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

Apr 2018

Project Reference Number

NIA_NGSO0007

Project Registration

Project Title

Investigation & Modelling of Fast Frequency Phenomena (“F2P”)

Project Reference Number

NIA_NGSO0007

Project Licensee(s)

National Grid Electricity System Operator

Project Start

April 2018

Project Duration

1 year and 1 month

Nominated Project Contact(s)

Dr Martin Bradley

Project Budget

£340,000.00

Summary

Renewable generation has been growing at historically high rates over the last decade in GB as well as other parts of the world. This rapid growth is predicted to continue at an increasing pace in order to achieve legally binding 2050 climate change targets as agreed for the UK. One important characteristic of this new generation is that it is connected through power electronic convertors and subsequently does not present any inertia to the power system. The aim of the F2P project is to accurately observe and consequently predict frequency fluctuations at an operational level across the GB power system.

Nominated Contact Email Address(es)

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Problem Being Solved

As the System Operator for the GB transmission system, National Grid publishes an annual ‘Future Energy Scenarios’ document that presents details of scenarios that are based on the energy trilemma (security of supply, sustainability and affordability) and provides credible pathways for the future of energy for Great Britain (GB) out to 2050.

As described in the scenarios, renewable generation has been growing at historically high rates over the last decade in GB as well as other parts of the world. This rapid growth is predicted to continue at an increasing pace in order to achieve legally binding 2050 climate change targets as agreed for the UK. One important characteristic of this new generation is that it is connected through power electronic convertors and subsequently does not present any inertia to the power system. This has two important consequences at the GB system operational level:

1. When unavoidable disturbances occur on the GB power system, for example faults causing large generators or transmission lines to trip, these events lead to larger frequency fluctuations than in the past;
2. Compounding this operational challenge, the renewable generation itself is also more likely to trip as a result of the frequency fluctuation, either due to the rate of change of frequency (“ROCOF”) or the sudden change in phase angle (“vector shift”).

National Grid is currently faces a number of challenges to measure and manage the impact of reduced inertia, which incur a significant cost in operating the GB system. ROCOF must be managed to avoid generation protection relays tripping and desensitizing ROCOF relays would allow the system to operate at lower levels of inertia. There is a need for frequency response which acts faster than the mechanisms used today and to provide the flexibility needed closer to real time. Vector shift is a more complex issue to manage because it can arise from either transmission or generation/demand trips, whereas ROCOF mainly arises from the latter (though some transmission trips can disconnect a large volume of generation/demand).

In parallel with the changes in embedded and non-embedded generation, the characteristics of demand have also been changing, with widespread deployment of energy-efficient lighting and power-electronic controlled loads. This means that the inertia of demand is likely to have changed significantly compared to historic behaviour, with change likely to continue into the future.

Method(s)

A potential response to the operational challenges described which this project is addressing, is enabled by the arrival and deployment of high-resolution synchronised measurement capabilities using "Phasor Measurement Units" (PMUs), which makes it possible to accurately observe and consequently predict these frequency fluctuations across the GB power system as a whole.

Such an accurate prediction capability would enable the potential impact of ROCOF and vector shift to be more cost-effectively managed. It should also enable the inertia of demand (sometimes referred to as “residual inertia”) to be estimated from actual incident data, such that this time-varying and load-varying parameter can be factored into prediction studies to improve their accuracy.

This project therefore proposes to use Phasor Measurement Units (PMUs) to accurately observe and consequently predict frequency fluctuations at an operational level across the GB power system. This will be achieve through three work packages which will be delivered as part of the project outlined below:

Work Package 1: Data Gathering, Visualisation and Investigation
Months 1-8:
1.1 Gather PMU data for system incidents of interest:

• Tasks: Large-scale data collection access and management will be established for PMUs operated by National Grid. In addition, data will be sought from the Scottish Transmission Owners (TOs) and other GB universities with PMUs.

- Identify events of interest and assemble relevant data.
- Deliverable: Report including associated datasets.

• Develop a visualisation approach for overlaying this data on the GB power system:

- Tasks: Collaborate with data scientists within the Brunel Smart Power Networks theme to explore data visualisation methods. Effective visualisation should help the project and the wider user community to understand the behaviour of fast frequency phenomena. It is expected that animating the spread of frequency waves will be quite illuminating in helping us understand the phenomena.
- Deliverable: Report including visualisation of actual power network events.

