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

Dec 2023

Project Reference Number

NIA2_NGET0052

Project Registration

Project Title

Detailed Analysis of Transformer Ageing Mechanisms for Intelligent Estimation of Reliability - DATAMInER

Project Reference Number

NIA2_NGET0052

Project Licensee(s)

National Grid Electricity Transmission

Project Start

January 2024

Project Duration

2 years and 3 months

Nominated Project Contact(s)

Gordon Wilson

Project Budget

£1,850,000.00

Summary

The application of laboratory studies to in-service transformers is often only indicative rather than leading to accurate assessment of remaining asset life. Challenges with interpretation of chemical markers measured through oil sampling of in-service transformer are uncertainties in production, partitioning and stability.

These uncertainties tend to make it harder to predict when transformers have reached end of life until they are already almost in that state. More predictability of degradation over a longer time horizon will enable more efficient planning.

This project aims to improve our understanding of insulation ageing for in-service assets and to make better assessments of when wound plant is likely to reach end of life.

Third Party Collaborators

University of Southampton

The University of Manchester

Nominated Contact Email Address(es)

box.NG.ETInnovation@nationalgrid.com

Problem Being Solved

Wound plant (transformers and reactors) experiences electrical, thermal, and mechanical stresses in service; its insulation system experiences chemical ageing and degradation processes over its lifetime. One key driver for long term planned transformer replacement is insulation ageing in the active part especially conductor and core insulation.

Despite much previous research the application of laboratory studies to in-service assets is often only indicative rather than leading to accurate assessment of remaining asset life. Challenges with interpretation of chemical markers measured through oil sampling of in-service wound plant are uncertainties in production, partitioning and stability.

These uncertainties tend to make it harder to predict when insulation systems have reached a state requiring replacement until they are already almost in that state; predictions are considered to be accurate within 2 years and to some degree 3 or 4 years out. More predictability of degradation over a longer time horizon will enable more efficient planning.

Method(s)

NGET has, over many years, used research to improve its understanding of the ageing mechanisms of transformers and how to detect when a transformer is approaching end of life. In combination with a strategy for analysis of retired assets, the knowledge gained through innovation has enable NGET to extend transformer asset lives and reduce capital investment. Through further university-based research we will continue to develop our understanding through lab testing and aligning indicators with specific transformer designs. As part of the project, we will extend our understanding of ageing mechanisms and indications in mineral oil filled transformers to those filled with esters.

This work will consider the factors that affect variability in service aged wound plant and take account of them in retrospective analysis of NGET data and in better models for understanding how ageing markers – traditional or novel – may be better evaluated to understand winding condition.

The research will involve in depth data analysis, development of both digital and physical models to represent transformer internal workings, wet chemistry and various analytical chemistry techniques.

Scope

Wound plant ageing mechanisms have been studied in depth in laboratory conditions and understanding of in-service systems has largely focussed on furans and, more recently, alcohols that are produced when cellulose based solid insulation breaks down. Laboratory studies show good correlation between the presence of these breakdown products in the insulating liquid and the condition of the paper as measured by degree of polymerisation. However, in service assets are more complex systems than laboratory models and the correlations are not always as clear. The difference between models and reality tends to reduce certainty around when wound plant may reach a state requiring replacement until a few years before it reaches that point when ideally replacement decisions could be made earlier.

Objective(s)

This project seeks to explain the difference between laboratory ageing studies of insulation systems for wound plant and service aged assets.

The project will develop guidance for interpretation of ageing markers in wound plant for more accurate understanding of the insulation system and for longer term visibility of when an asset may need to be replaced.

The project will extend understanding of mineral oil filled assets to those filled with esters as these become more widely used.

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 reducing costs associated with transformer replacements.

Success Criteria

The project will be successful if the following are true:

- The project delivers greater understanding of how to determine the condition of transformers and other wound plant from ageing markers found in the oil
- Specific guidance can be developed for interpretation of ageing markers enabling transformer replacements to be planned more efficiently over longer periods of time.

Project Partners and External Funding

Scottish and Southern Electricity Networks Transmission and Scottish Power Energy Networks have indicated that they are interested in the project and have been invited to join meetings on a benefit in kind basis and will cover their own costs resulting from their involvement in the project.

Potential for New Learning

The project will deliver reports for a each of the workstreams within the overall work package. The reports will describe the work carried out and the results that are achieved. The reports will focus on novel and independent findings in the following areas:

- Transformer life assessment through statistical methods
- Analysis of chemical marker behaviour through in-service and post-mortem data
- Partitioning studies through realistic transformer models
- Modelling the combined ageing and partitioning process
- Tools and policy guidance on transformer management
- Long term ageing of paper and oil samples
- Identification and quantification of furan markers in oil samples
- Identification and analysis of other compounds that may be used as ageing markers
- Impact of additives on furan concentration
- Ageing markers in Ester Oil Systems

Learning will be disseminated through defined project progress and completion reports. Learning will also be shared through conference presentations and an open dissemination event, e.g. a webinar, on completion.

Scale of Project

The project will largely be conducted at two universities employing desktop analysis of data, design and construction of a physical model to understand partitioning of markers between solid and liquid insulation, and testing and analysis in a chemistry laboratory.

The project scale has been selected to make greater effort to understand the situation for in-service assets and taking into account specific transformer designs. Reducing the scale of the project would reduce the scope of the project deliverables because it would limit the project to laboratory ageing investigations only, which is work that has been carried out before.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL5 Pilot Scale

Geographical Area

The project will be carried out at two university facilities and not on operational sites. The results will be applicable to all UK based networks regardless of geographical location.

