Multi-Terminal Test Environment (MTTE) for HVDC Systems

SSEN001

Future Business Model (SDRC 9.8.1)

PUBLIC

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1) Executive Summary

Introduction

The NIC funded MTTE project created The National HVDC Centre, which opened in April 2017.

In the short period since its opening, the Centre has developed into a critical component of Great Britain's (GB's) electricity infrastructure, enabling the delivery and integration of HVDC schemes onto the GB network; for example:

- The Centre supported the delivery of the Caithness-Moray (CM) HVDC project; which successfully commissioned in December 2018 (without the Centre's support, this project would have been significantly delayed);
- The Centre has delivered work improving GB's future Black Start capability, through maximising the use of HVDC schemes to provide Black Start services (commissioned by the Scottish Government);
- The Centre is preforming critical AC protection coordination testing, for the network surrounding the NSL link (commissioned by Scottish Power and National Grid);
- The Centre is informing the ESO's Stability Pathfinder project, to improve the stability of the GB network using HVDC (commissioned by the ESO); and
- The Centre is helping to shape the future of off-shore wind and HVDC; through the innovative EU PROMOTioN project (as a workstream leader), and by leading the technical workstream of the ENA's OFTOs working group.

These projects demonstrate how the Centre de-risks HVDC schemes, and beyond that can investigate the consequences of HVDC upon existing assets (such as protection & control) while ensuring the integrity of the GB grid.

Furthermore, the Centre is also supporting the development of the industry's knowledge, through:

- Delivering a range of training courses (incl: SHE Transmission Control Room training, RTDS® training, PSCAD training and HVDC fundamentals training);
- Running (and disseminating the results from) an annual HVDC research programme (currently delivering 3 projects with: EPRI, Cardiff University and University of Strathclyde);
- Engaging stakeholders and providing technical leadership (incl: the annual HVDC Operators' Forum, CIGRE (B4.82) Working Group, Grid Code Expert Working Group and IET's ACDC conference); and
- Supporting TOs on the design and development of new HVDC links planned in the next RIIO-T2 period.

The HVDC Centre has become a world-leading Centre of HVDC expertise (evidenced by our activities and liaisons with other such institutions on areas of common interest) and is providing critical support to projects in GB and the security of the GB network; directly benefiting GB's electricity consumers; evidenced by our stakeholders support for the Centres ongoing role and support into the RIIO-T2 period.

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1) Executive Summary

Purpose

From its inception in 2013, the MTTE Project intended to establish a facility that would provide long-term support (and de-risking) to HVDC projects and the electricity network, beyond the Network Innovation Competition (NIC) funded period (2014-2021).

The MTTE Project has the following Successful Delivery Reward Criteria (SDRC 9.8):

- *Criterion: "At least 12 months prior to the end of the funded operation of the MTTE (i.e. by end of March 2020), the MTTE management team will submit a proposal for the future operation and funding of the MTTE (post NIC funding), to Ofgem."*
- *Evidence: "Submission of proposal regarding MTTE ongoing operation and funding to Ofgem by end of March 2020."*

The Project Direction (14 March 2018) for the MTTE Project states:

- *"Prior to 31 March 2020, the Funding Licensee must submit a Notice to the Authority setting out its proposal for the future use of the MTTE facility following the Project's End Date. As part of the Notice, the Funding Licensee must explain how the approach will maximise future value to all customers (including those of the other transmission licensees)."*

This document is the proposal for the future operation and funding of The National HVDC Centre, to meet both this SDRC and the Project Direction requirements.

Summary of Need

The creation of The National HVDC Centre coincides with a huge expansion in HVDC interconnection of the GB Grid, which supports the progression to a low-carbon network.

HVDC interconnection is the tip of a larger iceberg of increased convertor penetration which includes large offshore HVDC connected Wind turbine arrays, and a substantial growth in solar and battery technology over the RIIO-T2 period (2021-26).

This expansion and integration of HVDC, together with a lower inertia and lower short circuit level GB Network, means that detailed system studies capturing control-level information are increasingly important to mitigate the risk of adverse interactions and system disturbances; and to diagnose faults/events that occur on the control systems (such as the power outages of the 9^{th} August 2019).

The HVDC Centre is uniquely placed to undertake such detailed studies, since:

- As part of a TO, it has access to the AC network models (through the STC arrangements);
- It is designed to securely manage Intellectual Property (IP) from multiple parties;
- Through the use of RTDS®, it undertakes Hardware-In-the-Loop (HIL) studies, including HVDC Replicas and AC protection relays; and
- It has a team of HVDC industry experts.

The HVDC Centre therefore provides an important "bridge" between manufacturers, developers, TOs and the ESO; thereby de-risking HVDC connections in their network context (not just stand-alone compliance testing).

A number of HVDC projects (interconnectors, embedded links and offshore wind farms), have also confirmed that they have included Replicas in their specifications, with the intent to host them at the HVDC Centre.

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Across the RIIO-T2 period (2021-2026), it is expected that up to 12 different HVDC schemes and, depending on FES scenario, at least four major HVDC based Offshore Wind connections will connect to the GB grid, with an estimated investment of over £10 billion. This would feature GB's: first HVDC interconnections to Scandinavia, first HVDC-connected offshore wind farms, the first HVDC island connection and the first multi-terminal HVDC system.

There are consumer benefits in the HVDC Centre supporting the efficient and timely integration of such HVDC projects onto the GB network, while de-risking adverse interactions (which could otherwise result in disruption to the GB system ultimately impacting the end consumer).

Proposed Future Business model

The HVDC Centre has considered a range of future activities. Noting the scale and evolving complexity of HVDC developments, and expanding role of the Centre to inform TO and ESO work, we believe that:

- The Centre's activities have met the objectives of becoming BAU, however given the Centre's unique "bridging" function across TO and ESO and manufacturer/developer activities, it continues to be appropriate for it to continue to disseminate and report consistent with existing NIC standards and expectations into the future.
- It is considered essential for the Centre to provide the current scope of support activities for the HVDC projects anticipated during the RIIO-T2 period, to ensure adequate de-risking, training and support of these projects and their grid connections.
- In order for the Centre to provide the required de-risking (of HVDC schemes and the GB Network), it requires access to the key network models (which are only available via the System Technical Code - STC). Therefore, the ownership and operation of the Centre should remain within a TO/ESO environment.
- Whilst other ownership models have been considered, SHE Transmission have demonstrated effective delivery of the Centre to date and specifically require the Centre to continue to support the Caithness-Moray link (and the potential Shetland extension). SHE Transmission are also taking forward the largest scale of HVDC proposals of the TOs in RIIO-T2.
- Given the pace of HVDC interconnector projects and TO proposals within RIIO-T2, a changed ownership of the Centre would represent a significant source of disruption to its activities. In particular this would affect the undertakings with manufacturers on protecting IP and confidentiality associated with hosting Replica control and protection systems, and the associated models at the Centre.

As such we propose the Centre be incorporated into the BAU activities of SHE Transmission, supported by a Technical Advisory Board comprising the TOs and ESO; and continue to act as a national resource to all TOs and the ESO across the RIIO-T2 period.