1.2 Investigate the variation of fast frequency phenomena vary with power system location and characteristics.

• Tasks: Access historical power system operation information from National Grid (demand levels, generation pattern) and investigate correlations with fast frequency phenomena in recorded disturbance events.
• Deliverable: Report setting out the variation of fast frequency effects with power system characteristics.
• Milestone: Publication submission covering all three WP1 elements (November 2018) to the IEEE Power Engineering Society General Meeting July/August 2019.

Work Package 2: Modelling & Validation using conventional power system analysis software
Months 3-10:
Explore and develop power system modelling to explain the observed phenomena.

• Tasks: Investigate and validate the use of National Grid simulation software (DigSilent PowerFactory) to accurately model high-speed frequency phenomena. Explore other simulation software and modelling techniques as appropriate.
• Deliverable: Report on the effectiveness of modelling fast frequency phenomena in DigSilent PowerFactory and any other packages investigated, including recommendations for any improvements in National Grid data, models and practices.

Work Package 3: Modelling & Validation using OPAL-RT
Months 6-12:
3.1 Install and configure OPAL-RT, and establish a range of test datasets from simple models, through the 32-bus Enhanced Frequency Control Capability (EFCC) project model to the full GB power system. At each stage, compare results with DigSilent simulations, and for more sophisticated models compare with actual PMU results. For OPAL-RT, the focus will be especially on vector shift effects, though ROCOF effects will also be validated.

• Tasks: Set up OPAL-RT software (RT-LAB 11 + ePHASORSIM) at Brunel University. Implement test models, EFCC 32-bus model and import full GB model from NG's OLTA system. Validate results against conventional power system simulation results and PMU measurements.
• Deliverable: Report on the effectiveness of OPAL-RT modelling, especially with respect to vector shift, and make recommendations as to its possible use within National Grid and any further modelling development that should be explored.

Scope

This project uses the capabilities of Phasor Measurement Units' (PMUs) accurate prediction capability to enable the potential impact of ROCOF and vector shift to be more cost-effectively managed.

A particular focus of this project is the spatial behaviour of system frequency following a disturbance. Examination of historic PMU data indicates that the initial ROCOF and vector shift varies with location on the system.

Depending on the location of the critical fault, the pattern of inertial generation and the disposition of vulnerable embedded generation, it may be possible to exploit this spatial behaviour to relax the inertia management criteria compared to current practice.

Objective(s)

The aim of the F2P project is to accurately observe and consequently predict frequency fluctuations at an operational level across the GB power system. The following objectives are being targeted:

1. Gather PMU data for GB power system incidents of interest;
2. Develop a visualisation approach for overlaying such gathered data on the GB power system;
3. Explore the variation of frequency phenomena with power system location and characteristics;
4. Explore and evaluate whether existing power system modelling software can comprehensively explain the observed phenomena. Make recommendations as appropriate for any improvements to National Grid's data, models or processes.
5. Implement a range of models in the OPAL-RT software (RT-LAB 11 + ePHASORSIM), from simple test models up to the full GB system.
6. Demonstrate simulation of actual incidents in the OPAL-RT software, validating results at the PMU level.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

Success Criteria

The project will be successful if National Grid is able to pursue new activities or modify existing activities, using robust research evidence gathered through this project.

The proposed methodology and activities to be undertaken by the project will aim to provide new insights for managing inertia, ROCOF and Vector Shift on the GB electricity system.

- It is expected that the accurate prediction capability of Phasor Measurement Units (PMUs) would enable the inertia of demand (sometimes referred to as "residual inertia") to be estimated from actual incident data, such that this time-varying and load-varying parameter can be factored into prediction studies to improve their accuracy.
- The project focus on studying the spatial behaviour of system frequency following a disturbance will help establish if this approach can be exploited to relax the inertia management criteria compared to current practice.

This project will therefore be successful if it can provide a better understanding and enhanced modelling capabilities of frequency and inertial characteristics. This will help inform the frequency management process and influence the design and deployment of regional frequency services where relevant. It could also drive detailed regional modelling of the frequency and inertial characteristics for the whole system (transmission and distribution).

Project Partners and External Funding

This project will involve one external partner Brunel University. There is no external funding involved in this project.