Revenue Allowed for the RIIO Settlement

N/A

Indicative Total NIA Project Expenditure

£1,665,000

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:

During the energy system transition it is expected that electricity demand and the utilisation of the networks will increase substantially, and load profiles will change. This project specifically targets knowledge of the aged status and consequent loading capability of network transformers. This is important as it leads to the ability to accurately target network interventions. In addition, it is expected that with capital investment in replacement of ageing networks and reinforcement to support the energy transition will place strain on the existing supply chain which could increase costs and impact on ability to deliver the transition. Any improvement in the accuracy of the knowledge of existing transformer ageing status (effective age), which is the goal of this project, has the potential to further optimize targeting of that investment.

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

This is a research project and a full cost benefit analysis is not specifically required but an assessment of the impact on the replacement of transformers similar to that undertaken for NIA2_NGET008 has been carried out indicating that the NPV for this project is positive and of the order of £2.9m over a period of 5 years from completion of the project and that embedding the learning into NGET processes will deliver further benefits into the future.

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

The project will be applicable to transmission assets, as indicated by the interest in the project from SSEN Transmission and SPEN.

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

The project will develop knowledge to support networks in their decision making for replacing wound plant and will not have an implementation cost as such.

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

While some of the research will focus on specific transformer designs and will make use of oil analysis data and post mortem information from NGET assets, there will be general principles that may be applied to transmission transformers generally. It is therefore learning that may be directly applied to other networks installing similar assets at similar voltages. The disseminated results will be shared with all licensees so that the reasons for the conclusions may be understood. It will be the responsibility of others to determine to what extent it applies to other equipment types and different voltages but the underlying work from this project is likely to help.

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.

NGET has shared the project details with SSEN Transmission and SPEN to confirm that all the transmission owners believe this project is necessary, beneficial and does not duplicate other research projects. The two universities involved have presented their project scope with each other to ensure there is no duplication within the project. Although there is no formal co-operation there will be ongoing sharing of work to ensure that they learn from each other and no duplicate effort.

Any residual risk of duplication will be addressed through dissemination of progress with other licensees and having SPEN and SSEN Transmission involved with the project.

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 is innovative and not business as usual because it incorporates elements of academic knowledge, experiment and data analysis not typically available in a commercial utility environment. Although some of the skills exist within utilities and are necessary to integrate the results, the ability to concentrate effort on the project and bring together existing in-depth academic study with analysis of operational data is unique to an industry funded academic project.

This project is university-based research involving the use and extension of existing knowledge on transformer insulation ageing combined with new data analysis of network transformer indications, operating conditions, design and post-mortem analysis to provide an improved basis for the asset management tools already used by National Grid and other utilities. The project therefore involves mainly research, but also elements of development and demonstration.

Relevant Foreground IPR

The foreground IPR will be the knowledge gained about the way that winding insulation ages in operational wound plant, why this is different from laboratory studies and how this understanding may be applied to oil test results for a transmission transformer fleet to make appropriate asset replacement plans.

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

Transformer asset management has always been a key consideration by utilities and hence a topic for multiple projects. There have been several projects funded by UK Licensees on transformers, including the following in no particular order:

- Condition and Climatic Environment for Power Transformers (ConCEPT) NIA_NGET0213
- Transformer Rating Modelling Tool Enhancements (TeRMiTE) (NIA_NGET0165)
- Economic Ageing of Transformers (NIA_NGTO038)
- EPRI Research Collaboration on Substations (P37) (NIA_NGET0123, NIA_NGET0157,
- NIA_NGET0172, NIA_NGET0195, NIA_NGET0210)
- Asset Risk Optimisation (NIA_ENWL005)
- Automated Transformer Monitoring System (NIA_ENWL_031)
- Power Transformer Real Time Thermal Rating (NIA_UKPN0001)
- Oil Regeneration Stage 1 & 2 (IFI)
- Transformer Research Consortium Phase 3 (NIA_NGET0088)
- Optimised Asset Life and Asset Management of Transformer and Transformer Oil Through Analysis and Modelling (NIA_NGET0214)
- Transformer Research Consortium Phases 1 and 2 (IFI)

The scope of this project has been developed recognising the work that these projects delivered and recognising the work that is being carried out in the active RIIO-2 projects - EPRI Substations (P37) and Analytics (P34) 2021-2025 (NIA2_NGET0008), Insulating Dielectrics - Esters & Alternative Liquids (NIA2_NGET0024) and Transformer Research Consortium – Phase 5: Future-proof Transformers in a Digital Twinning and Net-Zero World (NIA_SPEN_0084).

Research on paper ageing indicators is scarce in the last decade in the UK context. Past projects including TRC, and some other NIA projects delivered by EPRI can be identified as key contributors related to this topic. Most of the existing studies focused on small scale laboratory experiments to evaluate the relationship between chemical markers and the ageing state of paper insulation which is difficult to apply directly to transformers in-service. This proposed project will be the first to conduct a detailed evaluation of chemical

maker generation, and to consider the contributions of the whole winding, which is significantly different from those research projects focusing on the hotspot only. Obtaining a detailed thermal model for transformer under different operating conditions will provide the basis for this analysis.

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

NIA funding enables fundamental research that is not part of the business-as-usual activities for network utilities, in this case research into understanding the ageing of in-service assets and the way in which we can understand condition through detection of ageing markers.

This project has been approved by a senior member of staff

☑ Yes