Beta Phase - Annual Report

Application Number 10067854	**Project Title** Network DC
Date **11/11/2024**	**Author and Contact Details** Adnan Mahmood Project Manager adnan.mahmood@sse.com Colin Foote Senior Simulation Engineer Colin.foote@sse.com Martin Wilcox Technical Director martin.wilcox@mottmac.com

Section 1 -	**Beta Phase – Executive Summary**

Project Background

HVDC Circuit Breakers (DCCBs) will make possible new designs and operating strategies for High Voltage Direct Current (HVDC) links and connections as they develop into much more complex and sophisticated networks. The Holistic Network Design (HND) and Holistic Network Design Follow Up Exercise (HNDFUE) provides a recommended offshore and onshore design for a 2030 electricity network (and beyond), that facilitates the Government's ambition for 50 GW of offshore wind by 2030. A likely development from HND will be an increase in the deployment and flexibility of HVDC switching stations (DCSSs) designed to reduce cost and impact on the environment and local communities. Possible designs include multi-terminal HVDC systems with switching stations acting as control points and connection points for incoming offshore wind power. A DC switching station is now in operation at Noss Head within the Caithness-Moray-Shetland project. Another switching station may be installed at Peterhead by SSEN Transmission, supporting the recently approved HVDC links that will connect Peterhead to Spittal in Caithness, two different locations in England, and potentially also hosting connections of offshore wind farms and an international interconnector.

Without DCCBs, additional switching stations or point-to-point links will be required to support a 50 GW+ ambition for offshore wind and the growing network of HVDC connections around GB will be less flexible and responsive, leading to higher asset costs, and/or system operating costs. However, the GB Electricity System Operator, GB Transmission Owners, offshore wind developers and interconnector operators remain uncertain of the performance characteristics, network design implications, reliability, market availability and cost of DCCBs.

Scope of the Project

Network DC will investigate and demonstrate the use of DCCBs, an innovative technology untested in the GB and European markets. DCCBs will allow us to bring multiple wind farms into a DC system, containing the impact of any single failure safely and securely.

This project brings together international partners to accelerate the readiness of DCCBs for installation into the design of the emerging HVDC networks in GB and outlines a clear pathway for the installation of the first DCCBs.

The project will address uncertainties by demonstrating performance of DCCBs with detailed testing of protection and control philosophies, informing new technical specifications and addressing regulatory and commercial barriers.

The use-case selected for DCCBs is based on a DC switching station (DCSS) proposed at Peterhead that could support HVDC links connecting the transmission network in NE Scotland to locations in England and international interconnectors. The addition of DCCBs could provide capacity for additional power generation to be connected at the DCSS.

The project consists of 8 core work packages (WP):

WP1	Appoint OEMs
WP2	Design of a scheme-wide control & protection philosophy
WP3	Design of DCCBs
WP4	Use OEM's proprietary equivalent models to validate the DCCB parameters
WP5	Establish a replica
WP6	Use the replica to demonstrate performance in the GB network
WP7	Regulatory barriers and Cost Benefit Analysis
WP8	Innovation roll-out and scale-up

This report covers progress to date on WP 1, 2 and 7.

WP1 Progress:

- Whilst the scope of work for Original Equipment Manufacturers (OEMs) had been drafted and shared with OEMs in the Alpha stage, the Beta stage developed the commercial evaluation approach and re-visited the scope of work. This included review and sign-off from the Technical Authority within SSEN, Perry Hofbauer. Pre-tender calls were held with OEMs. The tender was issued in March 2024. Initial responses were received at the end of September 2024. Final responses are due in November 2024. longer than expected leading to late issue of tender to suppliers. Request for extensions from suppliers have extended WP1 timeline and potentially the overall timeline of the project.
- There has been further consolidation in the market since Alpha phase; one supplier (NR Electric) appears to be exiting the GB market; SciBreak is now a wholly owned subsidiary of Mitsubishi; Mitsubishi and Siemens have agreed a partnership to work on DC switching stations[1]; and SuperGrid Institute and GE Grid Solutions have signed a Memorandum of Understanding to work on DC circuit breaker technology[2].
- Some bidders are constrained for resource and have actively challenged taking part in another project. Siemens has elected not to bid.
- The next step is to review the bids received, discuss and agree with the Department for Energy, Security and Net Zero (DESNZ) any safeguards necessary if a Chinese OEM is one of the preferred bidders, and award contract.
- Initial technical responses were received by bidders on 13th September 2024, which are currently in evaluation.

[1] https://www.linkedin.com/posts/andrew-bailey-b211a067_siemens-energy-linkedin-activity-7134978425605287936-Yeb_?utm_source=share&utm_medium=member_desktop

[2] https://www.linkedin.com/feed/update/urn:li:activity:7130198930893484032/

WP2 Progress:

