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NIA Project Registration and PEA Document

Date of Submission

Aug 2017

Project Reference Number

NIA_NGET0214

Project Registration

Project Title

Transformer and Transformer Oil Life Optimisation and Management Through Analysis and Modelling

Project Reference Number

NIA_NGET0214

Project Licensee(s)

National Grid Electricity Transmission

Project Start

March 2017

Project Duration

4 years and 5 months

Nominated Project Contact(s)

Gordon Wilson

Project Budget

£2,322,000.00

Summary

The University of Manchester will be building on three 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. Some of the successes delivered within Phase 3 were:

- progress was made in the interpretation of methanol and ethanol as potential early indicators of transformer insulation ageing. The rates of production by oil and paper and the partition between the two is now better understood. More data and case studies are required to evaluate the usefulness further

- a methanol measurement technique was developed, benchmarked within IEC and transferred to the oil analysis service provider for routine testing.

- study of oil result database for the participating utilities led to conclusions about the relative merits of different tests to show when oil is degraded. Different diagnostic techniques were compared and recommendations for possible improvements in IEC guidance were made.

- extensive laboratory testing has developed our understanding of dissolved gas production under different fault conditions. The same experiments have improved our knowledge on the response of on line gas monitors

- very useful insights have been gained into partial discharge inception and propagation in ester fluids that might lead to a revision of transformer test requirements

- Computational Fluid Dynamic (CFD) studies have shown up significant issues with existing techniques used by manufacturers offering the promise of better designs. Experimental studies have been used to successfully validate the CFD models.

Phase 4 will continue to investigate all of these areas in more depth.Under the original TOPICS project, the University of Southampton investigated corrosive sulphur issues in transformers, delivering improvements in oil reclamation operating procedures to prevent corrosion of silver, especially tap-changer contacts and a greater understanding of the failure mechanism involved with copper sulphide deposition. Research is required to investigate further aspects of oil reclamation and mitigation of corrosive sulphur in transformer oil.

Nominated Contact Email Address(es)

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Problem Being Solved

Transformer asset management and the purchase of new transformers represents a significant challenge for transmission networks. Opportunities to deliver savings to customers through reduced capital investment in transformers can inadvertently result in a reduction in long term reliability and or increased operational costs that reduce or eliminate the value of the initial savings.

Power transformers are a significant component of the Electricity Transmission System, with over a thousand transformers and related static wound equipment in service today. National Grid's transformer fleet is ageing and 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 replaced at the appropriate time and frequency. Transformer ageing is influenced by a number of factors such as dielectric failure, mechanical failure, corrosive sulphur and ageing of insulation due to excessive temperature or simply time in service.

This project includes two streams of research that are complimentary to one another and complimentary to the research being undertaken within the scope of NIA_NGET0213 - Condition and Climatic Environment for Power Transformers (ConCEPT).

One work stream follows on from the successful work of the recently completed NIA_NGET0044 (Transformer Oil Passivation and Impact of Corrosive Sulphur (TOPICS)) and seeks to answer the following research questions:

- can recent anomalous measurements of ethylene in transformer oil (an indicator of a potentially serious fault) following oil reclamation/processing be explained by benign causes and if so how can it be distinguished from other causes that are an indication of a significant issue?
- does the process of oil reclamation (done as one of the measures that can extend transformer life) itself lead to loss of integrity in insulation paper in transformers which can reduce transformer life?
- is there a cost effective way of removing elemental sulphur (possibly a cause of accelerated corrosion of silver plating in transformer tap changers) during transformer oil reclamation?
- is it possible to develop field based measurements for detecting and monitoring corrosive sulphur compounds (notably copper sulphide) in transformer oil

The second work stream includes a programme of research that seeks to:

- provide recommendations of the highest temperature, peak load and arbitrary load profile for bubble formation in representative insulating fluids and paper conditions in transformers.
- conduct an assessment of the costs and potential benefits in terms of transformer life extension and rating improvement through retrofilling transformers with new or regenerated insulating fluids.
- develop fundamental understanding to inform the IEC 60422 equivalent criteria for alternative insulating fluids (natural and synthetic esters and gas to liquid fluids).
- recommend temperature base calibrations for better interpreting ageing marker measurement results for in-service transformers (for example 2-FAL, Methanol, LMA and Moisture)
- develop improved transformer and tap changer insulation health index formulas
- provide guidelines for key parameters (winding designs and manufacturing tolerances) that govern thermal performance of new transformers.
- test and determine the AC breakdown voltage of in service aged transformer liquids in conditions close to real insulation geometry, and
- investigate the creepage discharge on alternative insulating fluid- solid interfaces.

