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NIA Project Registration and PEA Document

Date of Submission

Jul 2024

Project Reference Number

NGED_NIA_077

Project Registration

Project Title

Low Voltage – Active power Control Transformer (LV-ACT)

Project Reference Number

NGED_NIA_077

Project Licensee(s)

National Grid Electricity Distribution

Project Start

August 2024

Project Duration

1 year and 3 months

Nominated Project Contact(s)

Greg Shirley

Project Budget

£554,169.00

Summary

The LV network is likely to experience voltage rise, transformer and cable thermal constraints, exacerbated by the increased uptake of LCTs. This project will determine the extent to which a new concept smart transformer can address LV constraints through active power control and feeder meshing. The project will also consider voltage constraints only and to what extent an existing smart transformer technology can address these. This will involve consideration of two key technologies; an existing Hybrid Intelligent Transformer (HIT) and a novel Active Power Control Transformer (ACT). During phase 1 the extent of each solution's applicability in relation to the NGED LV network will be assessed. Phase 2 will proceed depending on successful stage gate reviews and will involve detailed power systems analysis on typical LV networks. During phase 2, either the ACT prototype will be developed and tested or the HIT will be tested in relation to active power and/or voltage control capabilities.

Problem Being Solved

ED2 business plans and network modelling, along with the outcomes of our recent innovation project SILVERSMITH, forecast that a significant portion of the LV network will experience voltage rise, transformer and cable thermal constraints, exacerbated by the increased uptake of LCTs. Certain LV feeder archetypes will experience transformer and cable thermal constraints by the early to mid-2030s while voltage constraints are expected to affect LV feeder archetypes even sooner.

Whilst we are able to resolve these issues using conventional means and other recently developed novel technologies, there are significant restrictions and issues with the wide-scale deployment of these solutions, such as cost, disruption to customers or physical space constraints.

This project will explore and develop the use of a novel transformer technology alongside feeder meshing. The solution will aim to resolve voltage and/or thermal constraints out to 2050 and be deployable within the existing footprint of a secondary ground mounted transformer, thereby aiming to increase the number of probable deployments.

Method(s)

A novel transformer will be designed and pending successful completion of stage gate 1, a prototype developed, to assess its' ability to independently control active power flow in two feeders, either from the same substation (looped) or from adjacent substations (meshed). Load sharing will be facilitated, thereby removing constraints from one feeder by transferring load to another unconstrained feeder, while also controlling the voltage profiles along the feeders. Network modelling will be completed to validate the outputs from the active power control transformer model within meshed/looped networks. The meshing/looping of LV feeders will not be physically tested as part of this project. In addition to this, an existing smart hybrid intelligent transformer (HIT) which is able to dynamically control its voltage output, will be assessed.

The project will be delivered across four work packages, split across two distinct phases:

Phase 1: Active Power Control Transformer Design and Feasibility Studies

Phase 1 will be a desktop based feasibility study, including network application studies and the development of an initial engineering design concept. This phase will focus on first considering the technical viability and extent of potential deployment of both the active power control transformer solution and the HIT solution on the network (WP1), before developing a detailed design for the smart active power control transformer (WP2).

This phase will involve the following work packages:

WP1 – Feasibility and Network Application Studies

WP1 will involve exploration of the feasibility and applicability of the active power control transformer on the NGED network.

- **Shortlisting of substation archetypes** – involving identification of link boxes which are capable of forming a loop between two LV feeders supplied from the same substation, along with those that form a mesh between adjacent substations. Based on a number of categories, the dataset will be categorised into a list of representative substations (archetypes).
- **Bounding and input parameters** – parameters will be set to ensure analysis is representative of the likely networks that LCT uptake will be considered for.
- **Network constraint modelling** – analysis of LCT distribution along each of the two feeders will be completed, to determine voltage and thermal constraints that may occur for each archetype. LCT uptake will be applied to representative network archetypes in line with NGED's DFES studies out to 2050. Using these uptake rates, we will determine voltage and thermal constraints that may occur on these archetypes across a number of years. Estimations will be made with regards to the active power / voltage management that the smart transformer can provide to release capacity and the condition boundaries at which the performance of the smart transformer may become limited.
- **Active power flow or voltage control requirements** – using the above analysis, the following outputs will be produced for each archetype:

    - Quantification of the level of voltage control required to keep the network within voltage rise/drop constraints.

