Case Study: Caithness-Moray Project

The Caithness-Moray HVDC Project (CM Project) is the first HVDC scheme in the north of Scotland, and represents a £1.1bn capital investment by SHE Transmission in the electricity network.

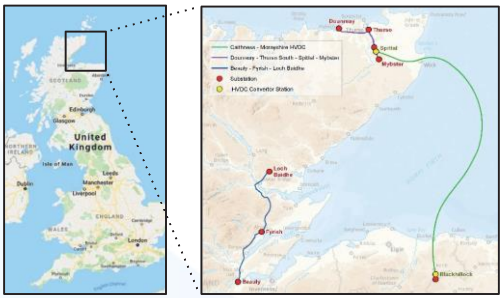
The first phase of the project links Spittal (in Caithness) and Blackhillock (in Moray) with ±320kV, 113km submarine HVDC cables. However, the scheme is designed as a three, four or five multi-terminal scheme allowing for future extension to connect the Shetland isles and other renewable generation.

The Caithness-Moray HVDC Project is a landmark project for developing the electricity network in Great Britain towards a low-carbon network; more specifically, the CM Project:

- Enables the export of electricity from one of the most productive renewables areas in Europe;
- Is the first multi-terminal designed project in Europe; and
- Demonstrates how a multi-terminal grid can be developed without the use of HVDC breakers.

However, it is also a technically challenging project:

- Connecting to a weak AC (275kV) network in the north of Scotland;
- Designed for multi-terminal operations; and
- Potential for multi-vendor extensions.



The HVDC Centre was able to help address these challenges and assure the delivery of this project through the use of Replicas of the control panels to test the operation of the system under a range of conditions, with a detailed representation for the AC network.

Furthermore, as the CM scheme is extended to multi-terminal operation, the HVDC Centre will have a pivotal role ensuring the operation of the complex multi-terminal controls, using the Replicas of all three terminals.

The National HVDC Centre

Support Provided by the HVDC Centre

The HVDC Centre has provided extensive technical support to the CM Project at each stage of the delivery of the project; and is able to provide the same services to any HVDC project.

The range of this support is represented in the diagram below.

> "The Centre has been an invaluable partner in supporting the project and providing the technical assurance that all large projects require. The team are very knowledgeable and experienced in the area of simulation and bring significant expertise to the project."
>
> Richard Hanson, Head of HVDC Engineering and Operations, SHE Transmission

Replica Control Hardware

Replicas Procurement	The HVDC Centre managed the procurement of the Replicas, from specification, supplier negotiation, Factory System Testing, through to delivery.
Replicas Installation and Commissioning	Following delivery of the Replicas, the HVDC Centre oversaw their installation, commission and testing.
Supported Replicas Hosting	Now that the Replicas are installed, the HVDC hosts and operates them in a secure environment, connected to our RTDS® system.

Training

Project Team Training	The HVDC Centre delivered training courses covering HVDC fundamentals, components and real-time simulation, followed by hands-on sessions where the attendees interacted the HVDC scheme in a simulated environment to build their understanding.
Control Room Training	The Centre enabled the control room team to train and practice the operation of the Caithness-Moray link, this aided their understanding HVDC control systems, and ensured a smoother and safer adoption of the scheme.

Grid Integration

Grid Integration Risk Management	The Centre has advised the CM project on identifying and mitigating grid integration risks, ensuring the security of the grid network.
Integration Compliance	The Centre supported the demonstration of grid code compliance of the CM scheme to the System Operator.
Interaction (& Fault) Studies	The HVDC Centre integrated the Replicas with a detailed real-time representation of the AC network (developed in-house) to test the operation of the HVDC scheme in conjunction with the AC network.