Potential for New Learning

The focus of this project will be on the spatial behaviour of system frequency following a disturbance on the GB electricity system. This project's methodological approach and proposed activities expect that it may be possible to exploit this spatial behaviour to relax the inertia management criteria compared to current practice. This will involve the following to be investigated as areas where there will be potential new learning generated:

- Exploration of the spatial behaviour of frequency for historic incidents using as much PMU data as can be accessed (both NG and non-NG sources);
- Re-creating system studies for the period of the historic events;
- Cross-checking observed spatial behaviour against model predictions for operating conditions on the day, including any trips of embedded generation that can be attributed to the disturbance;
- Refining the modelling approach if necessary depending on the results of the studies;
- Mapping the spatial frequency disturbance from known disturbance locations (largest loss of generation or demand) onto the distribution of vulnerable renewable generation to predict the likely impact of typical events;
- Developing operational procedures and measures that can be used in day-ahead and real-time operation to refine the application of the inertia management criteria.

Scale of Project

The project will predominantly involve laboratory or desk-based research activities.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

This work is of potential benefit to inform and manage inertia of the GB transmission system.

Revenue Allowed for the RIIO Settlement

None.

Indicative Total NIA Project Expenditure

The total indicative NIA expenditure for this project is £340,000.

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:

n/a

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)

It is conceivable that through this project and the insights which it will deliver can inform improvements in computer modelling and regionalisation of ROCOF and Vector Shift security criteria. This could lead to a saving in future years in the region of £1m-2m per annum resulting from the potential reduction of the ROCOF constraint level by 1% per annum.

Please provide a calculation of the expected benefits the Solution

National Grid currently spends around £500 million on frequency response and reserve generation [1]. By 2020, in the region of an extra £200-£250million per annum to manage the impact of reduced inertia on the GB electricity system [2].

Vector shift is a complex issue to manage because it can arise from either transmission or generation/demand trips, whereas ROCOF mainly arises from the latter (though some transmission trips can disconnect a large volume of generation/demand).

The innovation project will increase our insight into fast frequency phenomena on the GB power grid through analysis and visualisation, and make recommendations on data, models and processes for managing power system inertia.

The current spend on managing ROCOF is estimated at around £35m per annum, and this is likely to increase as inertia falls further. Securing Vector Shift faults may create additional challenges. The benefit of this project is to improve the management of power system inertia including

• The optimization of ROCOF constraint,
• The improvement in inertia estimation.

The “Roadmap for Flexibility Services to 2030” report from Imperial College London indicates that a potential saving of £100 million per annum on frequency response cost with 50% lower on ROCOF constraint level (Figure 23, [3]). The expected benefits from this innovation project could help to reduce ROCOF constraint level by an estimated 1% per annum (which equates to approx. £1million-£2 million per annum) on these costs.

[1] Electricity Balancing Services, National Audit Office
https://www.nao.org.uk/wp-content/uploads/2014/05/Electricity-Balancing-Services.pdf

[2] Smart Frequency Control Project Fact Sheet, National Grid
https://www.nationalgrid.com/sites/default/files/documents/NIC_Fact_Sheet_%28CG%29_0.pdf

[3] Roadmap for Flexibility Services to 2030 – A Report to the Committee on Climate Change, Poyry and Imperial College London.
https://www.theccc.org.uk/publication/roadmap-for-flexibility-services-to-2030-poyry-and-imperial-college-london/

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

This method is specific to the System Operator who is responsible for managing frequency in GB. However, it will benefit all market participants by giving National Grid improved capability for managing the power system.

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

The costs for implementation of the method are expected to be modest, since it is likely to consist of improved modelling within existing processes. Depending on the benefits from the project, National Grid may also choose to adopt use of the OPAL-RT software, in which case commercial versions of the hardware and licenses in the project would apply.

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

Renewable generation has been growing at historically high rates over the last decade on the GB electricity system. This rapid growth is predicted to continue at an increasing pace and one important characteristic of this new generation is that it is connected through power electronic convertors and subsequently does not present any inertia to the power system. This has consequences at the GB system operational level and as the GB System Operator, National Grid manages the impact of this reduced inertia.

The learnings from this innovation project will increase our insight into fast frequency phenomena on the GB power grid through analysis and visualisation, and through development of conventional modelling techniques together with the new OPAL-RT software. The project will make recommendations on data, models and processes for managing power system inertia that can be used by National Grid and other Network Licensees to enable and support both the current and future large-scale integration of renewable energy sources into the GB power system in an operationally secure and economic manner.