- At The National HVDC Centre, general management of WP2 activities and inputs to other project activities have progressed according to plan. Regular meetings are held with partners to discuss technical issues and collaboration has been positive and useful. There has been some delay in modelling the use case in more detail and subjecting the existing generic models of DCCBs to further testing, due to resource constraints at the HVDC Centre. Next steps will be to build out the models needed for testing and proceed with testing generic models ahead of future engagement with vendors.
- At SuperGrid Institute, progress is proceeding according to the planning concerning all tasks. The inputs and the use case study have been defined with the HVDC Centre. The functional requirements of the DC grid protection have been determined by identifying the types of faults to be considered in the study and defining the associated protection sequences and constraints to be respected. The use case has been implemented within the Electromagnetic transients program (EMTP) software, producing first results on DCCB and DC reactor (DCR) sizing, considering some simplistic models representing worst-case scenarios. First results show that a very high value of DCR is necessary if we need to avoid blocking of the Modular Multi-level Converter (MMC) in the healthy zones. Such high DC reactance could entail DC stability issues. Several solutions have been proposed to solve this issue. Next steps will be to analyse those different solutions and to define a strategy. After that, it will be possible to proceed with the determination of DCCB and DCR technical specifications.
- At University of Edinburgh, work regarding expanded DCCB models is progressing as planned. The activities related to HVDC hubs modelling have been delayed due to difficulties in the recruiting of a new post-doctoral research assistant (PDRA). However, a candidate has now been appointed and started working from early September on the planned activities. The Zhangbei hybrid DCCB model has been updated to include advanced functionalities, such as current limiting control, sequential activation and inner DCCB fault scenarios. Furthermore, the model has been packed as a user-configurable unit to be used in the HVDC hubs modelling and simulation activities. The following steps are the implementation of generic hybrid DCCB models considering a load commutation switch topology, and a current injection assisted topology. These models will be used in the HVDC hubs analysis to allow the development and evaluation of scheme wide protection philosophies.
- The WP2 programme has been extended by three months to recognise a slower start due to resource availability and the delay in appointing a DCCB vendor. The extension to May 2025 will allow time for the appointed vendor(s) to provide useful technical input that will inform the WP2 outputs and project Stage Gate 1.
- Key meetings and events are listed in section 11.
- Outputs and key findings are given in section 4.

WP7 Progress:

- Work on task 7.4 – Regulatory and commercial barriers to the adoption of DCCBs began in September 2024. This work is led by the Carbon Trust and will seek to develop and consult on a method to address the highest priority recommendations relating to regulatory and commercial barriers identified in the Alpha phase.
- The original plan was to conduct this work in 2025. However, following advice from the monitoring officer, it was recommended that regular quarterly updates be undertaken prior to 2025 to ensure continuous progress. We are currently awaiting a revision of the project plan, which will help finalize the timeline for this work. In the meantime, we will collaborate with UK and European projects and stakeholders to create a united voice advocating for a suitable landscape for DCCBs. To support this effort, we have assembled a group of key advisors who will meet quarterly to monitor sector progress and address any emerging changes.

Section 2 -	Beta Phase – Project Summary
Please provide a summary of the key findings from your Beta Phase Project.	

How your Project is meeting the aims of the relevant SIF Innovation Challenge and the problem and opportunity your project aimed to resolve and how the Project helped solve the issue.

Network DC is addressing the Whole System Integration innovation challenge. The challenge requires the coordination of design, to help deliver an integrated system capable of providing net-zero electricity generation. Network DC will support the coordination of offshore and onshore networks and the coordination of new generation connections with more general transmission reinforcement, by enabling more flexible DC grids that connect multiple wind farms into higher-capacity DC substations.

Approach
The project approach is based on the following:

- Engagement with vendors and other international transmission companies to ensure their knowledge and understanding is suitably incorporated into DCCB specification for GB
- Contracting with one or more vendors to be directly involved in analysis of power system behaviour, reliability and costs
- Partnering with a leading international industrial research organisation to benefit from their wide-ranging involvement in relevant work, past and present
- Partnering with a leading GB university to harness the latest developments in DCCB thinking, design and modelling
- Using state-of-the-art modelling and simulation facilities available at The National HVDC Centre to conduct a range of software-in-loop (SIL) and hardware-in-loop (HIL) testing of DCCB behaviour and performance
- Rigorous assessment of reliability risks by asking the contracted vendors to provide a Failure Mode Effects and Criticality Analysis of their design
- Robust assessment of DCCB cost models to inform future cost benefit analysis
- Maintaining a watching brief on relevant industry developments and engaging with diverse stakeholders to ensure their perspectives are reflected in project outputs

The goal is to produce functional specifications and supporting information that will support Transmission Owners (TO) in GB being able to specify and procure DCCBs in future network designs.

Benefits
A DCCB hub will reduce the need for new infrastructure and improve flexibility and operability of DC grids. This project will build confidence in DCCBs allowing utilisation across the network. The project will provide a pathway to making DCCBs a viable option for specification and implementation in HVDC network development projects in GB.

How the Project is performing relative to its aims and objectives
The project has incurred delays to the critical path, both occurring in WP1. An internal delay occurred as the review of the tender wording took longer than planned. An external delay occurred as OEMs asked for additional time to prepare bids and participate due to volume of tendering activity in the market and the fact that the tender pulls on the same technical resources as major HVDC converter station tenders.

The critical path is now governed by the sequencing of WP2 (where the consortium co-designs

DCCB switching stations with the OEMs); WP3 (where the OEMs document and present their DCCB design including Failure Mode and Effects analysis (FMEA) and WP5 (in which OEMs build a replica of the protection and control and ship it to The National HVDC Centre for use in simulations).

Until the OEMs respond with their bids, it is difficult to judge overall impact on timeline. The project end-date depends on whether OEMs are seeking a long or a short period of overlap and co-design with the existing team working on WP2, and whether OEMs are offering to construct Hardware-in-the-Loop and Software-in-the-Loop replicas using production software, or are proposing alternative approaches which save time, but need to be judged for their suitability to deliver the outcomes.

The project end-date does have a month-for-month knock-on delay on delivery of impacts. A mitigation to this is the approach taken by Energinet and 50Hertz, which has carried out procurement of HVDC converter stations for an offshore DC switching station whilst keeping HVDC circuit breakers as an option[3].

Any difficulties or delays encountered during the Project and how these challenges informed future thinking on undertaking innovation Projects effectively.

There have been delays to the WP1 timeline. This is due to the review of the scope of work taking longer than expected leading to late issue of tender to suppliers. Request for extensions from suppliers have also extended the WP1 timeline and potentially the overall timeline of the project.

