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.

NIA Project Registration and PEA Document

Date of Submission

Sep 2023

Project Reference Number

NIA_SSEN_0069

Project Registration

Project Title

Low Voltage Power Quality (LVPQ)

Project Reference Number

NIA_SSEN_0069

Project Licensee(s)

Scottish and Southern Electricity Networks Distribution

Project Start

October 2023

Project Duration

2 years and 8 months

Nominated Project Contact(s)

Tim Sammon Innovation Delivery Manager

Project Budget

£1,018,540.00

Summary

The Low Voltage Power Quality (LVPQ) project aims to test a range of high technology readiness devices that can restore power quality and boost network capacity. Power quality is impacted by new demands on the network including low carbon technologies. Conventional reinforcement takes time and may not always be the most economic solution. Therefore, alongside flexibility, we need a suite of technology based solutions to address these power quality issues including harmonics, voltage and phase imbalance. Testing will occur at the Power Networks Demonstration Centre (PNDC) with additional testing on the network. The project will also develop the processes for the rapid assessment, selection and installation of the most appropriate solutions.

Third Party Collaborators

PNDC

Threepwood Consulting Ltd

Energy Systems Catapult

Outram

Derryherk

Nominated Contact Email Address(es)

fnp.pmo@sse.com

Problem Being Solved

The transition to Net Zero will require a significant increase in the number of low carbon technologies (LCTs) being connected to the Low Voltage (LV) Network, including Electric Vehicles (EV), Heat Pumps (HP) and Photovoltaics (PV). As LCTs are mainly single phase and an inverter-based technology, they may have a negative impact on power quality (PQ). Their capacity and high duty cycle may result in phase imbalance on the network. These factors impact the efficiency of the distribution network and its ability to deliver required capacity to customers. By addressing this issue we will be able to increase the usable capacity of the network, speeding up and reducing the cost of connections and reducing the deterioration of network components such as transformers and cables.

Method(s)

Project approach
The project sets out to evaluate the likely impact on power quality from the connection of LCTs on an LV network, then will test a range of new technologies which could be used to mitigate these impacts. Initially this will be at an established network demonstration facility and then, if successful, by installation on the SSEN network. The project consists of various work packages, some of which will run concurrently.

Work package 1 – Install PQ Monitors
This would involve installing Power Quality (PQ) monitors at customer homes that have LCTs installed. The purpose is to provide real life PQ data that we can use in modelling studies during later work packages of the project. In addition, monitoring will also be installed at the relevant distribution substations to measure PQ at the network level.

Work package 2 – Identification of test scenarios
This would involve identifying typical and worst-case harmonic and phase imbalance scenarios, resulting from network loads, including domestic storage, PV, HP and Electric Vehicle Charge Point (EVCP) devices operating alongside other household equipment e.g. ovens, showers, etc. These typical and worst-case situations will be based on available literature and findings from WP1. Initial review of the literature indicates that the following reports will form the basis for establishing typical harmonic scenarios for later evaluation of the effectiveness of the power quality improvement devices:
a) “Impact of low voltage - connected low carbon technologies on power quality”, Low Carbon London Learning Lab, Imperial College London Report B3.
b) “TPE-006: Network Level Management of EVSE Power Quality Impacts”, PNDC Interim Report: WP3 – Data collection and analysis.

These harmonic impacts and phase imbalance scenarios will be implemented in a simulated version of the PNDC distribution network to understand the expected network impact prior to real world testing. The outputs from this work package will involve:
a) Identifying a worst-case scenario for PQ impact on the network e.g. multiple LCTs from the same manufacturer running at the same time causing PQ issues. A possible situation if EVs and battery units are charging off peak to benefit from low-cost tariffs.
b) Identifying a realistic case scenario for PQ impact on the network e.g. likely combination of LCTs running at likely times.

Work package 3 – Obtain LCT Equipment and PQ data
This will require project partner Threepwood to liaise with HP manufacturers and to acquire HP PQ data – Stakeholder engagement across the industry will be necessary as well as potentially testing HP equipment at manufacturer sites for PQ data. Additional LCT devices such as EV chargers and PV will be sourced by PNDC.

