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

Aug 2023

Project Reference Number

NIA2_NGESO049

Project Registration

Project Title

Data-Driven Online Monitoring and Early Warning for GB System Stability (DOME)

Project Reference Number

NIA2_NGESO049

Project Licensee(s)

National Grid Electricity System Operator

Project Start

July 2023

Project Duration

1 year and 6 months

Nominated Project Contact(s)

Can Li

Project Budget

£400,000.00

Summary

DOME will examine whether measuring on-line impedance spectra of a gird can give early warning of emerging oscillations, and beyond that, whether it is possible to identify which aspects of which equipment should be re-tuned to damp those oscillations. This is a data-driven method that will not require owners/vendors of wind farms to disclose their internal control models. The analytical methods for mode identification and participation assessment have been created in previous academic research, this project will assess whether these methods are capable of practical implementation. DOME is a desktop study that will use data gathered by Transmission Owners (TOs), example systems models and small-scale laboratory testing. The project will report on the viability of practical implementation and on how field trials could be conducted.

Nominated Contact Email Address(es)

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Problem Being Solved

As more inverter-based resources such as wind farms, solar PV, and interconnectors are connected to the power grid, there is a potential risk of increased oscillations occurring. These oscillations can cause a loss of generation and system security issues. Currently, the Electricity System Operator (ESO) does not have a reliable way to identify the risks and root cause of oscillations. This is due to the time, accuracy, and complexity limitations of time-domain simulation. Therefore, there is a need to explore new techniques and tools for identifying and mitigating oscillation risks.

Method(s)

DOME will examine whether measuring on-line impedance spectra of a gird can give early-warning of emerging oscillations, and beyond that, whether it is possible to identify which aspects of which equipment should be re-tuned to damp those oscillations. This is a data-driven method that will not require owners/vendors of wind farms to disclose their internal control models. The analytical methods for mode identification and participation assessment have been created in previous academic research and so this study will assess whether these methods are capable of practical implementation. DOME is a desktop study that will use data gathered by transmission owners, example systems models and small-scale laboratory testing. The project will report on the viability of practical implementation and on how field trials could be conducted.

This project will consist of the following five Work Packages (WPs) as listed below:

WP1: Assessment of Measurement Noise
It is important for the viability of the overall method to establish how a sufficiently large signal-to-noise ratio (SNR) can be achieved in practice. The first step is to determine the statistical properties of noise in measurements made on a real transmission network. Data made available by the Transmission Owners (TOs) from phasor measurement units (PMUs) will be analysed and a statistical noise model created. An assessment will be made of whether the noise model is influenced by the location of the measurement, the type of transducer and PMU or the operating point of the system (such as line flow). A crucial factor in the analysis is the update-rate or bandwidth of the PMU measurements and high bandwidth will be necessary.

Deliverable: Short technical report on noise characteristics of PMU data.

WP2: Optimal Injection Level
The noise model from WP1 will be added to a simulation model of an example transmission network and an assessment conducted of the amplitude of signal injection (shunt current injection with a voltage response or series voltage injection with a current response) to obtain a response signal with a large enough SNR for further processing. Two types of measurement will be considered: injection and measurement at the same node (a diagonal term in the impedance matrix) and injection at one node and measurement at another (an off-diagonal term). Various conditions will be considered such as electrical distance between injection and response measurement, the number of system modes to be identified, and the damping factors of those modes.

An important further factor to be considered is the consequence of exciting a system mode with the injected signal, albeit at low amplitude, and the need to trade-off SNR against avoiding mode excitation. The results will indicate the rating (in MVA) of the injection needed. An assessment will be made of the viability of creating the injection with a dedicate power electronic unit at a substation versus adding an additional control function to an inverter-based resource such as a battery energy storage unit or wind turbine. NREL will provide additional input on technical characteristics of megawatt-scale inverters used as injection devices.

Deliverable: Short technical report on the rating required of a dedicated injection device and the viability of injection via existing third-party inverter-based resources.

WP3: Location Choices for Injection
Ideally, a full identification of the system and all of its modes would use injection and measurement at every node. This is not feasible in practice: injection at every node would involve too much equipment but even measurement at non-injection nodes (for off-diagonal terms) may incur expense of very high accuracy time-stap alignment of measurements.

