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

Jan 2014

Project Reference Number

NIA_NGET0057

Project Registration

Project Title

DC Circuit Breaker Technologies

Project Reference Number

NIA_NGET0057

Project Licensee(s)

National Grid Electricity Transmission

Project Start

October 2012

Project Duration

3 years and 7 months

Nominated Project Contact(s)

Paul Coventry

Project Budget

£257,000.00

Summary

The project will examine and assess DC circuit breaker technologies available for use in VSC HVDC multi- terminal systems and DC grids. This in turn will ensure that National Grid is in a knowledgeable position if and when a DC breaker is required to be used on the UK network. Commencement of the research sooner rather than later will help in developing technical specifications for DC circuit breakers. It will also allow for greater time to develop the required international standards needed regarding DC breaker design and testing.

The European Union Renewable Energy Directive has committed the UK to a target of more than 30% of electricity to be generated from renewable sources by 2020. The report 'Our electricity network' by the Electricity Networks Strategy Group (ENSG) recognised that a key technology to achieve the above aims is Voltage Sourced Converter (VSC) HVDC transmission. This is well suited to multiterminal and HVDC Grid applications being considered for onshore and offshore network integration.

Nominated Contact Email Address(es)

box.NG.ETInnovation@nationalgrid.com

Problem Being Solved

The European Union Renewable Energy Directive has committed the UK to a target of more than 30% of electricity to be generated from renewable sources by 2020. The report 'Our electricity network' by the Electricity Networks Strategy Group (ENSG) recognised that a key technology to achieve the above aims is Voltage Sourced Converter (VSC) HVDC transmission. This is well suited to multi-terminal and HVDC Grid applications being considered for onshore and offshore network integration.

A major bottleneck for wide-scale HVDC use is DC circuit breaker technology. The present solutions to fault isolation on an HVDC system is to use AC breakers and de-energise the entire DC system, see Figure 1 below. For a heavily integrated DC system, such as that envisaged as giving the lowest cost in the National Grid Offshore Development Information Statement (ODIS, 2010, 2011), this would result in an unacceptable loss of simultaneous generation as stipulated by the Security and Quality of Supply Standards (SQSS) infeed loss risk limits. DC Circuit breakers, Figure 2 below, offer a better solution to isolate a smaller faulted section of the DC network

quickly, which ties in better with present AC protection philosophy. However, while the major manufacturers (ABB, Siemens, and Alstom Grid) are working on solutions, no commercial DC circuit breaker exists and breaker technology is unproven at the 500kV, 2kA level proposed for future offshore networks and DC grids. Outline documents to specify future DC products still need to be developed urgently though, as lower voltage and current prototypes are being developed by manufacturers with the intention of commercialising high voltage and current products.

It is essential, therefore that an adequate understanding of the possible technologies, their operational characteristics and application issues be developed.

Method(s)

Research

The method that has been proposed for this project includes;

1. DC Circuit Breakers – topologies and physics
1.1 Literature of prior art DC circuit breakers reviewing operation, physical limitations, speed of operation and

potential for VSC-HVDC integration. Areas covered include prior art from:

- Proposals for VSC-HVDC (papers, patents etc.)

- Past LCC-HVDC circuit breakers

- Railways

- Motor contactors/loads

- AC breaker circuits As well as:

- A review of methods for DC current breaking, and an indication of what could/could not be scaled up to HVDC voltage levels, to assess what might be proposed in the future by manufacturers.

- Impact of AC/DC grid characteristics and proposed grid and converter topologies on faults. 1.2 Application of technology The review will cover:

- Methodologies for testing.

- Specification quantities used

- Identification of the range of duties (electrical, environmental etc.) that the DC Circuit Breaker is likely

to experience

- Suggestion of possible tests and test circuits

The work will build on the initial scoping studies undertaken in EPSRC Supergen project ‘Wind energy Technologies’ and National Grid project ‘Multi-terminal VSC HVDC operation, control and ac system integration’, which involved in the University of Manchester and National Grid. The proposed work is however far more detailed than can be accommodated in either of these projects, within their timeframes and schedule of deliverables.

Deliverables:

- Interim Report 1.1

- Full Report 1.1

- Full Report 1.2

- First year PhD transfer report

2. Detailed Evaluation of Concepts

2.1. Simulation

The initial outline studies of 1.1 and 1.2 will be supplemented by detailed simulation to fully evaluate candidate new and potential concepts. Initial simulations will be undertaken in an appropriate software package (such as PSCAD, EMTP or SABER). Key dynamics to be captured will be identified in order to allow reduced order simulations to be carried out in more conventional power systems software, to ensure robust

modelling without excessive detail. These models will be used to determine in detail how testing can most sensibly be done to evaluate circuit breaker behaviour (both those presently proposed by manufacturers and future concepts). The goal is to build on the work of section 1 to ensure that the right tests are being proposed and that they correctly capture and predict the behaviour of the equipment in a real system. The tests proposed in section 1 will be reviewed and revised prior to synthetic testing in section 2.2.