Work package 4 – Testing LCT PQ Impact
In this work package the scenarios identified in WP2 will be implemented at the PNDC LV distribution network to test the PQ impact of LCTs on a representative distribution network under operating different conditions. Due to the volume of devices required to replicate an LV network, only a few typical LCT devices will be included in the test network to provide some realism, with the remainder being emulated using data from previous work packages. The conditions that will be considered in the study will include:
1. Operational conditions where the harmonic loading changes in both magnitude and associated current harmonic spectrum.
2. Network conditions where the location of the harmonic load on the network is changed (from the start of the feeder to the end)
3. The network topology is modified: changing between urban and rural networks archetypes.

This will involve detailed PQ monitoring across all test scenarios. To implement this test case, the harmonic and phase unbalance scenarios identified in WP2 will then be implemented in the PNDC test network using a combination of different loads including grid/load emulators (to simulate the combined impact of multiple houses on the network). The test case and PQ measurement will run for a specified length of time as agreed with SSEN.

The network test will have monitoring to capture power quality (including harmonics) at different locations on the network. The PQ monitoring would be led by Outram who are partnering with Threepwood on this project, and will be supplemented by PNDCs embedded power quality monitoring equipment.

Work package 5 – Testing Power Quality Improvement Devices to Resolve PQ Issues
This work package will trial a mix of PQ improvement devices (phase switchers / balancers, active filters and reactive power compensation) on the network to see how they can mitigate or remedy the PQ issues caused by LCTs. Monitoring the effectiveness of

the devices to restore phase balance and improve harmonic levels to acceptable limits will be carried out. In WP4 a baseline LCT impact (phase imbalance and harmonic loading) under typical and extreme conditions will be established. In WP5 each PQ improvement device will be connected into the PNDC network to evaluate the effectiveness of each specific device to reduce harmonics and/or improve phase imbalance. Testing and setup at PNDC will also inform deployment considerations and ensure products are safe for network deployment.

Work package 6 – Modelling the PQ Impact
In this work package of the project, Threepwood would develop a MATLAB or DigSilent model of an LV network with discrete harmonic models for LCT devices. These discrete models would be developed from known harmonic emissions for HPs (via the ENA HP database) and from data collected via earlier work packages. The model would also replicate the typical impedance and load for three types of LV network (rural, urban and mixed).

Once the PQ test case has been completed and the data collated, the MATLAB harmonic model would be validated, in particular the aggregation method for LCT harmonics. The PQ data would also inform the variations in harmonic emissions through variations in use of the devices. Typical background harmonics (low, medium and high) will also be considered in the model. Once the MATLAB model is configured and validated, different types of HPs and EVCPs will be simulated, in different combinations, at different levels of penetration and distribution along different types of LV network.

The objective will be to use the resultant simulated LV feeder harmonic voltage values to assess if and when network harmonic limits are likely to be exceeded for increasing numbers of connected LCTs. This would consider the variation across the time of day and year. This assessment would also be balanced against the thermal loading.

Work package 7 – Mapping the PQ Impact Using Distribution Future Energy Scenarios (DFES)
In this work package of the project we will use these findings with our DFES forecasts to identify locations on the SSEN network we think will experience PQ issues in the future based on the projected uptake of LCTs. We will deliver this by further developing the scenarios and analysis used in our DFES.

Work package 8 – Live Trials
This will involve live trials of power quality improvement devices, which proved to be the most effective during WP5 testing, on one or more locations on the SSEN network to test the efficacy of the equipment over time under normal network operating conditions. This will also allow to develop processes and technical aspect of the installation of the equipment on the LV network.

Work package 9 – Inform Standards
This work package focusses on bringing the learnings from the previous work packages to inform standards creation of power quality requirements for connected LCTs, as well as the specifications of power quality improvement devices.

Work package 10 – Fault/Complaint Response Development
LVPQ issues and solutions reported and characterised by the project are likely to require new operational response processes. This work package will establish the processes and tools that a fault team in Customer Operations would use in the event of a Power Quality (PQ) complaint or fault on an LV network.
• Development of possible datasets and technologies which could be used by Ops to analyse and identify the type and cause of issue.
• Development of possible solutions which could be used to help restore/maintain service to customers.

