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 Close Down Report Document

Date of Submission

Jun 2022

Project Reference

NIA_WPD_028

Project Progress

Project Title

Primary Networks Power Quality Analysis

Project Reference

NIA_WPD_028

Funding Licensee(s)

WPD - Western Power Distribution (East Midlands) Plc

Project Start Date

March 2018

Project Duration

3 years and 4 months

Nominated Project Contact(s)

Jonathan Berry

Scope

The project's scope consists of the following work packages:
Investigating transducers (VTs etc.) to confirm that harmonics are being passed through to power quality monitors without introducing further harmonics or eliminating them;
Selecting two areas of WPD's network (BSPs through to the LV side of Primary substations) for comparative assessments of harmonics and power quality. One area will be selected as a 'control' case with a low penetration of LCTs, whereas the other area will have a high penetration of LCTs;
Creating detailed models of the two areas for power quality and harmonics analysis;
Installing communicating power quality monitors within the two areas to generate data for comparison with the models. Also, comparing co-located power quality monitors with each other for consistency of results;
Generating power quality heat maps and decision support tools, including the modelling of future impacts of LCTs (with a 2030 horizon) based on sources such as WPD and DECC future energy scenarios;
Quantifying the harmonic content contribution of different types of power electronic devices and creating a series of templates for use in future analysis; and
Automating data retrieval and analysis tasks, which are currently manual and time-intensive, to allow valuable engineer resource to be used more effectively.

Objectives

The objectives of this project are to:
Understand the power quality / harmonics impact of LCTs throughout primary networks in a systematic way;
Understand the behaviour of PQ monitoring transducers in a systematic way;
Automate power quality / harmonics data retrieval and analysis processes;
Develop a decision support tool for modelling and forecasting harmonic / PQ effects

Success Criteria

Impact of LCTs on power quality and harmonics within primary networks better understood;
Power quality monitors installed at trial locations and remote retrieval of data successfully demonstrated;
Tools for automating power quality data retrieval and analysis demonstrated;
Policies created to implement project outputs in WPD's business.

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

Performance compared to original aims and objectives Aims & Objective Status

Understand the power quality / harmonics impact of LCTs throughout primary networks in a systematic way.
Complete - Over a year of PQ data was obtained for most of the monitored sites (LCT and non-LCT). The data obtained was analysed to reveal insights regarding the PQ impacts of LCTs and the PQ characteristics of Primary Networks more generally

Understand the behaviour of PQ monitoring transducers in a systematic way
Complete - Laboratory testing of VTs to validate their performance for capturing PQ measurements was performed by the University of Manchester (UoM) and at National Physical Laboratory (NPL).

Automate power quality / harmonics data retrieval and analysis processes.
Complete - Software to automate PQ data retrieval and analysis tasks was specified, developed, deployed, and demonstrated. The software was designed to be PQ monitor vendor agnostic and was used to retrieve and analyse data from all the communicating PQ monitors installed as part of the project

Develop a decision support tool for modelling and forecasting harmonic / PQ effects
Complete - The PQ analysis automation software included a tool to automate performing an ER G5/5 Stage 2C assessment, which is required for some classes of connection application

Performance compared against success criteria
Impact of LCTs on power quality and harmonics within primary networks better understood
Complete - All PQ monitors for the wide scale trial of communicating PQ monitors were installed. These monitors provided detailed data on the power quality within primary networks including the impact of LCTs.

Power quality monitors installed at trial locations and remote retrieval of data successfully demonstrated
Complete - All 46 PQ monitors for the project's trial were installed, data was successfully remotely retrieved from all installed PQ monitors

Tools for automating power quality data retrieval and analysis demonstrated
Complete - Six main features of the PQ analysis automation software were specified, developed, and deployed to the project's data server. Two additional reporting features (an EN 50160 compliance report and an ER G5/5 background report) were specified, developed, and deployed also.

Policies created to implement project outputs in WPD's business
Compete - Standard Techniques on PQ monitoring installs and PQ data analysis have been drafted.