Suppliers have indicated through Pre-tender discussions that it is challenging for them to engage from initial Alpha consultation to Beta tender – lots of movement in between phases on similar projects (Interopera) stretching their resource and making Network DC lower priority. One bidder (Siemens) has expressed this as their reason for not proceeding with a bid.

At University of Edinburgh the activities related to HVDC hubs modelling have been delayed due to difficulties in the recruiting of a new post-doctoral research assistant (PDRA). However, a candidate has been appointed and started work from early September on the planned activities.

[3] https://bornholmenergyisland.eu/en/index/energinet-and-50hertz-start-tendering-for-bornholm-energy-island

Section 3 -	Beta Phase – Knowledge creation and dissemination

What lessons were learned from the approach and the project's innovation for the relevant period? Provide insights gained from the project innovation and the approach employed. Where relevant, this should include the insights developed by the Project and the flexibility service providers on consumer demographics.

The offshore transmission sector continues to suffer from “key-person” constraints which act as a constraint on the GB ambitions for offshore wind unless addressed. Our observations are that:

- The bidding team for Network DC within Hitachi Energy are essentially the same team as bid the recent converter station tenders for Project Acquila to SSEN.
- Mitsubishi Electric has acquired additional specialist resource in the form of SciBreak but appears to be once again at bidding capacity.
- Hitachi Energy has expressly stated it has limited, if any, bandwidth to support a DCCB design which does not already meet the specification of its own internal product development.
- Siemens exiting the process due to engineering bandwidth.

We had set a high bar of expecting the OEMs to go back-to-back with the SIF’s principle of funding the first 10% of their activities as company investment and recover the remaining 90% from the SIF. We were conscious this was potentially hard to audit and was in practice causing additional difficulties in OEMs achieving internal management sign-on to bid. We have therefore removed the requirement and will fund 100% of activities.

These would appear to point towards GB needing to either take a radical approach to working with Chinese manufacturers to expand the supply chain, or to ensure that its designs and technical standards for DCCBs remain aligned with efforts in the EU and USA, to minimise work for the OEMs.

Section 4 -	Beta Phase – Intellectual Property Rights Generation

Provide a description of any relevant foreground IPR that has been developed from the project to date and the plans for sharing this across networks.

If the project has generated Intellectual Property Rights (IPR) that Ofgem has specified do not need to be shared, please explain this in detail.

Three reports have been issued from WP2 in year one, all being updated versions of previous documents to support the WP1 invitation to tender issued to DCCB vendors:

- DCCB Use Case Description
- Replica Hosting at the HVDC Centre
- DCCB Specification

In addition, several documents have been used to support internal technical discussion.

Key learning and relevant foreground IPR generated to date:

- Compilation of technical issues that should be considered further and may influence future DCCB specifications
- A greater understanding of global activities and other projects related to DCCBs
- Use case EMTP model of the test grid including cables, DCCB, DCR, bipolar MMC connected to onshore AC and MMC connected to aggregate Wind Farms
- Expansion of Zhangbei hybrid DCCB model to include advanced functionalities, such as current limiting control, sequential activation and inner DCCB fault scenarios.

Section 5 -	Beta Phase – Data Access Details

Provide a description of any data or insights you have produced/published from the Project, and where they may be found or requested.

No data or insights from the project are ready yet for publication as these are being internally reviewed.

Section 6 -	Beta Phase – Route to Market / Business as usual
How is your Project working towards integration into business-as-usual practices within your network and across other networks following the successful completion of the Beta Phase? What strategy do your Project Partners have for commercialising the innovation?	

You should describe:

How the Lead Network (and other Networks) will adjust their own networks processes, products and services based on the insights gained from the Project. Outline necessary steps and additional work required before it can be adopted.

The integration of Direct Current Circuit Breakers (DCCBs) into the network, whilst having significant advantages, is a substantial and disruptive change to the architecture of the GB transmission grid. DCCBs are not yet at the requisite technical, commercial, or integration readiness levels to be included in the holistic planning of the GB transmission network.

This Project cannot guarantee the selection of DCCBs as a part of the network's future design. However, without this Project and without raising the readiness level of DCCBs and progressing the work packages set out in this project, DCCBs may never be a viable option for the GB network. The risk is that without this optionality, the GB network may never reach optimal configuration for the benefit of the consumer.

Therefore, this Project considers that BAU adoption is achieved if DCCBs are viable options in designing the GB future network. Whether or not they are then subsequently deployed depends on the assessments applied to these future investment decisions.

This Project will engage with the key stakeholders to ensure that the equipment manufacturers can meet the technical and commercial standards required to install DCCBs on the GB network. We will work with the subject matter experts in the transmission networks and the Electricity System Operator (ESO) to ensure we meet all the appropriate engineering standards. SSEN-T is already considering options for retrofit of DCCBs in the design of proposed DC switching stations in the North of Scotland. The GB transmission network, the ESO, European subject matter experts, and equipment manufacturers will primarily support this innovation. We will also draw on Chinese manufacturers' experience in using DCCBs in the Chinese transmission network. We will work with DESNZ and Ofgem to ensure that consultation with Chinese manufacturers does not compromise the GB network security and stability.

As this Project design will set the technical and commercial standards for implementing DCCBs, the results will be disseminated to the ESO (who are project partners) and transmission network owners to establish appropriate industry codes and standards. These codes and standards will be publicly available. It is also the case that through this Project, a range of equipment manufacturers will come to understand how best to design the equipment and controls required for the GB market. Therefore, this Project can de-risk the supply chain for DCCBs. This approach will maintain a competitive market for the supply of DCCBs. Equipment manufacturers will be engaged in the Project and provide equipment for Beta Phase testing. However, this Project will treat equipment manufacturers as suppliers rather than project partners to maintain a competitive market in the future.