Data Quality Statement (DQS):
The project will be delivered under the NIA framework in line with Ofgem, ENA and SSEN internal policies. Data produced as part of this project will be subject to quality assurance to ensure that the information produced with each deliverable is accurate to the best of our knowledge and sources of information are appropriately documented. All deliverables and project outputs will be stored in our internal systems with appropriate backup and version management. Relevant project documentation and reports will also be made available on the ENA Smarter Networks Portal and dissemination material will be shared with the relevant stakeholders.

Measurement Quality Statement (MQS):
The methodology used in this project will be subject to supplier quality assurance regimes and the source of data, measurement process and equipment as well as data processing will be clearly documented and verifiable. The measurements, designs and assessments will also be clearly documented in the relevant deliverables and final project report made available for review.

Scope

The project scope covers a wide range of issues around power quality problems caused by LCTs on the distribution network.
1. We are monitoring PQ at customer houses, the number of which will be determined during Work Package 1.
2. The number of Power Quality Improvement Devices will be determined during Work Package 2.
3. Desktop studies will be focussed on improving Threepwood’s assumptions of PQ and the PQ impact on SSEN’s network based on

DFES projections.
4. Trials will take place at the PNDC.
5. Live trials will focus on a maximum of four network locations, most likely in SSEN's Southern Region where PQ may be more of an issue and limited in size due to time and budget considerations.

The project will have various benefits/outcomes including:
1. Update of the ENA database on the PQ impact of LCTs, made available to all DNOs.
2. Novel method of identifying PQ issues through DFES, which can be shared with all DNOs.
3. Identification of optimal solutions to resolve PQ issues, which can be shared with all DNOs.
4. Development of new methods and field assessment techniques for dealing with load related faults on LV networks.
5.Enable benefits of up to £2,604,000 to be realised by the deployment of up to 322 power quality improvement devices over 12 years to defer reinforcement of 1,325 feeders by four years over a 16 year period.

Objective(s)

This project has the following objectives.
1. Understand how LCTs impact Power Quality by installing PQ measuring devices in customer homes and monitoring over a minimum duration of one year.
2. Understand how various types and quantities of LCTs impact PQ on various types of LV network through testing at the PNDC.
3. Test a variety of phase balancing and filtering units within the PNDC to determine which units are most suitable for Business as Usual (BaU) implementation; including assessment of cost, installation requirements, reliability and effectiveness.
4. Perform desktop modelling studies to understand the present and future impact that LCTs have on Power Quality using DFES forecasts.
5. Install phase balancer units and filters on the network to test how they work in live environments to test their efficacy for improving PQ.
6. Utilising the results from objectives 4 and 5; establish tools and methods for assessing the most appropriate deployment solution for any specific site.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

This project will accelerate the process of approving the connection of new LCTs to the network and in doing so cases may reduce the amount of excavation required in the street. It will also improve power quality, reduce costs and improve reliability for all network consumers including those in vulnerable situations. No adverse impacts are envisaged for consumers in vulnerable situations.

Success Criteria

For the project to be considered a success the following criteria must be met:
1. We must be able to monitor power quality data from heat pumps installed in customer homes and use that data to analyse the impact they have on PQ over at least one summer and winter period.
2. We must be able to test a variety of LCT configuration arrangements that will identify worst-case and realistic case scenarios of PQ impact due to LCT uptake on the network within a live trial environment i.e. PNDC.
3. Identify available phase balancing units for use by SSEN through Procurement investigations and testing at the PNDC.
4. Improve PQ modelling capability by utilising data from trials and combining it with existing modelling knowledge and DFES in order to identify areas of the network most likely to be impacted by PQ.
5. Evaluate how effective phase balancing units are in live environments in order to inform Business as Usual (BaU) roll out and/or additional steps that might be required.

Project Partners and External Funding

Project partners include:
Threepwood – Energy consultancy who will assist in PNDC testing and PQ modelling exercises.
Derryherk – Energy service provider who will assist in powerflow analysis.
Power Networks Demonstration Centre – Provide testing and network simulation facilities for power quality improvement devices and LCTs.

Potential for New Learning

New learning potential includes:
1. The impact individual and multiple LCTs have on power quality. This will improve the accuracy of network modelling e.g. for new connections requests and long term modelling forecasts of PQ impacts on the network. This learning will be disseminated through industry events and NIA closure reports. We will also work with Threepwood to implement learnings straights into BaU by updating PQ assumptions used in the ENA Heat Pump database for all DNOs to make use of.

