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NIA ENWL007

Reliable, Low Cost Earth Fault Detection for Radial OHL System Faults

Closedown Report

22 December 2017

VERSION HISTORY

Version	Date	Author	Status	Comments
V1.0	22 December 2017	Dan Harber Project Manager	Final	Final version following internal review and comment

REVIEW

Name	Role	Date
Lucy Eyquem	Innovation PMO Manager	24 July 2018
Paul Turner	Innovation Manager	27 July 2018

APPROVAL

Name	Role	Date
Steve Cox	Engineering & Technical Director	31 July 2018

CONTENTS

GLOSSARY

Term	Description
ADMS	Advanced distribution management system
ARS	Automatic restoration scheme
CI	Customer interruption
CML	Customer minutes lost
DNP3	Distributed network protocol – a set of communications protocols used between components in process automation systems
FLA	Feeder load analysis
FPI	Fault passage indicator
GROND	Electricity North West's planning tool for 11kV networks
GSM	Global system for mobile (communications)
OHL	Overhead line
NMS	Network management system
RIIO-ED1	First electricity distribution price control to reflect the new RIIO (Revenue = Incentives + Innovation + Outputs) model for network regulation
SCADA	Supervisory, control and data acquisition system
TRL	Technology readiness level

1 EXECUTIVE SUMMARY

1.1 Aims

The aims and objectives of this project were:

- To reduce the time taken to locate faults on rural overhead line (OHL) networks
- To develop a method for reliable detection of earth fault and over-current on OHL networks
- Install OHL fault passage indicators (FPIs) for over-current and earth fault detection using live line techniques
- To develop a method of OHL FPI installation with minimal commissioning and set-up and without the need for shutdown (including location methodology and installation method statement)
- To understand the impact of OHL FPIs on a DNO's ability to locate faults more quickly and restore supplies to customers more efficiently.

1.2 Methodology

Prototype OHL FPI equipment was installed at ten sites. Locations were selected based on a range of factors including performance. The circuit selection also considered the number of customers, the overall length of OHL associated with the feeder and considerations towards straightforward installation. Monitoring equipment was installed at the selected sites to gather data to support development of the required algorithms. The FPIs are readily integrated via a DNP3 interface into Electricity North West's existing network management system and are monitored via Nortech's iHost system.

1.3 Outcomes

The following outcomes resulted from this project:

- A technical engineering specification was developed for OHL FPIs
- Installation and test procedures were developed and trialled for OHL FPIs
- Communication to central system (iHost) was proven with network management system (NMS) compatibility via DNP3 to Electricity North West's SCADA/NMS
- The performance of the OHL FPIs was validated (including their ability to deliver reliable communications, earth fault detection, over-current detection and corroborative information regarding other network faults).

1.4 Key learning

The following key learning points resulted from this project:

- Electricity North West's trials have demonstrated that it is possible to detect over-current and earth faults using clip-on-the-line sensors, which do not require additional earthing for voltage detection and therefore overcome health and safety issues and limitations associated with other vendors' OHL FPI solutions.
- The OHL FPIs harvest energy from the OHL and self-sustaining operation was demonstrated for average currents above 5A. During the course of the trial, network reconfiguration resulted in no load current through one OHL FPI site for a period of four weeks. During this time, the OHL FPI continued to communicate reliably using its back-up battery. Based on extrapolated results, the OHL FPI could have sustained operation for three months without harvesting any further energy from the OHL.
- Nortech pre-commissioned the OHL FPIs prior to installation. This confirmed the devices were working prior to installation and eliminated any on-site issues, reducing the time taken to install the devices. Depending on travel time between sites, up to eight sets of devices could be installed by an OHL team in a single day.

Electricity North West would make the following recommendations to any other DNOs looking to adopt the OHL FPI method:

- Choose FPI locations that are readily accessible (eg adjacent to roads) for ease of installation, inspection, maintenance (and, if required, decommissioning).
- Use a technique such as Electricity North West's FLA to help inform FPI location selection (to ensure the load current at site is sufficient for self-sustaining operation). Alternatively, the OHL FPIs can be used to monitor the load current at site for a period of time and then a decision can be made regarding the suitability of the installation location.
- Carry out a GSM coverage survey as part of the installation location planning to confirm that communications can be established.

