REPORT

Polesight Project Final Report

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Executive Summary

The Polesight project was an investigation of the feasibility and effectiveness of installing LV monitoring devices on pole mounted transformers (PMTs) to identify and locate PreFault events on LV overhead line (OHL) networks. The project employed two types of devices, Guard and VisNet, which have distinct triggering mechanisms and analytical algorithms. Data from the devices was collected and analysed for 11 months then the results from both algorithms were compared.

Polesight is a follow on from the Foresight Project (2017-2021) which developed equipment and methods aimed at identifying and locating LV cable PreFaults on underground circuits fed from Ground Mounted substations.

Polesight demonstrated that both Guard and VisNet devices were capable of enduring the physical impact of severe storm conditions whilst also providing data sets for live incidents. They also required minimal adaptations to be mounted on PMTs. The project also proved that OHL events can be located in a similar way to underground cable (UGC) events, and that voltage triggered devices can offer insights into HV network events. Some interesting LV OHL PreFault events were captured which could be associated with a range of OHL fault types ranging from clashing conductors to insulation breakdown on older types of OHL concentric service cables.

This project concludes that pole mounted monitoring devices can be implemented in a BAU capacity. Further research is necessary to enhance the analysis of events on split-phase transformers and the detection and localisation of HV events from LV insights.

Key Project Learning

- Present methodologies developed for UGC LV network monitoring for the purposes of PreFault and fault detection and locating are suitable for OHL three-phase LV networks.
- If LV monitoring devices are equipped to monitor three-phase currents alongside the neutral, then the location of PreFault and fault events is feasible, provided there are accurate circuit records for the feeders being monitored.
- LV monitors that are triggered on voltage disturbances can provide HV network insights, however the project shows the requirement for a higher density of LV monitors on the same HV feeder for accurate location.
- LV monitors require minimal physical adjustment to provide the same outputs monitoring pole mounted substations as when monitoring ground mounted substations.

Conclusions

C1. Monitoring devices require minimal physical alterations to be installed at pole mounted substations.

- C1.1 The devices can be installed within nondescript enclosures and mounted on poles in a safe and secure manner above the anti-climbing device.
- C1.2 Voltage connections required some adaption compared to the busbar connections, but modifications were suitable for the purposes of the project.

C2. Most of the located and localised PreFaults recorded by this project were on circuits monitored by Guard devices.

- C2.1 This proves voltage differential trigger will still capture the locatable PreFault events, provided the Guard devices monitor the three current phases of the feeder in addition to the neutral.
- C2.2 Voltage triggering provided a wider array of events that could be used for other purposes beyond LV PreFault location such as HV network insights and cable condition assessments.
- C2.3 Further work is required on the triggering and algorithms for split-phase networks due to the different voltage characteristics compared to three-phase networks.

C3. The existing algorithms categorising the events are largely suitable for use on OHL networks.

- C3.1 Guard event categories, including the HV categorisation, provide more information on the type of events being recorded by a device.
- C3.2 VisNet categories are suitable if the only type of event a user is interested in is locatable PreFault and fault events.
- C3.3 Development of algorithms suitable for split-phase network events is required.

C4. Voltage triggered devices can provide insights into HV network events.

- C4.1 This requires a suitable number of LV monitors on a feeder.
- C4.2 There needs to be accurate HV connectivity data for the feeder.
- C4.3 For automatic detection of HV events, the LV monitors should be clustered together by feeder and primary substation.

Recommendations

R1. Headline monitoring device specifications:

- R1.1 A two feeder monitoring solution is the most versatile option to roll out BAU. The majority of pole mounted substations supply two feeders or less. Device should monitor the three phases and the neutral of the feeder.
- R1.2 Pole mounted devices should monitor the three phases and the neutral of the feeder. The Guards can monitor up to eight current channels. At ground mounted substations only the neutrals would be monitored as there could be up to eight LV ways.
- R1.3 Voltage triggered devices provide the most comprehensive recording of event types across all sizes of transformers. VisNets could be configured to trigger on voltage if required.

R2. If detailed load monitoring information for rural feeders is of specific interest then the VisNet monitor is preferable to the Guard as the VisNet collects that data.

R3. Future rollout should be based on a prioritised list of feeders with higher instances of fault activity. From this, improvements to PreFault event categorisations and algorithms can be developed.

R4. Further investigation into the analysis of events recorded by split-phase networks is required to ensure successful future use.

R5. Further investigation into the detection and localisation of HV events from LV insights is required.

- R5.1 If a suitable number of LV monitors, voltage triggered, are installed on an HV feeder, then the detection and localisation of HV events is possible.

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1. Background and Introduction

Typically, rural (overhead line fed) customers are poorer served than urban (largely underground cable fed) customers. With plans for the introduction of proactive fault management on urban underground LV networks, the gap is likely to widen. Customer expectation of more reliable rural and mixed networks is likely to grow, making it increasingly important to improve visibility and management of the LV network, creating a need for better and faster fault location and restoration.

A significant proportion of long duration interruptions to customers' supplies result from faults on the LV network. This results in a lower income via the IIS incentive, increased operational costs and poorer customer experience than would be the case if these interruptions could be avoided. Mitigating the impact of LV Interruptions requires detection of developing LV faults, then localisation of each defect that could develop into a fault before it produces a supply interruption.

The Foresight Project, undertaken by Northern Powergrid (2017-2021) developed equipment and methods aimed at finding and fixing LV cable faults, on underground circuits fed from Ground Mounted substations, before they fail. The project has produced a dataset from a fleet of low-cost detectors providing health index information for LV underground cable circuits, utilised in both the areas of Asset Management and Operational Network Management. Asset health is derived from waveform signatures captured by the detectors. Most of the signatures captured are associated with events on the cable networks that 'self-heal' before protection operates (so-called PreFault events). Once a level of criticality has been reached, additional equipment is then deployed to determine the source of the PreFault activity and therefore the location of the developing fault. When located, positive proactive action can be taken to ameliorate the impact of unplanned supply interruptions with concomitant improvement in network performance indices and customer satisfaction.

Northern Powergrid (NPg) asked EA Technology to scope a project to enable the proactive fault management methods for improving the quality of supply, that have been developed for urban underground networks, to be applied to detection and location of developing faults in network fed from pole mounted equipment. It aimed to compare installations of a mixture of Guards and VisNet Hubs, in order to determine which was the more suitable pole top monitoring device.

It also anticipated that there could be a difference between cable PreFault breakdown and overhead line (OHL) PreFault breakdown, and hence a need to modify the PreFault detection algorithms.

The project aligns with NPg's innovation strategy as part of their continued commitment to find ways to deliver improvements and best value to their customers via the deployment of a more intelligent and flexible smart grid. Faster localisation and restoration of faults, plus detecting and locating developing LV faults before they result in supply interruptions, both within OHL/pole fittings and associated underground cable systems, would significantly improve quality of supply of those customers that are reliant on these networks. It would ensure that rural customers are inclusively able to benefit from proactive fault management methods currently envisaged for their urban neighbours.

This project builds on the Foresight learning and will provide NPg with an insight of what is possible with respect to pro-active management of these networks, and reducing the number of unplanned interruptions, whilst increasing the Quality of Supply (QoS) to customers. It also aims to improve understanding of indicative PreFault behaviour relating to pole mounted substations, their outgoing circuits, and the development of management options for LV rural overhead line and mixed networks.

Rural LV networks are large but connected customer numbers are small and access to equipment and measuring points is limited. They have had little monitoring to-date and no condition information relating to potential faults. If monitoring is to be introduced, a single piece of monitoring equipment providing multiple monitoring duties makes the most sense. The project considers the environmental challenges, both physical and electrical, of rural and mixed networks. It aims to assess the suitability of equipment deployed in the

Foresight project in this environment and use this assessment to design the prototype project monitoring systems.

Using learning from the practical application of the devices and the information they provide, suggested updates to NPg's Monitoring Specifications and, where appropriate, installation instructions for pole mounted substation monitoring will be provided in this report.

Around 57% of NPg's secondary substations are pole mounted. Monitoring even a fraction of these substations could provide much needed visibility of network issues in historically overlooked areas. This project monitored 50 kVA, 100 kVA and 200kVA pole mounted transformers.

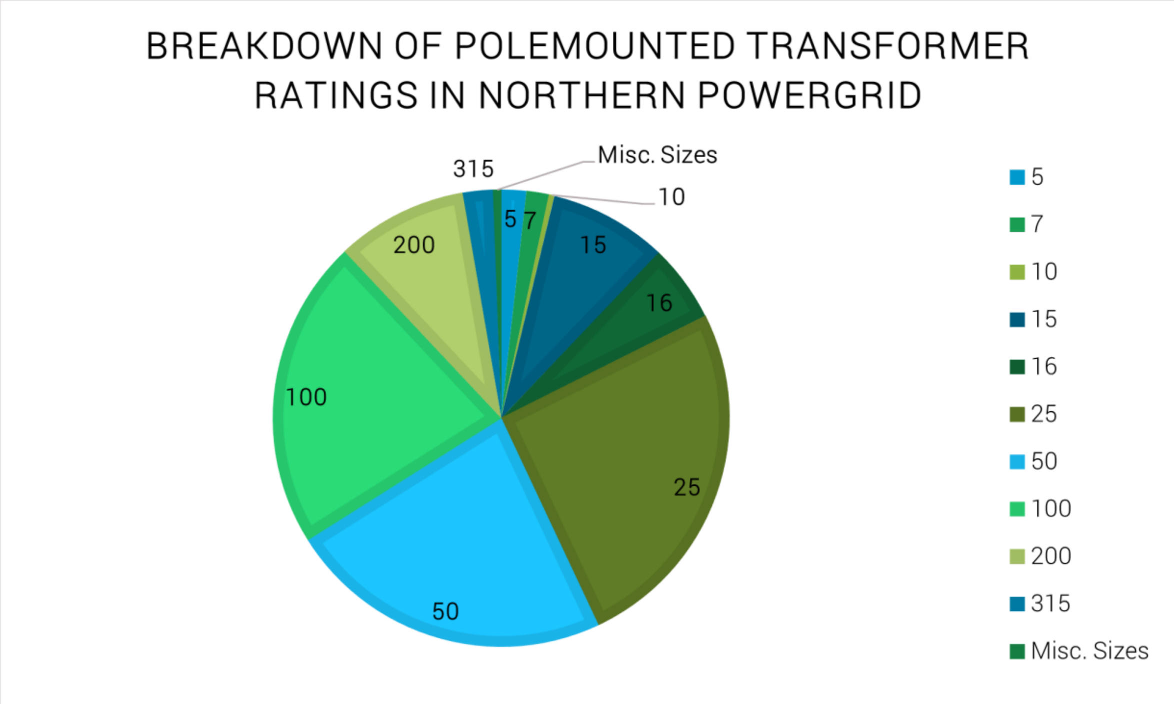


Figure 1 Overview of PMT sizes in NPg's network

While smaller, lower-rated transformers exist, there are limited opportunities for return on investment in monitoring them with fewer connected customers and shorter circuits allowing quicker localisation of faults. Less customers also minimise the impact on Customer Interruption (CI) numbers, and volumes of Customer Minutes Lost (CML) during an outage. Focusing the monitoring on 50 kVA, 100 kVA and 200 kVA pole mounted substations will account for over 25% of all NPg's secondary substations, with the learning likely being applicable to larger and smaller transformer sizes if monitoring is required.

Monitoring solutions have previously been designed with a greater focus on ground mounted substations. Generally, they are substations with greater numbers of connected customers, more concerns around overloading and with more underground cable networks. Foresight developed the PreFault detection algorithm for these cable networks.

Pole mounted substations generally monitor fewer customers, have lower levels of loading and feed overhead lines or mixed networks, where faults will occur in more a visible manner. Prioritising underground cable networks, for the purposes of fault finding, is sensible when considering the constraints involved with rolling out a large-scale LV monitoring programme.

Equipment was deployed at substations chosen by NPg at the outset of the project by NPg linesmen. EA Technology consulted with NPg linesmen to ensure the monitoring devices could be installed safely within their operational procedures and be secured for the duration of the project.

1.1 Scope and Objectives

The primary objectives of this project are:

- To determine the functional and practical design requirements for instruments to be used for monitoring overhead and mixed overhead and underground LV networks fed from pole mounted substations.
- To investigate whether:
    - The same equipment used to *detect*, *localise,* and *locate* PreFault events can also provide circuit and transformer load monitoring to help manage risks of increased load on these networks during the transition to net zero carbon emissions.
    - It is possible to provide additional insights relating to the condition and future reliability of HV overhead line networks from these pole mounted substation LV monitoring systems.
- To identify the practical requirements for installing, commissioning, operating and decommissioning suitable monitoring systems on pole mounted substations.
- To determine whether low-cost detectors / monitors with the required functionality can be practically deployed to these networks.
- To provide draft amendments to the NPg Technical Specification for Secondary Substation Monitoring Systems and to support NPg in producing draft amendments to standards documentation for installation of Pole Mounted Substation Monitoring Equipment.
- To explore whether it is possible to apply/ adapt existing proactive fault management algorithms and methods to customers in rural areas fed by LV overhead line and mixed overhead line and cable circuits.
- To support Northern Powergrid in disseminating the learning from the project.

The project outputs will provide DNOs with an assessment of the suitability and applicability to LV OHL, of existing PreFault detection algorithms and fault prediction algorithms, which have been developed in the Foresight project.

To achieve these objectives the project was divided into three workstreams, alongside a project management and reporting component.

- Workstream 1 – Pole Mounted Device Design and Development
    - Specify, design, build and supply 20 pole mounted monitoring systems, based on the VisNet Hub and the Guard, report on the performance of the equipment and update Technical Specifications.
- Workstream 2 – Pole Mounted Device Installation and Operation
    - Deployment of data collection devices and project data collection system.
- Workstream 3 – PreFault Data Analysis and Actionable Insights
    - Monitor the performance of Algorithms and Apps.
- Reporting and Dissemination.

This is the final report for the Polesight project and will report on all workstreams and provide discussion of the contained tasks.

2. Definitions

BAU	Business As Usual
DNO	Distribution Network Operator
HV	High Voltage
IPC	Insulation Piercing Connector
LV	Low Voltage – distribution network to customers
NPg	Northern Powergrid
OHL	Overhead Line
PMT	Pole Mounted Transformer
UGC	Underground Cable
VIR	Vulcanised Insulated Rubber

3. Workstream 1: Pole Mounted Device Specifications

The purpose of the Polesight project is to utilise the EA Technology monitoring devices in an "as sold" capacity and then investigate further the properties that may need to be adapted for use on OHL feeders. The only changes to the devices before installation were the necessary modifications required to install them outdoors, pole mounted below the transformer. These modifications were primarily additions to the device: a housing to hold the device and the fuses, voltage connection cables suitable for outdoor use and the bracket system to mount the whole assembly on the pole. For a comprehensive view of the modifications to the Polesight devices, please see the Polesight Monitoring Design Specification[1].

PreFaults, by definition, self-heal and therefore cause no outages when they occur. They are best used to understand the health of assets and, where possible, to locate the likely place where a fault may occur. The Foresight project also looked to investigate transient faults; these are faults that will blow a fuse or activate a circuit breaker, but the line can still be re-energised without restorative works occurring on the cable for example, excavating a joint to replace it. The definition of a fault within this report is a damage fault that causes an outage and requires a repair and not a non-damage fault that can be restored through the replacing of fuses at the substation.

Ten Guard and ten VisNet devices were installed on 20 different pole mounted transformers during March and April 2023, providing this report with 11 months of monitoring data to review. After one month of minimal VisNet device events the triggering settings were lowered in mid-June and the VisNet devices began to record more events.

3.1 Overview of Device Specifications and Functionality

Both devices have the fundamental purpose of detecting PreFaults. However, the VisNet has been designed with further capabilities and more onboard processing capabilities that allows for more versatile functions. One of the key additional features of the VisNet is that it can calculate load demands device side, which is one of the areas of discussion for this project.

Table 1 Comparison of Guard and VisNet Monitoring Devices

	Guard	VisNet
Event trigger	Voltage - differential voltage	Current – magnitude current, 700A
Monitoring ability	Can measure 8 individual currents – either 8 neutrals to monitor 8 feeders or 2 feeders, 3 phases + neutral	Can measure up to 6 feeders, 3 phases + neutral
Event Analytics	Voltage differential then neutral current differential	Phase current differential and neutral current differential
Device Side Load Calculation	No	Yes
Fault Detection	Yes	Yes
Fault location	No	Yes
Event categorisations	Pre-fault HV Other Abnormal	Non-fault Fault – no impedance Fault
LV-CAP Platform	No	Yes

[1] EA9744 – TR01 Polesight Monitoring Design Specification

For the Guard analytics categorisations, the PreFault event category is designated as "pre-fault" which is reflected in the table. In this report only PreFault has been used to simplify the terminology as well as reflecting the priority of locatable PreFaults in this project. HV events are generally those that recognise a voltage disturbance without an associated current rise. "Abnormal" events categorise data that falls outside the usual boundaries of standard operation of the network, for example interference or data stream disruption. "Other" events are generally, but not entirely, load events when reviewed, especially during this project with the lowered current triggers on the VisNets.

Within the VisNet categorisations "Fault" refers to fault and PreFault events. The device cannot make a judgement on whether an outage has occurred to differentiate between the two as both have similar characteristics. The primary difference between a fault and a PreFault is that there is a permanent outage after a fault. "Fault – no impedance" are events where the data is insufficient to provide an impedance to locate them. There is a difference between a "Fault" with an impedance that is not suitable for location and a "Fault – no impedance", the former is an event where the impedance is not locatable on the circuit while the latter is an event where an impedance cannot be generated. "Non-fault" refers to events that cannot be classified as a Fault event, they do not fit the criteria. There are no additional categorisations on the VisNet analytics.

3.1.1 Voltage triggering and Current Triggering

It is key to remember that any monitoring device can be designed to trigger in response to any voltage or current conditions. During this project it was capitalised on that the two devices naturally functioned in separate ways to test which is suitable for the purposes of monitoring OHL feeders. The Guard device does have an absolute current trigger of 450A in its settings however, during this project all events recorded by Guards that exceeded this current had an associated voltage differential, so the trigger was redundant. The VisNet can be updated while installed to trigger in any manner required, however, it was not done in this project due to the short timescales for monitoring in case it affected the success of recording events. Had there been an issue with the implementation, valuable events may have been missed.

This project report uses the Guard as a shorthand for voltage differential triggering devices and the VisNet as a shorthand for absolute current triggering devices.

3.1.2 ALVIN® Guard

The Guard detects PreFault events by measuring three-phase voltage and 8 current channels. The Guard detects dips in voltage that coincide with a current peak. When an event is detected, a waveform set is wirelessly transmitted to EA Technology's Substation 360 system. Substation 360 is EA Technology's custom data platform that, through a collection of micro-services and back-end databases, can ingest data from multiple sources. Data is aggregated, analysed, and modelled before being presented as information to the client via a dedicated user interface.

Figure 2 ALVIN® Guard

The Guard can monitor up to two feeders, with the additional connections required being the Rogowski coils on the second feeder. If a second feeder was connected there would be an additional 4 Rogowski coils connected to the Guard from the other feeder's 3 phases and neutral.

The unit consists of a single IP54 IK08 rated casing housing all power, measurement, and communication circuits to which CATIV 300V rated external current and voltage sensors connect.

For a complete overview refer to EA Technology's Guard Product Specification.[2]

3.1.3 VisNet Hub

The VisNet Hub is designed to provide visibility of voltage and current on LV distribution substations. The Hub monitors the outgoing ways of a LV board providing insight about load, faults, and condition across the network. It can measure three-phase currents, plus neutral, for up to six LV circuits and the busbar voltage.

The VisNet Hub utilises EA Technology's Low Voltage Common Application Platform (LV-CAP™) operating system, which allows a range of Applications (Apps) to be deployed at the distribution substation to expand the functionality of the unit beyond simple measurement.

Figure 3 VisNet® Hub

For a complete overview, refer to EA Technology's VisNet Hub Product Specification.[3]

3.1.4 Guard use on Polesight Project

When deployed during business as usual (BAU) work within NPg's network area, Guards are installed to only monitor the neutral of the feeder. This allows one Guard to monitor up to eight feeders within a substation by measuring the phase voltages and the neutral for each feeder. The triggering settings reflect this usage: Guards capture events based on voltage changes which are then analysed in conjunction with the neutral current to categorise the event.

On the Polesight project, to improve the likelihood of being able to detect and locate possible PreFault events within the limited timespan of the project, all Guards were installed with current monitoring on all three phases for three-phase networks, and two phases for split-phase networks.

[2] 3473-PRSPC-GRD1-V01.03.00 Guard Product Specification
[3] 3473-PRSPC-VNH1-V01.02.00 VisNet Hub Product Specification

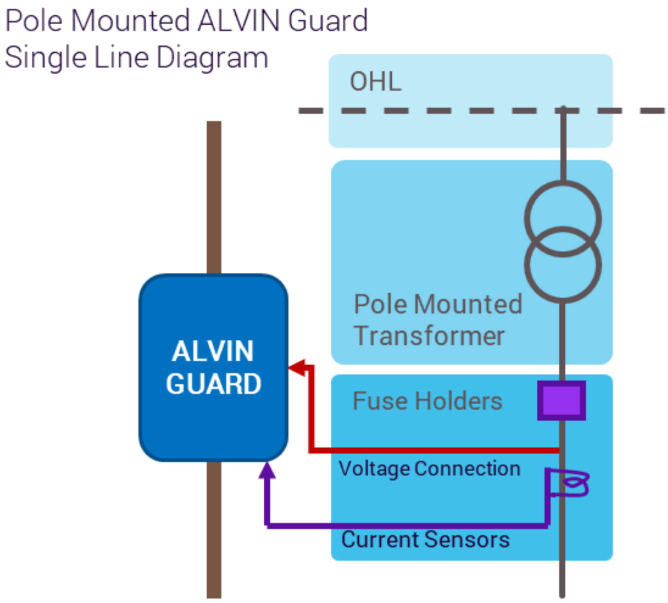


Figure 4 A simplified typical Guard installation for a single feeder

Figure 4 shows a single line visualisation of the Guard installation for a single feeder, the Installation Guide[4] will provide a detailed diagram showing connection points for all 3 phases and the neutral. For installations under this project, Northern Powergrid requested the voltage connections be made after the fuses; this has the disadvantage that the unit will lose supply if multiple fuses blow. The advantage is that the fuses provide an additional level of protection should there be an electrical fault.

As PMTs rarely have more than two feeders originating from them there was the opportunity to monitor all current phases. The monitoring of phase currents with the Guards allows Guard events to be located to a position on a feeder (where the data is available to a suitable confidence level). VisNets monitor current on all phases by default. Hardware triggering levels are set on the Guard and VisNet devices and the data they capture is analysed by EA Technology back-end systems. Separate analytics exist for VisNets and Guards and events captured by the Guards have been analysed by both analytics.

No change was made to the triggering conditions for the Guards during this project.

This course of action was agreed as it allows further investigation into the similarities and differences between the Guard and the VisNet devices, which could possibly support one device being favoured over the other for PMT and OHL monitoring.

3.1.5 VisNet Hub use on Polesight Project

The VisNet analytics categorises events into three types: “fault”, “fault – no impedance” and “non-fault”. An objective of the Polesight project is to understand whether these three event types are suitable for categorising OHL events.

When installed at ground mounted substations, the VisNet is connected to the busbar. On the Polesight project, the voltage connections were made after the fuses on one of the feeders, as requested by NPg.

While there were some initial concerns regarding the usefulness of returned information in the event of a fuse blow, this installation configuration proved suitable.

[4] EA9744-TR05 Polesight Installation Checklist.

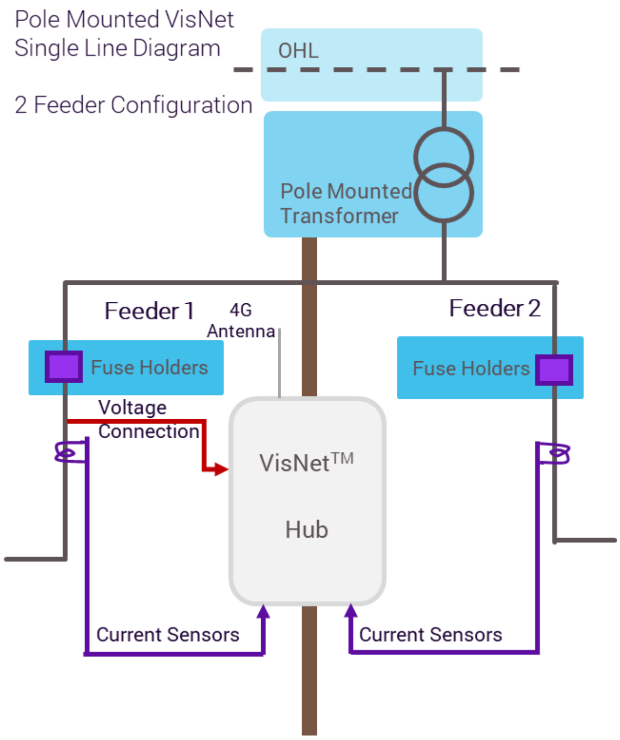


Figure 5 Typical VisNet Hub Installation for two feeders

Figure 5 shows a single line visualisation of the VisNet installation for two feeders, the Installation Guide will provide a detailed diagram showing connection points for all 3 phases and the neutral.

All VisNet devices for this project were provided with standard settings with the aim of understanding modifications that may be required to make the device suitable for use on PMTs. While Guards trigger on specific voltage conditions, the VisNets are set to trigger when the current surpasses 700A. This trigger setting is, by default, agnostic of the asset properties which is something that is being investigated during this project. In general, transformers fitted to poles are of smaller rating than their ground mounted substation counterparts. Following through the logic, generally PMTs see lower current draws than their ground counterparts as they are in more rural areas with lower connected customer numbers.

It was recognised that across all ten VisNets only one event was seen during the first 6 weeks of monitoring. While events recorded later in the monitoring period would show that PreFaults still can surpass the 700A threshold there was a concern that with the smaller rated assets the project could be missing key events that would be important to analyse. It was decided that the current triggering setting would be halved to 350A on the Polesight devices in an attempt to see an increase the number of events recorded. The neutral current trigger was also lowered.

The triggering settings were updated on the 13th of June and subsequently events were seen on multiple Polesight VisNets. This allowed events that looked like PreFaults but did not broach the existing current threshold to be seen and therefore they could be analysed. This reduction allowed for some initial investigation into events that may be signalling poor cable or line health and could become a persistent PreFault.

However, over the duration of the project it became apparent that the 700A trigger threshold was suitable if the primary purpose of the event capture was for the location of events. While events that looked like PreFaults occurred under the 700A threshold and the algorithms recognised them, not a single event under 700A was locatable.

3.2 Modifications Required for Pole Mounting

What are the functional and practical design requirements for instruments to be used for monitoring overhead and mixed overhead and underground LV networks fed from pole mounted substations?

This section provides an overview of the additions required to the standard LV monitors used for this project. Despite both devices being designed for internal use the Guard and the VisNet are IP54 and IP55 rated respectively, which would likely be suitable for external use without modification.

However, as both devices have visible lights and require a cover to be attached after installing of the current and voltage connections, it was decided that they would be installed within an external housing. The housing chosen for this project was IP65 rated.

Figure 6 Visualisation of the Guard and VisNet monitoring devices inside the external enclosure, showing the fuse rail and the location of the cable glands

The housing also allowed for the installation of external fuses. These external fuses were required as the standard voltage connections for both devices include fused cable connectors. As this project modified the device to use different voltage cables and Insulation Piercing Connectors (IPCs) to connect to the phase voltages, the fuses had to be installed in the enclosure.

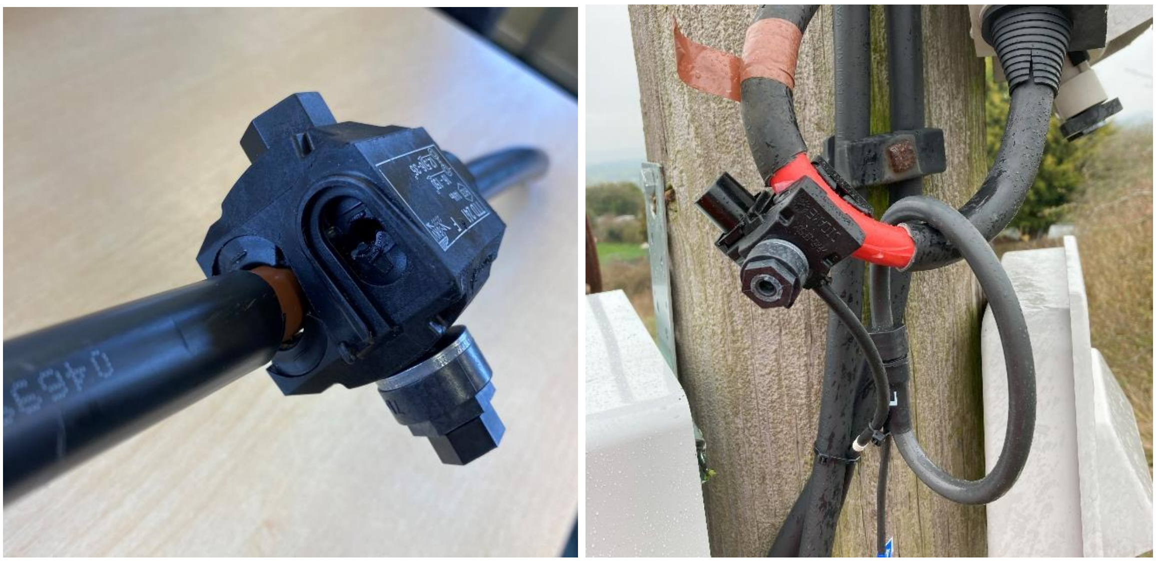


Figure 7 Insulation Piercing Connector for connections with voltage phases

The IPCs used on this project were supplied by NPg as they are available in the standard kit. For future pole mounted monitoring devices, it is likely that fused IPCs would be used instead, removing the need for the fuses within the external enclosure. This is likely to reduce the profile of the enclosure further.

The right picture in Figure 7 also shows the Rogowski coil, which were used to monitor the currents. These required no modifications to be used on this project as they only needed to be wrapped around the cable in the correct orientation. Even if they were installed the wrong way around the EA technology was able to rectify the issue when the final commissioning checks were completed.

For further details on any part of the modifications required for the monitoring devices used within the Polesight project, please see the Polesight Monitoring Design Specification.[5]

The Polesight devices were mounted on the rear side of the wooden pole of where the LV fuses are mounted. The device was connected downstream of the fuses and installed above the anti-climbing guard. The device was delivered to site, pre-installed in its enclosure, with all cables ready to be attached by the linesmen.

