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.

Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

NIA Project Annual Progress Report Document

Date of Submission

Jul 2024

Project Reference Number

NIA2_NGESO049

Project Progress

Project Title

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

Project Reference Number

NIA2_NGESO049

Project Start Date

July 2023

Project Duration

1 year and 6 months

Nominated Project Contact(s)

Can Li

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.

Objectives

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.

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.

Performance Compared to the Original Project Aims, Objectives and Success Criteria

Project Aim:
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 university research and so this study is to assess whether the method is capable of practical implementation. DOME is a desktop study that will use data gathered by transmission owners, example systems models and some small-scale laboratory testing. The project will report on the viability of practical implementation and on how field trials could be conducted.

Project Objectives:
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 (WPs) 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.

Success Criteria:
The following will be considered when assessing whether the project is successful:
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.

Required Modifications to the Planned Approach During the Course of the Project

These modifications have been done for this project:

- WP1: Assessment of Relationship Between Oscillation Tracing Methods and Participation Factors:

WP1 was modified to address a recent and pressing need to assess the effectiveness of oscillation tracing methods that are known to work for synchronous machine systems but where efficacy with IBR is unclear. It now addresses the theoretical basis and limits of model-free methods of oscillation tracing (such as Dissipative Energy Flow, DEF) and how they compare with identification of participation factors from state-space and whole-system impedance models (which are the focus of the rest of the project). DEF has been used by some system operators for several years to identify the sources and sinks of oscillations in traditional synchronous machine systems. Two questions now need answering. First, can DEF, or modifications of it, be relied upon for systems containing or dominated by IBR? Second, how close is the DEF method to identifying mode shapes and participation factors for free and forced oscillations? This will be a theoretical study supplemented by examination of case-study networks in the Simulink environment.

- WP2: Impedance Identification Methods:

Impedance models are very useful for participation analysis when the white-box state-space models are not made available. One major benefit of using an impedance model is that it can be identified through data-driven approaches without needing access to the detailed internal model. In this work package, impedance identification methods using frequency scanning data and using step-response data will be assessed, together with a comprehensive comparison of their relative merits. A simple simulation case study will also be employed to provide results for both of the methods. Suggestions will be made on how to select the appropriate method for root-cause tracing and system early warning in different circumstances.

Lessons Learnt for Future Projects

Lessons learnt from the work in WP1 are:

- Free oscillations in power systems are becoming a major concern around the world. The dissipative energy flow (DEF) method, together with its variants, for system oscillation tracing is not guaranteed to be correct for all cases, especially for oscillations where IBRs are dominating.

- The impedance participation analysis can indicate the root-cause correctly, but their calculation requires knowledge of both the left eigenvector (representing the input to the system) and the right eigenvector (representing the output from the system, also known as the mode shape). Even if the output can be acquired from the PMU data, it will remain difficult to obtain knowledge of input since there is no input for free oscillations. Further examination is needed to determine the useful information that can be extracted from the mode shape, and if it possible to introduce a known input disturbance in order to calculate the participation factor.
- The present tools for oscillation tracing are limited. Even if a method indicates specific participants, the lack of a known ground-truth makes it difficult to validate the inferences. A proper small-signal model which could reproduce the oscillations and can offer theorical insights would greatly enhance the study of oscillations and their tracing.

Lessons learnt from the work in WP2 and WP3 are:

- Impedance/admittance model identification is useful for analysing potential oscillations and for post-event analysis to identify the root-cause. Both the time-domain identification and frequency-domain identification methods can be used. Whereas the proper equipment for system frequency scan is still under study and is absent for now, the time-domain identification making use of responses during events like step changes in the voltage or in the load would be an appropriate solution. Various algorithms can be chosen for time-domain identification, such as least-square method and eigensystem realization algorithms.
- For time-domain impedance (or admittance) identification, it is important to know the details of the system input, including: the location where the event happened, the size of the change, and, preferably, a record of the waveform of the input. It also requires knowledge of system power flow, especially the information of loads and lines. It is preferable to know the parameters of synchronous generators (SG) so that analytical models of SGs can be applied as a priori information. A difficult case is buses which are not monitored by PMUs but with IBR connected where some assumptions have to make, such as using a generic model to represent the IBR, or, in a very simplified case, using an ideal current source. Most of the above knowledge will be accessible by the system operator so the issues raised can be dealt with.
- When the input location is far from the locations measured, the estimation of the relevant off-diagonal elements of the whole-system impedance matrix will be inaccurate. Multiple inputs at a variety of locations during a certain period would be useful to improve the accuracy but a proper method to merge the over-determined systems is needed. This needs further study.
- For a long-term system monitoring purposes, special equipment designed for frequency sweep, used in conjunction with frequency-domain identification, will be needed.

Note: The following sections are only required for those projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

The Outcomes of the Project

- A detailed technical report for WP1 has been completed and submitted to National Grid ESO.
- A joint technical report for WP2 and WP3 is being compiled and with the aim to submit to National Grid ESO during May 2024.
- An academic paper on the impedance/admittance model identification is being drafted and with the aim to submit later in 2024.

Data Access

Details on how network or consumption data arising in the course of NIA funded projects can be requested by interested parties, and the terms on which such data will be made available by National Grid can be found in our publicly available “Data sharing policy related to NIC/NIA projects” and www.nationalgrideso.com/innovation.
National Grid Electricity System Operator already publishes much of the data arising from our NIC/NIA projects at www.smarternetworks.org. You may wish to check this website before making an application under this policy, in case the data which you are seeking has already been published.

Foreground IPR

The following reports are expected to be released on to the Smarter Networks Portal:

- Technical reports on each work package which will give detailed exposition and analysis on the issues being studied and the solutions that have been created.
- Matlab codes for the system identification process.
- Presentation slides that have been presented in public dissemination events.