    - Quantification of the level of passive load sharing achievable through meshing (based on impedance and voltage differences).

    - Quantification of the additional active power transfer required to keep the network within operational constraints (based on thermal and voltage limits).

- **Initial business case** – results from the archetypes in the above analysis will be used to carry out a high level applicability study of the solution on the NGED network. This will enable a high level functional requirement for the smart transformer to be determined around the level of active power transfer that would be essential to deliver any value along with how greater transfer could release more value. The number of substations that could benefit from voltage control using the HIT along with the potential duration of any reinforcement deferral due to alleviation of voltage constraints will be determined. Taking this data, analysis will be carried out to scale the potential opportunity across all of the longlist substations initially identified based on the archetype assignment.

WP2 – Functional Requirements and Solution Development

WP2 focuses on the design of the smart active power control smart transformer (ACT), alongside independent review of the existing hybrid intelligence transformer (HIT).

- **Concept development** – ACT objectives, network and technical requirements will be defined. Functionality of the device system and subsystems will be developed, and integration of the device into the network will be outlined.
- **Independent Review** - During the initial stages of work package 2, an independent review of the design and technical performance of the HIT device will be completed by Cardiff University. The first stage gate will occur following the completion of the active power control transformer concept. If the review of the active power control transformer does not pass the stage gate review, then the project may proceed to phase 2 utilising the HIT device. This is dependent on a successfully independent review of the HIT device by Cardiff University and a positive initial business case for voltage control only from WP1.
- **Design and modelling of device** – depending on the outcome of a successful stage gate review, the active power control transformer will be designed and modelled in detail. This will include development of a mathematical model of the device, its

operational states and its integration into the distribution system.

There will be 2 stage gate reviews during phase 1 to assess the efficacy of the transformer design and to review the network application. The first stage gate will occur mid-way through WP1 and WP2, when the functional requirements have been defined and initial design is complete. The second stage gate review will be completed at the end of phase when full design is complete.

Cardiff University have subject matter experts in both Power Electronic technology and Electromagnetics who will be providing an independent review of the active power control transformer and HIT technologies during both stage gate reviews.

Phase 2: Functional Requirements and Solution Development

Phase 2 will only proceed depending on successful stage gate reviews during phase 1, and may consider either the active power control transformer and/or the HIT transformer depending on the outcomes of the stage gate reviews. This phase will involve detailed power systems analysis on typical LV networks where the solution would be effective and to also understand the impact of the solution's implementation on other network aspects, such as fault level and power factor. The level of voltage control required to alleviate voltage constraints will also be considered in the cases where this will defer reinforcement (WP3). The extent of active power control and load sharing will be determined to inform the design and manufacturing of a benchtop prototype of the ACT. The benchtop prototype will be tested to assess its performance in relation to active power and voltage control capabilities (WP4).

This phase will involve the following work packages:

WP3 – Headroom Assessment and Cost Benefit Analysis

Work package 3 commencing is dependent on successful outcomes from the stage gate reviews.

The aim of WP3 is to assess the amount of headroom that can be achieved through utilising the smart transformer, using detailed power systems analysis of representative LV networks. This headroom will be defined as the level of thermal and/or voltage constraints that can be alleviated on the constrained feeders. The stages involved will be as follows:

- **Development of PowerFactory model for smart transformer** - detailed network models for Power system studies will be created using Power Factory and validated in a test network model, to demonstrate whether expected behaviour is in line with available design standards.
- **Development of representative networks** – full LV network models will be produced for up to 5 LV network feeders from WP1 that are forecast to benefit from the technology. Models will include representation of LV link points to enable two neighbouring feeders to be coupled, and will be developed with sufficient detail to enable modelling of the effects of LCT update, thermal, voltage and fault level constraints.
- **Applying LCT uptake** - the LCT uptake rates deployed during WP1 (EV, PV and heat pumps) will be deployed to each feeder model. The models will be run with the link box open and closed, and a comparison will be made to compare the differences and understand whether looped feeders offers a viable option for increasing thermal and/or voltage capacity on the network for each archetype.
- **Applying smart transformers** – the smart transformer(s) will be tested on a number of factors, to determine its ability to alleviate common network constraints that have been identified during the development of representative networks.
- **Cost Benefit Analysis** – a cost benefit analysis of deployment of a smart transformer solution will be completed using Transform, including a comparison with other BaU and Novel solutions.