[5] EA9744 -TR01 - Polesight Monitoring Design Specification

Figure 8 Location of installation of Polesight device on a single pole and on a H Pole, showing the Rogowski coils measuring the second feeder

For the Polesight project, installations were only be carried out where it was not necessary to take an outage on the HV (11kV or 20kV) network. To avoid requiring an outage there must be a safety clearance of 1.1m between any part of the installer and the nearest exposed live HV conductor at all times during the installation. Some substations were not suitable as the neutral cable between transformer neutral bushing and the LV overhead lines does not drop down the pole far enough, so it was not possible to attach the required IPC or Rogowski coil.

More locations for monitoring were shortlisted than monitoring devices available for the project to ensure that all 20 devices could be installed without having to review further locations. Some locations on the longlist had vegetation on the pole, which would have required further effort to clear to install the devices.

For H-pole sites with limited space on the reverse of the pole from the fuses the device can be fitted on the pole with the most suitable clear space and the connections can be made from there.

Both devices have standard mounting systems for installations within substations, comprising strong magnets that attach to any flat metal panel in or near the LV board. To mount the entire assembly on the pole the following method was to directly secure the device to the pole.

First, a coach bolt was drilled into a clear location on the pole, then the device was hung from the coach bolt, Figure 9. The top bracket was slotted to allow it over the coach bolt and then to be anchor once it was hung. Then a second coach bolt was drilled through the hole at the bottom of the device.

This fixing method is the accepted way of installing equipment on poles. It allows the device to be installed by one person and therefore ensures the job can be completed by a two-person team.

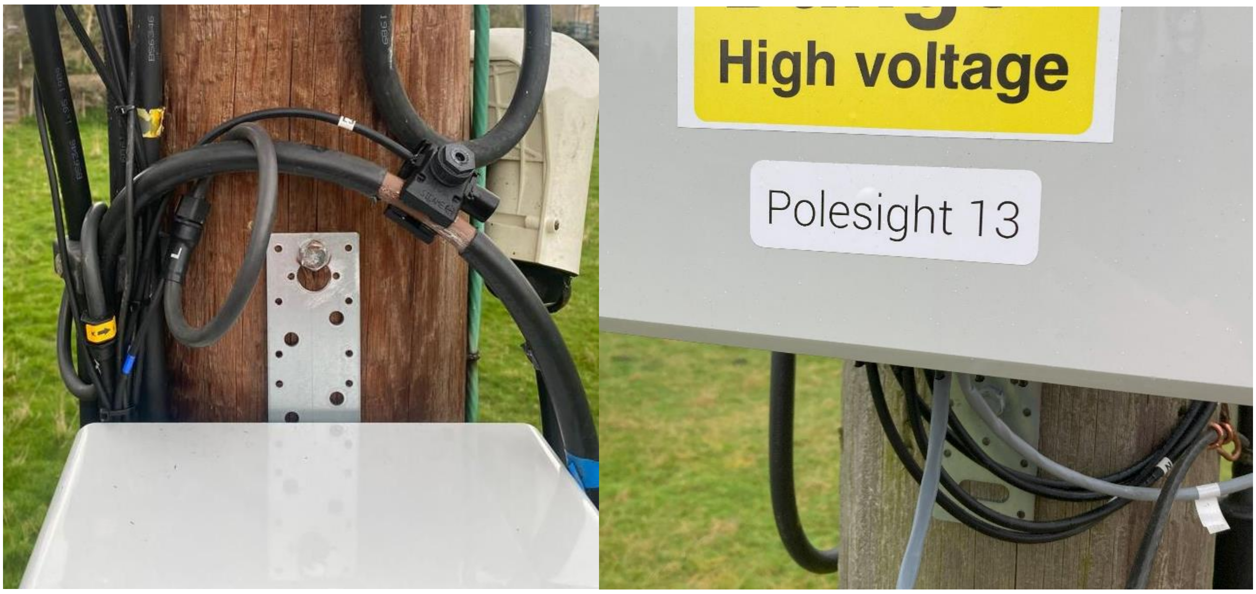


Figure 9 Attachment points, left hand side showing the top bracket to hand the coach bolt on and right hand side showing the bottom bracket to fix the device with the second coach bolt

As all devices remained in place for the duration of the project, it can be assumed that this method of fixing the devices to the pole is suitable. Multiple storms impacted the monitoring area, including one that brought down some of the poles on a feeder being monitored.

Further details regarding installation can be found in the Polesight Installation Guide.[6]

Both types of monitors were pre-commissioned and had a suitable number of current connections installed by EA Technology before they were delivered to NPg. This allowed the cable glands to be correctly installed before the devices arrived at site, ensuring the IP rating was maintained. While this was an acceptable product solution for an innovation project, in BAU the commissioning and installation of the correct number of current connections would have to be done on site.

This was not done on the Polesight project as standard commissioning techniques involve connecting a laptop to the monitoring device once it is installed. As the device must be installed to be commissioned and a laptop cannot be used while working at height the pre-commissioning solution was used.

Any future pole mounted monitoring device will be required to have some form of secure, reliable, and wireless connection to initiate the commissioning on site. The short-range communication can be switched off after commissioning has been completed to ensure the device cannot be interfered with.

Once the device was correctly installed and the status lights were lit, the enclosure could be closed and the installation was completed.

3.3 Comparison of Device Suitability for Load Monitoring on Rural LV Networks

Can the same equipment used to detect, localise and locate PreFault events also provide circuit and transformer load monitoring to help manage risks of increased load on these networks during the transition to net zero carbon emissions?

For this project, two types of monitoring devices were used, both of EA Technology design. The first, a Guard, is generally used to detect, but not to locate, PreFault and HV events. It does this by monitoring the voltage at the transformer and the neutrals of the feeders from the transformer. The purpose of this is to monitor multiple feeders for a lower cost. The Guard can monitor the neutrals of up to eight feeders and classify cables at risk

[6] EA9744 – TR02 - Polesight Installation Guide

by watching for increasing PreFault activity, month on month. The Guard, if used as in BAU, cannot locate PreFaults or Faults as they do not monitor the three-phase currents of a feeder, which is required for the location of events.

Guards do not automatically provide information on the loading of the individual feeders as they were not designed for that purpose.

For the purposes of the Polesight project, the Guards monitored the phase currents of the feeders as well. This is possible as most pole mounted substations feed a maximum of two feeders and a Guard can monitor up to eight individual currents. In this case, the loading could be determined using the RMS current provided and the voltage readings. However, as load information is not automatically provided by the Guard software it is not the optimum device to use for determining the feeder and transformer loading levels.

The other device type used for this project, the VisNet, was designed to provide information on the loading of the circuits and transformers. As standard, within BAU use, the VisNet monitors the three phases and the neutral of up to six feeders (although multiple VisNet units can be linked together for larger substations). It provides the mean current and voltages over 30 minutes and calculating the active, reactive and apparent power before the information is provided for the customer. This is easily accessible and with future developments of applications to be loaded to the VisNet devices there will likely be more ways to use the power data provided for automatic alarms.

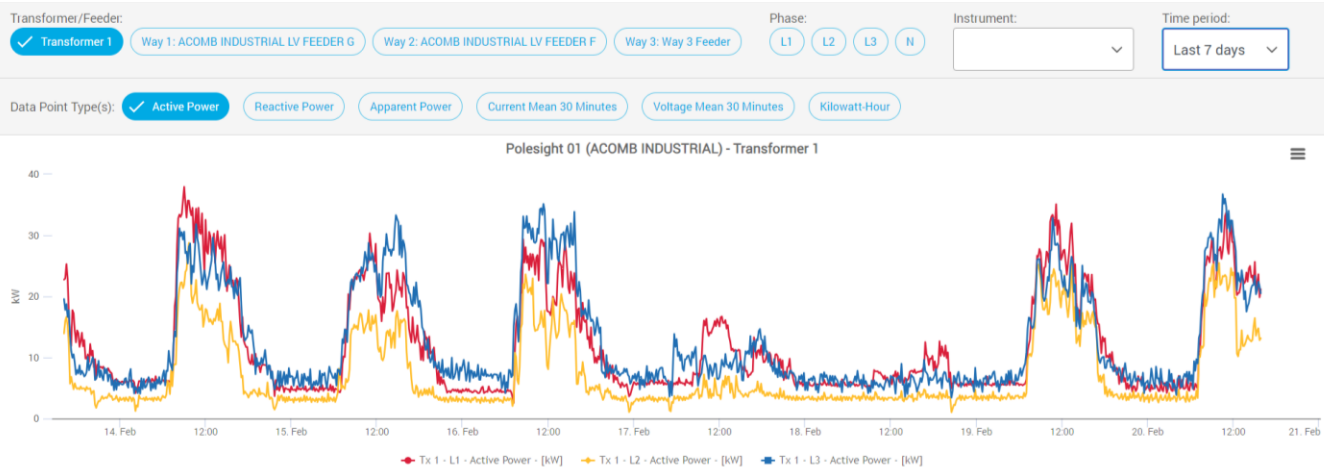


Figure 10 Polesight 01 (Acomb Industrial) Weekly Loading

Both devices deployed for this project have the capability of delivering insights on the loading of transformers and circuits. However, if the load monitoring of pole mounted transformers is of high interest or importance then the VisNet provides the better "off the shelf" product. The Guard will always require a degree of user calculation once the information is provided.

3.4 Discussing Changes to Existing Pole Mounted Monitoring Standards

Functionally, the existing monitoring devices achieved success in monitoring the PMTs with the physical modifications described in section 3.2 for both mounting on the pole and connecting to and around the cables from the fuse holders. However, some further insights were gained in the duration of the project that would be beneficial to implement if further pole mounting monitoring systems are to be considered BAU.

Feedback was provided by NPg staff and the EA Technology VisNet monitoring team, and alongside observations from the project team, baseline technical specifications of future LV pole mounted have been drafted.

Specifications:

1. IP65 rated.
2. No external lights.
    a. If status lights are required for commissioning, they must be able to be turned off.
3. Capable of monitoring all phase currents and the neutral with each current sensor connected independently, like the Guard device.
    a. This will allow clearer monitoring of split-phase, and possibly single phase, transformers.
    b. It will also reduce the number of trailing wires, as if the Rogowski coils are grouped together, if one is not required it must be tied away or attached to an already monitored phase.
4. Capable of monitoring two outgoing feeders.
    a. Many pole mounted substations will only supply one feeder so a device designed to monitor one outgoing feeder would likely be suitable.
    b. However, for versatility a two feeder monitoring solution would allow the same device to be used across more transformers.
5. Physical voltage connections made using Insulation Piercing Connectors (IPCs).
    a. Fused IPCs are preferred to reduce the need for fuses within the external casing.
    b. While not provided for this project, they are available and would allow the profile of the monitoring device to be shrunk further as no external fuses would be required.
6. Mounted and attached using two standard coach bolts.
    a. This is a standard requirement for fixing any device to a pole.
7. Short-range wireless commissioning.
    a. Connections should be checked on site before departure to ensure correct orientation and working connections.
    b. Wireless connection should be disabled after commissioning with the option to enable it if required for future maintenance.

4. Workstream 2: Pole Mounted Device Installation and Operation

The purpose of this workstream was to understand how low-cost monitors with the desired functionality can be practically deployed to the network.

This was the first opportunity to understand how operational differences between installing an LV monitor on a ground mounted substation and pole mounted substations could be overcome.

4.1 Differences Between Ground Mounted and Pole Mounted Substation Installations

What are the practical requirements for installing, commissioning, operating and decommissioning suitable monitoring systems on pole mounted substations?

BAU devices are commissioned using a laptop which allows for the device to be set up in real time and ensure that the connections are installed correctly. This is especially important to ensure the Rogowski coils for the current readings are oriented in the correct direction, if they are installed the wrong way around then the reading will be negative.

When installing a device on a pole, the additional work of using a laptop to commission the device is not compatible with ensuring the job can be completed by a two-person team.

EA Technology developed the Polesight devices to suit NPg's conditions:

- Device stored inside an external casing.
- Installation must be completed by a single person climbing the pole.
- Fixing method is two coach bolts screwed into the wooden pole.

As per NPg's request, the Polesight devices were pre-commissioned at EA Technology's headquarters before they were shipped to NPg. This allowed the devices to be installed with minimal additional onsite work. The installer mounted the device close to the fuses, connected the voltage leads and attached the Rogowski coils around the feeder cables. Then, upon checking the device was powered and the status lights were lit correctly, the cabinet could be closed over and the installation was completed.

The installer completed a checklist specifically designed for this project to allow EA Technology to ensure the connections were fitted correctly and the device was functional.[7] This checklist allowed EA Technology to then check the health of the monitor, ensure connections were fitted correctly and assign the monitor to the correct substation.

This method of commissioning is not recommended for a widescale rollout of LV monitoring on PMTs as it is time consuming and increases the likelihood of the installer having to return to the site to rectify issues. As discussed in section 3.4, a BAU LV PMT monitor would have to be commissioned onsite at install.

[7] EA9744-TR05 Polesight Installation Checklist

4.2 Project Site Selection Overview

NPg provided a longlist of PMT sites that had historic outage or voltage quality issues which would be valuable to monitor for the purposes of this project. There was always the risk of no, or minimal, events occurring in the duration of the project so circuits that had fault history were targeted. This is likely how LV monitoring for fault location would be rolled out in BAU processes.

EA Technology checked the list and provided some insights on the practicalities of installing the Polesight devices, which created a further shortlist with more than 20 locations as options. The extra locations were to allow for sites that were not suitable for installation on the day to be passed over for another site to reduce time wasted if another callout was required. NPg chose the final installation sites as the knowledge of the substations and their fault history ultimately lay with them.

The substations chosen for monitoring by NPg are all located in the Northeast part of their network, more specifically around the Hexham area. Some of the feeders monitored are split-phase, which is typical of rural LV connections and therefore useful to investigate during this project.

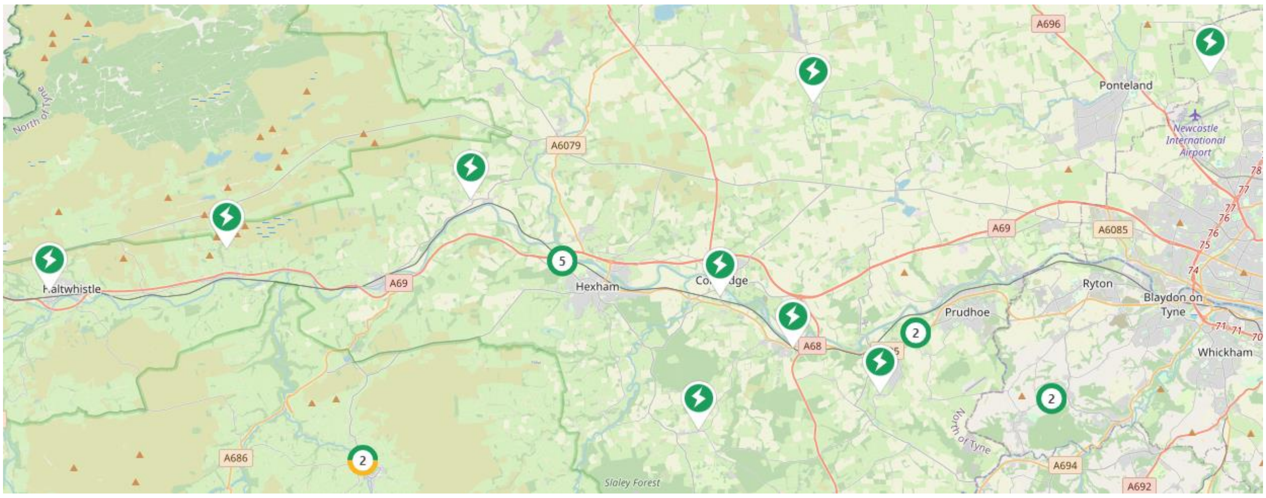


Figure 11 Polesight monitoring locations.

These sites are generally typical of NPg's rural network, with a mixture of OHL and UGC feeders (many mixing both types of conductors), domestic and rural industrial customers, and transformer ratings (50, 100 and 200 kVA). A majority of the feeders being monitored are three-phase but a few are split-phase.

Table 2 provides an overview of the transformers and feeders monitored for this project.

Table 2 Polesight installations by transformer, with feeder information

Polesight ID	Instrument Type	Tx Rating	Substation Name	Feeder Type	% OHL	Tx Type
Polesight 01	VisNet	200	ACOMB INDUSTRIAL	Mixed	58%	Three-phase
Polesight 01	VisNet	200	ACOMB INDUSTRIAL	U/G	0%	Three-phase
Polesight 02	Guard	200	CORBRIDGE STATION	Mixed	42%	Three-phase
Polesight 03	Guard	50	BIRKSHAW	Mixed	75%	Split-phase
Polesight 04	Guard	100	TOWNLEY TERRACE	O/H	100%	Three-phase
Polesight 05	Guard	50	CHOPWELL WOOD	Mixed	78%	Split-phase
Polesight 06	Guard	100	HALTWHISTLE WESTLANDS	Mixed	38%	Three-phase
Polesight 07	Guard	100	SYNTAX	Mixed	55%	Three-phase
Polesight 08	Guard	200	ACOMB GRAVEL	Mixed	84%	Three-phase
Polesight 09	Guard	100	HIGH CATTON	Mixed	53%	Split-phase
Polesight 10	Guard	100	SUMMERRODS	Mixed	95%	Three-phase
Polesight 11	Guard	200	BROOMHAUGH	Mixed	28%	Three-phase
Polesight 12	VisNet	200	FOURSTONES SCHOOL	Mixed	74%	Three-phase
Polesight 13	VisNet	200	MATFEN	Mixed	34%	Three-phase
Polesight 14	VisNet	100	WEST CAUSEY HILL	Mixed	93%	Three-phase
Polesight 14	VisNet	100	WEST CAUSEY HILL	U/G	0%	Three-phase
Polesight 15	VisNet	100	SLALEY POLICE	Mixed	45%	Split-phase
Polesight 16	VisNet	100	WENTWORTH ALLENDALE	Mixed	24%	Split-phase
Polesight 17	VisNet	100	MICKLEY MOUNT (HEX)	Mixed	96%	Split-phase
Polesight 18	VisNet	100	MICKLEY JUNCTION		62%	Split-phase
Polesight 19	VisNet	200	ACOMB WEST	U/G	0%	Three-phase
Polesight 20	VisNet	100	DINNINGTON VILLAGE	Mixed	42%	Three-phase

A full list of sites, their substation details, number of feeders, volume of faults captured, and their feeder composition are included in Appendix I.

4.3 Review of Device Health for Project Duration

Apart from Polesight 20, which had current monitoring issues, and Polesight 09, which was removed during the project because of a transformer upgrade, the Polesight devices remained in place for the duration of the monitoring period. Even in conditions which brought down other poles in the regions, the devices remained connected and functioning. There is confidence that the IPCs and Rogowski monitors are suitable for use in stormy conditions.

While the project proposal stated that the devices would be decommissioned at the completion of the monitoring stage of the project, it was decided that the functioning devices would remain in situ. In some cases, like Polesight 04, Townley Terrace, there is a real opportunity to watch for the development of an OHL PreFault. In the remaining cases, the Guard devices have successfully detected PreFault events with no further adjustment required and should the VisNet devices require any configuration changes, this can be done remotely.

Leaving them installed will provide additional learning for NPg and EA Technology following the project around the durability and ultimately the lifetime of these devices.

Polesight 09 and Polesight 20, a Guard and a VisNet respectively, were uninstalled by two different teams under different circumstances and for different purposes. The transformer being monitored by Polesight 09, High Catton, was decommissioned in the process of upgrading the substation for new connections and the device was removed by non-NPg personnel. Polesight 20, Dinnington Village, was disconnected while the transformer was still operational and therefore live.

Figure 12 Polesight 09 and 20, post removal

As can be seen from Figure 12, Polesight 09 had all connection wires cut when removed. There was no information provided about the ease of removal as the transformer being dead allowed the contractor to remove the device without disconnecting the cables. No condition assessment could therefore be performed on the cables, connectors, or coils; however, the box and the cable glands were intact and showed minimal signs of wear and tear.

The enclosure of Polesight 09 was visibly more discoloured than Polesight 20 (Figure 13), although this could be due to being stored in the depot for six months and therefore it is not possible to make a further judgement on the discolouration. Polesight 20 was exposed weather for longer and did not discolour as visibly, but there was a scrape on the front of the box that removed part of the warning label. It was determined that this likely happened in transit as the scrape continued across the front of the enclosure door and looks more like a friction rub than possible UV damage.

Figure 13 Difference in discolouration of devices

Polesight 20 was removed while the transformer was still live, in the same manner as they were installed, and therefore can provide more insight into the ease of decommissioning. The Rogowski coils were removed and tied away and the voltage connections were removed by simply unscrewing the IPCs.

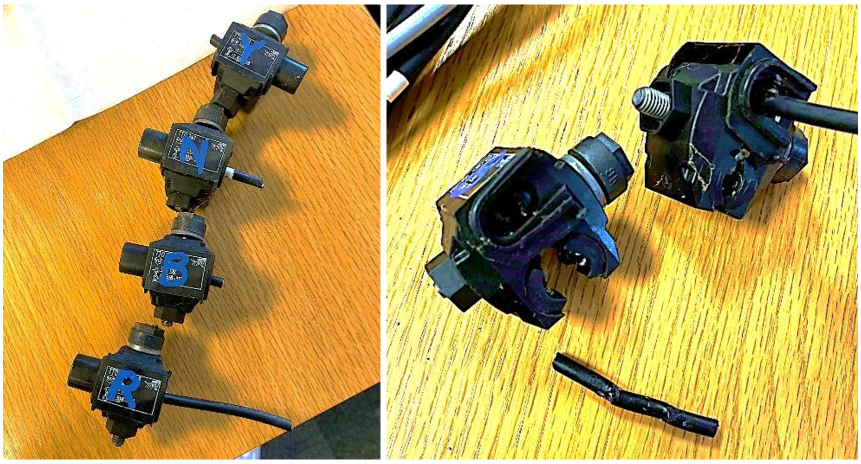


Figure 14 IPCs for voltage connections

The cable chosen for the voltage connections was suitable for making good contact within the IPCs as the teeth pierced the cable with ease. There are no photos available of the voltage cables on the transformer side however, they would have been made safe using standard methods. The linesman who installed these devices labelled each IPC (Figure 14) continuing from the labelling on the devices cables themselves.

Lessons learned from the device health review:

- Both devices had no signs of damage that could be attributed to their time installed.
- The IPCs could be removed from a live installation and the transformer made safe with no supply interruption.
- The standard Rogowski coils showed no damage from external elements.
- The external enclosures were suitable for the purposes of this project and similar specifications should apply to future pole mounted monitoring devices.

5. Workstream 3: PreFault Data Analysis and Actionable Insights

The Polesight project marks the first occasion where Guard and VisNet monitors have been used within the same project for the same ultimate purpose. This has provided the unique opportunity to compare how each system of monitoring manages the challenge of monitoring OHL networks.

Section 3.1 provided an overview of how both devices record and analyse events. The Guard triggers upon recording voltage differentials, often looking like “notches” in the voltage waveform, while the VisNet triggers when a certain current magnitude is surpassed. The waveforms both devices transmit back are usually analysed by their respective algorithms before the result is provided to the Detect platform.

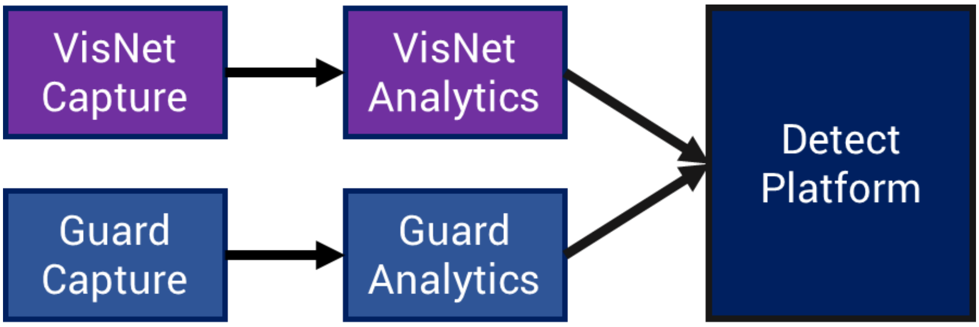


Figure 15 Standard event analytics pathway

The devices were originally designed for different purposes: the Guard for low-cost detection of PreFault events and the VisNet for the load measurement and analysis, plus detection, locating and localisation of PreFaults and faults. This is why there are two different data and analytics streams for the devices.

To investigate the most suitable method of monitoring OHL networks, the Polesight project used this opportunity to run the events captured by each device type through the analytics algorithm of the other. In other words, all events captured by both the Guard and VisNet devices were analysed by both the Guard algorithm and the VisNet algorithms.

During this project, both device types, the voltage triggered Guard and the current triggered VisNet, were installed to record events in their standard configurations. During the project is became clear that the voltage triggered devices offered versatility with the types of events that could be captured. While implementing voltage triggering on the VisNets is possible, implementing this will require further development work to ensure that it will not cause data flooding. Beyond the completion of the Polesight project, further investigation into the use of voltage triggering on the VisNets is being undertaken.

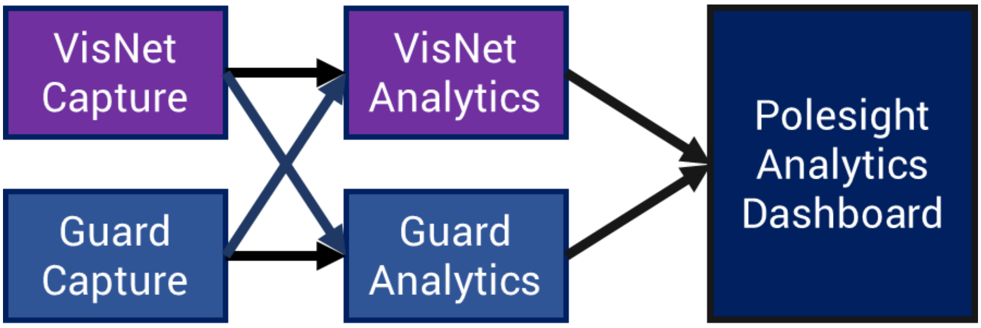


Figure 16 Polesight event analytics pathway

Interestingly, when the Guard devices were installed to monitor three-phase currents they were automatically analysed using the VisNet algorithm. This is a result of the back-end analytics recognising the three-phase data from the Guards which filtered them to be analysed by the VisNet algorithm. While this had benefits, locatable PreFaults were automatically categorised in Detect, the downside of this automatic analysing was that HV events captured on the Guard devices were not immediately categorised. To ensure HV events and locatable PreFault events can be displayed on the same dashboard output this will have to be adjusted and is something that EA Technology will be rectifying post project.

A separate analytical dashboard was created to analyse the events using different current trigger levels when using the VisNet algorithm and provide the output of the Guard algorithm analytics. This allowed the events to be compared and key questions to be answered:

- Are locatable events recorded by the Guard devices using the default triggering settings?
- Can the VisNet devices record HV events?
- Does altering the current trigger level of the VisNet devices have actionable results?
- What is the preferred combination of monitoring device, detection trigger, and analytical process for use on OHL networks?

In brief, the answer to these questions are as follows:

- Events recorded by Guards, with three-phase current monitoring, can be located.
    - See sections 5.3.1, 0 and 5.6.2.
- VisNets cannot detect HV events occurring on the network. They will sometimes record the results of heavy wattmetric loads re-energising post fault but not the events themselves.
    - See section 5.7.1 for further discussion of HV events seen by LV monitoring.
- Altering the triggering level of the VisNets did not have any actionable results in regards to locating more events. It did, however, increase the number of non-fault and non-PreFault events recorded.
    - See section 5.1 for further discussion of the VisNet triggering level reduction.
- While both methods of triggering produced actionable results during the project, the voltage triggered devices:
    - Recorded locatable events, like the VisNets.
    - Recorded less load events than the VisNets while recording a greater variety of events of interest.
    - Recorded HV events, providing another avenue to provide visibility to the network.

This section of the report provides details on the insights gained during the 11 months of monitoring for this project.

5.1 BAU Monitoring Devices Review

NPg has over 2000 Guards monitoring ground mounted substations on their network, some of which are monitoring LV OHL feeders. These BAU Guards do not monitor the phases of the feeders and therefore cannot be used to locate LV OHL PreFaults and Faults. However, they can be used to provide supplemental evidence that existing algorithms are suitable for the monitoring of OHL feeders.

As these devices have been installed for longer than the Polesight monitoring devices there is greater historic tracing of events and more evidence is available in the form of repeating events.

Section 5.4 reviews a selection of events from multiple substations that are likely OHL events and provides some evidence of the applicability BAU Guard data from NPg's network providing insights on persistent OHL events.

5.2 Review of Monthly Monitoring Learning

Each month all events captured by active devices were analysed using both the Guard and VisNet algorithms and the results were compared. This provided a high-level overview of what was happening across the device types and allowed adjustments to be made.

5.2.1 VisNet Triggering Level Reduction

When no events were recorded by VisNet devices for the first month of monitoring, the current triggering level was reduced to 350A. There was a recognised risk of event flooding, due to the trigger level interacting with possible high load events on some of the larger transformers. However, this value was chosen based on evidence from the Guard devices, where PreFault events had been seen with lower max event currents.

It was known that on smaller transformers, reducing the current trigger threshold to 350A would still not capture the same number of events of interest as the voltage triggered devices. The Guard devices captured events with maximum event currents under 150A, which would never be a suitable current trigger for any device. As will be discussed further, HV events are generally not associated with large currents on the LV network so the VisNet absolute current triggering level could not be set to successfully capture HV events.

5.2.2 VisNet Interference Issues

It is important to note that as some the VisNets used on this project were of an older model version and were refurbished for the purposes of the project. These devices were susceptible to external interference and large volumes of interference waveforms were seen on a few of the Polesight VisNet devices. The interference occurred at currents under 700A, so in normal BAU operation these events would not have been seen. They have broadly been treated like the load events, insofar that they have been disregarded from detailed analysis.

However, these events, alongside the load events seen when the current triggering level was reduced to 350A, had some use. The Guard analytics has categorisations for “abnormal” and “other” events, of which interference events were broadly categorised as the former while load events were broadly categorised as the latter. As the VisNet algorithm only categorises events as “fault” or “non-fault” there was no way to automatically filter the interference and load events from the “non-fault” events that could be of interest for further investigation.

The Guard algorithm therefore provided a further avenue of investigation when analysing the VisNet captured events.