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

Some minor modifications to the project approach were made that enhanced the amount we learnt:

1. Three different PQ monitor types were trialled rather than two types as originally planned. This allowed for more to be learnt regarding the performance and differences between PQ monitors. This was achieved at no extra cost as the integration work for the third monitor was provided as a contribution by the main project partner, Nortech.
2. The number of 11 kV sites monitored was increased from the originally planned number of 1-2 distribution substations per trial area due to several reasons and as the project budget would allow it. In the Meaford C area, 9 distribution substations were monitored at 11 kV: some provided PQ measurements at or Primary substations were 33 kV monitoring was not possible, whilst others provided baseline PQ measurements for 11 kV feeders with no identified LCTs. In the Ryeford area, 3 distribution substations were monitored at 11 kV, to provide PQ measurements for specific LCTs and for the length of one feeder that had an LCT (a solar PV farm) in the middle. Additionally, two 11 kV sites outside the main trial areas were monitored: one was a battery energy storage unit, and the other a rapid EV charge station.

Lessons Learnt for Future Projects

· Primary Network PQ

The standard way of assessing PQ is to use the 95th percentile aggregates of data taken over a week-long measurement period. However, the year or more of monitoring data gathered by the project has revealed that the 95th percentile aggregates can vary significantly from week to week, so basing PQ assessments on a single week of measurements may over- or under- represent existing PQ issues.

· Primary Network PQ

Monitoring every site within a 33 kV network has revealed that PQ can vary significantly across the sites, meaning that PQ data gathered at a single site may not be representative of the conditions at other sites. Therefore, monitoring should ideally be located at the network infeed and the remote ends as a minimum to achieve broader PQ visibility and capture more representative data.

· LCT PQ impacts

Comparing PQ during LCT operation and during outages is a very straightforward way to understand the PQ impact of a specific LCT, but realistically this can only be achieved through constant monitoring.

· LCT PQ impacts

The influence of LV-connected LCTs, such as heat pumps and electrics vehicles, on higher voltage networks (e.g. Primary Networks at 33 kV) is still uncertain, and could be a major source of PQ issues as the uptake of LV-connected LCTs accelerates.

· PQ monitor features

Market research revealed at least 20 manufacturers of PQ monitors that met the basic requirements expected for the project. However, none had identical interfaces meaning bespoke work was needed for each to enable remote communications with the monitors.

· PQ monitor features

Whilst the 3 different PQ monitor models trialled during the project allowed the same aggregated continuous PQ monitoring data to be obtained (typically aggregated every 10 minutes), they varied significantly in their event triggering and recording capabilities. The ability to record high-resolution waveform data and RMS data – typically at half-cycle resolution, ideally for 10s or more – were both found to be useful. Triggers for rapid voltage change (RVC) were useful at capturing data during network faults, even at sites that did not see the fault current. Triggers for rate of change of frequency (RoCoF) were only available for one of the monitors but are useful for capturing RoCoF events that can lead to distribution generation tripping such as the low frequency event of 9th August 2019.

· PQ data transfer

Communications surveys during the pre-installation site surveys revealed that no single mobile network provider could provide coverage at all sites, particularly for 4G. Therefore, roaming SIM cards were used so the communications hub could use whatever providers are available at each site.

· PQ data transfer

Two different monitors were interfaced with using IEC 61850. Testing of these monitors revealed differences in their implementation of IEC 61850, in particular the file transfer mechanism, which prevented a single “standard” interface from being used for both monitors.

· PQ data transfer

One of the monitors interfaced using IEC 61850 required constant polling in order to obtain the most recent measurements. This approach occasionally led to small amounts of data being lost as the monitor was sometime unable to reply to all requests. Furthermore, if communication between the monitor and communication hub was lost for a period, almost all monitoring data for the period cannot be subsequently retrieved using the IEC 61850 protocol as implemented on the monitor. As the PQ monitoring data does not need to be transmitted continuously, transfer of the data via file transfer is preferred as it can be carried out asynchronously, is more robust to temporary communications loss, and is less resource intensive.

· PQ data transfer

Generally, file-based transfer of monitoring data from the remote sites into the central data analysis server was found to be very robust, even when faced with very poor signal strength and communication outages of a week or more. Generally, the data for a single day of monitoring could be compressed into a few MB, so many months – or even years – of data could be stored locally prior to upload.

· Remote reconfiguration

PQ monitors that use files for configuration and firmware updates allowed remote reconfiguration and updates to be achieved, which was used effectively in the project to avoid site visits to achieve the same outcome. This was not possible for the monitors that needed a direct connection to the vendor’s software for updates due to: 1) IT rules preventing the software being installed and used on the central monitoring server, 2) network routing preventing direct traffic between the central monitoring server to the PQ monitors, and 3) the potential for poor signal strength to slow or stop communications between the central software and remote PQ monitors. Furthermore, file based transfers could be automated, removing the need for manual intervention to reconfigure or update PQ monitors in the field.