The ESO has confirmed they would like to have DCCBs as an option for network design. Four equipment manufacturers have provided initial technical responses as part of the bidding process.

Establishing DCCBs as a viable network engineering option could benefit the consumer by:

(1) lowering the cost of bringing on more renewable energy

(2) reducing the size of the network, with fewer landfall sites bringing environment and sustainability benefits
(3) maintain the reliability of energy supply through improvements in the ability to manage faults.

The likelihood that the innovation will be deployed on a large scale in future.

The use of HVDC for offshore wind connections, subsea and long-distance interconnectors, and general transmission reinforcement is expected to expand globally. As these individual DC links transform into emerging DC networks there will be a need for DCCBs to be widely deployed.

What considerations have the Project consortium made for the commercialisation of the proposed solution or innovation

Two groups can be considered customers of our innovation:

1. Developers of offshore wind or other offshore technologies of similar power rating.
2. Developers of interconnectors between GB and other systems.

The customer value proposition is aimed at developers seeking connections that will require the use of High Voltage Direct Current (HVDC) links into the GB system. Developers with Projects that reach landfall close to a Direct Current Switching Station (DCSS) can connect to that DCSS, rather than being connected via a new point-to-point link. Developing a new point-to-point link requires additional land purchases, consenting, and Alternating Current (AC) reinforcement works and will take longer compared to exploiting additional potential capacity in the existing DCSS.

Additional capacity could be created at the DCSS if Direct Current Circuit Breakers (DCCBs) are used to unlock the capacity for various stakeholders connecting to the system. As such, the risk of new technology is spread across all customers of the DCSS, at the TOs risk. The TO will own the DCCBs. In the event of an unplanned outage of the DCCBs, a maintenance outage of the DCCBs, or a fleet defect requiring the DCCBs to be taken out of service whilst remedial actions are taken, the DCSS falls back to operating as it did initially, with its original capacity and capability.

The route-to-market strategy is based on DCCBs being supplied like conventional HVDC substation equipment. Traditional HVDC substation equipment is competitively tendered, typically as a turnkey equipment supply agreement and Long-term Service Agreement (LTSA). Procurement of conventional HVDC onshore and offshore substation equipment in GB is based on a credible market of three leading European HVDC suppliers and challenger suppliers from China. Options remain for the TOs to split activities, such as enabling works, civils, and construction of a building to contain the HVDC converter, from the supply of the core equipment if desired.

It is a pre-condition of our commercialisation strategy that DCCBs are self-contained and can be added to an existing Direct Current Switching Station (DCSS), irrespective of which manufacturer(s) provided the equipment for the original DCSS. This pre-condition has been shared with manufacturers in the scope of work issued for consultation.

We foresee that the first DCCB installations will comprise a single supplier winning the contract to supply all DCCBs required at a particular DCSS, to a single common design. We will nevertheless seek to avoid any designs which prevent a multi-vendor approach from being pursued in the future, whereby multiple suppliers provide the DCCBs into a single DCSS, to increase the speed of delivery and resilience to fleet defects.

To commercialise the product, equipment will need to be type-tested against the Minimum Functional Specification (MFS). In our scope of work for manufacturers, we have encouraged them to carry out High Voltage testing of their design (in a laboratory such as the DNV GL (ex. KEMA) laboratories in the Netherlands). We are however not providing funding from the SIF for this, to avoid distorting the market. Players will be expected to "catch up" on their own funds, where necessary, in time for the first DCCB procurement in GB. The OEMs appear to have accepted and understood this.

How the Project is providing support for non-network partners to move towards commercialisation.

The project consortium consists of 5 partners, which include 3 non-network partners. The project is also looking to bring one or more OEMs on to support the project. The project is providing support for these parties moving towards commercialisation by dissemination and through technical understanding.

Include as an appendix your post-Beta Phase Roadmap.

As discussed with the monitoring officer in the quarterly review meetings (QRM) the output of the WP1 tendering process will inform the roadmap design. Therefore, the post-Beta phase roadmap will be developed following the completion of WP1 and the appointing of OEMs on the project.

Section 7 -	Beta Phase – Policy, Regulatory and Standard Barriers

Provide a summary of any regulatory, policy, or standards barriers which may require derogations or any proposed changes which would be necessary in deployment of the innovation.

Regulatory barriers or regulatory uncertainties affecting the delivery of the Beta Phase Project

There are no specific regulatory barriers that would prevent the Beta phase of Network DC from being carried out, however, it is plausible that the lack of regulatory clarity may dissuade transmission operators from accepting DCCBs and thereby dissuading manufacturers from investing in technology development. Furthermore, the lack of regulatory clarity disincentivises the network owners from investing in the infrastructure.

Longer-term regulatory barriers to the adoption of HVDC Circuit Breakers

In the Alpha phase of the Network DC project, we identified a number of regulatory and commercial obstacles to the uptake of HVDC circuit breakers in the GB electricity network; these obstacles still exist.
We identified three key regulatory and technical obstacles as follows:

1. The requirement for the development of legal and regulatory frameworks for DCCBs
2. The uncertainty of the technical specifications for HVDC Hubs containing DCCBs in the GB network.
3. The uncertainty in commitment to the evolution of infrastructure and how this impacts the delivery model for DCCBs.

Regulatory conditions for Beta Phase delivery

The proposed scope and activities require no derogation, license exemption or sandbox for the Network DC project Beta Phase.

Involvement of Government, Ofgem, and other relevant organisations

In addition to the regulatory obstacles that were identified, we also identified a series of recommendations, actions, and action owners who are required to overcome the obstacles. Many recommendations require input from parties outside the project team, including Ofgem, Department for Energy Security and Net Zero (DESNZ), and others.

