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NIA Project Registration and PEA Document

Date of Submission

Jul 2025

Project Reference Number

NIA2_NGET0089

Project Registration

Project Title

Suitability Assessment of Type Testing Procedures against SF6-free Switchgear (SATPaSS)

Project Reference Number

NIA2_NGET0089

Project Licensee(s)

National Grid Electricity Transmission

Project Start

September 2025

Project Duration

1 year and 1 month

Nominated Project Contact(s)

Prem Ranjan

Project Budget

£464,335.00

Summary

There are knowledge gaps on the behaviour of SF6 alternative gases, especially for the C4-FN mixtures being used widely in GB networks. Type test procedure/standards developed for the SF6 gas may need to be updated for the non-SF6 gas mixtures especially for switching applications. A comprehensive literature review, experiment and arc modelling will be conducted to 1) understand the key aspects of the circuit breaker Type Testing standards and procedures and summarise the gaps in technical specifications in relation to the adoption of SF6 alternative technologies in the power grids, and 2) present and analyse the existing evidence in relation to the long-term variation in composition of the mixtures of C4-FN with CO2, CO2/O2, or N2/O2 in a switching environment.

Third Party Collaborators

University of Liverpool

Nominated Contact Email Address(es)

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Problem Being Solved

The power industry needs to phase out SF6 gas (due to its significant global warming effect) from high voltage equipment. However, the alternative gases being considered (particularly mixtures containing C4-FN as an active insulation species) behave very differently from SF6 and the existing Type Testing procedures may not be adequate to ensure their long-term reliable and safe operation. Unlike SF6 which is chemically stable and returns to its original form after decomposition, C4-FN (when mixed with CO2, CO2/O2, or N2/O2) gets consumed during electrical arcing and forms different decomposition products. As a result, the concentration of the active species (C4-FN) also decreases. Specifically, there are several critical uncertainties that need to be addressed:
The current Type Testing standards do not account the unique properties of SF6 alternative gases because

- They were developed for SF6 which has been used reliably for over 50 years

- Type Tests are conducted over short periods and not able to capture the long-term effects
- They do not consider the consumption of active species in alternative gas mixtures

There are knowledge gaps on the behaviour of SF6 alternative gases, especially for the C4-FN mixtures, in switching applications:

- How does the active species vary its concentration and re-distribute by gas flow and diffusion during interruption
- How does partial discharge patterns change after high current interruption
- Will the active species (C4-FN) maintain sufficient concentration in high electrical stress areas over time
- Will the decomposition products react with equipment materials and cause failures

Method(s)

The need for partial discharge (PD) and gas species monitoring inside the switchgear will be investigated by recording and analysing the PD activity before and after arcing in a laboratory set-up. Arcs in a representative gas mixture containing C4-FN will be generated between a pair of contacts and PD sensors placed at a location that reflects the arcing effect and transport of the active species and by-products in the gas environment.

An existing switching arc model, developed for simulating the arcing process in SF6, will be adopted to the SF6 alternative gas by

- implementing a set of real gas material properties for the SF6 alternative gas mixture,
- solving an additional species concentration equation to quantify the variation of the active species,
- and adding new source terms to represent the consumption of the active species.

Numerical simulation will then be performed on a model gas blast circuit breaker under conditions typical to Type Test duties to characterise the local change of the concentration of the active species as well as the influence of the gas flow and diffusion on the transport of the active insulation species during and immediately after the highly transient arcing process.

Based on the findings, the technical need and key requirement for online sampling of the gas medium inside circuit breakers will be established to propose a method for real time monitoring of the active species.

Scope

The SATPaSS project is a 12-month research initiative examining whether current Type Testing standards and procedures remain adequate for SF6-free switchgear technologies employing C4-FN gas mixtures. The project specifically focuses on analysing the unique behaviours and characteristics of these alternative insulating and interruption gases compared to SF6, particularly regarding their stability, distribution, and performance following high-current switching operations.

The project encompasses three integrated work packages:

- Review of existing standards and Type Testing procedures to identify gaps
- Computational modelling of C4-FN gas behaviour during switching operations
- Experimental assessment of partial discharge behaviour and development of monitoring methodologies

The research addresses critical knowledge gaps in the long-term reliability of SF6-free technologies that current Type Testing procedures may not adequately evaluate, focusing on uniformity of gas distribution, partial discharge patterns, stability of gas mixtures, and material compatibility concerns.

