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NIA Project Registration and PEA Document

Date of Submission

Nov 2021

Project Reference Number

NIA2_NGET0006

Project Registration

Project Title

Non-invasive In-situ Monitoring and Interpretation of SF6 Alternatives in GIS Equipment

Project Reference Number

NIA2_NGET0006

Project Licensee(s)

National Grid Electricity Transmission

Project Start

February 2022

Project Duration

4 years and 0 months

Nominated Project Contact(s)

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

Project Budget

£1,900,000.00

Summary

This project will focus on developing a full-scale demonstrator retro-filled with a suitable SF6 alternative with condition-based monitoring systems incorporated to perform non-invasively, in-situ monitoring during the long-term energisation. The project will develop an optical test setup which addresses the missing link between long-term safe operation of equipment and traditional academic material testing and characterisation. The project will focus on the applicability of such techniques and critically assess their suitability to give asset managers the information required for retro-filling an SF6 alternative on the transmission network.

Preceding Projects

NIA_NGET0199 - Alternatives to SF6 for retro-filling existing equipment

Third Party Collaborators

The University of Manchester

Nominated Contact Email Address(es)

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Problem Being Solved

Sulphur hexafluoride (SF6) is primarily used as an insulant and arc-extinguishing medium in electricity transmission and distribution equipment with an estimated 10,000 tons of SF6 used annually, equivalent to 80% of the global SF6 usage. This gas has successfully delivered industry the ability to install compact high voltage substations. As such, the global SF6 high-voltage circuit breaker market has grown at a rapid pace. However, SF6 has the highest known global warming potential (GWP) at 23,500 times that of CO2, and with a long atmospheric lifetime. Successfully identifying viable SF6 alternatives and delivering a technically viable SF6-free solution is expected to provide significant value to the high-voltage electricity transmission and distribution sector. Existing SF6-free pilot

projects at transmission voltages use new equipment containing insulating gases based on fluorocarbons. For the large amount of existing SF6 filled equipment, reduction of CO2e emissions could be achieved through retro-fill if a suitable gas could be used with a lower GWP. Although retro-fill has been shown to be technically feasible, technical challenges remain for these mixtures which will differ from those used in new equipment. The long-term stability for novel gas mixtures is still to be understood, including the potential generation of harmful by-products due to partial discharge and breakdown. There is also still a lack of understanding on how new SF6 alternatives interact with solid insulation materials (spacers) in terms of the surface flashovers, tracking and breakdown behaviour.

Method(s)

This project aims to develop technical underpinning knowledge on the characteristics of Novec™ 4710 gas mixtures with a specific focus on the long-term gas stability to demonstrate performance in service where retro-filled in existing SF6-designed equipment. It will focus on developing a full-scale demonstrator retro-filled with a suitable SF6 alternative with condition-based monitoring systems incorporated to perform non-invasive in-situ monitoring during the long-term energisation. The project will focus on the applicability of such techniques and critically assess their suitability to give asset managers the information required for retro-filling an SF6 alternative on the transmission network.

The project will be delivered in two parts (1) initially a laboratory test campaign including breakdown testing, partial discharge monitoring and in-situ gas diagnostics work, and (2) live substation trial at the Deeside Centre for Innovation (DCI). The initial laboratory programme will focus on (i) experimental investigation of binary and tertiary gas mixtures at representative test conditions as found in practical equipment including breakdown, thermal cycling, partial discharge (PD) with/without defects; and (ii) development of an optical technique for in-situ diagnostics of breakdown by-products, this will be combined with kinetic modelling of breakdown to enable the gas degradation analysis of SF6 alternatives under representative conditions. With successful laboratory investigations and method development, the trials at DCI will proceed involved long term energisation with in-situ analysis of breakdown products.

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 (2 TRL steps)

Cost = 3 (£1.9m)

Suppliers = 1 (1 supplier)

Data Assumption = 3 (Assumptions unknown to be explored and validated within project)

Assessed risk score 8 - Medium

Scope

The work will be delivered in discrete work packages each with a focus on different objectives linked to the overall aim to develop deeper understanding of the performance of retro-fill gases in GIS designed for SF6.

Work Package 1 will characterise different options for the mixture of gases to be used to retro-fill SF6 assets. This work will identify the most suitable gas mixture to be used for retro-filling based on technical and environmental considerations

Work Package 2 will investigate the interactions between gas mixtures and solid insulation. This work will demonstrate which solid insulating materials will be suitable for use with retro-fill gases and whether the materials in existing GIS need to be replaced.

