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# NIA Project Registration and PEA Document

### Date of Submission

Dec 2022

### Project Reference Number

NIA2_NGET0030

## Project Registration

### Project Title

Voltage Interaction and Thermal Dynamics of Tertiary Connection

### Project Reference Number

NIA2_NGET0030

### Project Licensee(s)

National Grid Electricity Transmission

### Project Start

April 2023

### Project Duration

2 years and 4 months

### Nominated Project Contact(s)

Xiaolin Ding (box.NG.ETInnovation@nationalgrid.com)

### Project Budget

£590,000.00

### Summary

Tertiary windings of super grid transformers in transmission networks provide a cost-effective and efficient connection solution for BESS (Battery Energy Storage Systems). Numerous connections to BESS and small-scale renewable generation projects are planned. This could result in flows of active and reactive power through the transformers that were not anticipated or planned for in the original system design. This project will develop appropriate modelling methodologies for assessing the dynamic thermal performance and voltage interactions of grid transformers with active usage of tertiary connections. A methodology for combined assessment of system and thermal impacts of grid transformer tertiary connections will be completed to understand the voltage control interactions as well as the dynamic thermal performance of the transformer and risks to asset health.

### Third Party Collaborators

The University of Manchester

### Nominated Contact Email Address(es)

box.NG.ETInnovation@nationalgrid.com

### Problem Being Solved

Tertiary windings of super grid transformers in transmission networks provide a cost-effective and efficient connection solution for BESS (Battery Energy Storage Systems). Numerous connections to BESS and small-scale renewable generation projects are planned. However, this could result in flows of active and reactive power through the transformers that were not anticipated or planned for during the original system design.

Previous studies have identified that new tertiary connected equipment could affect the local voltage control on the transformers (i.e., interact with the OLTC control), which could result in excessive mechanical wear and may lead to additional constraints if compliance with voltage limits cannot be maintained. As system fault level reduces and system voltages become more sensitive to power flow

changes, there is an increasing concern over the potential of these voltage controller interactions to propagate through the system and become a wide-spread issue. In addition, active and reactive power flows through the tertiary windings could also affect the cooling control of the transformer and its thermal performance. Currently, there is no appropriate dynamic thermal model (with representations of cooling systems, three windings and tap-changer) available to assess the impact in detail, which could lead to deleterious consequences for the transformer.

## Method(s)

The project will develop appropriate modelling methodologies for assessing the dynamic thermal performance and voltage interactions of grid transformers with active usage of tertiary connections. It will develop dynamic models of voltage control systems for identifying the conditions under which undesired system performance occurs. It will also develop a dynamic thermal model of the transformer with representation of the three windings, cooler control, and tap-changer control. Finally, a methodology for combined assessment of system voltage and thermal impacts of grid transformer tertiary connections will be carried out to understand the interactions between voltage control and the dynamic thermal performance of the transformer, as well as and risks to asset health.

**Data Quality Statement (DQS):**

The project will be delivered under the NIA framework in line with OFGEM, ENA and NGGT / NGET internal policy. 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 on our internal sharepoint platform ensuring access control, 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 the supplier's own quality assurance regime. Quality assurance processes and the source of data, measurement processes and equipment as well as data processing will be clearly documented and verifiable. The measurements, designs and economic assessments will also be clearly documented in the relevant deliverables and final project report and will be made available for review.

**Risk Assessment:**

TRL Change = 1

Cost = 2

Supplier = 1

Data = 2

Total risk score = 6 Low (L)

## Scope

**WP1: System Voltage Control Interactions**

- Develop appropriate dynamic models of voltage control systems (for tertiary connected equipment and transformer tap-changers) which are appropriate for a variety of general substation configurations.
- Identify worst case transformer dynamic loading conditions for WP2 modelling.
- Assess impacts on voltage control interactions for active tertiary connections against various scenarios.
- Identify conditions and configurations where the tertiary connected equipment can be used to improve the voltage performance through appropriate control.

**WP2: Dynamic Thermal Modelling and Assessment**

- Develop a dynamic thermal model to accommodate requirements of three windings, dual-temperature cooling modes and tap changers.
- Conduct Computational Fluid Dynamics (CFD) based modelling to understand transformer thermal performance under unbalanced loading scenarios
- Identify suitable thermal parameters or equations to improve the three-winding dynamic thermal model developed.

- Apply the dynamic thermal model under critical scenarios identified from WP1 to assess the impact of tertiary connections on the health condition and lifetime reduction of transformers.

