

## NIA Project Registration and PEA Document

### Date of Submission

Jan 2018

### Project Reference Number

NIA\_NGSO0004

## Project Registration

### Project Title

Virtual Synchronous Machine (VSM) Demonstrator

### Project Reference Number

NIA\_NGSO0004

### Project Licensee(s)

National Energy System Operator

### Project Start

January 2018

### Project Duration

1 year and 7 months

### Nominated Project Contact(s)

Richard Ierna

### Project Budget

£456,000.00

## Summary

As we head towards higher penetrations of converter fed generation, mainly interconnectors and renewables, a variety of problems are anticipated in the System Operability Framework (SOF). A project was run with Strathclyde (ref. NIA\_NGET0106) over the last couple of years to simulate Virtual Synchronous Machines (VSM) which are converters behaving like synchronous machines. Compared to constraints on synchronous compensation, this technology potentially provides a more economical way of operating the system so reducing cost to end consumers.

## Preceding Projects

NIA\_NGET0106 - Control and Protection Challenges In Future Converter Dominated Power Systems

## Third Party Collaborators

University of Nottingham

TTPi

## Nominated Contact Email Address(es)

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## Problem Being Solved

As we head towards higher penetrations of convertor fed generation, mainly interconnectors and renewables, a variety of problems are anticipated in the System Operability Framework (SOF) which are either a direct result of or influenced by this type of generation:

- Increased Rate of Change of Frequency (RoCoF)
- Loss of synchronising torque / power and reference voltage
- High frequency instability and controller interaction
- Difficulties in modelling electricity system dynamic behaviour
- Reduced or delayed fault current in-feed
- Voltage instability during or post fault, e.g. collapse, blocking or over voltage
- Sub-synchronous oscillations and interactions with conventional machines
- Increased sensitivity to load imbalance and harmonics

Typically for converter penetration levels below 50% the conventional synchronous plant can provide the appropriate response, mitigating these problems and allowing normal system operation and modelling. However it is anticipated that between 50% and 100% converter penetration one or more of these problems will adversely affect operation and/or modelling. If the problems above are not resolved, either very large amounts of convertor fed generation will need to be constrained off or additional synchronous plant (Generators or Compensators) will be needed to stabilize the system. Both of these options could carry significant costs.

A project was run with Strathclyde (ref. NIA\_NGET0106) over the last couple of years to simulate Virtual Synchronous Machines (VSM) which are convertors behaving like synchronous machines. Compared to constraints or synchronous compensation, this technology potentially provides a more economical way of operating the system so reducing cost to end consumers. It was also found that unlike some other solutions which only solve one or two of the problems listed above; VSM is likely to solve several problems at once.

The simulation of VSM used the PowerFactory software package. Currently we have no experience of VSM hardware to validate the simulation. We believe some manufacturers are looking at VSM, or something similar, but there is no incentive for them to develop it for the UK market because it costs more than what they currently provide and there is no requirement for them to do so. Furthermore to develop the concept further they would need indication of the converter requirements which would be provided by the System Operator having reviewed system requirements.

## Method(s)

This project will implement VSM in a lab environment to test its behaviour. The outline methodology is:

- Build a simple test network using one big lab convertor (larger than 50 kW) to represent the system and smaller converters to represent VSM and /or current convertor technology.
- Test the network to validate the behaviour of VSM. Replicate studies performed in PowerFactory to compare results and prove the model for wider system study. The tests could include (but won't be limited to):
  - voltage step response
  - loss of generation or load
  - Islanding
  - 140ms short circuit performance
  - 500ms short circuit performance.
- Establish a test sequence suitable for future compliance testing of VSM.

Two overlapping phases of work will be carried out over eighteen months. Phase 1 will implement and test VSM based on lab converters to prove the concept. Phase 2 will begin in parallel with Phase 1 to build a VSM prototype to study further impacts and possible mitigating strategies. The VSM prototype will then be subjected to the same tests used in Phase 1.

## Scope

The project will test the performance of a lab converter based VSM and a prototype VSM in a lab environment. The tests will compare the performance of VSM to PowerFactory simulations and its ability to address the problems listed in the Problems section. The intention is to prove the concept in hardware and derive network requirements from it. Developing and testing a commercial product for field deployment is not in scope. The expectation is that manufacturers and developers will use the findings of this project and network requirements derived from it to develop and test their own commercial offerings.

## Objective(s)

The objectives of this project are to:

- Demonstrate a physical implementation of VSM and compare laboratory results to simulations in PowerFactory.
- Understand any risks or issues in the design and construction of VSM devices.
- Provide evidence either to support mandatory changes in converter fed generation performance, e.g. through Grid Code and/or Distribution Code modifications, or to support development of balancing service markets to value the abilities of VSM generation. Evidence would include:
  - Required behaviour of converter fed generation to operate as VSM.
  - Quantity or proportion of synchronous and/or VSM generation required at different penetrations of converter fed generation.
  - Required capability of VSM generation depending on the quantity or proportion required.

## Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

## Success Criteria

To be a success this project would have developed and tested a prototype VSM convertor in the lab demonstrating the behaviours observed in previous PowerFactory simulations.