All of these factors are potentially material to decisions affecting the best options for transformer condition monitoring, best practice in terms of maintenance and ultimately the timing of transformer replacement.

Method(s)

Research

National Grid will continue its programme of research with both the University of Manchester and the University of Southampton following previous successful NIA funded projects.

The University of Manchester will conduct a research project: Transformer Research Consortium Phase 4 (TRC4) on behalf of a consortium of companies in the following areas:

- bubble formation and lifetime extension of transformers through experimental studies (WP1)
- ageing assessment of transformer insulation (WP2)
- data analytics for transformer and tapchanger asset management (WP3)
- computational fluid dynamic (CFD) modelling of transformer thermal behavior (WP4)
- discharge and breakdown of transformer liquids under conditions close to real insulation geometry (WP5)

The University of Southampton will conduct a research project: Transformer Oil Passivation and Impact of Corrosive Sulphur (TOPICS2) directly on behalf of National Grid in the following areas:

- understanding ethylene production in transformers as a single fault gas (WP1)
- effect of reclamation on aged insulation paper (WP2)
- silver corrosion in transformers (WP3)
- corrosive sulphur detection in oil (WP4)

Scope

The University of Manchester will be building on three 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.
Some of the successes delivered within Phase 3 were:

- progress was made in the interpretation of methanol and ethanol as potential early indicators of transformer insulation ageing. The rates of production by oil and paper and the partition between the two is now better understood. More data and case studies are required to evaluate the usefulness further
- a methanol measurement technique was developed, benchmarked within IEC and transferred to the oil analysis service provider for routine testing.
- study of oil result database for the participating utilities led to conclusions about the relative merits of different tests to show when oil is degraded. Different diagnostic techniques were compared and recommendations for possible improvements in IEC guidance were made.
- extensive laboratory testing has developed our understanding of dissolved gas production under different fault conditions. The same experiments have improved our knowledge on the response of on line gas monitors
- very useful insights have been gained into partial discharge inception and propagation in ester fluids that might lead to a revision of transformer test requirements
- Computational Fluid Dynamic (CFD) studies have shown up significant issues with existing techniques used by manufacturers offering the promise of better designs. Experimental studies have been used to successfully validate the CFD models.

Phase 4 will continue to investigate all of these areas in more depth.

Under the original TOPICS project, the University of Southampton investigated corrosive sulphur issues in transformers, delivering improvements in oil reclamation operating procedures to prevent corrosion of silver, especially tap-changer contacts and a greater understanding of the failure mechanism involved with copper sulphide deposition. Research is required to investigate further aspects of oil reclamation and mitigation of corrosive sulphur in transformer oil.

Objective(s)

Leading experts and academics have discussed and established a number of areas of research which has been developed into the following packages of work.

The University of Manchester program of work will investigate the following:

WP1 - (i) Review existing loading guides for mineral oil immersed transformers to optimise operational performance and develop fundamental understanding on key factors influencing bubble formation in alternative liquids immersed transformers to ensure reliable operation. (ii) Assess the applicability of retrofilling for life extension and/or uprating of transformers and investigate the gelling phenomenon and possible negative impacts of natural ester thin films.

