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

Feb 2018

Project Reference Number

NIA_NGSO0005

Project Registration

Project Title

Phase Lock Loop-Related Improvements to Non-Synchronous Generation Models

Project Reference Number

NIA_NGSO0005

Project Licensee(s)

National Energy System Operator

Project Start

February 2018

Project Duration

0 years and 10 months

Nominated Project Contact(s)

Ben Marshall

Project Budget

£80,000.00

Summary

The intention of this project is to bring about revolutionary change to our non-synchronous models by introducing PLL-informed non-synchronous dynamic performance models into our power system analysis tool digsilent. We can validate the models against real experience so as to be as accurate as possible. This validation process is in itself innovative given there is no precedent or process for doing this today, here or internationally. The intended internal outputs from this exercise would be both a step change in our modelling capability of non-synchronous technology and a pathway to sustain this step change into normal business. The intended external outputs from this project would be to provide the wider industry with reference modelling insight for different types of PLL informed control, and also provide a recommended process which allows these reference models to be validated, adapted or allocated based on the Users own technology choices and connection context.

Third Party Collaborators

Power Systems Consultants UK Limited

Nominated Contact Email Address(es)

box.so.innovation@nationalgrid.com

Problem Being Solved

Synchronous machines are inherently coupled electromagnetically with the Electrical Transmission and Distribution Systems; this means that during a disturbance in Voltage, Frequency and power angle, they immediately inject reactive and active current in predictable and beneficial ways to support the power systems recovery and resilience. Non Synchronous Technologies (NST) based

on the control approaches normally applied have no inherent electromagnetically coupled “sense “of the system, they instead need to be “told” via their control systems how to relate themselves to a measurement of the synchronous AC Power system and then respond in the right way to remain synchronised to that power system at all times. NST do this by means of use of a Phase Lock Loop (PLL) assisting the synchronisation which polls the power system for information on its voltage, current and phase, and from that informs complex control algorithms that predict where the system will then be at the point of injection so the NST can synchronise. A PLL and the related control algorithms are only as effective as the quality of information of the system it can extract in its measurement and the speed it can then respond to that information with an aligned “synchronised” current infeed.

Core to the operation of all non-synchronous technology is the function of the Phase Lock Loop in providing the technology with the information it needs to synchronise to and follow the behaviour of the GB transmission system. Recent SOF assessment has illustrated the importance of reflectively modelling the impact of this and related control elements across system disturbances going forward across all non-synchronous technology. Without representative modelling, various operability challenges emerge, some examples are discussed briefly below.

1. **Voltage and Frequency management**- during a disturbance, the ability of a PLL to reference the power system is compromised, this means that during a fast dip in voltage the PLL may either

1) Do nothing, meaning the output of the controller does not change , or it operates in a pre-defined manner for such situations, or

2) It switches off ahead of receiving better information.

This means in practice that the way in which NSTs support voltage during a fault depends on the nature of their PLL- based control, which can be different. If the frequency is disturbed, and the system inertia is low, again the PLL cannot perfectly follow, with a delay of roughly 60ms before being able to re-establish synchronisation. Modelling this behaviour becomes important in the study of frequency disturbances - in particular in scenarios of rapid changes in frequency nationally and regionally, and in cases where both frequency and voltage are simultaneously disturbed.

2. **PLL interaction**- at low levels of Short Circuit Level the PLL-informed current injections into the power system become increasingly more prominent, informing other PLL and non-PLL based control systems. Without modelling these behaviours representatively, new frequency modes of control instability can be missed, but equally other frequencies or instability can be at risk of being overstated. Our SOF analysis is already noting that these new forms of instability have the potential to influence practical capacity upon the power system.

3. **Loss Of Mains (LoM)** Protection is normally of a RoCoF or Vector shift type. Increasingly we are becoming exposed to the operation of these protections removing Distributed Generation in response to a disturbance at transmission system level which can create or compound frequency or voltage events. We currently lack sufficient insight into these events to adequately inform our modelling. For example Vector Shift – we do not understand why or what influences the risk of embedded generation trip due to it. As a result, we can only attempt to contain the worst case effect of a loss of all those embedded generators tripping in the area of the transmission system effected, leading to higher operational cost spend than if it were possible to accurately model this issue. The PLL behaviour informs our modelling across these initial periods of frequency and voltage disturbance. Improved PLL modelling allows validation of real events and, from that, forecasting and mitigation of these LoM scenarios.

Method(s)

The intention of this project is to bring about revolutionary change to our non-synchronous models by introducing PLL-informed non-synchronous dynamic performance models into our power system analysis tool Digsilent. We can validate the models against real experience so as to be as accurate as possible. This validation process is in itself innovative given there is no precedent or process for doing this today, here or internationally.