WP4 – Smart Transformer Development and Testing

Depending on the outcomes of WP1 and WP2, either a prototype of the active power transformer will be manufactured and tested, or the HIT will be tested to reflect likely network scenarios.

- **Design of prototype** - the prototype design will be informed from WP2 findings and functionality requirements will be informed from WP3 findings.
- **Prototype testing** - a specialised test rig will be designed to allow benchtop testing of the prototype to be completed. This will include source and load control capabilities for primary and secondary sides for all required testable functionality.
- **Design optimisation** - As procured hardware becomes available, the electrical and electronic components of the device will be built and tested as sub-assemblies to identify and resolve issues, optimising the final prototype. The performance of the prototype will be fully assessed by Cardiff University as well as NGED policy engineers.
- **Results and recommendations** – an independent review of the results from prototype testing will be completed and recommendations will be made for future project phases.

Scope

This will be a research and development-based project, which aims to deliver a proof of concept by determining the extent to which a smart transformer solution could remove constraints from NGED's network.

The technology, if proven to work, has the potential to significantly reduce the amount of LV cable reinforcement required on NGED's network in the future, when network constraint issues start to increase. If proven to be effective in 20% of cases on the NGED network, conventional reinforcement could be avoided on 24,134 LV feeders, resulting in an estimated net benefit of £193 million.

In addition to this, the solution would also be applicable across other DNOs.

Objective(s)

Objectives of this project are to determine if this concept is viable, to understand the extent to which the LV-ACT solution can alleviate forecast thermal and voltage constraints and to produce a positive benefits case for the solution. This will be facilitated through delivery of the following outputs:

WP1 - Feasibility and Network Application Studies

· Shortlist of network/feeder archetypes where solution shows benefit.

· Report detailing analysis and results of high level power flow and voltage profile assessment.

WP2

· Functional Requirements document for the active power control Transformer.

· Detailed design documentation of active power control transformer and communication requirements

· Draft bill of materials for active power control transformer.

· Drawings, Datasheets and Device Models for the Active power control transformer.

· Review of linkbox switch technology and communication requirements as well as LV distribution board alterations

· Independent review of the active power control transformer and two winding HIT

WP3

· Detailed network models for Power system studies.

· Results of power systems analyses, duration and level of active power control required

· Impact of active power control and feeder meshing on other network aspects, i.e. voltage, power factor, fault levels etc

· Cost benefit analysis of active power control transformer solution using Transform

· Cost benefit analysis of two winding HIT providing voltage control only.

· Comparison of active power control transformer with other BaU and Novel solutions.

WP4

· Final design and bill of materials for benchtop prototype.

· Prototype testing plan

· Prototype testing results

· Device Control panel factory acceptance testing

· Device transformer IEC factory acceptance testing

· Independent review of prototype testing

- Recommendations for further project phases

- Project closedown report

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

If proven to be successful, the concept has the potential to significantly reduce the amount of LV cable reinforcement required on NGED's network in the future, when network constraint issues start to increase. This will minimise outages and disruption to all customers. This particularly impacts vulnerable customers, for whom the impacts of outages and network disruption can be greater, for example due to reliance and increased need to access electricity for medical equipment.

Success Criteria

This project will have been successful if the following outcomes are achieved:

- Demonstrate that either

  - Load sharing between feeders is achievable using an active power flow control transformer or;

  - The HIT dual winding transformer is able to alleviate network voltage constraints.

- Demonstrate that the active power control Smart Transformer or the HIT transformer is cost effective when compared to BaU and other novel solutions.
- The active power control Smart Transformer or the HIT transformer meets other network requirements including protection, communications and physical space restrictions.
- There are sufficient use cases within an LV network for load sharing through active power control and feeder meshing or voltage control using the dual secondary or two winding HIT transformer.
- Thermal and voltage constraints forecast to be experienced on the LV network can be removed using the LV-ACT solution.

