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

Nov 2016

Project Reference Number

NIA_NGET0188

Project Registration

Project Title

WI-POD- Wind turbine control Interaction with Power Oscillation Damping control approaches.

Project Reference Number

NIA_NGET0188

Project Licensee(s)

National Energy System Operator

Project Start

June 2016

Project Duration

2 years and 1 month

Nominated Project Contact(s)

Ben Marshall

Project Budget

£350,000.00

Summary

The scope of the project is to evaluate the impact of the POD control on the existing control and mechanical performance of the offshore wind turbines. It includes developing appropriate model for the interactions between the offshore wind turbine and grid using Matlab Simulink based simulation package. The model will be validated using available simulation and test data that can be obtained from other sources. A POD will be incorporated to suppress the relevant oscillation frequency of this model. This investigation will then be extended to assess possible impact of POD control actions on the existing control systems and mechanical performance of the turbines.

Nominated Contact Email Address(es)

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Problem Being Solved

Increasing penetration of offshore wind farms

Wind power has and will continue to become an important source of power generation and the proportion of global wind power capacity is expected to increase from 2.5% in 2010 to 9.1% by 2020 (World Wind Energy Association, World wind energy report 2010). In order to capture the highest quality wind resource, much larger wind turbines are being further deployed offshore. The UK has over 4GW offshore and 6.7GW onshore wind capacities in 2013/14 and is projected to increase to 12.5GW and 13.6GW respectively by 2020 with a combined wind capacity potential of over 50GW by 2030 (National Grid, UK, “UK Future Energy Scenarios”, July 2014). This is in line with the UK Government target of cutting greenhouse gas emissions by at least 80% below an agreed 1990 baseline by 2050.

Uncertainties on power oscillation damping capability of offshore wind turbines

As the penetration of offshore wind increases, more displacement of conventional non-low carbon synchronous generation in future years is expected, particularly during system minimum demand conditions. At these times certain boundary transfers of power-flow (eg the Anglo-Scottish transfer) is expected to remain high. The stability of these boundary flows will be largely dependent upon the control response performance of connected renewables both on and offshore. The inter-area characteristic frequency of the Anglo-Scottish transfer oscillation has known to be around 0.5 Hz. Any oscillation near this frequency could excite the system into this mode of oscillation and the increase of system operating cost in managing this could be significant. This is one of the major reasons for the Grid Code mandatory requirements of Power System Stabilizer (PSS) on major synchronous generators. The PSS are tuned to dampen any power oscillations around 0.2 to 3 Hz. This approach is known as Power Oscillation Damping (POD).

Within the GB Grid Code under CC.A.7.2.4. National Grid has the right as GBSO to specify a requirement for any generator (including offshore wind) to be fitted with a power system stabiliser if such an arrangement is required for system reasons such as POD. This is further required under cc.6.3.16 c) where the offshore wind farm is connected wholly via a HVDC converter connection to the GB transmission system. These arrangements will be specified within the bilateral agreement of that connecting project. In its discussions with developers surrounding the delivery of such arrangements, National Grid has noted significant concern being expressed within some areas of the offshore wind community relating to the practical impact active power oscillation could have in inducing interaction with the mechanical frequencies of oscillation the wind farm turbines themselves, which may inhibit or invalidate such control options. To date however no detailed investigation of this potential phenomenon has been undertaken.

The fundamental research questions for this project are;

1. is there a *plausible* risk to wind turbines (operation life, performance, structural integrity) from interaction with PSS requirements that may be imposed by National Grid, and
2. if so, is the risk negligible or potentially material.

Risk

In addition to the 0.5 Hz characteristic frequency identified there were other modes of oscillation recently reported as potentially present in the GB system (J. Turunen, H. Renner, W.W. Hung, A.M. Carter, P.M. Ashton, L.C. Haarla, Simulated and measured inter-area mode shapes and frequencies in the electrical power system of Great Britain, IET Resilience of Trans. and Distribution Network Conf., Sept 2015). The stability of the GB system will face more significant challenges in the coming years as more synchronous generators with well-established PSS damping capability are to be replaced by wind farms which may potentially have issues in providing full POD capability. This when coupled with the more sparsely connected generation (ie weaker electrical connections) in particular large offshore wind farms and degradation of system inertia could pose significant risks to future system stability arising from insufficient capability or flexibility to damp the range of inter-area modes present at those times. Given the future levels of penetration of offshore windfarms, there is a need to clarify the uncertainties of POD and wind turbine control interaction and seek early resolution ahead of design and control solutions being fixed by the developer community. It is also known that certain oscillation modes may not be detected at all times depending on the system configurations and operating conditions. This implies that certain oscillation modes may not be detected during the commissioning of an offshore wind farm but could be problematic in the subsequent years. This will increase system security and operational cost risks. The retrofitting of POD on offshore wind farms could also be very costly and possibly impractical if the initial design considerations associated with wind turbines operating subject to POD are not fully understood.

