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NIA Project Registration and PEA Document

Date of Submission

Apr 2025

Project Reference Number

NIA2_NGET0074

Project Registration

Project Title

CODA: Coordinated design and control of multi-infeed HVDC integrated power systems

Project Reference Number

NIA2_NGET0074

Project Licensee(s)

National Grid Electricity Transmission

Project Start

June 2025

Project Duration

1 year and 10 months

Nominated Project Contact(s)

Xiaolin Ding

Project Budget

£570,000.00

Summary

For the integration of offshore wind in the eastern region, a multi-infeed HVDC power system will be formed. However, the geographical proximity poses a risk of converter interactions, potentially diminishing or even worsening regional grid support performance. This project aims to develop a coordinated design and control strategy for the multi-infeed HVDC power system to prevent converter interactions and enhance regional voltage and frequency support. It is anticipated that this coordination will improve voltage retention and recovery, mitigate voltage and frequency variations, and reduce the likelihood of cascading instability events.

Preceding Projects

NIA_NGET0029 - Optimising the operation of an integrated DC link within an AC system (ICase Award)

Third Party Collaborators

Cardiff University

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Problem Being Solved

To facilitate the integration of a significant amount of offshore wind, the Holistic Network Design proposes multiple HVDC connections that will create more integrated multi-infeed HVDC systems. However, this also introduces considerable complexity due to the variety of technologies and control methods involved.

The dynamic behaviour of the network and its regions will become increasingly intricate, with limited understanding of how multi-infeed HVDC systems interact and behave collectively. The presence of multiple infeed HVDCs in close geographic proximity may lead to significant converter interactions without adequate coordination in design and control. This lack of coordination can diminish grid

support capabilities and pose considerable risks, resulting in deteriorated performance in voltage and frequency support, and potentially leading to cascaded instability within the network.
Reactive power for voltage support in HVDC systems requires additional current capacity. Uncoordinated reactive power management may reach its current limitations, resulting in degraded voltage support. Additionally, the characteristics of short-circuit current injection from converters differ significantly from those of synchronous generators. Different types of converters and control modes exhibit varying short-circuit current dynamics, which could lead to inadequate voltage retention and hinder system recovery.
Furthermore, the intermittent nature of offshore wind generation may limit HVDC's ability to provide consistent active power for frequency support. The dynamics of frequency response also vary across different entry points and inertia designs. Uncoordinated frequency responses of multi-infeed HVDCs may cause undesirable frequency fluctuations in the region.

Method(s)

To ensure the regional grid's support capabilities and derisk the future networks that incorporate multi-infeed HVDC systems, this project will explore a coordinated approach to the design and control of these integrated power systems.
Coordinated design in the planning stage aims to minimise the physical limitations of multi-infeed HVDCs on grid-support capabilities by optimising the adoption of different HVDC technologies, control modes, power ratings, and entry point locations. An evaluation of voltage strength and frequency inertia requirements at given entry points will be developed. The grid-support capabilities of different HVDC technologies, power ratings, and control modes will be investigated. A specification and recommendation for coordinated design will be provided based on the analysis of grid conditions and HVDC capabilities.
The coordinated control will explore the maximum effectiveness of multi-infeed HVDCs on grid-support capabilities by optimising the dynamics of converters from different entry points. Both centralised and decentralised control strategies will be developed and compared in terms of voltage and frequency support. A control approach to coordinate the dynamics of various HVDC technologies and control modes will be proposed. Various voltage and frequency impacts due to different entry points will be considered in the coordinated control. Furthermore, the project will investigate the reactive current injection requirements of such integrated power systems during both fault and recovery periods to ensure voltage retention and recovery in future networks.
The eastern GB power system including HVDCs will be modelled in PSCAD/EMTDC. A Power Hardware in the Loop (PHIL) test will be conducted, integrating one real converter with the simulated power system.

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 the 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 (risk score) = 2
Cost = 2
Supplier = 1
Data = 1
Total risk score = 6 Low (L)

Scope

The scope of the work will include following tasks:
Task 1: Review and evaluate the voltage and frequency support capabilities of HVDC technologies for offshore wind integration.
Review the operational characteristics of point-to-point HVDC and multi-terminal HVDC, and analyse how these characteristics apply to grid-support capabilities;
Review the control characteristic of grid-following and grid-forming VSC, and analyse how these characteristics apply to grid-support capabilities;
Review the generation uncertainties of offshore wind generation and analyse how these uncertainties impact grid-support capabilities.

Deliverable 1:

A review and assessment report on the characteristics of HVDC technologies for active power and reactive power injection, short-circuit current injection, and inertia provision in the context of offshore wind energy collection.

Task 2: EMT modelling of multi-infeed HVDC integrated power system.
Modelling multi-infeed HVDC systems with multiple HVDC links and multi-terminal HVDCs, based on the Holistic Network Design;
Modelling the offshore wind collection system with aggregated models of wind turbines to emulate the power dynamics of offshore wind, and maintain power electronic and mechanical dynamics;
Modelling the onshore AC power system, including the 400 kV and 275 kV transmission systems, and large power plants to represent the mechanical dynamics.