1.5 Conclusions

This project succeeded in achieving all of its key aims and objectives. Further information on Electricity North West's OHL FPI solution can be obtained from the innovation team.

1.6 Closedown reporting

This project was compliant with the governance for Network Innovation Allowance (NIA) projects, and so this report has been structured to meet these governance requirements. The structure and headings in this report reflect these requirements.

A version of this report – including only sections 2-6, 7.1, 8.1, 9.1 and 10-12 – is available via the Energy Networks Association's Smarter Networks learning portal at www.smarternetworks.org.

This version of the report provides additional information that is useful in understanding the project.

2 PROJECT FUNDAMENTALS

Title	Reliable, Low Cost Earth Fault Detection for Radial OHL Systems
Project reference	NIA_ENWL007
Funding licensee(s)	Electricity North West Limited
Project start date	October 2015
Project duration	2 years
Nominated project contact	Daniel Harber (innovation@enwl.co.uk)

3 PROJECT BACKGROUND

Rural distribution networks are largely comprised of long OHLs, controlled via one or more circuit breakers and manually operated line switches, with typically low customer number densities. These networks often represent an operational challenge to network operators owing to the higher-than-average incidence of faults, the large geographic regions they serve, and the reduced availability of network automation. It is therefore imperative that reliable, robust, low-cost solutions are sought to advance the performance of these networks.

This project targeted how network operators respond to faults, after they occur, by providing fault passage information to control engineers in real-time via SCADA. It builds upon existing architectures, already deployed for underground cable fault detection, using earth FPIs and extending this functionality to rural OHLs.

Rural circuit configurations often give rise to longer-than-average restoration times during HV faults. This is due to the time it can take to locate the fault using traditional methods and to carry out the switching operations to restore supplies. Locating faults on these overhead networks traditionally involves operational teams patrolling a line on foot or by vehicle. Multiple faults in an area, which can occur during storm conditions, can become extremely resource-intensive and impact the restoration performance considerably.

In order to improve restoration times, DNOs need ways of reliably identifying the fault location with appropriate accuracy thus reducing the time taken to isolate faulty parts of the network. This project has developed a low cost OHL-mounted fault passage sensor that can be deployed at volume on OHL networks and reliably communicates back to the main network management system.

These devices communicate in real time via existing SCADA to allow control engineers to see if fault current has passed specified points on the network, thus significantly reducing the possible number of circuit sections where the fault may be situated. The newly developed FPIs leverage existing architectures deployed for underground cable systems and were installed at specified locations on Electricity North West's overhead networks, based on a defined site selection methodology. Analysis was then carried out on the performance of the system, based on monitoring data collected throughout the trial period.

4 PROJECT SCOPE

Prototype OHL FPI equipment was installed at approximately ten sites. Locations were selected based on a range of factors including performance. The circuit selection also considered the number of customers, the overall length of OHL associated with the feeder and considerations towards straightforward installation. Monitoring equipment was installed at the selected sites to gather data to support development of the required algorithms. The FPIs were integrated via a DNP3 interface into Electricity North West's existing network management system and monitored via Nortech's iHost system.

5 OBJECTIVES

The objectives of the project were as follows:

- To reduce the time taken to locate faults on rural OHL networks
- To develop a method for reliable detection of earth fault and over-current on OHL networks
- Install OHL FPIs for over-current and earth fault detection using live line techniques
- Develop a method of OHL FPI installation with minimal commissioning and set-up and without need for shutdown (including location methodology and installation method statement)
- Understand the impact of OHL FPIs on a DNO's ability to locate faults more quickly and restore supplies to customers more efficiently.

6 SUCCESS CRITERIA

The success criteria of the project were:

- Development of a technical engineering specification for OHL FPIs

- Installation and test procedures for OHL FPIs
- Communication to central system (iHost) with NMS compatibility via SCADA
- Validation of OHL FPI performance (reliable communications, earth fault detection, over-current detection).

