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

Nov 2023

Project Reference Number

NIA_SPEN_0084

Project Registration

Project Title

Transformer Research Consortium – Phase 5: Future-proof Transformers in a Digital Twinning and Net-Zero World

Project Reference Number

NIA_SPEN_0084

Project Licensee(s)

SP Energy Networks Transmission

Project Start

November 2023

Project Duration

4 years and 0 months

Nominated Project Contact(s)

Ahmed Salama

Project Budget

£1,260,000.00

Summary

The transformer research consortium project brings together academics, network operators and manufacturers to deliver on cutting-edge research topics.

Phases 1 and 2 focused on the use of synthetic and natural esters in transmission-level transformers, leading to sufficient understanding of the technology for National Grid to be able to deliver an inner London substation design incorporating them.

In Phase 3, a methanol measurement technique to support ageing assessment of cellulosic insulation was developed and benchmarked within IEC, with digital thermal models validated through practical application.

Phase 4 added significantly to our understanding of thermal modelling of transformers including cooling loop and the risk of bubble formation with changing temperatures.

This phase aims to solve the technological challenges of electrical power systems and networks with a focus on future-proofing transformers in a digital twinning and net-zero carbon emission world.

Preceding Projects

PRJ_1133 - Transformer Research Consortium (Phase 3)

NIA_NGET0088 - Transformer Research Consortium

Third Party Collaborators

The University of Manchester

Nominated Contact Email Address(es)

innovate@spenergynetworks.co.uk

Problem Being Solved

Transformers are a critical and important part of the electricity networks. In the foreseeable future the conventional AC networks will continue to dominate electrical energy generation, transmission and distribution. Transformer asset management represents a significant challenge for transmission and distribution networks. In order to ensure that the system is fit-for-purpose, maintaining reliability and availability for its customers, it is essential that the transformers are assessed effectively and replaced at the appropriate time. Understanding the ageing and breakdown performance of transformer insulation systems would lead to more efficient asset management practice by identifying mitigation measures and improving transformer life expectancy and reliability.

Due to the sheer number of units and the long lifetime of transformers, transformer losses including no-load loss and load loss are one of the major contributors to the carbon footprint of the power network. Development of a life cycle assessment (LCA) based transformer carbon footprint optimisation methodology would provide SPEN the tool to inform transformer procurement, operation, and maintenance for reducing overall carbon footprint.

Achieving carbon net-zero ambitions requires electrification of heat and transport, which put pressure on existing network equipment. Development of transformer dynamic thermal modelling would enable SPEN to either release further capacity headroom or manage overloading scenarios safely.

Method(s)

SP Energy Networks will join a consortium consisting of academics and transformer manufacturers to continue its research programme with University of Manchester and University of Exeter following previous successful NIA funded projects phases. While this work will be led by academics it will benefit from practical inputs from SPEN as end user and transformer manufacturers. The following key deliverables are planned:

State-of-the-art literature review on transformer dynamic thermal modelling and digital twin.

Building on the complete-cooling-loop modelling methodology, developed in Phase 4, to understand thermal profiles under different operating conditions.

Development of a framework of transformer digital twin and define the functionality of each layer/interface.

Development of a complete life cycle assessment (LCA) based transformer carbon footprint accounting methodology.

Discharge and breakdown tests of transformer insulation systems under combined stresses that would appear in future power network.

Ageing experiments of thermally upgraded paper insulation in combination with various transformer liquids using an advanced dualtemp ageing system.

Development of molecular dynamic based ageing simulation methodology.

Experiments based verification of the developed dynamic thermal model.

Recommendations on technical and policy aspects for developing a transformer digital twin.

Recommendations on potential means to reduce transformer carbon footprints through appropriate mid-life intervene approaches.

Scope

The University of Manchester will be building on four successful phases of the transformer research consortium, which has delivered world class research and results.

Phases 1 and 2 focussed on the use of synthetic and natural esters in transformers at transmission voltage levels, this work led to sufficient understanding of the technology for National Grid to be able to deliver an inner London substation design incorporating synthetic ester filled transformers which is currently a BaU solution where fire safety is required.