SHE Transmission fully supports this Proposed Future Business Model; and has included it within its RIIO-T2 submission, incorporating the cost in its regulatory cost base.

Stakeholder Perspective

The National HVDC Centre has consulted its Technical Advisory Board and its range of stakeholders on its Proposed Future Business Model and received statements of support across TOs, developers and the ESO for the continuation of The National HVDC Centre under SHE Transmission.

1) Executive Summary

Conclusions

The period 2021-26 will see a huge investment in HVDC schemes in GB; the most concentrated development of HVDC in the world. Such extensive development poses significant risks to the reliable operation, control and resilience of the GB network.

Furthermore, the continuing reduction of synchronous generation on the GB network is leading to a lower inertia and lower short circuit level network; which is more vulnerable to adverse interactions.

To mitigate these risks requires a testing facility that can host detailed models (and control/protection hardware) from multiple suppliers and from TOs/ESO; and has the expertise (and technology infrastructure) to undertake specialist studies; along with the credibility that the results can be relied upon.

The models that are currently used by TOs and the ESO are not accurate enough to detect adverse interactions, which could cause system failures. The best way to model such system is in Real-Time, with actual control hardware, and vendor-supplied control models; so that control interactions can be identified.

Ofgem, the TOs and the ESO have been developing such a facility to address these challenges since 2013: “The National HVDC Centre”.

The Centre is an important asset for GB, valued across the industry. To demonstrate this, we asked our stakeholders to describe their view of how the Centre will support and de-risk future HVDC deployments.

The HVDC Centre has become a world-leading Centre of HVDC expertise and is providing critical support to projects in GB and the security of the GB network; directly benefiting electricity customers.

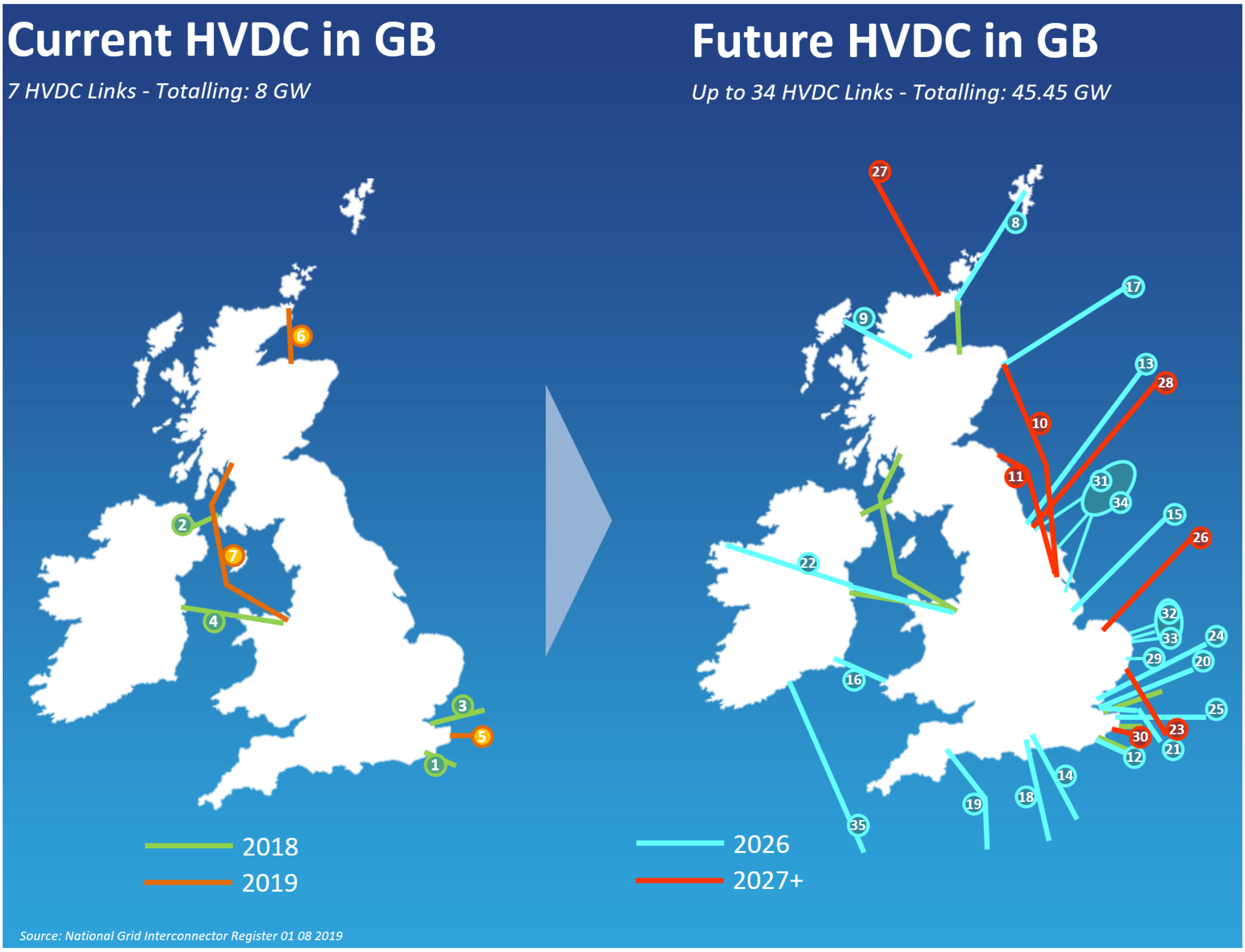
2) Needs Case

HVDC Context

National Grid ESO's Future Energy Scenarios document illustrates the range of total interconnection between GB and external networks (ranging between 8-17GW by 2025). The growth in offshore generation, again as quoted within National Grid ESO's FES, is between 7-27GW up to 2030, where a significant proportion of the overall capacity would be HVDC connected.

Such a volume of new schemes within close electric proximity, and on an increasingly electrically weak network, brings significant risks.

The diagram below shows the HVDC links planned to be developed in GB.