2. Identification of the different phase balances available and an evaluation on how they perform in test environments and live environments. Learning will be disseminated through industry events and NIA closure report.

Scale of Project

The project scale has been kept as small as reasonably practicable in terms of testing power quality improvement devices and trialling them on the network. A rigorous procurement exercise will be carried out beforehand to narrow down the need to test multiple units and keep costs down. The modelling exercise will utilise the existing tools, which are capable of large-scale modelling and contains the majority of the data SSEN require for this project. This will keep costs down while allowing large-scale modelling to take place for maximum benefit.

Technology Readiness at Start

TRL6 Large Scale

Technology Readiness at End

TRL8 Active Commissioning

Geographical Area

The testing will occur at the Power Network Demonstration Centre, (PNDC), where the trial phase is likely to occur, and in SSEN's Southern Region where we expect more PQ issues to arise due to the nature of LCT uptake being higher. However, trials could take place in SSEN's Scottish Region if we find areas adversely affected by PQ. Modelling will occur across both North and South Networks.

Revenue Allowed for the RIIO Settlement

No revenue has been allowed for this project in the RIIO-T2 settlement.

Indicative Total NIA Project Expenditure

The total expenditure expected for the project is £1,018,539.50.

Project Eligibility Assessment Part 1

There are slightly differing requirements for RIIO-1 and RIIO-2 NIA projects. This is noted in each case, with the requirement numbers listed for both where they differ (shown as RIIO-2 / RIIO-1).

Requirement 1

Facilitate the energy system transition and/or benefit consumers in vulnerable situations (Please complete sections 3.1.1 and 3.1.2 for RIIO-2 projects only)

Please answer **at least one** of the following:

How the Project has the potential to facilitate the energy system transition:

The energy system transition requires large scale deployment of LCTs on the network. This project has the opportunity to identify problem areas of the network that may have PQ problems and also target those areas with phase balancing units so that they do not manifest and cause network issues, such as early replacement of assets.

How the Project has potential to benefit consumer in vulnerable situations:

A potential benefit to customers in vulnerable situations is the deployment of power quality improvement devices to maintain reliable supply to customers. This would be a benefit experienced by all customers, including those in vulnerable situations. Please see 3.2.2 for further detail of this potential benefit.

Requirement 2 / 2b

Has the potential to deliver net benefits to consumers

Project must have the potential to deliver a Solution that delivers a net benefit to consumers of the Gas Transporter and/or Electricity Transmission or Electricity Distribution licensee, as the context requires. This could include delivering a Solution at a lower cost than the most efficient Method currently in use on the GB Gas Transportation System, the Gas Transporter's and/or Electricity Transmission or Electricity Distribution licensee's network, or wider benefits, such as social or environmental.

Please provide an estimate of the saving if the Problem is solved (RIIO-1 projects only)

N/A

Please provide a calculation of the expected benefits the Solution

Deployment of Single Power Quality Improvement Device

Base Cost – Traditional reinforcement of LV Feeders
It is assumed that the device can be deployed four times during its useful life of 16 years at Years 0, 4, 8 and 12 extending the life and deferring traditional reinforcement of four separate LV feeders each by four years during its lifespan. Therefore, the base cost reflects traditional reinforcement of four separate feeders at 4-year intervals.

Estimated cost for traditional reinforcement of a typical 0.5km feeder = £70,000.

Year 0 = £70,000 (F1 reinforcement)
Year 4 = £70,000 (F2 reinforcement)
Year 8 = £70,000 (F3 reinforcement)
Year 12 = £70,000 (F4 reinforcement)

Reinforcing 1 different LV Feeder in Years 0, 4, 8 and 12 at £70,000 each with an applied Discount Rate of 8% returns an estimated Net Present Value (NPV) of £187,069 for traditional reinforcement.

