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

May 2025

Project Reference Number

NIA2_NGET0072

Project Registration

Project Title

Evolution of VSC HVDC Control

Project Reference Number

NIA2_NGET0072

Project Licensee(s)

National Grid Electricity Transmission

Project Start

October 2025

Project Duration

2 years and 1 month

Nominated Project Contact(s)

Xiaolin Ding

Project Budget

£599,095.00

Summary

As the network evolves rapidly, its dynamic behaviour is becoming increasingly complex, potentially introducing new performance challenges for inverter control. The control and performance requirements for inverters are also evolving in tandem with these network changes. This project aims to enhance our understanding of emerging and applied VSC HVDC modelling and controls, which includes evaluating their suitability for the required performance, examining the interaction and instability mechanisms of multiple converters, and providing validated generic models of these systems. This understanding is essential for identifying the necessary control and performance requirements, gaps in specifications, and areas for modelling improvement. Ultimately, this will help mitigate risks for Great Britain's future network and support the energy transition needed to achieve the Net Zero target.

Third Party Collaborators

The University of Manchester

Nominated Contact Email Address(es)

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Problem Being Solved

Holistic Network Design (HND) proposes the integration of more complex HVDC systems into the existing power network to facilitate offshore wind integration and support the energy transition. As the network evolves rapidly, its dynamic behaviour will become increasingly complex, potentially posing new performance challenges for inverter control. The control and performance requirements placed on inverters also continue to evolve alongside changes in the network. What new VSC HVDC control behaviours and strategies are emerging, and how relevant are they to the GB context? A better understanding of emerging and applied VSC HVDC modelling and controls, along with validated generic models of these systems, is essential to identify the necessary control and performance requirements.

Method(s)

To derisk Great Britain's future network and support the energy transition, Studies are needed to explore existing and emerging control scheme proposals and identify which converter and control functionalities need improvement as inverters are connected in closer proximity, adopt new topologies, and exhibit stronger interactions. The proposed method includes:

- Conduct a comprehensive horizon scan on evolving VSC-HVDC control developments through literature review, classification, and gap analysis.
- Formulate a common analysis framework that enables the comparison of different proposed control behaviours (control layers) based on a unified mathematical analysis and common metrics.
- Investigating power-loop and supplementary control solutions in terms of dynamic performance, identifying new or combined control strategies to meet key requirements for integrating new VSC HVDC systems into the AC network.
- Examining the impacts of multiple HVDC inverter integration under the HND model (and other relevant topologies) on existing AC networks, using simulations complemented by mathematical analysis.

PSCAD/EMTDC will be used as a leading, and widely accepted, detailed EMTDC modelling package, in combination with Matlab/SIMULINK simulations.

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 Change = 1
Cost = 1
Supplier = 1
Data = 2
Total risk score = 5 Low (L)

Scope

Work Package 1: Horizon Scan on Evolving VSC Control Developments
This task will capture the latest research on controllers that provide services from Voltage Source Converter (VSC) systems, including High Voltage Direct Current (HVDC), energy storage, renewable energy generation, and Static Synchronous Compensators (STATCOMs). A review of hardware configurations will also be conducted. This initial analysis will facilitate a gap analysis, mapping controllers against required services to identify opportunities for new techniques. The project will begin with an initial period of research, supplemented by regular updates and reviews.
Deliverable: Study report and paper for submission.

Work Package 2: Investigation of Power-Loop and Supplementary Control Solutions
This work package focuses on the dynamic performance of VSC systems in power networks, which are rapidly evolving. As the demand for increasingly complex services grows, it is essential to assess proposed solutions and models in the literature. The objective is to capture the dominant dynamics of the converter within a general model and to determine the extent to which model order reduction can be applied to analyse future proposed controllers while preserving relevant dynamic phenomena.
2.1 Analytical Controller Framework and General Model Formulation
Many control structures operate using different approaches, making direct comparisons challenging. To facilitate this, individual controllers will be reformulated into a common representational framework. This unified model will enable comparative assessments. Simulation verification will ensure that this approach does not overlook any critical characteristics. The control framework will be integrated into the previously developed PSCAD/EMTDC multi-level VSC HVDC model.
Deliverable: Framework analysis report and paper for submission.