Method(s)

We propose to develop an offshore wind turbine model based on the widely accepted NREL (National Renewable Energy Laboratory) offshore 5MW baseline wind turbine model (J. Jonkman, S. Butterfield, W. Musial and G. Scott, Definition of a 5-MW reference wind turbine for offshore system development, National Renewable Energy Laboratory (NREL) Report, 2009.), which represents the current typical offshore wind turbines to investigate the impact of POD control actions on offshore wind turbine control performance. NREL is government-owned and funded through the United States Department of Energy. The NREL model has been used as a reference by researchers throughout the world to standardize baseline offshore wind turbine specifications. Our research results could easily be adapted to cover onshore wind turbines. This will include where available sensitivities to the data assumptions within the NREL model to reflect particular developer technology selections of wind turbine. The model development and simulation studies will be conducted on Matlab Simulink which could potentially be adapted by National Grid for inclusion in its processes for system stability investigations in DigSilent Power Factory.

The NREL 5MW wind turbine model represents a three-bladed upwind variable-speed variable blade-pitch-to-feather-controlled turbine. It has a generator-torque controller and a collective blade pitch controller to regulate power generation. It can be simulated within the FAST (Fatigue, Aerodynamics, Structures, and Turbulence) code [5], which allows for tower bending, blade bending, nacelle yaw and rotor speed torsional oscillations etc. Full-field turbulence and stochastic inflow turbulence effects can also be simulated. We have successfully applied the NREL model (within FAST) and own-developed wind turbine model (which agrees very well with the NREL one) for various wind turbine control studies (J. Jonkman, L. Marshall and J. Buhl, FAST user's guide, National Renewable

Energy Laboratory (NREL) Report, 2005. X. Tong, X. Zhao, and S. Zhao, Load reduction of monopile wind turbine towers using optimal tuned mass dampers, 2016. X. Zhao and G. Weiss, Well-posedness and controllability of a wind turbine tower model, IMA J. Math. Control Inf. 28 (2011). As such interactions between electrical oscillations and mechanical oscillatory behaviours whether induced upon or produced by the turbines may be considered by these models. Under this project, The NREL model will be reviewed and refined for the current application. A grid model and its interconnection with the refined NREL model will then be developed to allow simulation studies of power oscillation phenomena. An appropriate POD will be incorporated to increase the damping of such an oscillation and assess its impact on the existing wind turbine control functions, mechanical performance and tolerances. The following stages of work will be followed

1. Develop a wind turbine model based on the NREL model to enable the study of wind turbine-grid interaction.
2. Develop a simplified grid model with its offshore interconnections with the above wind turbine model.
3. Integrate the turbine model in (1) with the grid model in (2); carry out model validation and verification.
4. Conduct simulation studies to identify oscillation modes between the wind turbine and the system.
5. Incorporate a POD to the wind turbine-grid model in (3) to increase the damping on the above oscillations.
6. Conduct sensitivity studies using the model in (5) which contains a POD, under various scenarios (different structural parameters of the turbines, various turbulence/wave situations and system fault etc); analyse the results mainly including the impact of the POD on existing wind turbine control functions and mechanical performance.

Scope

The scope of the project is to evaluate the impact of the POD control on the existing control and mechanical performance of the offshore wind turbines. It includes developing appropriate model for the interactions between the offshore wind turbine and grid using Matlab Simulink based simulation package. The model will be validated using available simulation and test data that can be obtained from other sources. A POD will be incorporated to suppress the relevant oscillation frequency of this model. This investigation will then be extended to assess possible impact of POD control actions on the existing control systems and mechanical performance of the turbines.