· Time synchronisation

Time synchronisation using NTP over the 2G/4G network was observed to deliver adequate performance for general PQ monitoring, with generally <1 s difference in clocks between sites. Adding GPS-based high resolution time synchronisation would have added some cost of the PQ monitoring equipment and complicated the installation process as an external antenna must be fitted to access the GPS signals.

· PQ monitor installations

Occasional instability of one PQ monitor was observed, so a method of remotely triggering a power cycle was developed using a non-latching relay to interrupt the power supply, driven by the communications hub. This was used a few times and avoided needing to visit site to reset the units.

· PQ monitor installations

The project trialled semi-permanent “plug & play” PQ monitor installations, which used PQ monitors in small enclosures that could be placed inside existing cabinets – or on the top or side using magnetic mounting feet – with voltage test lead and current (clamp CT) inputs. The “plug & play” monitors could be installed with 1-2 hours with 1-2 personnel, including sourcing power and post-install checks, and did not require any outages. There was no significant time saving if current monitoring is skipped.

· PQ monitor installations

The “plug & play” PQ monitor installations were sped up by pre-configuring and pre-commissioning the monitors (using secondary injection) and communications hubs prior to going to site. This reduced the complexity of install checks on site to a simple single A4-sized checklist.

· PQ monitor installations

One downside of the “plug & play” installations was that the power supplies used were not backed up, so if a network fault occurred the power supply to the PQ monitors could be lost along with the monitoring data up to the point of the outage. This could be solved by attaching the monitors to the substation batteries (if spare capacity is available) or by integrating a small uninterruptable power supply (with battery) alongside the PQ monitors.

· PQ data analysis

Most PQ monitoring is based on average measurements taken every 10 minutes. However, having some metrics (e.g. voltages and currents) also available at higher sampling intervals and with minimum and maximum aggregates was found to be useful in understanding device behaviour (e.g. short term variations in solar PV power output) and for observing network faults (e.g. by looking for short-term spikes in current and dips in voltage).

· PQ data analysis

For offline analysis of large PQ datasets, using the hierarchical data format (HDF) rather than CSV or spreadsheets allowed for much more efficient storage and retrieval of data, and easy integration in to automated analysis scripts.

· VTs for harmonic monitoring

33 kV and 11 kV VTs pass through signals at the harmonic frequencies typically measured (up to the 50th harmonic) but introduce attenuation in the output magnitude at higher frequencies.

· VTs for harmonic monitoring

Close attention must be paid to the frequency response of the measurement system in addition to the VT under test, as this can influence the results. Calibration of the equipment at harmonic frequencies is vital in addition to calibration at the fundamental frequency.

· VTs for harmonic monitoring

The ability of 3-phase VTs to transfer triplens harmonics – which typically are in phase – varies significantly depending on the construction of the VTs.

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

Technical Papers

 V. Peesapati, R. Gardner, J. King, S. Jupe, J. Berry: "Understanding the harmonic performance of voltage transformers for distribution system power quality monitoring", 25th International Conference and Exhibition on Electricity Distribution (CIRED), Madrid, June 2019

 P. Davis, P. Wright, J. King, S. Jupe, S. Pinkerton-Clark: "Voltage Transformer Harmonic Characteristics for Distribution Power Quality Monitoring", 26th International Conference and Exhibition on Electricity Distribution (CIRED), 2021 (accepted for presentation)

 J. King, A. Forster, S. Jupe, S. Pinkerton-Clark: "A View of 2020 Power Quality within GB Distribution Networks", 26th International Conference and Exhibition on Electricity Distribution (CIRED), 2021 (accepted for presentation)

 J. King, D. Wiley, S. Hoda, S. Jupe, S. Pinkerton-Clark: "An Integrated Platform for Power Quality Monitoring", 26th International Conference and Exhibition on Electricity Distribution (CIRED), 2021 (accepted for publication)

Reports

PQM Market Research Report:
This report summarises the findings from a market research exercise on power quality monitors (PQMs) that was undertaken to inform the selection of PQMs for the PNPQA project. The research exercise comprised of identifying vendors of PQMs and examining their products to determine the key features of different PQM devices.