Specific Project Support

Controls Development	Prior to the CM project being commissioned, additional functionality was added to the scheme. The Replicas enabled this functionality to be fully tested at the HVDC Centre without delaying the commissioning of the scheme.
Commissioning Support	The HVDC Centre supported the commission of the CM Project through: • Pre-running commissioning tests on the Replicas, to show the results that should be anticipated; • Reviewing (on a daily basis) the outputs of the on-site commissioning tests, to provide in-depth analysis; and • Analysing and diagnosing faults and/or events that occur during commission.

To find out more, please contact us to discuss or to arrange a visit:

01236 687 240 | **info@hvdccentre.com** | **hvdccentre.com**

Case Study: North Sea Link Protection Coordination Testing

The HVDC Centre supports the protection co-ordination testing for the new HVDC North Sea Link interconnector to ensure the security and resilience of the GB electricity network.

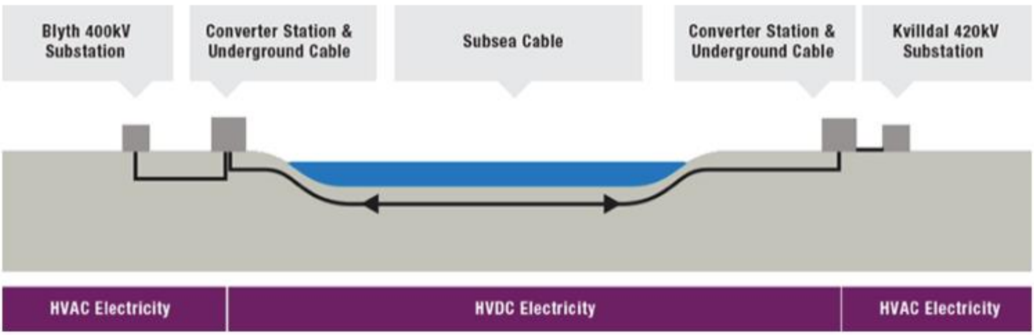
The North Sea Link (NSL) is a new HVDC interconnector connecting Blyth in the north east of England, to Kvilldal in Norway.

The introduction of a new HVDC interconnector onto the Grid network requires the surrounding AC network protection to be reconfigured, so that they operate appropriately to protect the network in the event of a fault.

Conventional protection setting calculations and protection testing would not reveal any unforeseen protection coordination problems near HVDC Converter Station.

Hence, to be confident that the reconfigured protection relays operate correctly, the HVDC Centre is testing them in a Real-Time (Hardware-in-the-Loop) simulation environment. The Real-Time Simulation environment in the HVDC Centre includes RTDS® and Power amplifiers.

Scottish Power Energy Networks (SPEN) and National Grid Electricity Transmission (NGET) considered it a critical requirement to test and validate the reconfigured protection system prior to NSL connecting to their transmission network; and commissioned The National HVDC Centre to undertake these protection studies.



Testing Scenarios

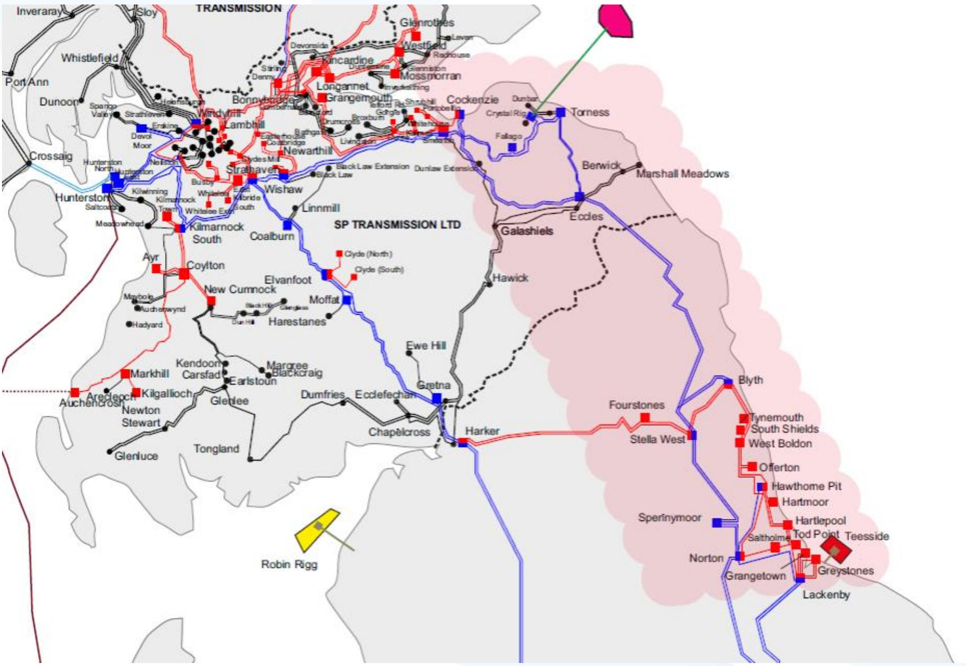
To undertake these studies the HVDC Centre combined the following elements in their RDTS® simulation environment at the Centre, so that testing scenarios could be undertaken:

- 9 protection relays from the Eccles, Blyth and Stella West substations;
- A model of the NSL Interconnector (provided by ABB);
- A model of the series compensator (provided by GE); together with
- Models of the AC network (provided by the ESO and Scottish Hydro Electric Transmission).

Predicted Outcomes

The output from these studies is a set of recommendations on the protection and control of the reconfigured network.

The HVDC Centre sees such validation studies as becoming increasingly important to ensure the security and resilience of the GB electricity network as more HVDC links are connected.



To find out more, please contact us to discuss or to arrange a visit:

01236 687 240 | info@hvdccentre.com | hvdccentre.com

Case Study: Maximising HVDC for Black Start

The HVDC Centre leads the improvement of Great Britain's Black Start capabilities using HVDC.

The evolution of a low carbon economy is driving changes in the electricity system. The changing profile of electricity generation in GB results in a lower system 'inertia' making the network more vulnerable to outages in the future. 'Black-Start' services are required to re-energise the electricity grid following a system shut down.

GB's current Black Start strategy is based on 6 zones (see Figure below) with Scotland and the North of England being most vulnerable in terms of low system strength due to the high concentration of renewables.

HVDC has the potential to provide excellent black start capabilities (as well as fast frequency support and synthetic inertia services), and there are a significant number of HVDC schemes planning to connect to the GB network.

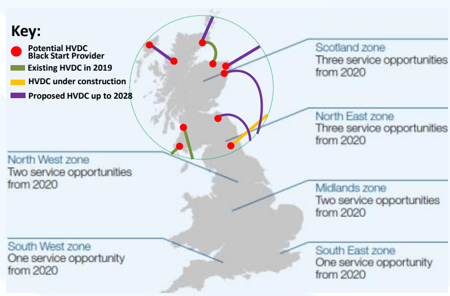
With costs the HVDC Centre to lead this review. rising of providing Black-Start services over the last 10 years, the Scottish Government wanted to investigate how to maximise the use of   HVDC schemes to support Black-Start energisation, from a technical perspective; and commissioned

The HVDC Centre methodically reviewed how HVDC schemes can be utilised to support Black Start energisation

The HVDC Centre technical experts, in collaboration with specialists from SHE Transmission, Scottish Power, National Grid and the Scottish Government, carried out an in-depth study which included:

- Review of existing Black Start arrangements in GB alongside analysis of how HVDC schemes perform against Black Start technical requirements;
- Evaluation of global HVDC Black Start experience and examination of global black-out events;
- Mapping these findings against GB's current and future HVDC schemes (with a focus on Scotland and the North of England) to identify practical opportunities; and
- Developing specific recommendations, in consultation with Stakeholders, to maximise the use of HVDC schemes for improving GB's Black Start arrangements.

