Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form. The full completed submission should not exceed 6 pages in total.

Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

NIA Project Annual Progress Report Document

Date of Submission

Jun 2022

Project Reference

NIA_WPD_041

Project Progress

Project Title

Automatic Location of Arc-faults through Remote Monitoring (ALARM)

Project Reference

NIA_WPD_041

Funding Licensee(s)

WPD - Western Power Distribution (East Midlands) Plc

Project Start Date

September 2019

Project Duration

2 years and 9 months

Nominated Project Contact(s)

Chris Harrap

Scope

The project will follow a two phase approach.
In Phase One, monitors with the supplier’s existing fault location capability will be installed, and data will be analysed by the supplier. This Phase One data will primarily be used to confirm operating parameters for
improved data capture hardware that the supplier has also already designed. This improved fault location
hardware and capability will then be deployed and tested in Phase Two of the project.

Phase Two will then seek to demonstrate optimised fault location data for monitored feeders to the
distribution business.

Objectives

1. Test the feasibility of a technical alternative and lower cost fault locating device.
2. Derive insight into the potential to more widely and cost-effectively deploy such monitoring equipment to feeders showing early indications damage (e.g. transient fuse operations).

Success Criteria

Overall success will be:

- Identification of pecking faults within monitoring data, reliably distinguishing them from other network transients and disturbances

- Capture of sufficient pecking fault data to estimate confidence in DtF indications for transient arc-faults;
- Quality of captured auxiliary data (e.g. upstream and downstream network impedance indications) is sufficient to support reliable distance to fault calculations.
- Quantitative understanding of the frequency and magnitude of transient arc-faults on monitored feeders.
- Automatic generation and notification of distance to fault indications; and

DtF indications are successfully used by local teams to guide repairs ahead of permanent faults developing.

Performance Compared to the Original Project Aims, Objectives and Success Criteria

Objective

Test the feasibility of a technical alternative and lower cost fault locating device
COMPLETE: This objective was met with the devices proving that the technology works at reasonable cost.

Derive insight into the potential to more widely and cost-effectively deploy such monitoring.
COMPLETE : The devices were proven within the project and now a comparative project is being undertaken in BaU to determine the most cost effective and suitable device for a business wide roll out.

Success Criteria

1) Identification of pecking faults within monitoring data, reliably distinguishing them from other network transients and disturbances.
ACHIEVED: We were able to identify pecking faults in a way that distinguished them from other faults and moreover as detailed below were able to then rectify them in both a business as usual context as well as team attendance on site visits to progress activities.

2) Capture of sufficient pecking fault data to estimate confidence in DtF indications for transient arc-faults.
ACHIEVED: The team were able to generate a variety of representations of the data to highlight the location of the fault.

3) Quality of captured auxiliary data (e.g. upstream and downstream network impedance indications) is sufficient to support reliable distance to fault calculations.
ACHIEVED: Phase 1 monitoring produced upstream impedance estimates that were comparable to transformer nameplate data. Further refinement of upstream impedance estimates were delivered with Phase 2 monitoring. We used passive boards for Phase 1 and for Phase 2 active boards. These enabled us to ensure that we were producing accurate locations in both phases and calculating the impedances correctly.

4) Quantitative understanding of the frequency and magnitude of transient arc-faults on monitored feeders
ACHIEVED: Data was collated on the number of events that occur on an individual monitor, and is available for all monitors. The magnitude of individual events can be seen from the waveforms captured for each event as shown through this report and both Phase learning reports.

5) Automatic generation and notification of distance to fault indications
ACHIEVED: -Within the Phase 1 monitoring period, automated scripts were run to screen and assess captured events. These scripts estimated a distance to fault for an individual event, plus process metrics associated with an individual event. Histograms of numbers of events versus DTF are also automatically generated. Learning from Phase 1 monitoring was used to refine this assessment process. Further work was undertaken throughout Phase 2 to automatically generate and appropriately display DTF indications, and provide associated automated notification (e.g. current DTF indications on a regular basis, and upon specific events such as a fuse operation)

6) DtF indications are successfully used by local teams to guide repairs ahead of permanent faults developing
ACHIEVED: The devices and subsequent verification phase did allow us to identify and locate faults on the network and carry out subsequent repairs.

Required Modifications to the Planned Approach During the Course of the Project

There have been no changes to planned approach/methodology other than a short extension to the verification phase to cater for COVID 19 delays. This extension did not in any way impact on timescales though.

