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NIA Project Registration and PEA Document

Date of Submission

Aug 2022

Project Reference Number

NIA2_NGET0024

Project Registration

Project Title

Insulating Dielectrics: Esters & Alternative Liquids

Project Reference Number

NIA2_NGET0024

Project Licensee(s)

National Grid Electricity Transmission

Project Start

September 2022

Project Duration

2 years and 6 months

Nominated Project Contact(s)

Gordon Wilson (Box.NG.ETInnovation@nationalgrid.com)

Project Budget

£700,000.00

Summary

Ester-based insulation fluids offer several benefits for the operation of transformers. They have improved fire safety, reduce the risk of moisture build-up in paper insulation, they are biodegradable, and some are from sustainable sources. They also offer the possibility of improved thermal performance, due to their typically lower viscosity. However, such liquids are typically more expensive than mineral oil, and have only been used in high voltage power transformers relatively recently, so operational experience with them is limited. This project will work to improving the understanding of the impact of alternative liquids on transformers through simulations and experimental investigations. Particular attention will be given to the thermal performance of such liquids, and the possibility of improved ratings.

Third Party Collaborators

University of Southampton

Nominated Contact Email Address(es)

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Problem Being Solved

Mineral oil has been used for insulation in transformers for more than a century, it is relatively inexpensive and, in combination with cellulose based solid insulation, performs well at providing insulation and heat transfer. Previous research has shown that natural and synthetic esters are viable replacements for mineral oil in transformers at transmission voltages. Esters offer advantages over mineral oil such as improved fire performance, biodegradability and longer life for solid insulation.

Esters and other non-mineral fluids also offer the possibility of improved thermal performance, due to their typically lower viscosity. However, such liquids have only been used in high voltage power transformers relatively recently and operational experience with them is limited so there is still some uncertainty about above-nameplate ratings in emergency situations.

The chemistry of natural esters is such that they require special handling procedures reducing their attractiveness for practical reasons. Alternative fluids are typically more expensive so the benefits of changing from mineral oil remain to be quantified except when increased fire performance is needed; currently synthetic esters are the preferred option in those situations. Drivers for sustainability make renewable materials more attractive and any obstacles to their use need to be overcome.

Method(s)

This project seeks to understand the thermal performance of alternative liquids, both currently in service and for potential designs, in high voltage power transformers, to inform loading guidance. Coupled thermal and Computational Fluid Dynamics (CFDs) simulations would be used to calculate oil flow within transformers. The governing equations underlying mineral oil loading guides will also be analysed to assess whether they can be modified for alternative liquids.

In conjunction with these simulations, experimental investigations would also be undertaken to understand material properties and their suitability for high voltage power transformers. State-of-the-art characterisation techniques will be used to understand the oxidation behaviour of alternative liquids, with a focus on the influences on chemical and biological degradation, and compatibility with other insulation materials found in transformers at high temperatures. Since the oxidation behaviour and reaction to humidity have been identified in literature as limiting factors for biodegradable insulation fluids, these measurements will be performed in regular intervals when subjecting candidate liquids to extreme conditions and voltages.

The results from this project will inform the use of novel insulation fluids in HV transformers, and outline how properties and stability of the next-generation of naturally-derived fluids might be improved.

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 our 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 Steps = 1

Cost = 2

Suppliers = 1

Data Assumption = 2

Assessed risk score 6 – Low.

Scope

The project will be delivered in the following six workstreams which will in totality investigate thermal performance of synthetic esters, natural esters and a bio-based insulating oil compatible with mineral oil:

WS1: State of the Art Review and Analysis

WS2: Modelling of thermal conditions in operational transformers that use alternative liquids

WS3: Identification of Natural Ester Liquid degradation processes

WS4: Development of thermal network models for 'Business as Usual' activities

WS5: Performance and degradation of alternative insulation fluids

WS6: Recommendations for asset management, ratings & operations

Objective(s)

This project will deliver greater understanding of the thermal performance of mineral oil alternatives that may be used in power transformers. Specifically, the following objectives are planned:

- Practical solutions to enable calculation of rating enhancements for synthetic ester-filled transformers
- Evaluation of the benefits and barriers of natural esters
- Quantification of the uprating opportunity and other benefits for retro-filling transformers with bio-based oil.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

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 reduce the costs for households over the long term as a result of reduced capital investments in transformers through increasing capacity – it may lead to deferral of a requirement for increased capacity and smaller transformers at reduced cost. Part of the work of this project will be to understand and quantify potential benefits.

Success Criteria

At the conclusion of this project, it will be considered successful if we develop:

- A modified loading guide equation for synthetic ester-filled transformers based on IEC 60076-7 or identify the requirements to enable it to be developed through further study.
- Generic post-fault ratings for ester-filled transformers.
- Understanding of the chemistry of natural esters for use in power transformers and methods to avoid the potential issues arising from gelling.
- An assessment of the potential benefit of using a bio-based transformer oil with low viscosity in new and existing transformer designs.