5.2.3 Overview of events recorded

The Guard devices recorded consistent volumes of events throughout the monitoring period. Excluding May, the months that recorded the most events generally coincided with storm events but otherwise there is minimal variation month to month. The reason for the reduced number of events in February is because monitoring for this project concluded halfway through the month.

As previously discussed, once the current trigger level was reduced, the VisNets recorded numerous load and interference events. Generally, these events were classified as “other” or “abnormal” within the Guard analytics and can be broadly removed from the tally. The original count of events has been provided to show the effects of a reduced trigger setting. The Guards also recorded events classed as “other” but in general they did not appear to be load related events and were a result of insignificant voltage dips.

Table 3 Events recorded by month, split by device type

Month	VisNets	VisNets excl. interference and load events	Guards
April	0	0	339
May	10	1	612
June	1807	36	417
July	3942	482	350
August	3066	48	383
September	1290	64	450
October	8656	103	440
November	10504	127	367
December	3419	104	346
January	8266	169	446
February	2758	105	240
Total	43718	1239	4051

It was recognised in the duration of the project that the only events that could be reasonably located were those with maximum event currents greater than 700A. The event current is the variable that correlates best with the calculated impedance. It was investigated whether the fault energy was a good indicator of whether a fault would produce a locatable impedance but no correlation was found. Therefore, events where the maximum event current surpassed 700A were the events of greatest interest to attempt to locate.

Table 4 Events with maximum event currents greater than 700A recorded, by device

Polesight Device	No. of Events
P01 – Acomb Industrial	2
P04 – Townley Terrace	2
P06 – Haltwhistle Westlands	1
P07 – Syntax	4
P10 – Summerrods	3
P11 – Broomhaugh	3
P12 – Fourstones School	1
P13 – Matfen	1
P14 – West Causey Hill	390
P17 – Mickley Mount	1
P18 – Mickley Junction	3
P19 – Acomb West	1

Polesight 14, West Causey Hill, experienced a major cable fault that generated all but 3 of the events greater than 700A recorded by that device. Key events analysed and other observations from monitoring activities were discussed throughout the project, to ensure any adjustments to the process could be adopted.

A general conclusion that can be drawn from analysing all events with both the Guard and the VisNet algorithms is that a PreFault will generally be recognised as a PreFault by both. The only exception is split-phase devices, which neither monitor was primarily designed for and will require further review.

Table 5 shows a selection of events that were found to be categorised as PreFaults by both analytics algorithms, however for conciseness, only a selection of events have been included in the discussion. Where an event has been categorised as a PreFault by both algorithms but is not locatable, the maximum event current recorded was not greater than 700A. Events that could not be located have not been focused on during this section as they add minimal additional information to the discussion.

Table 5 Comparison of Event Categorisations for Locatable PreFaults

Device	Event	Guard PreFault	VisNet PreFault	Locatable
P04	12/01/2024 22:03	Yes	Yes	Yes
P04	22/01/2024 06:02	Yes	Yes	Yes
P07	21/01/2024 20:23	Yes	Yes	Yes
P10	23/01/2024 23:44	Yes	Yes	Yes
P11	01/06/2023 00:10	Yes	Yes	No
P14	22/06/2023 23:48	Yes	Yes	No
P14	22/07/2023 17:38	Yes	Yes	Yes
P14	23/07/2023 05:20	Yes	Yes	Yes
P18	22/01/2024 02:36	No*	Yes	Yes

*Polesight 18, Mickley Junction, is a split-phase transformer. The Guard analytics had difficulty in analysing any events recorded on split-phase transformers, even when a Guard device had captured the event.

5.2.4 Split-phase Transformer Monitoring

Split-phase transformers were monitored by both voltage triggered and current triggered devices during Polesight. Rural networks often have split-phase feeders and therefore a selection of the substations chosen for monitoring were split-phase.

The split-phase transformers monitored by VisNets captured less events than their Guard monitored counterparts, evidenced by Table 6. However, the only locatable event recorded on a split-phase transformer was on Polesight 18, which recorded the least number of events, excluding the interference events.

No events that could be categorised as PreFaults were recorded by the Guard devices. The PreFault events recorded by VisNets monitoring split-phase transformers were never categorised as PreFaults by the Guard algorithms. This suggests that the method by which the Guard algorithm analyses events relies on voltage characteristics, which are different for split-phase transformers.

Table 6 Split-phase transformers monitored by Polesight project

Polesight ID	Monitor	Tx Rating	Substation Name	% OHL	Events of Interest
Polesight 03	Guard	50	BIRKSHAW	75%	129
Polesight 05	Guard	50	CHOPWELL WOOD	78%	94
Polesight 09	Guard	100	HIGH CATTON	53%	54*
Polesight 15	VisNet	100	SLALEY POLICE	45%	38
Polesight 16	VisNet	100	WENTWORTH ALLENDALE	24%	35
Polesight 17	VisNet	100	MICKLEY MOUNT (HEX)	96%	20
Polesight 18	VisNet	100	MICKLEY JUNCTION	62%	6

*Polesight 09, High Catton, was removed in August 2023 and not reinstated. This was due to transformer upgrade works and not because of any failure with the device.

The Guard devices recorded only “HV” or “other” events when monitoring split-phase transformers. It can be reasonably assumed that for PreFault events on split-phase devices, provided the current phases available are monitored, the events should be detectable and locatable. There is limited evidence available beyond the event at Polesight 18 (discussed in Section 5.6.4) but the current analysis seems to have had more success in analysing the events regardless.

Split-phase Monitoring and HV Events

This is evidenced further in Section 5.7.6, which covers HV events detection on LV monitors in greater detail. However, in brief, it was seen that the Guard devices monitoring split-phase transformers did not trigger on HV events as consistently as their counterparts monitoring three-phase transformers.

The split-phase devices are connected to only two of the three HV phases. When investigating why the split-phase transformers did or did not trigger for particular upstream events, it was determined that constructional differences between the two different transformer types meant that the measured voltage excursions following a voltage disturbance on a higher voltage system could not be compared like-with-like with the three-phase devices.

Therefore, only devices connected to three-phase were used in comparative data studies for investigating potential HV network insights from LV monitoring equipment.

5.3 Transient Events and Developing Faults

During this project none of the OHL PreFaults recorded by the pole mounted Guards or VisNets developed into faults. However, NPg has installed a substantial number of Guards in ground mounted substations. Some of these substations have mixed LV feeders. OHL PreFaults, which developed into faults during the timescales of the project, were detected by a few of these substations. These are reviewed in section 5.3. All LV OHL Fault events recorded by Polesight devices were damage events due to adverse weather.

However, this does not mean there were no PreFaults that looked to be developing faults. Polesight 04, Townley Terrace, had a promising and locatable PreFault event, followed by a non-locatable, but still promising PreFault event under two weeks later. While the feeder had not experienced a Fault at the time of writing, this feeder could provide the first monitored OHL developed Fault.

When reviewing events captured by the monitoring devices, three questions were posed to be answered:

- Could there be something interacting with the line, a tree branch for example, at any of these locations?
- Are there visible signs of damage around any of the prospective fault locations? Scorches or broken conductors for example.
- Were there any outages on the feeder around the time of the event?

These questions were the starting points for contextualising recorded waveforms within the physical world.

5.3.1 Polesight 04 – Townley Terrace PreFault Events

1st PreFault Event

At 22:03:38 on the 12th of January, the Guard device monitoring the Townley Terrace substation, Polesight 04, recorded a PreFault with a credibility of 3 out of 10. This is relatively low, but the impedance recorded was locatable, so EA Technology implemented the methodology used on LV cables to attempt to locate the fault on an LV OHL.

Townley Terrace is the only monitored substation on the Polesight project with a feeder that consists entirely of OHL. For this reason, it was of top priority to investigate any viable events on this device.

1st Recorded Event Waveform

The recorded event occurred primarily on the L3 phase of the feeder. The analytics defined this event as a PreFault. This was the algorithm developed for cable faults and, should the location of the event determined to be correct, would provide evidence that PreFaults seen on OHL networks can manifest similarly to underground cable networks.

The red, yellow, and blue sinusoids are the L1, L2 and L3 voltages. The grey line is the neutral current while the green, orange and purple lines are the L1, L2 and L3 currents respectively.

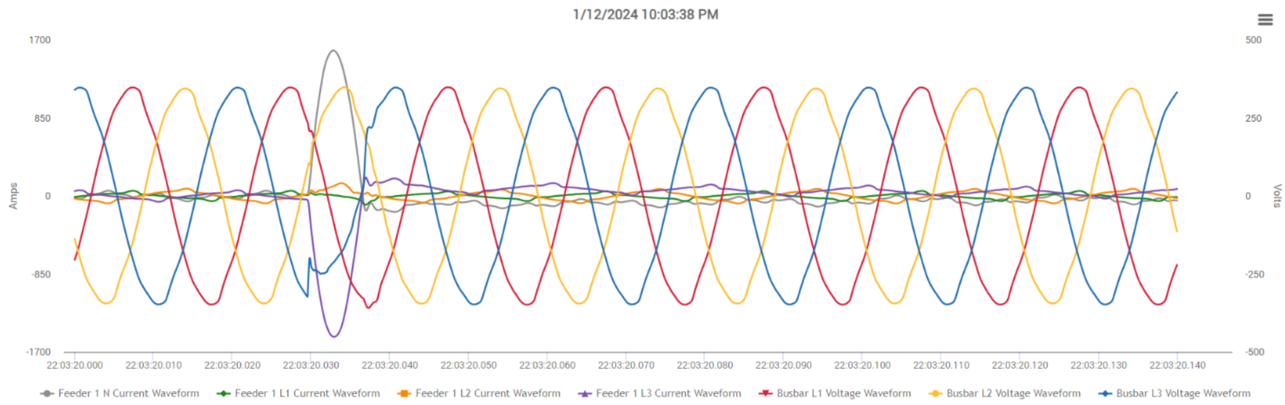


Figure 17 Polesight 04 – Townley Terrace PreFault Event

The distinctive PreFault shape on the waveform, where the large current spike on L3 is mirrored by a large current spike on the neutral, occurs at the same point a clear voltage notch is visible on the L3 voltage. This is what would have triggered the Guard to capture the event. The algorithms then categorise the event based on multiple characteristics on all waveforms to differentiate it from other commonly seen events.

1st Event Possible Locations

Using the standard algorithms for PreFault location the iSmart feeder map was marked up in red where the algorithm provided locations. The three locations are shown below. Three locations were given due to the branching nature of the feeder, the recorded impedance corresponding to different parts of a feeder.

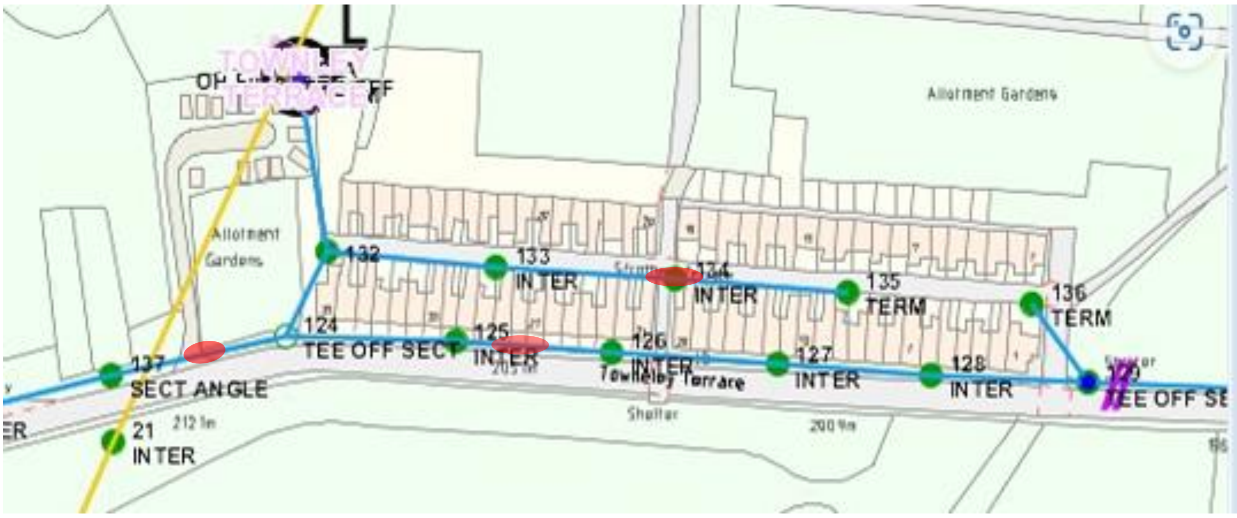


Figure 18 Polesight 04 – Townley Terrace 1st event identified PreFault locations

1st Event Location 1: Pole in Strothers Terrace

This location seemed the most likely out of the three determined due to the number of opportunities for joint or other asset breakdowns.

The benefit of looking for evidence of an OHL PreFault is that the possible branches are visible by a pedestrian.

In this location, since the impedance indicated the PreFault was somewhere around the pole, it could be that the service to one of the domestic properties was the source of the PreFault. It is not uncommon that service faults are identified by monitoring as there is no way to discern between the mainline and a service until a fault has occurred.

1st Event Location 2: Clayton Terrace Road, in front of houses

Nothing of note can be highlighted at this location to determine where the PreFault could be located. Like the previous example is could be located on a service or there could have been an event at the pole. Without a related fault this is speculative.

1st Event Location 3: Clayton Terrace Road, above junction

Like the other Clayton Terrace Road location there is nothing that immediately suggests the location of the PreFault. However, the line being hard drawn bare copper (HDBC) could suggest that the transient PreFault was the result of clashing conductors. This was a hypothesis provided at the time of the event but further evidence from other events suggest that this is not the cause of this PreFault.

This event was classed with a low credibility, so the impedance calculated by the algorithm has given likely, but not exact, location. Until further locatable PreFaults occur, either with higher credibility or more clustering in one location on the circuit, this location should be used to build a picture of the health of the circuit. Locations may not be accurate but offer opportunities to investigate and test hypotheses, especially when combined with further events.

2nd PreFault Event

On the 22nd of January at 06:02:17 there was a recorded PreFault on this feeder. Occurring primarily on the L2 feeder, this event has some differences to the previous event. Unfortunately, the second event provided a different location, which suggests it is a different event. As it occurred on this OHL feeder some further investigation took place to investigate hypotheses.

2nd Recorded Event Waveform

Figure 19 Polesight 04 – Townley Terrace 2nd PreFault Event

This event was locatable with the present algorithm. It had a lower peak event current than the first PreFault recorded on this feeder and the event occurred on a different phase. Although the voltage disturbances bear resemblance to the previous PreFault seen at this substation, this event has a larger effect on the other phases.

These factors suggest that this event is different from the one previously recorded, so a location check was undertaken.

2nd Event Possible Locations

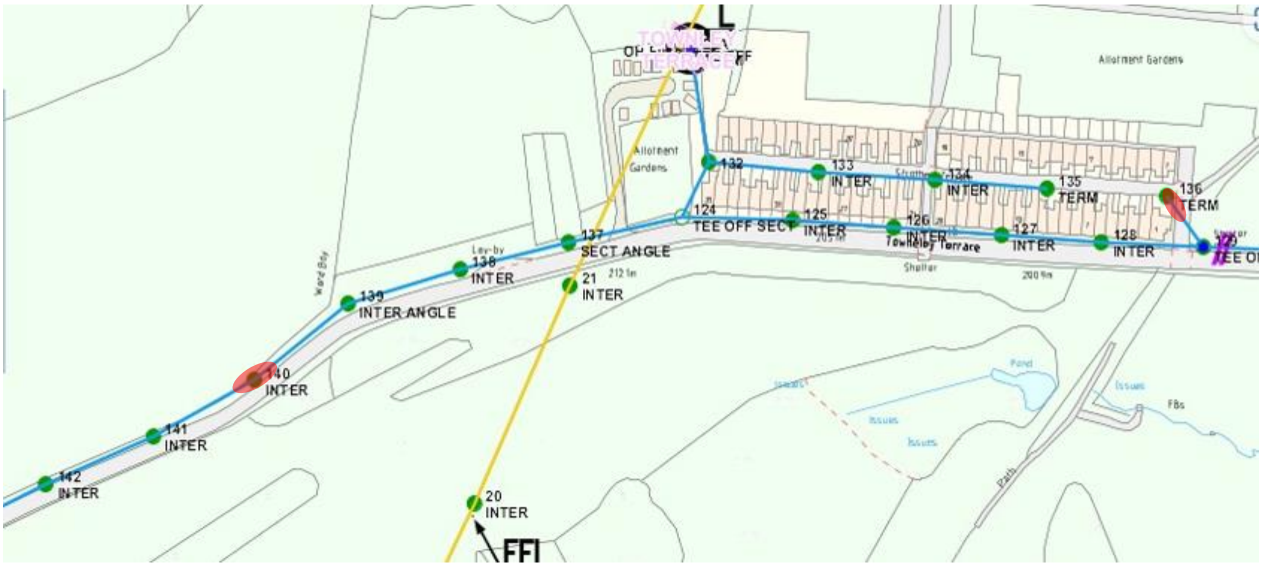


Figure 20 Polesight 04 – Townley Terrace 2nd event identified PreFault locations

It is likely that this event is not the same event as the 1st event located. In both cases, an outage or some other customer impact would have had to be reported to support the generation of any further hypotheses.

2nd Event Location 1: Pole 136 on Strothers Terrace

The sagging conductors visible in these images could be the cause of the PreFault event. While this waveform does not align with other suspected clashing conductor events, Storm Isha was in effect around the 22nd of January and was causing windy conditions.

This location also leads to service supplies, which could also be the location of the event.

2nd Event Location 2: Pole 140 on Clayton Terrace

This location is in an open environment, with minimal obvious objects to interact with the line.

Without a fault, none of the locations can be calculated for these two events can be determined to any level of accuracy. There are likely two distinct PreFaults on this feeder, which provides more opportunities to follow the development of a fault, enabling these PreFaults to be used in conjunction with future events to understand how a fault develops.

It is likely that Townley Terrace will provide a use case for monitoring the development PreFaults into faults on LV OHL feeders, however this has not occurred within this project.

5.4 LV Overhead Line PreFaults and Faults as Seen by Ground Mounted Substations

A substantial number of Guards monitor the ground mounted substations of NPg's network, with some of them clearly feeding LV OHL feeders. While these Guards do not monitor the phases of the feeders, and therefore cannot be used to locate LV OHL PreFaults and Faults, they can be used to provide supplemental evidence that existing algorithms are suitable for the monitoring of OHL feeders.

These devices have often been installed for longer than the Polesight monitoring devices, which allows for greater historic tracing of events. More evidence is available in the form of greater numbers of repeating events.

Summary LV Fault data from the NPg OMS system for FY 2023/24 to early January, which was provided by NPg, was cross checked against the names of substations that have a Guard, an Alvin and/or a VisNet installed and have sent event data.

5.4.1 Review of Brickgarth Incidents

The information in each Incident Report was compared with information from the iSmart GIS system and captured Waveforms from LV network Events recorded by the Guard Device installed at Brickgarth Substation and displayed by EA Technology Detect Pro system. It has been assumed that a loss of supply occurred shortly before the Open datetime in the relevant incident report.

Table 7 Brickgarth Substation Way Identification of Active Feeders

Way	Identification	%OHL
Way 2	BRICKGARTH WEST	0%
Way 3	BRICKGARTH EAST	34.3%
Way 4	P.64	52%
Way 5	HIGH STREET	0%

The Brickgarth incident reports were for:

- One O/H Mains repair.
- Four O/H Service repairs.
- One Intermittent Non-Damage.
- One Safety Interruption, which was for a cable and therefore not discussed in this report.

It is probable that the O/H Mains fault was detected by the monitoring Guard at Brickgarth.

Two of O/H Service faults were probably detected. These faults were reported as types:

- X2 FAULTY NECK ENDS.
- Vulcanised Insulated Rubber (VIR) cable.

The faulty neck ends fault had a series of harbinger PreFault events which preceded the fault.

The other two O/H Service Faults were not detected. These were of type:

- Faulty insulink.
- Hole found in cable.

However, it is possible that the operational topology of the LV network at the time of the fault might not be as shown in iSmart and that these faults were on a circuit fed from Elemore substation.

The Safety Interruption was reported as cutting LV Main for safety to enable a repair of a cable thumping adjacent to 91 Brickgarth. This incident is not of interest to the Polesight project because it relates to a cable.

O/H Mains Repair

The Guard at Brickgarth recorded a L2 phase/neutral event at 16:22:42 on 20th October 2023, approximately 38 minutes before the open datetime of INCD-446847-A. However, if this was a fault then the fault current was much lower than those observed from cable faults.

There was no loss of voltage on any phases, and the fault report states that six customers lost supply for 5 hours 8 mins. This implies no fuse blow as there would have been a larger number of customers off supply. The incident report states, "Loose Connection on Pole 99 Repaired/Supplies restored 10:05". Pole 99 is a termination pole on a short spur of Brickgarth Way 4 (from a Tee point at Pole 62). Way 4 neutral current varied between 45A and 105A between 16:00 and 18:00, which is a similar variation to that seen earlier times in the day.

There were 3 events detected (Figure 21) on 20th October 2023. All were on Way 4 P64, determined from the neutral current and all were classified as PreFaults. The first two, at 15:36:34 and at 16:05:43, were blue phase to neutral events with peak current less than 700A. The third event, recorded at 16:22:42, was a L2 phase to neutral event with peak current of 985A.

All these events have much lower peak neutral current than is typically seen from a cable fault.

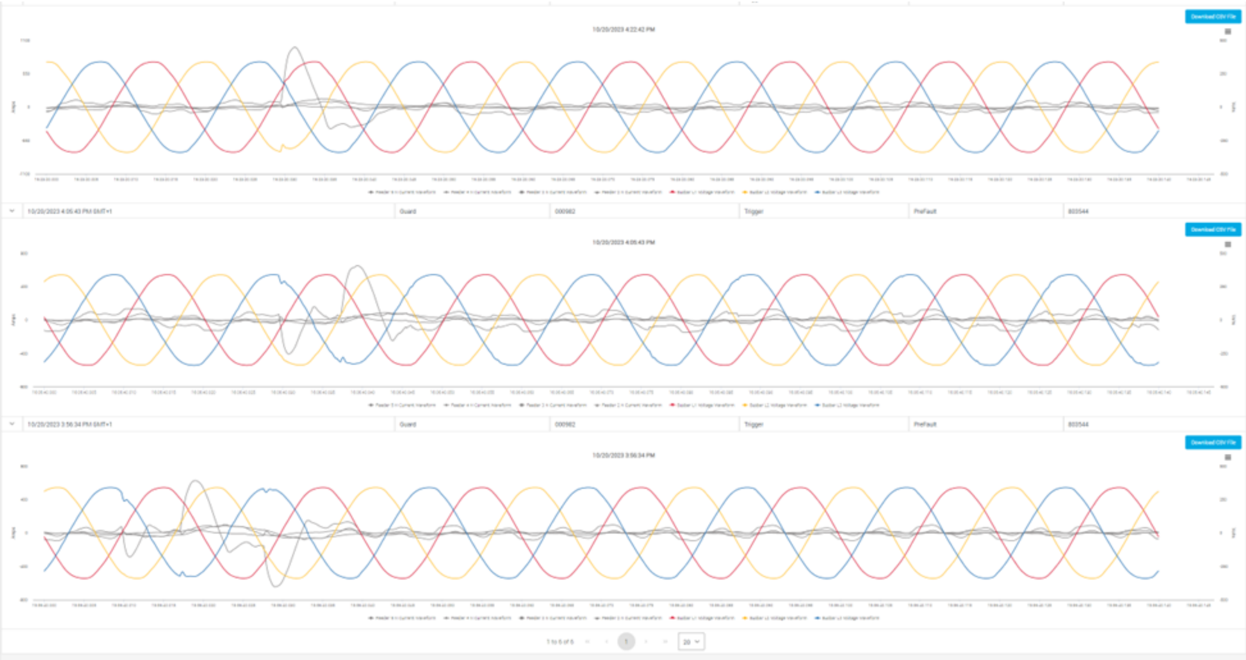


Figure 21 Screenshot of events captured on the 20th of October 2023, Brickgarth Way 4.

It is possible that the Guard at Brickgarth recorded a fault event at 16:22:42 however if this was a fault then OHL fault currents are much lower than cable fault currents. It is likely that that the I^2T of this event is insufficient to blow a 400A fuse.

Therefore, it is likely that the event was recorded and is one of these PreFault events shown. This provides some evidence that O/H mains faults are detectable by the Guard monitors, even in the event they do not blow the fuses.

Likely Detected O/H Service Repairs

There was an O/H service repair at 9 & 10 Girvan Terrace on the 22nd of July 2023. Seven PreFault events were captured from Brickgarth Way P 64 on the day of the fault. The last event is probably the fault event and had a peak neutral current of 1,265A which continued for three cycles. The first event was 8hr 37m before the loss of customer supply.

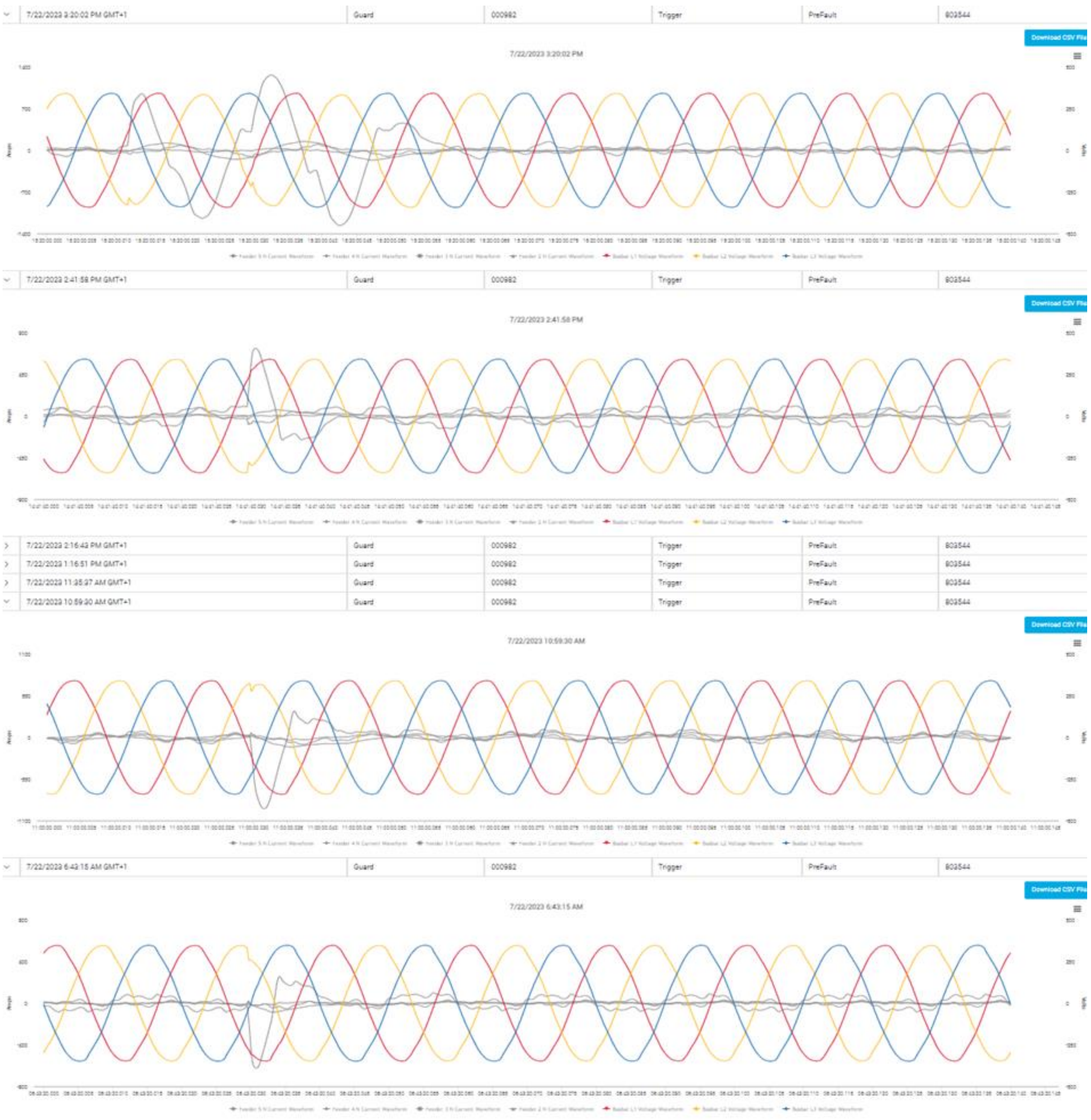


Figure 22 Screenshot of the most pertinent of the seven events captured on the 22nd of July 2023, Brickgarth Way 4.

It seems that a developing fault was detected in an OHL service connection, which faulted at 15:20:02 on 22nd July 2023, and was reported by the customer at 16:45pm. All the captured events, including the fault, were categorised by the algorithms as PreFaults. The fault type was reported as "X2 FAULTY NECK ENDS REPAIRED, POWER OFF AT 1645, POWER RESTORED AT 1725".

The final event in this sequence can be called a fault in this instance. If there had been current phase information associated with this event then it is likely that a location could have been identified.

There was an O/H service repair on the 26th of October 2023 and it is probable that this fault was detected. The fault type was recorded as: "VIR cable repaired, 2x customers on L1 phase, restored at 21:00." VIR refers to an older type of concentric single phase service cable. The centre core is the phase, and the neutral is the concentric conductor. Where the neutral and live are separated, this is referred to as the neck end. Faults can occur here as the rubber on these older VIR cables deteriorates over time allowing water ingress and eventual flashover.

There was a PreFault event recorded from Brickgarth on Way4 P64 at 12:39:01 i.e., 44 minutes before the incident was opened (the incident presumably was opened when a customer outage was reported). This looks to be between L3 phase and neutral. With 7 repeats. Then the Way 4 neutral current trace returns to “normal”. This is indicative of a fault that has blown clear (faulted open circuit) without blowing the source fuse.

There was a previous PreFault event recorded on 25th October at 09:15:59 where the waveform shows a PreFault between L3 phase and L2 phase. There was also a PreFault between L2 phase and neutral recorded on 24th October at 05:32:27.

Since the suspected fault event recorded was between L3 phase and neutral, that customers’ supply was restored by moving then from L3 to red phase. However, previous PreFaults indicate that either the L2 phase was involved in this fault or that there is another fault developing on this feeder.

These incidents provide some evidence that the Guard monitors can detect O/H service faults and will categorise them as PreFaults.

Undetected O/H Service Repairs

The two service repairs occurred on the 22nd of May 2023 and the 12th of October 2023. Neither of these service repairs can be associated with events as there were none on either feeder in the preceding days.