This project will use a test system mode to examine how many injections and measurements are needed to find and identify the dominant modes of a system. It will consider how much reliance to place of prior knowledge of a system such as a known vulnerability to oscillation in a region of the network. DNV-GL will provide advice and guidance on representation of wind farms in system models.

Deliverable: Short technical report on how many injection points and measurement points are needed to identify adequately the modes of a region of the GB transmission system or indeed the whole system.

WP4: Verification
Through WP1 to WP3, a series of system models will be built (noise statistics, injection equipment, injection locations) which will be combined into a final verification model. The intention is to create a test system that has similar characteristics to the GB system. The model will be used for a final set of verification and demonstration tests to verify how well one can expect to find mode participation factors from data-driven models. This model or a reduced version of it will be run in real-time on an OPAL-RT platform with a power-hardware-in-the-loop (PHIL) arrangement of a power amplifier and inverter to give reassurance that practical issues of measurement and control of the injection device are accounted for.

Deliverable: A set of results verifying the work of WP1 to WP3.

WP5: Global Engagement
The project will draw conclusions on the size and extent of equipment required for a viable identification of system modes from measurement data. This will include the geographic reach obtained by injection and therefore how coverage is obtained for a national-scale system, the extent to which existing PMUs are sufficient for measurement, the extent to which root-cause can be identified as a

function of measurement coverage. These conclusions will be disseminated though workshops and working groups of professional organisations (such as Cigre and IEEE).

If the conclusions indicate that the method is indeed viable as a means to find, identify and analyse emergent oscillation to provide both early warning of problems and mitigation measures, a high-level plan for progressing to field trials will be created.

Deliverable: Dissemination activities and report that outlines how a field trial of the method could be conducted.

<u>In line with the ENA's ENIP document, the risk rating is scored Low.</u>
TRL Steps = 2 (3 TRL steps)
Cost = 1 (£400k)
Suppliers = 1 (1 supplier)
Data Assumptions = 2
Total = 6 (Low)

Scope

This project aims to prove the viability of online monitoring and confirm whether a full implementation would provide benefits, including:

- Early Warning and Reduced Risk for Possible Oscillations: By continuously monitoring the power grid in real-time, online monitoring can detect the early signs of oscillations and alert grid operators before they escalate into a more significant issue. This can reduce the risk of system instability and potential blackouts.
- Reduced Renewable Curtailment: Online monitoring can provide grid operators with more accurate information about the behaviour of renewable resources such as wind farms and solar PV. This can help to reduce the curtailment of renewable energy, which occurs when the power grid cannot absorb all the renewable energy being generated.
- Reduced Model Dependency: Traditional methods for detecting oscillations rely on accurate models of the power grid and its components. Online monitoring can provide more accurate and up-to-date information about the power grid's behaviour, reducing the reliance on models.
- Increased System Security: By providing grid operators with more accurate and timely information, online monitoring can increase the overall security of the power grid.
- Contributing Toward Net Zero Target: Online monitoring can help to integrate more renewable energy into the power grid, which is critical to achieving net-zero emissions targets.
- Deeper Understanding of the Root Cause of Oscillation Instability and Potential Solutions: Online monitoring can provide grid operators with more detailed information about the behaviour of the power grid, helping to identify the root causes of oscillation instability and potential solutions to address them.

In summary, the implementation of online monitoring could bring several benefits, including increased system security, reduced renewable curtailment, and a deeper understanding of the behaviour of the power grid.

Objective(s)

The main objective of the DOME project is to investigate whether measuring online impedance spectra of a grid can provide early warning of emerging oscillations and whether it is possible to identify which aspects of the equipment should be re-tuned to dampen those oscillations. The project aims to develop a data-driven method that does not require the disclosure of internal control models by the owners/vendors of wind farms. The project consists of five work packages that will focus on different aspects of the methodology, including assessing measurement noise, determining the optimal injection level for obtaining a response signal with a large enough signal-to-noise ratio (SNR), identifying the location choices for injection, verification, and global engagement.

Overall, the project aims to assess the viability of the proposed method for practical implementation and to determine how field trials could be conducted. The project also aims to draw conclusions on the size and extent of equipment required for a viable identification of system modes from measurement data, including the geographic reach obtained by injection and the extent to which existing PMUs are sufficient for measurement.

