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NIA Project Registration and PEA Document

Date of Submission

Dec 2013

Project Reference Number

NIA_NGET0044

Project Registration

Project Title

Transformer Oil Passivation and Impact of Corrosive Sulphur (TOPICS)

Project Reference Number

NIA_NGET0044

Project Licensee(s)

National Grid Electricity Transmission

Project Start

October 2011

Project Duration

4 years and 9 months

Nominated Project Contact(s)

Gordon Wilson

Project Budget

£458,000.00

Summary

The long-term effects of passivation as a remedial strategy to keep transformers in operation are poorly understood and largely informed by experience over a limited number of years rather than laboratory studies that consider the potential chemical reactions. The effectiveness with which copper surfaces are coated with passivator following retrospective addition of Irgamet 39 TM to a transformer has not been studied.

In this study we will investigate, and gain a greater understanding of, the chemical effects of passivation through laboratory based experiments, and visits into the field. The proposed work will involve collaboration between the School of Chemistry at the University of Southampton and the Tony Davies High Voltage Laboratory, building upon a highly effective collaborative relationship developed during the recently completed, IFI-funded feasibility study on corrosion in the gas phase. Questions that are to be addressed during this study include:

- What is the long term stability of passivator on the surface of copper?
- Is it necessary to add more passivator when it is consumed in the oil? How might one analyse the surface of copper for the presence of passivator?
- Can this be used on scrapped transformers to investigate whether the passivator gets through all the paper insulation to where it is needed?
- If passivator works by coating the surface of copper, which has a fixed surface area, why have others reported that more is required when you have a higher concentration of DBDS?

Nominated Contact Email Address(es)

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Problem Being Solved

Formation of corrosive sulphur in oil and subsequent copper sulphide deposition in paper has led to a number of large transformer failures worldwide, it was the cause of the failure of Lackenby SGT4 and other transformers will be removed from the system early because the problem is believed to be advanced.

Part of the complex process leading to transformer failure involves the mobilisation of copper containing material into the paper insulation surrounding the windings, which is known to be influenced by the presence of corrosive sulphur species in the oil, and extreme operating conditions.

Although there have been many attempts to better understand the mechanism by which formation of copper sulphide occurs none have yet been conclusive, they have not led to sufficient understanding to allow diagnosis of the problem without inspection and better mitigation methods may still arise if the mechanism is better understood.

Laboratory studies of the mechanism have largely focussed on the thermal aspects of the mechanism and also the interactions between oil, paper and the surface of copper conductors. This study will use facilities in the Tony Davies High Voltage Laboratory at the University of Southampton to evaluate corrosive sulphur formation in covered conductor samples that are carrying current and will attempt to recreate more accurately the conditions in a transformer in order to better replicate the mode of failure witnessed in transformers i.e. turn to turn failure. The mechanism by which copper sulphide migrates through the paper and the possible interaction of mobile copper ions and/or complexes in the oil will also be investigated.

One mitigation strategy employed by transformer owners, including National Grid through OESB 9/08, is to protect the copper surface of the windings by the addition of chemical passivators, such as Irgamet 39TM, to the oil. Passivators are designed to interact with the copper surface to provide a protective barrier and reduce corrosion.

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Irgamet 39 TM is itself a reactive species designed to be soluble in transformer oil, which liberates a benzotriazole derivative (the active passivator molecule) at the copper surface. There are two byproducts from this process, namely formaldehyde and an amine, both of which may have an impact on the properties of the oil. The effect of these compounds may not emerge until additional amounts of passivator have been added. The effects of these compounds may also be studied using the vial tests.

Samples of paper-wrapped windings from failed transformers (provided by National Grid) will also undergo passivation tests, to assess how effective passivation is on “at risk” plant. In parallel with developing understanding of the chemistry involved in the addition of passivators to transformer oil, studies will be undertaken to determine its effect on the thermal/mechanical/electrical properties of the paper/oil insulation system over time. In particular it is necessary to establish whether the addition of passivation effect interturn losses or cause increased operating temperatures. The work on passivation will involve close collaboration between two PhD students, one based within Chemistry and the other in the Tony Davies Laboratory.

