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

Dec 2019

Project Reference Number

NIA_NGTO045

Project Registration

Project Title

Risk mitigation of power electronics connections

Project Reference Number

NIA_NGTO045

Project Licensee(s)

National Grid Electricity Transmission

Project Start

March 2020

Project Duration

1 year and 1 month

Nominated Project Contact(s)

Robin Gupta

Project Budget

£255,000.00

Summary

Power electronics devices rely on complex dynamic control and high-frequency switching to perform their basic functions and meeting power quality and dynamic response requirements. However, the rapid dynamic control and fast switching of power electronics are introducing new system integration problems. A growing issue in the industrial community is the influence of these complex dynamic control systems and grid parameters (AC/DC) on the resonance and oscillatory behaviour of the entire system due to control interactions.

The two main goals of this research project are to:

- Establish a methodology to predict control interactions using impedance modelling and measurement.
- Develop impedance-based design guidelines for power electronic converter control systems to manage the risks of control interactions.

Nominated Contact Email Address(es)

box.NG.ETInnovation@nationalgrid.com

Problem Being Solved

Traditionally, power electronic has been used with HVDC and flexible AC transmission systems (FACTS) technologies within electricity transmission networks. But in the recent past, the number of power electronic converters connected to electrical networks has grown rapidly due to their application with renewable energy generation. The trend is going to continue, as further growth is inevitable for both renewable energy generation and HVDC interconnectors. Additionally, the need for power flow controllability is driving the integration of more FACTS devices into the network.

Power electronic devices rely on dynamic control and high-frequency switching to perform their basic functions and meet power quality and dynamic response requirements. However, the rapid dynamic control and fast switching of power electronics are introducing new system integration problems. The active nature of power converters can result in control interactions and resonance with AC networks, which may lead to unplanned network outages.

Conventional power system stability analysis using phasor-based modelling ignore fast dynamics and therefore, they are not suitable for the evaluation of control interaction problems as they ignore network dynamics/transients. In converter control interaction the network transients play an important part. Detailed electromagnetic transient (EMT) simulation studies need to be carried out to predict the control interactions. While EMT simulation must be performed to check system stability under specific conditions, it doesn't lend itself well to control design and cannot be relied upon for stability analysis of complex systems.

Therefore, there is a requirement to develop an analytical approach to predict the control instabilities under various operating scenarios and to provide design guidelines for power electronic converter control systems to mitigate the risks of control interactions.

Method(s)

The research project will develop a methodology to predict control interactions using impedance modelling and measurement in the frequency domain, and impedance-based design guidelines for power electronic converter control systems to manage the risks associated with control interactions.

The project will establish an impedance measurement method for the black-box models received from the suppliers for Wind-farms and STATCOMs. The impedance dependence on different operating modes and control parameters such as hardware delays will be estimated. The project will also develop a method for the estimation of the impedance of the network with a high degree of power electronics. The potential control interaction of a new power electronic connection will be investigated using impedance stability analysis. A reduced network model will be developed to represent the AC network for this analysis. The proposed methodology will be further validated by EMT simulations and eigen value analysis.

Scope

Work Package 1:

A) Impedance characterisation of STATCOMs

(i) Develop a dynamic model for full bridge modular multi-level converter (MMC) based STATCOM which will meet the requirement of the dynamic aspect of GB grid code.

(ii) Estimate the impedance characteristics of the STATCOM from the network connection point and analyse the impact of various gains, different control strategy, operating mode and delays including negative sequence impedance.

B) Impedance characterisation of Windfarms

i) Develop a dynamic model of a Type 4 single wind turbine to meet the GB grid code dynamic requirements.

ii) Estimate the impedance of individual wind turbines for various operating scenarios such as impact of control modes, controller gains and hardware/ software delays.

iii) Develop an aggregated wind farm model for impedance stability analysis.

C) Develop the general guidelines and methodology for modelling and estimation of power electronic converter impedance for stability analysis.

Work Package 2:

A) Development of network Impedance estimation method

(i) Explore how the various components of electrical networks should be modeled, especially power electronic converters, for impedance estimation.

(ii) Develop a methodology to perform the network impedance estimation for predicting potential instabilities.

B) Stability analysis using impedance estimation

i) Evaluate the control interaction issue for a new power electronics connection (Windfarm/ STATCOM) with the modelled network. Perform a sensitivity analysis of possible control interaction risks for different operating conditions and control parameters.

ii) Validate the identified issues using EMT simulations and eigen value analysis.

iii) Perform parameter tuning or design a new control loop for the new power electronics connection to mitigate the risks identified using sensitivity analysis.
Develop impedance-based design guidelines for power electronic converter control systems to mitigate the risks of control interactions.