Project Partners and External Funding

M&I Materials is a potential project partner offering in-kind support to the project.

Potential for New Learning

The project will result in a number of reports that will be delivered as the work progresses. The reports will describe the work carried out and the results that are achieved. The reports will focus on novel findings in the following areas:

- Thermal simulations of high voltage power transformers using alternative liquids taking into account case studies of transmission transformers
- Analysis of the oxidation behaviour of alternative fluids from renewable sources, their compatibility with other insulation materials and methods to ameliorate any adverse effects
- Creation of network models for synthetic ester filled transformers and evaluation of the suitability of loading guide equations
- Dielectric and thermal testing of alternative fluids and the effect of thermal and electrical ageing

Learning will be disseminated through defined project progress and completion reports. In addition learning will be shared through at least four conference publications in the UK and elsewhere.

Scale of Project

The project will take place in the laboratory and using theoretical models – using both Computational Fluid Dynamics (CFD) and Thermal Hydraulic Network Models (THNM). Our understanding of the capability and performance of the different fluids is at different levels of maturity, this project moves understanding of each fluid on and seeks to apply the understanding of one fluid to others where possible in an efficient and synergistic manner. The benefits that could be accrued for sustainable fluids is still uncertain, so this project will examine the potential benefits before committing to additional steps at greater cost.

The project has been developed to answer a number of innovation questions and with a supplier on a framework contract achieved through tender and negotiation to be as economic as possible. A smaller scale project would deliver less as it would require a reduction in scope. Some elements could be removed and carried out later but it would be less efficient.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL5 Pilot Scale

Geographical Area

Laboratory and 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

£630,000

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:

This project supports the energy transition to a net zero network by exploring efficient and economic methods to increase the thermal ratings of transformers supporting the connection of new renewable generation. It will also consider the potential environmental benefits of using sustainable, reduced embodied carbon sources for the insulation fluids in transformers instead of those based on mineral oil.

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 (RIIO-1 projects only)

Not applicable

Please provide a calculation of the expected benefits the Solution

This is a research project into thermal performance of three different fluids that may be used instead of mineral oil in transformers, it is possible that all three may have future benefits depending on the circumstances. In each case further development will be required to move to a Business-as-Usual solution.

Ahead of any further developments a more detailed assessment of benefits will be carried out.

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

Any learning about any of the fluids should be replicable for other transmission owners interested in the use of alternative fluids in power transformers, as mentioned above, some of the learning may need to be developed before it becomes usable.

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

Enhanced ratings for ester-filled transformers may require development of existing software (developed as part of NIA project NIA_NGET0165 "Transformer Rating Modelling Tool Enhancement"), an assessment of the likely cost of this will be undertaken on successful completion of this project.

This project will investigate the benefit of using natural esters in transformers in applications where these benefits are expected to be maximised. Natural esters are more expensive than mineral oils, but the impact of using them in a new transformer scheme takes into account a number of factors such as availability of transformer design, civil requirements and need for fire-fighting measures.

The results of this project will indicate both the costs and benefits of using a low viscosity fluid based on natural sources and compatible with mineral oil.

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

NGET will share the learning from the project ensuring that the context of what is learnt is understood. Licensees would be able to apply updated loading guide equations for ester filled assets in the same way that they are used currently.

Any learning from the project will be accompanied by recommendations for either further work or steps that might need to be taken to make use of it.

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

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.

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

This project does not duplicate any work that NGET is aware of. The state of the art will be thoroughly investigated to ensure the project builds on existing knowledge rather than duplicating it. It is intended that relevant suppliers as far as possible to take into account existing knowledge.

Any residual risk of duplication will be addressed through dissemination of progress with other licensees and being open to co-operate with licensees working in this space.

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

NGET has been involved in research into mineral oil alternatives in previous projects (NIA_NGET0088 “Transformer Research Consortium”, NIA_NGET0214 “Transformer and Transformer Oil Life Optimisation and Management Through Analysis and Modelling”) and this project builds on the work carried out in them, largely filling gaps in understanding that could lead to their use on the network. It is already known that some of the work has been looked at previously, but it has not been carried out on transformers operated at transmission voltages, a factor that is important in the performance of dielectric fluids.

Relevant Foreground IPR

The foreground IPR will be the knowledge associated with the investigation of the thermal capability of alternative insulating fluids for use in transformers. The experiments, modelling approaches and results will be recorded in written 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 apart of it's business and usual activities

This is a research project that will lead to knowledge that may underpin future decisions about transformer procurement, operation and management. It will not lead directly to benefits; further work will likely enable benefits to be achieved over the longer term.

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

There are technical risks associated with any innovation project as the proposed investigations may not generate actionable results.

At this stage the commercial benefits have not been evaluated because it is a research project. It is expected that benefits will be achieved over a longer period of time than any commercial organisation would consider reasonable for business as usual investment.

This project has been approved by a senior member of staff

☑ Yes