**WP3: Combined Voltage and Thermal Assessments**

- Through population analysis, identify weak tertiary connection points by consideration of system performance and transformer asset condition.
- Propose a scheme (e.g. protection and control settings, operational parameters) that allows dynamic control of the transformer tertiary connected load with consideration of both transformer voltage control and cooling control for maximising the utilisation of tertiary connected assets without comprising the lifetime and operational reliability of the transformer.

## Objective(s)

The objectives of the project are as follows:

- Develop appropriate dynamic models of voltage control systems for tertiary connected equipment and transformer tap-changers.
- Develop a dynamic thermal model with good representation of three windings, dual-temperature cooling modes and tap changers
- Understand the impacts on voltage control and dynamic thermal performance of super grid transformer with active tertiary connections.
- Propose a scheme that allows dynamic control of the transformer tertiary connected load for maximising the utilisation of tertiary connected assets.

## Consumer Vulnerability Impact Assessment

An assessment of distributional impacts (technical, financial and wellbeing related) for this project has been carried out using a bespoke assessment tool, which assesses the project as having a positive, negative or neutral effect on consumers in vulnerable situations. To help inform the assessment, this tool considers the categories of consumers identified in the Priority Services Register.

This project has been assessed as having an overall positive impact on consumers in vulnerable situations. The assessment has identified that this project will look to enhance power flow control capability of the network which will reduce the costs for households.

## Success Criteria

- Appropriate dynamic models of voltage control systems for tertiary connected equipment and transformer tap changers.
- Appropriate dynamic thermal model with good representation of three windings, dual-temperature cooling modes and tap changers.
- In-depth understanding of the impact of active tertiary connections on the voltage control interaction and thermal performance of super grid transformers in the network.
- Recommendation of a scheme that allows dynamic control of the transformer tertiary connected load for maximising the utilisation of tertiary connected assets.

## Project Partners and External Funding

None

## Potential for New Learning

It is expected that a transformer dynamic thermal model which is appropriate for the analysis of tertiary connections by consideration of three windings, cooler control and tap-changer control, will be developed. Currently such a dynamic thermal model is not available.

The project plans to develop innovative analysis methods to investigate complex voltage control interaction in the system under rapidly changing local conditions and brings in-depth understanding on the impacts on voltage control.

The project also intends to develop an effective method to identify the weak points / risks of tertiary connection by considerations of both system and thermal performances.

The key findings of the projects will be shared with other Transmission and Distribution Owners and the System Operator via workshops, technical documentation and/or publications.

## Scale of Project

The project aims to develop suitable models that are capable to assess the impacts of tertiary connections to BESS or other similar systems. To achieve this critical objective, both voltage and thermal assessments need to be considered, which also require very different skill sets for the developments. Therefore, two work packages, WP1 and WP2, are designed for developing suitable voltage interaction models and dynamic thermal models, respectively. The final stage in WP3 is to conduct the synergetic assessments by

considering both voltage and thermal performance for identifying the week points in terms of tertiary connections. Appropriate mitigation measures will be explored to maximize the utilisation of tertiary connected assets.

All stages are logically linked and designed to deliver a comprehensive solution to assess the grid transformers' tertiary connections. To deliver all the project objectives and associated potential benefits, the scale of the project is as specified with a supplier on a framework contract achieved through tender and negotiation to be as economic as possible. There would be inadequate potential for new learning and benefits with a less ambitious and smaller project.

## Technology Readiness at Start

TRL2 Invention and Research

## Technology Readiness at End

TRL4 Bench Scale Research

## Geographical Area

Computer-based studies to be carried out at the innovation provider's facilities.

## Revenue Allowed for the RIIO Settlement

Not Applicable

## Indicative Total NIA Project Expenditure

£531k

# Project Eligibility Assessment Part 1

## Requirement 1

Facilitate the energy system transition and/or benefit consumers in vulnerable situations

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

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

Wider integration of low carbon technologies like EV charging, BESS and small-scale renewables to the power network is essential for the decarbonisation of the energy industry and the transition towards net-zero 2050. Super Grid transformer tertiaries offer cost effective solutions to connect them. However, the risk and impacts need to be fully understood to ensure the safe operation of the network. This project will help eliminate potential risks and enable optimal operation of tertiary connected equipment to maximise asset life and capability utilisation.