7 PERFORMANCE COMPARED TO THE ORIGINAL PROJECT AIMS, OBJECTIVES AND SUCCESS CRITERIA

7.1 Summary of performance

Based on the performance of OHL FPIs during the trials, it was confirmed that the use of FPIs on OHL networks can improve post-fault location by at least 20 minutes versus traditional methods. This is because the OHL FPI devices provide Electricity North West with additional information regarding the location of the fault and type of fault that has occurred.

In this project, Electricity North West has succeeded in developing a method for reliable detection of earth fault and over-current on OHL networks. This is facilitated by the development of OHL FPIs for over-current and earth fault detection, which can be installed using live line techniques (and therefore remove the need for circuit outages as part of the installation programme).

As part of this project, Electricity North West and Nortech developed a method of OHL FPI installation with minimal commissioning and set-up and without the need for shutdown. This included the development of a location methodology by Electricity North West and the development of an installation method statement by Nortech.

Electricity North West gained an understanding of the impact of OHL FPIs on its ability to locate faults more quickly and restore supplies to customers more efficiently.

A technical engineering specification for OHL FPIs was developed and can now be used as the basis to stimulate the market and issue a competitive tender for OHL FPI devices.

Installation and test procedures for OHL FPIs were developed by Electricity North West's policy teams in conjunction with Nortech. This allowed Electricity North West to train its OHL teams on the installation of the devices during the course of the project.

Reliable communication to a central system (iHost) was achieved using secure DNP3 communications over the GSM network. The DNP3 communications provide future-proofing with NMS (ADMS) compatibility via SCADA.

The performance of the OHL FPI devices was validated and the reliability of communications, earth fault detection and over-current fault detection was quantified. In addition, the ability of the OHL FPIs to provide corroborative information about other network faults was assessed and proven.

8 THE OUTCOME OF THE PROJECT

8.1 Summary of outcome

This project has specified, developed, tested, and demonstrated communicating FPI units that are suitable for application in OHL distribution networks. The use of such units has significant potential to speed up fault identification, location, and isolation, and consequently improve restoration times.

Prototype OHL FPI equipment was installed at ten sites. Locations were selected based on a range of factors including historic network performance. The circuit selection also considered the number of customers, the overall length of OHL associated with the feeder and

considerations towards straightforward installation. Monitoring equipment was installed at the selected sites to gather data to support development of the required algorithms.

The FPIs are readily integrated via a DNP3 interface into Electricity North West's existing network management system and are monitored via Nortech's iHost system.

A technical specification for communicating OHL FPIs has been developed based on the learning of this project and the functional specification that was used as an input to the development process for the OHL FPI units. The technical specification includes network and operational environment, fault detection, power supply, and communication requirements, and can be used for future procurement and deployment of OHL FPIs.

The development of the prototype OHL FPI units was undertaken by Nortech Management Ltd and their parent company Dipl.-Ing. H. Horstmann GmbH, with Electricity North West defining requirements. The functions of the prototype units were developed in several work packages, including current sensing, voltage presence detection, energy harvesting, communications, and housing and installation. A comprehensive factory test schedule was developed and implemented, which included electrical and mechanical testing.

Installation and field commissioning procedures were developed by Electricity North West in conjunction with Nortech and were designed to be as quick and straightforward as possible. The installation and removal of the trialled OHL FPI units takes only minutes using standard live-line working practices and, as such, requires no circuit outages. The installation method was trialled in a controlled environment before being used in the field.

The selection of trial sites considered multiple criteria. The primary consideration was to install units on worst performing circuits – in terms of customer interruptions (CIs) and customer minutes lost (CMLs) – in order to maximise the likelihood of the trial OHL FPI units experiencing network faults during the trial period. Additional considerations were the accessibility of the installation locations, the availability of mobile telecommunications at each site, and the average line current being sufficient for self-sustaining operation of the FPI units. Following site selection, installations were completed at three sites in May 2017, and at seven sites in August 2017.