The final outputs should include:

- Deliverable from WP1 is a short technical report on noise characteristics of PMU data.
- Deliverable from WP2 is a short technical report on the rating required of a dedicated injection device and the viability of injection via existing third-party inverter-based resources.
- Deliverable from WP3 is a short technical report on how many injection points and measurement points are needed to identify adequately the modes of a region of the GB transmission system or indeed the whole system.
- Deliverable from WP4 is a set of results verifying the work of WP1 to WP3.
- Deliverable from WP5 is a set of dissemination activities and report that outlines how a field trial of the method could be conducted.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

The ESO does not have a direct connection to consumers, and therefore is unable to differentiate the impact on consumers and those in vulnerable situations. Benefits to all consumers are detailed below.

Success Criteria

The success of the DOME project will be determined by its ability to demonstrate the viability of using online impedance spectra measurements to identify and analyse emerging oscillations in the power grid. The project's success will be measured by its ability to achieve the following objectives:

- Establishing a statistical noise model of measurements made on a real transmission network and assessing whether the noise model is influenced by the location of the measurement, the type of transducer and PMU, or the operating point of the system.
- Assessing the amplitude of signal injection required to obtain a response signal with a large enough signal-to-noise ratio (SNR) for further processing and identifying the rating required of a dedicated injection device and the viability of injection via existing third-party inverter-based resources.
- Determining how many injection points and measurement points are needed to identify adequately the modes of a region of the GB transmission system or the whole system.
- Verifying the work of WP1 to WP3 through a final set of verification and demonstration tests using a test system that has similar characteristics to the GB system.
- Drawing conclusions on the size and extent of equipment required for a viable identification of system modes from measurement data and disseminating these conclusions through workshops and working groups of professional organizations.

If the project can achieve these objectives, it will provide a reliable and effective method for identifying and analysing emerging oscillations in the power grid, which can lead to early warning of problems and mitigation measures. Ultimately, the success of the project will be determined by its ability to pave the way for field trials and practical implementation of the method.

Project Partners and External Funding

Imperial College will be carrying out the work, no external funding required.

Potential for New Learning

The DOME project has the potential to provide several new learnings in the field of power system dynamics and control. Here are a few potential areas of new learning:

- The feasibility of using data-driven methods for early-warning and mitigation of power system oscillations. If the DOME project is successful, it could pave the way for new approaches to power system control that rely less on traditional control models and more on data analytics.
- The effectiveness of injecting signals into the power system to identify system modes and participation factors. The DOME project will investigate the optimal injection level and location choices for signal injection. The results of this investigation could provide new insights into the use of signal injection as a tool for power system analysis.
- The impact of measurement noise on power system analysis. The DOME project will assess the statistical properties of noise in measurements made on a real transmission network. This analysis could provide new insights into how measurement noise affects power system analysis and control.
- The requirements for field trials of the DOME method. If the DOME project is successful, it could provide a blueprint for conducting field trials of new power system control methods. This could help to accelerate the adoption of new control methods in the power industry.

Scale of Project

The project spans 18 months with one project partner. The project consists of desktop-based research and workshops with the relevant teams across the ESO.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL5 Pilot Scale

Geographical Area

The project will be based upon the GB ESO area of operations.

Revenue Allowed for the RIIO Settlement

None

Indicative Total NIA Project Expenditure

£400,000

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 detection of oscillations in the power grid is an important step towards creating a more reliable and stable grid, which is essential for the net-zero energy transition. Oscillations in the grid can occur due to a variety of reasons, such as fluctuations in demand, changes in supply, and faults in the system. These oscillations can result in voltage and frequency variations that can disrupt the operation of power systems and cause blackouts.

By detecting these oscillations, the ESO can take proactive measures to mitigate them and prevent power outages. This will help create a more reliable, efficient, and sustainable energy system, which is crucial for the net-zero energy transition.

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 project aims to prove the viability of online monitoring and confirm whether a full implementation would provide benefits, including:

- Early Warning and Reduced Risk for Possible Oscillations: By continuously monitoring the power grid in real-time, online monitoring can detect the early signs of oscillations and alert grid operators before they escalate into a more significant issue. This can reduce the risk of system instability and potential blackouts.
- Reduced Renewable Curtailment: Online monitoring can provide grid operators with more accurate information about the behaviour of renewable resources such as wind farms and solar PV. This can help to reduce the curtailment of renewable energy, which occurs when the power grid cannot absorb all the renewable energy being generated.
- Reduced Model Dependency: Traditional methods for detecting oscillations rely on accurate models of the power grid and its components. Online monitoring can provide more accurate and up-to-date information about the power grid's behaviour, reducing the reliance on models.
- Increased System Security: By providing grid operators with more accurate and timely information, online monitoring can increase the overall security of the power grid.
- Contributing Toward Net Zero Target: Online monitoring can help to integrate more renewable energy into the power grid, which is critical to achieving net-zero emissions targets.
- Deeper Understanding of the Root Cause of Oscillation Instability and Potential Solutions: Online monitoring can provide grid operators with more detailed information about the behaviour of the power grid, helping to identify the root causes of oscillation instability and potential solutions to address them.