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

Not applicable

## 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

Not applicable

### Please provide a calculation and/or description of the expected benefits of the solution

The project aims to develop appropriate modelling and methodology for assessing the dynamic thermal performance and voltage interactions of grid transformers with active usage of tertiary connections, which will help to prevent an increased risk of Super grid transformers failure and reducing the cost of the resulting loss of tertiary connections. Based on our cost benefit analysis, the benefits is estimated to be around £4.69m by 2034/2035 in NPV (Net Present Value) if the project is successful.

Note that there could also be potential savings that are derived from the avoidance of wider network failures induced by possible voltage volatility in a weak grid, and potential savings that could be made by transformer lifetime extension and the savings in labour costs from a reduced need for maintenance. These are not included in the above cost benefit calculation. The cost of benefits will be reviewed and updated once the project is completed.

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

The relevant conditions pertaining to NGET are the same for other transmission network owners and operator, so key learning points from this project should be easily replicable. Methods and algorithms developed in the projects would be equally appliable to network licensees across GB.

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

This project is to develop appropriate modelling methodologies for assessing the dynamic thermal performance and voltage interactions of grid transformers with active usage of tertiary connections. If successful, the methods can be further developed to roll out across GB. The estimated cost will be reviewed at the completion of the project.

## Requirement 3 / 1

Involve Research, Development or Demonstration

Projects 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

Involve Research, Development or Demonstration - Please select all that apply

☐ 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

The key findings of the projects will be shared with other Network Licenses (Transmission Owners and Operator) via workshops, technical documentation and/or publications. The key learnings from this project should be easily replicable. Methods and algorithms developed in the projects would be equally appliable to network licensees.

Not applicable

### 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. Networks must explicitly mention similar projects that they have considered and how these differ.

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

Previous innovation project NIA_NGTO035-Power Electronic Enabled Transformers (PEETs) in T1 is relevant to this project. PEETs project highlight a concern that tertiary connections to BESS or similar systems might affect the local voltage control, cooling control and thermal performance of the grid transformers. However, there are no suitable existing models available to assess the impact to develop in-depth understanding of the risks, which could lead to deleterious consequences for the transformer. This project is to develop appropriate modelling and innovative analysis methods that can be used to conduct appropriate voltage and thermal assessments of grid transformers with active usage of tertiary connections. No duplication will occur as a result of this project.

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

Not applicable

# Additional Governance And Document Upload

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

Tertiary connection could affect the local voltage control and cooling control on the transformers. No suitable models available to assess the impact in detail, which could lead to deleterious consequences for the transformer. This project develops adequate dynamic thermal models with consideration of three windings, cooler control and tap-changer control and innovative analysis methods that can be used to effectively assess the voltage control interaction and thermal impacts for grid transformers with active usage of tertiary connections.

## Relevant Foreground IPR

The expected Foreground IPR from this project includes multiple voltage interaction and thermal models developed for assessing tertiary connections, a methodology of combined voltage and thermal assessments for identifying the weak points of connections and recommendations that allow dynamic control of the transformer tertiary connected load for maximising the utilisation of tertiary connected assets. The Foreground IPR also includes technical reports developed for the projects and any publications associated. The findings will be recorded in written technical reports along with recommendations for further steps to be taken to bring the knowledge into Business as Usual activities

## Data Access Details

Data for this project and all other projects funded under the Network Innovation Allowance (NIA), Network Innovation Competition (NIC) or the new Strategic Innovation Fund (SIF) can be found or requested in a number of ways:

- A request for information via the Smarter Networks Portal at https://smarter.energynetworks.org, to contact select a project and click 'Contact Lead Network'. National Grid already publishes much of the data arising from our innovation projects here so you may wish to check this website before making an application.
- Via our Innovation website at https://www.nationalgrid.com/uk/electricity-transmission/innovation
- Via our managed mailbox box.NG.ETInnovation@nationalgrid.com

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

This is a research project that involves the development of new voltage and thermal models for assessing the operation performance and health conditions of grid transformers with tertiary connections to BESS or similar low carbon technologies. Currently no such models are available and implemented in transmission network operation and asset management. This cannot be considered as a business as usual activity as there is a considerable risk associated with the development of the models.

## 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 project contains high technical and commercial risk in developing the complex voltage control models and dynamic thermal models considering the interaction with tap-changer and unbalanced loading among three windings, fast changing of the loadings on the tertiary connections. The proposed methodology and developed model need to be verified before implementation and the risk of failure is high. The benefits will accrue to multiple parties in the transmission network. Therefore, it can only be undertaken with the support of NIA.

## This project has been approved by a senior member of staff

☑ Yes