No events were recorded on Brickgarth Way 4 (P64) on 22 May 2023.

Therefore either:

1. The trigger threshold is too low to detect OHL service faults of this type (faulty insulink replaced on front of no.8, restored @ 09:25), even when the fault is very close to the substation; or
2. The operational topology of Brickgarth Way 4 might not be as shown in iSmart. No 8 Bradley Terrace might have been fed from Elwood Way 5 on 22nd May 2023.

No events seen on Brickgarth Way 4 P64 from 10th October 2023 to 12th October 2023 inclusive.

Either:

1. The trigger threshold is too low to detect OHL service faults of this type: (HOLE FOUND IN CABLE SO NECK END REPAIRED); or
2. The operational topology of Brickgarth Way 4 might not be as shown in iSmart. No 9 Girven Terrace might have been fed from Elwood Way 5 on 12th October 2023.

Note: This is the same property that received an ad-hoc repair for a service fault which was detected approximately 3 months earlier.

Intermittent Non-damage Fault Event

On the 5th of September 2023 there was an Intermittent LV fault on Brickgarth Way 3. The initial loss of supply, which was reported at 09:01, was not captured as an event. The initial fuse blow event of the Intermittent Non-Damage fault was not detected. However, PreFault events that were captured between 10:25 and 10:28 are probably the failed attempts at restoration using 400A fuses reported in the incident report, before supplies were restored using 500A fuses. PreFault events restarted approximately 5h 45m after the restoration and continued to be detected on Way 3 which were likely produced by the defect which caused the Intermittent Fault.

It is unclear whether this fault was caused by a cable defect or OHL defect, and it is still producing PreFault events after the replacement.

This case provides an example of a situation where monitoring the three-phase currents alongside the neutral would likely provide a location of the intermittent fault. This would allow for the underlying problem to be fixed at the source of the intermittent fault. However, as there is no information as to whether this intermittent fault is on an OHL or a cable, no further conclusions can be drawn from this incident.

5.4.2 Review of Maria Pit Incidents

This section describes the findings from a review of the Incident Reports relating to Maria Pit Substation. The information in each Incident Report was compared with information from the iSmart GIS system and captured Waveforms from LV network Events recorded by the Guard Device installed at Maria Pitt Substation and displayed by EA Technology Detect Pro system. It has been assumed that a loss of supply occurred shortly before the Open datetime in the relevant incident report.

Table 8 Maria Pit Substation Way Identification of Active Feeders

Way	Identification	% OHL
Way 1	NURSING HOME PONTELAND RD	0%
Way 2	HARDIAN HOUSE AGED PERSONS FLATS	0%
Way 3	MARIA PIT W3	0%
Way 4	LB 605 & 536	20.2%
Way 5	HEXHAM RD LB 503	0%
Way 6	HEXHAM RD LB 502	0%

The Maria Pit incident reports found were for:

- One O/H Mains repair.
- One O/H Service repair.
- Two Non-Damage Restorations, both were for cable feeders and therefore not discussed in this report.
- One Intermittent Non-Damage, again for a cable feeder and therefore not discussed in this report.

O/H Mains Repair

The O/H mains fault was caused by vegetation shorting out L2 phase.

It is probable that the fault which was reported at 12th of December 2023 11:28:00 was an event detected by the guard at Maria Pit SS at 11:13:01.There were a large number of PreFault events, both single phase and multi-phase, recorded on this feeder, from September 2023 to January 2024, plus a similar number of events that were not categorised as PreFault but by eye clearly indicate a developing fault.

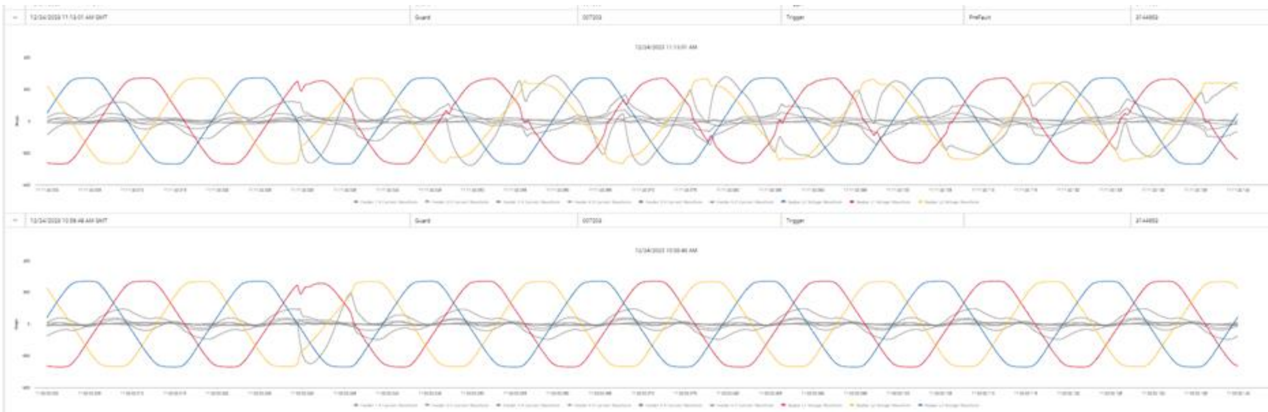


Figure 23 Screenshot of the event captured before the O/H mains fault at Maria Pit and the top event believed to be the fault

The waveform shows a clear extended repeating breakdown on sequential half cycles, between L2 Phase, L1 Phase and Neutral of feeder 4. The event extends beyond the end of the capture, which is indicative of an extended arc breakdown.

There were 30 events categorised as single-phase PreFaults and 79 events categorised as multi-phase PreFaults recorded on Feeder 4 from September 2023 to January 2024. The output of the PreFault event trending dashboard can be found in Section 5.5. There were also a similar number of events, similar to the event at 10:58:48 on 24th December 2023, that were not categorised as PreFault but by eye clearly indicate a developing fault. These mainly involving L1 and L2 phases, but also some involve the L3 phase. It is possible that the L3 phase events relate to another developing fault in this feeder.

The recording and categorisation of this vegetation encroachment event provides some evidence that the Guard monitors, already installed in NPg's network, can recognise OHL events and will categorise them as PreFaults.

O/H Service Repair Fault

The O/H Service Repair fault was caused by a failed Vulcanised Insulated Rubber (VIR) neck end supplying 1 & 2 Oak Street. It is possible that the L3 phase to neutral event on Feeder 4 captured on the 10th of November 2023 at 00:02:13 was the fault causing supply loss reported at 11th of November 06:36:00. There were previous L3/neutral PreFault events recorded.

There was a PreFault event captured on the 11th of November 2023 at 06:32:41 however this was a L2 phase to neutral event on Feeder 6, not the feeder of interest.

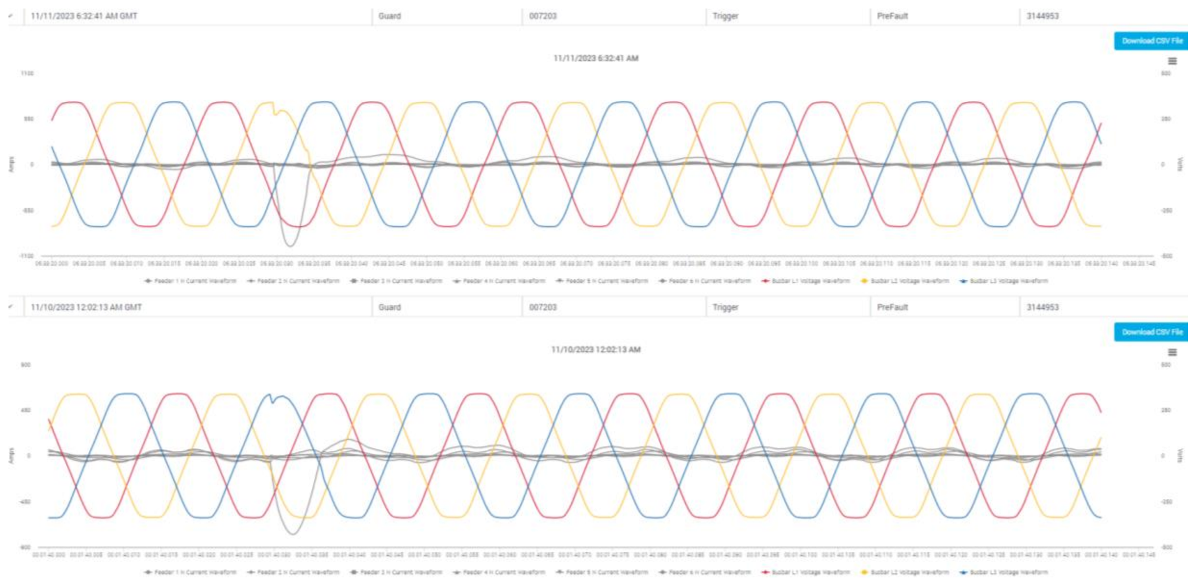


Figure 24 Screenshot of the events captured before the O/H service fault at Maria Pitt

There were previous L3/neutral PreFault events recorded, plus some including L2 phase in addition to L3 phase. Some Y-B-N events were not categorised as PreFault but are clearly a developing fault.

Alongside the previous events surrounding the O/H service repairs on different substations, this event provides some evidence supporting the fact that Guard monitors can detect and identify OHL events.

5.4.3 Review of Warthill Incident

This section describes the findings from a review of the Incident Reports relating to Warthill Substation. The information in each Incident Report was compared with information from the iSmart GIS system and captured Waveforms from LV network Events recorded by the Guard Device installed and then displayed by EA Technology Detect Pro system. It has been assumed that a loss of supply occurred shortly before the Open datetime in the relevant incident report.

No data for LV feeders from Warthill Substation was available in the connectivity data used for feeder tracing. Therefore, the following information for Warthill Substation was obtained manually by inspection of iSmart.

Warthill Substation has two spare ways (Way 1 and Way 5), one feeder with a single section of cable to a pot end (Way 3) and 2 active feeders.

Table 9 Warthill Substation Way Identification of Active Feeders

Way	Identification	% OHL
Way 2	NETWORKPOLE 9	38.4%
Way 4	Un-named	0%

Bird Strike Incident

An event was detected at 07:46 on 26th December 2023 and was the only event captured on that day.

A customer stated, "[he] saw a pheasant fly into the LV OH Line outside his house @0730/45 and all the lines were bouncing about and flashing". The line taps were burnt off.

The waveform shows a three-phase plus neutral discharge on Way 2. This discharge triggered the capture but it was not categorised as a PreFault. The captured waveform is shown below.

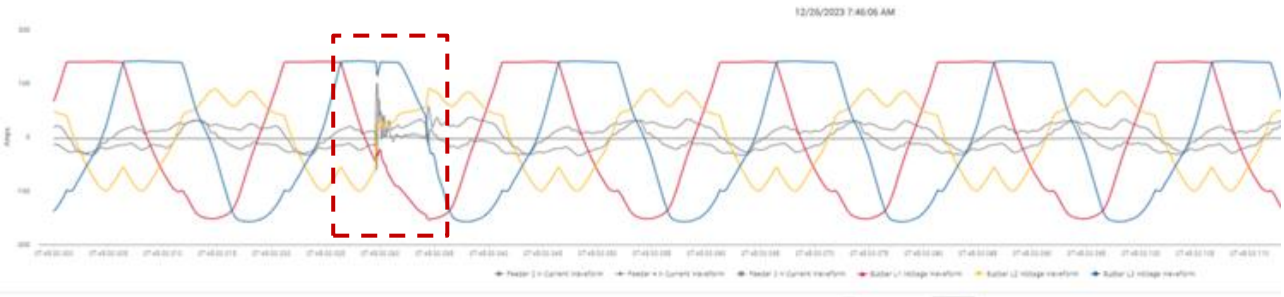


Figure 25 Screenshot of the events captured before the bird strike (in box) incident at Warthill

The capture shows an unusual voltage waveform. The L1 and L3 phases show clipping on the positive half cycle plus notching on the negative half cycle. The L2 phase is more symmetrical with features that coincide with the points at which the L1 and L3 phases become non-sinusoidal, plus significant harmonics. However, this voltage waveform is seen in every event capture from the substation which has been manually checked visually, including the very first capture on 1st of March 2023.

Therefore, these unusual voltage waveforms are likely to indicate another fault exists, which has not interrupted supplies.

However, the neutral current disruption on Way 2 that was captured as result of the pheasant interacting with the lines does provide an indication of what bird, or other animal, strikes look like on the waveform capture. This would require further investigation to understand if it is quantifiable for a future OHL event type.

5.5 PreFault Event Parameter Correlation with Time to Fault

"Time to fault" refers to the period between the first identified PreFault event and the fault becoming permanent. It is important to note that the first identified PreFault may not be the first PreFault to occur, only that it is the first one recorded by monitoring devices. Monitoring aged assets is important and the most likely place LV monitoring will be implemented, but the information gained from monitoring can only provide insights from the start of the monitoring period. The historic performance and activity of an asset cannot be accounted for when considering time to fault.

Assessing when an asset will fail is not an exact prediction, it is a statistical analysis.

EA Technology provides a Watchlist of assets monitored by Guards in the NPg area already. It does not predict when an asset will fail but it counts the number of PreFault events occurring in a period and sorts them into five categories:

- Healthy.
- Early Warning.
- Poor Condition.
- Failure Likely.
- Failure Imminent.

These categories do not account for the severity of the possible fault, only considering the number and types of events recorded by the Guard devices. A device moving from one category to the next, for example Poor Condition to Failure Likely, is of more concern than a device sitting in one category for a period of time. Each device has its own "Event trending" chart which can be used to look back at the historic events on the device and assess the level of activity recorded.

PreFault events have been detected on some of the circuits with pole mounted Guards and VisNet monitoring instruments, however the faults which have occurred on these circuits have been due to storms and not due to degradation or other gradually operating causes. Therefore, it has not been possible, using these instruments, to track the development of circuits with recorded PreFault events to a fault.

However, as a separate initiative to the Polesight project, NPg has installed a number of Guard instruments in ground mounted substations, including some that have mixed underground and overhead LV circuits.

Brickgarth, Maria Pit and Elemore Lane had LV overhead line faults preceded by PreFault events, i.e. asset degradation and deterioration was the cause of the fault. Warthill had an LV Fault caused by a bird strike, so no PreFault events preceded the fault.

This section describes the tracking PreFault events, which were detected by Guard Device installed at each of the substations, which developed into to one or more recorded OHL faults on LV circuits. The faults are considered by LV circuit in chronological order. The PreFault events that were detected are considered and related to faults which have occurred.

The likelihood of further faults is highlighted if the PreFault information indicates that further faults can be expected. Then the applicability of the time to fault information to LV OHL of the Cable Condition indicator that was developed in the Foresight project is explored in the final section.[8]

5.5.1 Brickgarth

Brickgarth distribution substation has two purely underground circuits and two circuits which are mixed, with underground and overhead feeder sections. The mixed circuits are:

1. Way 3: BRICKGARTH EAST, 34.3% OHL
2. Way 4: P.64, 52% OHL

Between April 2022 and January 2024 there were 38 single phase PreFaults recorded on Brickgarth Way 4 P64, of which 33 were L2 to neutral, 3 were L3 to neutral, 2 were L1 to neutral plus 16 multiphase PreFaults.

[8] Foresight Report | EA Technology

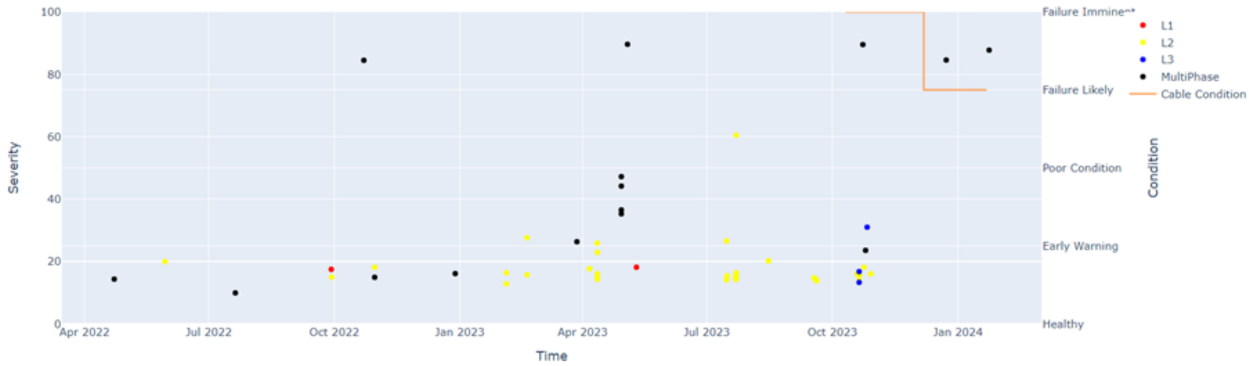


Figure 26 Chart of Brickgarth Way 4 events categorised as PreFaults

The L2 PreFault events that were detected all have a severity between 13 and 27, with the exception of one event with a severity of 60. These appear to be mainly clustered into five groups each occurring within a period of several days. There are relatively long durations between these clusters, with an occasional solitary event. It is possible that this pattern is weather-related.

Events were identified as likely to be the faults which resulted in one O/H Mains repair and two O/H Service repairs.

There was an overhead service fault first reported at 16:45 on the 22nd of July 2023. Seven single phase L2 events were recorded on the 22nd of July. The last of these is the event with a severity of 60. It is likely that this is the fault event and that the other events on that day are also related to this fault.

There was an overhead mains damage fault which caused loss of supply that was first reported at 17:01 on the 20th of October 2023. Six customers lost supply due to a loose connection on Pole No.99. Pole 99 is a termination pole on a short spur of Brickgarth Way 4 (from a Tee point at Pol 62). An L2/Neutral event waveform was recorded by the monitoring Guard on Brickgarth Way 4 at 16:22:42, approx. 38 minutes before the open datetime of INCD-446847-A. It is probable that this event was the O/H Mains fault. There were two L3 single phase PreFault events recorded shortly before the single phase L2 event at 16:22:42.

There was an overhead line service fault reported at 13:03 on the 26th of October 2023. A single phase L3 PreFault was recorded at 12:39:01. It is likely that this is the fault event. The two L3 events that were recorded on the 20th of October more likely relate to this service fault than to the mains fault.

It is not possible at this time to determine which of the L2 PreFaults relate to the mains fault and which relate to the service fault, except to say that there were L2 PreFaults after the service fault was repaired, indicating that there was another incipient fault on this feeder. This suggests that the L2 PreFault events were being produced by more than one defect. The three L2 PreFault events recorded after the mains fault was repaired indicate than there is yet another incipient L2 fault on this feeder. The absence of L3 PreFaults since the service fault was repaired suggest there currently is not a developing L3 fault.

However, there does appear to be a multiphase fault that is continuing to generate PreFault events which are growing in severity. It is likely that there will be another fault on this circuit soon.

5.5.2 Maria Pit

Maria Pit distribution substation has five purely underground circuits and one circuit which is mixed, with underground and overhead feeder sections. The mixed circuit is:

1. Way 4: LB 605 & 536, 20.2% OHL

Between September 2023 and January 2024 there were 30 single phase PreFaults recorded on Maria Pit Way 4 P64, of which 9 were L1 to neutral, 10 were L2 to neutral, 11 were L3 to neutral, plus there were 79 multiphase PreFaults.

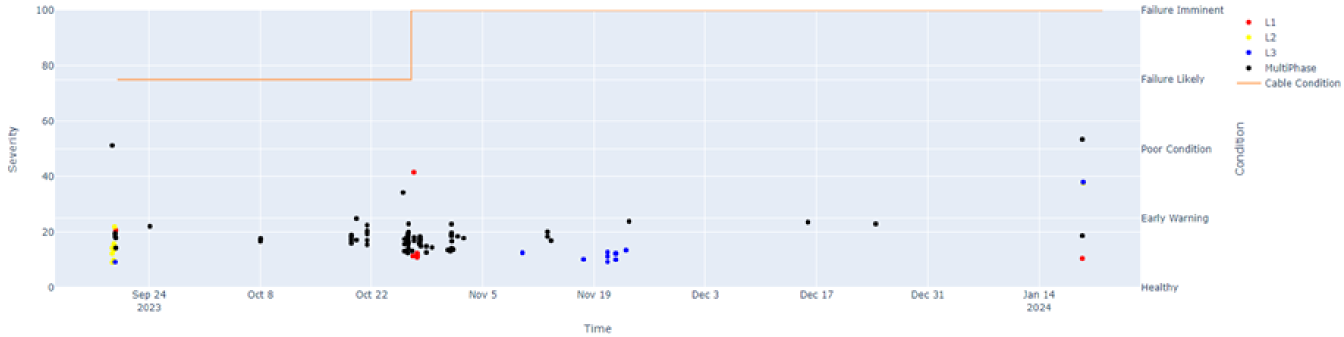


Figure 27 Chart of Maria Pit Way 4 events categorised as PreFaults

There was one O/H service repair reported on 11th November and one O/H Mains repair incident reported on 24th December on Maria Pit Way 4.

The O/H service fault was due to a failed VIR neck end. It is possible that the L3 (to neutral) event on feeder 4 captured on the 10th of November 00:02:13 was the fault causing supply loss reported on the 13th of November at 18:36:00. However, there were a cluster of L3 events captured between 17th November and 23rd November, plus a more severe L3 event was captured on 19th January 2024. Therefore, there is a gestating L3 fault which has not yet occurred. The event, which was captured on 10th November, was over 24 hours before the fault was reported, therefore it is more probable that this event is a pre-cursor of a fault that has not yet occurred.

The O/H Mains fault on the 24th of December was due to vegetation shorting out L2. It is probable that the fault which was reported on the 24th of December at 11:28:00 was an event detected by the guard at Maria Pit SS at 11:13:01. The waveform shows a clear extended repeating breakdown on sequential half cycles, between L2, L1 and Neutral of feeder 4. There were 77 multiphase events, categorised as PreFaults, recorded between 19th September and 24th December. Six of these events were on the 19th of September. There were also nine L2 PreFaults, one L1 PreFault and one L3 PreFault detected on this day. There were several clusters of multiphase PreFaults between 19th October and 2nd November. There were many more events on this day than on the day of the supply loss. This behaviour may be indicative of vegetation causing discharges which eventually lead to a supply loss event.

If this observation is duplicated on other circuits that have faults caused by vegetation then this signature could be useful as an early sign that vegetation needs cutting.

There have been two multiphase PreFaults detected on Way 4 since the O/H Mains fault repair, both occurred on 19th January 2024. An L1 (to neutral) PreFault and an L3 (to neutral) PreFault were also detected on 19th January. It is probable that these events are related to another developing fault, possibly the gestating L3 fault is growing to include other phases.

5.5.3 Elemore Lane

Elemore Lane distribution substation has three purely underground circuits and one circuit which is mixed, with underground and overhead feeder sections. The mixed circuit is:

1. Way 6: P.49 ELEMORE LANE & P15 THAMES ST, 53%

Between March 2023 and January 2024 there were 1392 single phase PreFaults recorded on Elemore Lane Way 6 P.49 ELEMORE LANE & P15 THAMES ST, of which 1385 were L1 (to neutral), 5 were L2 (to neutral), 2 were L3 (to neutral), plus there were 31 multiphase PreFaults. The last L1 event was recorded on the 12th of December. There were two L3 PreFault events recorded on 14th of December 2023 but nothing since then.

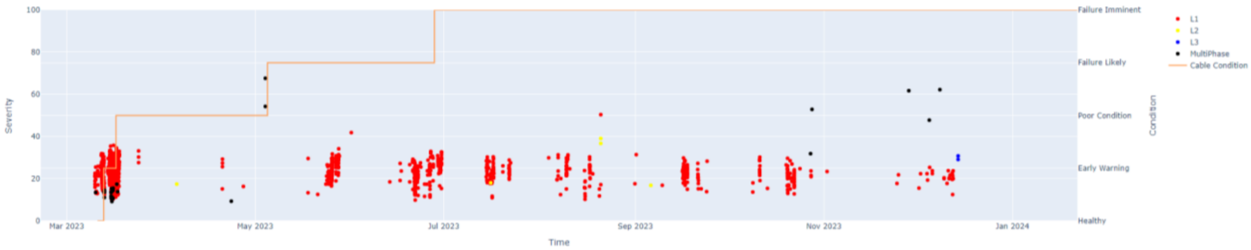


Figure 28 Chart of Elemore Lane Way 6 event categorised as PreFaults

There was an O/H Mains fault on the 12th of December caused by tail burning on an ABC box. The discharging within the ABC box, which led to the burning that resulted in a supply loss incident, is very clear from the Event Tracking Chart. There were 1385 individual L1 PreFault events recorded between the 10th of March 2023 and the 12th of December 2023.

There is an early indication of a defect on L3, which might progress to a fault in time. It is not clear whether the L2 PreFault events, which occurred between the 5th of April 2023 and the 6th of September of 2023 are related to the developing fault in the ABC box or are an indication of another developing fault.

5.5.4 Cable Condition

In addition to recording the time, severity and phase of PreFault events, the charts shown in the previous sections also have an indicator of feeder condition.

This indicator has five possible states, ranging from Healthy, indicating that a fault on the circuit is unlikely, to Failure Imminent, indicating that a fault on the circuit is highly likely in the near future. This condition indicator was determined from a statistical analysis of LV cable faults in the Foresight Project, therefore is called the Cable Condition.

Although this indicator was developed for LV cables, it does appear to have relevance for LV OHL. The Cable Condition of Brickgarth Way 4 was indicating the state Failure Imminent when the overhead service fault occurred on the 22nd of July. It remained in this state until after the overhead mains damage fault on 20th October. It dropped to state Failure Likely on the 7th of December. This is because there was less activity in the 12 months to the 7th of December than in the 12 months to earlier dates.

The Cable Condition of Maria Pit Way 4 was indicating the state Failure Likely on 19th of September. This is primarily because of the significant number of PreFault events on that day. It moved to state Failure Imminent on the 28th of October, during the period when there were several clusters of multiphase PreFaults. It has remained in this state since the faults occurred because activity has been recorded for less than 12 months so far and the NPg have not used the facility to report fault repairs for this feeder, which would change the Condition state. There was an O/H service fault caused by a failed VIR neck end reported on the 11th of November and an O/H Mains fault caused by vegetation reported on the 24th of December.

The Cable Condition of Elemore Lane Way 6 was in the state Healthy on the 11th of March, however there was a large cluster of L1 PreFaults of increasing severity, plus several lower severity multi-phase PreFaults recorded between the 10th of March and the 17th of March. The Cable Condition increased to Early Warning on 13th March and increased again to Poor Condition on the 17th of March, because of these PreFault events. It increased again to Failure Likely on the 5th of May, due to several more L1 PreFaults and a few multiphase PreFaults. It increased again to Failure Imminent on the 28th of June. There was an O/H Mains fault on the 12th of December caused by tails burning on an ABC box. There were strong indications that a fault would occur on this circuit many months before the fault occurred.

In summary, although the Cable Condition indicator was developed for LV underground cables, it does appear to be useful for indicating future and imminent failure of at least some types of LV OHL faults. In each of the case studies described in this technical note, the Cable Condition State was Failure Imminent more than one month before each fault occurred. In the case of the fault caused by caused by tail burning on an ABC box the Cable Condition State was Failure Imminent nearly six months before the fault occurred.

5.6 Comparison of Location Information from Monitoring Systems with the Physical Locations of Faults

A "credibility score" is used to categorise events that could be located on the network. Impedance calculations are made using the information contained in Voltage/Current PreFault and fault waveforms then assigned credibility scores based on the likelihood of a location being possible. For faults in the early (pre-interruption) stages of development, the prevalence of significant impedance at the point of fault makes determination of impedance of the cable to the fault non-trivial.

The impedance is given in milliOhms (mΩ). The type is either Phase or Loop indicating a multi-phase fault or single-phase fault respectively. These are the values that can be used with pre-prepared contoured (marked-up) cable plans to determine candidate locations.

If a visual inspection of the area is undertaken it may provide a positive identity of the location, or at least rule out the possibility of some of the locations.

Key questions had to be answered to ensure the investigation was thorough and could support future discussions of suitability of pole mounted monitoring and the overall ability of the algorithms to detect and identify OHL events. Some of these questions were:

- Could there be something interacting with the line, a tree branch for example, at any of these locations?
- Are there visible signs of damage around any of the prospective fault locations? Scorches or broken conductors for example.

A point of future discussion would be to understand if the procedure for desk top fault location should be the same for OHL feeder as with cable feeders. Less accuracy may be acceptable if the reporting could provide some early opportunities for locating OHL faults, which may be more visible than their underground counterparts. A visual observation of 100 metres of OHL where persistent fault activity has been recorded may allow for early interventions to take place on assets that are damaged or being interacted with by external objects.

5.6.1 Polesight 07 – Syntax Line: Downed Conductor Event

At 20:23:29 on the 21st of January, the Guard device monitoring the Syntax substation, Polesight 07, recorded a PreFault with a credibility of 5 out of 10. This provides reasonable confidence of the event being a PreFault and the impedance recorded was locatable. EA Technology implemented the methodology used on LV cables to attempt to locate the PreFault on an LV OHL.

Syntax's feeder is comprised of around 63% OHL and like many of the feeders connected to pole mounted transformers has a mix of cable and OHL. This makes locating PreFaults on Syntax a useful exercise, as it is representative of many rural networks.

It is important to note that Storm Isha was in effect on the 21st of January, which was evident from the number of events that were recorded on all devices. OHL networks are especially susceptible to events due to windy weather, from the line moving themselves to other objects interacting with them.

Recorded Event Waveform

The recorded event occurred primarily on the L1 and L3 phases of the feeder, indicating there was likely an interface between the two phases. The PreFault detection algorithm defined this event as a PreFault. This is the algorithm developed for cable faults and, should the location of the event determined be correct, will provide evidence that PreFaults seen on OHL networks can manifest similarly to underground cable networks.