Lessons Learnt for Future Projects

The project successfully and accurately located a number of underground cable network faults and provided learnings about the real world performance of the DTF system on a live network with all of its quirks and features, and insight into how best to integrate information about potential issues on the network into the workflow of managers and field teams. The learnings below are summarised by category.

1.1. Event classifications and patterns

The sites chosen for the trial had a history of faults. Prior to installation of this equipment, local teams suspected that pecking events at these sites were relatively common but evidence for this was only anecdotal. As a result of this trial hard evidence has been produced about the frequency and behaviour of pecking faults. This evidence suggested that information taken from pecking events can be used as a leading indicator of power cuts.

1.2. Classification of transient events

The events recorded comprised (in approximate order of most to least common):

- Pecking events Phase to Neutral
- Pecking events Phase to Phase
- High inductive load start transients
- Fuse operation transients
- Fuse replacement transients

One of the key aims of the project was to automatically classify these transients to ensure only the pecking events were considered in the algorithm – e.g. load start transients were not misclassified as pecking events. The GridKey solution successfully isolated pecking events from other types of transients based on the specific characteristics of the transients and the majority of pecking events fitted the expected model and could be analysed.

1.2.1. Patterns of transient events

A number of distinct patterns of behaviour were observed across different installation sites:

- Regular pecking as single events, spaced by hours to days or even weeks
- Bursts of pecking events with e.g. 10 strikes in the space of a short period (seconds) with long gaps (days/weeks/months) between

As expected there were also large variations between sites in both peak currents and overall duration of arcing leading to large variability in likely cable damage (and ozone gas generation – hence why using a “sniffer” or IR camera is not always successful in locating the fault).

Despite the sites having been selected as having a history of faults, some substations had no pecking events at all, however at other substations there were hundreds of pecking events per month, albeit there was no evidence that all were eventually identified as faults.

Whilst there were occasions where there were fuse operations without any or only a few previous pecking events the trial proved that in the majority of instances, pecking events did occur, and with sufficient frequency to build up statistics to locate the event on the network with a known prediction uncertainty in a reasonable timeframe. Where events happened more frequently, this allowed the location uncertainty to be lowered more quickly.

The trial showed a wide range of variability in correlation with prior pecking events, but where there were significant prior pecking events, there was a strong chance that the permanent fault developed at the location of the prior pecking events, as the pecking events were eliminated after the fault was repaired. However, there was not a strong indication of the timing of an impending fuse operation from the immediately preceding frequency of pecking events although physics would dictate that the more energy in the faults would tire the fuse more quickly and make it more susceptible to operating.

A learning was that some measure of the cumulative damage impact on the cable would be valuable in prioritising intervention or further investigation. This would be based on the frequency, current and duration per event, so distinguishing between the damage caused by lower current events at the far end of long feeders and high current events close to the transformer, and between short duration arcs and sustained multi-cycle arcing.

1.3. Equipment performance

The GridKey equipment performed well in the field where the existing hardware was supplemented with an additional circuit board to allow the magnitude of the current spikes to be accurately measured. Two variants were trialled, differing primarily in their analogue resolution, and in their ability to manage multiple successive transients. It was found that the higher resolution captures did not materially improve location statistics, whilst reducing the time between captures did allow fewer transients to be missed during bursts of transients and hence quicker location statistics to be gathered but again this did not improve the overall location statistics.

1.4. Analysis of transient events to determine cause and location

Analysis and modelling learnings

Prior to this trial, it was expected that phase-phase arc transients would be common because the electric field levels are highest between adjacent phase conductors, but the trial showed that phase-neutral were far more common.

Also, when there was a large pecking fault on one feeder/phase, we observed large current transients on different feeders but the same phase as the feeder with the pecking event. These had not been expected prior to the trial of the equipment and we initially suspected instrumentation issues such as cross-talk within the electronic components. However , when the team considered the complete network model these were found to be explained by the model and once this was understood, these “parasitic” transients were eliminated from subsequent location analysis, eliminating some early misidentification of feeders with events. In fact, the presence of these transients further validated that the network model used by GridKey was correct.