2) Needs Case

HVDC Projects

The following are the HVDC projects that are considered likely to be commissioned in the RIIO-T2 period, requiring the support of the HVDC Centre:

Moyle Interconnector	Plans to replace their control systems (hardware & software), connecting South Ayrshire to Northern Ireland completing in 2022. Range of support including hosting Replicas, supporting compliance and interaction studies.
Shetland Island link	Extension to the Caithness-Moray project. Since this will form a multi-terminal, the first of its kind in GB, the testing of the Shetland hardware will be undertaken at the Centre.
North Sea Link (NSL)	Connecting the UK and Norway. It connects directly into the eastern side of the Anglo-Scottish Boundary, which is currently dynamically managed via a parallel Western HVDC link route, a collection of dynamic compensation devices and series compensation devices. It is a boundary subject to well documented stability considerations. NSL will be the world's longest subsea interconnector when operational in 2021 and will need to complement the stability of the Anglo- Scottish boundary with its performance. Network integration, bespoke control verification (such as black start related) envisaged.
Aquind interconnector	Expected to commission an HVDC converter station in Lovedean connecting to France in 2022. This interconnector would complement a nearby HVDC converter at Chilling near Lovedean (IFA2) currently undergoing development, and contributes to some 7.2GW of HVDC connected along the south coast double circuit ring between Lovedean and Kemsley. Centre activities expected similar to NSL.
Dogger Bank	Offshore windfarm has situated its converter stations between Beverley and Cottingham, connecting to the substation at Creyke Beck. The project aims to begin commencing construction in 2022 (comprising multiple DC links). As the first offshore HVDC connected windfarm, the Centre may support detailed analysis for both the design and commissioning phases.
Viking Link	Interconnector between the UK and Denmark. It is due to be operational in 2022. It connects between the above Dogger Bank development and the similarly large offshore network of East Anglian One, Three and Four, connecting via a range of long offshore AC cables and DC connections between now and 2027. Centre activities expected to be similar to NSL.
Norfolk Vanguard	Offshore windfarm will connect to Happisburgh in eastern Norfolk. The project's onshore cable route connects to the National Grid substation at Necton, due to be fully commissioned by 2026 (expected to comprise multiple DC links). Centre activities expected to be similar to Dogger Bank but may include additional design and commissioning validation of multi-terminal and/or integrated offshore HVDC design concepts.
Hornsea Project 2 & 3	Offshore windfarm connecting to shore at Horshore Point, in Lincolnshire, to a substation in North Killingholme due to commission in 2022 & 2025 (expected to comprise multiple HVDC links). Centre activities anticipated to be similar to Norfolk Vanguard.
Greenlink interconnector	Expected to commission an HVDC Converter station in Pembroke connecting to the Republic of Ireland in 2023. Centre activities expected to be similar to NSL.
Western Isles	Embedded link between Arnish Point, Stornoway to Beauly. Centre activities expected to be similar to Shetland Island link.
NorthConnect interconnector	Expected to commission an HVDC converter station in Peterhead connecting to Norway in 2024. Centre activities expected to be similar to NSL.
Eastern HVDC	Proposes two separate HVDC links, one connecting Peterhead to Hawthorn Pit/ Cottam/Drax commission in 2026, and the other connecting Torness with Hawthorn Pit/ Cottam/Drax which will be under construction in 2026. Centre activities expected to be similar to Shetland Island link, noting the scale of these projects may encompass larger across- GB simulation encompassing many of the above and existing HVDC projects also.

2) Needs Case

Needs Case

High Voltage Direct Current (HVDC) is the most efficient way to transmit electricity over long distances and is the only way to connect GB with the asynchronous Ireland and European networks. HVDC also often represents a lower environmental impact for construction, with reduced losses and increased capacity.

Not only is HVDC an efficient way to transport energy, it also brings additional benefits:

- System support (e.g. managing reactive power - similar to a STATCOM, providing power oscillation damping - similar to the capabilities of a large generator);
- Ancillary services (e.g. frequency support);
- Black Start capability; and
- New Stability support services (such as inertia and immediate non-voltage dependant fault current support), as currently being explored under the National Grid ESO Stability Pathfinder project.

However, the integration of HVDC (and related technologies), at the scale envisaged over the RIIO-T2 period brings significant challenges and risks to the GB network:

Difficulty sharing accurate models between suppliers/ TOs/ESO (due to IP restrictions)	This limits interaction investigations and the ability to manage the associated risks. A neutral environment where suitably detailed/open models can be integrated with a similarly detailed model of the GB system is required.
Adverse AC system interactions (e.g. system resonances)	Requiring relevant network modelling and HVDC control detail to be brought together to ensure the TO and ESO can respectively design, plan and operate networks appropriately.
Adverse interactions with other HVDC systems (or FACTS devices)	Requiring TOs to ensure the performance and behaviour of HVDC control is taken into account when designing and optimising the operation of other devices used to support network capacity and security.
Adverse interactions with existing users	Requiring TOs and the ESO to ensure the design, planning and operation of new HVDC does not lead to mechanical or other impacts upon existing synchronous generation and other already connected Users.
Design and setting of Network protections	Requiring the TOs to quantify in detail the effect of HVDC during a fault condition to ensure protection functions appropriately without risk of non-operation, slow operation or increased network depletion following a fault.
Challenge of multi-terminal and/or multi-vendor systems	Requiring new standards, specifications and analysis of DC systems by TOs and others developing and delivering such designs.
Lack of standardisation and interoperability	Requiring manufacturer specific HVDC solutions to be understood in detail and limiting the extent to which any one manufacturer can understand its risk of interaction with another design.
Limited HVDC experience in GB of the interactive analysis across HVDC and other convertor solutions	Requiring training and capability development across the industry across a range of analysis platforms and with respect to particular forms of new interaction, together with control room training in operating in this evolving environment.

The HVDC Centre has been established to address these challenges by providing an environment to simulate and test the operation of HVDC schemes and their interactions, specific examples include:

- The SO and TOs cannot allow HVDC interconnectors to connect to the Grid unless they are satisfied that their own network protection scheme will not be compromised. This can require the detailed testing of multiple vendor supplied models, together with the dynamic network model and real protection relays (as is the case for NSL protection coordination study that the Centre has been commissioned to undertake).

2) Needs Case

- We understand from our liaison with HVDC owners, the ESO and TOs, that converter control interactions have already been evidenced within the GB network. These interactions require specific detailed modelling, however neither the TOs, the ESO, nor the developers have the capabilities to analyse the performance of HVDC at this level within the context of the GB network that they are connected.
- The proposed multi-terminal extension of the Caithness-Moray link to Shetland will require testing against the detailed model of the Shetland network to avoid adverse effects on the AC and DC networks.
- The Eastern HVDC interconnector capacity will result in more than 50% of the overall circuit capacity between Scotland and England being HVDC in nature. It is critical that this transmission boundary with a range of known historic stability considerations is considered in sufficient detail with HVDC performance appropriately defined to maintain system security and reliability.
- The Moyle interconnector's requirement to validate their new control and protection system against detailed models of the AC network, to avoid adverse interactions.

Industry Consensus Shift

Over the last year (and especially since 9th August), there has been a distinct change of opinion across the industry on the need for TOs/ESO/Developers to take ownership for the detailed study of the impact of HVDC schemes on the GB network.

Previously we encountered comments, such as:

- Testing and system studies are the responsibilities of suppliers, and if we start to undertake studies we automatically move accountably and risk from the supplier to the developer;
- We can see the benefit for the GB network, but as developers we need to focus on meeting our grid code obligations;
- In theory it is sensible to undertake interaction studies, but we can't justify the cost;
- The models we provide are sufficient to meet Grid Code requirements.

However, over the last year, there has been a notable, shift, illustrated by comments such as:

- TOs/ESO are the only people who can take the holistic system view to mitigate interactions;
- We cannot allow the HVDC link to connect unless we can prove it is not going to impact protection function which could otherwise impact the security of the surrounding network;
- We (developers & owners) see a gap in the data we receive that limits how well we can optimise our design;
- We (network owners and operators) require more data and better models to support de-risking, beyond the basic Grid Code requirements;
- The only way to resolve the interaction issues we have experienced is though detailed simulations, but the current frameworks prohibit us from sharing these models.

