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 Close Down Report Document

Date of Submission

Mar 2025

Project Reference Number

NIA2_NGESO023

Project Progress

Project Title

Inertia Measurement Method Optimisation

Project Reference Number

NIA2_NGESO023

Funding Licensee(s)

NESO - National Energy System Operator

Project Start Date

September 2022

Project Duration

2 years and 1 month

Nominated Project Contact(s)

Anna Blackwell

Scope

- Understand the accuracy of the inertia monitoring systems and dependencies on different generation / demand profiles.
- Understand regional differences of inertia.
- Establish standardisation methodology for measuring inertia and RoCoF.
- Clarity on accuracy of inertia measurement will feed into specification for inertia products with both Control and planning timescales.

Objectives

Using the metering data from the two new inertia system tools developed following earlier innovation and IT projects, along with the existing NGESO inertia “estimate” and operational data, the project will:

- Analyse and verify the quality of the data from these new tools through comparisons to the existing NGESO estimation.
- Establish different scenarios / use cases for inertia and RoCoF, for example based around levels of synchronous and renewable generation and demand.
- Compare the different solutions based on the established use cases.
- Identify regional inertia variations and representations.
- Develop measurement parameters and specification for reference instrumentation.
- Build on data and use cases to establish standardisation for inertia measurement by comparing measured results to modelling.

Success Criteria

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

- The project delivers against objectives, timescales and budgets as defined in the proposal
- Verification of the innovative real-time inertia monitoring solutions
- Deeper understanding of how different generation scenarios impact the inertia on the network
- Deeper understanding of regional inertia variations across GB
- Standard methodology developed and documented for assessing inertia measurements

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

The project has been concluded with the completion of all deliverables within the planned 2-year timescale and budget. The project has met its overall objective of understanding and assessing the accuracy of measured inertia data from two commercial monitoring tools as well as NESO's inertia estimation.

A detailed analysis of the measured inertia data from the commercial monitoring tools and comparison with NESO estimations was carried out in Work Package 1. The analysis considered data from a 2-year period between 2022 and 2024, thus including the full calendar year 2023 which enabled consideration of seasonal variations and dependencies. Across the whole time period, the extent of differences between measured inertia data and NESO's calculated values was evaluated to assess the level of agreement. The results enabled a comprehensive validation of the plausibility of measured inertia data based on known transmission-connected inertia sources and NESO's operational experience. The variation of differences between measured and estimated inertia data with different power system scenarios was studied in detail, including correlation to time of day, day of week, time of year, share of non-synchronous generation, level of demand, and inertia level. The results provided deeper understanding of how different generation scenarios impact inertia measurement and estimation. Additional analysis aspects were the extent of variation of measured inertia over short times scales up to 2 hours and whether this is attributable to real inertia changes or measurement noise; the level and variation of residual inertia calculated from measurements by subtracting inertia from known synchronous machines; consideration of analysis results in the context of the confidence intervals of measured inertia values including implications on predicting the rate-of-change-of-frequency (RoCoF) for large loss of infeed events. The analysis was carried out continuously throughout the project duration with interim results formally reviewed in 7 meetings with NPL and NESO. The final results were documented in a report completed in July 2024, which was submitted to NESO and also reviewed in a further meeting.

The activities completed in Work Package 2 led to a deeper understanding of regional inertia variations across GB. Using the reduced 36-bus model of the GB power system, simulation studies have been completed to evaluate the extent of regional differences in frequency and RoCoF in historical and future scenarios. The results indicate that under transient conditions, short-term (<1 second) differences may occur between frequency and RoCoF in different locations, and differences are significant with respect to measurement accuracy. Furthermore, the sensitivity of local RoCoF to variations in regional inertia has been studied and found to be significant over timescales less than 500 milliseconds based on the simulation outputs. Two interim reviews of results have been held and the final report for WP2 was completed in June 2023.

In Work Package 3, a standard methodology for verification of inertia measurements was developed and documented. For the purpose of inertia measurement verification, the primary system operators use case for inertia measurements was considered to be the prediction of the maximum power system RoCoF that occurs immediately in response to sudden loss of a large power system infeed or export. The aim of the verification is to assess to what extent the measured inertia values can meet this use case by comparing predicted RoCoF with reference measurements of RoCoF provided by NPL. The accurate measurement of RoCoF in the transient phase up to 0.5 seconds following a large power loss is a well-known problem as the voltage signals are affected by local oscillations and phase steps resulting from regional power exchanges and impedance changes. In this project, NPL has developed a new measurement method to provide robust reference values for frequency and RoCoF under transient system conditions. The method is based on empirical mode decomposition (EMD) to successfully remove the oscillation modes and phase steps to determine the underlying grid centre-of-inertia frequency regardless of the measurement location. The method has been documented and submitted for publication in a peer-reviewed journal.