Oil reclamation of transformer oil through heated clay columns has been used as a remedial measure when corrosive oil is detected and was successfully demonstrated as an effective technique in a previous IFI project. However, through that study and following regeneration of oxidised oil in recent years there has been undesirable corrosion in silver tap changers (OESB 4/09 refers). There is also some evidence of increased gassing in some transformers using reclaimed oil. It is suspected that the reclamation process is itself adversely affecting the oil, and possibly even introduces corrosive substances such as elemental sulphur.

Method(s)

The method that has been proposed for this project that will solve / investigate the problem includes;

- Initial review of current understanding of the impact of passivation on power transformers
- Interim report on silver corrosion of tap changers
- Report on initial studies into effects of passivation
- Recommendations to minimise silver corrosion in tap changer units
- Interim report on the chemistry of passivation and its effects on thermal and electrical properties
- Interim recommendations on use and application of passivators
- Interim report on the development of condition assessment techniques
- Final Recommendations and Report

Scope

The long-term effects of passivation as a remedial strategy to keep transformers in operation are poorly understood and largely informed by experience over a limited number of years rather than laboratory studies that consider the potential chemical reactions. The effectiveness with which copper surfaces are coated with passivator following retrospective addition of Irgamet 39 TM to a transformer has not been studied.

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   of copper for the presence of passivator?
3. Can this be used on scrapped transformers to investigate whether the passivator gets through all the

   paper insulation to where it is needed?
4. If passivator works by coating the surface of copper, which has a fixed surface area, why have others reported that more is required when you have a higher concentration of DBDS?

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To address the questions above, it is planned to develop chemical tests using a variety of analytical methods to study and quantify the passivator (e.g. Irgamet 39 TM) on copper strips in heated oil over time. Irgamet 39 TM reacts with the copper surface to provide a “protective coating” of benzotriazole on the surface, which can be analyzed using a variety of surface techniques. For example, SEM EDX can be used to monitor surface elemental composition (C, O, S and N), or some more sophisticated surface spectroscopic techniques such as surface Raman spectroscopy, TOF/SIMS to directly probe the nature of the chemical species bound to the surface). Oils designated as “corrosive” and “non corrosive” would be studied, and the effect of the passivator assessed both at the copper surface and through mobilisation of copper into oil. The effect of temperature and time on the passivated copper will be studied. Techniques such as Gas Chromatography-Mass Spectrometry (GC MS) and x-ray fluorescence spectroscopy are established in Southampton, and will be employed for oil analysis. The simultaneous application of techniques to monitor the condition of the oil and the copper surface will be powerful, and allow a more detailed understanding of the interactions of passivator, copper and DBDS (paper wrapping may also be added to the study at any point).

During the first 12 months of this project a Research Assistant, predominantly based in Chemistry will also consider the issue of this silver corrosion in tap-changers. The aim of this study is to gain an improved understanding of how the reclamation process affects the chemical composition of the oil and how the amount of specific components such as elemental sulphur, DBDS and passivators are influenced by the reclamation process. Ultimately, an enhanced understanding of the reclamation process should provide methods to monitor oil quality and provide methods to remove corrosive substances from the oil.

Objective(s)

The objective of this proposal is to reduce the risk of transformer failure and unreliability resulting from corrosive sulphur in oil.

This key objective will be met by:

- Better understanding of the mechanism by which copper sulphide failures occur and the effectiveness of passivation
- Fully understanding the effects, both chemical and electrical, of passivation on transformer insulation performance
- Investigating the reasons for silver corrosion in tap changers and to formulate monitoring/assessment strategies in order to provide a measure of asset health.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

Success Criteria

This project will be successful if we understand and have an increased learning around the transformer oil passivation issue, specifically around silver corrosion on tapchangers.