Or, please describe what specific challenge identified in the Network Licensee's innovation strategy that is being addressed by the project (RIIO-1 only)

This project will help address the strategic innovation areas (Managing volatility in a low-inertia system, Supporting Voltage and Reactive Power) in the National Grid System Operator Innovation Strategy document published in Feb 2018.

☑ Has the Potential to Develop Learning That Can be Applied by all Relevant Network Licensees

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.

Relationship of this innovation project to other known initiatives which it complements and builds on:

1) NIA_NGET0192 - SIM ("SAMUEL Inertia Measurement"; project now complete) Complementary

Project SIM ("SAMUEL Inertia Measurement NIA_NGET0192") deployed switched load-banks onto the network to attempt to measure system inertia by simultaneously switching a total of 3MW and examining the impact on system frequency. The project investigated methods to accurately measure inertia and proved that it could actively measure inertia round the clock for the whole Great Britain Grid. This F2P innovation project could be used to simulate the effect of the load switching, including known spatial variations, and this simulation could be validated against measured results to provide a richer estimation of system inertia parameters rather than just attempting to calculate an "average" value of inertia for the whole system.

2) SPTEN01 - Project VISOR ("Visualisation of Real Time System Dynamics using Enhanced Monitoring"; project now complete). Will build on results

Project VISOR had three main goals: enhanced visibility of power system oscillations, validation of dynamic models and better understanding, visibility & representation of true system limits. As such, it was not addressing inertia-related issues, but it created a valuable network of PMUs across the GB transmission networks, together with datasets from actual incidents. Results showed that existing simulations do not reproduce the fastest initial transients (over the first 1/10s) which are believed to give rise to vector shift effects, and hence the results support the need for this F2P project.

3) NGETEN03 - EFCC ("Enhanced Frequency Control Capability"; in-flight). Will build on EFCC modelling work

This inflight project is looking at using wide-area control based on PMUs to deliver high-speed frequency response provision. It does not address vector shift issues, and the focus is on response delivery rather than improving modelling and prediction of frequency effects, but the modelling aspects of EFCC are relevant to thisF2P project. EFCC is using a 36-bus network model, and the project will engage with EFCC participants for knowledge transfer. F2P would explore modelling on the full NG network, running simulations on National Grid's OLTA infrastructure, as has been established in previous projects with Brunel.

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

In order to address the operational challenges which National Grid as the GB System Operator faces for managing inertia, this project leverages on the arrival and deployment of high-resolution synchronised measurement capabilities using "Phasor Measurement Units" (PMUs). Using PMUs, it is possible to accurately observe and consequently predict these frequency fluctuations across the GB power system as a whole. The specific focus of this project and its innovative approach is centered on understanding and visualising the spatial behaviour of system frequency following a disturbance on the system. Examination of historic PMU data indicates that the initial ROCOF and vector shift varies with location on the system; depending on the location of the critical fault, the pattern of inertial generation and the disposition of vulnerable embedded generation, it may be possible to exploit this spatial behaviour to relax the inertia management criteria compared to current practice. This has not been tried before as the growth and increasing impact of renewable generation on the inertia of the GB electricity system is being faced only recently, thus triggering the need for innovative approaches to better understand and manage the resulting consequences.

Relevant Foreground IPR

n/a

Data Access Details

n/a

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

The scope of work involved in this innovation project involves research and development activities which need to be carried out in a laboratory environment before the methods can be validated and used to support real-time control room operations to manage the challenges of a low inertia system. The proposed methodology for this project has not been tried beforehand is dependent on the specialist skills and knowledge of the academic partner.

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

NIA funding is the chosen funding route for this project as this would facilitate collaboration with the chosen academic partner for this innovation project to access the required specialist skills and expertise in a cost-effective and timely manner. Due to the risks (e.g. accessing PMU data, setting up the OPAL-RT equipment in the laboratory to import the data and achieving correlation between modelled and actual results in Work Package 2) associated with the project, the proposed method for this innovation project will be investigated and tested in a laboratory environment before it can be validated for use in the real-time operational systems to manage the GB system. Through running the project under the NIA scheme, this would also allow National Grid to disseminate the learnings from the project to the energy sector and GB network licensees. This is expected to contribute to enhancing the knowledge and capabilities for managing inertia on the GB electricity system as well as influencing the direction for future R&D activities at National Grid, the energy sector and academic community. It is expected that the learnings from this project will also benefit the distribution network operators (DNOs) and support the GB whole system operability strategy

This project has been approved by a senior member of staff

☑ Yes