In order to obtain greater clarity on the regulatory landscape governing the use of HVDC circuit breakers, we strongly advocate the greater involvement of Ofgem in the Beta Phase of the Network DC project.

In investigating the commercial and regulatory barriers to the adoption of HVDC circuit breakers, the work that we are conducting in WP 7 of the Network DC projects has two distinct phases.

- Initial ‘light-touch’ stakeholder engagement
- Extensive stakeholder engagement into regulatory and commercial barriers

We are currently in the first phase of the work. We are identifying if any developments or progress has been made in the sector that may have a bearing on the adoption of DCCBs.

A small group of industry experts have been assembled as the Network DC Regulatory and Commercial Advisory Group. Meetings with these individuals are held quarterly and we discuss any developments in the sector impacting HVDC and DCCBs in particular.

The most recent meetings of the advisory group identified a number of relevant developments in the sector, namely:

- Energinet and 50Hertz start tendering for Bornholm Energy Island, DCCBs are an optional addition and technical specification is to be defined by OEMs.

- TenneT's tendering process is influencing OEM approach to tenders, which has led to OEMs favouring framework agreements and standardised sizing based on TenneT's orders.

- Ofgem availability stance on in-service projects might deter developers from using DCCBs as not yet a reliable technology.

- ENTSOE; Offshore Network Development Plan; estimates investments required with and without DCCB technology.

Following the onboarding of manufacturers and the possible need to re-scope the project we will start to develop the framework for the full stakeholder engagement currently scheduled for 2025.

Section 8 -	Beta Phase – User Needs
Summarise who your prioritised users are for your project, outlining their specific needs and how the project is addressing these needs and issues.	

You should describe:

- **what the user journey is for you new product, process or service**
- **how you are translating these user needs into your project design and requirements**
- **how your understanding of User Needs has been improved as a result of the Project**
- **how you are testing your own assumptions against the needs of your users**
- **how the approach you are taking will minimise the burden on your future users and avoid duplication of effort through user journeys.**

The key users of this innovation include offshore wind developers; interconnector developers; and the Offshore and Onshore Transmission Owners and operators managing the interface between DC and AC circuits.

For offshore developers, DCCBs will enable DC grids to be developed and therefore rationalise the number and location of connections with the on-shore AC Network. Developers of Interconnectors will be able to connect into grid systems more easily and will be faced with lower initial project development costs as less infrastructure will be required.

For Transmission Owners, the introduction of DCCBs will mean a much more flexible and dynamic system more able to cope with varying demands, new connections and maintenance and replacement of existing infrastructure.

By developing a common set of requirements for DCCBs we will help to unlock the potential of DC Grids and support all users in gaining the benefits and enabling best use of existing and future infrastructure.

This Project reduces the risk that the system design is not specified sufficiently for certification and acceptance of equipment onto the network. The risks will be addressed through replica testing.

This Project will result in reduced infrastructure costs and enable a coordinated and efficient grid infrastructure critical to delivering secure, reliable, and clean energy at the lowest price to consumers.

The ESO will utilise the project learning to review network design rules, e.g. considering DC hubs with DCCBs for future offshore coordination where beneficial. For DCCBs to become an optional element in planning the future grid, this project will carry out replica testing of DCCBs and establish performance standards so that the supply chain can develop the capability to service any future GB market.

Section 9 -	Beta Phase – Impacts and Benefits
Describe your expected net benefits to consumers and justify any changes in proposed impacts since the Application stage.	

The benefit of implementing Direct Current Circuit Breakers (DCCB) is that more offshore wind can be connected at lower costs and with a reduced environmental impact. This approach addresses the Government's net-zero targets by enabling the connection of more renewable technologies and reducing energy transmission costs, which could lead to savings for end consumers.

The benefits of this Project and the long-term adoption of DCCBs into the energy grid are understood by comparison with counterfactual design cases. Alternative to DCCBs, the expansion of offshore wind can be accommodated by:

1. Increasing the number of converter stations or Direct Current Switching Stations (DCSS) built around the coastline (necessitating correspondingly greater quantities of transmission infrastructure)
2. Allowing more connections to existing DCSSs and offsetting the resulting risk of grid instability with increased contracting of ancillary service providers

Compared to the preferred use case of:

- Using DCCB to connect more generation capacity to an existing DCSS (or other connection nodes), managing the risks, and increasing operational flexibility.

Compared with (1), using DCCBs can save valuable space by reducing the number of transmission assets, thus reducing impacts on local coastal communities and those who would otherwise be disrupted by expanded transmission infrastructure. It also reduces costs by avoiding the need to build additional infrastructure. This approach increases the Direct Current (DC) network's flexibility, allowing wind power to be routed more efficiently to centres of demand with reduced constraints and likely reduced curtailment on wind generation. Cost savings can be passed on to consumers.

Compared with (2), DCCBs can reduce expenditure on ancillary services. Given some of these services are provided by high inertia fossil-fuel powered turbines, there is also the potential to save on greenhouse emissions.

The CBA analysis submitted within the Beta application shows a combined positive benefit of NPV(3.5%) ~£3.5 million over the first ten years of operation and NPV(3%) ~£350 million in the expected 35-year lifetime of operation.

The benefits case relied on three critical pieces of information, and on wider market sentiment:

1. the estimated cost of an individual DCCB
2. the quantity of DCCBs required within each DC switching station, which is a function both of the design of the DC switching station arrangement, the number of incoming and outgoing feeds, but also the inherent reliability of each DCCB[4]
3. the cost of alternative onshore solutions which can allow larger DC switching stations to be built, without DCCBs, and yet defend the onshore system against major losses of infeed.
4. the market sentiment in Europe and USA to consider DCCBs in their offshore wind development.