Objective(s)

The objectives of this project are to

- Identify potential gaps in Type Testing regimes and international standards for SF6-free switchgear, particularly circuit breakers.
- Develop a computational model to predict dynamic composition changes and distribution of C4-FN inside gas-blast circuit breakers.
- Assess potential long-term operational and maintenance risks associated with C4-FN gas mixtures in transmission network assets.
- Generate empirical evidence regarding changes in partial discharge behaviour in C4-FN mixtures following current interruption.
- Propose methodologies for active species monitoring in SF6-free switchgear.

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 informed choices of procuring non-SF6 switchgear.

Success Criteria

The success of the project will be judged against the following criteria:

- The completion of a literature review summarising the existing technical specifications in circuit breaker Type Test standards and evidence associated with the consumption of the active insulation species (C4-FN) in switching tests to inform the knowledge gaps that are to be filled.
- Adoption of an existing switching arc simulation model to arcing processes in a mixture containing a consumable active insulation species.
- Obtaining simulation results for a model circuit breaker at three current levels and extracting information on the variation of the active species concentration as a function of time.
- Generation of an arc in the laboratory set-up at three current levels.
- Acquisition of the partial discharge sensor output before and after arcing processes.
- A proposed method for online gas sampling.

Project Partners and External Funding

The University of Liverpool will be delivering the work. The subject matter experts from all three TOs of GB, NGET SSEN-T and SPT will be involved in the project.

Potential for New Learning

Through this project, it is expected that new knowledge in the following areas will be learnt:

- The extent of the knowledge gap between the existing circuit breaker Type Test standards and the test and monitoring needs to ensure safe and reliable operation of SF6 alternative technologies.
- How differently SF6 alternative gases behave in terms of their partial discharge patterns following an arcing process.
- How the concentration of the active species in an SF6 alternative gas circuit breaker containing a consumable species vary in space and time under the influence of arcing and strong gas flow.
- Insulation performance indicators of SF6 alternative gases used in gas circuit breakers.

The outcome from the project will be reported to NGET and disseminated at the UHVnet 2027 colloquium, CIGRE Congress in 2028, International Symposium FSO (Physics of Switching Arcs) in 2027 and International Conference of Gas Discharges and Their Applications in 2028.

Scale of Project

The project will conducted as desktop exercise including simulation and laboratory experiments at The University of Liverpool (UOL). The existing lab facilities of UoL will be used with some consumables costed on the project. Most of the cost is for labour charges for involved researchers from UoL.
The project has been scaled with the intention of delivering efficiently and with reasonable expection of success. The initial studies regarding gap in Type testing procedure of non-SF6 gas mixtures carried out using that of developed for SF6 will help the GB utilities to make an informed decision on adoption of non-SF6 switching equipment which comes at consumer's cost.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL3 Proof of Concept

Geographical Area

The project work will be carried out at the University of Liverpool with input from the team of NGET. The results will likely be applicable to all UK based networks regardless of geographical location.

Revenue Allowed for the RIIO Settlement

N/A

Indicative Total NIA Project Expenditure

£417,901

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 reducing direct, Scope 1 emissions of SF6. 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:

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 therefore no CBA undertaken at this stage.

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

The knowledge and method developed in this project should be applicable to SF6 alternative gas circuit breakers containing at least one a

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

N/A

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

Gas blast circuit breakers (puffer type and self-blast type) operate at different voltage levels from distribution to transmission. The potential findings from this project are related to the process of arc-heat induced dissociation of the active species (C4-FN) in the mixture and its influence on the partial discharge patterns of the gas mixture. The root cause is due to the differences in the gas material properties between the SF6 free gas mixture and SF6. Therefore, the knowledge and understanding gained from this study can be used by relevant Network licenses who own in-service circuit breakers filled with the SF6 alternative gases studied in this project. Although NGET will
focus on transmission assets the model has already been developed for higher distribution voltages (132 kV). It will be the responsibility of others to determine the extent to which the models might be directly applicable to not only their assets but their asset management approach to managing this type of equipment.

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.

The proposed work focuses on the potential consequences of switching arcs on the operation and maintenance of switchgear asset filled with gas mixtures containing C4-FN, and how these can be accounted for by Type Testing procedures and technical specifications.

The simulation results of the dynamic distribution of the active species (C4-FN) will provide information to the Beta phase of the SIF Project on SF6 Whole Life Strategy in that the prediction of differential leakage and top-up of the active species in the SIF project will require knowledge of active species concentration during the service life, especially the change following fault current interruption.