2.2 Synthetics testing

The study work to date will be validated by performing the tests proposed/identified in section 1 and 2.1 on candidate circuit breaker topologies. This is to see if the right tests are being proposed, and if the test/models represent and predict the behaviour of the physical system. The most promising topologies will be evaluated in the high-voltage laboratory at Manchester, in module or sub-module form. Such systems will be a small part of the high voltage direct current breakers to be tested and so performance of each breaker can be extrapolated from the testing of a small part. Such physics-based testing will allow an evaluation to inform specifications, simulations and establish detailed device functionality. The current break rating of the sub-modules is chosen to be up to 2 kA (as appropriate depending on the level required to satisfactorily test the technology) since this level has been proposed in ODIS. A test rig comprised of a capacitor energy store, high current diodes, inductor, vacuum switch, varistors, shunts, voltage dividers and measurement system will be used to test each proposed topology, for fitness of purpose.

2.3 Fault Current Limiters

Many of the proposed topologies have a severe limit on their over-current breaking capability. The integration of fault-current limiter technology into future DC breaker topologies thus forms an important adjunct to any DC breaker study. A literature review of candidate topologies will lead to simulation of appropriate designs and an evaluation of their ability to enhance DC breaker performance.

Scope

The project will examine and assess DC circuit breaker technologies available for use in VSC HVDC multi- terminal systems and DC grids. This in turn will ensure that National Grid is in a knowledgeable position if and when a DC breaker is required to be used on the UK network. Commencement of the research sooner rather than later will help in developing technical specifications for DC circuit breakers. It will also allow for greater time to develop the required international standards needed regarding DC breaker design and testing.

The European Union Renewable Energy Directive has committed the UK to a target of more than 30% of electricity to be generated from renewable sources by 2020. The report ‘Our electricity network’ by the Electricity Networks Strategy Group (ENSG) recognised that a key technology to achieve the above aims is Voltage Sourced Converter (VSC) HVDC transmission. This is well suited to multi-terminal and HVDC Grid applications being considered for onshore and offshore network integration.

Objective(s)

The above areas have been identified as needing to be addressed as part of the risk managed introduction of multi terminal VSC HVDC technology onto the transmission system and the future development of DC grids. In particular, if the UK plans on developing truly economical and secure DC grids, a thorough understanding of both the operation and the application of DC breakers will be required. The project will deliver reports on the results of studies and a documented set of models for use in National Grid’s internal system studies. The work forms an essential step in being able to implement the technology on the transmission system.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

Success Criteria

Deliverables:

- Interim 1 - Report 2.1
- Interim Report 2 – Report 2.2
- Full Report 2.1

- Interim Report 2.2
- Full Report 2.2
- Full Report 2.3

Project Partners and External Funding

n/a

Potential for New Learning

n/a

Scale of Project

This project is being delivered on a laboratory scale.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

The project is being delivered in Manchester.

Revenue Allowed for the RIIO Settlement

Zero

Indicative Total NIA Project Expenditure

IFI - £45,600

NIA - £212,000

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)

This project has the potential to contribute towards the saving of the problem which in total would be estimated at £100million.

The proposed work forms part of the risk managed introduction of multi-terminal VSC HVDC onto the transmission system and the future development of DC grids. VSC HVDC has not previously been implemented on the UK transmission system and multi-terminal VSC has not previously been implemented anywhere. No DC circuit breakers at the required voltage of 500kV and 2kA are commercially available. Present industrial demonstrators have reached 80kV. The last 'full scale' tests on DC circuit breakers in the 1970's and 1980's used designs that are too slow for use with voltage-source HVDC, and required that current be limited by converter action, a facility that is not available with VSC-HVDC designs.

It is essential therefore to understand the physical limits and potentials of DC circuit breaker technology and the limits of their potential physics of operation places on the DC and AC systems. The proposed work is intended to identify application issues associated with the technology and allow control measures to be evaluated. Failure to identify and manage such issues ahead of commissioning might have severe implications for operation of future multi-terminal DC systems.

The outputs of this research will directly inform the development of any required National Grid policy documents or technical specifications relating to both DC breakers and DC grids. This research will also inform future work leading to any potential full scale trial application of DC breaker technology.

Please provide a calculation of the expected benefits the Solution

Research project - Not applicable.

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

This methodology will be applicable to all HVDC systems.

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

The output from this project will be mid TRL and therefore further work will be needed in conjunction with manufacturers. Roll out costs would be part of the VSC HVDC developments,minimizing risks.

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

n/a

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 addresses the issues of connections and smart transmission network philosophy through enabling DC circuit breaker technology on wide-scale HVDC. The present solution to fault isolation on an HVDC system is to use AC breakers and de-energise the entire DC system.

☑ 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.

n/a

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