[4] Until proven otherwise, the cost-benefit case has assumed that two DCCBs connected in parallel are required to provide the reliable function of a single DCCB; since internally, any DCCB contains an AC circuit breaker to ultimately open the contacts. This would appear (until we see OEMs' proposals) to create a single point of failure.

Through WP1 and the release of the tender to the market, the routes remain to retrieve improved cost information and reliability information (items 1.) and 2.) above). The tender responses will allow us to true up the programme for cost-benefit analysis according to when and at what level of detail the information will be shared by OEMs in their proposed programme.

National Grid ESO publishes its costs of procuring inertia and the Frequency Risk and Control Report for 2024 was recently finalised following consultation (the main contributors to 3.) above); we have not re-analysed this data at this time.

The market sentiment for DCCBs appears to remain strong: for example, the ENTSO-E grouping of European electricity transmission system operators found that the addition of DCCBs did not materially increase the overall capital expenditure required across the EU, but can deliver significantly more capacity[5].

The project will re-assess the phasing of the CBA work in WP7 once tenders are received and the OEMs' offers are known.

[5] https://www.entsoe.eu/publications/ondp2024/web_entso-e_ONDP_PanEU_240226.pdf

Section 10 -	Beta Phase – Risks, issues, and constraints
Provide a summary outlining the risks and issues the Project is encountering, including impact, and mitigating actions to address these challenges.	

You should describe:

- **any actual or potential constraints in regulation, legislation, commercial contracts, or legacy technology that has/will hinder your ability to implement the findings of this into Business as Usual or delayed progress to roll out which could be relevant to future Projects**
- **the actions taken by the Funding Party to facilitate the removal of any barriers encountered.**
- **how you have adapted the Project outcomes to meet user needs while operating within these constraints.**
- **if you have identified constraints that can be removed in the short or long term, describe how these can be overcome based on the learnings from this project.**

A Risk Register has existed since Discovery Phase of the Network DC project and has been provided to UKRI. This risk register manages, rates, and reviews all identified risks and assumptions, as of the writing of this report there are currently 37 live risks, the most notable of which are discussed below.

Risk		Mitigation
1	Manufacturers are insufficiently motivated to develop the equipment due to lack of commercial incentives, since regulators and TSOs have not promoted development of DC networks. As a result, there is a lack of depth/breadth in the supply chain for DCCBs long term.	The field of OEMs has consolidated, with one exiting the UK market, one purchasing another, and two working in partnership. Maximum bidders is now 4. After follow up calls with OEMs, final extension has been granted to Friday 1st November 2024 for bid submission.
2	Wider uncertainty around cost to supply DCCBs and cost of avoided converters far exceeds the accuracy of any simulated benefits	Scope of work included in WP1 supplier tender requires manufacturers to provide indicative prices of a DCCB. Assumptions have been provided including a Minimum Order Quantity, to increase likelihood that they provide a price estimate.
3	Wider uncertainty around cost of ancillary services in the Alternative Case far exceeds the accuracy of any simulated benefits	Technical Note was prepared and issued to NGESO and ancillary services volumes and unit cost estimates agreed with NGESO. Review of unit cost estimates against most recent NGESO data should be held as part of the project re-phasing/re-baselining following completion of WP1.
4	There is a lack of data to support reliability assessments that satisfies the requirement of GB asset owners and investors.	Alpha phase has identified this risk, Beta will seek to mitigate. All calls with the OEMs have discussed the need for information about reliability.
5	Policy and regulatory developments, and activity from NG ESO, do not progress at a sufficient pace to enable the development of a refined regulatory assessment for DCCBs and onshore HVDC hubs using DCCBs.	The Alpha phase revealed a fast pace in policy and regulatory developments around coordination of offshore wind, which will affect the case and model for DCCBs. Network DC project is actively engaging organisations involved in the regulatory landscape for DCCBs and onshore HVDC hubs using DCCBs: NGESO and SSEN are

		part of the project consortium; assessment of regulatory developments has been enhanced through Alpha phase. Network DC will seek discussions with Ofgem to specifically assess DCCBs in the future.
6	Suppliers do not proceed with bid submissions beyond their initial technical response.	Initial technical responses received 13th September. All suppliers have confirmed their intent to submit a final bid in November 2024.

Section 11 -	Beta Phase - Working in the open
How are you ensuring transparency and stakeholder engagement during the Beta phase?	

You should describe:

The methods you are using to communicate publicly about the project.

The Network DC Beta Phase will disseminate through publications and public presentations throughout the project.

Dissemination events in year one includes:

- Presentation at RTDS European User's Group Meeting, Germany, September 2023
- Public webinar, October 2023
- Presentation at the Energy Innovation Summit, Liverpool, October 2023
- Presentation and discussion at The National HVDC Centre's Operator's Forum, Cumbernauld, June 2024

How the Funding Party and Project Partners collaborate with stakeholders to promote and refine the project. The ways in which you invited challenges and external input on your project approach.

The Network DC Beta Phase project has continuously sought project partner input, through regular meetings with all parties involved in the project, and additional meetings with external stakeholders such as Ofgem, DESNZ, and other parties.

WP1 Pre-tender and follow up meetings have also provided OEMs the opportunity to provide their insight and challenges to the project.

How you shared your learnings to avoid duplication of efforts and to accelerate industry progress on related initiatives.

The Network DC project has engaged industry stakeholders in year one as part of WP2 to transparently share learnings. Currently no additional research projects are investigating these technologies in GB. The project has made efforts to engage with European TSOs to more fully understand projects in Europe looking at similar technologies.