Partial discharge (PD) monitoring before and after arcing will provide information on the PD behaviour of SF6 alternative gases influenced by high power arcing, which is not covered by the NIA2_NGET0006 project Non-invasive In-situ Monitoring and Interpretation of SF6 Alternatives in GIS Equipment. In addition, the internal insulation design of GIS is different from that in switching devices such as circuit breakers, posing different PD conditions. Investigation of potential differences in PD activity post-arcing relating to the behaviour of SF6 alternative IIGs can provide recommendations for calibrating the measurement and/or analysis appropriately to reduce false positives.

NIA2_NGET0028 project Identification and quantification of C4-FN gas arcing by-products and their implication for GIS operation will quantify the arcing by-products under credible fault scenarios in switchgear for C4-FN mixtures and study the effect of moisture

ingress, pressure, air on the concentration and rate of production of the by-product. The experimental conditions and test results from NIA2_NGET0028 will be used (assuming made available during this project) to inform the evidence collection process and help identify the work in future on the long-term ageing of the gaseous environment in switchgear asset.

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

SF6 will have to be replaced in electricity grids, such as in GIS for insulation and switching devices for insulation and current interruption. While an SF6 alternative gas mixture (C4-FN + CO2) has been trailed in UK National Grid as an insulation medium (GIS and GIL) following extensive research and laboratory test, no verified information on the long-term stability and the partial discharge behaviour of the gas mixture in circuit breakers, especially the concentration of the actives insulation species inside the breaker space following electrical arcing, is yet available.

This is the first project to use a combination of laboratory experiment and computer simulation to acquire information that is still missing but critical to complement the existing Type Test standards for performance verification and develop switchgear asset management and maintenance procedures required by the network operator.

Relevant Foreground IPR

Computational Models and Algorithms
The project will develop modelling methodologies to predict the dynamic distribution of C4-FN during circuit breaker operations. These computational models represent valuable IP that could be used to simulate gas behaviour in different switchgear designs and under various operating conditions. The algorithms for calculating gas consumption rates and replenishment patterns would be particularly valuable for manufacturers developing new SF6-free switchgear.

Testing Methodologies
The project will develop novel methodologies for assessing partial discharge behaviour in SF6-free switchgear before and after arcing events. These testing approaches could be formalised into proprietary testing protocols that more accurately evaluate the long-term performance of equipment using C4-FN gas mixtures. These methodologies could be incorporated into future industry standards or commercialised as specialised testing services.

Monitoring System Specifications
The proposed methodologies for online monitoring of active species in SF6-free switchgear represent significant IP that could be developed into commercial monitoring systems. The technical specifications, sensor configurations, and data analysis techniques developed for this purpose could form the basis for patentable monitoring technology.

Data Sets
The experimental data generated on partial discharge patterns, gas composition changes, and by-product formation in C4-FN mixtures represents valuable reference information that are rather scarce in the industry. These benchmark datasets could be licensed to manufacturers or used to develop commercial software tools for equipment assessment.

Technical Know-How
The project will generate significant tacit knowledge regarding the interpretation of test results, risk assessment frameworks, and practical implementation considerations for SF6-free switchgear. This know-how represents intellectual capital that could be leveraged for consulting services, training programs, or further research projects.

Recommendations for Standards Development
The project's recommendations for updating Type Testing procedures and technical specifications for SF6-free switchgear could form the basis for contributions to international standards bodies. While standards themselves are not typically protectable as IP, the underlying research methodologies and technical rationales represent valuable intellectual assets.

Data Access Details

Data for this project can be found or requested in a number of ways:

- A request for information via the Smarter Networks Portal at https://smarter.energynetworks.org.
- Via NGET Innovation website at https://www.nationalgrid.com/uk/electricity-transmission/innovation
- Via NGET 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

There are still unknowns about the non-SF6 gas mixtures as interrupting and insulating gas medium, adapted by the networks. The unknowns in switching application especially when the TOs are discussing about the non-SF6 switching equipment needs the innovation to understand the feasibility especially when the type test procedure was developed for SF6 containing equipment. The innovation will help to adopt the technology in BaU after gaining the confidence.

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 innovative work that is not part of the business-as-usual activities for network utilities, in this case research into understanding the type test procedure for non-SF6 gas mixture for switching application using modelling and experimental tools that will be supplied by an academic partner.

This project has been approved by a senior member of staff

☑ Yes