HVDC Black Start Potential is Scotland and North of England Zones



Source: National Grid ESO & The National HVDC Centre

Outcomes

Out of this technical analysis, seven recommendations are being progressed with relevant stakeholders.

Opportunity	Recommendation
There is little guidance for HVDC Schemes on what Black Start services should be specified.	Define (and promote) the Black Start services that should be specified in all future schemes.
Since Black Start is a highly unusual situation, the AC network protection, or the HVDC system protection, may may trip during energisation.	The protection settings for both the AC system and HVDC system should be tested (as a combined system), for restoration scenarios.
During re-energisation; energised 'islands' need to be connected (and re-synchronised), requiring complex control and data exchange.	System studies are required to ensure the HVDC controllers transition as required during re-synchronisation.
The limited testing of HVDC Black Start functionality does not give the required level of confidence that it would act as expected on the real network.	Combine factory testing, real-time demonstration and field trials to build confidence in the robustness of Black Start operation.
The Black Start services that HVDC schemes provide could be significantly enhanced if combined with an synchronous condenser.	Investigate enhancing the Black-Start services by combining HVDC Converters with synchronous condenser.
The criteria to provide Black Start services are not appropriate for HVDC schemes.	Review the Black Start service criteria to ensure that HVDC schemes are not unnecessarily dis-qualified.
There are additional HVDC Black Start enhancements that merit further investigation.	Investigate further: • Using offshore windfarms (or island generation) to help energise the network; and • Reducing system voltage during restoration to speed-up the time-to-restore.

Impact

These recommendations will help improve GB's Black Start capability by maximising the use of HVDC schemes.

Leading to the following benefits:

- Improving the stability of the Network (reducing the likelihood of outages);
- Facilitating quicker restoration times;
- Reducing the cost (to consumers) of Black Start services; and
- Providing assurance that restoration services will operate as expected, when required.

Case Study: ESO Stability Pathfinder

The HVDC Centre investigate the impact of declining system strength on stability of HVDC links.

With climate change providing a massive threat to the UK, there is a requirement to decarbonise the UK energy system using renewable technologies. Doing this will result in large volumes of fossil-fuel power stations being replaced by renewable generation and other low-carbon technologies such as wind, solar and HVDC interconnectors. This could potentially result in a decline in system strength, and increased risk of the network operation, as the system becomes more volatile.

The National Grid Electricity System Operator (ESO) identified that Scotland could be one of the most vulnerable areas of the network to investigate in terms of low system strength, due to the high penetration of renewable technologies in the region.

The ESO sought guidance from the HVDC Centre to investigate the impact of declining system strength on stability of HVDC links and other low carbon technologies that are connected through power electronic converters.

Current practices were to undertake GB-wide system studies in RMS-type simulation tools, but this is not 100% accurate and does not accurately represent the dynamic operation or control performances that would be apparent in the EMT-type model.

The piece of work carried out by the HVDC Centre used EMT (PSCAD) and RMS (Digsilent) simulations to test the hypothesis of the ESO 2017 study that when HVDC links are connected to very weak AC grids, the HVDC system no longer operate correctly.

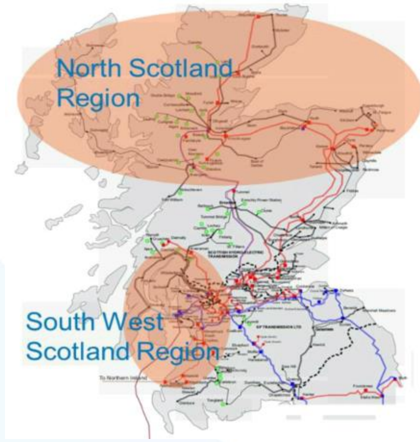


Figure 1: Map of area of focus for the stability pathfinder project (Source: NG ESO)

- The HVDC Centre used power system simulation tools to model HVDC links and different low-carbon technologies (including wind farms and battery inverters), by testing their stability performance across a range of different system conditions on the electricity grid.
- The Centre used open-access converter models to repeat the studies that the ESO had conducted in 2017 to prove whether their models were true in the same conditions and uncover what component in the HVDC system triggers those adverse interactions between the converter and the AC network.