Work Package 3 will investigate gas degradation under representative conditions and the potential for spectroscopic methods to

detect the chemical species produced. The objective of this work is to develop an optical monitoring system for monitoring novel gas mixtures in GIS

Work Package 4 will deliver continuous, long-term energisation testing at DCI with optical and electrical monitoring applied. The objective is to demonstrate the performance of the chosen retro-fill gas in equipment designed for SF6.

Work Package 5 will take data generated during the other work packages to deliver a decision support tool to estimate the performance of different novel gas mixtures in a range of electrical equipment.

Objective(s)

Existing Gas Insulated Substations (GIS) are optimised for SF6, this project will develop a greater understanding of the interaction between spacers and the new insulating medium in long-term energisation tests. It will underpin efforts to develop more environmentally sound retro-fill solutions for SF6-filled equipment that are currently operating the electricity network, where SF6 is passive insulation.

Consumer Vulnerability Impact Assessment

In the short-term reduction of SF6 emissions are targeted through prevention of losses i.e. effective leak sealing. As the GWP of SF6 is so high, the most effective way to prevent emissions in the long term is through reduction of the inventory of the gas to zero, NGET has an ambition to do this by 2050. Given the long asset lives of high voltage equipment, complete removal of SF6 in this time would not be achieved through natural asset replacement. The aim of this project is to support a more economic and environmentally sound option for reduction of SF6 inventory than through asset replacement of equipment that has not reached end of life, although each installation would need to be considered on a case-by-case basis for the best option for consumers. The intention is therefore to achieve environmental goals that will benefit all consumers in the most economic method, again benefitting all consumers. Efficient investment ensures that the cost of transitioning to a low-carbon energy network is not unfairly shouldered by vulnerable consumers.

Success Criteria

The project will be considered successful if the objectives are achieved, specifically:

- An optical method is developed for the in-situ analysis of breakdown products from the chosen insulating gas mixture
- A retrofilled GIB test rig is filled with an alternative gas mixture, energised over an extended period and monitored for performance while energised
- Sufficient knowledge would be gained for retro-fill to be considered a technical and economic option for reduction of SF6 inventory.

Project Partners and External Funding

The following project partners will be supporting the project:

The University of Manchester will provide a full PhD studentship to the project (£73k) and access to equipment not already funded by the project (valued at £47k)

EPRI will provide £50k for the purchase of equipment needed for gas decomposition analysis

HVPD Ltd will provide technical support (£22k)

3M will provide technical support (£13k) and Novec™ 4710 (£5k)

Potential for New Learning

The following will be new knowledge expected from carrying out the project:

- Comprehensive insulation characterisation of different test gases developed into an order-of-merit to assess the viability of different binary and tertiary mixtures based on C4F7N (heptafluoroisobutyronitrile)
- Scaled testing will be conducted to establish a baseline knowledge on the material interaction process of SF6 alternatives and existing GIS insulators to identify ways to minimise tracking and flashover
- A novel optical technique will be developed to monitor and analyse degradation products in a non-obtrusive way. By-products will be quantitatively characterised under breakdown, which will be an enabler to determine the degradation mechanisms and quantify their impacts on gas mixes. These data will help to assess parameters responsible for the long-term gas stability, namely, influence of partial discharge (PD) over long-term energisation.
- Exploration of the interpretation of PD signals in terms of defects in insulating and conducting parts within the full-scale GIS demonstrator over an extended period in a live substation environment
- Development of a unique approach that will enable the integration of insulation and the degradation mechanisms of gaseous

dielectrics as a modelling tool, which can be used to assess existing gas candidates and formulate guidance for high-voltage gas-insulated applications

Scale of Project

Laboratory studies have already been undertaken to demonstrate that retro-fill is technically feasible. There will be additional laboratory work in this project but ahead of moving the research into an activity that would be undertaken as business-as-usual the transition is being managed through scale testing at Deeside to ensure all of the risks are understood and that retro-fill is an appropriate activity for transmission assets.

Technology Readiness at Start

TRL5 Pilot Scale

Technology Readiness at End

TRL7 Inactive Commissioning

Geographical Area

Laboratory studies to be performed at the University of Manchester. Long-term energisation studies to be carried out at Deeside Centre for Innovation in North Wales.

The results of the research will impact GIS sites across the network.