There are also certain criteria that the project will have to meet within the two stage gates reviews in order to proceed, which may be refined as the project progresses.

Project Partners and External Funding

Ionate Ltd

- Responsible for delivering WP2 and WP4
- Design, prototype manufacture and testing of the active power control transformer

EA Technology

- Responsible for delivery WP1 and WP3
- Technical input into WP2. Will complete review of current linkbox switches
- Produce a Power Factory model of active power control transformer

Cardiff University

- Providing independent review of the technology and design.

Potential for New Learning

This project aims to identify whether either the active power control transformer or hybrid intelligence transformer would be a viable solution to minimise and remove constraints from NGED's LV network.

The learning and outcomes from the project will be disseminated via monthly website updates, reports and conferences (such as the ENA's Energy Innovation Summit).

Scale of Project

This project will be desktop based in phase 1. The active power control transformer will be designed/smart transformer independently reviewed (WP2) and a network assessment will take place (WP1).

Following a successful stage gate review, phase 2 of the project will include detailed network power systems studies (WP3) and potential development of a prototype of the active power control transformer in a laboratory setting (WP4).

Meshing/looping of LV feeders will not be physically tested as part of this project. No network trials will take place.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

Network analysis may include circuits across NGED’s four license areas. The first phase of the project will be desktop based and the second phase will be laboratory based. No network trials will take place.

If the ACT prototype or HIT technology is proved to be successful, this solution will be applicable to all DNOs.

Revenue Allowed for the RIIO Settlement

N/A

Indicative Total NIA Project Expenditure

NGED will contribute a total of £53,472.90 to this project, requiring total NIA funding of £481,256.10

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:

This project will help facilitate the transition to net zero, ensuring quick installation of low carbon technologies on the LV network assisting customer's transition to low carbon heat and transport. Through a one off installation of a smart transformer technology as a direct replacement for existing ground mounted transformers, LV cable reinforcement can be avoided therefore ensuring that connection and operation of LCTs will be enabled with minimal impact on customers and reduced cost.

The learning from this project will be applicable to all UK DNOs.

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

If proven to be successful, the concept has the potential to significantly reduce the amount of LV cable reinforcement required on NGED's network in the future, when network constraint issues start to increase. This will minimise outages and disruption associated with reinforcement on the network. Many categories of vulnerable customers are particularly impacted by outages and disruption to the network, for example those with critical medical equipment. Therefore, innovations that can prevent faults from occurring are beneficial to everyone, but especially to vulnerable customers.

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

The solution explored as part of this project, seeks to avoid conventional reinforcement on LV feeders, through load sharing between two or more pairs of LV feeders (one constrained and one unconstrained, or both experiencing constraints at different times of day). There are a number of potential use cases for the active power control transformer integrated into the LV network. These are:

- Existing LV feeder loops from the same substation
- Additional LV feeder loops from the same substation
- Meshed feeders from two adjacent substations
- Combination of a meshed feeder pair and looped feeder pair.

Base Cost

The base cost consists of a new distribution transformer and the reinforcement of an LV feeder, assumed to be 300m length.

- Cost of Conventional transformer (1MVA) - £18,000
- Cost of 300m LV cable reinforcement – 300 * £100 =£30,000

Total base cost would therefore be £48,000. For reinforcement of two LV feeders the base cost increases to £78,000.

Method Cost

The method cost is based on the new active power control HIT and the installation/modification of an automated link box switch.

At this stage it is assumed that the HIT cost will be in the region of £35,000 and the automated link box switching will cost £5,000. WP2 of this project will produce more exact costings for the solution.

Therefore, the method cost is estimated to be £40,000. This would increase to £45,000 for the looping/meshing of two feeder pairs.

Financial Benefit

The net benefit that could be achieved for one secondary substation where the solution would be applicable, is between £8,000 and £38,000 depending on what LV reinforcement would have been required without the solution in place.

As it is estimated that the solution would be applicable on around 24,000 LV feeders the total benefit from utilising the solution would be approximately £193 million out to 2050.