Outcomes

The scope of the project will be analysed in 3 stages:

- In Phase 1 the project output is expected to inform the ESO on the fundamental principles of devices within HVDC links and low-carbon technologies that could interact adversely with the electricity grid. This should provide insights on the specifications that the ESO should provide to customers who want to connect with the GB network and outline opportunities for improving system stability.

- Phase 2 of the project will be to explore with the ESO how customers, looking to connect with the GB network, can test the technology models to provide the confidence that they would respond in the same way as when connected to the network. Considering that any power electronic based source that connects with the network will experience this challenge of declining inertia, the HVDC Centre developed model description guidelines, which was fed as input to the customer Request for Information, published by the ESO in August 2019.

- Phase 3 of the project is expected to feature system testing of a range of different stability technology solutions in a real-time simulation environment, using both hardware and software models of equipment manufacturers to increase confidence level of industry in the effectiveness of the proposed solutions.

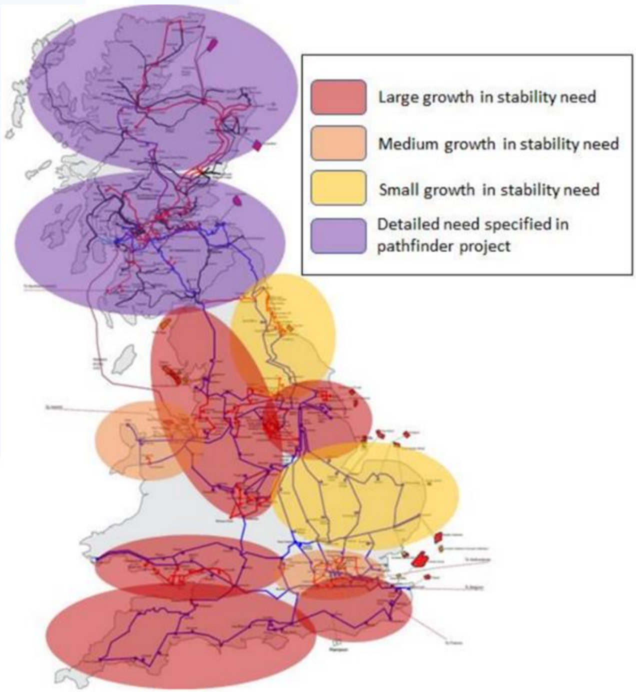
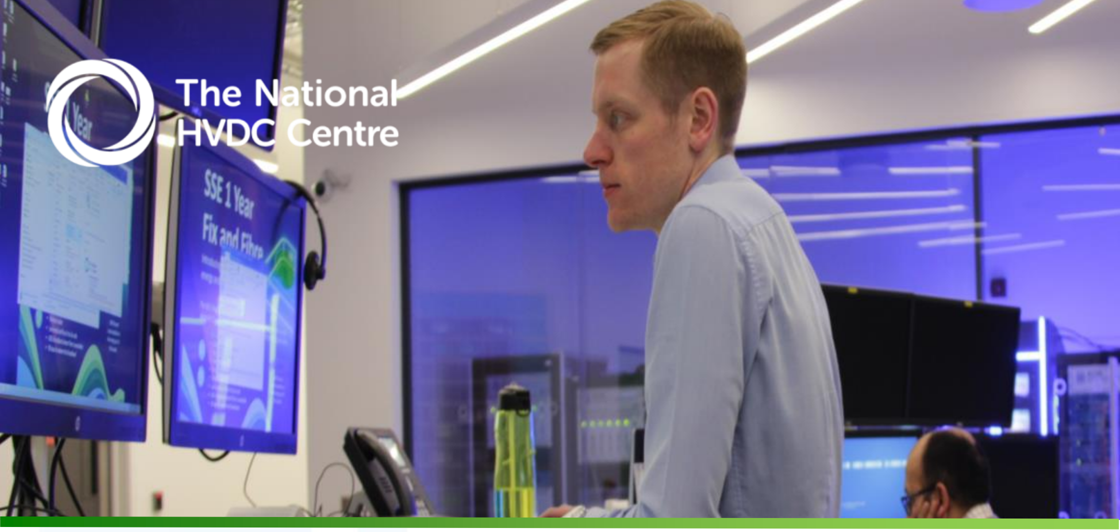


