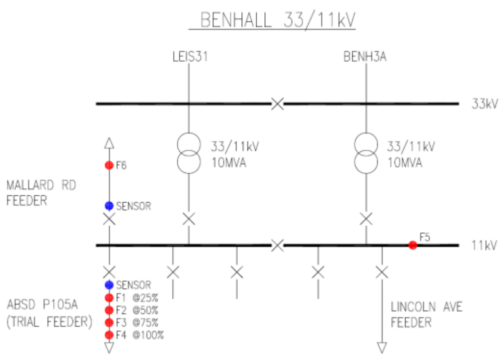

Fig. 12 Sensor and simulated fault locations at Benhall 33/11 kV substation for MetrySense type test at PNDC

A range of phase-to-earth, phase-to-phase, three-phase, and three-phase-to-earth faults were applied at different locations on the Benhall model. The sensors successfully detected all faults that were tested, including successfully identifying the fault location with respect to the sensor, the classification of the fault, and the faulted phases. The sensors successfully detected all high impedance faults including a 10 kΩ phase-to-earth fault impedance with less than 400 mA fault current [2].

3.3. Measurement transducers

An additional benefit of the MetrySense 5000 sensors is their ability to function as accurate measurement transducers. Measurement transducers are traditionally installed in the substation incoming and outgoing feeder circuit breakers. However, the MetrySense units allow detailed power flow and voltage measurements at remote locations along the 33 kV feeders. In particular, the data has given the project team a greater insight into the intermittency of connected Distributed Generation (DG) and previously unseen patterns in power flows across the meshed 33kV network. There may be many applications for this data beyond the primary motivation for this project, which is associated with fault location. One application could be the use of Grid Analytics to identify 'weakspots' in an overhead line network by tracking the incidence and location of transient faults/disturbances, which would not normally be visible to network operators.

4 Conclusion

At this stage of the project there have been no occurrences of permanent earth faults on the ASC earthed 33 kV network fed from St. Austell 132/33 kV BSP. Therefore, the project team has been unable to determine the capability of the MetrySense 5000 units to accurately locate earth faults on live ASC distribution networks.

However, the MetrySense 5000 sensors have been successfully type tested at the PNDC in Glasgow, UK. The type tests used a HIL testbed to simulate several balanced and unbalanced faults on a primary substation electrical model provided to PNDC by UKPN. The tests showed that that the MetrySense 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.

Furthermore, the MetrySense system has detected several transient earth fault events throughout the live trial on the St. Austell network. This has provided important data for Metrycom engineers to configure and tune their fault detection algorithms, whilst also giving encouragement that the system can provide a new solution for fault detection and location for network operators.

Finally, the MetrySense 5000 advanced sensors 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.

The data from the MetrySense 5000 sensors will continue to be monitored up until project completion, which is due in December 2021. Currently all cellular sensors have been installed (16 out of 20 sets) and the next step is to integrate the sensor data from the cellular sets into the WPD NMS. This will enable the control engineers to observe the fault location information on their mimic screens. Following successful integration, the remaining radio connected sensors will be installed and included in the trial.

6 References

[1] Metrycom, MetrySense 5000 advanced Smart Grid Sensor Installation Guide
[2] PNDC, Metrycom MetrySense-5000 sensor HIL Testing: Final Report