In Work Package 4, reference instrumentation for inertia measurement verification was developed. The development of reference instruments was completed by September 2023 in time for onsite installations (see WP5 below). The instruments have been refined to register candidate power system events when measured rate-of-change-of-frequency (RoCoF) exceeds a specified threshold. Automated consolidation of the measurement data streams from multiple instruments has been implemented to distinguish system RoCoF events from local excursions caused for example by normal power system switching operations. Three instruments have been setup at NPL labs in London, Glasgow and Huddersfield to verify time synchronization, remote access, and measurement data processing. All units were calibrated against national standards of AC voltage and current and are recording frequency and RoCoF in real-time as well as other standard phasor measurements. For each event, the underlying waveform measurement samples are captured with high resolution in addition to real-time frequency and RoCoF values, to allow reproducibility and further investigations of the measurement results. The software has been configured to provide daily event reports. Further software has been written to analyze frequency event data using the EMD method. The technical specifications of the instrumentation have been documented.

In Work Package 5, onsite verification of inertia measurements was carried out using NPL reference instruments. The project team worked with the 3 Transmission Owners to arrange installation of NPL's instruments in several network locations. By July 2024, instruments were installed in high-voltage substations in North Scotland, South Scotland and in England in addition to instruments connected to the low-voltage network at NPL sites in London, Glasgow, and Huddersfield. The methodology developed in WP3 was applied to frequency measurements from these instruments to obtain reference RoCoF values for 50 large losses of power infeed/exports. The centre-of-inertia RoCoF determined from different measurement locations differed by no more than 0.02Hz/s in most cases. For each loss event, the predicted RoCoF from measured inertia data and from NESO's estimated inertia values were compared with the reference measurement, thus providing an assessment of the accuracy of the inertia values with respect to the primary use case under consideration. The variation of accuracy with different power system conditions (demand, wind generation, inertia level) was investigated. All results were presented in formal review meetings and documented in a two-part report submitted to NESO. A subset of the results was included as a case study in the paper documenting the verification method which was submitted for publication in a peer-reviewed journal. It was found that in most cases the NESO inertia estimation predicts a higher RoCoF value than the NPL reference measurement, hence, the estimation method yields a conservative inertial response.

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

The planned approach was to primarily use reference measurements taken in high-voltage substations to verify the inertia measurements in a lower noise environment compared to low-voltage network connection. Since the installation of NPL's instruments in high-voltage substations was slower than planned and due to some instruments not measuring continuously due to intermittent remote access, the approach was modified to include reference measurements from instruments connected to the low-voltage at NPL sites which met the accuracy requirements and enabled a larger number of frequency events to be used in the verification.

Lessons Learnt for Future Projects

Future projects should anticipate that setting up data access and installation of non-standard software packages can take several months. Contingency should be allowed for delays in installation of instruments in high-voltage substations. The verification procedure requires information about the size of the power loss which is published in NESO's system incident report GC105 which has a lag time of 3 to 4 months, this should be considered in the timeline of future projects using information from this report.

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

1. Assessment of the plausibility of results from commercial inertia measurement systems with respect to existing inertia estimation. Identification of scenarios in which measured and estimated inertia have smaller/larger divergences.
2. Assessment of the extent and effect of regional differences in frequency, its rate of change and inertia in the GB power system. Along with frequency measurement results, the results may be used to plan regional inertia monitoring requirements and optimize local frequency management.
3. Use cases and measurement requirements for frequency, its rate of change and inertia have been documented. This information may be used to review existing and specify new requirements for response times of frequency services.
4. Methodology for validation of inertia measurements has been developed. This includes a method for reference measurements of the RoCoF due to inertial response to loss of large infeed events. The methodology provides a framework to assess the extent to which inertia measurement results from commercial systems meet the requirements of the main use case of predicting the frequency

trajectory after large disturbances. The methodology has been presented to international Working Group CIGRE C2.45 which is preparing a technical brochure providing guidance on ‘Estimation, evaluation and provision of power system inertia in networks with a high share of renewable generation’ due to be published in 2026, and to IEC TC8 for considerations on a future standard on power system inertia.
5. The absolute accuracy of the commercial systems measurement results and of NESO’s inertia estimation has been quantified using reference RoCoF measurements from NPL’s instruments installed in different network locations. The results enable NESO to assess and optimise the reliability of inertia measurements and estimations for operational use.