This is a remarkably rapid shift in industry opinion (a symptom of the pace of change of the GB network), and validates our collective decision to invest in developing the HVDC Centre.

This change in industry opinion is further demonstrated by:

- The increasing agreement (at the Grid Code working group) of the need to change the Grid Code to require the exchange of EMT models;
- More projects are building Replicas into their requirement specifications; and
- The letters from across industry stakeholders.

The logical resulting implications are that we can expect:

2) Needs Case

- A change in the Grid Code to require the provision of validated EMT models;
- A change in the Grid Code to require the provision of Replicas (where there is the potential of converter interactions);
- More projects purchasing Replicas, to de-risk their own project delivery; and
- A change in the Grid Code (or individual connection agreements) to require the HIL (hardware-in-the-loop) testing of AC protection in coordination with HVDC schemes.

The HVDC Centre is the natural facility to support these activities (coordinated and efficiently).

Counterfactual Case

If the HVDC Centre did not exist, the TOs and ESO would need to develop alternative capabilities and infrastructure to manage their individual network development system security risk; such as RTDS-HiL hubs developed by each TO/ESO or on a project-by-project basis. As interaction risks cannot be contained to a given TO area, the coverage of such sites would then flex and overlap as their activities change.

In such scenarios, the lack of consistency of these hubs (incl their approaches, design, models, replicas etc) would lead to inconsistency of analysis, delays and costs for each bespoke activity. Where analysis across TO boundaries is required, it would become necessary to migrate replicas/models between facilities temporarily, provided these hubs were compatible with doing so or drive still greater hardware costs otherwise. Such arrangements would be significantly more costly than a shared National facility.

Furthermore, the Electricity System Operator would need to review arrangements to confirm whether, to meet its needs of compliance testing and operational de-risking, the above activity was sufficient without further additional investment or whether a separate facility would be required to support its needs.

Conclusion

There is currently no facility in GB other than the HVDC Centre that can undertake this work, given the access the Centre has to data, models, specialist hardware, software and associated expertise in HVDC analysis. As levels of converter concentration increase in GB, the need for the Centre's expertise and activities will grow. In looking across a range of ownership and scope options, we believe that extending the Centre's scope and moving the Centre's activity into BAU within SHE Transmission, whilst continuing to maintain the Centre's engagement and dissemination across partners, represents the best value to consumers.

3) Evolution of the HVDC Centre

Introduction

The National HVDC Centre is a Network Innovation Competition (NIC) funded simulation and training facility established in 2017, as a collaboration between SHE Transmission, Scottish Power Energy Networks, National Grid Electricity Transmission and National Grid ESO.

The Centre supports all HVDC schemes, both already in operation and in development, that connect to the Great Britain (GB) electricity grid, including:

- HVDC interconnectors to European countries and Northern Ireland;
- HVDC connections to large offshore wind projects, under development;
- Embedded HVDC links within the GB network; and
- HVDC connections to islands.

The Centre provides insight, and in-depth simulation analysis to inform these and other HVDC and converter dominated developments. This information and practical support can then be used by the TOs and the ESO to ensure the integrity and security of the grid network as a significant number of HVDC schemes are deployed on the GB grid over the RIIO-T2 price control period.

The Centre is also GB's real-time testing facility for HVDC schemes using replica hardware to study and resolve network interactions; and a National hub for HVDC knowledge exchange, expertise and innovation.

The Centre has an enablement role, that includes providing support to developers of HVDC schemes during their design, commissioning, compliance, and operational support and investigations.

The ability for the Centre to deliver the above activities has been evidenced in its support for both Caithness-Moray (CM) and other HVDC projects within the RIIO-T1 period and, as such, we believe these activities are moving from "proof of concept" to "Business as Usual" (BAU) going forward.

As part of RIIO-T2, the operational costs of the HVDC Centre over 5 years (2021-2026) are being sought so that, on behalf of all the Transmission Licensees and the System Operator, the HVDC Centre can support all HVDC schemes that are being planned, deployed and/or operational during 2021-2026.

2013-2017: Establishing the HVDC Centre

From 2013 to 2017, the MTTE Project secured funding and established The National HVDC Centre:

2013: The GB TOs (and the SO) agreed that SHE Transmission was the most appropriate TO to lead the NIC funding request (given their plans for a multi-terminal HVDC scheme); and SHE Transmission submitted the NIC funding application for the MTTE project. The application was successful and the project direction was issued by Ofgem in December 2013.

2014: The project received NIC funding; to fund the establishment of The National HVDC Centre, and cover its operational costs for the first 4 years (up to March 2021); during 2014 the project focused on agreeing collaboration agreements with all the project stakeholders.

2015: The project focused on developing the plans (for the people, processes, technology and the building).

2016: Focused on building works (and recruitment).

2017: The National HVDC Centre was formally opened on 27^{th} April.

3) Evolution of the HVDC Centre

2017-2018: Supporting the CM 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 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; 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 its 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.

Support Provided by the HVDC Centre

The HVDC Centre provided extensive technical support to the CM Project at each stage of the delivery of the project; the range of this support is described below.

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

HVDC 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 of 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.

3) Evolution of the HVDC Centre

2019-2021: Supporting HVDC Projects

In addition to the specific operational support of the CM project, the Centre is delivering a range of high-profile and project-critical projects for a range of stakeholders.

Commissioned Projects/Support

HVDC for Black Start (Scottish Government)	Analysing and recommending actions to maximise HVDC Support of GB Black Start and System Restoration.
Stability Pathfinder (National Grid ESO)	Evaluating the stability of HVDC schemes at other inverter connected sources under varying short circuit levels.
NSL Protection Study (Scottish Power & National Grid)	Testing and validating the protection systems to enable the connection of the NSL link.
PROMOTioN project (Horizon 2020)	Leading WP9. This work package demonstrates the operation of the DC grid protection systems using hardware prototypes with real-time simulation to test and demonstrate interoperability of DC Grid protection systems.
Eastern Link Project Support (TOs)	Provide ongoing support to the Eastern link project teams.
Caithness-Moray-Shetland Support (SHE Transmission)	Operational support for the CM scheme (& Shetland extension), including: • Emergency Power Control (EPC): to understand the operation and optimise the EPC mode; • Shetland Fault-Level/Modelling; • PowerOn Implementation: Integrating 'replica' SCADA system; • Multi-Vendor Implications for Shetland; and • 3rd Terminal Extension of CMS Support.

Research Programme

Converter Models (University of Strathclyde)	Developing open-source detailed converter models.
Stability assessment (University of Strathclyde)	Stability assessment and mitigation of HVDC converter interactions: Impedance modelling of HVDC converters for system stability studies.
Black Start Protection Coordination (EPRI)	Coordination of AC network protection during grid energization from HVDC schemes: Assess suitability for existing AC protection for Black start from HVDC.
Grid Code Compliance (Cardiff University)	Improving Grid Code Compliance of existing and upcoming HVDC Schemes in GB: Assess and test HVDC Grid Code compliance using simulation and experimental tools

Training *(In addition to running the HVDC Training and Control Room Training)*

RTDS® Training	Endorsed to run RTDS® training courses.

