nationalgrid

Date of Submission

July 2016

Network Innovation Allowance Progress Report

Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form.

Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

Project Progress

Project Title

Application of DC circuit-breakers in DC Grids

Project Reference

NIA_NGET0060

Project Licensee(s)

National Grid Electricity Transmission

Project Start Date

Jul 2012

Project Duration

5 Years

Nominated Project Contact(s)

Paul Coventry (.box.innovationtransmission@nationalgrid.com)

Scope

The European Union Renewable Energy Directive has committed the Member States to National targets for renewable energy production such that at least 20% of the EU's energy will be produced from renewable sources by 2020. Meanwhile, the creation of an internal market for energy remains one of the EU's priority objectives. The development of an interconnected internal market will facilitate cross-border exchanges in electricity and improve competition. The potential role of HVDC in integrating renewable energy generation and cross-border electricity exchanges is widely recognised and many ideas for dc grids linking the transmission systems of different countries and renewable generation are being promoted.

At present, no dc circuit-breaker is commercially available and any dc fault will affect the entire dc network. A dc grid is, therefore, restricted to a single protection zone at present and the capacity of generation connected to it may not exceed the infrequent infeed loss risk limit prescribed by the Security and Quality of Supply Standard. The dc circuit-breaker is therefore an essential technology in enabling the concept of a dc grid to develop.

Objective(s)

The objective of the proposed work is to understand the application issues associated with dc circuit-breakers in dc grids. The work will study the impact of dc circuit-breaker operation on the dc system, the HVDC converters and the connected ac systems. In particular, the challenges presented by protection and fault clearance in dc grids will be addressed. The work forms an essential component of the risk-managed introduction of the dc circuit-breaker onto the transmission system in accordance with PS(T)013. The results of the work will inform technical specifications and risk-registers for the dc circuit-breaker and for the protection and control of dc grids.

The project will deliver reports on the results of studies of the system behaviour and the results of experiments performed on a model (low voltage simulation) dc circuit-breaker in the analogue HVDC test facility at Cardiff University. The work complements a closely-related project at the University of Manchester which aims to study the electrical operating environment of the dc circuit-breaker and derive design and test requirements for the device itself.

Success Criteria

This project is successful if we improve the understanding of the issues associated with application of dc circuit breakers. There is a high likelihood that such studies will allow application issues to be identified, better understood and enable their mitigation to be evaluated. The work will contribute significantly to the specification of requirements for dc circuit breakers and protection for dc grids.

Performance Compared to the Original Project Aims, Objectives and Success Criteria

Project overview

This project, Application of DC Circuit Breakers in DC Grids (NIA_NGET0060) and the related project on DC Circuit Breaker Technologies (NIA_NGET0057) are concerned with aspects of managing the risks of introducing HVDC circuit-breakers into service. This project, NGET0060, is concerned with understanding the impact of the HVDC circuit-breaker on the system in which it is installed. The project studies the implications of the HVDC circuit-breaker for the HVDC system, its HVDC converters, the connected active current (AC) transmission systems and strategies for fault clearance and protection when the HVDC circuit-breaker is used. Whereas the complementary project, NGET0057, is concerned with understanding the electrical operating environment of the high voltage direct current (HVDC) circuit-breaker in order that design and test requirements for the device may be developed. The latter are necessary so that the HVDC circuit-breaker may be specified adequately and demonstrated to have the necessary strength and capability to perform its duty.

The research in this project (NIA_NGET0060) looks to identify the requirements of a DC circuit-breaker, including breaking current and fault clearance time. Since direct current (DC) circuit-breakers will be expensive, DC fault isolation with the aid of AC circuit-breakers and fast DC isolators can be used to minimise the number of DC circuit-breakers in a DC grid. The proposed work will address fault isolation schemes and post-fault restoration of the DC grid. Various types of voltage sourced converters (VSC) will be studied and compared along with DC switchgear in fault analysis and system restoration.

Although the DC circuit-breaker is not yet commercially available, one supplier published their developments in the area towards the end of 2011 and it is expected that other suppliers will follow. It is, therefore, timely that the research and development was initiated in order that the DC circuit-breaker will be introduced in a risk-managed way.

Project plan

The following steps were undertaken in the course of the project:

- literature review of AC protection, Grid Code, DC grid, DC protection and DC circuit breakers (June 2013)
- Model of DC grid and DC circuit breaker (DCCB) in PSCAD and determined strategy of DC fault response and post-fault restoration (June 2014)
- experimental model of DC grid available for DC fault test and determined characteristics of voltage, current and response time of DCCB (June 2015)
- impact of DC faults on AC and DC grids and experimental model of DCCB ready for use (June 2016)
- validated DC fault response and impacts from DCCB characteristics. Recommendations on DC protection and DCCB specifications (June 2017).
- a PhD thesis.