1.4.1. Location statistics

The statistics (repeatability) of location for an individual pecking source varied significantly from one installation site to another. Some sites created relatively tight distributions, others relatively broad distributions. For those locations with broad distributions, a larger number of transients needed to be collected to achieve a reasonable degree of confidence in the actual location. A number of root causes of this variability were considered and eliminated:

- Equipment cross-talk
- Equipment resolution
- Level of load on the affected feeder
- Time of day
- Quality of fit for individual events

1.4.2. Dealing with multiple events at a location

In some instances where there appeared to be a broad distribution of predicted fault locations, we found that a single feeder could have more than one fault on it, but at different locations. In addition, these multiple faults could be on different feeders but also on the same feeder. These faults were initially displayed just as a single feeder but due to the multiple locations this gave a large position of uncertainty. As a result GridKey introduced a clustering algorithm to separate out events associated with different locations on the same feeder, and to analyse the statistics of these separately to give multiple sets of location information.

1.5. Validating the location information

A key part of this project was the validation of the locations identified using the GridKey system – this was done using different technologies or as a result of an actual repair.

There were 5 instances where fuse operations followed a number of pecking events on a feeder and multiple instances of the pecking events, and the local crews located and repaired the cable. Eliminating the cases where the transient event corresponding to the fuse operation itself was analysed, the agreement between the predicted and actual fault location was generally good and in general terms did reduce the time spent checking up and down the relevant feeder, the results being consistently within tens of metres.

1.6. TDR Verification Equipment

Validation with other industry tools was challenging and required experience to interpret and use. The TDR systems when used correctly are able to provide extremely accurate fault location. Typically, each TDR unit only monitors a single three phase feeder whereas the GridKey system was monitoring up to 6 feeders simultaneously. There was also a marked contrast between the simplicity of a GridKey system providing a distance and associated uncertainty and the TDR system that required a degree of skill and understanding to both locate the installed equipment correctly and also to interpret the results.

However, there was generally good agreement obtained in those instances where the TDR equipment was successfully deployed.

1.6.1. Ozone detection

Using a CableSniffer to detect the ozone generated when there was a pre-fault pecking event was not successful. There were a number of reasons for this:

- Feedback from field crews was that even when there has been a fuse operation, the amount of ozone released is quite small
- Lack of a good process to get location information to field crews fast enough before the gases from the arcing had dissipated.

1.7. Making use of the location information

The true value of a fault location system is in connecting with maintenance and repair crews, either to enable proactive maintenance before a permanent fault occurs, or to speed the process of restoration after a fuse operation, embedding this process into Business as Usual (BAU).

1.7.1. Presentation of information

Engagement with the WPD team helped to change the representation of the statistics of fault location from a simple histogram based on frequency, to a smooth bell curve, to make the uncertainty of the distance calculations clearer. This bell curve presentation method also enabled potential multiple faults on the same feeder/phase to be shown more clearly.

The local teams use tablet computers to view their network maps. Ideally, there would be further development of the mapping system to enable the distance to fault system to highlight predicted fault locations directly on these maps, including where there are multiple possible locations because of branches or links, reducing the time to positively identify the locations of the potential sites to investigate.

1.7.2. Alerting the local field teams

A method of alerting local teams when a significant event occurs could be implemented to help in further identifying locations quickly using other techniques such as using a Sniffer, as there is a very small window of time after an arc when this is an effective method of fault detection This would enable higher probability of successful preventative maintenance prior to a permanent fault occurring. This would require BAU engagement to integrate with the existing work order management practices and systems that are in use.

Note: The following sections are only required for those projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

The Outcomes of the Project

Two detailed learning reports have been produced for the project, each detailing the learning from each of the two trials. Both can be found on the ALARM project page of the WPD Innovation Website.

Data Access

Anonymised data will be available to share in accordance with WPD’s data sharing policy www.westernpower.co.uk/Innovation/Contact-us-and-more/Project-Data.aspx.

Foreground IPR

All relevant background IPR was declared in the project Collaboration Agreement. The arrangements reflect the default provisions in respect of IPR as prescribed by the NIA Governance Document. In outline, the relevant background IPR includes Lucy Electric GridKey’s:

- locally installed monitoring equipment and Data Centre solution;
- the processing algorithms that generates the DtF indication; and
- the methods employed to automatically implement the algorithm to captured data

The purpose of the project was to test, refine and validate the existing DtF algorithm by using real data collected at WPD LV substations.

Any relevant foreground IPR generated through this project relates to the results and findings of the live network trial (not the in-depth workings of the DtF algorithm).