Scope

WP1 - Literature and Model Review.
Identify across each technology (wind, solar. HVDC, Battery etc) the options for modelling PLL based control within Digsilent powerfactory to reflect the different control behaviours discussed above. Key output of this work package is proposed outline models for these controllers, and their settings.
WP2 – Model Verification (setting the rules).
Identify the key indicators of performance across these models which would inform the allocation and calibration of them to specific projects; outlining test information, compliance performance and event review data that would inform this. For example, for a specific fault ride through test: what performance characteristics (for example levels and speed of reactive power injection) would inform the use of one PLL-based control approach over another, which could then be used in compliance test work; and if seeing a fault upon the GB system, what system data from PMU measurements could then be used across the fault (for example the time dependant voltage

dip observed or magnitude of post fault overvoltage) to ensure that we are seeing the behaviour we expect?
WP3- Model Creation and Validation.
Construct validated PLL based controller proposals for the NGET Digsilent GB master model based on the above steps, utilising test and event review data. For example, wind project convertors prior to a given date have one assumption, those after that date another, and/ or by manufacturer. Produce also a set of un-validated but indicative DG models (i.e. for small and medium scale solar or wind projects, what is a typical or conservative assumption ahead of further information?).
WP4- Modelling dissemination.
Produce an end project report identifying:

- Generic principles of PLL modelling,
- A set of generic reference models for default assumptions by network operators (e.g. if wind= use PLL model x, if solar use PLL mode =y), together with the processes which would further inform them.,
- Recommendations surrounding the processes that would be required to support and maintain/ improve the position delivered under WP3, together with any area of technical code change as appropriate.
- Quantification of success of new approach vs BAU

Objective(s)

The intended objectives from this exercise would be

1. Develop a step change in our modelling capability of non-synchronous technology in the context of future network conditions across which more detailed modelling now becomes more important, developing the new processes and techniques to assure the validity of these models, and developing a pathway to sustain this step change into normal business.
2. To provide the wider industry with reference modelling insight for different types of PLL informed control, and also provide a recommended process which allows these reference models to be validated, adapted or allocated based on the User's own technology choices and connection context.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

Success Criteria

The project success will be achieved by delivery of the above objectives. Objective 1 would be measured by the suitability of these models to be integrated into BAU process within the National Grid Electricity System Operator. Objective 2 will be measured by the delivery of the project report, its dissemination and ability to influence wider industry modelling activity.

Project Partners and External Funding

This project involves collaboration with Power System Consultants ltd which offers the required expertise to perform the analysis and modelling proposed during this project in a timely manner.

There is no external funding.

Potential for New Learning

Today there has been no known work done into creating and validating PLL models based on type within the standard power system models utilized within the industry.

Scale of Project

This project will involve one external partner, last for 6 months.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

This work is of potential benefit to synchronous areas with high convertor penetration such as are found within the GB transmission and distribution systems; further information of these locations and timeframes of emergence may be found within National Grids' SOF (System Operability framework).

Revenue Allowed for the RIIO Settlement

Not Applicable

Indicative Total NIA Project Expenditure

£79,000

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)

As this is TRL 3-4, and is developing a model which we do not currently have, the potential benefits from rolling out the solution will only become clear at the end of the project.
Were our models not to be updated it would continue to be impossible to fully dimension the risks associated with new areas of system risk which include the areas of Vector shift protection of DG, DG stability across fault ride through, regional RoCoF, interarea oscillation, Transient Over Voltage, and other modes of control interaction across disturbances, for example at harmonic and interharmonic frequencies. In practice, in these areas we are unable to align our current modelling with existing system events and as such cannot predict or plan our modelling exposure with confidence.
As an example, the cost of managing Vector Shift post-2020 for all types of embedded generation is estimated to be in the range of £149m - £241m (from the GC0079 Working Group). Just a 5% improvement in that risk management as brought about by improved modelling would pay for itself within a financial year.

Please provide a calculation of the expected benefits the Solution

Not required - research project.

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

This modelling could be applied by all electricity Licensed Network Operators.

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

The reference modelling insight and recommended process for validation and implementation will be provided free of charge within the end project reporting.

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

The aim of the project is to provide the wider industry with reference modelling insight for different types of PLL informed control; this also provides a recommended process which allows these reference models to be validated, adapted, or allocated based on the User's own technology choices and connection context.

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

The project deals with several of the System Operator's Innovation Priorities, namely:

- Managing Volatility in a Low-Inertia System
- Enabling More Non-Synchronous Connections
- Supporting Voltage and Reactive Power
- Reimagining System Restoration
- Leveraging Analytics in a Data-Enabled Future

☑ 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.

An existing internal initiative is underway to improve our dynamic models to the extent we can within our existing skills towards new system analysis areas as discussed in the SOF. This further work would complement and augment, but would not overlap with the existing initiative.

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

Today there has been no known work done into creating and validating standard PLL-related models within the standard RMS power system models utilized within the industry.

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

We would usually expect users connected to transmission and distribution networks to develop these models, however there is no provision within existing codes for the levels of data exchange necessary to deliver models to an agreed framework which describe PLL and related control behavior. The SO is not best placed to deliver these models, so we are committing resource and NIA funding to enable someone who is best placed to undertake this innovative work.

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

This project breaks new ground in testing new ways of data exchange and analysis, working through complex and uncertain approaches to identify a path for such data to be supported under BAU. This testing approach is needed before a code change is designed. This is also an industry-wide problem, and project outcomes will be valuable to share with the entire industry.

This project has been approved by a senior member of staff

☑ Yes