Deliverable 2:
A PSCAD power system model of the investigated eastern region, including on-shore AC power system, offshore multi-infeed HVDC and HVAC transmission system, and offshore wind collection system.

Task 3: Analyse the requirements of short-circuit current in power systems for voltage support and recovery.
Analyse the mechanisms of short-circuit current supporting the system voltage;
Identify the effectiveness of levels and duration of short-circuit current in maintaining voltage security;
Specify the requirements for short-circuit current to ensure voltage security and recovery in power systems, taking into account both the current power system and the anticipated changes resulting from the extensive integration of offshore wind energy targeted in the UK.
To identify the reactive current injection requirements from system point of view during the fault and recovery time.
To identify the mechanism that the above-mentioned fault current to be provided by different technologies.

Deliverable 3:
A report on an understanding of the impact of short-circuit current on system voltage dynamics, along with recommendations for system requirements regarding the levels and duration of short-circuit current to ensure voltage security and recovery.

Task 4: Develop a coordinated design for multi-infeed HVDC systems, including short-circuit levels, ratings, and control modes, to enhance grid support capabilities.
Specify the grid-support capabilities for voltage and frequency of HVDC systems, including short-circuit levels, power ratings, various converter configurations, and control modes;
Specify the characteristics of short-circuit current injection from multiple converters and compare them to synchronous generators. Further, study the characteristics of short-circuit current distribution among AC network circuits resulting from various total converter capacities in the region, different converter configurations, converter control modes, and AC network operating conditions;
Evaluate the impact of HVDC characteristics on power systems, including voltage strength, inertia, the impact of short-circuit current injection on voltage security, and the impact of short-circuit current distribution on AC network overcurrent capacity;
Develop the coordinated design that considers the grid requirements of the entire multi-infeed HVDC system as a whole to enhance the performance of power-electronic grid-support capabilities in a given region, including the design of converters, locations, control modes, and power ratings;
Evaluate the cost-effectiveness of the coordinated design by comparing it to the individual design of HVDCs.

Deliverable 4:
A report on an understanding of the system characteristics altered by multi-infeed HVDCs, including voltage strength, inertia, the impact of short-circuit current injection on voltage security, and the impact of short-circuit current distribution on AC network overcurrent capacity; the specifications and recommendations for the coordinated design of multi-infeed HVDC-integrated power systems, ensuring balanced regional grid support and the mitigation of control interactions.

Task 5: Develop a coordinated control for multi-infeed HVDC systems, incorporating control dynamics and the impacts of multiple entry points, to enhance voltage and frequency support performance.
Specify the dynamics of various HVDC technologies and control modes, and analyse the impacts of different entry points on grid-support capabilities;
Develop coordinated control for the multi-infeed HVDC system using centralised and decentralised strategies. Identify the pros and cons of each strategy and make a final recommendation for offshore applications. Develop clear indications for the system operator to coordinate HVDC operations as planned;
Incorporate different entry points in the coordinated control to maximise grid-support capabilities by improving voltage and frequency response, increasing the short-circuit level, and maintaining the minimum ROCOF;
Research on coordinated control focuses on the system's ability to support voltage and frequency during power system faults and recovery from those faults;
A comparative study between typical synchronous generators and multi-infeed HVDCs will be performed to demonstrate the differences and characteristics of grid-support capabilities.

Deliverable 5:
A report on
the specifications and recommendations for the coordinated control of multi-infeed HVDC-integrated power systems for voltage and frequency support.
A report on the assessment of multi-infeed HVDC coordination in a given region, focusing on improvements in voltage and frequency response, inertia, and short-circuit levels.

Task 6: Conduct a power hardware-in-the-loop case study in the lab.
The coordinated design and control will be tested in the GB system model for the eastern region;
A power hardware-in-the-loop setup, including RTDS simulation and a hardware converter, will be used to test the performance of the coordination.

Deliverable 6:
A final project report on the overall performance evaluation of multi-infeed HVDC coordination in the integrated power system of the eastern region, including lab test results.
Disseminate key results and learnings via workshops, conference and/or journals.

Objective(s)

Coordinated design and control will be investigated to maximise offshore wind power accommodation and enhance grid-support capabilities from multi-infeed HVDC systems. The objectives of the project are as follows:

The regional voltage and frequency response characteristics of reactive and active power will be specified. Additionally, the fault response characteristics, including short-circuit current and the rate of change of frequency (ROCOF) in coordinated current control, will be defined.

The dynamics of different converters and the impacts of various entry points on regional grid-support performance will be analysed and specified.

A coordinated design of converter power ratings and control modes will be developed for the planning stage to ensure adequate current injection in the close region and mitigate or avoid control interactions.

A coordinated control strategy will be developed to maximise regional voltage and frequency support, enhance renewable energy integration, and ensure voltage retention and recovery in the region.

Risks associated with complex coordinated control within power systems will be identified, and corresponding mitigation measures will be investigated and recommended.

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 evaluated as having a positive overall impact on consumers in vulnerable situations. It aims to enhance the coordination of multi-infeed HVDC systems, supporting the design and operation of the network on future GB network. By maximising offshore wind power integration and strengthening grid stability, the project is expected to contribute to a more resilient and efficient energy system. These advancements will ultimately lead to reductions in energy costs for households.