Revenue Allowed for the RIIO Settlement

Not Applicable

Indicative Total NIA Project Expenditure

£1,530,000

Project Eligibility Assessment Part 1

Requirement 1

Facilitate the energy system transition and/or benefit consumers in vulnerable situations

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 reducing direct, Scope 1 emissions of SF6 through reduction of inventory which is a more effective, long-term method for reducing risk of SF6 emissions than repairing leaks. Reducing SF6 losses has a direct impact on transitioning to a low carbon network.

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

Not applicable

Please provide a calculation and/or description of the expected benefits of the solution

The benefit of this project is based on an assumption that NGET will achieve its ambition of reducing SF6 inventory to zero by 2050. If this project is successful a proportion of the SF6 in equipment not expected to have reached end of asset life by 2050 will have been retro-filled with an alternative gas rather than being replaced entirely to achieve the inventory reduction.

Over a 25-year period from the end of the project until 2050, an estimated 62,500 kg of SF6 could reasonably be expected to have been removed by replacement with another gas in the same asset. Compared with complete replacement of the asset close to the 2050 target, this would provide a net benefit of £14.8m in avoided capital investment.

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

Not all SF6 filled GIS installations will be suitable for retro-fill. Each site would need to be assessed in turn to determine the most beneficial option for reducing the SF6 inventory. In assessing the potential benefits of the project, 36 sites across England & Wales have been identified where retro-fill would be considered. The net benefit has been calculated on an assumption that it would be implemented on sufficient sites to replace a quarter of the total SF6 mass in this way. Other licensees may benefit from employing retro-fill solutions to reduce SF6 inventory but this has not been assessed in determining the value of the project. Other licensees have been made aware of the project and have expressed an interest in access to the learning as the project progressed

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

Conservative estimates of costs have been made for the purposes of assessing the value of this project as retro-fill, they are based on the cost of retro-filling using a commercially available gas mixture. Based on these estimates, retro-fill of GIS would be approximately 55% of the cost of asset replacement. The actual cost using a specific gas mixture is expected to be lower in practice as there will be no need to increase the pressure to accommodate it.

Requirement 3 / 1

Involve Research, Development or Demonstration

Projects 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

Involve Research, Development or Demonstration - Please select all that apply

☐ 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 research is being conducted to understand potential for retro-filling assets filled with SF6 at transmission voltages. It is therefore learning that may be directly applied to other networks with 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.

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. Networks must explicitly mention similar projects that they have considered and how these differ.

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

This project builds on, but does not duplicate, work that was carried out in T1. The project is supported by EPRI (Electric Power Research Institute) as it sees the work as innovative and of interest to its utility members. There may be other projects in development looking at retro-filling SF6 assets at lower voltages. The 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

This work builds on research carried out in RIIO-T1 (NIA_NGET0199 Alternatives to SF6 for retrofilling) that successfully demonstrated the feasibility of using a bespoke gas mixture for retro-fill purposes. Since then retro-filling has been considered by others but is focussed on refurbishing existing assets to be capable of using the same alternative gases as used in new equipment. This project is different as it seeks to reduce the refurbishment requirement, primarily by maintaining the same pressure and insulating materials. This project is also concerned with the longer term performance by developing a new technique for monitoring the alternative gas and then applying it over an extended energisation period.

Relevant Foreground IPR

The foreground IPR will be the knowledge gained about the performance of a dielectric gas mixture suitable for retro-fill purposes in HV gas insulated busbars at transmission voltages. The learning will be brought together in a decision support tool which will also form part of the foreground IPR.

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 a part of it's business and usual activities

While reduction of SF6 inventory is a publicly stated ambition for NGET and seen as a step on the road to Net Zero, there is currently no financial or regulatory driver to do so. This project will demonstrate that retro-fill is achievable and a more efficient commercial solution than asset replacement but the benefits will only accrue over the period to 2050. We recognise that over that period, other technical solutions may be developed that will mean the anticipated benefits are not achieved.

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 solution may not work. Testing to date suggests that the work will be successful, but it cannot be guaranteed. If the laboratory work proves unsuccessful the project will not proceed to the long term study at Deeside Centre for Innovation.

The project is anticipated to generate sufficient benefit to justify the expenditure over 30 years so the success of the project will only become truly apparent over a longer period of time, during that time alternative, currently unforeseeable, solutions may arise that provide greater benefit. Clearly over such a long period there is significant uncertainty over the extent to which retro-fill may be carried out.

This project has been approved by a senior member of staff

☑ Yes