Phase 3 progress was made in the interpretation of methanol and ethanol as potential early indicators of transformer insulation ageing,

as well as the validation of the digital thermal models using a practical application.

Phase 4 added significantly to our understanding of thermal modelling of the whole transformer including cooling loop and the risk of bubble formation with changing temperatures.

Phase 5 aims to solve industry-wide technological challenges of electrical power systems and networks with a particular focus on future-proof transformers in a digital twinning and net-zero world.

The research and innovation activities are divided into five work packages including:

WP 1. Digital Twin of Power Transformers,

WP 2. Dynamic Thermal Modelling of Transformers,

WP 3. Ageing Assessment of Transformer Liquid and Solid Insulation Systems,

WP 4. Discharge and Breakdown of Transformer Insulation Materials, WP 5. Carbon Footprint Optimisation for Power Transformers.

WP 5. Carbon Footprint Optimisation for Power Transformers

Objective(s)

WP 1. Digital Twin of Power Transformers

- Contribute to SPEN RIIO-T2/ED2 innovation themes 'Energy System Transition – Digitalisation'.
- Develop a framework of transformer digital twin and define the functionality of each layer/interface.
- Develop a prototype transformer digital twin to demonstrate the proposed functionalities.
- Propose both technical and policy guidance on a transformer digital twin in particular about the data flow and ownership issues.

WP 2. Dynamic Thermal Modelling of Transformers

- Contribute to SPEN RIIO-T2/ED2 innovation themes 'Energy System Transition – Digitalisation / Network Modernisation'.
- Develop complete-cooling-loop based dynamic thermal modelling methodology.
- Use experiments to verify the developed dynamic thermal model.
- Propose guidance on transformer thermal loading management to enable integration of more low carbon technologies.

WP 3. Ageing Assessment of Transformer Liquid and Solid Insulation Systems

- Contribute to SPEN RIIO-T2/ED2 innovation themes 'Energy System Transition – Network Modernisation Sustainability'.
- Assess the ageing performance of thermally upgraded paper insulation in combination with various transformer liquids using an advanced dual-temp ageing system.
- Develop molecular dynamic based ageing simulation to explore new chemical markers for transformer ageing assessment.

WP 4. Discharge and Breakdown of Transformer Insulation Materials

- Contribute to SPEN RIIO-T2/ED2 innovation themes 'Energy System Transition – Network Modernisation / Sustainability'.
- Investigate the discharge and breakdown performance of transformer insulation systems under combined stresses that would appear in future power network.
- Compare the dielectric performance of conventional mineral oils and new biodegradable hydrocarbon liquids to enable the adoption of new materials for improving the sustainability of transformers.

WP 5. Carbon Footprint Optimisation for Power Transformers

- Contribute to SPEN RIIO-T2/ED2 innovation themes 'Energy System Transition –Sustainability'.
- Develop a complete life cycle assessment (LCA) based transformer carbon footprint accounting methodology.
- Compare the effects of different optimisation objectives including total carbon footprint reduction and Total Cost of Ownership reduction.

- Investigate potential means to reduce transformer carbon footprints through appropriate mid-life intervene approaches.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

This project has been assessed as having a neutral impact on customers in vulnerable situations.

This is because it is a transmission project.

Success Criteria

The delivery of the above objectives, within budget and within agreed timelines, as is reasonable depending on the knowledge at this stage of the development phase.
Production of the final technical reports containing all the learnings and recommendations.

Project Partners and External Funding

Project Delivery Team:

- The University of Manchester
- University of Exeter

Industrial Sponsors:

- SGB-SMIT
- Shell Global Solutions
- The Electric Power Research Institute
- WEIDMANN Electrical Technology

Potential for New Learning

The outcomes of this research work are applicable to all networks with transmission and distribution transformers.

The outcomes will disseminate information and new learning generated by the projects through conferences and publications to GB Network Licensees.

Scale of Project

This project is focused on a laboratory scale, but will take into account system issues.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

The projects will be delivered at the sites of the research providers.