WP2 stakeholder engagement activities in year one include:

- Meetings with Energinet (TSO in Denmark working on DC hub projects with DCCBs considered as possible future option) in March and April 2024
- Discussion with the National Renewable Energy Laboratory (NREL) and Oak Ridge National Laboratories (ORNL) on research activities relating to DCCBs
- Meeting with TenneT (TSO in Germany and the Netherlands) in August 2024
- Informal discussions with various TSOs about plans for DCCBs
- Forming plans to build on the above with the creation of a project technical advisory group to commence in late 2024 or early 2025

How your team has been working openly and building relationships with organisations and teams responsible for other parts of the user journey, such as infrastructure/data owners, regulators, policymakers, investors, and others.

As part of WP7.4 activities led by the Carbon Trust, a small group of industry experts have been assembled as the Network DC Regulatory and Commercial Advisory Group. Meetings with these individuals are held quarterly and we discuss any developments in the sector impacting HVDC and DCCBs in particular.

Section 12 -	Beta Phase – Costs and value for money

Provide a detailed account of how the Project funds are being spent, referencing the original forecasted budget.

You should describe:

- **how the project is delivering value for money to consumers.**
- **reasons for any significant variations between the planned and actual spend.**
- **any unspent SIF funding that may be returned to consumers.**
- **any additional funding or contributions beyond those outlined in the Project Direction, noting that these will be considered Disallowed Expenditure.**
- **Any revenues earned related to the Project that will be returned to consumers.**

Include the summary table below with the final project expenditure by each Project Partner.

The budget of this project is managed through budget trackers held by SSEN-T on a joint SharePoint.

The delays and subsequent extensions to WP1 and knock-on impact to later work packages, as discussed in Section 2 of this report, has resulted in variation between the planned and actual spend. If the project is successful in contracting OEMs, the timeline and project will be revised accordingly.

There is no additional funding or contributions beyond those outlined in the Project Direction. No revenues have been earned related to the Project.

Project Partner name	SIF funding requested	Total actual project spend	Total project contribution made (incl. contributions in kind)
Scottish and Southern Electricity Networks (SSEN-T)	£3,929,422	£357,699	£35,770
University of Edinburgh	£1,117,237	£91,107	£9,111
Carbon Trust	£141,072	£22,975	£0
National Grid Electricity System Operator Limited	£92,999	£55,495	£5,550
SuperGrid Institute	£206,064	£102,006	£10,201

Section 13 -	Beta Phase – Special Conditions
Describe how you have met any requirements of any project specific conditions set out in the Project Direction.	

No.	Project Specific Condition	Status
1	The Funding Party must not spend any SIF Funding until contracts are signed with the Project Partners named in Table 1 for the purpose of completing the Project.	Complete
2	The Funding Party must report on the financial contributions made to the Project as set out in its Application. Any financial contributions made over and above that stated in its Application should also be reported and included within the Project costs template.	Ongoing
3	The Funding Party must participate in all meetings related to the Project that they are invited to by Ofgem, UKRI and DESNZ during and after the Beta Phase	Ongoing
4	The Funding Party must, with support from Innovate UK/UKRI and, where applicable Ofgem, scope the requirements and success criteria for each stage gate within a Project at the quarterly reporting meetings ahead of any stage gate. These will be used to determine what criteria a Project must meet in order to pass a stage gate, and whether any additional information, such as a report, must be produced as part of the stage gate.	Ongoing
5	Each of the annual progress reports that the Funding Party publishes in the Beta Phase must, at a minimum, be uploaded to the ENA's Smarter Networks Portal. We also strongly encourage wider dissemination of the annual progress report(s) and support from all Project Partners in ensuring it reaches a wide audience.	September 2024 annual progress report to be uploaded to ENA Smarter Networks Portal.
6	As part of the end of Project Phase report, the Funding Party must produce a Project Impact Monitoring and Evaluation Plan. This plan must outline how the Project plans to monitor and evaluate the delivery of benefits outlined in the Beta Phase Application following the end of the Beta Phase. The plan must also include the methodology that will be utilised for quantifying and qualifying benefits realisation and how the Funding Party plans to report this to Ofgem 1, 3, 5 & 10 years post-Beta Phase completion. Further details on how to approach the development of this plan may be provided by Ofgem or IUK.	To be provided as part of end of Project Phase report.
7	The Funding Party and all Project Partners must make reasonable attempts to attend, participate and/or contribute at SIF Community Forum events occurring during the Project delivery. We anticipate there being approximately one event per year	SIF community forum attended in February 2024.
8	The Funding Party must provide verbal updates at each quarterly meeting on any regulatory, policy and standards barriers and any change requirements which may impact delivery of the Beta Phase activities. The Funding Party must also include as an attachment to each of its annual progress report an update on any regulatory, policy and standards barriers which may require derogations and articulation of any proposed regulatory, policy and standards changes which would be necessary in deployment. The Funding Party must	Updates provided at each quarterly review since start of project.