Objective(s)

The objective of this work is to develop a methodology for:

(1) Identifying the risks associated with the stability and control interaction before a new power electronic device (e.g. Windfarm, interconnector, STATCOM) is introduced to the network using impedance based stability analysis.
(2) Develop impedance-based design guidelines for power electronics converter control systems to manage the risks of control interactions.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

Success Criteria

The project will be considered successful if:

1. an impedance based stability method is developed, which can analyse the control interactions for a new power electronics connection to the GB network.
2. The impedance-based design rules are formulated for power electronic converter control systems to mitigate control interaction issues.

Project Partners and External Funding

No project partners and no external funding

Potential for New Learning

The control interaction problem, resulting from the growing number of power electronic devices on the network, is applicable to all utilities. The reduction in short-circuit capacity has made the networks even more vulnerable to instability due to control interactions. This project aims to develop an analytical approach to analyse and mitigate the control interactions. The developed method can be used to provide control system design guidelines to a new power electronic connection to maintain the stability. The learning generated through the project will be relevant to other network licensees operating both transmission and distribution networks.

Scale of Project

The proposed scale is the right size to develop an analytical approach to address the control interaction problem. The project will develop representative models to investigate the impedance behavior and dependence on various operating conditions. With the help of these models, an impedance based stability method will be developed. A larger project is not presently required, and a smaller project would leave key questions unanswered or answers underdeveloped.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL5 Pilot Scale

Geographical Area

Desktop based

Revenue Allowed for the RIIO Settlement

None

Indicative Total NIA Project Expenditure

£255,000

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)

The project can provide cost benefits to customers in multiple ways:

1) This project is likely to avoid costs associated with engineering change orders which may be due to not identifying the correct technical requirements for converter control systems during project award stage. The project can also save cost by de-risking the project and avoiding project delays due to resonance or control interaction issues.

2) The reinforcement of the grid for solving the control interaction may cost hundreds of millions in future if the correct technical measures are not introduced (roughly £5m – £10m per active device). However, impedance based stability guidelines for new power electronic connections could result in significant savings.

Please provide a calculation of the expected benefits the Solution

NA, as it is a research project.

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

AC/DC Power converters are connected to the systems of all GB transmission and distribution systems. Thus, the impedance based stability requirements could potentially be deployed on equipment connected to all GB transmission and distribution systems.

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

Ways to roll out the impedance based stability requirements for converter control system will be examined as part of this project and this will inform the assessment of the potential costs of roll out.

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 control interaction problem is applicable to all the relevant utilities. Therefore, the analytical method developed in this project will be applicable and useful to all TNO and DNOs in the UK. All the information from this project that can be shared with GB Network Licensees will be made available after the completion of the project. Any commercially confidential information will be redacted from any output that is published, subject to any restrictions arising from competition law. Additional material may be sharable with other GB Network Licensees under a suitable non-disclosure agreement.

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

Efficient Build - Building new assets faster and at lower capital and whole-life costs
☑ 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.

The impedance based stability analysis has been discussed in the literature. However, it lacks the practical implementation. The project will research the impact of various control parameters such as hardware delays and negative sequence on impedance estimation. It will also provide guidelines for windfarm model aggregation for stability analysis. The project will develop impedance models for full-bridge MMC for STATCOM operation, which has not been reported in the literature.

NGET_0187 project verified that a high penetration of power electronics can result in control instabilities using EMT simulations. However, the intended research from this project will develop an analytical approach as the EMT simulation approach doesn't lend itself well to control design and cannot be relied upon for stability analysis of complex systems.
NGET is also creating two other projects on this topic. The first project is going to investigate the process to carry out network reduction while the second project will look at the application of the outcome of these projects.

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

The project, if successful, will provide an analytical approach to predict instability due to control interactions. Even though the impedance modelling approach has been reported in the literature, the aspects of its practical implementation are missing. The project will develop a practical methodology to apply an impedance based stability analysis and design to a new power electronic connection by researching the impact of various modes and parameters on the impedance estimation.

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 nature of a research programme means it inherently carries a risk that the research may be unsuccessful and/or identify unforeseen barriers to implementation and National Grid is unable to consider research of this scale as business-as-usual. The NIA funding offers the most appropriate route for NGET to evaluate the risk associated with control interaction.

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

The inherent risk of the project is detailed above and the learning from the project will be directly relevant to all Network Licensees. For this reason, NGET believe this project is appropriately funded through NIA.

This project has been approved by a senior member of staff

☑ Yes