Project activities prior to 2015/16

2012/13: in the first year of the project a literature review was carried out in five areas, as outlined below.

1. fundamentals of voltage source converter (VSC) HVDC technologies and multi-terminal HVDC grid technology

2. summary of HVDC system faults
3. summary of Grid Code framework and requirements, and protection Grid Code requirements
4. development of DC circuit breakers and HVDC breaker design constraints
5. HVDC protection including properties of a DC protection system against short circuits.

In addition to the above, the role of the DC circuit-breaker in the network to determine its functional and operational risks were briefly analysed.

2013/14: in the second year, the work was focusing on the modelling of Multi-terminal DC (MTDC) grid and DCCB.

The simulation tool used, the power systems computer aided design, electromagnetic transients including direct current (PSCAD/EMTDC) system, is a worldwide professional software tool in power electronics transient analysis.

A multi-terminal VSC HVDC transmission system was introduced first. Different converter configurations, asymmetrical and symmetrical monopole, bipole and hybrid configurations are discussed. MTDC grids can be created with these configurations. After that, the development and different configurations of HVDC switchgear are introduced.

The solid state circuit breaker and resonant circuit breaker have significant drawbacks in terms of on-state losses and fault interruption speed. A hybrid HVDC circuit breaker is developed combining the advantages of both mechanical switch and power electronic switch. The manufacturer continues to pursue developments to improve rated voltage, current and fault current interruption capability.

An integrated AC/MTDC transmission system with hybrid HVDC circuit breakers installed is modelled in PSCAD/EMTDC. The AC system of the integrated AC/DC system is a standard 4-machine two-area system cited by researchers worldwide.

The DC grid is a 4-terminal HVDC grid, the converter station configuration is bipolar using ground as fault current return path. The converters are all two-level VSCs. Two of the converters 3 and 4 are connecting with the AC system at two buses, transferring power in parallel with the HVAC transmission line. A detailed model of a manufacturer’s hybrid HVDC circuit breaker is modelled. First, a scaled-down prototype is tested to study the basic principles. Then the characteristics of fault voltage, current and responses time are studied through simulations. The function of the current limiting reactor is studied. At last, DCCBs are designed and applied in the AC/DC model to test the performance of fault current interruption. The fault voltages and currents of each DCCB were studied. Also, the impacts of DCCB on AC system power angle stability are studied. Fault behaviours are studied by a method of measuring the impedance of converter AC side voltage.

2014/15: in the third year, voltage, current and response time of DCCB were investigated.

The factors that affect the DC fault current flow through the DC circuit-breakers (DCCBs) and converter AC side voltage were studied. The simulation results show that different components in a converter station have different effects on the DC fault current. The DCCB should be designed with consideration of other components in the DC grid to get a good fault clearance option. The modelling of half-bridge MMC has been carried out and applied in the DC grid modelling. Results from the study on modelling full-bridge MMC and its implementation in DC grid will be presented in the final completion report.

Project activities in 2015/16

In the fourth year of the project, two main areas were studied, as outlined below.

1. Impact of DCCB on AC/DC system stability

Since electrical distances within a DC grid are short, a fault in the DC system will be seen from the AC system as simultaneous faults at each of the connection points with the DC system. The influence of DCCB operating time and the influence of the DCCB current limiting reactor were investigated. The project showed that a longer DCCB operating time leads to more severe phase angle oscillations in the AC system, a more severe AC system voltage drop and a higher current interruption duty for the DCCB. If the DC fault is not cleared rapidly, the electrical distance between the AC connection points reduces to zero. It was shown that a large DC reactor limits the rate of rise of DC fault current significantly and increases the electrical distance between the AC system connection points. With a large DC reactor, the impact of a DC fault on the stability of the overall system is reduced. On the other hand, a large DC reactor will increase the time constant of the system. It is important therefore that the design of the DC reactor should be project specific.

2. DC grid post-fault restoration using DC circuit breakers and AC circuit breakers

The study looked at two alternative solutions for fast clearance of a DC fault when DCCBs are available:

a. The first solution is based on a fully selective approach and applies the same protection philosophy and principles as used in AC systems. Only the DCCBs associated with the faulted line are tripped. This means that time is taken for communications and fault discrimination logic between fault detection and tripping of the DCCBs. Post fault restoration consists of restarting the converters which have been blocked during the DC fault.
b. The second solution is based on the ‘open grid’ concept, where each DCCB is allowed to trip autonomously on detection of a fault. The time taken for communications and fault discrimination logic is eliminated. Post fault restoration consists of re-closing the DCCBs of the healthy circuits based on post-fault voltage measurements and then restarting the converters which have been blocked during the DC fault.

The two studies showed that the fully selective approach imposes a very high current interruption duty on the DCCBs associated with the faulted line and has a greater impact on the host AC system than the ‘open grid’ approach. This was due to the longer fault clearance and restoration time.