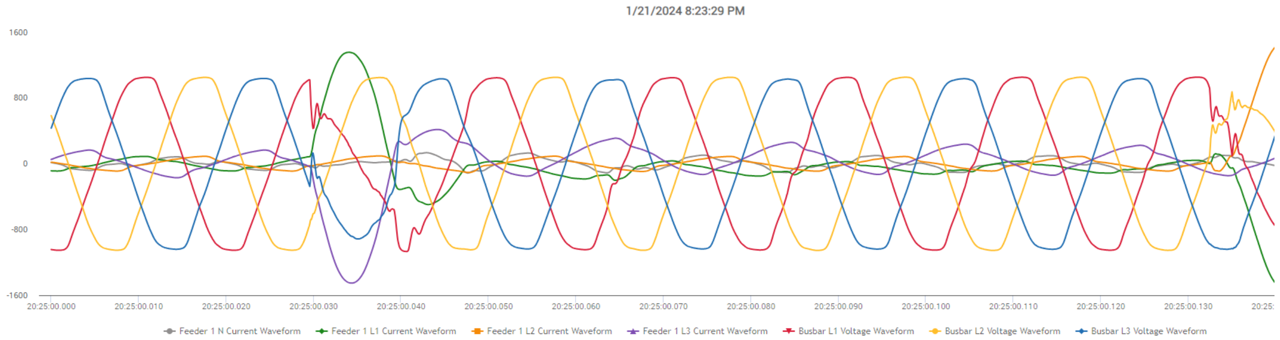


Figure 29 Polesight 07 (Syntax) PreFault event

There was another event that was cut off by this waveform capture which looks to show a larger current event. Unfortunately, the triggering settings for the Guard have a "lock-out" criteria, which is meant to ensure the device is not flooded unnecessarily with events if something faults continuously. The second event looks to occur on the L1 and L2 phases, different from the first event. This could suggest that the phases are coming into contact with each other, which would suggest bare wires.

All locations determined by the algorithms were on bare conductors, which supported this hypothesis.

Possible Locations

Using the standard algorithms for PreFault location the iSmart feeder map was marked up in red where the algorithm provided locations. The three locations are shown below, three locations are given due to the branching nature of the feeder.

Figure 30 Polesight 07 (Syntax) Fault Locations

All three locations determined were close to poles. If this PreFault develops to a fault, or there is evidence of damage from a PreFault around the poles, it will be a good case study for what OHL PreFaults look like and allow for the opportunity to begin categorizing them.

All sections of interest on this feeder were serviced by 4 x 0.05 HDBC (Hard Drawn Bare Copper), a common conductor type for OHL feeders and therefore this event was of use for developing thoughts around PreFaults on OHLs.

The locations were as follows:

Figure 31 Location 1 – Pole outside West House

In this location, the PreFault could have occurred on an LV service or around the pole itself.

Figure 32 Location 2 – Poles near Mole Cottage

As with the previous location, the PreFault could have occurred on an LV service or on, or near, the pole.

Figure 33 Location 3 – Pole outside Stocksfield Golf Club

From an initial observation this location seems like the least likely. However, as Storm Isha was in effect at the time of the event there is the chance that something may have interacted with the OHL.

This would be supported by the suspected phase interactions, since open wire, if not tensioned correctly, can interfere in windy conditions.

Identification of Physical Event

NPg were provided with the locations associated with this event on the 25th of January. Following a walk around inspection of the locations determined by EA Technology, no conclusive evidence of an event could be determined.

Further querying of the operational team provided the source of the event: two poles outside Stocksfield Golf Club snapped due to inclement weather and the conductors were grounded. These poles were restored by the time the walk around had occurred, leaving minimal physical evidence of the event.

Figure 34 Location 3 – Pole outside Stocksfield Golf Club, grounded

In a positive outcome for the project, as this was Location 3, there is evidence to support the use of previous PreFault and Fault location techniques for OHL feeders.

Comparing the Location to the Incident Report

To identify learning from this event, which was classed as a PreFault, some further investigation was undertaken. Once it had been clarified that a repair had taken place, the Incident and Fault reports from this time and date were provided and a clearer understanding of the event could be discerned.

INC-485836-A and FREP-485870-A relate to the reporting and repair process required to return the network to service. Section 3.3 provides a visual of where the fault occurred.

The incident report states:

Actual (Incident Start)	1/21/2024 8:34:00 PM

This aligns with the first event and suggests that the lines did not go down until after, which would make it a PreFault. No more events were analysed as PreFaults until 23:28:48. However, this is likely to be a cold load pick up, typically seen after line has been reenergised. The incident log states:

1/21/2024 11:30:00 PM	l/v network isolated at P13, and s/s fuses replaced, to restore at 23:30. This will leave the Golf Course off supply, as it is fed via u/g, 3 Phase CNE from P12

This log of events is consistent with the other monitoring data from the Guard as the device was offline between 21:13:58 and 23:27:58.

There were five events between the initial PreFault and the device powering down. In the Guard analytics a second event, a spike on the first phase current at 20:25:10, was also analysed as being a PreFault. In the VisNet analytics, with a lowered current threshold, this event was also classed as a PreFault. This consensus is useful evidence to support the claim that both algorithms are suitable for PreFault detection. Polesight 07 is a Guard device, which triggers on voltage disturbances, and has been analysed by both algorithms.

Three events at 21:05:21, 21:05:27, 21:05:32 were all classified as HV events by the Guard analytics. The were classified as non-faults by the VisNet analytics. This is to be expected as there are no HV categorisations in the VisNet algorithms. These events would also not have been recorded had Polesight 07 been a VisNet as there are no current spikes associated with the events. The events can be described as showing diminished volts, particularly on phase three.

As this was a damage event, the events analysed as being PreFaults are more accurately classed as Faults. This damage event was called in by customers and fixed in the standard method however, had this event occurred in a more remote area, being able to locate a fault like this could support a quicker and safer return of supply.

Insight Gained from this Event

The analysis of this event from EA Technology demonstrates:

- Overhead line events can be recognised by the existing algorithms.
- The event location process developed for underground cable networks are suitable for overhead line networks.
- There is a case to be made for voltage triggering for LV monitoring to capture a wider range of events, which could be useful for triaging other events.
- The three 21:05 events that were classified as HV events are not likely to be HV events.
    - There is opportunity to analyse these events further to provide more accurate categorisations in the future.

5.6.2 Polesight 10 – Summerrods: Likely Clashing Conductors Event

At 23:44:56 on the 23rd of January, the Guard device monitoring the Summerrods substation, Polesight 10, recorded a PreFault with a credibility of 9. This provides a strong indication of where the PreFault occurred, and the impedance recorded was locatable. EA Technology implemented the methodology used on LV cables to attempt to locate the fault on an LV OHL.

Summerrods' feeder is comprised of around 95% OHL which makes locating PreFaults on Summerrods an important exercise for the project, as it is likely the PreFault will have occurred on a section of OHL. Due to the nature of the events seen after the PreFault was recorded, wherein phase 1 of the feeder was shown with near zero voltage readings for over 12 hours, it is likely that this PreFault has a repair associated with it.

Recorded Event Waveform

The recorded event occurred primarily on the L1 and L2 phases of the feeder, indicating there was likely an interface between the two phases. The PreFault detection algorithm defined this event as a PreFault. This is the algorithm developed for cable faults and, should the location of the event determined be correct, will provide evidence that PreFaults seen on OHL networks can manifest similarly to underground cable networks.

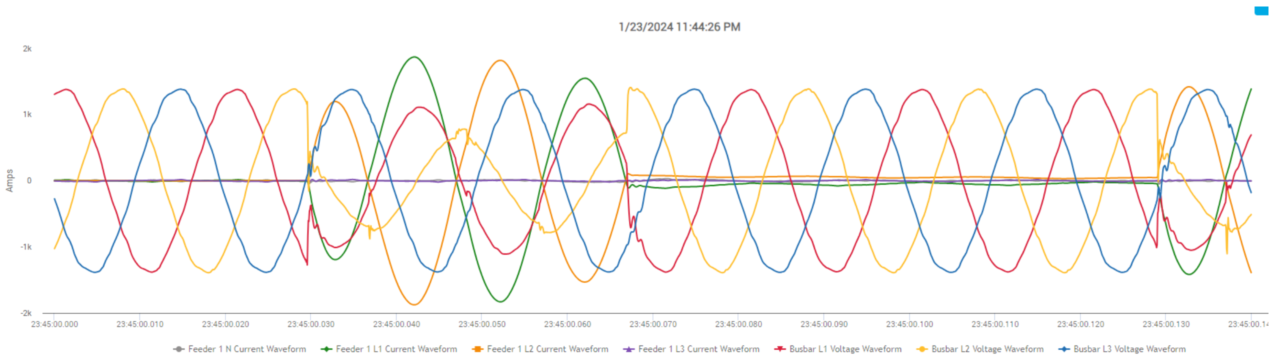


Figure 35 Polesight 10 (Summerrods) PreFault Event

Possible Locations

Using the standard algorithms for PreFault location the iSmart feeder map was marked up in red where the algorithm provided locations. The three locations are shown below, three locations are given due to the branching nature of the feeder.

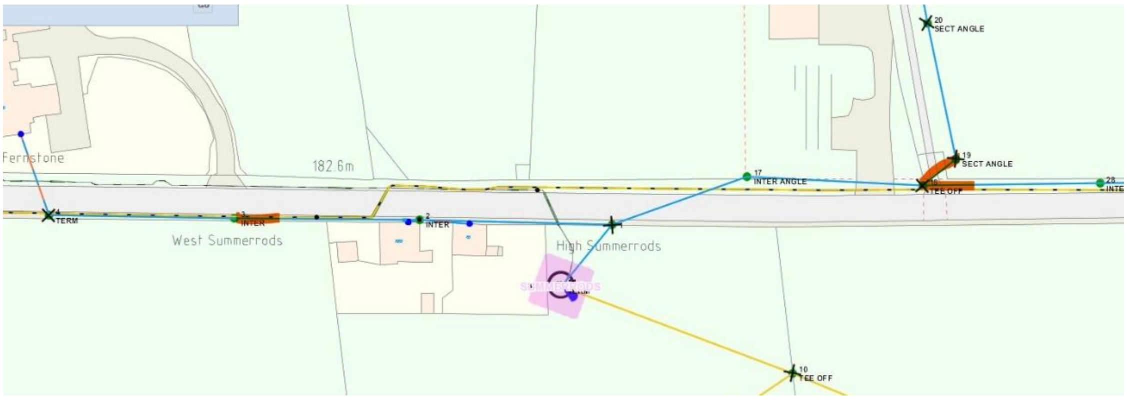


Figure 36 Polesight 10 (Summerrods) Possible Locations

All three locations determined are close to poles. If this PreFault develops to a fault, or there is evidence of damage from a PreFault around the poles, it will be a good case study for what OHL PreFaults look like and allow for the opportunity to begin categorising them.

Using the voltage monitoring data, it is possible to develop a theory of what may have happened after the PreFault. The PreFault was recorded on phase 1 and 2 of the feeder and phase 1 seems to have lost supply soon after the event. It is likely that there was a repair or fuse replacement around 13:00 on the 24th of January as the phase was returned to service.

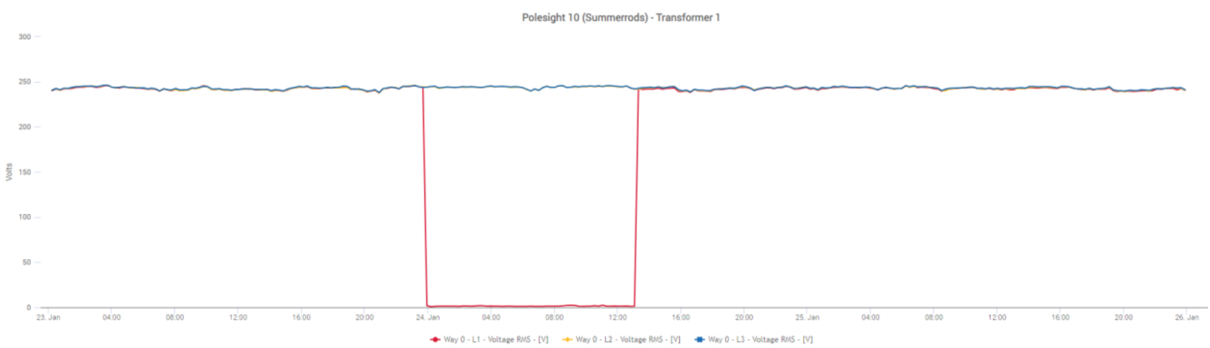


Figure 37 Polesight 10 (Summerrods) loss of L1

As there was a loss of supply, while this event is classified as a PreFault within the analytics, it is a Fault.

The locations determined are as follows:

Figure 38 Location 1 – Pole opposite farm entrance

As the next two locations are close together, they have been shown in one picture. It could be that this PreFault location is on the pole where the feeder tees off.

Figure 39 Location 2 and 3 – Tee section

Identification of Physical Event

To identify learning from this event, which was classed as a PreFault, some further investigation was undertaken. The FY 23/24 Fault records were searched for anything relating to Summerrods substation on this day or the next day (24th). This yielded an Incident log and an associated Fault report.

INCD-488379-A and FREP-488413-A relate to the reporting and repair process required to return the network to service.

The key information from this report is the following:

1/24/2024 1:08:29 AM	Incident Comment changed to 'P WHARTON REPORTS - O/H CHECKED TO BEST OF ABILITY ALL LOOKS OK, TOO WINDY TO ONE MAN CLIMB, LINESMEN RQD NONE AVAILABLE AS NO HOURS LEFT, LINESMEN RQD WED AM'

There were no visible signs of damage on the line or any of the associated assets. This suggests that the fault is a transient fault of some kind and as the weather was described as windy there is a good likelihood that the fault was due to clashing conductors.

1/24/2024 3:22:31 PM	Incident Comment changed to 'RP FUSEFOUND OPERATED. 160A FUSE REPLACED 1315'

As the event occurred across two phases that could be assumed to be adjacent to each other, in the physical space, the suggested cause of this outage is that the conductors clashed. The waveform recorded was recognised as being similar to other cases of metal on metal and the incident report suggests this is the transient fault.

Further Relevant PreFault

A second PreFault event was recorded on the 6th of February on this feeder. This event had a credibility of 6 and was also locatable. In a positive outcome for the project, the locations match those from the first PreFault event. This suggests that the same issue that occurred previously occurred again, however this time there was no fuse blown.

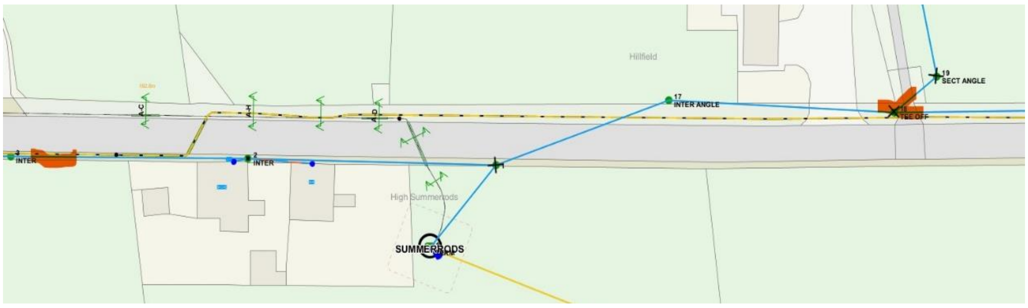


Figure 40 Polesight 10 (Summerrods) second PreFault event possible locations

The primary difference between this event and the previous event is that the affected phases are the L2 phase and the neutral phase. This causes some issues with the previous hypothesis as it is unlikely in the physical space that these two conductors would be adjacent. Whereas previously conductors for phase 1 and 2 would be assumed to be adjacent this is less likely in this event.

Figure 41 Polesight 10 (Summerrods) second PreFault event waveform

As there was no incident log associated with this event and no repair was required in either event there are minimal further conclusions that can be drawn from this feeder. It is most likely that the conductors are sagging, and the stormy conditions of the week caused them to clash, causing a transient fault in the first instance and a PreFault in the second. However, this is a hypothetical and not a definite conclusion.

The analysis of this event from EA Technology demonstrates:

- Overhead line events can be recognised by the existing algorithms.
- The event location process developed for underground cable networks are suitable for overhead line networks.
- An example of a, likely common, OHL PreFault event.
- PreFault event waveforms and locations could be used to locate and triage transient faults.

5.6.3 Polesight 14 – West Causey Hill: Underground Cable Fault Fed from Pole Mounted Transformer

On the evening of Saturday the 22nd of July, a PreFault event was recorded. According to NPg incident logs, the fuses on the transformer were replaced at 03:38 on the morning of the 23rd and the customers that had been affected were restored. Before this event occurred, only one event that could be classified as a PreFault, using the standard analytical methods, had been recorded at this substation. There was little indication that a significant event was likely to occur due to the short time the monitoring devices had been in place. As previously discussed, there was only one event (23rd of June) categorised as a PreFault by the analytics, which is not a large enough sample size to assess the asset health.

Later in the morning of the 23rd of July, NPg received multiple calls from residents on the affected feeder and investigation and restoration activities took place as per standard operating procedures. During this time, the VisNet monitoring the feeder recognised over 400 events as PreFaults during the period of fault activity. Many of these events would have been suitable for locating the fault had it been required.

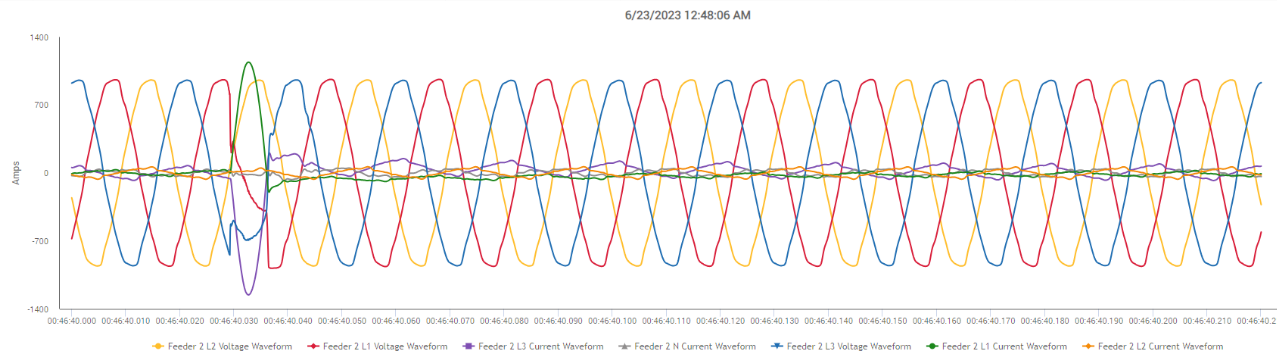
NPg were called and attended the site to return the feeder to service and did so on the day of the fault. Since restoring the cable to service on the 23rd of July there have been seven events recognised by the analytics, but none have been classified as PreFaults.

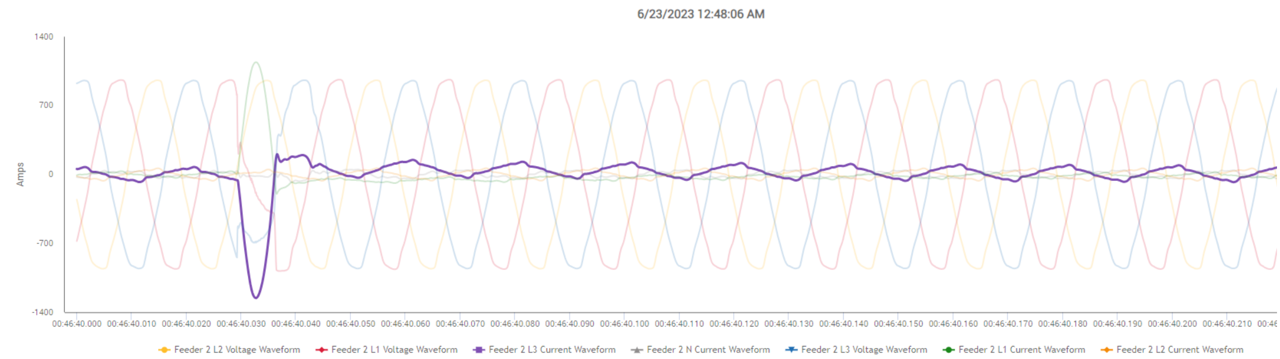
The feeder on which the event took place is entirely cable and the fact that the events were seen and correctly categorised suggests that the algorithms formulated during the Foresight project work on cables fed by pole mounted transformers. This event was early confirmation that the pole mounted monitoring devices record events in the same manner as their ground mounted counterparts.

This section discusses both events, the first PreFault and the PreFaults leading to the permanent fault on the cable.

Recorded Event Waveforms

The first recorded event occurred at 00:48:06 on this feeder on the 23rd of June and was reported by NPg as they had to replace the fuses at the substation.





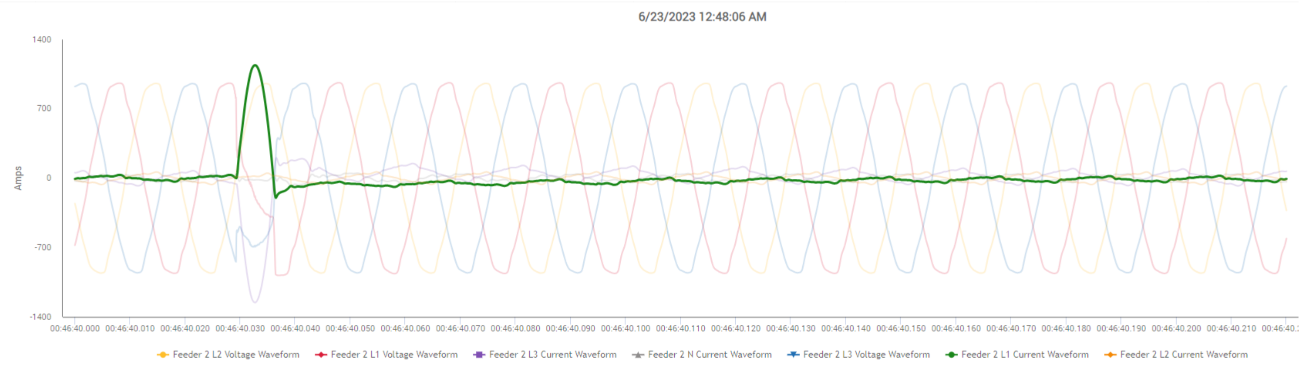


Figure 42 Polesight 14 (West Causey Hill) first PreFault event waveform

This event was categorised as a PreFault, and the 2-phase event occurred on L1 and L3.

However, on the waveform for the second event the extraneous currents are on L2 and L3.

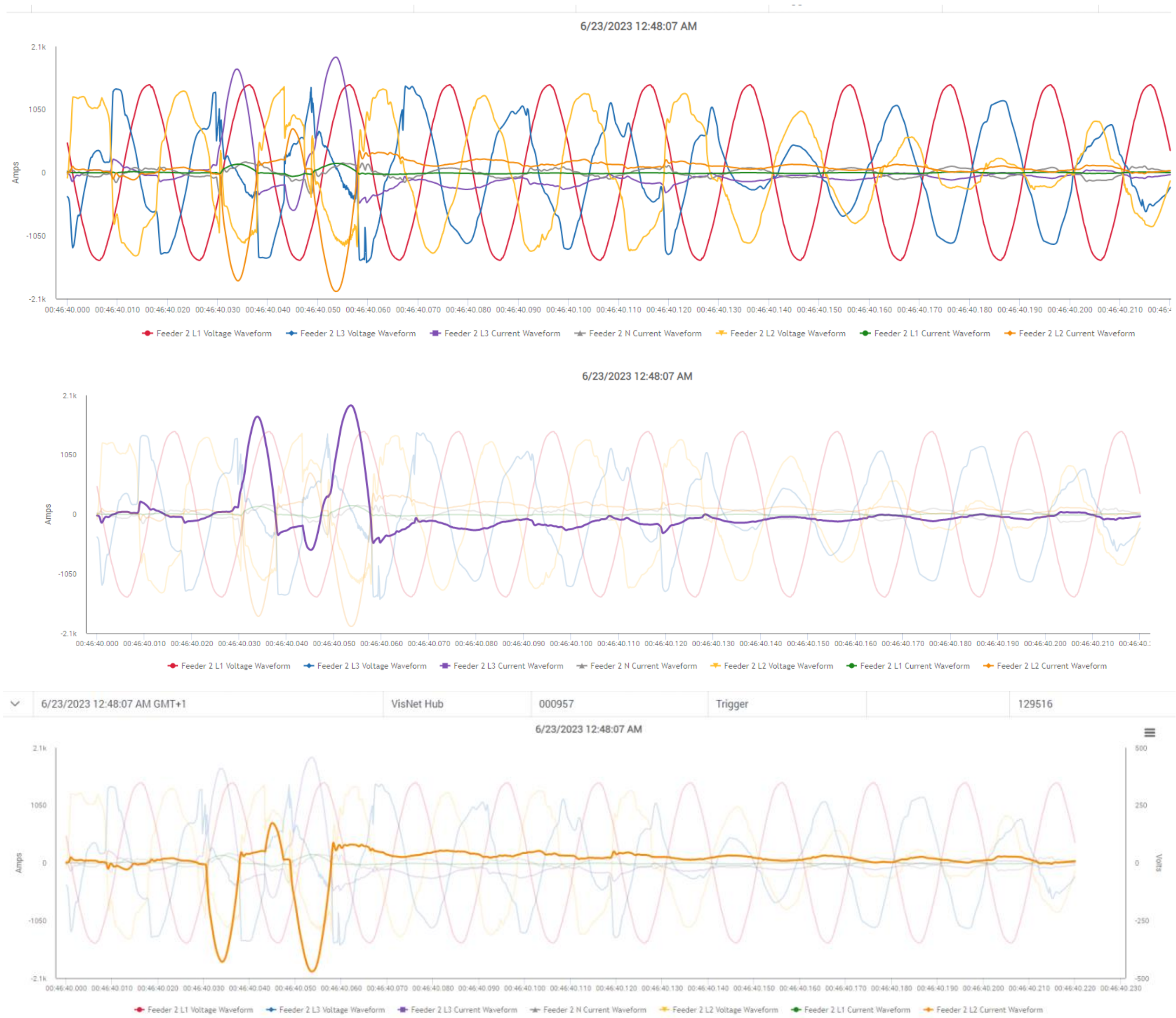


Figure 43 Polesight 14 (West Causey Hill) second event waveform

The second event was not categorised as a PreFault:

Polesight 14 (West Causey Hill SS)	West Causey LV Feeder F	2	2023-06-22 23:48:06	[1, 3]	2.0	fault	1255.0	1.0	0.10607	0.094286	0.076344	0.075417	2.0	1.577685	-225.91	-2396.0	-2995.491613
Polesight 14 (West Causey Hill SS)	West Causey LV Feeder F	2	2023-06-22 23:48:07	None	NaN	non-fault	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Figure 44 Extract of the event analytics

After this second event the waveforms became more distorted and these are being compared against other waveforms to see if there's commonality with other events. It can be seen that the L1 voltage seems mostly unaffected.

Figure 45 Example of post event, pre fix waveforms

The events captured following the first PreFault have generally only been recorded due to the neutral current exceeding the triggering level.

The event on the 23rd of June was not able to be located due to a low credibility score. Otherwise, the feeder recorded very little activity that would indicate an imminent fault, using the existing algorithms and categorisations. This means that there was no opportunity to investigate a time to fault, due to the lack of prior events recorded before the fault occurred. To see examples of the PreFault waveforms please see Appendix 3 of this report.

Other examples of fault events within this report show events on OHL feeders. Polesight 14 provides an example of a cable fault event, which develop differently. Figure 46 shows the most credible event out of the over 400 recorded on the day of the event.

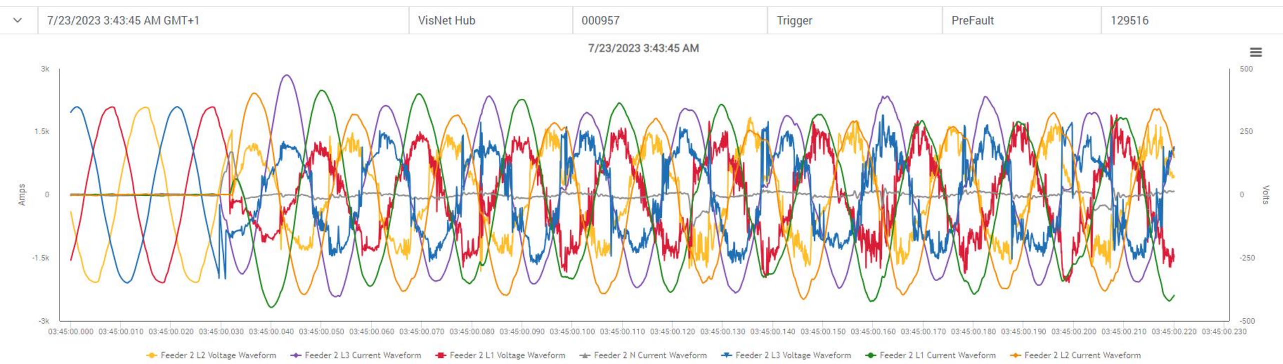


Figure 46 Polesight 14 (West Causey Hill) most credible event

Identification of Fault Location

Unfortunately, as the event occurred entirely over the course of a weekend, from Saturday evening until Sunday afternoon, all fault locating could only be done post fault restoration. This would not usually be done on faults that are repaired however, for the purposes of the Polesight project, the predicted fault location was found and compared to the actual location of the fault. NPg logs state that the fault was in the footpath outside property numbers No.28 and 30 Dickson Drive, shown on the right-hand map. EA Technology's location options for the fault are shown on the left-hand map.

Calculated fault location | Actual location of fault

Figure 47 Comparison of calculated fault location and actual fault location

As the feeder splits in two directions before the fault, two locations were provided by the calculations (1 & 2). Margins of error occur due to the digital twin of the feeder not being an exact clone of the physical feeder, however in normal operations both paths would be investigated, and the target area provides a start point for operatives searching for the fault.

5.6.4 Polesight 18 – Mickley Junction: Conductor Interaction

At 2:36:57 on the 22nd of January, the VisNet device monitoring the Mickley Junction substation, Polesight 18, recorded a PreFault with a credibility of 6. This could provide a good indication of where the PreFault occurred, and the impedance recorded was locatable. EA Technology implemented the methodology used on LV cables to attempt to locate the fault on an LV OHL.

Prior to the event, Mickley Junction recorded four events, that while not classified as PreFaults, do bear resemblance to PreFaults. The first of these occurred at 00:57:08 on the 22nd and the next three occurred at 02:63:53, 02:36:54 and 02:36:55, directly preceding the categorised PreFault event.

Mickley Junction's feeder is comprised of around 62% OHL which makes locating PreFaults here a useful exercise for the project. Many of the feeders connected to pole mounted transformers will have a mix of cable and OHL. This makes locating PreFaults on Mickley Junction a useful exercise, as it is representative of many rural networks.

Recorded Event Waveform

The recorded event occurred primarily on the L1 phase of the feeder. The analytics defined this event as a PreFault. This is the algorithm developed for cable faults and, should the location of the event determined be correct, will provide evidence that PreFaults seen on OHL networks can manifest similarly to underground cable networks.

Figure 48 Polesight 18 (Mickley Junction) PreFault event waveform

Mickley Junction is a split-phase feeder and in this waveform there is only one of the voltages being displayed. This could suggest that the other voltage had already been lost.