Engagement

ENA's OFTOs Working Group	Leading the technical report on offshore electricity transmission technologies required to connect large offshore wind farms to GB grid.
CIGRE Working Group (B4.82)	Investigating interactions between HVDC schemes and FACTS devices in close proximity.
CIGRE (Paris) Paper	Multi-terminal extension of existing HVDC schemes.
HVDC Operators' Forum	Continuing our prominent annual event to share knowledge and experience; and facilitate industry collaboration.
Grid Code development	Supporting the Expert working group developing GB- Grid forming convertor solutions with technical expertise and proposals on data exchange and verification activities

3) Evolution of the HVDC Centre

HVDC Centre Support 2021-26

Considering the expected significant Grid developments during 2021-26, the Centre plans to broaden the scope of its support to better deliver its continued aim of the de-risking of grid integration. Therefore, in addition to the above scope the Centre will:

- Provide support to NIA/NIC innovation projects (e.g. smart technology that can benefit from real-time simulation facilities such as RTDS), to de-risk their deployment whilst reducing the cost of the NIA/NIC projects;
- In addition to providing real-time (RTDS) simulation capability to support HVDC schemes, the Centre will also provide support for off-line simulation support (including PSCAD, DIgSIlent & PSSE), to facilitate validation between RTDS and more streamlined and simplified models in other formats to both support TO and SO BAU planning needs and capture and track future GB system design and operation;
- Broaden its training programme, providing a broader range of specialist training courses for GB TOs, ESO, HVDC owners, developers and manufacturers to drive value across all areas of HVDC integration from a more informed stakeholder community;
- Develop academic engagement projects to address key challenges to integration of HVDC projects into AC grids in collaboration with both the TOs and SO to ensure our analysis captures new risks as they emerge and HVDC technology evolves; and
- Maintain a library of updated off-line and real-time simulation models for HVDC projects and FACTs devices in GB network, in particular STATCOMs; supporting their deployment, to facilitate system integration studies involving multiple equipment manufacturers whilst preserving IP arrangements.

Furthermore, in continuance and development of existing areas where the Centre has had influence, we will:

- Proactively engage with industry groups (e.g. Supergrid, ENTSOE, CIGRE) and GB academic and research institutions to support the development of DC Grids;
- Develop an international community of TSO-Led HVDC Centres, including RTE (France), Hydro Quebec, Manitoba Hydro, NALCOR (Canada), etc. to leverage our collective learnings/expertise;
- Continue to host events at the Centre for: Transmission Licensees, Innovation Projects (NIA/NIC) and other HVDC-related events (e.g. IET events).

3) Evolution of the HVDC Centre

Capabilities of the HVDC Centre

As a result of the NIC funding to develop a world-class facility, combined with hiring subject matter experts together with the experience of delivering high-profile project-critical studies; we now have an internationally recognised HVDC Centre of excellence - which is ideally positioned to support GB's HVDC plans.

World-Class Facility

We have developed a bespoke simulation facility; which is designed to manage IP protection (with segregated rooms), while facilitating stakeholder engagement (with meeting rooms and an auditorium).

The technology combines state-of-the-art real-time simulation capabilities (RTDS®'s NovaCor™); with Replicas and other hardware in the loop.

The Centre has also developed protection relay testing infrastructure (with RTDS interfaces, power amplifiers and DC supplies).

We believe these provide the best HVDC-focused simulation facilities in the world.

Subject Matter Experts

We have assembled a team of HVDC experts who, through our stakeholder engagement, are internationally recognised as leaders in the field.

Together they provide HVDC experience across: academia, system operator, power systems consultancy, transmission innovation and HVDC suppliers.

Assessment of Progress against Objectives

As set out in the NIC Submission for the MTTE project, the objectives of the Centre (and the progress against them) are as follows.

Establish the MTTE Facility	The world-class "National HVDC Centre" was established in April 2017.
Support transmission planning and improve specification of HVDC schemes	The Centre supported the planning and specification of CM project, and has provided input to the specification of a number of other HVDC projects.
Facilitate multi-terminal solutions	The Centre is integrally involved in the development of the multi-terminal Caithness-Moray-Shetland project, and has also led the demonstrations of the PROMOTioN project on multi-terminal DC grids.
De-risk control interactions	As part of the NSL protection coordination study, the Centre investigated interactions between the HVDC link, substation protections and a series compensator.
Facilitate competition and multi-vendor HVDC schemes	The Centre has engaged with emerging suppliers (including: NR Electric, Mitsubishi, Toshiba and Hitachi).
Train and develop Transmission Planning and Operational Engineers	The Centre has run a programme of training courses (over 10 courses delivered across 2018/2019 targeted to over 50 engineers).
Undertake post-commissioning scenario planning and operational optimisation	Following the commission of the CM Project, the Centre has supported the investigation, testing and optimisation of control setting.
Model new HVDC technologies	As part of the PROMOTioN project, the Centre has modelled the operation of DC circuit breakers, together with multi-terminal protection IEDs.

4) Stakeholder Engagement

Current Stakeholder Engagement (2017-2021)

A continual key focus of the HVDC Centre is Stakeholder engagement.

The Centre undertakes extensive engagement activity to ensure that we:

- Keep potential users of the Centre informed of our capabilities;
- Ensure that the work we undertake is developed in collaboration with relevant stakeholders; and
- Effectively disseminate the knowledge gained at the Centre to the right people.

We do this through a range of engagement activities:

Website	The Centre's website (hvdcCentre.com) continues to be updated to support knowledge dissemination.
Newsletter (quarterly)	We have continued to produce quarterly newsletters. This is mailed to our mailing list and published on our website.
HVDC Operators' Forum (annual)	We have established this forum as a regular annual two-day event, where HVDC projects in GB, relevant TOs and the ESO come together to share experience and lessons learnt; and also to share the outputs of relevant HVDC innovation projects.
Events held by the Centre	In addition to the above, the Centre will continue to convene relevant collaboration events across TOs and the ESO; examples being the holding of Joint Planning Committee meetings under the Technical code, together with themed workshops and events based on the research conducted at the Centre- an example being the recent workshop on HVDC black start arrangements (sponsored by the Scottish Government).
Tours of the Centre	Tours of the Centre have been provided to GB and European TOs and ESO, Government, HVDC developers and others within the electricity industry.
Individual meetings	Project focused activity as discussed above, support also for a range of HVDC engineering team activities and for future new HVDC projects.
Industry Group Participation	The Centre is a member of the CIGRE B4 committee, the Offshore Wind operators working group, and the GB Grid Code VSM expert working group, and was previously involved in a number of European code implementation work groups (for example the HVDC code). The Centre would intend to participate in further HVDC technical code and technical implementation and support activity across the sector in future years as part of its role in facilitating increased HVDC integration.
Conference participation	The Centre has participated in relevant conferences, including: • RTDS User Group conferences; • LCNI conferences; • IET's ACDC conferences; and • CIGRE conferences.
Engaging students	The Centre routinely engages with the academic community both in respect to partnering on project activities and in more general areas of dissemination where a mutual interest and benefit exists

[Refer to the 'Event' listed on hvdccentre.com, for details of the events and dissemination activity planned for the Centre in 2020].