WP2 - (i) Analyse ageing results published in the literature to inform laboratory ageing experiments. Use the ageing results as well as considering ageing mechanisms, functional change of oil and paper and the end-of-life points so as to help forge the specification criteria for alternative materials which are equivalent to the ones used in IEC 60422 (oil management) and support transformer replacement decisions. (ii) Support interpretation of oil testing through the study the dynamic behaviour of ageing markers in a model transformer under various loading profiles and recommend the temperature based calibration methodology for ageing markers.
WP3 - Maximise the utilisation of growing databases for transformer condition assessment and develop database analysis methodologies to support transformer asset management.
WP4 - (i) Apply developed CFD modelling capability in simulating different winding designs and their manufacture tolerance, provide guidance for key parameters governing thermal design to support specification and design evaluation during transformer procurement. (ii) To support ongoing operation of a design with known cooling issues, develop a complete transformer CFD model including windings and cooling system, and study the temperature profile under various load levels.
WP5 - (i) Correlate PD partial discharge (PD) characteristics of transformer liquids detected by ultra-high frequency (UHF) sensor with conventional PD detector and high speed imaging technique. Investigate the effects of tip radius/oil quality on PD and breakdown performance of transformer liquids. (ii) Characterise creepage discharges on alternative liquid-solid interface for applications in transformers and tapchangers.

The University of Southampton programme of work will investigate the following:

WP1 – Investigate a relatively new phenomenon of ethylene as a single fault gas experienced in some transformers by use of high temperature flow reactors to investigate conditions leading to ethylene production from mineral oils, and propose mechanisms for its formation and potential mitigation strategies
WP2 – Support oil management in older transformers through investigation of the potential for mechanical damage to aged insulation paper caused by either the flow of oil or abrasion, through the action of suspended particulates
WP3 – (i) Evaluation of techniques to remove elemental sulphur from contaminated transformer oil and thereby reduce the risk of silver corrosion in tap-changers and the remediation work required to restore condition (ii) Understanding silver corrosion in contaminated and aged transformer oil
WP4 - Electrical and spectroscopic techniques will be assessed as measurement methods to quantify corrosive sulphur species in transformer oils as a way of identifying where copper corrosion may be occurring.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

Success Criteria

The outputs from the research being undertaken will provide the industry with improved knowledge and understanding of the optimised asset life and asset management of Transformers and Transformer Oil.

Project Partners and External Funding

Work with the University of Manchester is cofounded by the following project partners:

- Cargill
- EPRI
- M&I Materials
- Scottish Power
- Shell
- SMIT
- TJH2B Analytical Lab
- WEIDMANN

The total cost of the consortium project is £1.581m; National Grid's contribution to this total is £302k. It is also anticipated that Scottish Power will also apply for NIA funding for their contributions to the consortium. National Grid will be responsible for registering and reporting.

The total cost of The University of Southampton project is £656,485 of which the Tony Davies High Voltage Laboratory is providing a project contribution of £111,432.

Potential for New Learning

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 to all 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, i.e. in Manchester and Southampton.

Revenue Allowed for the RIIO Settlement

None.

Indicative Total NIA Project Expenditure

£1,073,000

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:

n/a

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)

Transformers are a critical part of the electricity network. Improvements in management of existing assets are expected to lead to more efficient day to day operations, improved reliability and/or life extension. The benefits expected from this project are closely related to the benefits expected from the complimentary NIA project Optimised Asset Life and Asset Management of Transformer and Transformer Oil Through Analysis and Modelling.

Both projects are undertaking research into phenomena that, if successfully understood and mitigation measures identified, could National Grid to extend the operational life of some transmission transformers. In practice any future decisions to extend the life of transformers will be made on the basis of information arising from both of these projects, so the potential benefits have been assessed collectively.
An estimated CAPEX expenditure of £11.5 million over the next 17 years could be avoided if these projects are successful.

Please provide a calculation of the expected benefits the Solution

The estimated CAPEX reduction of £11.5 million over the next 17 years is based on the relatively conservative assumption that the reliable operational life of just one transformer a year is extended by 5 years and one transformer replacement can be removed from the RIIO T2 plan every three years.

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.

It is anticipated that the results of this research will potentially change monitoring regimes and maintenance practices. Detailed costing associated with these changes will be investigated and better understood as the project progresses.

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)

This project fits within the Managing Assets - Managing assets throughout their lifecycle value area of the Electricity Innovation Strategy:

☑ Has the Potential to Develop Learning That Can be Applied by all Relevant Network Licensees

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.

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

n/a

Relevant Foreground IPR

n/a

Data Access Details

n/a

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

n/a

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

n/a

This project has been approved by a senior member of staff

☑ Yes