It should be noted that there were four events prior to the event that was classified as a PreFault, shown below.

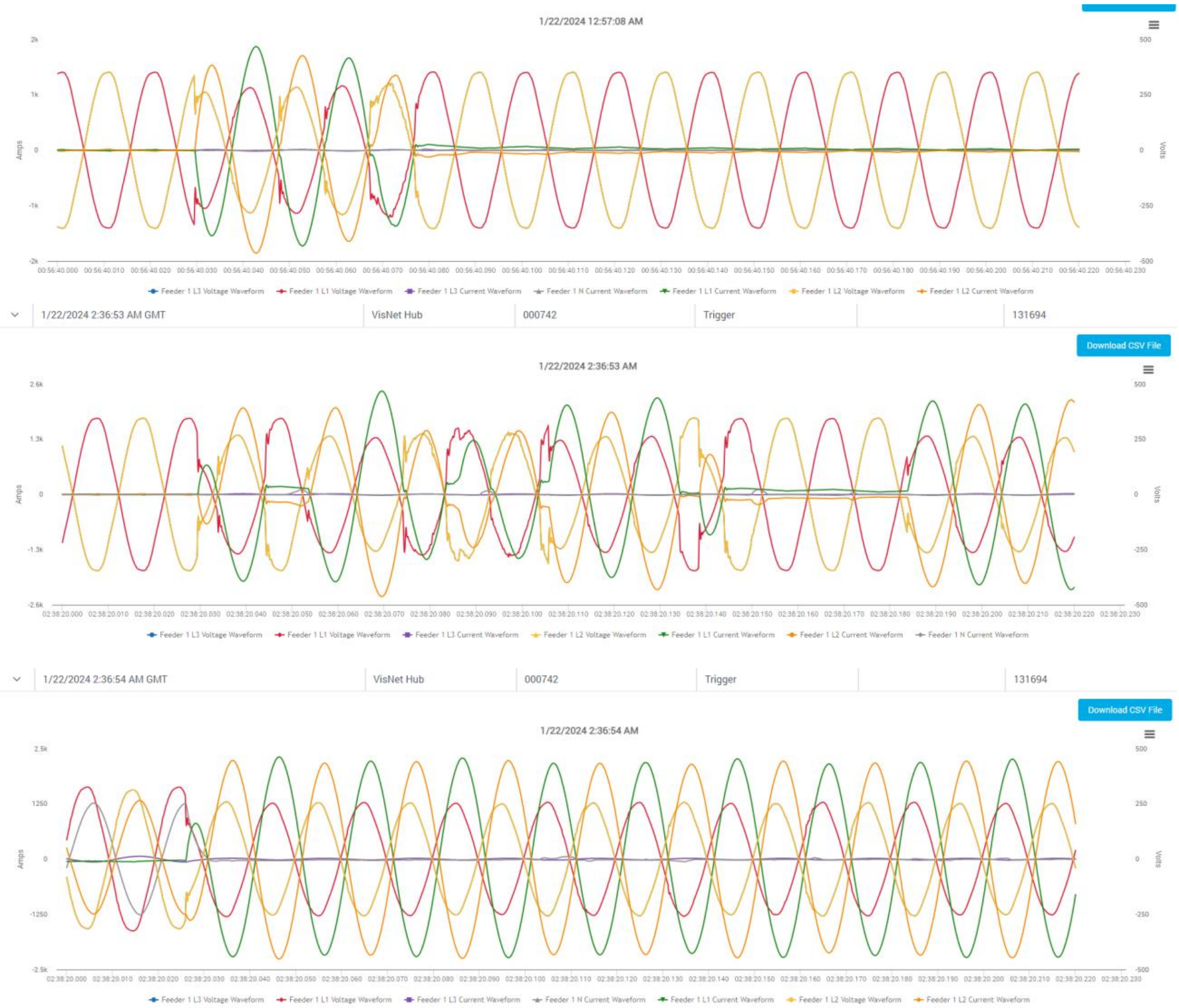


Figure 49 Polesight 18 (Mickley Junction) non-PreFault event waveforms

Only two of these events could be analysed by the Guard analytics and neither of them were recognised as PreFaults. This is consistent with other events recorded by devices monitoring split-phase transformers, where, if events are analysed at all by the Guard analytics, they are not classified as PreFaults when they are likely to be PreFaults.

If the currents are large enough, then there is more of a likelihood that the events are analysed to be PreFaults within the VisNet analytical space.

The third waveform, at 02:36:54, bears resemblance to the PreFault seen by Polesight 10 where the likely cause of the PreFault was clashing conductors. As this event was not categorised as a PreFault some further investigation into how split-phase transformers are analysed may be required.

This event seems to have blown the fuse on phase two of the feeder. The device was unresponsive for around 8 hours on the 22nd of January, between 11:20 and 20:10 so it is possible there was a repair occurring on the feeder.

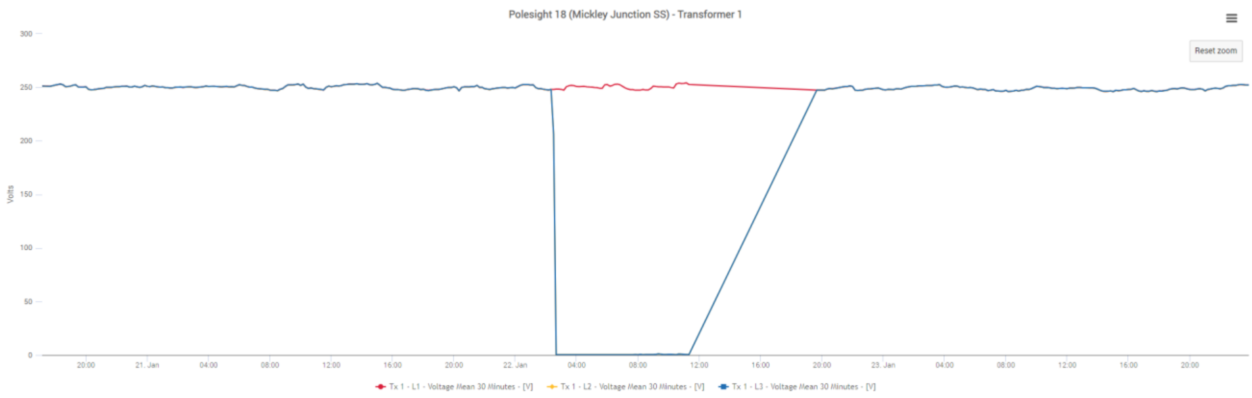


Figure 50 Polesight 18 (Mickley Junction) device voltage around the time of the event

This image shows phase two with no voltage and the unresponsive device at 11:20, where the diagonal blue line jumps from zero to a standard voltage.

Possible Location

Using the standard algorithms for PreFault location the iSmart feeder map was marked up in red where the algorithm provided a location.

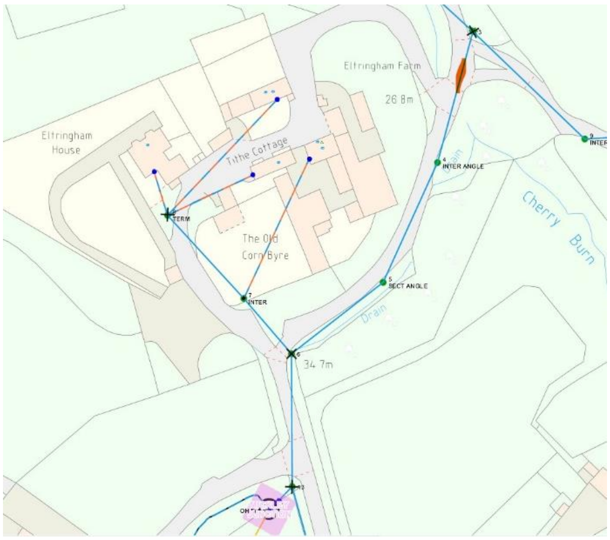


Figure 51 Location determined by impedance calculation

Only one location has been determined for this PreFault, a heavily wooded area that suggests that there could have been interaction with a tree.

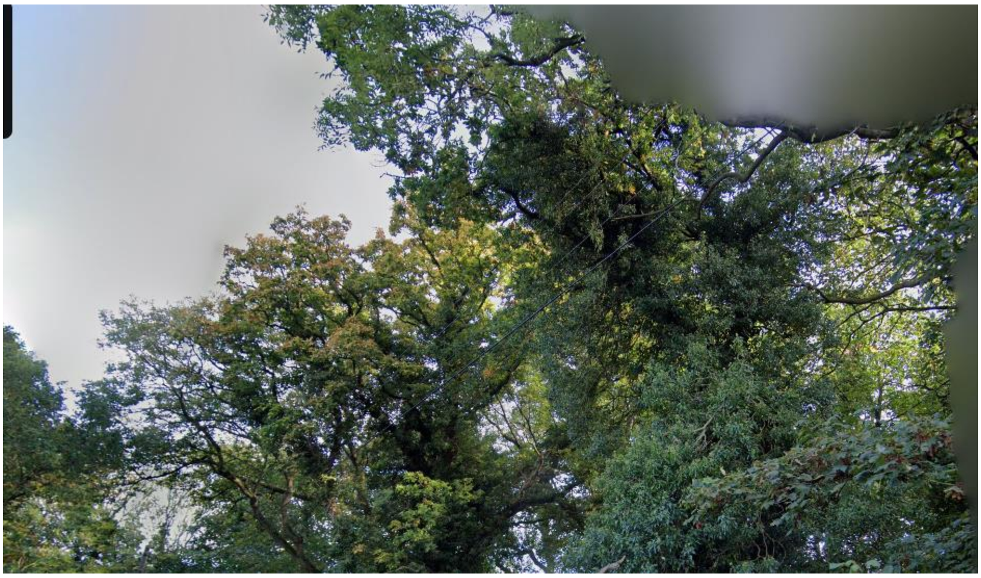


Figure 52 Location determined by impedance calculation

Identification of Physical Event

To identify learning from this event, which was classed as a PreFault, some further investigation was undertaken. The FY 23/24 Fault records were searched for anything relating to Mickley Junction substation on this day or the next day (23rd). This yielded an Incident log and an associated Fault report. INCD-486208-A and FREP-486242-A relate to the reporting and repair process required to return the network to service. Once it had been clarified that a repair had taken place, the Incident and Fault reports from this time and date were provided and a clearer understanding of the event could be discerned.

INCD-486208-A and FREP-486242-A relate to the reporting and repair process required to return the network to service.

The incident report states:

Actual (Incident Start)	1/22/2024 2:48:00 AM

This is after the PreFault event and is therefore likely to be when it was called in by a customer.

1/22/2024 5:36:38 AM	R+Y phases dead at 2 PH C/O, between Pole1 & Pole2 R+Y phases are wrapped together. Line team req to fit spacers and check fuses @ O/H SS.

This incident is a damage incident, in that there were no PreFaults before the event that would suggest there was to be a fault. These events are not predicted, as they are due to stormy weather in the region.

1/22/2024 8:00:00 PM	'SPLIT-PHASE OPEN WIRE NETWORK RE-ERECTED, SUPPLIES RESTORED 20:00'

This log of events is consistent with the other monitoring data from the Guard as the device was offline between 11:20 and 20:10.

As this was a damage event, the events analysed as being PreFaults are more accurately classed as Faults. This damage event was called in by customers and fixed in the standard method however, had this event occurred in a more remote area, being able to locate a fault like this could support a quicker and safer return of supply.

The analysis of this event from EA Technology demonstrates:

- Overhead line events can be recognised by the existing algorithms.
- The event location process developed for underground cable networks are suitable for overhead line networks.
- There is a case to be made for voltage triggering for LV monitoring to capture a wider range of events, which could be useful for triaging other events.
    - The three 02:36 events that were not classified should be analysed further to provide more accurate categorisations in the future.
- This event provides additional evidence of a specific type of LV OHL events.

5.7 Insights on HV Monitoring Using LV Monitors

Is it possible to provide additional insights relating to the condition and future reliability of HV overhead line networks from these pole mounted substation LV monitoring systems?

Transient voltage disturbances are plentiful on electricity distribution networks, whether from upstream voltage regulation events, network switching, load and generator switching or faults.

This section of the Polesight Project report provides a first pass look at this data and how it may be used to provide information, which may previously have been unavailable, about incidents on the higher voltage networks.

The devices with voltage-triggered waveform capture enabled (the Guards) act as LV connected disturbance recorders at multiple nodes. Events at higher voltages that cause voltage perturbations which meet the triggering criteria will cause capture on multiple downstream devices. The number of devices that capture a disturbance, their electrical connectivity and size, and shape of the waveform captures, all provide information on the severity of the disturbance and its relative electrical proximity to the triggered devices.

Of the twenty Polesight Installations, ten had Voltage Triggering enabled. This enabled capturing of voltage disturbances caused by events on the HV networks to which they were connected, as well as those caused by developing faults on the LV networks they were directly monitoring.

Normally, higher voltage disturbances (classified as Out of Zone) are eliminated from the captured data set for further analysis. As a tangential part of the Polesight Project these Out of Zone events have been retained and are analysed here to better understand what value they may have in providing previously unavailable insights to Network Operators.

Therefore, HV insights from LV monitoring is an area of additional analysis that would not require any further equipment costs if LV monitoring were to be rolled out.

5.7.1 Overview of Polesight Device Electrical Connectivity

As the primary focus of the project was on LV events (In Zone events), the Project Site Selection Criteria made no special conditions to arrange these to give the maximum data for HV Event analysis. When following through the Electrical Connectivity it emerged that they cover four different HV (20kV) groups, three different EHV (66kV or equivalent) groups and two different Supergrid Groups. The other ten devices (of the twenty total installed on the Project) did not have voltage triggering (the VisNets), and apart from one recognised event on one of the devices[9], only capture In Zone events. As such they play no part in the HV Insights Analysis.

Furthermore, the Polesight 09 (High Catton) Voltage-triggered device was removed early in the project. It has also therefore been excluded from this analysis.

The electrical connectivity hierarchy of the nine remaining devices that form the source for this HV Insights study is shown in Table 10. There are four main groups (based on the supplying Primary substation) identified by colour.

[9] Polesight 17 Mickley Mount (Current Only Triggered) co-captured (with Voltage-triggered devices) an HV event (07-05-2023). Presumably, this was due to re-acceleration of large motor load, the voltage recovery (when the LV voltage suppression caused by the event was cleared) caused an inrush current with a peak current greater than the trigger threshold caused capture.

Table 10 Electrical Connectivity Hierarchy of Voltage-triggered Polesight Devices (default operating arrangements)

Polesight Substation	Primary Group	EHV Group	Grid
P02 Corbridge Station	West Wylam 20kV Low Close 20kV Feeder	Coalburns 66kV Prudhoe West Feeder	Stella South 132kV - Annfield Feeder
P03 Birkshaw	Spadeadam 20kV (ENWL) Moscow SW STN No 2 Feeder	Spadeadam (ENWL)	Spadeadam (ENWL)
P04 Townley Terrace	Dunston 20kV Derwenthaugh Skiff Feeder	Dunston 66kV	Stella North 132kV
P05 Chopwell Wood	Dunston 20kV Derwenthaugh Skiff Feeder	Dunston 66kV	Stella North 132kV
P06 Haltwhistle	Spadeadam 20kV (ENWL) Moscow SW STN No 2 Feeder	Spadeadam	Spadeadam (ENWL)
P07 Syntax SS	West Wylam 20kV Low Close 20kV Feeder	Coalburns 66kV Prudhoe West Feeder	Stella South 132kV - Annfield Feeder
P08 Acomb Gravel	Hexham 20kV Acomb Westfield SW Teed Feeder	Coalburns 66kV Riding Mill Pumps Feeder	Stella South 132kV - Annfield Feeder
P10 Summerrods	Hexham 20kV Tyne Metal SW Feeder	Coalburns 66kV Riding Mill Pumps Feeder	Stella South 132kV - Annfield Feeder
P11 Broomhaugh	West Wylam 20kV Low Close 20kV Feeder	Coalburns 66kV Prudhoe West Feeder	Stella South 132kV - Annfield Feeder

All the substations are fed from Stella Supergrid apart from P04 (Birkshaw) and P05 (Haltwhistle) which are fed from an adjoining Network Operators Supply System. The Hexham and West Wylam Primary Groups are fed via different feeders from Coalburns 132kV/66kV Substation. The Dunston Primary Group substations are fed from the 132kV/66kV substation at the same site (Dunston 132/66kV).

For the specific purpose of generating HV insights from LV monitoring, it is interesting to note that the three substations on the West Wylam group are all on the same HV feeder whereas for the Hexham group the two substations are on adjacent feeders. The feeder names have been taken from System Diagrams provided to the project. In the absence of information to the contrary, the examples demonstrating HV insights that can be gained later in this section assume the default (normal) operating arrangements for the networks.

To give context, the geographic arrangement of the central group of the Polesight monitoring sites is shown in Figure 53. The sites written in blue text are those with Voltage Triggering enabled, the ones in black do not have voltage triggering enabled.

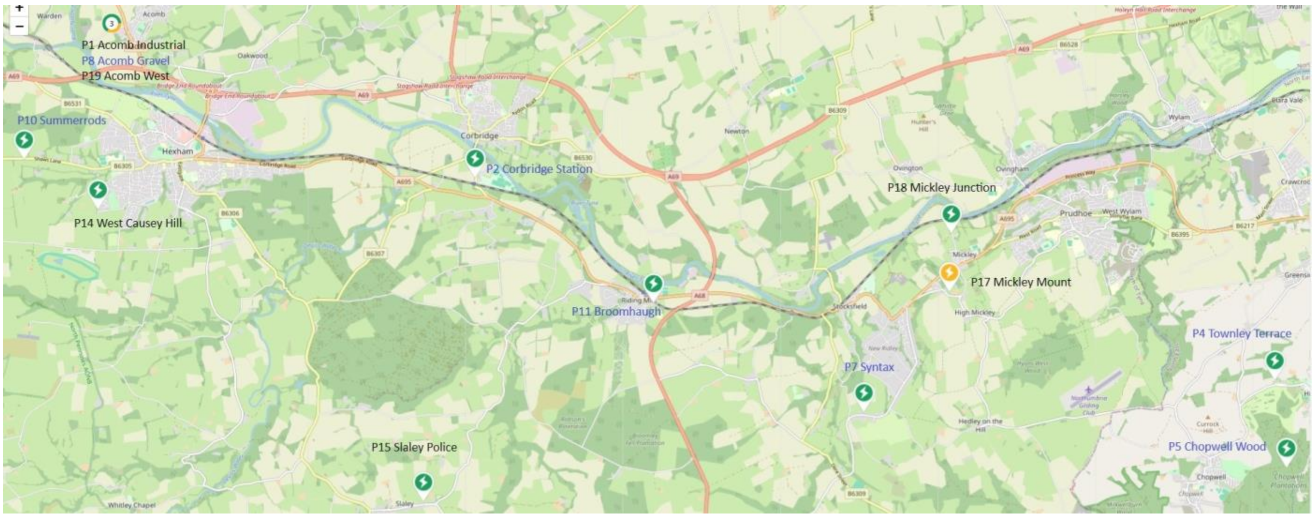


Figure 53 Geographical location of a selection of Polesight monitoring sites, those in blue have voltage triggering enabled.

It is the electrical proximity, not the geographic proximity, which is of most importance when considering HV insights from the LV Monitoring equipment. To help present the Out of Zone Event insights presented later, the schematic connectivity diagram shown in Figure 54 which was created from the connectivity information provided. Similar to a family tree, by following each of the substations back, the nearest common 'ancestor' for a network event (in this case Network Asset) can be determined.

Depending where a disturbance occurs on the higher voltage systems, the voltage dip being experienced by individual devices will be different and where they are the same, that is an indication that they likely share a nearest point of common connection. In those instances, a common asset can be identified.

It is postulated that by analysing the voltage disturbances seen by LV-connected devices distributed over separate locations in the network, an indication of the source of the disturbance is given.

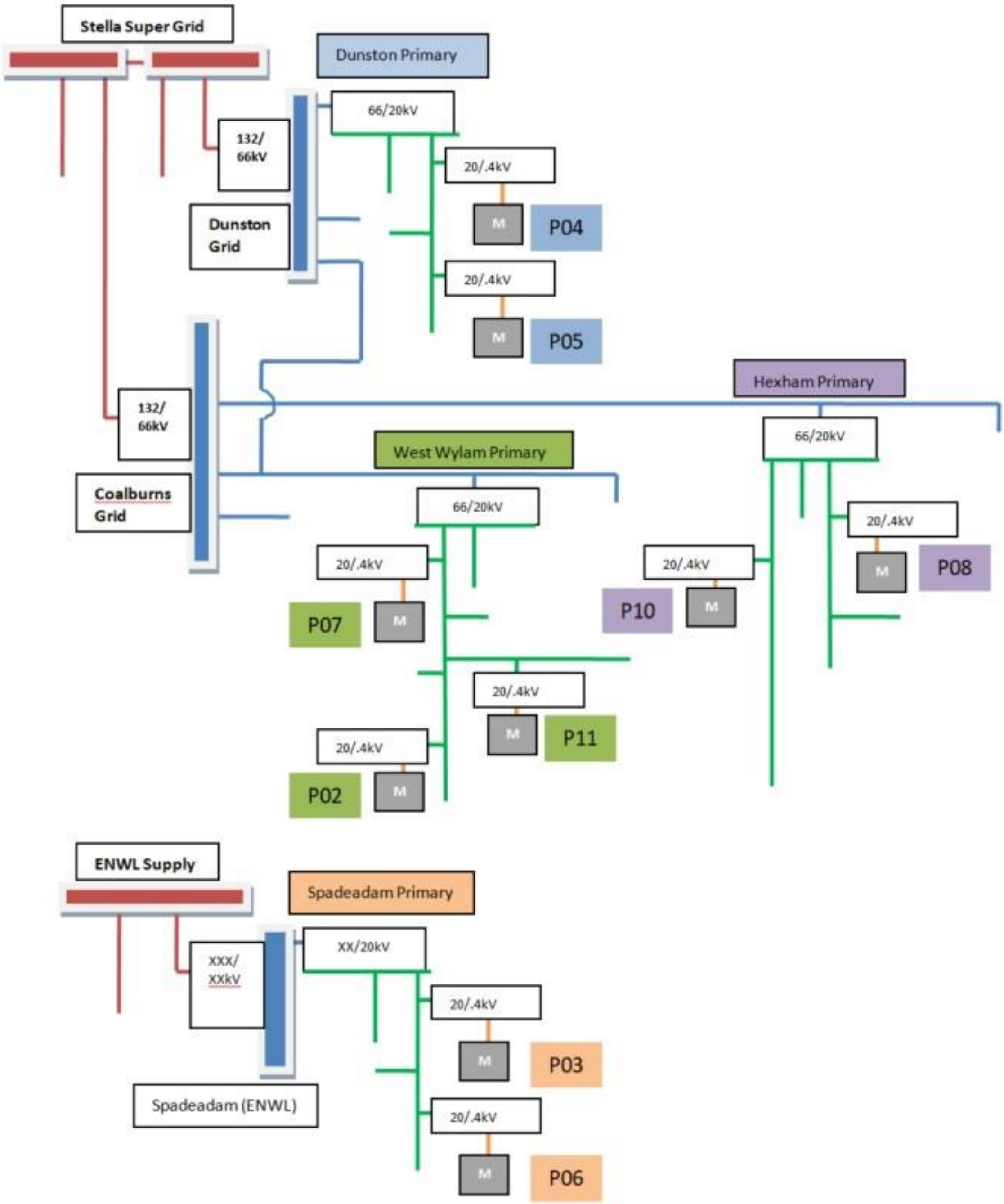


Figure 54 Schematic diagram of Electrical Connectivity of voltage-triggered Polesight devices from information provided

5.7.2 Insights from Analogue Data Returns

As well as having the ability to capture events caused by voltage perturbations from events on the higher voltage systems (waveforms), all the voltage-triggered devices provide regular analogue (RMS) data back to the central database[10].

The primary use for this data is for system planning purposes as it indicates how close the monitored transformers and feeders (LV) are to capacity. A by-product of this returned information, particularly the voltage data, is to indicate potential issues or deficiencies in voltage control or network integrity higher up the system supply chain. Although the examples here are from devices with voltage triggering waveform capture enabled, similar analogue (RMS) data is also provided by current triggered devices.

The following example is presented to illustrate how this simple data can be of use to make Network Operations or Planning Staff aware of issues, should they arise.

The below diagrams show the 24-hour analogue voltage and current profiles measured on P02, installed on the LV side of the three-phase HV/LV Pole mounted transformer at Corbridge Station in the West Wylam Primary group of substations. Although all within acceptable limits, on the voltage chart, L1 can be seen to be consistently lower than L2 and L3.

The voltage on the LV side of a transformer is a function of the HV voltage, the transforming ratio, and the load drop through the transformer. In a healthy transformer, transforming ratio should be the same in each of the phases. In this instance, it can be observed that the load delivered through the transformer is balanced between the phases. The implication therefore is that there is a slight difference in HV voltages at this point in the network. Where the voltages remain outside acceptable tolerances and these conditions persist, use of this analogue voltage insight could be used to alert operational management for possible investigation. Where there are multiple devices deployed on the same network the location, the point at which any out-of-tolerance condition arises becomes apparent.

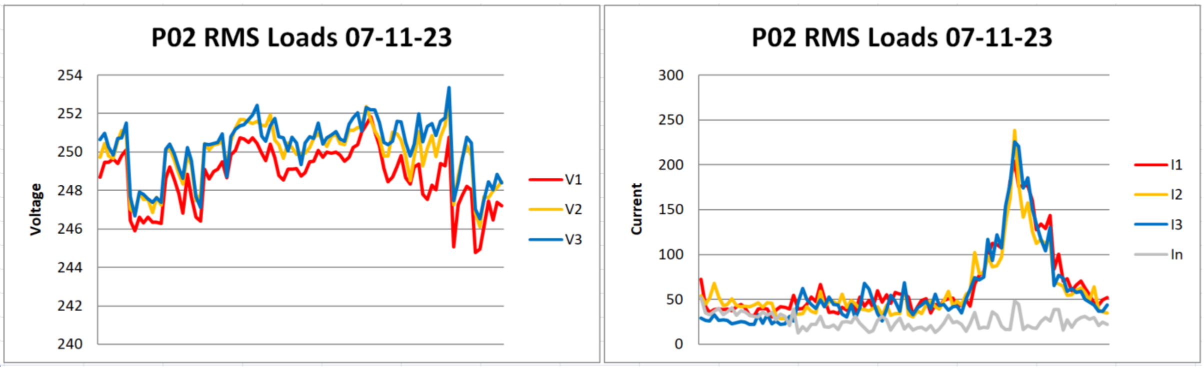


Figure 55 Example of HV Insights from Analogue Measurements, balanced load yet slightly unbalanced voltages

5.7.3 Insights from waveforms captured by voltage-triggered devices

All devices with voltage-triggered waveform captures enabled were on pole-mounted substations on Northern Powergrid's 20KV overhead line network. Two of the pole-mounted substations, P05 (Chopwell Wood) and P06 (Haltwhistle) had split-phase transformers (providing two LV phases), the rest were standard three-phase transformers. Only devices connected to three-phase were used in comparative data studies for investigating potential HV network insights from LV monitoring equipment.

The split-phase devices are connected to only two of the three HV phases. When investigating why the split-phase transformers did or did not trigger for particular upstream events, it was determined that constructional

[10] RMS voltage and current data for the devices in the examples here are returned to the central database once every 15 minutes.

differences between the two different transformer types meant that the measured voltage excursions following a voltage disturbance on a higher voltage system could not be compared like-with-like with the three-phase devices.

5.7.4 Use of differential voltages for analysing Out-of-Zone events

Absolute differences between devices (even those connected in close electrical proximity) exist, even under normal operating conditions. Absolute voltage differences, due to different loading and potentially different (and unknown) tap positions, can mean even adjacent devices can imply different HV voltages.

As the voltage before the event already factors in the load and ratio differences, it was postulated that it would be the change in these voltages due to an Out-of-Zone event that would be more easily directly comparable between devices. Some errors may remain, for example, where loads react differently to a significant voltage dip or different tap settings are in place, but by using the voltage differential at each device, major sources of error are much reduced.

Figure 56 shows an example of an Out-of-Zone (higher voltage) event that triggered a capture on several of the devices. The normal voltage has been reconstituted (dashed lines) to show the effects of the event on the LV side of the transformer at this location.

The voltage dip is the difference between the dashed and solid lines for the individual phases.

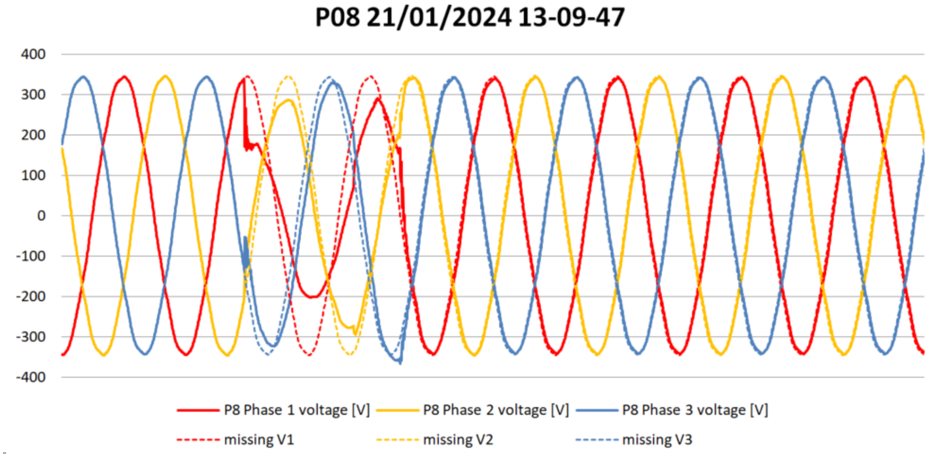


Figure 56 An example showing the voltage suppression during an out of zone event on a voltage-triggered device

5.7.5 Determining if an event is In-Zone or Out-of-Zone

In-Zone events are disturbances caused by current flow on the LV networks being measured. Out-of-Zone events are everything else.

When all the outgoing currents from a substation are monitored by a device, first pass discrimination between In-Zone and Out-of-Zone events looks for events that cause a voltage dip that are not accompanied by a significant current increase in one or more of the outgoing phases. In practice, most cases show the load reduced while the voltage is depressed but in other cases current increases can be observed. These slight increases are most probably due to connected wattmetric (motor-type) equipment where a dip in voltage is accompanied by an increase in current to meet the physical load duty (in watts) that the motor-type equipment is connected to. Such load changes are generally incommensurate (in magnitude) with the voltage dip being seen and can therefore be rejected from the In-Zone data set.