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 outputs will be owned per IPR arrangements between ESO and NPL:

-Methodology, interim presentations and final report of analysis and comparison of inertia measurement results
-Methodology, presentations and final report on investigation of regional differences in frequency, RoCoF and inertia
-Documented use cases and requirements for frequency, RoCoF and inertia measurement
-Documented reference method for inertia measurement verification
-Technical specification for reference measurements
-Presentations and reports on results of onsite verification of inertia measurements

Planned Implementation

The project has been successful in enabling deeper understanding of both measured and estimated inertia data, as well as in developing a verification approach and applying this to an initial set of field measurements. The following next steps are recommended:

It is recommended to continue verification of inertia data to increase the diversity of the results set, strengthen conclusions and more clearly identify patterns related to different power system scenarios. The reference method could be retrofitted to existing phasor measurement units to enable NESO to make long-term comparisons.

The existing verification method is event-based and assesses the accuracy at specific points in time depending on when large frequency events occur. The development of a real-time tool to indicate reliability of inertia measurements and estimations based on the analysis insights from this project is recommended.

One of the inertia monitoring systems is currently only implemented regionally for Scotland with planned system-wide rollout. As this rollout progresses, it is recommended to apply the developed analysis and verification methods to new inertia measurement results.

Net Benefit Statement

Through project activities NPL has successfully developed a methodology for validation of inertia measurements which has been submitted for peer review and considered for a future inertia measurement standard. This proposal could lead to an internationally recognised benchmark for evaluating inertia measurement techniques.

Additional learning captured has highlighted the challenges and potential limitations with relying on deployment of reference instruments for field measurements for event-based inertia measurement validation, though a further development of the approach to apply the methodology to existing phasor measurement units in additional locations can increase the robustness of any conclusions drawn from future work.

Increased clean power generation and reduction in constraint payments: Inertia is a critical parameter that determines whether the power system is able to withstand sudden changes in generation or demand. Therefore, NESO has to ensure that sufficient inertia is present in the power system at all times. This can sometimes mean that clean power sources that provide no inertia, in particular wind generation, are constrained in favour of fossil-fuelled spinning machines that provide inertia. As more accurate inertia monitoring is becoming available, NESO can better assess the safety margin from the minimum inertia level and allow more low-inertia clean power generation. Since clean power generation has to be paid to constrain their power output, there is also a financial benefit in reducing these occurrences.

Optimise costs of inertia and frequency response services: As clean power generation capacity continues to increase, there is less inertia that is provided as a by-product of active power generation. To maintain minimum inertia levels, NESO has already started to procure inertia from several units through the Stability Pathfinder. The simulation studies and the approach used to carry out the analysis from Work Package 2 can be utilised for future assessment and planning for regional frequency management. The assessment of the two commercial inertia measurement systems compared to existing inertia estimation has led to a deeper understanding of the variability of inertia measurements by identifying scenarios of greater or smaller divergences. Further work is needed to have sufficient confidence in the output from the commercial systems, though this comparison analysis aided the reevaluation of the inertia estimate to ensure NESO takes appropriate operational actions to maintain system security. Accurate inertia measurements and estimates benefit economic system operation, since the procurement of inertia in planning and control room timescales can be optimized, i.e. by ensuring sufficient but no unnecessary inertia is available. Since the level inertia also determines how far the frequency falls after a sudden loss of power infeed, the planning and procurement of frequency response services can be similarly optimized to ensure the system is secured at minimal cost to customers.

Security of supply: Another benefit of sufficient inertias security of supply. If inertia levels are too low, the power system is at risk of not being able to recover from system frequency disturbances such as interconnector trips. Reliable inertia monitoring enables NESO to prevent inertia from dropping to critically low levels and thus preventing large RoCoF that could cause customer disconnections. The number and capacity of interconnectors is steadily increasing, so another benefit is that there is sufficient inertia to enable an unconstrained internationally connected power system, which can compensate variable power availability in the UK and provide UK customers access to cost-effective clean power from Europe and beyond.

Other Comments

The Project outcomes and results contain confidential information and intellectual property rights that cannot be disclosed in this Report due to their proprietary nature. Should the viewer of this Report ("Viewer") require further details this may be provided on a case by case basis following consultation of all Publishers. In the event such further information is provided each and any Publisher that owns such confidential information or intellectual property rights shall be entitled to request the Viewer enter into terms that govern the sharing of such confidential information and/ or intellectual property rights including where appropriate formal licence terms or confidentiality provisions. Dependent upon the nature of such request the Publishers may be entitled to request a fee from the Viewer in respect of such confidential information or intellectual property rights.

Standards Documents

Article submitted for peer-reviewed publication: A Proposed Reference Method to Verify Electrical Power System Inertia Measurements
Pre-print available at https://doi.org/10.36227/techrxiv.173202802.22056769/v1