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 2025

Project Reference Number

NIA2_NESO103

Project Registration

Project Title

Assurance of Stability :Digital-Twin based Stability Analysis Tool

Project Reference Number

NIA2_NESO103

Project Licensee(s)

National Energy System Operator

Project Start

November 2025

Project Duration

1 year and 11 months

Nominated Project Contact(s)

innovation@nationalenergyso.com

Project Budget

£700,000.00

Summary

Currently vendors are obliged to provide NESO encrypted ‘black-box’ simulation models of inverter-based resources (IBRs). However, there isn’t an easy way to use these black-box IBR models to form a state-space model of the IBR-dominated power grid for analysing sub-synchronous oscillations (SSO). Use of the white-box generic IBR models is an option but proper parametrisation of these across a range of operating conditions remains a challenge.
This project will use a digital twin (DT) of IBRs with its parameters estimated based on perturbed data from high-fidelity real-time simulation. The parameterised IBR models in conjunction with the known dynamic model of the rest of the grid (including synchronous machines, loads etc.) would form the overall state-space model for studying SSO under different operating conditions.

Nominated Contact Email Address(es)

Innovation@neso.energy

Problem Being Solved

At present, IBR vendors (OEMs and developers) only provide a ‘black-box’ EMT simulation model of IBRs along with a user-defined ‘white-box’ RMS (Root Mean Square) model. A black box EMT model can’t be used to develop a state-space model of the IBR-dominated power system in a bottom-up way to analyse SSO. Use of the white-box RMS model is an option but proper parametrisation of these models across a range of operating conditions remains a major challenge. This is a major barrier towards systematic stability analysis of IBR-dominated power grids.

Method(s)

This project will be delivered with a work package approach and will form part of the larger Assurance of Stability program of work.
WP1 – Estimate the parameters of IBR digital twin (DT) based on the inputs (perturbed references) and outputs of the IBRs from a high-fidelity EMT simulation model.
Use a digital twin (DT) for each IBR and estimate its parameters based on the perturbed inputs and outputs of the IBRs from high-fidelity EMT simulation. The DT model structure would be based either on vendor supplied white box RMS model (if available) or a 'generic' (e.g., WECC) IBR model.
WP2 – Develop the stability analysis tool based on the IBR DTs to study SSO and locate its root cause.
The parameterised IBR models in conjunction with the known dynamic model of the rest of the power system (the network, synchronous machines, loads etc.) would form the overall state-space model for studying SSO and locating its root cause under different operating conditions.
WP3 – Validate the effectiveness of the stability analysis tool with the physical system mimicked initially by high-fidelity EMT simulation followed by real-time simulation in Opal-RT.
This would initially be desk-based research to create dynamic models, develop underpinning methods and algorithms for parameter estimation, and validate performance through frequency-domain analysis and time-domain simulation. There will be significant laboratory work involved in mimicking the physical system in Opal RT real time simulator.

In line with the ENA's ENIP document, the risk rating for the Assurance of Stability programme is low.
TRL Steps = 1 (2 steps)
Cost = 1
Suppliers = 1 (1 supplier)
Data Assumptions = 2
Total = 5 (Low)

Scope

This project is expected to develop a small-signal stability analysis tool/framework based on the IBR Digital Twins. This is meant to identify the risk of potential SSO and its root cause for effective mitigation. Without properly parameterised DTs of IBRs, a state-space model of an IBR-dominated power system cannot be developed in a bottom-up way to study SSO and locate its root cause. This either risks SSO events or forces NESO to operate conservatively by constraining off renewables which hinders net-zero transition.

Objective(s)

The objectives of this project are to:

- Develop a small-signal stability analysis tool based on digital twins of IBRs in a bottom-up way
- Use the developed stability tool to systematically identify and mitigate potential risks of SSO

Consumer Vulnerability Impact Assessment

NESO 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 in 3.1.

Success Criteria

The success of the project would be based on the following:
Validation of simulated SSO events in EMT and real-time simulation platform using the developed DT-based stability analysis tool.
Accuracy of obtaining the stability margin and tracing the root cause of SSO.

Project Partners and External Funding

Imperial College will carry out the research in collaboration with NESO. No external funding is needed

Potential for New Learning

This project expects to deliver new methods for developing digital twins (DTs) for IBRs and a DT-based stability analysis framework to analyse and mitigate SSO. There is potential for new learning in terms of:
Method for parameter estimation to implement IBR DTs
Development of a DT-based stability tool
Analysis of SSO and its root cause using the DT-based stability tool
Standard routes of dissemination such as regular project review meetings, stakeholders' workshops and international conferences

would be used as well as any relevant reports published on Smarter Network Portal.

Scale of Project

The project spans 24 months with 1 project partner. The project consists of desk-based research and workshops with relevant NESO teams such as operability policy.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL5 Pilot Scale

Geographical Area

The project is based in Great Britain within NESO's jurisdiction

Revenue Allowed for the RIIO Settlement

None

Indicative Total NIA Project Expenditure

£700,00

Project Eligibility Assessment Part 1

Requirement 1

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

Please answer **at least one** of the following:

How the Project has the potential to facilitate the energy system transition:

This project will deliver a stability analysis tool based on digital twins of IBRs to analyse the risk of SSO in IBR-dominated power grids. This would help NESO foresee IBR-induced SSO in planning as well as operational timescales enabling less conservative operation in terms of constraining off renewables. This way higher fractions of renewables (IBRs) can be accommodated on the grid without compromising the security of supply to facilitate net zero transition while providing reliable and affordable electricity to the customers.