Where multiple devices are deployed on the same network, a second check to determine whether a neighbouring device has co-triggered on a similar-type event can confirm the source of the voltage dip being Out-of-Zone. For this, use is made of the device waveform timestamping. Though some drift between device clocks does occur, this is kept within plus or minus 2 seconds by design.

Table 11 shows a sample of the events co-captured by multiple devices. This information alone is an indication of the voltage level at which the voltage disturbance event occurred. However, as the probability of separate events being caused at the same time on different parts of the network is non-zero, further metadata from the waveforms captured can be used to confirm the events are from the same source.

Table 11 Suspected of Out of Zone Event Timestamps – from voltage-triggered devices connected to three-phase transformers

P2 Corbridge Station	P7 Syntax SS	P11 Broomhaugh		P8 Acomb Gravel	P10 Summerrods		P4 Townley Terrace		P6 Haltwhistle
27/04/2023									
05:08:24	05:08:24	05:08:24		05:08:24	05:08:24		05:08:24		
07/05/2023									
02:04:07	02:04:06	02:04:06							
02:04:12	02:04:12	02:04:12		02:04:11	02:04:10				
02:04:16	02:04:15	02:04:16		02:04:15	02:04:15				
02:21:53	02:21:52	02:21:53		02:04:54	02:21:53				
04/07/2023									
09:07:37	09:07:37	09:07:37		09:07:37	09:07:37				
20/10/2023									
16:35:48	16:35:49	16:35:48		16:35:49	16:35:49		16:35:51		16:35:49
21/01/2024									
	13:09:48			13:09:47	13:09:48				
14:38:23	14:38:23	14:38:22							

These events were manually associated with each other. There is no process presently in place to automatically associate events between separate monitoring devices. That would require a new function or feature to be added for automation of this process, along with including the electrical connectivity between the monitors.

5.7.6 Review of HV Events Identified by Polesight Devices

For all the substations equipped as part of the Polesight Project, the nomenclature HV here means the 20kV network. Being a largely rural area, the majority of this network is overhead line with some cable sections.

Using the logic previously postulated, a disturbance on the HV network would be expected to have a large effect (voltage dip) on devices[11] which are fed from the same Primary substation busbars. Distant faults, particularly those more than one voltage-level apart, have been seen to have smoothed transitions in contrast with those closer to the fault. It is therefore further speculated that the sharpness of transition at the onset of the fault, representing the point at which whatever insulation systems apply breakdown, provides another indicator of relative electrical closeness[12].

27th of April 66kV Event

The first suspected Grid event, captured on the 27th of April 2023 by all three-phase connected voltage-triggered devices except the one supplied from the neighbouring Network Operators grid supply is shown in Figure 57. The example is included to demonstrate the difficulty in localising faults on networks higher than HV (20kV in

[11] It is now also known these faults may also be noticed by devices which are fed from other primary substations on the same EHV network but that the voltage dip experienced will be much diminished.

[12] Assuming the network paths to the point of fault are electrically similar in terms of resistance, inductance and capacitance per unit length.

this case) from LV monitor information. To avoid clutter, only one of the substations from each of the primary groups is shown. P2 represents the West Wylam group, P4 is in the Dunston group, and P8 represents the Hexham group. P6 in the Spadeadam group did not capture this event.

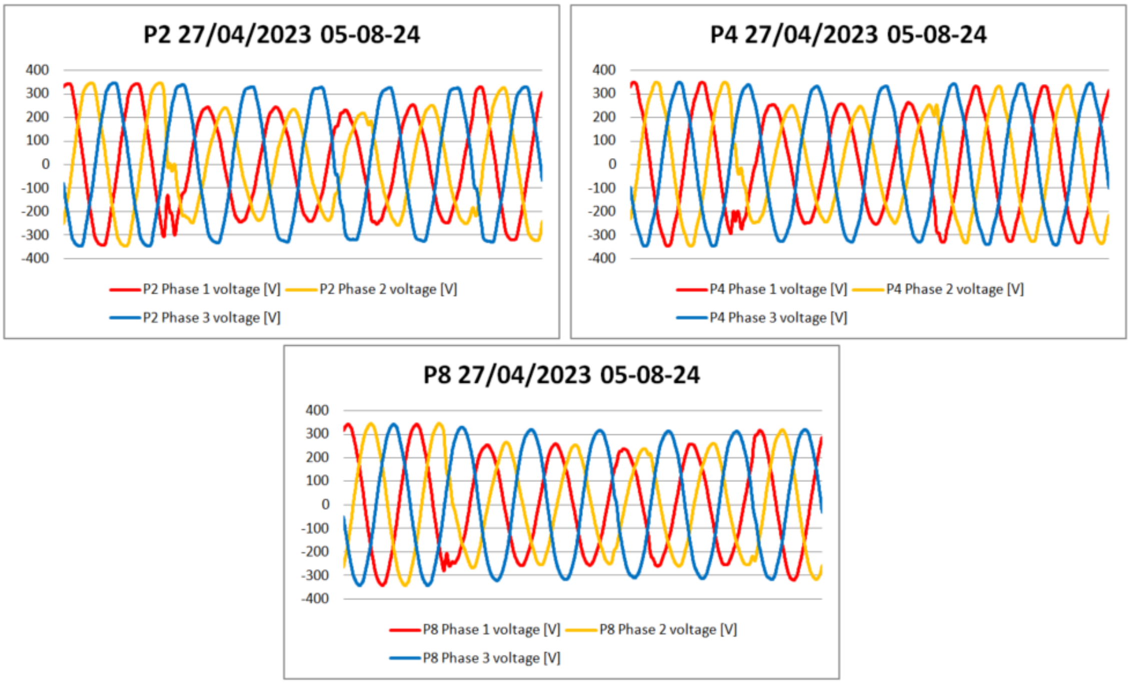


Figure 57 Example captures from devices in three of the 4 primary groups from suspected Grid event on 27/04/2023

By eye, whilst in steady state the voltage dips look similar, P2 appears to have a more vigorous reaction to the onset of the event.

Putting the captures for L1 from each of the devices onto the same chart shows subtle differences.

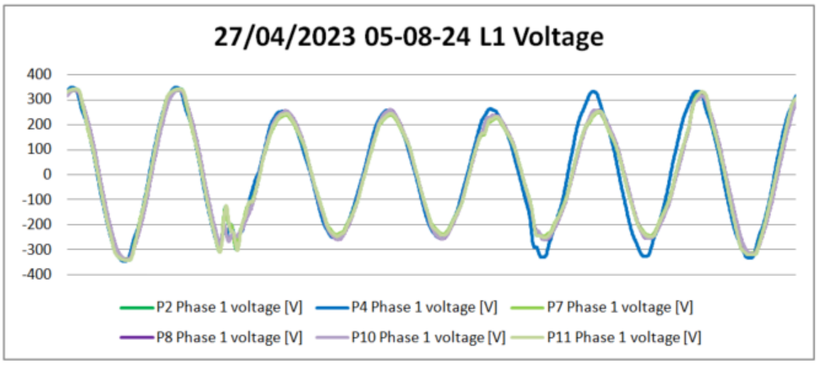


Figure 58 Voltage on LV phase L1 from each of the devices that captured the suspected Grid event on 27/04/2023

The chart appears to show that the event was seen for longer on the Hexham (P08, P10) and West Wylam group (P02, P07, P11) substations than it was on the Dunston group substation (P04). This dis-similarity may therefore give an additional clue as to the location of the event.

Finally, to complete the evidence available from this event, a voltage difference study for L1 voltage is presented in Figure 59.

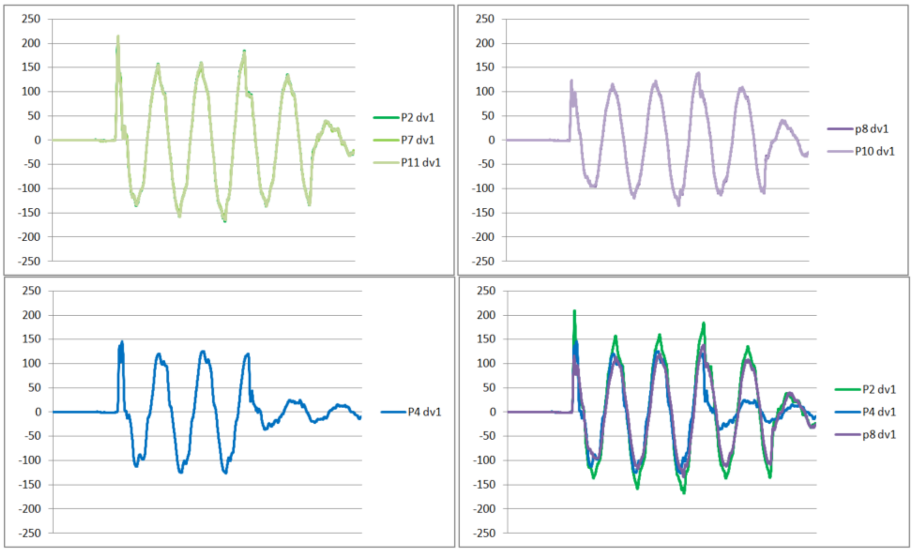


Figure 59 Voltage difference study for the three groups that experienced the suspected Grid event on 27/04/2023 05:08:24

The additional chart in the bottom right on Figure 59 compares the difference in V1 voltage dips seen between one device in each of the groups. In this instance, the West Wylam Groups appears to have seen the largest voltage difference drawing attention to the possibility of this event being on the 132kV network feeding Coalburns. The Hexham group again appears to have less of voltage dip that the West Wylam group, again strange given that they are fed from the same Grid substation at Coalburns, but at least consistent with the previous example. The Dunston group (fed from Dunston Grid) however has a similarly large dip and appears to have had a faster protection response that clears the cause of this event more quickly than the substation fed out of Coalburns. This draws attention to the 66kV network and the fact that these two grid sites run interconnected.

In considering the possible location of the source of this event, the absence of capture from the Spadeadam group, it being associated with the Stella North and South Supergrid group, the interconnection at 132kV and 66kV obfuscates confidence in any further localisation. The balance of probability, because of the sharpness of response, is that this major event was actually on the 66kV network interconnecting Dunston Grid and Coalburns but there is little confidence in that assessment.

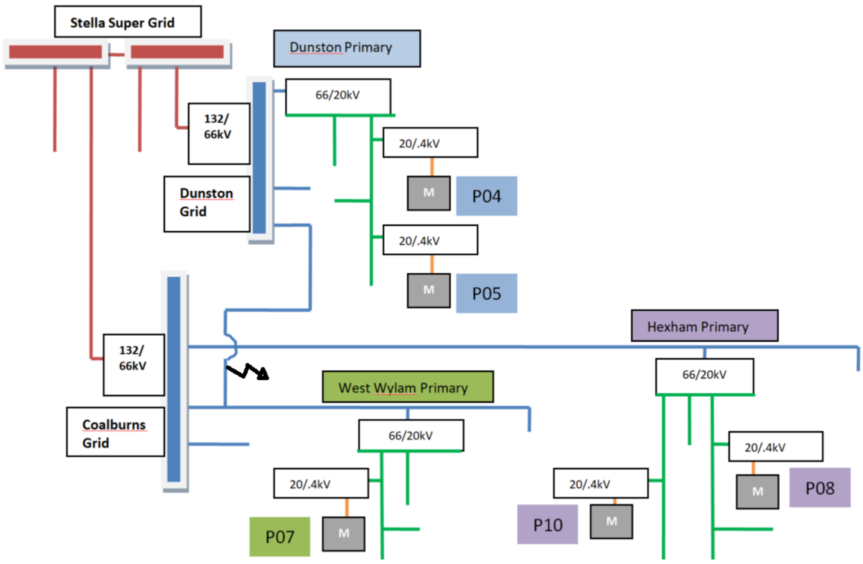


Figure 60 Network schematic showing potential location of 27/04/2023 (low confidence)

No incident report was available at the time of writing, so it is not possible to report the actual source and why the Dunston group voltage recovered more quickly than the other groups.

7th of May 20kV Event

Using the 02:04:16 event on 7th of May 2023 as an example of a suspect 66kV fault, Table 11 indicates that three-phase connected transformers in two groups (West Wylam and Hexham) captured this event. These substations are both on a 66kV network fed out of Coalburns 110/66kV substation.

Interestingly, Table 11 shows other events around this period affect the same Polesight substations. These other events (like the event in the previous section) appear to stabilise after 3 cycles. The event studied in more detail in this example continues off the end of the waveform capture indicating a different location (or at least protection/clearance response). At least some of these events, and possibly this one, appear to be transient as they reoccur in relatively quick succession suggesting that a long-term network change (as would happen during a permanent fault for instance) has not occurred.

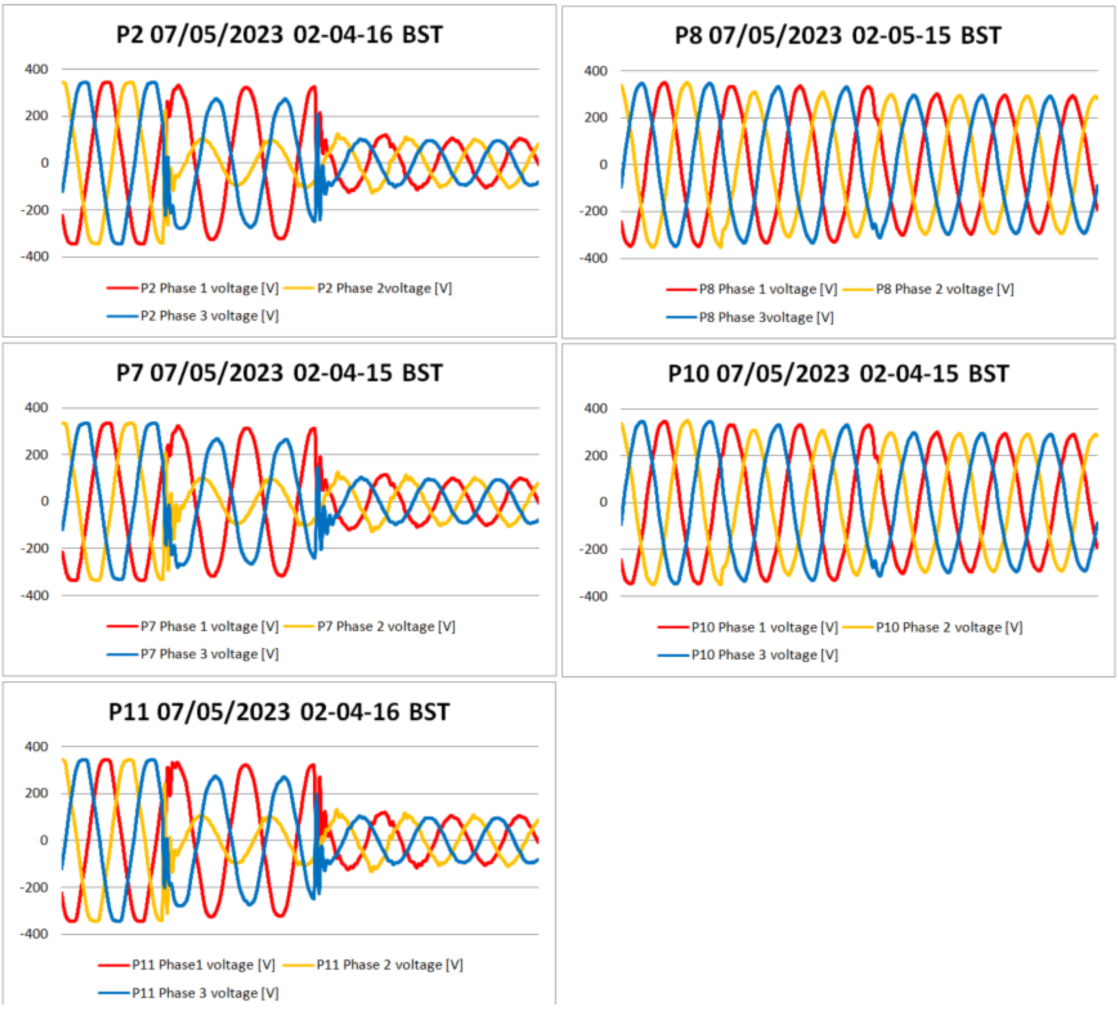


Figure 61 Captures from substations in the Wylam Group and Hexham Groups for suspected 66kV Fault on 7th May 2023

For this example (see Figure 61), the differences between the captures from the two groups involved (the West Wylam group on the left and the Hexham group on the right) are clearer than previous examples. The event has distinct characteristics, being split into two stages: the first causing a large collapse in L2 voltage, and partial collapse of L1 and L3 (as seen at LV), the second appearing as a full, balanced three-phase fault, collapsing all three phases consistently and significantly.

Though both groups of substations are supplied from the same 66kV bars at Coalburns, Figure 62 shows how the voltage dips experienced by the West Wylam group and vigour of response to the onset of the fault are much larger than those experienced by the Hexham group.

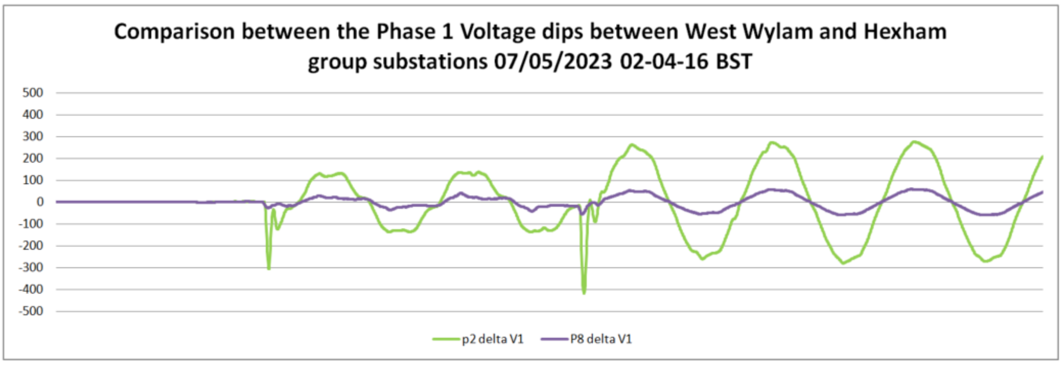


Figure 62 Difference in voltage dips for phase 1 between the captures on West Wylam Group and Hexham Group substations

It is considered improbable that a three-phase 66kV fault, even at the extreme end of the 66kV network would produce such a small dip on the bars at Coalburns which, unless there is significant generator support nearby, which would be also experienced by the Hexham group. The probability, therefore, is that, despite the event being picked up by substations in two adjoining groups, this fault is actually on the West Wylam Primary Substation group 20kV system. In high level analysis therefore, information on the degree of voltage dip (and potentially other event characteristics) would be needed in order to discriminate between EHV faults and HV faults reflected onto the EHV system through which they are also fed[13].

If this is a fault on the 20kV system, comparing the voltage dips experienced by the three substations on the same 20kV feeder is of interest (see Figure 63).

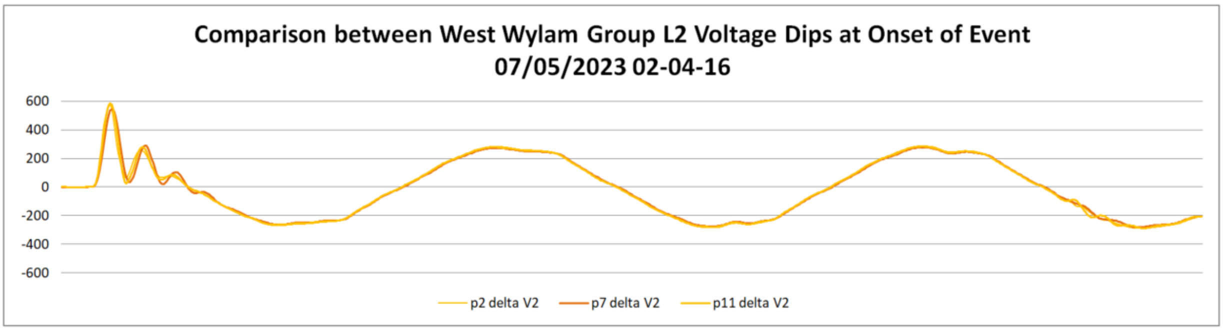


Figure 63 Comparison between L2 voltage differences between the three West Wylam group substation captures

Though there are slight differences during the oscillatory period at the onset of the fault, the voltage dips experienced by each of the substations in the group during the steady state period are equal. This equality would indicate that this is either a fault between the busbars and the nearest monitored substation (P07 in this case) on the feeder that these three substations share or, more likely, that it is a fault on one of the other feeders fed from West Wylam and that each of the Polesight devices on this feeder experience the resulting voltage dip caused on the 20kV busbars at West Wylam.

[13] There is no evidence of faults on the LV system causing dips on the HV system which then cause devices on other HV/LV substations in other groups with voltage triggering to co-capture.

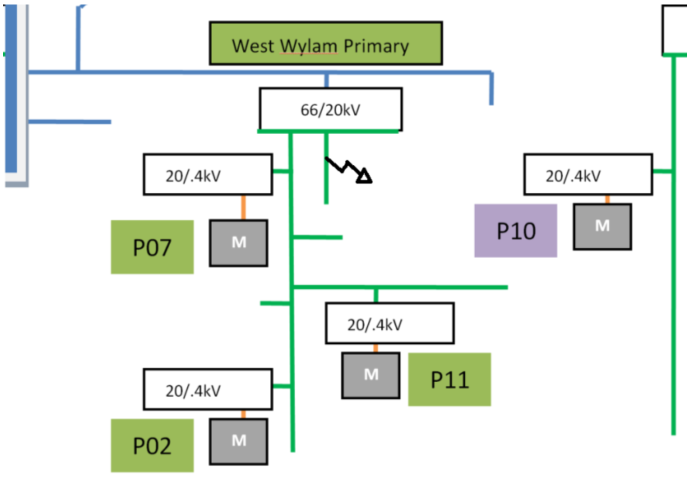


Figure 64 Anticipated location of the 07/05/2023 02:04:12:16 fault from Voltage Difference analysis

An incident report for this fault was provided by Northern Powergrid. There was a HV (20kV) cable fault reported at this time. It was in a protection zone that maps to Kittys Burn SW 20kV Feeder out of West Wylam Primary. The devices are fitted on the adjacent feeder (Low Close 20kV) from the same 20kV busbar.

Figure 64, showing the speculated location of the fault, derived from the voltage difference analysis and Network Connectivity schematic, was correct in this instance.

21st of January 20kV Event

The next example of the potential use of Out-of-Zone events from LV connected monitors to generate HV network insights was recorded on several devices on the 21st of January 2024[14]. The event was captured on both devices in the Hexham Primary Group (P08 and P10), but just one in the West Wylam Primary Group (P07). The captures are shown in Figure 65 with the West Wylam Group substations on the left and Hexham Group substations on the right.

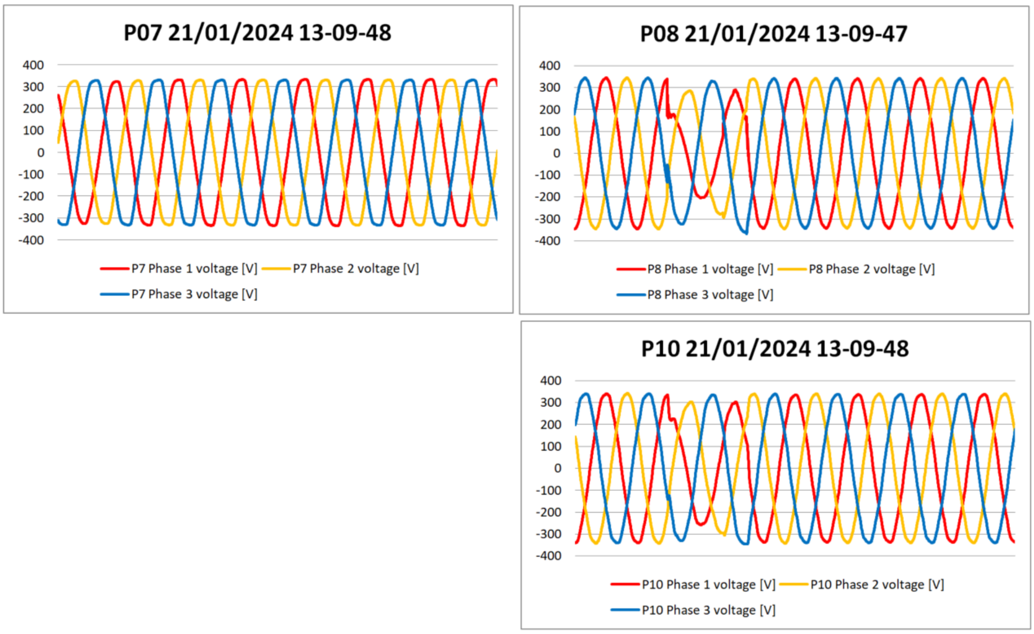


Figure 65 A suspected 20kV event captured on three devices at 13:09:48 on 21st of January 2024

[14] This was during named storm Isha which brought widespread strong winds including a reported 99 mph gust in Northumberland.

It can be observed that the voltage suppression during the event was much greater for the Hexham Group substations (P08 and P10); it is virtually unnoticeable on the West Wylam substation (P07). Further analysis revealed that the trigger condition on this device (P07) was only marginally met. This is a credible explanation of why the other two substations (P02 and P11) in this primary group failed to capture.

The fault (or given its short duration, potential PreFault) event was therefore highly likely sourced within the Hexham 20kV network.

The two devices in this group are on two separate 20kV feeders – of eleven feeders registered in the records for this primary. If the fault or PreFault was on one of the monitored feeders, away from the busbars, it would be expected that the voltage difference experienced by that device to be greater than other as it includes some feeder voltage drop (whereas the other device experienced just the voltage drop on the busbars). Comparing the voltage differences seen on P08 and P10 confirms this to be the case for this event. Figure 66 shows the relative voltage difference seen by the two devices. Only L1 (the phase that experiences the largest voltage dip) is shown to avoid clutter.

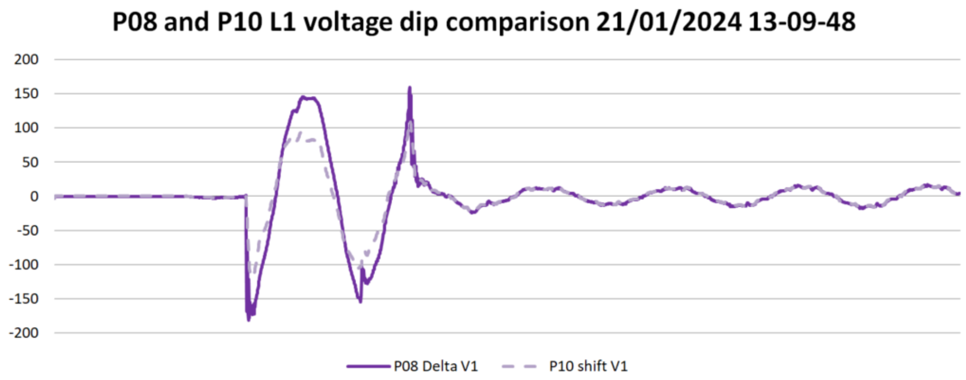


Figure 66 Relative Voltage Dip between two devices on different feeders on the network

The voltage dip experienced by P08 (Acomb Gravel) is significantly higher than that experienced by P10 (Summerrods). It appears, using the hypotheses presented at the beginning of this section on HV insights, that the source of the event (Fault or PreFault) was on the same feeder as P08 (Acomb Westfield SW Teed 20kV Feeder). The P10 (Summerrods device) here is experiencing the relative voltage drop 'seen' at the busbars on the Hexham primary substation.

If in a future rollout of LV monitoring equipment, if there were several devices distributed along the Acomb Westfield SW Teed Feeder, a more exact location or this Fault or PreFault could be relatively simply deduced from similar voltage difference analysis. Automation of such a function, though it would rely on a connectivity model, would be straight forward.

If it was a fault, as supplies do not appear to have been lost, then it is likely that it was in a protection zone further from Hexham Primary Busbars than the location of the P08 device or just as likely it was on a separately fuse protected Spur.

The implied location of the fault from this analysis for the event at 13:09:48 on 21st of January 2024 is shown on the schematic in Figure 67. The above analytics strongly suggest that it was on the feeder also occupied by P08 (Acomb Gravel).

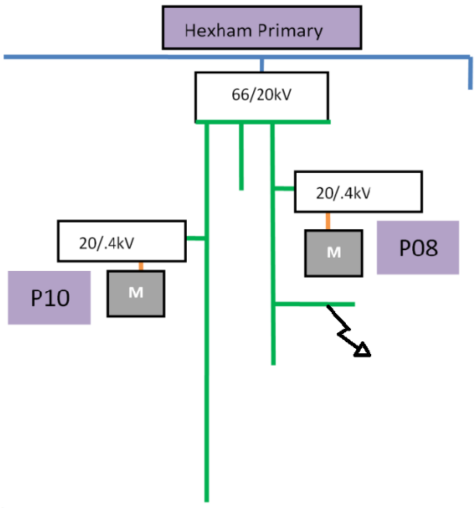


Figure 67 Implied location of the 20kV network fault or PreFault from 13:09:48 on 21st of January 2024 on the Acomb Westfield SW feeder out of Hexham Primary

There was a Northern Powergrid report posted at around this time noting the affected area as being identified as the part of the network just past the tee which P08 is on. The implied location in Figure 67 was correct in this instance. P08 was indeed close to the fault location which was on a separately fused leg of the Acomb. The lack of other devices on this feeder prevented any further location profiling.

21st of October 20kV Storm Event

The final example here is provided by data from the voltage triggering enabled devices on the West Wylam group only. The event is one of many from this day (during Storm Babet) in October 2023. The captures are shown in Figure 68.