2.2 Converter Control Analysis Applied to Selected Scenarios
This task aims to evaluate the suitability of individual converter performances in delivering specific services across various scenarios. The controls developed in section 2.1 will be used to analyse converter performance based on scenarios created in collaboration with industrial sponsors. The ability of different controller sets to respond to these scenarios will be examined, identifying any performance gaps or necessary services. A model order reduction methodology will be applied to determine which relevant dynamic phenomena need to be captured for different system interaction studies. While a combination of services with varying timeframes will be used, the full-order model will verify the reduced-order models, which will help identify limit cases and generalizability.
Deliverable: Study report and academic paper for submission.
A 'back-to-fundamentals' approach will be adopted, developing dynamic models of both the system (small but representative) and the converters (more detailed). However, model order reduction will be employed to simplify the detailed models for analytical study, as these models may be too complex for direct mathematical analysis and physical generalizability.

Work Package 3: Understanding the Suitability of Public Domain Models
This work package will investigate the impacts of integrating multiple HVDC inverters under the HND model on existing AC networks, using simulations complemented by mathematical analysis. It will examine the interaction and instability mechanisms of multiple converters (with varying topologies and operation modes—grid-forming or grid-following) operating concurrently within the network. The goal is to develop a comprehensive understanding of interaction and instability-related limitations on network utilization.
3.1 Interaction and Instability Mechanisms of Power Systems with Multiple Converters
The previously developed PSCAD/EMTDC multi-level VSC HVDC model will serve as the foundation for converter representation. Initially, two converters will be introduced into a small, representative test network to illustrate characteristic cases. Various candidate scenarios recommended by industry will be tested to investigate emerging topology and control scenarios, focusing on gaps in converter performance and specifications.
Deliverable: Testing report and paper for submission.

3.2 Investigation of Model Order Reduction of Converters and Gap Analysis
Model reduction and mathematical analysis will further explore the critical conditions identified in section 3.1, verified through simulation studies on full PSCAD models. This will involve multiple methodologies, including a physics-based method that considers the dominant eigenmodes associated with each set of control frequencies and mathematical reduction using residual minimization and truncation. Suitable methodologies will be applied to analyse the reduced-order mathematical models to identify causes and potential control remedies based on emerging literature.
Deliverable: Model description, study report, and paper for submission. Disseminate key results of the project and learnings via final dissemination workshop.

Objective(s)

The key objectives of this project are as follows:

- Conduct a Comprehensive Horizon Scan to capture and analyse the latest research and developments in VSC control technologies and models, including HVDC, energy storage, renewable energy generation, and STATCOMs, and to identify gaps and opportunities for innovation in control techniques.
- Investigate power-loop and supplementary control solutions and identify new or combined control strategies that meet the integration requirements of new VSC HVDC systems into existing AC networks.
- Develop a common representational framework for various control structures, enabling direct comparison and assessment of individual controllers within a unified model, while ensuring that critical characteristics are preserved through simulation verification.
- Assess the suitability of individual converter performances in delivering specific services under a variety of operational scenarios, identifying performance gaps and necessary services through model order reduction methodologies.
- Investigate Interaction and Instability Mechanisms of multiple HVDC inverters operating concurrently within AC networks, focusing on different converter topologies and operation modes to understand their impact on network utilization.
- Develop appropriate generic modelling details and techniques that accurately capture VSC instability and interaction mechanisms, offering guidance on model reductions.

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 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 a neutral impact on customers in vulnerable situations. This is a transmission project.

Success Criteria

The success criteria of the project are as follows:

- A comprehensive Horizon Scan report that details the latest research and developments in VSC control technologies and models, along with identified gaps and opportunities in control techniques.
- Identification of new or combined control strategies that meet the integration requirements for new VSC HVDC systems within the existing AC network.
- Development of a robust common framework that enables direct comparison and assessment of individual controllers within a unified model, along with recommendations for the most promising new controls for VSC-HVDC in the future Great Britain network.
- A report detailing suitability assessment studies of individual converter performances in delivering specific services under various operational scenarios, including gap analyses in performance and necessary services.
- Application of the chosen controls to a multi-infeed VSC-HVDC model and subsequent evaluation.
- Effective dissemination of the project's key findings and learnings through a workshop at the end of the project and related publications.

Project Partners and External Funding

N/A

Potential for New Learning

The project will evaluate options for controls proposed for VSC HVDC in the public domain, assessing their potential benefits, applicability, suitability, and modelling needs for future network scenarios. This initiative will enhance our understanding of emerging and applied VSC HVDC modelling and controls, as well as the interaction and instability mechanisms of multiple converters. Additionally, it will help identify the necessary control and performance requirements, gaps in specifications, and areas for modelling improvements.

The key findings will be shared with other Transmission Owners and the System Operator through regular project meetings, workshops, technical documentation, and/or publications.