Revenue Allowed for the RIIO Settlement

0

Indicative Total NIA Project Expenditure

SP Energy Networks: £180,000

National Grid Electricity Transmission £180,000

Contribution from other partners:

SGB-SMIT: £180,000

Shell Global Solutions: £360,000

The Electric Power Research Institute:	£180,000
WEIDMANN Electrical Technology:	£180,000

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:

- Better asset management for replacing the asset and improving the network.
- The development of the life cycle assessment tool will help inform of transformer procurement, operation, and maintenance for reducing overall carbon footprint.
- Development of Dynamic Thermal modelling can help identify areas of stress on the network and help mitigate risks to achieve carbon net-zero.

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

n/a

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

As this research project is in a low TRL state, the benefits of its outputs are not yet quantifiable. However, these research activities described in the work packages are designed to help solve the industry-wide R&D problems faced by the electrical network operators, material/equipment manufacturers, and testing/research service providers. The benefits for the research consortium members will also be to increase the knowledge and understanding of these technical issues, with the hope to directly contribute towards the transformer design, manufacture, operation and maintenance. Phase 5 in particular would help the power network to achieve net-zero carbon target by optimising the utilisation of existing transformer assets and adopting future-proof transformers equipped with advanced materials and digital features.

Since we have multiple research consortium members contributing into the project, it is the most cost-effective way to sponsor transformer research conducted in the UK. The platform is beneficial for all the members of the research consortium and also provides for knowledge sharing and communication within the wider UK and international transformer communities.

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

The work form this project will be fully applicable to GB Transmission transformers and would have some relevance to distribution transformers.

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

This project's learnings will be fully applicable to GB Transmission transformers and would have some relevance to distribution transformers.

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

The phenomena that these two research groups are investigating are relevant to all networks with high voltage transformers and most aspects will be relevant to transformers on the distribution networks as well.

Both research providers will disseminate information and new learning generated by the projects through conferences and publications and at open forums to which Network Licensee representatives will be specifically invited.

Other Network licensees will have the option to learn from the research and to integrate any relevant learning in their own asset management of transformers.

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.

We have reviewed the ENA portal and have not identified any other past or ongoing projects that would give rise to unnecessary duplication of research effort. Two ENA members are involved in this development and have confirmed that this project is innovative and does not replicate previous work in either network.

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 aims to solve industry-wide technological challenges of electrical power systems and networks with a particular focus on future-proof transformers in a digital twinning and net-zero world that has not been investigated before. The outputs of the project will help achieve net-zero carbon targets by optimising the utilisation of transformer assets in existing networks and help network owners and transformer providers to adopt into future-proof transformer technologies that will be equipped with advanced materials and digital features.

The Phase 5 industrial consortium members include Electric Power Research Institute, National Grid, SGB-SMIT, Shell Global Solutions, SP Energy Networks and WEIDMANN Electrical Technology. The consortium produces excellent research outputs and provides a platform for knowledge sharing among industrial consortium members and the University. Through the research consortium a critical mass can be formed to steer/influence the decision-making process at all levels of research, development, and operation of transformers. The Phase 5 consortium will continue to deal with industry-wide issues with a particular focus on digital twining of transformers, dynamic thermal modelling, ageing and electrical assessments of transformer insulations, and life cycle based transformer carbon accounting.

Relevant Foreground IPR

All research outputs and learnings such as:

- Transformer Digital Twin framework
- Methodology for transformer dynamic thermal modelling
- Investigation of the aging performance of thermally upgraded paper in combination with various transformer liquids
- Potential new aging indicators of transformer insulation systems
- Discharge and breakdown behaviour of various liquids under DC and combined stresses
- Optimisation methodology that reduces both the Total Cost of Ownership (TCO) and the Carbon Footprint (CF)

Will be disseminated to other networks. The reports and project documents will be publicly available under SPEN's data sharing policies.

Data Access Details

Access to this data will be according SPEN Data Sharing Policy and NIA governance requirements.

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

There is no allowance within our RIIO-T2 settlement for carrying out this innovation project

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 uncertainty in the outcomes of this research activities and the low TRL of the project present commercial an technical risks. Therefore, this activity could only be performed with NIA funding.

This project has been approved by a senior member of staff

☑ Yes