Success Criteria

The delivery of the following items will be used to evaluate the success of this project:

A PSCAD power system model of the investigated eastern region, including on-shore AC power system, offshore multi-infeed HVDC and HVAC transmission system, and offshore wind collection system.

In-depth understanding of short-circuit current impact on system voltage dynamics, along with recommendations for system requirements regarding the levels and duration of short-circuit current to ensure voltage security and recovery.

A coordinated design approach for multi-infeed HVDC systems, ensuring optimised regional grid support and the mitigation of control interactions.

A coordinated control for multi-infeed HVDC systems, incorporating control dynamics and the impacts of multiple entry points, to enhance voltage and frequency support performance.

Identification of potential risks of multi-infeed HVDC coordination in a given region and recommendation of corresponding mitigation measures.

Project Partners and External Funding

This project is in collaboration with NESO.

Potential for New Learning

It is expected to learn:

the characteristics of power-electronic grid support capabilities in multi-infeed HVDC power systems.

the mechanism of fault current injection in HVDCs for voltage retention and recovery.

the mechanism by which regional performance diminishes due to converter interactions, including the impact on regional grid support capability caused by varying converter response times.

the coordinated design and control, to enhance regional grid support capabilities and improve system security.

Learnings of this project will be disseminated via workshops of the industry and academia, international conferences and published journals.

Scale of Project

This project involves computer simulations along with laboratory testing. The EMT simulation is used for power system-level analysis. The laboratory power-hardware-in-the-loop testing is conducted to evaluate the performance of a single converter device within an emulated power system, with minimal hardware testing. As such, there is no scope to further reduce the scale of the project.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

The project will be a combination of computer-based studies and lab-demonstration.

Revenue Allowed for the RIIO Settlement

N/A

Indicative Total NIA Project Expenditure

£513000

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:

The project focuses on developing a coordinated design and control strategy to facilitate the integration of multi-infeed HVDCs into the power system. This aims to ensure and enhance regional voltage and frequency support while minimising converter-driven oscillation issues in future complex multi-infeed HVDCs system. By addressing these challenges, the project helps maximise the integration of renewable energy, ensuring a stable and reliable electricity network for the future.

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 focuses on developing a coordinated design and control method to facilitate the integration of multi-infeed HVDCs into the power system. This will help optimise regional grid support performance to enhance system security and mitigate undesirable control interactions. The project will also bring in-depth understanding of short-circuit current impact on system voltage dynamics, along with recommendations for system requirements regarding the levels and duration of short-circuit current to ensure voltage security and recovery. The project will contribute to the effective and reliable integration of offshore wind energy, ensuring a stable and resilient electricity network for the future.
This project is a research focused project and therefore the calculation of the expected benefits is not required.

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

The research outcomes and the developed mythology 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 begins at a low Technology Readiness Level (TRL) and concludes at a development level. It will not result in a direct rollout or Business as Usual (BAU) implementation. Therefore, 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 workshops, 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.

The previous project, "Optimising the Operation of an Integrated DC Link within an AC System" (project reference NIA_NGET0029), focused on optimizing the operation of a single LCC-HVDC system to enhance renewable energy integration. Another related project (project reference NIA2_NGET0053), "Optimise Fault Infeed," aimed to manage maximum fault levels.
Distinct from these previous projects, this project investigates the coordination of multi-infeed HVDC systems in the eastern power system to enhance grid support capability and stability. Additionally, it focuses on identifying the reactive current injection requirements from a system perspective during both fault and recovery periods.

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

Multi-infeed HVDCs in close proximity will be established on the east coast based on the Holistic Network Design. The mechanisms of converter interaction need to be understood to identify potential risks in the region. This includes issues related to uneven short-circuit currents, risks of inadequate voltage and frequency support, and cascading instability incidents.
To ensure regional grid-support capabilities and stable operation, this project has innovatively developed both coordinated design at the planning stage and coordinated control at the operational stage to ensure that regional voltage and frequency performance align with Grid Code requirements. The project provides valuable insights into the interaction characteristics of multiple HVDCs, explores potential risks associated with diminished regional grid-support performance, and assesses instability risks. Additionally, the project will develop innovative mitigation measures to reduce any identified instability risks.

Relevant Foreground IPR

The expected Foreground IPR for the project includes:

- a PSCAD/EMTDC simulation model of a multi-infeed HVDC power system.
- specification of regional voltage and frequency support capabilities affected by converter interactions.
- coordinated design and control of multi-infeed HVDCs to enhance regional voltage and frequency performance and stability.

The Foreground IPR also includes technical reports, and any associated publications in conference or journal of the project.

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 apart of it's business and usual activities

The project involves developing a coordinated design and control strategy for multi-infeed HVDC power systems. It is not a business-as-usual activity, as there are considerable risks involved in development and no guarantee of success.

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 nature of a research programme means it inherently carries a high risk that the research may be unsuccessful. Therefore, this project cannot be carried out as business and usual activities.

This project has been approved by a senior member of staff

☑ Yes