Scale of Project

The project aims to assess the control options available in the evolving field of VSC-HVDC, focusing on how these can be applied to VSC-HVDC models and their suitability and applicability for Great Britain's future network. It will help identify the necessary control and performance requirements, gaps in specifications, and areas for modelling improvements. All phases of the project are strategically linked and designed to achieve the defined objectives. Consequently, the scale of the project is intentionally set to be comprehensive, as a smaller project would not provide the in-depth insights and new learnings necessary to deliver key outputs, thereby significantly limiting the benefits to the industry.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

The project will be a combination of computer-based studies and mathematical analysis. The project will be carried out at the innovation supplier's facilities in the UK.
Relevant Foreground IPR
Details of expected Relevant Foreground IPR which will be generated in the Project. If applicable, this must also explain if Background IPR will be required to use the Relevant Foreground IPR.

The project is based on public domain material. Foreground IPR will include the control frame-work and reduced order models for inverter controls.
The Foreground IPR also includes technical reports developed for the projects and any publications associated. The findings will be recorded in written technical reports along with recommendations for future work.

Revenue Allowed for the RIIO Settlement

N/A

Indicative Total NIA Project Expenditure

£539,186

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:

Holistic Network Design (HND) proposes the integration of more complex HVDC systems (such as multiple point to point HVDC systems) into the existing power network to facilitate offshore wind integration. As the network evolves rapidly, its dynamic behaviour is becoming increasingly complex, potentially introducing new performance challenges for inverter control. The control and performance requirements for inverters are also evolving in tandem with these network changes.

This project aims to enhance our understanding of emerging and applied VSC HVDC modelling and controls. This includes evaluating their suitability for the required performance, examining the interaction and instability mechanisms of multiple converters, and providing validated generic models of these systems. This understanding is essential for identifying the necessary control and performance requirements, gaps in specifications, and areas for modelling improvement. Additionally, it will help determine whether existing HVDC models are sufficient to capture the new set of use cases for future network topologies. The project will also identify supplementary functionalities that may be required or beneficial for VSC-HVDC systems, as well as understand their implications, performance, and interactions with nearby inverter controls. Furthermore, it will provide a better understanding of the necessary capability envelope of future HVDC inverters, ensuring better alignment with the needs of the future network.

The work carried out in this project will help mitigate risks for Great Britain's future network and support the energy transition needed to achieve the Net Zero target.

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

The project is R&D focused with relatively low TRL level, hence no detail CBA assessment is conducted.

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

The research outcomes and the developed methodology are of generic nature and would be applicable to all electricity network Licensees across GB.

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

The project is concluding at a relatively low Technology Readiness Level (TRL) and will not result in a Business as Usual (BAU)

implementation. As such, no rollout plan is currently scheduled.

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 key findings of the projects will be shared with other Network Licenses (Transmission Owners and Operator) via workshop activity, technical documentation and/or publications. The key learnings and methods developed in the projects would be equally appliable to relevant network licensees.

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.

Previous studies on VSC HVDC networks have predominantly assumed sparse HVDC distribution. Current live research, such as "Grid Forming Modelling and Stability" (NIA2_NGET0036) and "DETECTSII" (NIA2_NGES0040), focuses on producing improved models of isolated converters for studying converter interactions when connected to an AC grid. Other relevant research (NIA_NGET0084) has concentrated solely on small offshore DC networks, while the recent CODA project (NIA2_NGET0074) has focused exclusively on the coordinated design and control of converter systems for integrating multi-infeed HVDC systems into the existing network.

This project aims to understand the emerging and applied VSC controls, their models, and their suitability and applicability in future complex multi-point-to-point HVDC systems within the Great Britain network. No similar innovative projects have been identified, and there is no duplication or overlap with any previous projects.

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 innovation of this project lies in the development of a common framework that enables a detailed assessment of new VSC-HVDC controls. It also involves establishing methods for adequate model order reduction, identifying gaps in VSC control performance and the services required for the future network, and proposing new VSC HVDC control solutions that will facilitate ACDC integration in the future Great Britain network.

Relevant Foreground IPR

The project is based on public domain material. Foreground IPR will include the control frame-work and reduced order models for inverter controls.
The Foreground IPR also includes technical reports developed for the projects and any publications associated. The findings will be recorded in written technical reports along with recommendations for future work.

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 several 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

The work is innovative and involves a derisking, innovative horizon scanning approach. This initiative is not a business-as-usual activity, and there are significant risks associated with the project. Additionally, there is no guarantee that the development of the model and frame-working methodology will be successful (fully generalizable) for all the use-cases studied.

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

The project involves significant technical and commercial risks during its development. The proposed methodology requires thorough verification, and the potential for failure is considerable. Therefore, it can only be undertaken with the support of the NIA.

This project has been approved by a senior member of staff

☑ Yes