Several network fault events occurred during the trial period and these were detected by the installed OHL FPI units. Both over-current and earth faults occurred and were detected by the FPI units, which reported fault indications back to a central data collection and monitoring system within seconds of fault detection. Providing fault indication information in seconds is a significant improvement over the traditional method of locating faults using foot and vehicle patrols, which can take hours.

The voltage presence function of the FPI units was able to detect a loss of voltage caused by a 33 kV network event, which affected several trial FPI units fed by the same 33 kV primary substation. This is a useful additional feature of the trialled FPIs that allows rapid visibility of the extent of the network affected by a fault and provides corroborative information regarding the OHL FPI performance.

The trialled OHL FPI units also continuously logged load currents and periodically communicated these logs back to a central database. The logged load currents were found to be significantly different to standard network planning estimates for several sites, indicating that the FPI units could be used to provide useful data and reduce uncertainty for network planning processes and network reinforcement decisions. By using refined estimates, network reinforcement investments could be better targeted to where they are most needed.

Based on the performance of OHL FPIs during the trials, it was confirmed that the use of FPIs on OHL networks can improve post-fault location by at least 20 minutes versus traditional methods. This is because the OHL FPI devices provide Electricity North West with additional information regarding the location of the fault and type of fault that has occurred.

As a result of the trial in this project, the technology readiness level (TRL) of the method has increased from five to eight.

Building on this project, Electricity North West is planning a scaled-up deployment of OHL FPIs, initially extending the scope to incorporate a further 35 sites with a view to a large-scale deployment in the final few years of RIIO-ED1.

8.2 Example site installations and device photos

Figure 1: Dead-line installation of voltage logger device (used as part of earth fault detection algorithm development)

Figure 2: The OHL FPI device

Figure 3: Example installation of OHL FPIs installed using live-line techniques at a trial site in the Lancaster area

Figure 4: Post-commissioning checks of the OHL FPIs using the field support kit

9 REQUIRED MODIFICATIONS TO THE PLANNED APPROACH DURING THE COURSE OF THE PROJECT

9.1 Summary of modifications

The main changes to Electricity North West's planned approach involved refinements to the planning stage of the OHL FPI installations:

- The initial desktop survey to determine appropriate sites for installations was based on GROND (Electricity North West's planning tool for 11kV networks). Following installations at the first three sites, it was found that GROND was leading to an overestimation of the load current at the FPI installation sites. The accuracy of load current prediction was improved using Electricity North West's FLA technique and this led to a refinement in the selection of sites for the trial.
- Following the installation of the OHL FPIs at the first three sites, the next seven sites were selected based on proximity to primary substations. This had a two-fold benefit: (i) It improved the likelihood of the FPIs seeing fault activity during the course of the trial; (ii) The load current near primary substations is generally higher.
- During the installation of the OHL FPIs, a slight refinement was made to the location as some issues with the target poles were observed. For example, one target pole was assessed to be unsuitable for climbing due to its stability; one target pole was unsuitable for climbing due to woodpecker damage and one pole was not readily accessible.
- The installation of the OHL FPIs was also affected by weather conditions (as the OHL teams are restricted from working on lines and climbing poles in high winds and/or persistent rain). This was noted as a factor but did not materialise during installations.

9.2 Cost variance table

Item	Category	Estimated Costs (£k)	Final Costs £k (rounded)	Variance
1	Project management	145.00	18.9	-126.1
2	Nortech	200.0	151.8	- 48.2
3	Dissemination costs	5.0	1.0	- 4.0
	Total	**350**	**171.7**	**-178.3**

10 LESSONS LEARNED FOR FUTURE PROJECTS

The following key learning points resulted from this project:

- Electricity North West's trials have demonstrated that it is possible to detect over-current and earth faults using clip-on-the-line sensors, which do not require additional earthing for voltage detection and therefore overcome health and safety issues and limitations associated with other vendors' OHL FPI solutions.
- The OHL FPIs harvest energy from the OHL and self-sustaining operation was demonstrated for average currents above 5A. During the course of the trial, network reconfiguration resulted in no load current through one OHL FPI site for a period of four weeks. During this time, the OHL FPI continued to communicate reliably using its back-up battery. Based on extrapolated results, the OHL FPI could have sustained operation for three months without harvesting any further energy from the OHL.
- Nortech pre-commissioned the OHL FPIs prior to installation. This confirmed the devices were working prior to installation and eliminated any on-site issues, reducing the time taken to install the devices. Depending on travel time between sites, up to eight sets of devices could be installed by an OHL team in a single day.

Electricity North West would make the following recommendations to any other DNOs looking to adopt the OHL FPI method:

- Choose FPI locations that are readily accessible (eg adjacent to roads) for ease of installation, inspection, maintenance (and, if required, decommissioning).
- Use a technique such as Electricity North West's FLA to help inform FPI location selection (to ensure the load current at site is sufficient for self-sustaining operation). Alternatively, the OHL FPIs can be used to monitor the load current at site for a period of time and then a decision can be made regarding the suitability of the installation location.
- Carry out a GSM coverage survey as part of the installation location planning to confirm that communications can be established.

During the course of the project, Electricity North West did not discover any significant problems with the trialled methods.

Based on the outcomes of the project, it is highly likely that Electricity North West will look to deploy the method on a large scale in future.

The development and demonstration were very effective because Electricity North West's requirements were captured as part of the initial stage of the project. This was embodied in the design of the OHL FPI devices, and used for the witness test specification and pass criteria prior to installation of the devices in the field.

11 DATA ACCESS

Electricity North West's innovation data sharing policy can be found on our website.

12 FOREGROUND IPR

Ref. No.	Description	Type	Ownership
IP01	Policies and procedures relating to the installation and maintenance of OHL FPIs using live line techniques	Relevant Foreground	Electricity North West
IP02	Training materials relating to the installation and maintenance of OHL FPIs using live line techniques	Relevant Foreground	Electricity North West
IP03	Methodologies for selecting OHL FPI deployment locations	Relevant Foreground	Electricity North West
IP04	Data relating to the detection of OHL faults and performance of the OHL FPIs in the field	Relevant Foreground	Electricity North West
IP05	Technical engineering specification for OHL FPIs and their detection of earth faults and overcurrent faults on OHLs	Relevant Foreground	Electricity North West
IP06	Design, testing and production of OHL FPIs to Electricity North West's technical engineering specification	Foreground	Nortech Management Limited
IP07	Specification, design and testing of remote communications from OHL FPIs to iHost (using secure DNP3 protocol)	Background	Nortech Management Limited

13 PLANNED IMPLEMENTATION

Based on learning from the project, Electricity North West is planning to modify its operations through the use of OHL FPI devices to locate faulty 11kV circuit sections more quickly.

The method is now ready to be used and implemented by Electricity North West as part of its business-as-usual operations. Through scaled deployment of the devices, the next step will be to integrate the OHL FPI devices into Electricity North West's new ADMS. This will unlock the potential to use the OHL FPI devices as part of Electricity North West's automatic restoration scheme (ARS).

Electricity North West does not intend to submit a notice under Special Condition 6E (The Innovation Rollout Mechanism) or Charge Restriction Condition 3D (The Innovation Rollout Mechanism).

14 FACILITATE REPLICATION

As a result of this project, Electricity North West has produced a technical engineering specification for OHL FPIs. Moreover, a commissioning checklist was developed for the end-to-end commissioning and field testing of the OHL FPI devices. These specifications are available to other DNOs on request via any member of the innovation team.

In addition, the Electricity North West policy team produced a training module for OHL teams covering the safe installation, maintenance and decommissioning of the OHL FPI devices.

Figure 5: Demonstration of the OHL FPI devices during the 2017 Low Carbon Networks & Innovation conference

15 APPENDICES

A1: Technical engineering specification for a communicating overhead line fault passage indicator

A2: Witness test report