Another solution for clearance of a DC fault was demonstrated, in which the DC fault is cleared by tripping the circuit breakers on the AC side of the converters and no DCCB is used. Following fault clearance, DC switches are used to isolate the faulted transmission line (if the DC current is low enough). The comparatively long fault clearance time associated with this solution will lead to de-energisation of the entire MTDC grid.

When the DC fault was cleared using AC circuit-breakers, the overall system became unstable due to the long fault clearance and restoration time. It was also shown that where AC circuit-breakers are used for DC fault clearance, the post-fault restoration scheme should be designed to mitigate overcurrent and voltage oscillations during the restart up process.

Next steps

- characteristics of DC circuit-breaker continues to 2017
- DC fault-handling strategies and verification of fault response schemes continues to June 2017
- Experimental verification of results obtained by simulation – June 2017
- PhD thesis submission – June 2017
- project completion and final report – late 2017
- dissemination will continue through the ENA smarter networks portal.

Required Modifications to the Planned Approach During the Course of the Project

There were no changes to the planned research approach for this project prior to 2015/16.

In 2015/16 a change was made to modify the project plan. The project end date has been extended to allow time for completion at the end of the project in 2017, and there was an increase to the budget because more project management resource has been required to deliver (and close, in 2017) the project than anticipated at its outset. This approach was considered acceptable to maximise the benefit of the work for the industry and consumers.

Lessons Learnt for Future Projects

Lessons learned prior to 2015/16

In the course of the project, a need has been identified for standard models for AC and DC grids for use in studies. While some models exist, such as the IEEE standard AC systems, the systems and the parameters of their components are not sufficiently representative of the GB transmission system. The development of suitable AC and DC system models is time consuming. There is consequently a need for standard models of both AC and DC systems for use in academic studies of future DC grids and their impact on the AC system to which they are connected.

The project is certain to increase understanding of the issues associated with the application of DC circuit breakers. There is a high likelihood that such studies will allow application issues to be identified, better understood and enable their mitigation to be evaluated. The work will contribute significantly to the specification of requirements for DC circuit breakers and protection for DC grids. The ability to deploy DC circuit-breakers will be a key step in enabling the construction of large DC grids integrating renewable generation and facilitating cross border electricity exchanges in an efficient manner. This in turn will benefit consumers through improved access to renewable generation and increased competition.

Lessons learned in 2015/16

There has been progress on the relevant next steps as reported in last year’s progress report. A summary of lessons learned to date are provided below.

1. Characteristics of DC circuit breaker learnings in 2015/16:

Research to date shows that a large DC reactor will reduce the impact of DC-side faults on the stability of the AC/DC system, but will also increase the time constant of the system. It is important therefore that the design of the reactor should be project specific and take into account the local transmission topology.

2. Work on DC fault handling strategies and verification of fault response schemes continues. Learnings in 2015 include the following:

a. a DC-side fault in a DC grid is seen from the AC network as simultaneous faults at all points of connection between the AC and DC networks
b. fast fault clearance using DC circuit breakers will reduce the impact of DC-side faults on AC/DC system stability.

The changing landscape of renewable generation

From the start of the project it's been recognised that an integrated offshore transmission network will help achieve the EU's targets for renewable generation. Since then, significant developments in the electricity industry and the wider economy have had an impact on the expected development rate of offshore wind generation. The Integrated Offshore Transmission project (IOTP) was established in 2012 to assess the potential benefits of a coordinated approach. The IOTP was formed by a collaboration of industry leaders, including National Grid and offshore wind developers Forewind, Smart Wind, Dong, Scottish Power Renewables and Vattenfall. The IOTP report [2], published in August 2015, concluded that an integrated design solution would benefit consumers only if the installed capacity of offshore wind is very high. It now seems that these high levels of offshore wind generation are unlikely to be reached in the near future. Consequently, the urgency of understanding the application issues associated with DC circuit-breakers on an integrated system is likely to have reduced since the project commenced. Nevertheless, continued research in this area is relevant and valuable to the industry as it allows an integrated offshore network solution to become a viable option in the future.

Knowledge dissemination

The learnings from this research project have been shared in annual project reports on the ENA smarter networks portal and in a publication presented to the industry in May 2015 [1].

Project publications

1. Li, G, Liang, J, Ugalde-Loo, C E, Coventry, P and Rimez, J, 'Dynamic interactions of DC and AC grids subject to DC faults', IPEMC 2016 – ECCE Asia, Hefei, China, 22-25 May 2016.

Other publication referred to in the report

2. National Grid, Vattenfall, Scottish Power Renewables, Smart Wind and Forewind, 'Integrated Offshore Transmission Project (East) – Final Report', August 2015.