	also provide an as an attachment to its end of Project Phase report a summary of the Project's findings on regulatory, policy and standards barriers, including any considerations for future work, and where applicable, where specific regulatory, policy and standards changes would be required for deployment.	
9	The Funding Party must provide within the first three months of the Project beginning (i.e. by 1 October 2023) an updated 60-second video. If the Project is greater than two years (longer than 24 months) in length, an updated video must also be provided at the Project's mid-point meeting. All Projects must also provide an updated 60-second video as part of their end of Project phase report. Innovate UK can share its guidance for 60- second videos with the Funding Party, if necessary.	First updated video submitted to UKRI on 30th October 2023
10	The Funding Party must provide to the monitoring officer within six months of the Project beginning (i.e. by 1 January 2024) a roadmap for activities post-Beta Phase. This can build on the Project's Application question (question 11) and must focus on how and when the proposed solution will become business as usual within your network and across the other GB gas or electricity networks. As part of this, the Funding Party must include consideration for:	Output of tendering process to inform the roadmap design. Roadmap to be taken forward as part of WP 8.0. Potential for delays due to shift in tendering timeline.
11	The Funding Party must provide at every second quarterly monitoring meeting (i.e. every six months) an update on its commercialisation strategy. This can build on the Project's Application question (question 12) and must focus on what considerations have the Project consortium made for the commercialisation of the proposed solution or innovation, and how the Project provides support for non-network partners to move towards commercialisation. As part of this, the Funding Party may wish to include consideration for:	Updates provided at QRMs.
12	As part of the Project's stage gate 1, the Funding Party must submit to the Project's monitoring officer its plan to improve the competition between original equipment manufacturers (OEMs) in the Project to ensure the Project is maximising its potential value for money and that it does not undermine the development of competitive markets. In addition, the successful OEM(s) must provide a statement of either their intent to participate in a physical demonstration/deployment after the SIF Project completion and should the SIF Project successfully conclude the Beta Phase, or reasoned justification as to why they will not participate in a physical demonstration/deployment following the SIF Project completion and should the SIF Project successfully conclude the Beta Phase. A statement must be in place by stage gate 1 for the Project to progress beyond this point.	To submit ahead of stage gate 1
13	The Funding Party must provide to its monitoring officer ahead of or as part of stage gate 1 an outline of how its Project governance will ensure the Project will react appropriately in the event of change of assumptions (e.g. policy or regulatory changes) which may impact the Project's overall proposed	To submit ahead of stage gate 1

	value or proposed solution. This could include, for example, additional opportunities for stage gates or reviews.	
14	During the Project, the Funding Party must include greater consideration as to how the Project's proposed solution would feed into and influence global HVDC and DCCB standards. The Project must also provide an update on these efforts at each stage gate and must include as part of or as an attachment to its end of Phase report, including if the Project concludes or ends early, a summary report of these efforts and the outcomes.	Updates to be provided at each stage gate and included as attachment to end of phase report.
15	At each stage gate, the Funding Party must include considerations of the policy and regulatory risks to the Project and its proposed solution, and opportunities for it. We expect this activity to be an ongoing and iterative activity where an update is provided at each stage but the Project maintains this work as part of its activities.	To submit at each stage gate
16	The Funding Party must provide as an attachment to each of its Beta Phase annual progress reports a summary of policy and regulator developments since the Project's inception, including updates from the involvement of Ofgem and DESNZ (formally BEIS) in the Project.	See Appendix 1 of this report.
17	The Funding Party must provide as an attachment to its year one annual progress report a summary of it plans to influence wider industry and EU standards on DC circuit breakers and how it plans to incorporate any current or pre-existing work done in the wider industry, including in the EU, on DC circuit breaker standards. In particular, the report must demonstrate consideration for how the Project's learnings and findings will look to also be applicable in the EU. The summary must also be published on the ENA's Smarter Networks Portal to support dissemination of the Project's findings.	Agreed with monitoring team that due to delays in contracting OEMs, this condition will be addressed more fully in the second Annual Report.
18	Prior to formally beginning any work on the Project, the Funding Party must provide a report summarizing how the IPR arrangements which the Project may generate will be handled should the HVDC centre change ownership as part of the next price control. As part of this, the report must include an outline of any risks to the IPR generated from the Project and a proposed contingency plan for any of the risks.	Provided to UKRI 5th March 2024.

Section 14 -	**Beta Phase – Material Changes**
Provide a summary of any material changes submitted which has occurred in the relevant reporting period. It should describe why the planned approach proved to be inappropriate and how the alternative approach improved the original approach. No material changes have been submitted.	

Appendix 1	Project Specific Condition 16
The Funding Party must provide as an attachment to each of its Beta Phase annual progress reports a summary of policy and regulator developments since the Project's inception, including updates from the involvement of Ofgem and DESNZ (formally BEIS) in the Project.	
1. Mitsubishi Electric bought start-up company SciBreak to develop DCCB technology[6] 2. Mitsubishi Electric and Siemens Energy announced collaboration on DC Switching Stations[7] 3. GE announced an MOU with SuperGrid Institute to develop the DCCB technology[8] 4. ENTSOE; Offshore Network Development Plan; estimates investments required with and without DCCB technology.[9] 5. Energinet and 50Hertz start tendering for Bornholm Energy Island, DCCBs are an optional addition and technical specification is to be defined by OEMs.[10] 6. ESO enabled by mission control to provide advice on reaching net zero aims for 2030, this could enable first movers in all technologies (as ESO will have more influence). [11]	

[6] https://www.mitsubishielectric.com/news/2023/0220.html
[7] https://gb.mitsubishielectric.com/en/news/releases/global/2024/0828-a/index.html#:~:text=News%20Releases-,Mitsubishi%20Electric%20Receives%20Contract%20from%20Siemens%20Energy%20for%20Co%2Ddevelopment,DC%20Circuit%20Breaker%20Requirement%20Specifications&text=TOKYO%2C%20August%2028%2C%202024%20%2D,Siemens%20Energy%20Global%20GmbH%20%26%20Co.
[8] https://www.linkedin.com/posts/gegridsolutions_technology-hvdc-power-activity-7130198930893484032-f_Qk/
[9] https://www.entsoe.eu/publications/ondp2024/web_entso-e_ONDP_PanEU_240226.pdf
[10] https://en.energinet.dk/about-our-news/news/2023/11/29/energinet-and-50hertz-starts-tendering-for-bornholm-energy-island/
[11] https://www.nationalgrideso.com/news/developing-plan-clean-power-2030