Power Quality Monitor Remote Communications Initial Feasibility Assessment:
A report of early work done in the project; this consisted of assessing the feasibility of interfacing with several PQMs that were in use by WPD or that had been identified for potential future use by WPD, so that PQ data can be communicated remotely.

Envoy/PQube3 Interface Factory Acceptance Tests:

This report is both a test specification and a test record for the Factory Acceptance Test of the Envoy firmware modifications to interface with PSL PQube3 PQ monitor.
Envoy/a-eberle PQI-DA smart Interface Factory Acceptance Tests:
This report is both a test specification and a test record for the Factory Acceptance Test of the Envoy firmware modifications to interface with a-eberle PQI-DA smart PQ monitor.

Envoy/Siemens SICAM Q200 Interface Factory Acceptance Tests:
This report is both a test specification and a test record for the Factory Acceptance Test of the Envoy firmware modifications to interface with Siemens SICAM Q200 PQ monitor.

Power Quality Monitor Pilot Trial Analysis:
Prior to the wide scale trial of communicating PQ monitors, a pilot trial with a single monitor took place to help guide the preparations and reduce uncertainties. The monitor and a communication hub were installed at Meaford C Bulk Supply Point (BSP) in June 2018 and data from the 6 weeks after installation was analysed and the findings presented in this report.

Trial Area and Site Selection:
This report describes the development and application of a methodology for the selection of trial areas and sites for the wide scale power quality monitoring trial within the project.

Proposal for Additional 11 kV Sites:
This report described and applied a methodology for identifying and selecting additional 11 kV sites to be monitored as part of the PNPQA project, which was developed as the project budget allowed for additional monitoring to be installed.

PQ Trial Data Analysis Scope:
This report outlined the scope for PQ trials data analysis. As the project would generate around 1.5 billion measurements, having a clearly defined scope for the analysis of that amount of data was vital.

PQ Trial Data Analysis Report:
This report contains the analysis and key findings from the remote PQ monitoring trial.

Power System Analysis Tools Review:
This report is a review of several power system analysis tools in order to recommend which tool would be used for the future-looking power quality studies as part of the PNPQA project. Requirements for the tool were developed and used to compare 20 different tools that were available at the time, including those is use in WPD.

PQ Study Objectives & Methods:
This report outlined objectives and methods for the future-looking power systems studies as part of project.

PQ Study Results:
This report presents the implementation, results, and key findings from the future-looking power system studies of the potential impacts of increased penetrations of LCTs.
Six monthly project progress reports:
These are standard project progress reports that are produced every 6 months.

Project close down report:
The project close down report as required under the NIA process.

Documents
 Standard Technique Relating to the Installation, Configuration, and Commissioning of Power Quality Monitoring Using the PSL

PQube3
 Standard Technique Relating to the Retrieval, Monitoring, and Analysis of Power Quality Data using iHost
Systems
 Automated software for vendor-agnostic retrieval and analysis of PQ data from remote monitors, integrated in to Nortech's iHost platform
Processes
 Process for installing and commissioning PQ monitors as defined by the Standard Technique.
 Process for analysing PQ monitors data as defined by the Standard Technique.
Presentations & Dissemination Events
 CIGRE UK webinar on project findings
 Presentation at ENA Power Quality & EMC Working Group

Data Access

To request access to project data, please visit: www.westernpower.co.uk/Innovation/Contact-us-and-more/Project-Data.aspx

Foreground IPR

New foreground IPR was generated by the project in the following areas:
1. Methodology and results of VT harmonic response testing.
2. Development and application of a methodology for trial area and site selection.
3. Implementation of interfaces for retrieving PQ data off PQ monitors.
4. Requirements and designs for PQ analysis automation software.
5. Implementation of PQ analysis automation software.

Planned Implementation

The communicating PQ monitoring system and software for automating PQ data retrieval and analysis is becoming a part of WPD's usual activities. Documentation has been drafted on PQ monitor installations and PQ data analysis based on the outcomes of the project. Deployment of PQ monitoring using the systems developed through the project are being planned for the remainder of RIIO-ED1 and throughout RIIO-ED2.
In addition, another Network Licensee – UK Power Networks – is adopting the automated PQ data retrieval and analysis tool developed through the PNPQA project for routine use. The result of this is the Method developed through the project will be rolled out to half of the distribution license areas in GB.

Other Comments

n/a

Standards Documents

n/a