In summary, the implementation of online monitoring could bring several benefits, including increased system security, reduced renewable curtailment, and a deeper understanding of the behaviour of the power grid.

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

The methodology developed in this project is designed to detect and locate power system oscillations across the entire GB ransmission system. Therefore, the project will be relevant to all network licensees.

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

The method will be run for GB and as part of the project a CBA will be conducted to understand the cost of rolling out the method.

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

- Tangible deliverables will include final technical reports and publications, e.g., conference/journal papers, which will be shared with the network licensees.
- During and after project delivery, all relevant Network Licensees will be invited for a series of knowledge dissemination events based on work-package deliverables
- The relevant Network Licensees will be invited to training opportunities on the developed tools and methods

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 project aims to provide a novel approach to the detection of power system oscillations in the GB network, which is tailored to the unique characteristics and challenges of this network. Hence, this novel approach to oscillation detection in this frequency domain will be the first of its kind on the GB system. However, other notable projects include:

- Impedance Scan Methods (NIA2_NGET0001) which plans to investigate various impedance scan methods and compare them to the inbuilt PSCAD tools.

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 DOME project will use analytical methods for mode identification and participation assessment created in academic studies and assess whether these methods are capable of practical implementation. The project proposes a novel method for identifying and mitigating emerging oscillations in the power grid that is not reliant on proprietary control models and has the potential to be more efficient and effective than current methods.

The project could provide several new learnings in the field of power system dynamics and control. Potential areas of new learning include:

- The feasibility of using data-driven methods for early-warning and mitigation of power system oscillations. If the DOME project is successful, it could pave the way for new approaches to power system control that rely less on traditional control models and more on data analytics.
- The effectiveness of injecting signals into the power system to identify system modes and participation factors. The DOME project will investigate the optimal injection level and location choices for signal injection. The results of this investigation could provide new insights into the use of signal injection as a tool for power system analysis.
- The impact of measurement noise on power system analysis. The DOME project will assess the statistical properties of noise in measurements made on a real transmission network. This analysis could provide new insights into how measurement noise affects power system analysis and control.
- The requirements for field trials of the DOME method. If the DOME project is successful, it could provide a blueprint for conducting field trials of new power system control methods. This could help to accelerate the adoption of new control methods in the power industry.

Relevant Foreground IPR

The following foreground IPR is expected to be generated in the course of the project:

- A technical report on noise characteristics of PMU data.
- A technical report on the rating required of a dedicated injection device and the viability of injection via existing third-party inverter-based resources.
- A technical report on how many injection points and measurement points are needed to identify adequately the modes of a region of the GB transmission system or indeed the whole system.
- A set of results verifying the work of WP1 to WP3.
- A report that outlines how a field trial of the method could be conducted.

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:

1. 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 ESO already publishes much of the data arising from our innovation projects here so you may wish to check this website before making an application.
2. Via our Innovation website at https://www.nationalgrideso.com/future-energy/innovation
3. Via the ESO Data portal at https://data.nationalgrideso.com/
4. Via our managed mailbox innovation@nationalgrideso.com

Details on the terms on which such data will be made available by National Grid ESO can be found in our publicly available “Data sharing policy relating to NIC/NIA projects” at https://www.nationalgrideso.com/document/168191/download.

Please identify why the Network Licensees will not fund the project as apart of it's business and usual activities

As this project will be assessing methods not previously demonstrated in an electricity system operation environment with high levels of uncertainty and risk, this would not fall into BAU activities.

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 TRL of the overall framework is relatively low. Therefore, innovation funding is more suitable for exploring the project's potential and increasing the TRL before transferring into BAU activities.
- Conducting this project with NIA funding will ensure that the project findings can be shared more widely with other interested network licensees in TO/DNO, as the oscillations in the network affect multiple users of the power system.

This project has been approved by a senior member of staff

☑ Yes