4) Stakeholder Engagement

Future Stakeholder Engagement (2021 – 2026)

Fundamentally, we believe that our approach to stakeholder engagement is appropriate, and we plan to continue (and expand) the open stakeholder focussed engagement activity described above.

The Centre has a key role in facilitating industry engagement and knowledge exchange on HVDC in GB.

In addition to the activities described above we plan to expand by:

- Expand our training offering into an integrated programme of training courses;
- Continue to hold the annual HVDC Operator's Forum, to share knowledge and experience between HVDC projects;
- Engage and support HVDC related workstreams with Super Grid Institute, ENTSO-E, CIGRE, and other relevant industry bodies;
- Develop an international community of TSO Led HVDC Centres (incl RTE, Hydro Quebec, Manitoba Hydro, NALCOR, New York State etc);
- Host events at the Centre for: TOs, Innovation Projects (NIA/NIC), for HVDC projects and other HVDC related events (e.g. IET); and
- Support the dissemination of knowledge of HVDC related academic and innovation projects.

5) Governance

Current Governance Arrangments

The governance arrangements of the HVDC Centre are designed to ensure that the Centre is a collaboration between the Project Partners, it comprises:

- The Senior Owner for the Centre, who is ultimately responsible for the Centre.
- The Governing Board to provide governance and management oversight for the Centre.
- The Technical Advisory Board to provide strategic technical direction, comprising representatives of Transmission Licensees and the Electricity System Operator.
- The Centre Manager responsible for the day-to-day management and operation of the Centre, who reports to the Governing Board.

Future Governance Arrangements (2021-26)

Over the 2021-26 period, the Centre plans to maintain similar governance arrangements as above, with the Technical Advisory Board assuming a formal role in the prioritisation of core resource year-on-year across the range of TO and ESO work areas; however governance and management of the Centre will be through BAU SHE Transmission management structures rather than a dedicated governing board. Where workload extends beyond core activity, charging arrangements will be available to support further activity - see section 6 of this report for further information.

Ofgem Oversight

Currently Ofgem oversees the HVDC Centre through a combination of the following:

- 'Project Direction' and NIC governance document, which define the project and governance requirements;
- Annual progress report, which is prepared by SHE Transmission and submitted to Ofgem;
- Defined SDRCs, which are reported on as they are completed;
- Project close-down report, which will be submitted after the MTTE project has been completed;
- Successful Delivery Reward application, which reviews achievement against all the project's SDRCs; and
- The nominated Ofgem Project Support Officer who provides guidance as required.

6) Future Business Model Options

Introduction

We intend and foresee that the Centre will be able to support and benefit the GB network for the long-term (i.e. over the next ~40 years), as similar Centres have done in other countries. However, there are a variety of different business models that could be adopted to enable the Centre to continue to operate, from being fully funded through innovation funding or RIIO-T2 settlement, through to an independent profit-making entity.

We see that there are three aspects to the business model:

- **Scope:** what is the proposed future scope of the Centre;
- **Ownership Model:** how should the Centre be owned and operated; and
- **Funded Option:** how should the Centre be funded.

The options for each of these, and our recommended approach, are described in the following sections.

Scope Options

Current Scope

The current scope of the HVDC Centre (as defined in the MTTE NIC Bid document) is to reduce the risks, costs and time-to-deployment of HVDC systems for GB transmission Customers through the following:

- Support transmission planning and improve specification of HVDC schemes;
- Facilitate multi-terminal solutions;
- De-risk control interactions between multi-terminal and electrically connected converters, and with other active controlled equipment;
- Facilitate competition and multi-vendor HVDC schemes;
- Train and develop Transmission Planning and Operational Engineers;
- Undertake post-commissioning scenario planning and operational optimisation; and
- Model new HVDC technologies.

Over the period 2021-26, the Centre proposes to expand its scope, to continue to provide this support, but also to provide additional support described below.

6) Future Business Model Options

Future Scope

We see the HVDC Centre playing a critical role to ensure the integrity and security of the grid network as a significant number of HVDC schemes are deployed on the GB grid during 2021-26.

To support this, the HVDC Centre proposes to provide the following:

HVDC Leadership	There is currently no leadership, coordination or strategic direction of HVDC development in GB; which we believe will limit the benefit that the GB grid (and its customers) get from these schemes. Therefore, we believe that the HVDC Centres should take a lead to: • Develop a strategy for HVDC schemes in GB; • Develop GB's HVDC research and innovation strategy; • Act as the 'Architect' for offshore wind connection with HVDC; so that the potential future benefit of a HVDC meshed network can be realised; • Facilitate and ensure the coordination between HVDC schemes (and other active controlled equipment) in close proximity; • Progress the Centre's involvement in HVDC projects (enabled by potential technical code changes), to ensure that HVDC schemes are suitably tested, and provide required models/replicas for future analysis; and • Become the repository of up-to-date off-line and real-time models of all HVDC schemes in GB, and maintain the models for future use.
Supporting Individual Projects	For each HVDC project, the HVDC Centre should perform in-depth analysis of interactions and test the operation of the HVDC schemes, enabling issues to be anticipated and resolved, ensuring the integrity and security of the GB Network, including: • Replicas: Where replicas are required, the Centre will support the project from procurement support through to 'Supported Hosting' of Replicas; • Training: General HVDC training for project teams, through to detailed training of Operational Engineers, using practical experience and simulated scenarios; • Grid Integration and Interactions: De-risking control interactions between convertors, and with other active controlled equipment, through real-time simulation studies and off-line studies; • Operational Support: Diagnosing and resolving operational issues, undertaking post-commissioning scenario planning and testing system changes; and • Technical Support: Including auxiliary services and model validation.
Broader Scope of Support	In additional to supporting these HVDC projects, the HVDC Centre also see its role as: • Continuing with a focus on GB Grid, but expanding focus to include: Ireland Grid HVDC connections and Offshore wind DC connections to GB; • Support the development of MVDC (Medium Voltage DC) in GB; and • Providing support for off-line modelling of HVDC schemes (e.g. PSCAD, DigSilent & PSSE). Leverage the use of our RTDS capability to support non-HVDC projects: • Providing support to NIA/NIC innovation projects (e.g. smart technology can benefit from RTDS); • Developing the Centre's expertise in STATCOMS (and then support their deployment on the grid); and • Supporting the integration, testing and deployment of FACTS devices on the GB Grid.
Training	We are currently an endorsed training provider for RTDS, and we also provide training on general HVDC, and HVDC operator training. We plan to provide more in-depth training (e.g. on studying converter interactions), including developing an HVDC training programme/accreditation.