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

n/a

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

It is not straightforward to quantify exactly the benefit of using a digital-twin based stability tool in terms of the savings in GB system operation cost due to reduced wind curtailment, for example. Nevertheless, there is anecdotal evidence that potential savings by avoiding unnecessary wind curtailment could run into several tens of millions each year.
This project is expected to provide several benefits, including:
Enhanced system security and reliability by reducing system risk and avoiding negative control interactions (ranging from small wobbles to extreme blackouts), allowing higher fractions of renewables (IBRs) without compromising the security of supply.
Improved quality of supply and services.
Lower bills for consumers by reducing the probability of downtime, brownouts or blackouts.
Progress towards Net Zero ambitions.

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

The digital twin based stability tool is meant for system-wide stability analysis and hence is applicable across the GB system in principle.

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

This will be assessed during the project.

Requirement 3 / 1

Involve Research, Development or Demonstration

Projects must have the potential to have a Direct Impact on a Network Licensee's network or the operations of the System Operator and involve the Research, Development, or Demonstration of at least one of the following (please tick which applies):

☐ A specific piece of new (i.e. unproven in GB, or where a method has been trialled outside GB the Network Licensee must justify repeating it as part of a project) equipment (including control and communications system software).

☐ A specific novel arrangement or application of existing licensee equipment (including control and/or communications systems

and/or software)

☐ A specific novel operational practice directly related to the operation of the Network Licensees system

☐ A specific novel commercial arrangement

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

☐ A specific piece of new equipment (including monitoring, control and communications systems and software)

☐ A specific piece of new technology (including analysis and modelling systems or software), in relation to which the Method is unproven

☑ A new methodology (including the identification of specific new procedures or techniques used to identify, select, process, and analyse information)

☑ A specific novel arrangement or application of existing gas transportation, electricity transmission or electricity distribution equipment, technology or methodology

☑ A specific novel operational practice directly related to the operation of the GB Gas Transportation System, electricity transmission or electricity distribution

☐ A specific novel commercial arrangement

Specific Requirements 4 / 2a

Please explain how the learning that will be generated could be used by the relevant Network Licensees

The outcome of this project can be taken forward by NESO as follows:

- Work with recorded PMU and DSM data to demonstrate the effectiveness of the DT-based stability tool for tracing the root cause of real SSO events from the past.
- Work with commercial software vendors to integrate the DT-based stability tool as an add-on or as a third-party tool.
- Work with IBR vendors/developers and software vendors on near real-time implementation of the tool.

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

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

- This project has some synergy with an ongoing NIA project - NIA2_NGESO050 Enhanced RMS modelling for stability assurance (e-RMS) – which is focused on modelling the adequacy of IBR-dominated power systems and demonstrating the benefits of data-driven IBR modelling.

The aim of the proposed project is to develop the underpinning method and algorithms for data-driven parameterisation of IBRs in the form of digital twins. In NIA e-RMS, the physical system is mimicked by EMT simulation while the proposed project would use real-time simulation using Opal-RT platform.

- SSO Identification Automated Identification of Sub-Synchronous Oscillations (SSO) Events | ENA Innovation Portal

The SSO Identification Tool project has recently concluded, resulting in the development of a Python- based tool designed to identify potential system operating conditions that could lead to Sub- Synchronous Oscillations (SSO). The tool, created through the project, employs a combination of innovative frequency domain methodologies and machine learning techniques. This allows for the unattended execution of Electromagnetic Transient (EMT) simulations and the automatic identification of SSO events.

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 core innovation in this project is in answering the following research questions which have not been answered before:
What kind of probing is needed on IBR references (e.g., active power, reactive power or voltage) in terms of amplitude, persistence and signal type?
How to estimate the parameters of an IBR digital twin based on perturbed data from high-fidelity simulation?
How to develop the stability tool based on individual IBR digital twins (DT)?

Relevant Foreground IPR

The project deliverables are as follows.

- A report and code for an algorithm for parameter estimation to implement digital twins (DT) for IBRs
- A report and code for an algorithm for a stability tool based on IBR DTs to study SSO and locate its root cause.
- A report on performance validation of the stability analysis tool under varying grid conditions

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 Energy System Operator 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 Innovation | National Energy System Operator
Via our managed mailbox innovation@nationalenerygso.com
Details on the terms on which such data will be made available by National Energy System Operator 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 a part of it's business and usual activities

The project has a relatively low TRL and therefore has high level of uncertainty and risks, making it inappropriate for NESO to pursue it as part of business as usual.

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 has a relatively low TRL. Therefore, innovation funding is more suitable for exploring the project's potential and increasing the TRL before transferring into BAU activities. The methods are novel and have not yet been developed or trialled. There are potential risks associated with the availability of required data and the acceptable performance of the methods. Standard procedures may also need to change to integrate the developed tool due to the practicality of the runtime and the need for high computational resources. There are risks associated with acceptable performance of the methods when applied to the detailed GB network model.

This project has been approved by a senior member of staff

☑ Yes