## Project Partners and External Funding

The Project Partner in Phase 1 of the project will be Nottingham University who has been chosen for the following reasons:

- Variety of facilities appropriate for this work including a FlexElec Microgrid with access to 10kW Triphase and 90kW programmable convertors (Bespoke programming platform for converter control.)
- Extensive expertise and practical experience in developing power electronic systems.

The Project Partner(s) in Phase 2 of the project will be tendered.

There is no external funding.

## Potential for New Learning

There are many aspects of VSM technology we hope to resolve, improve or quantify. Equally we anticipate there may be unexpected results too. The previous project (NIA\_NGET0106) highlighted many things we were unaware of e.g. some types of Synthetic Inertia can aggravate high frequency instability making the situation worse. Results and insights of this nature are extremely valuable to the System Operator in steering the development of VSM technology, assessing its suitability for application on the electricity system and developing the commercial environment to incentivise its deployment. Manufacturers and developers may also use learning from the project to accelerate VSM deployment in response to these commercial developments.

## Scale of Project

This project will involve one or two external partners, last for 18 months and cost around £456,000.

## Technology Readiness at Start

TRL4 Bench Scale Research

## Technology Readiness at End

TRL6 Large Scale

## Geographical Area

This work is of potential benefit to synchronous areas with high convertor penetration such as the GB transmission and distribution system.

## Revenue Allowed for the RII Settlement

Not applicable

**Indicative Total NIA Project Expenditure**

£456,000

## 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)

£300M/Year.

#### Please provide a calculation of the expected benefits the Solution

The above figure is the annual cost of constraining synchronous generation on and converter fed generation off to reduce the penetration of converter fed generation. It is calculated from the IET paper "System Strength Considerations in a Converter Dominated Power System" which stated a cost of £100/MWh with a constraint limit of 75% and a cost range of £229M - £1099M.

However, the earlier project (NIA\_NGET0106) indicated that the constraint limit was only 65% which would increase constraint costs.

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

VSM behaviour could be applied to new or existing converter fed generators as is used in most renewable projects. The extent of implementation would depend on whether it is implemented as a service and/or mandated connection requirement.

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

A mandated change to connection requirements would require all generators and/or storage providers to comply depending on whether it applied to existing or future installations. Service provision would only affect those generators and/or storage providers choosing to offer the service and would only be taken up by generators where it was economic to do so.

Additional costs to meet the revised Grid Code or provide the service would be met by generators and/or storage providers but in the service case could be offset by additional income from the service. Costs will vary depending on the generator type but for a simple solar generator are estimated to add 4% to installation costs. Cost to the industry is estimated at £100-300m or £7-22m p.a. (20 year life, 4% discount rate).

## 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 System Operator could use the results of the project to inform the development of balancing service markets, including:

- Specifying synchronous or VSM behaviour from existing or future installations.
- Defining the quantity of this service required at different levels of inverter penetration.
- Defining tests to validate provision of this service.

The System Operator could use the results of the project to change converter fed generation connection requirements including:

- Proposing changes to the Grid and/or Distribution Codes to mandate VSM behaviour in converter installations.
- Defining tests to validate compliance with these changes in connection requirement.
- Whether the changes should apply to existing as well as future installations.

The System Operator, Transmission Owners and Distribution Operators could use the results of the project to improve modelling of converter fed generation.

The System Operator could present the results of the project at the ENTSO-E Expert Group on “Converter performance related aspects in power systems with 50-100% instantaneous penetration of RES”.

## **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 fits with the System Integrity theme of the System Operator’s innovation strategy.

Specifically it addresses the challenge of RoCoF, high frequency instability, loss of synchronising reference, and modelling systems with low levels of inertia.

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.**

Papers published as the output of the project with Strathclyde (NIA NGET0106) led to a new ENTSO-E expert group being established in December 2016 branded “Converter performance related aspects in power systems with 50-100% instantaneous penetration of RES”. This group identified Britain and Ireland as the synchronous networks likely to first encounter issues with converter fed penetration levels but the group has focused on simulations rather than developing the VSM concept.

Researchers have proved the VSM concept in the lab and in simulation models but not in a manner that facilitates operational scale assessment. To the best of our knowledge, no academic papers or manufacturers have demonstrated a fully-functioning VSM-like converter (algorithm) that appears to be service-ready, i.e. able to deal with balanced and unbalanced faults; able to operate up to 100% penetration at transmission scale; able to share power seamlessly with other converters through droop settings and set-points; and provide system inertia, frequency support services and power quality mitigation.

### **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 simulation of VSM uses the PowerFactory software package. Currently in the UK we have no experience of VSM hardware to



validate the simulation. National Grid understands some manufacturers are looking at VSM, or something similar, but there is no incentive for them to develop it for the UK market because it costs more than what they currently provide and there is no requirement for them to do so. Furthermore to develop the concept further they would need indication of the converter requirements which would be provided by the System Operator having reviewed system requirements.

### **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 intention is to prove the concept in hardware and derive network requirements from it. Developing and testing a commercial product for field deployment is not in scope.

### **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 expectation is that manufacturers and developers will use the findings of this project and network requirements derived from it to develop and test their own commercial offerings.

### **This project has been approved by a senior member of staff**

Yes