Energy Networks Innovation Process

Annual Project Progress Form

Notes on Completion: Please refer to the NIA Governance Document to assist in the completion of this form.
Do not use tables

Step 1 - Initial Project Details

Project Title

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

Project Reference

NGED_NIA_077

Nominated Project Contact(s)

Greg Shirley

Project Start Date

08/24

Project End Date

05/26

Scope (15000 Characters max)

This is 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.

The project is being delivered across four work packages, split across two distinct phases. WP1 and WP2 are in phase 1 of the project, WP3 and WP4 are in phase 2.

Phase 1:

- WP1 – Feasibility and Network Application Studies
- WP2 – Functional Requirements and Solution Development

Phase 2:

- WP3 – Headroom Assessment and Cost Benefit Analysis
- WP4 – Smart Transformer Development and Testing

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.

A novel transformer is being designed during phase 1. Pending successful completion of stage gate 2, a prototype will be 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 is being 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 is being assessed.

Objective (15000 Characters max)

The following objectives/outputs are expected from each work package as follows:

WP1
- 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 smart transformer benchtop prototype.
- Smart transformer prototype testing plan
- Smart transformer prototype testing results
- Smart transformer control panel factory acceptance testing
- Smart transformer IEC factory acceptance testing if applicable
- Independent review of prototype testing
- Recommendations for further project phases

Success Criteria (15000 Characters max)

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 is cost effective when compared to BaU and other novel solutions.
- The active power control Smart Transformer or the HIT 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.
- 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.

Step 2 - Performance Outcomes

Performance Compared to Original Project Aims, Objectives and Success Criteria

Details of how the Project is investigating/solving the issue described in the NIA Project Registration Pro-forma. Details of how the Project is performing/performed relative to its aims, objectives and success criteria. (15000 Characters max)

The LV-ACT project was mobilised in September 2024 and has made good progress through work package 1 and work package 2.

Progress made against the objectives of the LV ACT project during the reporting year ending March 2025 is as follows:

WP1 - Feasibility and Network Application Studies

- Producing shortlist of network/feeder archetypes where solution shows benefit.
  - Low voltage network data has been analysed to assess which LV feeders could form existing loops from a shared linkbox and which could be meshed with other distribution substations. A longlist of networks which could most readily benefit from the LV-ACT solution was produced based on whether this potential shared connection existed as well as recording customer numbers and cable length/impedances. These networks were taken forward to network application studies.
  - Cable data and customer numbers were obtained for all of the circuits to be analysed. Elexon load profiles were assigned to customers depending on their recorded profile. To assess the potential worst case for cable thermal constraints on each of the networks, peak loads for domestic customers were taken from Elexon profiles at 6pm. Low carbon technology loads which included electric vehicle chargers and heat pumps were taken from 2040 DFES load profiles at 6pm.
  - The network application studies included this network information and completed 50 Monte Carlo simulations across all the longlisted networks. Within the Monte Carlo simulations, LCTs were randomly assigned to various customers within the networks. The analysis was completed in Microsoft Excel using a Python-based script considering a range of LCT deployment on each network.
  - Voltage rise constraints were also analysed using Monte Carlo simulations on all networks using baseline loading at 12pm on a typical summer day along with the typical output from a domestic PV system when exporting to the grid.
  - The Monte Carlo studies were able to determine which of the networks from the longlist would experience, thermal, voltage or both voltage and thermal constraints in 2040 based on current LCT uptake rate predictions. Considering the constrained networks only, the amount of load sharing/power flow or voltage control required from the Smart Transformer solution to alleviate these constraints was determined. The analysis also highlighted which network constraints could not be solved using load sharing/power flow control. From this, a shortlist of networks where the solution shows potential benefit was produced.

- Report detailing analysis and results of high level power flow and voltage profile assessment.
  - A detailed report was produced using the outputs from the Monte Carlo studies, outlining the amount of load sharing/power flow control and voltage control required by the Smart Transformer solution.
  - The report outlines the methodology used. It also outlines the limitations and assumptions used within the analysis as follows:
    - Linkboxes are assumed to be at the end of a radial circuit.
    - Customers are placed at equal divisions along the feeders.
    - Branching of the network was not considered.
    - Only looped networks with available cable data were included in this study.
    - Analysis is at a single point in time (6 pm for load and 12 pm for generation).
    - Active power control begins at the linkbox and moves load from the more loaded network to the least loaded network.
  - These assumptions were used due to the high-level nature of these studies and to provide a worst-case scenario for thermal/voltage constraints that the Smart Transformer may need to resolve. These assumptions will be addressed during the more detailed power systems network analyses in WP3.
  - For the analysis of thermal constraints a high-level overview of the results outlined in the report are:
    - 4668 looped networks were assessed within the studies which equates to 8% of U/G distribution substations. Only looped networks where network cable data was available was analysed so this figure could be higher.
    - 2494 (53%) of these networks are forecast to experience either thermal/voltage or both constraints in 2040. 549 (12%) experience thermal constraints only, 328 (7%) experience voltage constraints only and 1617 (35%) experience voltage and thermal constraints.
    - Out of these 2494 networks, a solution for the constraints was found using voltage control and/or load sharing for 1102 or 24% of the total networks analysed.
    - It was found that to alleviate the most amount of network constraints, the optimum operating conditions for a Smart Transformer was power flow control between 5% and 12.5% (of total network load) and between +4.5% and +5% voltage control. 33% of all constraints can be solved with a voltage shift of up to +5% and 75% of networks experiencing voltage and thermal constraints can be solved within a 5% power share and between 0% and +5% voltage shift.
  - Overall there are a sufficient number of networks that could benefit from the solution in terms of alleviating thermal and/or voltage constraints. The detailed power system analysis that will take place in work package 3 may highlight some other network issues that would prevent the solution from being deployed in certain network archetypes. During later stages of the project there will also be an assessment of the number of overall LV networks that could benefit from the solution including networks for which a network loop/meshing point will have to be established.