Method Cost
Rather than carrying out traditional reinforcement of four separate LV feeders in Years 0, 4, 8 and 12, the device could be installed on the 1st feeder in Year 0 as an alternative to traditional reinforcement for a period of 4 years whereafter the device would be removed from the feeder, the feeder would then undergo traditional reinforcement and the device moved to a 2nd feeder in Year 4 and so on for deferment of traditional reinforcement of subsequent feeders and redeployment of device in Years 8 and 12. Therefore, traditional reinforcement is carried out in Years 4, 8, 12 and 16.

Necessary cost of power quality improvement equipment to prove financially viable = £15,000
Average cost of installing power quality improvement equipment = £10,000 (assumed)
Costs of installing power quality improvement equipment per feeder = £25,000 (£15,000 + £10,000)
Estimated LV feeder reinforcement deferment time due to PQ equipment = 4 years
Estimated power quality improvement device lifespan = 16 years

Year 0 = £15,000 (Device procurement) + £10,000 (Device deployment on F1) = £25,000
Year 4 = £70,000 (F1 reinforcement) + £10,000 (Device redeployment on F2) = £80,000
Year 8 = £70,000 (F2 reinforcement) + £10,000 (Device redeployment on F3) = £80,000
Year 12 = £70,000 (F3 reinforcement) + £10,000 (Device redeployment on F4) = £80,000
Year 16 = £70,000 (F4 reinforcement)

NPV (Discount Rate 8%) cost to install device four times over next 12 years, while deferring 0.5km x 4 feeder reinforcement by four years and carrying out in Years 4, 8, 12 and 16 = £179,225

Base Cost – Method Cost (Savings)
£187,069- £179,225= £7,844 per unit
This saving is the total expected saving over the 16-year lifespan of the power quality improvement devices.

<u>Deployment of Multiple Power Quality Improvement Devices</u>

Base Cost - Reinforce LV Feeder
Estimated number of LV feeders on SSEN network = 265,000 (53,000 Ground mounted substations with 5 feeders each)
Estimated number of LV feeders 0.5km or greater, highly imbalanced and likely to become constrained over next 12 years= 1,325 (265,000 feeders x 0.5%)
NPV Costs to reinforce 1,325 feeders that are imbalanced and constrained over next 12years = £62,107,000

Method Cost – Install Device
Number of power quality improvement devices required to defer reinforcement on 1,325 feeders = 332. One phase balancer will defer four feeders by four years over its 16-year lifespan.
NPV Cost to install 322 power quality improvement devices over next 12 years, while deferring 0.5km x 1,325 feeder reinforcement by four years = £59,503,000

Base Cost – Method Cost (Savings)
£62,107,000- £59,503,000 = £2,604,000. These are the expected savings of deploying 322 power quality improvement devices over 12 years to defer reinforcement of 1,325 feeders by four years over a 16-year period.

The above calculations assume that the power quality improvement devices can extend the life of the feeder by four years. If the devices prove to extend the asset life beyond four years further savings could be realised. Should it not be feasible to redeploy the devices after first installation it is estimated that the minimum period of deferment required to make deployment more economically favourable than immediate reinforcement is six years.

It should be noted here that another potential benefit of implementing power quality improvement devices is to maintain reliable supply to customers. If the project demonstrates that low voltage power quality poses the risks to the network being investigated, unplanned reinforcements may be required. As reinforcement can take months/years customers may be exposed to intermittent supply interruptions until the work is completed. Power quality improvement devices are intended to provide a solution which can be deployed rapidly should these situations arise. Any resulting tangible benefits identified will be reported.

Please provide an estimate of how replicable the Method is across GB

All GB DNOs will face the same issues as SSEN and therefore the benefits from Phase Balancers will be replicable across all GB. We anticipate that other DNOs will be able to deploy these technologies at a similar scale i.e. around half a percent of their networks. Based on a simple extrapolation of number of impacted feeders we estimate that around 8,500 feeders will experience power quality issues over the next 16 years across GB.

Please provide an outline of the costs of rolling out the Method across GB.