Figure 2: Stability needs across GB electricity grid (Source: National Grid ESO)



Case Study: Testing the feasibility of meshed DC grids protection

The HVDC Centre supports PROMOTioN, one of Horizon 2020's largest research and innovation projects

PROMOTioN is a European Horizon 2020 research and innovation project, working with 33 consortia partners from across 11 countries, that seeks to address the challenges of developing meshed HVDC offshore grids for cost-effective and reliable electricity supply. Currently the high cost of converter technology and a lack of experience with protection systems and fault clearance components, alongside limitations in European regulations in this area, hamper the deployment of meshed HVDC offshore grids.

A meshed European offshore transmission grid connecting offshore wind farms to shore could provide significant financial, technical and environmental benefits to the European electricity market and PROMOTioN's aim is to explore and identify these potential benefits.

And by connecting the windfarms together using existing links will provide a much more resilient connection to a HVDC grid.

PROMOTioN is focused on research of four key technologies; multi-vendor HVDC grid protection systems, HVDC network control systems, long duration testing of HVDC GIS (Gas Insulated Switchgear) and full power testing of HVDC circuit breakers. This is being delivered within 16 work packages

The HVDC Centre are working with the other consortia partners to demonstrate the protection of the DC grids

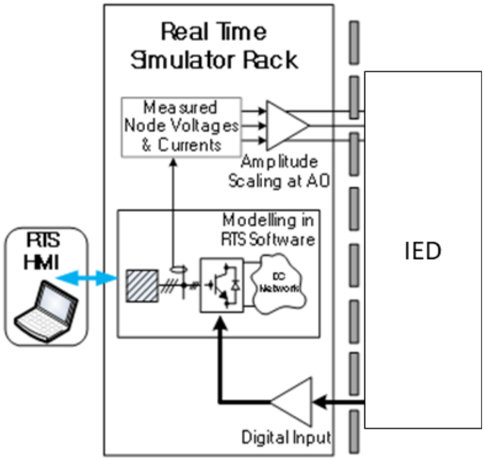
The National HVDC Centre is leading on Work Package 9 which is a conglomeration of the outputs of work package 4 that focuses on the protection of meshed HVDC grids, and work package 6, which investigates HVDC circuit breakers, to create an end to end protection system with an ultimate goal of raising TRL levels.

The objective of work package 9, led by the HVDC Centre, is to demonstrate the protection of the DC grids by investigating when faults arise, how the system is protected and kept online during the process.

The National HVDC Centre

The Centre received models of DC breakers from other work packages within the consortia and used physical intelligent electronic devices to decide which breakers should be tripped.

For example, the HVDC Centre built a model of an offshore grid including the HVDC circuit breakers and interface this with an academically developed IED from KTH Royal Institute of Technology in Sweden and an industry prototype from Mitsubishi. This demonstrated the model working in real time using simulation, which could be realised in a physical relay that could be installed onsite.



Outcomes

A demonstration event, held in the National HVDC Centre in August 2019, shared experience and learning around the operation of the protection regime.

A final event to be held at the end of the project will provide results and evidence around:

- The feasibility of protection of meshed DC grids
- Results around how it performed and identification of interoperability issues
- The aim is to provide developers with the information and confidence they need to start planning these networks and to feed into the development of a common European market.

Full details on PROMOTioN can be found on their website at https://www.promotion-offshore.net