WP2 - Functional Requirements and Solution Development

- Functional Requirements document for the active power control Transformer.
  - A functional requirements document has been produced for the two secondary winding power control transformer. This included the overall scope of what needed to be achieved by the power control transformer including power flow control, voltage regulation, harmonic mitigation and load imbalance compensation.
  - The major elements of the Smart Transformer have been defined at a high-level including transformer core, power electronics, control and firmware, communication interface and sensor interface. The design is ongoing in work package 2.
  - Potential operating environments, network conditions, design constraints, assumptions and dependencies have been defined which would influence the final design of the Smart Transformer prototype. The standards to which the Smart Transformer must confirm have also been outlined.

- Detailed design documentation of active power control transformer.
  - Initial smart transformer concepts have been produced and are currently being analysed using MATLAB models representative of networks identified during work package 1. This will aid in selecting the most effective concept to be used in order to fulfil the functional requirements before proceeding to a more detailed design.

- Independent review of the active power control transformer and two winding HIT.
  - An independent review of IONATE's existing two winding hybrid intelligent transformer has been completed by Cardiff University and reviewed by NGED. A literature review of other similar technology was completed to facilitate comparison with the HIT.
  - Design documentation and testing results of the first full-scale 500kVA Hybrid Intelligent Transformer were provided by IONATE to Cardiff university for review. The main observations from this review are:
    - The HIT maintained stable secondary side voltages within 210V and 250V L-N, with nominal values around 230.9V during downstream voltage variations.
    - Effectively reduced 5th, 7th and 17th harmonics, lowering total harmonic distortion to below 5% and individual harmonics to below 3%.
    - Successfully regulated reactive power towards unity on the HV side for downstream reactive power variations, showing strong correlation between reactive power changes and power factor setpoints.

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

The Network Licensee should state any changes to its planned methodology and describe why the planned approach proved to be inappropriate. Please confirm if no changes are required. (15000 Characters max)

- The project required additional network models to be produced during work package 2 to aid in development and analysis of several concepts for the smart transformer. The development of these models has resulted in a 3 month delay to work package 2 and therefore the project will require an extension to the original planned end date.

Lessons Learnt For Future Projects

Recommendations on how the learning from the Project could be exploited further. This may include recommendations on what form of trialling will be required to move the Method to the next TRL. The Network Licensee should also state if the Project discovered significant problems with the trialled Methods. The Network Licensee should comment on the likelihood that the Method will be deployed on a large scale in future. The Network Licensee should discuss the effectiveness of any Research, Development or Demonstration undertaken. (15000 Characters max)

- Independent review of the existing two winding hybrid intelligent transformer has shown that it has demonstrated voltage regulation, harmonic mitigation, phase balancing and reactive power control capabilities. It would be worthwhile performing some further controlled testing of this technology with a set-up representative of a typical UK low voltage network.

Outcomes of the Project

When available, comprehensive details of the Project's outcomes are to be reported. Where quantitative data is available to describe these outcomes it should be included in the report. Wherever possible, the performance improvement attributable to the Project should be described. If the TRL of the Method has changed as a result of the Project this should be reported. The Network Licensee should highlight any opportunities for future Projects to develop learning further. (15000 Characters max)

As this project is still ongoing it would be too soon to provide comprehensive details of the project outcomes at this stage. These will be documented in the next annual progress report.

To date three reports/documents have been produced as outputs of the project. These are:

- Independent review report of the existing two winding hybrid intelligent transformer.
- Smart Transformer (two independent secondary windings) Functional Requirement Document
- Network Feasibility Study Outcomes report.

Further reports will be produced as the work of the project progresses.

Step 3 - Outputs And Implementation

Data Access Level & Quality Details

A description of how any network or consumption data (anonymised where necessary) gathered in the course of the Project can be requested by interested parties. This requirement may be met by including a link to the publicly available data sharing policy. (15000 Characters max)

Relevant data generated during the project will be made available at nationalgrid.co.uk.

Foreground IPR

A description of any foreground IPR that have been developed by the project and how this will be owned. (15000 Characters max)

Standard Network Innovation Allowance intellectual property (IP) terms were agreed for this project and are being applied to all IP generated by it. Some of the reports produced are commercially or operationally sensitive, and therefore can not be released onto the open Smarter Networks Portal or nationalgrid.co.uk website.