GB Base Cost - Costs for upgrading imbalanced and constrained cables
Total SSEN costs over 16 years = £62.2m
Total licence area costs = £31.1m
Total GB costs = £404.3m (£31.1m x 13 licence areas)

GB Method Cost - Costs for rolling out the solution across GB
Total SSEN costs over 16 years = £59.6m (includes cable reinforcement costs)
Total licence area costs = £29.8m
Total GB costs = £387.4m (£29.8m x 13 licence areas)

GB Base Cost – Method Cost
£404.3m - £387.4m = £16.9m over 16 years

Requirement 3 / 1

Involve Research, Development or Demonstration

A RIIO-1 NIA Project must have the potential to have a Direct Impact on a Network Licensee's network or the operations of the System Operator and involve the Research, Development, or Demonstration of at least one of the following (please tick which applies):

☐ A specific piece of new (i.e. unproven in GB, or where a method has been trialled outside GB the Network Licensee must justify repeating it as part of a project) equipment (including control and communications system software).

☐ A specific novel arrangement or application of existing licensee equipment (including control and/or communications systems and/or software)

☐ A specific novel operational practice directly related to the operation of the Network Licensees system

☐ A specific novel commercial arrangement

RIIO-2 Projects

☐ A specific piece of new equipment (including monitoring, control and communications systems and software)

☑ A specific piece of new technology (including analysis and modelling systems or software), in relation to which the Method is unproven

☑ A new methodology (including the identification of specific new procedures or techniques used to identify, select, process, and analyse information)

☐ A specific novel arrangement or application of existing gas transportation, electricity transmission or electricity distribution equipment, technology or methodology

☐ A specific novel operational practice directly related to the operation of the GB Gas Transportation System, electricity transmission or electricity distribution

☐ A specific novel commercial arrangement

Specific Requirements 4 / 2a

Please explain how the learning that will be generated could be used by the relevant Network Licensees

New PQ factors can be used to assist with LCT connections and long-term modelling studies seeking to understand the impact of PQ on the network as a result of LCT uptake.

Evaluation of different power quality improvement equipment that has been tested and trialled in a live environment will assist DNOs in their own procurement activities and provide a wider range of mitigation options

Or, please describe what specific challenge identified in the Network Licensee's innovation strategy that is being addressed by the project (RIIO-1 only)

N/A

Is the default IPR position being applied?

☑ Yes

Project Eligibility Assessment Part 2

Not lead to unnecessary duplication

A Project must not lead to unnecessary duplication of any other Project, including but not limited to IFI, LCNF, NIA, NIC or SIF projects already registered, being carried out or completed.

Please demonstrate below that no unnecessary duplication will occur as a result of the Project.

Work has been done to date by UKPN on NIA Project Phase Switch System. This project is leveraging the learnings from UKPN, while testing alternative options to phase switching using a broader range of technology solutions.

If applicable, justify why you are undertaking a Project similar to those being carried out by any other Network Licensees.

We are building on the learnings from the UKPN phase switching project. Although similar, this project investigates harmonic impact as well as the ability to address this using power quality improvement devices of varying topology and as such as inherently different as it will be trialling different equipment with different use cases.

Additional Governance And Document Upload

Please identify why the project is innovative and has not been tried before

This type of equipment has not yet been trialled on the UK network and the modelling work will enhance the learnings gathered to date.

Relevant Foreground IPR

Foreground IPR expected to be generated will be on how power quality should be modelled so it can update network issues based on Distribution Future Energy Scenarios (DFES) and what power quality factors should be added to or modified on the ENA database.

Data Access Details

Data on harmonic findings will be made available via NIA Closure reports and to DNOs via the ENA.

Data on how power quality impacts SSEN network based on DFES projections will be made available upon request to DNOs, and may be available to other parties dependent on their use case.

PNDC and Live Trial test data of phase balancing units will be made available upon request to DNOs, and may be available to other parties dependent on their use case.

Please identify why the Network Licensees will not fund the project as apart of it's business and usual activities

No BaU funding exists for this type of work yet, as the problem is only beginning to manifest as more LCTs connect to the network. The technology solutions being deployed in the project have yet to be fully proven and their suitability has never been fully demonstrated.

Please identify why the project can only be undertaken with the support of the NIA, including reference to the specific risks(e.g. commercial, technical, operational or regulatory) associated with the project

This project requires collaboration between DNO and technology companies to be successful as well as live trials on a DNO network. Therefore the funding provided via NIA is suited for this type of project in order for it to progress into BaU. The ability of these devices to successfully manage PQ and phase imbalance issues has yet to be proven.

This project has been approved by a senior member of staff

☑ Yes