Objective(s)

The main objective of the project is to investigate if there are unfavourable interactions between the POD power modulation actions on offshore wind turbine control performance. Should such interactions exist, this project will further detail and suggest where available suitable mitigations to these issues. A final report comprising these findings will be made available to inform further developers in meeting the requirements as recorded within their bilateral agreements. In a longer term, the developed model for wind turbine-gird interactions could be applied to explore control strategy options including their integration with HVDC and energy storage connections and their broader ranges of interaction with power systems.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

Success Criteria

1. Successful development of an offshore wind turbine model based upon the NREL 5 MW wind turbine representation and an equivalent grid model including offshore connections.
2. Successful integration of the above 2 models to enable simulation studies for identifications of oscillation modes.
3. Complete sensitivity studies to assess the implications of oscillation modes under various scenarios (different structural parameters of the turbines, various turbulence/wave situations and system fault etc).
4. Successful incorporation of a POD to the wind turbine-grid model in (2) to improve damping of power oscillation.
5. Successful evaluation of POD's impact on the control systems and mech. performance of offshore wind turbines.
6. Biannual milestone progress reporting with interim and final reports delivered at the end of the 1st and 2nd year.
7. Successful dissemination of acquired knowledge to the relevant industry sectors, including the way via the National Grid System Operability Framework (SOF) Workshop.
8. Publication of relevant papers at leading journals and presentations at major international conferences.

Project Partners and External Funding

National Grid, Warwick University and FTI Consulting Ltd

Potential for New Learning

This project will study the impact of the POD (Power Oscillation Damping) control on the existing control and mechanical performance of the offshore wind turbines. The model for wind turbine-grid interactions developed in this project could also be extended to investigate different control issues on the grid connection of wind farms and explore control strategy options including their integration with HVDC and energy storage connections.

Scale of Project

This project will study the impact of the POD (Power Oscillation Damping) control on the existing control and mechanical performance of the offshore wind turbines. This model for wind turbine-grid interactions developed in this project could also be extended to investigate different control issues on the grid connection of wind farms and explore control strategy options including their integration with HVDC and energy storage connections.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL3 Proof of Concept

Geographical Area

The project will be carried out mainly at Warwick Univ. with close collaboration with National Grid at Warwick.

Revenue Allowed for the RIIO Settlement

Zero

Indicative Total NIA Project Expenditure

The estimated total NGET NIA project costs are £350,000

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)

If the project outcome helps to clarify the POD issues with offshore wind turbine developers, it will enable the incorporation of POD controls on future wind turbines/farms. From a wind farm developer/manufacturer perspective, the cost of including PODs at the design stage is less when compared with retrofitting them afterward on all offshore wind turbine units. From a System Operator perspective, any wind farm oscillations arising from lack of power oscillation damping capability would require deloading of them and replacing with more expensive plant. Depending on the spread of the problem, the potential annual cost saving could be in the range of millions of pounds.

Please provide a calculation of the expected benefits the Solution

The current project will provide an indicator of whether the POD issue could be resolved with the key stakeholders and allow the industry to make informed decision to minimize future risks on system security and cost implications. This is a fundamental research project for which it is not possible to provide cost benefit estimate based on base minus method cost approach.

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

The research results and the developed model for wind turbine-grid interactions are of generic nature and they can be applied onto any wind turbine/farm (including the onshore ones) across GB.

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

The results obtained in this project could be applied across the GB network at no additional cost.

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)

- [x] 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 project outcome will give indication of whether the POD will have an unfavourable impact on the existing control system and mechanical performance of offshore wind turbines. The finding will be equally applicable to other wind turbines/farms (including the onshore ones) connected to any part of the network across GB.

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 is related to National Grid’s innovation priority focus on operating the system with high levels of non-synchronous generation.

- [x] Has the Potential to Develop Learning That Can be Applied by all Relevant Network Licensees

Is the default IPR position being applied?

- [x] 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.

Given the unique approach in assessing the impact of POD on the offshore wind turbine control performance, there will be unlikely any unnecessary duplication as the result of this project. There may be some literature on the mechanical interactions of wind turbines with power oscillation but their turbine models used for analysis are much simpler (which may not represent the dynamics correctly) than this project’s model.

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

n/a

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

n/a

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

n/a

This project has been approved by a senior member of staff

☑ Yes