It should be noted that this is a research project to prove the efficacy of the solution and extent of applicability on the network. The detailed CBA will be completed during the project, once initial costs are available.

Through developing a smart transformer that will facilitate load sharing between existing LV feeders, the need for conventional cable reinforcement will be reduced and therefore reduce impact on customers due to fewer street works.

It is also envisaged that due to reducing cable reinforcement with the need to only replace the distribution transformer, the outage for network reinforcement will require less time.

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

The method developed in this project is expected to be widely applicable across GB, as the technology developed is intended to be compatible with a wide range of the LV network.

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

Due to the low TRL of the technologies in this project, alongside its nature as a research and development project, rollout across GB is not expected as a specific outcome of this project. However, the technology developed is intended to be compatible with a wide range of the GB LV network.

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

This project will develop a prototype novel hybrid intelligent transformer which can facilitate load sharing between adjacent LV feeders. This has not been explored before within the DNOs. This project aims to help facilitate the transition to net zero, by ensuring quick installation of low carbon technologies on the LV network assisting customer's transition to low carbon heat and transport.

The learning from this project will be applicable to all UK DNOs.

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.

Electricity North West previously completed an NIA project, Smart Street, which focused on controlling voltage between feeders using switching devices.

UK Power Networks are currently completing their Active Response to Distribution Network Constraint project, which focuses on three distinct solutions comprising of network add-on technologies which are capable of either active response or feeder meshing techniques to manage network constraints.

LV ACT is distinct from these projects, due to its focus on simultaneous feeder meshing and active power control, to manage both voltage and thermal constraints. In contrast to the Smart Street and Active Response projects, which focus on adding devices to existing network, LV ACT will focus on development of a smart transformer which will offer a long-term solution and a direct replacement for distribution transformers. This will minimise the need for network reinforcement while alleviating both thermal and voltage constraints.

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

N/A

Additional Governance And Document Upload

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

The project seeks to explore the feasibility of a distribution transformer with two secondary windings, where active power output can be independently controlled. Combining this smart transformer with feeder looping or meshing, either from the same substation or adjacent substations, the project aims to remove both voltage and thermal constraints from affected LV feeders. This approach has not been done on the low voltage network before.

While other solutions exist that can reduce voltage and thermal constraints, most require equipment in addition to a distribution transformer, which impacts their effectiveness due to cost or space constraints. This novel smart transformer designed in the project, will aim to be cost effective and a direct replacement for a distribution transformer. In addition to exploring the feasibility of the active power control transformer, an existing dual winding hybrid intelligent transformer (HIT) will be reviewed and assessed to understand the extent to which it can alleviate voltage constraints on the network. The HIT transformer has one Primary winding and one secondary winding where the voltage output and power factor of individual phases can be controlled independently. Feeder looping/meshing would not be considered in this case.

Relevant Foreground IPR

Relevant Foreground IPR will be:

- All documents and reports produced during this project. This is subject to redaction where Ionate's HIT concept is used or referred to.

Details of what information will and will not be included in design documentation of the active power control transformer is to be subject of an NDA and will be outlined in more detail in the project collaboration agreement.

The relevant background IPR required to produce the project outputs is:

- National Grid's Network data
- Ionate Ltd's Hybrid Intelligent Transformer (HIT) Device
- EA Technology Ltd's Transform Model®

Sufficient detail will be included in documents and reports to enable other DNO's and external parties to understand the capabilities of the active power control transformer and the extent of its' applicability on the network.

Data Access Details

All project findings will be published on National Grid's website.

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

The low technology readiness level (TRL) of the technologies being developed and unproven methodology means that this project is unsuitable for BaU activity.

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

The risks associated with this project are too high to justify business funding without NIA support. In particular, due to the low TRL of the technologies in this project. The project involves an immature technology and requires significant research and development.

The Network Innovation Allowance will facilitate the design, development and testing of a prototype of this immature technology. The technology, if proven to work, has the potential to significantly reduce the amount of LV cable reinforcement required in the future, when network constraint issues start to increase.

This project has been approved by a senior member of staff

☑ Yes