6) Future Business Model Options

Scope Options

Therefore, for the future scope of the HVDC Centre, we see the options as:

- Do Nothing;
- Minimum Support;
- MTTE Scope; or
- Future Scope.

Scope	Description/Assessment
Do Nothing	**To decommission the HVDC Centre scope, provide no support to projects.** This option would have an immediate impact of: • Withdrawing support to existing connected projects- within the TOs this would therefore remove operational support to the Caithness- Moray project and incur costs associated with Centre decommission; • Cancelling control refurbishment support to Moyle; • Remove BAU support to TOs and ESO in specific areas of HVDC convertor work such as protection review and modelling to support stability pathfinder; and • Cancelling support of innovation to increase the efficiency of the existing network (e.g. PMU deployment informing optimal STATCOM and SVC control). This option would also impact future projects by: • Removing insight to specify performance and develop HVDC models supporting new connections; • Removing ability to validate models and control changes post commissioning; • Removing ability to post event investigate HVDC behaviour; • Remove ability to study and de-risk HVDC integration into the planned GB network; and • Remove ability to train developers and network and system operators on new HVDC projects. While this is the lowest Centre funding cost option (£0 future cost), it is considered high-risk that new HVDC projects would experience delays or operating issues without the support of the Centre, resulting in significant mitigations and direct costs. This in turn would also limit the levels of HVDC connecting to GB over the period. This option would also require TOs and ESO to indirectly manage the implied risks discussed above, leading ultimately to additional costs and resources being duplicated across licensees overall.
Minimum Support	**To reduce the current scope of service, and focus on only delivering TO commissioned HVDC integration projects** (indicatively ~95% of proposed operating cost). This proposal would have the effect of: • Removing the critical Centre support to model validation and development which informs TO and SO risk management of new HVDC; • Reduce post event support; and • Limit training activity. As with the above “do nothing” option, the impact to new external interconnectors, would be to delay those projects. For a relatively minor cost saving, the support provided would be significantly cut and the industry would continue to see increased costs from delayed and more limited HVDC integration than currently planned.
MTTE Scope	**To continue with the same scope as defined for the MTTE project** (indicatively ~95% of proposed operating cost). This option provides a good level of support to existing project activities but is not able to deliver the range of additional support as identified as being required to support the scale of TO and developer project activities across the RIIO-T2 period. As such, while this support will mitigate HVDC integration, the pace at which they can be delivered would be impacted.

6) Future Business Model Options

Future Scope	**To undertake the enhanced scope proposed in this document** (the proposed operating costs cover this scope). As described earlier, we believe that the proposed future scope maximises the benefits of the Centre to the GB Network, the SO, TOs and Customers; and this is the proposed option. We believe that this option represents both the most cost effective option and the option which leads to the best outcome in facilitating the integration of HVDC and other convertor related low carbon technologies, consistent with green energy targets.

Recommendation

The 'Future Scope' (as described in this section), provides the optimal level of support for the next period. It represents the appropriate de-risking of envisaged HVDC activity, and we believe represents the best value option to the consumer.

Post-2026: Plans after RIIO-T2

While the RIIO-T2 period will see significant growth in HVDC interconnectors; this is expected to slow down post-2026. The continuing reduction of synchronous generators is expected to lead to an increasingly low inertia system, and this in turn will cause the operation and performance of a number of HVDC dominated areas to need to be further reviewed. In addition, by this time a number of existing interconnectors will have approached or be undergoing control system change, which (as with the Moyle Interconnector) represents an opportunity for control system re-design and re-optimisation to be supported by the Centre.

There will also be significant growth in HVDC connections to wind farms (the distance from the mainland of most of the remaining Crown Estate round three and all of round four leased area windfarm sites, means use of HVDC is highly likely).

Also, there is expected to be a huge growth in more 'intelligent' devices connected to the network (at both Transmission and Distribution) [e.g. MVDC solutions, smart EV chargers, solid-state transformers etc.] all of which would benefit from real-time simulation (with Hardware-in-the-Loop) of their control system to ensure grid integration.

Therefore, post-2026, the HVDC Centre expects to focus more on:

- Supporting the operation (and refurbishment) of interconnectors;
- Supporting the deployment of HVDC connected wind-farms; and
- Supporting the deployment of smart technologies (in the context of a low inertia system, with many more independently controlled devices).

6) Future Business Model Options

Ownership Models Options

There are a number of options for the future Ownership and Operation of the HVDC Centre:

- SHE Transmission, continues as present;
- National Grid ESO adopts the Centre;
- Scottish Power or National Grid (TOs), or a shared adoption of costs;
- Adopted by a university or research institute;
- Nationalised/ funded directly via BEIS; and
- Spun-off as a separate entity.

The implications of these different ownership models are discussed in turn:

Ownership model	Description/Assessment	Conclusion
SHE Transmission	This option presents minimum disruption to current activities and scope of the Centre's business. • SHE Transmission have noted within their RIIO-T2 transmission submission a variety of new projects constructing new HVDC and extensions to the existing CM link and as such could be considered the most active in this area. • SHE Transmission has on behalf of the Centre contracted for the existing CM replicas and is as such uniquely placed for the smooth development of functionality at the Centre as the CM project extends to include connection of Shetland. • SHE Transmission has noted the need for significant upgrading of its existing overhead line and substation infrastructure to support the North Connect HVDC project within the period which will also be informed and supported by the Centre's activities. • SHE Transmission are convinced of the ongoing value of the Centre to its own activities and of the broader future scope as proposed. As such this represents the preferred option.	Optimal, most consumer benefit.
National Grid ESO adopts Centre	National Grid ESO have expressed support for the future scope discussed above and have noted how it would support their own considerations surrounding control room training and modelling. • National grid ESO would need to adopt/ host replicas procured as a result of Centre activities. The contractual framework for doing this, which would necessarily include transfer of Caithness-Moray replicas and associated facilities, is not clear. • The extent of the Centre's scope in facilitating new HVDC projects has the potential to conflict with the existing nature of compliance activities by the National Grid ESO, by placing it too directly in the "solution space" of projects it would ultimately be expecting to see projects demonstrating acceptable performance. • Adoption of the facilities, associated IP and confidentiality arrangements and management of ongoing activities would need to be first defined in detail within the System Technical Code. While potentially viable, this option would introduce excessive disruption to the existing and future scope of the Centre.	Possible, but would require role / scope changes which would limit consumer benefit.