Project Partners and External Funding

Southampton University

There is no external funding being brought to this project.

Potential for New Learning

Large, the learning will be disseminated through the standard portals, and through national and international conferences, also there will be reports in the annual report produced by National Grid. Specifically, the learning will be in the area of oil passivation & corrosive sulphur impacts on transformers.

Scale of Project

This project is being completed on a laboratory scale.

Technology Readiness at Start

TRL4 Bench Scale Research

Technology Readiness at End

TRL6 Large Scale

Geographical Area

This work will be completed at Southampton

Revenue Allowed for the RIIO Settlement

Zero

Indicative Total NIA Project Expenditure

IFI=136k

NIA=322k

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)

A large proportion of National Grid's transformers are affected by corrosive sulphur to some extent because of the long period during which the problem oil was available and the relatively low concentration of corrosive molecules required to make an oil corrosive. There are 31 transformers considered to be at high risk because they are of a design which means they operate at higher temperatures than typical transformers. From this group, Lackenby SGT6 and Rochdale SGT5 are scheduled for replacement in 2011 and 2012 respectively because they are believed to be at highest risk of corrosive sulphur related failure. The results of the scrapping of these transformers will be part of the proposed project. The information gained from the scrapping of these transformers will inform the future strategy for other transformers considered to be at greatest risk of reduced asset life or failure because of corrosive sulphur and their individual operating conditions. Due to evidence of localised ageing or heavy loading seven of the transformers are at Asset Health Index 2a or 2b the replacement cost of these assets is approximately £28m. Ensuring that mitigation strategies are effective will provide some protection against early asset write-off. Most immediately, understanding how the copper sulphide formation is developing in the two transformers already scheduled for replacement will impact directly on the decision on whether to replace Drakelow SGT5 and Ferrybridge SGT1A or whether they can be left in service for another 5+ years (approximate deferred cost of £100k pa per transformer). It should not be forgotten that the transformers may need to replaced early because of the thermal design limitations even if 5 copper sulphide formations can be prevented.

Around 175 other transformers are known to contain oil with the potential to become corrosive because of their age and the remainder of the population (around 700 transformers) are being tested for potential corrosivity resulting from top-ups and maintenance activity.

The mitigation strategy for these transformers has been to add passivator to the oil on the basis that this will coat all copper surfaces and prevent catalytic conversion of DBDS and other sulphur molecules into a more reactive form. Although this is the most widely used mitigation strategy its effectiveness is not fully known and whether there is a need to add more passivator after it has been consumed is open to question.

The effectiveness of National Grid's mitigation strategy for transformers at risk from corrosive sulphur formation will be evaluated and improved through better understanding of the mechanism of copper sulphide formation and passivation of copper surfaces.

The project sets out to achieve the following business benefits:

- National Grid will be able to better understand and potentially monitor the condition of transformers that are believed to be susceptible to corrosive sulphur

- Passivation can be used appropriately as a mitigation strategy and with knowledge of the

likely long term effect on transformer performance.

- Better mitigation strategies should lead to a reduction of early asset write offs and

avoidance of failures.
An estimation of the saving if the problem is solved is £5m if one transformer is saved.

Please provide a calculation of the expected benefits the Solution

Base Cost - £5m

Method Cost - £366k

B-M= £ 4.634

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

This is applicable to all sites where Transformers are installed.

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

The cost of roll out will be covered in the project as part of the embedded knowledge within National Grid.

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

n/a

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 addresses transformer reliability and addresses the area of optimizing asset management.

☑ 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.

Given a review of all companies IFI reports and the known academic and industry literature and international committees, the project engineer confirms that no duplication of innovation work. On top of this, having checked our standard supply base, including Universities and EPRI, and the ENA portal, we confirm that this work hasn't been done before.

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