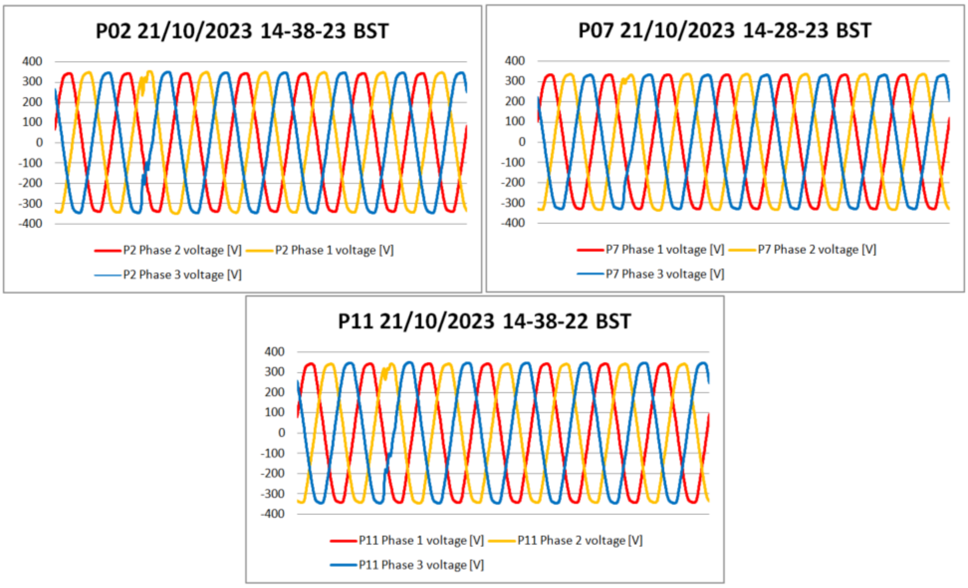


Figure 68 An event affecting the LV phases L1 and L2 captured on all three of the West Wylam group of substations

Though it is an insignificant event that, which given the stormy conditions at the time, may have been a switching/control related action as well as possibly being due to a transient insulation breakdown, it has been included here to demonstrate the principle of localisation of events with multiple devices distributed along the feeder. It is also the sort of event that will have been invisible to Network Operations staff and which, if it is found to be repeating, may provide information of use.

A voltage difference analysis zoomed in to focus on the short event is shown in Figure 69.

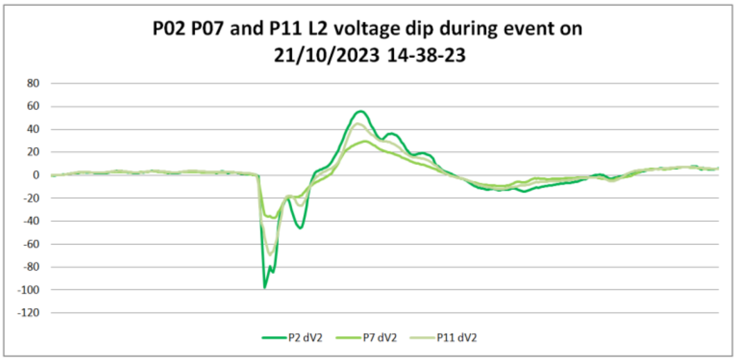


Figure 69 Relative magnitude of voltage dip for the series of devices on the Low Close 20kV Feeder out of West Wylam Primary

Both the sharpness of response and degree of voltage dip can be seen to be greater on P02 (Corbridge) than on P11 (Broomhaugh) and on P07 (Syntax SS), indicative of this event being closer to P02 than the other devices. P02 is near to end of the circuit open point in the normal running arrangement. Gratifyingly, in keeping with what was postulated for an event (even a small one like this) on a feeder with distributed voltage-triggered LV monitors, the voltage dips on the other devices correlate with their relative distance from the primary (see Figure 70).

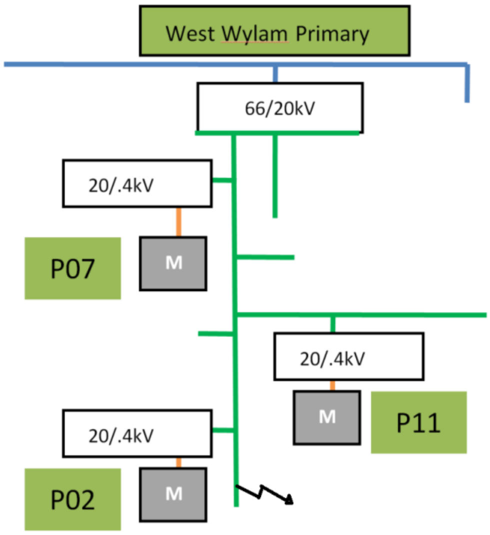


Figure 70 Captured event on West Wylam 21/10/2023 14:38:23 mapped to near P02 location on connectivity schematic using first pass insight analytics

A reoccurring event like this, particularly if associated with wet and windy weather could prompt investigation for vegetation management or other maintenance intervention, not as a priority but as an information/insight driven proactive action.

5.7.7 Next Steps for HV Fault Identification from LV Monitoring Devices

LV Monitoring providing HV Insights does not have to be for immediate reactive use, there are opportunities to take proactive action based on these determinations.

How can insights on the HV network be used:

- Transient fault analysis, for example identifying locations requiring vegetation clearance.
- Locating faults on the network enabling faster return to service.
- Confirming re-energisation of HV circuits post outage.
- Potential early warning of voltage control issues.

HV events are easily recognised by the devices monitoring both phase voltage and current as the voltage dips are not matched by In-Zone current increases. Comparison of event timestamping across a group of devices indicate those which have co-triggered and provide a simple means of determining the reach of a particular event.

Practical requirements to recognise and provide information on Out-of-Zone events using LV monitors:

- Significant coverage of multiple feeders with LV monitors.
    - Not all LV substations need to be monitored to provide this service, as demonstrated in this report, more monitors will provide more accurate locations.
- HV electrical connectivity diagrams for relevant feeders.
- LV monitoring of all phase currents and voltages.
- LV monitors must have voltage triggering enabled.

The area of most potential gain is in providing visibility on HV networks, the 20kV voltage level in this report. The voltage changes seen on the LV monitors are reflections of the voltages and current conditions at HV.

HV faults could be successfully localised by assessing the difference in the voltage change seen by the devices and considering that in light of the connectivity diagram. Both topological arrangements have benefits but it is clear that a combination of both (i.e. LV Monitors with voltage triggering enabled devices spread across different feeders and different locations on these feeders) gave the richest source of location for faults that were cleared by protection and for suspected transient and potential PreFault insulation, neither of which cause protection operation.

5.8 Assessing the Efficacy of Existing PreFault Detection and Impedance to Fault Algorithms for Overhead Line Circuits

Do overhead line assets fed from Pole mounted substations provide PreFault signatures capable of giving predictive insights into impending off-supply events?

In pure engineering terms, when considering faults and PreFaults, there are minimal practical and electrical differences between an underground cable and an overhead line. Both have joints and impurities that can be locations likely to fault and both have impedances that are required to locate those faults and any PreFaults arising ahead of the fault. The purpose of this project was to understand how those faults would present themselves and to understand if there are material differences in how the monitoring devices should be configured to record them. Both the Guard and VisNet devices have proven able to record and analyse events on overhead lines.

The primary learning, in terms of types of faults and PreFaults identified during this project, is that electrical contact between phases on OHL feeders does not necessarily indicate a permanent fault. On underground circuits, electrical contact between phases would likely be a permanent fault, whereas on OHL feeders inclement weather can result in poorly tensioned or spaced conductors clashing. However, both types of event are recorded by the present monitoring device settings and the algorithms will correctly identify them.

Provided with correct and accurate asset information for the feeders from the monitored substations there is no process difference between locating a PreFault on an underground cable network to an overhead or mixed network. The main investigation point for this project concerned whether PreFaults manifested in the same manner on OHL circuits. This project has recorded multiple events that fit the profile of PreFaults as seen by UGC circuits and the algorithm successfully identified them as events of interest, and they were locatable.

5.9 Assessment of the Efficacy of Existing Proactive Responses for Use on Overhead and Mixed Circuits

How might the systems be used operationally to improve quality of supply for customers fed from pole mounted substations with overhead and mixed overhead and underground LV circuits?

The present method of fault finding, without monitoring, is for customers to call their network operator when there has been an outage. This is the same for both OHL networks and the underground cable networks. Especially apparent during storm outages, customers will call when they see a downed line and then the networks can respond to those calls.

The ideal endpoint of this PreFault detection and location feature would be to automate the process. At present there is a certain level of manual input required to locate the PreFaults, which limits the number of events that can be located in both response time and in volume of locations.

Automatic location of the events will allow the network field force to limit their search area to those highlighted by the software, likely reducing the time required to identify the issue that caused the outage. This will improve the quality of supply by decreasing the return to service for customers fed by pole mounted substations.

From an operational standpoint, reducing outage times will reduce CMLs. If proactive location of PreFaults can be made standard practice then a network could reduce both CIs and CMLs, improving supply quality for customers by moving from unplanned outages to planned and coordinated outages.

The second insight available from analogue measurements is the approximate time and duration of outages. During outages, the devices are unpowered and no longer send the data. When power is restored, the devices reboot and data calculation and transmission resume. For those with access to the web-viewer for these devices, the gap in the data becomes apparent on the full day data view for the devices affected by the outage. This acts therefore as a convenient means to confirm approximate outage periods and, particularly where remote switching is being employed, that networks have been successfully restored, and the approximate time that this occurred. Figure 71 shows the web-viewer analogue data view for an outage that occurred on this particular substation on 21st of October 2023[15]. The missing data is apparent to the right-hand side of the view (between 21:00 and 23:00).

In this instance, the outage was local to this substation. The example has been retained to demonstrate the potential use of the analogue data for this purpose.

[15] This is in the aftermath of a named storm (Storm Babet) that caused much disruption in the UK due to high winds and flooding. In this case the outage was due to the need for repair of a section of LV line affected by the storm. If this was a HV outage, multiple devices would show the same period of lost data.

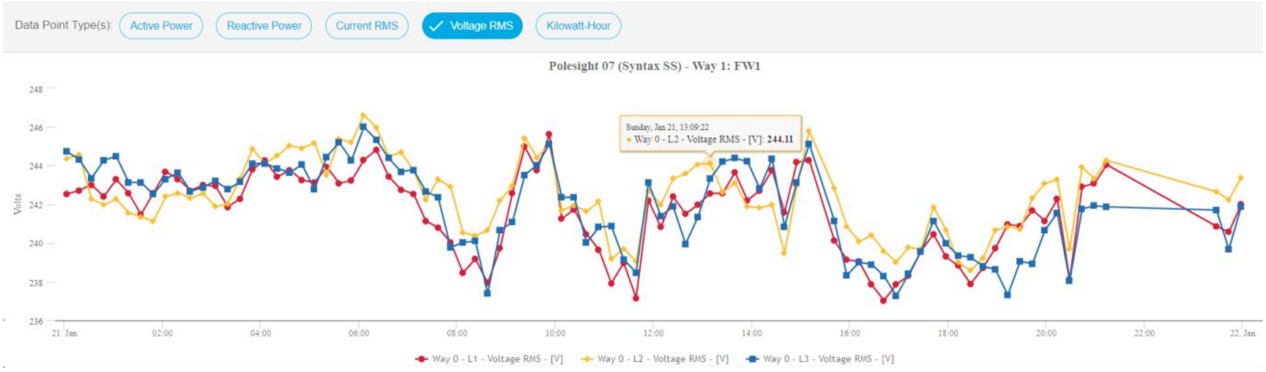


Figure 71 Missing data confirming the time that the P07 device is re-energised at around 23:30 pm

Figure 72 is an Excel scatter graph from around the time of the outage. The data labels for current L1 have been left on to show how this data can be used to approximate the time that this substation was off supply: 21:13 (or soon after) to 23:27 (or soon before).

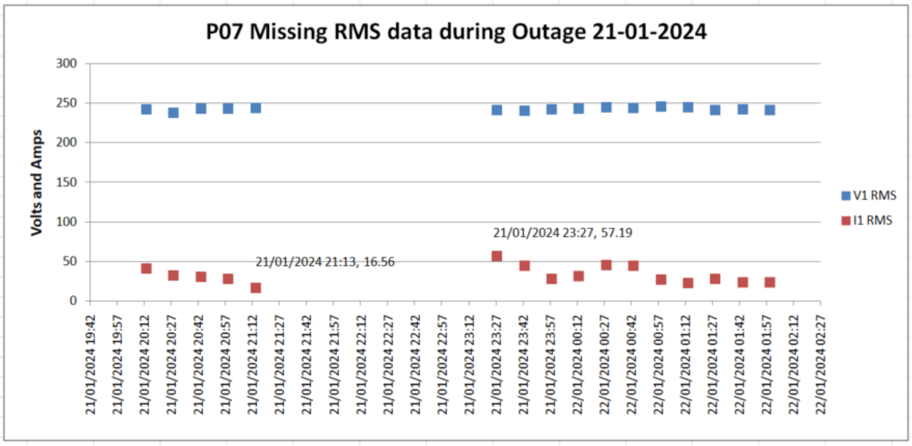


Figure 72 Excel scatter chart showing RMS data for V1 and I1 indicating the period off supply being approximately 2 hours

The data provided by LV monitoring can have a multitude of uses beyond the primary purpose of LV network fault finding. With a device like the VisNet hub, which has the capability to receive new applications once it has been deployed, the LV monitors could perform more analysis on the device side before the data is transmitted to the client.

6. Further Discussion

The previous section covered specific workstreams that were proposed at the outset of the project. This section will now bring together the outputs from those workstreams to discuss the key learnings from this project.

6.1 Current Triggering or Voltage Triggering: Which is More Suited for OHL Circuit Monitoring?

The project reinforced the reason for using a 700A phase current trigger on the VisNet devices, if the key use for the device was to be for **locating and localising** PreFaults. While PreFault-like events could be **detected** when the triggering value was lowered to 350A, these events were never able to reach the criteria to allow them to be located. In all cases observed during this project, the events that were recorded with an event current under 700A could not be located by the present algorithmic settings.

No evidence was gained during this project to suggest that the absolute current trigger should be adjusted in relation to the rating of the transformer. If there are concerns around event capture rates, voltage triggering should be used.

Figure 73 shows all events categorised as PreFaults by Polesight 07 (a Guard) with a maximum event current greater than 150A. In this graph, the lower the event impedance (X-axis) the more likely that the impedance is locatable to somewhere on the feeder. The only event that was locatable on this graph was the credibility 5 event in the top left-hand corner. This was the event discussed in section 5.6.1.

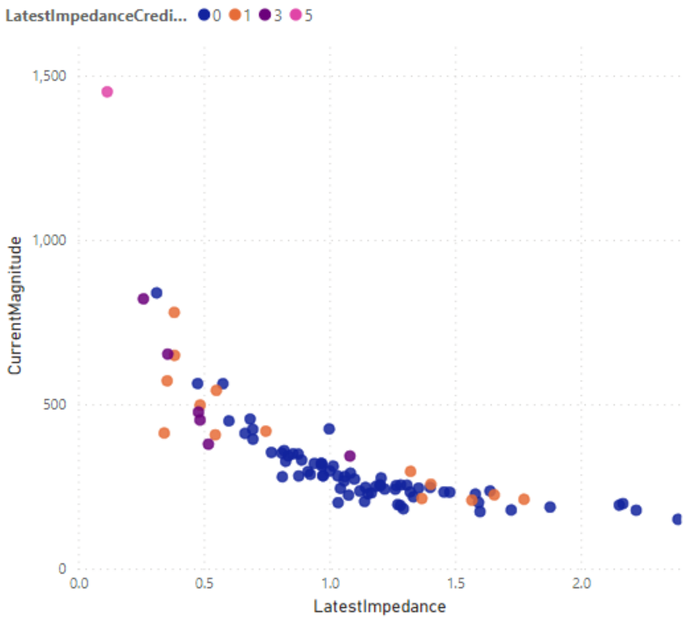


Figure 73 Polesight 07 (Syntax) event impedance correlated with maximum event current

Credibility, in the context of event categorisation, only refers to the event fitting the profile of a PreFault. There are aspects of non-PreFault events that can bear resemblance to a PreFault, hence why a credibility score is useful to support the determination of an event type.

However, locating PreFault events are not the only method of determining an assets likelihood of failure. One, singular PreFault does not necessarily tell an asset manager anything about the health of their network. Presently the event information from Guard devices installed BAU within NPg are added to a monthly watchlist, in this case the number and frequency of events are the key factor for assessing the urgency of investigation required. A device being on the watchlist is not an indication that immediate repair works need to commence but a device moving from the "Poor Condition" to "Failure Likely" categories would suggest that some investigation needs to occur.

The VisNets used during the Polesight project, as previously discussed, had their current trigger lowered to a magnitude of 350A. This allowed for some events that would have previously been missed to be recorded. The primary issue with this method of triggering was that devices would frequently record load events. This was most evident on the device monitoring Acomb Industrial substation. As can be ascertained from the name, this substation feeds an industrial load, likely something requiring a motor. What evidence supports this hypothesis? Large number of non-fault events occur during the business hours of 8.30am and 6pm during the week, with currents above the 350A threshold being recorded while the device turns on, when the largest current is required.

Lowering the threshold has no impacts on the overall analytics, the analysis ignores non-PreFault events and can recognise the events as such. The issue is that recording events that are not of interest to the analytics will create larger data costs with the methods EA Technology are presently using, as transmitting the data associated with load events is not economic. If overloading alarms are of interest to a network operator, then the better method would be to use the VisNets processing power on the device to analyse heavy loading events and only upload the findings, rather than all associated data. If a lowered current magnitude trigger is the method chosen to move forward with monitoring pole mounted substations, then there would likely have to be a filter to ensure that the storage would not be filled with non-PreFault event data.

From the quantitative evidence generated when comparing the volume of "junk" events recorded by the VisNets and the Guard devices, the voltage differential triggering has not been associated with capturing load events. Substations that were monitored by Guards saw fewer events in every month of the project while still capturing a majority of the PreFault events of interest. Of course, these devices happened to be monitoring feeders that had those large events, but the voltage trigger still captured all the events.

The Guard devices also have an absolute current trigger of 450A, which while not definitively seen in use on this project, would function in the exact same way as the VisNet absolute current trigger. Any event in the 450A to 700A range is still unlikely to be locatable but the event could be used, as previously discussed, as evidence for condition monitoring of a feeder.

6.2 What Effect Does Inclement Weather Have on PreFault and Fault Activity on OHL Networks

It is commonly witnessed that more cable faults and PreFaults occur following periods of heavy rain, when the ground becomes more saturated. This is due to water ingress in joints and other defects on cable networks causing flashovers, which is some cases may be the cause of transient faults.

At the outset of the Polesight project it was hypothesised that more OHL events would be seen during inclement weather, rather than the delay that is seen on underground networks. OHLs are more susceptible to interactions with vegetation and even other conductors due to wind. They also experience more asset damage events, such as demonstrated at Polesight 07 in section 5.6.1, where poles can snap and lines be downed.

Weather events affecting OHL networks can be broadly categorised into two types of events:

- Non-damage, transient fault interactions.
    - Clashing conductors and vegetation encroachment are two examples.
- Damage, permanent faults.
    - Broken assets.

Locating transient faults, especially those caused by weather, can be nearly impossible as they do not leave much evidence in their wake. LV monitoring with PreFault location can be used to great effect to resolve issues before the next storm event.

While locating broken assets digitally seems to be slower than the current practice, where faults are called in by customers witnessing a fault or experiencing an outage, there are some clear use cases, especially for rural networks. None of the LV feeders monitored for this project extended beyond a kilometre from the LV substation and generally remained alongside roads and pathways. However, if a damage fault was to occur on a section of a feeder that was in a less noticeable area, for example in a field or behind a treeline, it may take longer to locate.

Automatically detecting and locating where fault events are occurring would allow for the quicker triaging of faults and possibly quicker implementation of solutions to those fault events.

6.3 Are Overhead Line Events Locatable?

As discussed in Section 5.6, there is ample evidence to show that OHL events can be located in a similar manner to the UGC events. While there were no proven PreFault events that would go on to fault during the project's data capture period, the Townley Terrace events discussed in Section 5.3 provides evidence that PreFault events on OHL circuits are likely to show similar characteristics to UGC PreFaults. When the first PreFault events were recorded it was clear that the algorithms would be able to categorise the events without modification.

The events recorded at Summerrods are useful evidence of how possible transient faults, even those specific to OHL circuits like clashing conductors, can be located even without physical evidence after the fault. Locating transient faults could provide actionable insights for proactive works, to reduce CI and CML by preventing outages from occurring.

The primary issue faced when locating the events was incomplete conductor information for the feeders. Accurate location of PreFault events requires the correct conductor type to ensure the calculated event impedance will be as accurate as possible. Some of the feeders had missing conductor data which slowed the development of locations of the PreFaults.

If this type of monitoring was to be deployed in BAU then an accurate digital twin with the correct conductor types and the associated correct attributes is required. To automate the whole location process a digital twin of the LV network will be a fundamental building block.

7. Conclusions

The Polesight project has successfully provided evidence that existing LV monitoring devices can detect and, when provided with three-phase current information, locate and localise PreFault and fault events. The devices withstood severe storm conditions while monitoring the PMTs and required minimal modifications to do so.

Both devices used during this project could be installed with minimal alterations, excepting the mounting enclosure for the pole and voltage connections, and with no LV outage required.

The voltage triggered devices, the Guards, required no modifications to their settings to begin capture of events on the LV network. The current triggered devices, the VisNet, did have the current triggering level lowered in the duration of the project, however it was discovered that this ultimately made no difference in locating PreFaults of interest. This shows that both the Guard and VisNet devices' standard settings are suitable for detecting and locating PreFaults when installed monitoring the three phase currents of a feeder. However, the choice of device is dependent on whether cable condition assessments and HV network events are of interest.

Events recorded and located to OHL sections of the feeder were categorised correctly on both types of devices. On the voltage triggered devices, HV events were correctly identified when recorded.

Although future work is required, this project laid foundations for the use of LV network monitoring to provide insights in HV network events. This could provide major benefits for the network and provide further justification for a large-scale LV network monitoring rollout.

C1. Monitoring devices require minimal physical alterations to be installed at pole mounted substations.

- C1.1 The devices can be installed within nondescript enclosures and mounted on poles in a safe and secure manner above the anti-climbing device.
- C1.2 Voltage connections required some adaption compared to the busbar connections, but modifications were suitable for the purposes of the project.

C2. Most of the located and localised PreFaults recorded by this project were on circuits monitored by Guard devices.

- C2.1 This proves voltage differential trigger will still capture the locatable PreFault events, provided the Guard devices monitor the three current phases of the feeder in addition to the neutral.
- C2.2 Voltage triggering provided a wider array of events that could be used for other purposes beyond LV PreFault location such as HV network insights and cable condition assessments.
- C2.3 Further work is required on the triggering and algorithms for split-phase networks due to the different voltage characteristics compared to three-phase networks.

C3. The existing algorithms categorising the events are largely suitable for use on OHL networks.

- C3.1 Guard event categories, including the HV categorisation, provide more information on the type of events being recorded by a device.
- C3.2 VisNet categories are suitable if the only type of event a user is interested in is locatable PreFault and fault events.
- C3.3 Development of algorithms suitable for split-phase network events is required.

C4. Voltage triggered devices can provide insights into HV network events.

- C4.1 This requires a suitable number of LV monitors on a feeder.
- C4.2 There needs to be accurate HV connectivity data for the feeder.
- C4.3 For automatic detection of HV events, the LV monitors should be clustered together by feeder and primary substation.

8. Recommendations

Within the short, 11 month, monitoring period of the Polesight project, almost all of the questions posed at the outset have been answered in some capacity.

There is no reason that more pole top monitoring devices should not be installed within a BAU capacity. Some consideration should be taken with how the device triggers and what the capabilities of the device are but pole mounted transformers should be considered for monitoring in the same BAU process as ground mounted transformers.

Either device used in this project could be utilised for further PMT monitoring. However, if a device was to be favoured over another, a voltage triggered monitoring device would be preferrable to capture smaller, persistent PreFault events that can be used for cable condition assessments, like how the Guard devices installed BAU in NPg's network do already. The Guard devices in BAU are not installed with phase current monitoring as standard. For a pole-mounted solution phase current monitoring should be provided as standard to ensure location of PreFault events recorded. The Guard devices installed in BAU are designed to be replaced by fault-locating devices if a persistent, intermittent fault is recorded. To avoid multiple linesmen callouts to fit the replacement devices, a pole-mounted monitor should be installed with phase current monitoring as standard.

Further work is required to understand how PreFaults should be analysed on split-phase transformers, where the analytics need to be adjusted to manage the differences in event waveforms.

It was shown in this project that there are real and actionable insights on the HV network available, with no real change to data provided, from LV network monitoring. While developing this workstream further was out of scope for the Polesight project, a future project analysing HV insights should be taken forward. Clear investigation into the effectiveness of LV monitoring for HV events would require a comparison with HV connected disturbance recorders. However, if LV monitoring is to be widely implemented, then utilising already provided data from those devices would provide efficiencies of scale.

R1. Headline monitoring device specifications:

- R1.1 A two feeder monitoring solution is the most versatile option to roll out BAU. The majority of pole mounted substations supply two feeders or less. Device should monitor the three phases and the neutral of the feeder.
- R1.2 Pole mounted devices should monitor the three phases and the neutral of the feeder. The Guards can monitor up to eight current channels. At ground mounted substations only the neutrals would be monitored as there could be up to eight LV ways.
- R1.3 Voltage triggered devices provide the most comprehensive recording of event types across all sizes of transformers. VisNets could be configured to trigger on voltage if required.

R2. If detailed load monitoring information for rural feeders is of specific interest then the VisNet monitor is preferable to the Guard as the VisNet collects that data.

R3. Future rollout should be based on a prioritised list of feeders with higher instances of fault activity. From this, improvements to PreFault event categorisations and algorithms can be developed.

R4. Further investigation into the analysis of events recorded by split-phase networks is required to ensure successful future use.

R5. Further investigation into the detection and localisation of HV events from LV insights is required.

- R5.1 If a suitable number of LV monitors, voltage triggered, are installed on an HV feeder, then the detection and localisation of HV events is possible.

Appendix I Polesight Data Tables

Table AI.1 Polesight Substation Information

Polesight ID	Monitor	Tx Rating	Substation Name	Feeder Name	UGC or OHL	Feeder Type	% OHL
Polesight 01	VisNet	200	ACOMB INDUSTRIAL	W1(ACOMB INDUSTRIAL LV FEEDER G)	Mixed	Three-phase	56%
Polesight 01	VisNet	200	ACOMB INDUSTRIAL	ACOMB INDUSTRIAL - TX 1 - LVF DLFU-00149911 - W 1	U/G	Three-phase	0%
Polesight 02	Guard	200	CORBRIDGE STATION	CORBRIDGE STATION - TX 1 - LVF CORBRIDGE STATION LV FEEDER H - W 1	Mixed	Three-phase	43%
Polesight 03	Guard	50	BIRKSHAW	BIRKSHAW - TX 1 - LVF BIRKSHAW LV FEEDER G - W 1	Mixed	Split-phase	59%
Polesight 04	Guard	100	TOWNLEY TERRACE	TOWNLEY TERRACE - TX 1 - LVF TOWNLEY TERRACE LV FEEDER E - W 1	O/H	Three-phase	100%
Polesight 05	Guard	50	CHOPWELL WOOD	CHOPWELL WOOD - TX TTXF-00271409 - LVF CHOPWELL WOOD LV FEEDER A - W 1	Mixed	Split-phase	78%
Polesight 06	Guard	100	HALTWHISTLE WESTLANDS	HALTWHISTLE WESTLANDS - TX 1 - LVF HALTWHISTLE WESTLANDS LV FEEDER G - W 1	Mixed	Three-phase	32%
Polesight 07	Guard	100	SYNTAX	LV FUSE UNIT:DLFU-00103562 - LV FUSE UNIT:DLFU-00105416 TEED	Mixed	Three-phase	63%
Polesight 08	Guard	200	ACOMB GRAVEL	ACOMB GRAVEL - TX 1 - LVF ACOMB GRAVEL LV FEEDER G - W 1	Mixed	Three-phase	84%
Polesight 09	Guard	100	HIGH CATTON	HIGH CATTON - TX 1 - LVF SERVICE - W 1	Mixed	Split-phase	70%
Polesight 10	Guard	100	SUMMERRODS	SUMMERRODS - TX TTXF-00209454 - LVF NETWORK - W 1	Mixed	Three-phase	95%
Polesight 11	Guard	200	BROOMHAUGH	BROOMHAUGH - TX TTXF-00211868 - LVF 1 - W 1	Mixed	Three-phase	29%
Polesight 12	VisNet	200	FOURSTONES SCHOOL	FOURSTONES SCHOOL - TX 1 - LVF 1 - W 1	Mixed	Three-phase	72%

Polesight 13	VisNet	200	MATFEN	MATFEN - TX TTXF-00208522 - LVF MATFEN LV FEEDER H - W 1	Mixed	Three-phase	34%
Polesight 14	VisNet	100	WEST CAUSEY HILL	WEST CAUSEY HILL - TX 1 - LVF DLFU-00149889 - W 1	Mixed	Three-phase	93%
Polesight 14	VisNet	100	WEST CAUSEY HILL	WEST CAUSEY HILL-TX1-LVF1-W1(WEST CAUSEY HILL LV FEEDER E)	U/G	Three-phase	0%
Polesight 15	VisNet	100	SLALEY POLICE	SLALEY POLICE - TX 1 - LVF 1 - W 1	Mixed	Split-phase	37%
Polesight 16	VisNet	100	WENTWORTH ALLENDALE	WENTWORTH ALLENDALE - TX 1 - LVF WENTWORTH ALLENDALE LV FEEDER A - W 1	Mixed	Split-phase	24%
Polesight 17	VisNet	100	MICKLEY MOUNT (HEX)	MICKLEY MOUNT (HEX) - TX 1 - LVF MICKLEY MOUNT (HEX) LV FEEDER E - W 1	Mixed	Split-phase	96%
Polesight 18	VisNet	100	MICKLEY JUNCTION	MICKLEY JUNCTION - TX TTXF-00209462 - LVF MICKLEY JUNCTION LV FEEDER B - W 1	Mixed	Split-phase	62%
Polesight 18	VisNet	100	MICKLEY JUNCTION	MICKLEY JUNCTION - TX TTXF-00209462 - LVF MICKLEY JUNCTION LV FEEDER D - W 1	Mixed	Split-phase	
Polesight 19	VisNet	200	ACOMB WEST	ACOMB WEST - TX 1 - LVF 1 - W 1	U/G	Three-phase	0%
Polesight 20	VisNet	100	DINNINGTON VILLAGE	DINNINGTON VILLAGE - TX 1 - LVF 1 - W 1	Mixed	Three-phase	42%

Appendix II Referred to Documents

All relevant documents are available alongside this document on the NPg innovation website:

https://www.northernpowergrid.com/innovation/projects/polesight-nianpg-036

Table AII.1 Documents referred to throughout this report

Name
EA9744 – TR01 Polesight Monitoring Design Specification
EA9744 – TR02 - Polesight Installation Guide
3473-PRSPC-GRD1-V01.03.00 Guard Product Specification
3473-PRSPC-VNH1-V01.02.00 VisNet Hub Product Specification
EA9744-TR05 Polesight Installation Checklist
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