6) Future Business Model Options

Scottish Power, NGET (ETO), or shared model	Other TOs whilst continuing to support the Centres activities have expressed no desire to adopt the Centre within the RIIO-T2 period, nor its part funding within their RIIO- T2 proposals. • TOs already have the opportunity to influence Centre direction via the Technical Advisory Board; and as such would gain no greater or lesser influence in Centre activities based on this. • The option to host and support TO replicas already exists under the current proposed model. • Adoption of the facilities, associated IP and confidentiality arrangements and management of ongoing activities across different/ multiple parties would need to be defined in detail. This option represents disruption to Centre activity for no obvious additional benefit and as such is not recommended.	Possible, but would disruptively impact Centre operation and support and introduce new operating cost.
Adopted by a University	No University or relevant institute has access to the network models which are commercially confidential across TOs and the ESO, nor the experience of managing confidentiality and IP to this scale. Accordingly, this option is not considered desirable or viable and would dramatically reduce the activity and benefits arising from the Centre.	Implausible if existing activities are to be maintained.
Nationalised/ funded directly by BEIS	This model most closely aligns with the "catapult" model. Whilst this model could sustain the scope of activity, the practical ability of the Centre to maintain network models and insight whilst simultaneously closely engaging with ESO and TOs within the established frameworks, would be diminished. As with other options this would be disruptive to planned Centre work, is not recommended, and is not expected to deliver equivalent value to consumers.	Requires new frameworks to maintain role and manage disruption.
Spun-off as a separate entity	It is not clear if this was done what entity this would be, to what extent it would be regulated and whether it would support its intended scope of activities. As such this option has the highest disruption and suffers from the least clarity. As such it cannot be recommended at this time.	Highly disruptive, no clear path to maintain activities - disbenefit to consumers.

Based on the above assessment, it is considered a fundamental requirement that the Centre is owned and operated by a transmission licensee/ System Operator; both to maintain access (through STC arrangement) to detailed network models; but also to respect and leverage the IP commitments to suppliers and other organisations. This echoes the rationale which underpinned the original NIC project being taken forward by SHE Transmission.

Any of the TOs or the ESO could in principle own and operate the Centre going forward. However, we believe that SHE Transmission is best placed since:

- Most of the future embedded links will connect to SHE Transmission's area;
- All the agreements in place at present for collaboration across industry and its suppliers are with SHE Transmission.
- For the setting up and operating of the Centre, SHE Transmission are most familiar and capable to continue doing so with minimal disruption; and
- SHE Transmission has a clear vision of its future strategy and capability and that whilst supportive of this the other TOs/SO have not identified a similar requirement to take on the responsibility of operating the Centre within their RIIO-T2 plans.

Recommendation

Therefore, our recommendation is that the Centre continues to be owned and operated by SHE Transmission.

6) Future Business Model Options

Funding, Charging, Prioritisation and Revenues

Funding Options

For the future funding of the Centre we have considered:

- Membership model (similar to EPRI or PNDC);
- Pay per use;
- Innovation funding; or
- Regulated funding allowance (through RIIO-T2).

Funding Option	Description/Assessment	Conclusion
Membership model	Members (e.g: SHE Transmission, Scottish Power, National Grid, ESO, Mutual Energy, etc.) would pay an annual membership fee.	Adds additional administration costs in maintaining and developing criteria and cost structure. Limits activity to the costs supported by the model. Recovery of membership costs by regulated entity unclear.
Pay per use	Each project/study/support provided by the Centre would be individually costed and charged to the 'client'.	Unstable revenue stream limiting capability to sustain activities and maintain required expertise. Potential for model to increased costs to end consumer.
Innovation funding	Seek funding though NIA/NIC or other innovation funding routes (e.g. Innovate UK).	Unclear mechanisms for ongoing funding.
Regulated funding allowance	Seek regulated funding allowance, though RIIO-T2, either directly as SHE Transmission, or each TO/SO seeking funding allowance and transferring to SHE Transmission.	Consistent with NIC principles of successful projects being adopted into BAU. Most efficient option for end consumer for core activities required for TOs & ESO.

6) Future Business Model Options

Charging Approach

We propose a blend of the above funding options:

1) The Centre's operating costs have been requested as a regulated allowance in SHE Transmission's RIIO-T2 submission.
2) This allowance enables the Centre to provide 'core' services (as defined below) free-of-charge to the TOs/ESO.
3) Additional 'Chargeable' services (for the TOs/ESO) would be charged at a 'cost recovery' rate (using the 'basis of transmission charges').
4) Services to other 'Commercial' organisations would be charged at a fair market rate (with the ability to reduce this charge where there is a direct benefit to TOs/ESO or Consumers).

'Core'	'Chargeable'	'Commercial'
Core TOs/ESO Services	**Additional Chargeable TOs/ESO Services**	**Chargeable Services for Other Organisations**
The Centre delivers these services on behalf of the TOs/ESO (within the Centre's available resource)	The Centre will incrementally charge, above the baseline funding, the TOs/ESO for these additional services.	The Centre would charge for services provided to 3rd party organisation.
○ Deliver HVDC Training ○ Manage the delivery of an HVDC innovation (NIA) programme ○ Maintain a library of HVDC models & support their validation ○ Engage with industry groups (e.g. OFTOs Working Group, Grid Code Expert Working Panel, CIGRE B4, etc) ○ Host industry events at the Centre ○ Facilitating sharing (and use of) accurate models between suppliers/ TOs/ESO ○ Demonstrating and testing multi-terminal and multi-vendor HVDC systems ○ Supporting the definition of standards and interoperability requirements. ○ Support TO-led HVDC projects (e.g. Shetland Island link, Eastern HVDC), including: • Providing technical advice/support • Modelling and analysing adverse AC system interactions • Modelling and analysing adverse interactions with other HVDC systems (or FACTS devices) • Modelling and analysing adverse	○ Network protection and control coordination testing (e.g. SSTI analysis, AC protection, wide area control) ○ Bespoke EMT studies supporting network integration (e.g. energisation, transient overvoltage, power quality) ○ Support NIA/NIC innovation projects ○ Host Replicas for TO owned HVDC projects ○ Host Replicas for other TO owned devices (e.g. FACTs devices) ○ Provide enhanced support to TO-led HVDC projects, including: • Enhanced FST • Compliance demonstration support	○ Support the Moyle Interconnector's refurbishment ○ Support Interconnector Projects: NSL, NorthConnect, Aquind interconnector, Viking Link, Greenlink interconnector ○ Support the Dogger Bank windfarm project ○ Host Replicas for interconnector and windfarm projects *[Note, where there is a network benefit associated with support activity, the Centre would deliver the services at a reduced cost to reflect the system benefit]*

interactions with existing users • Procurement, installation and commissioning of Replicas • Commissioning support • Operational Support ○ Support TOs/ESO with the connection of 3rd party HVDC links to their network, including: • Modelling and analysing adverse AC system interactions • Modelling and analysing adverse interactions with other HVDC systems (or FACTS devices) • Modelling and analysing adverse interactions with existing users		

Prioritisation

The Centre has limited resources, therefore, the Centre will deliver services within its available resources, and prioritised collaboratively by the Technical Advisory Board (TAB).

Revenues

It is proposed to use the RIIO-T2 Totex incentive mechanism for any: excess allowance, overspend, revenue generated from TOs/SO and revenues generated from other organisations.

Therefore, it is proposed that, each year, any excess allowance or revenue (after costs and investment in the Centre), are shared between customers and SHE Transmission through the Totex Incentive Mechanism.

This is intended to provide an incentive reward to SHE Transmission for the efficient running of the facility and for the risks associated with operating the Centre.

Recommendation

Therefore, we propose that the Centre is funded to deliver the 'Core' services to the TOs/ESO, charges for other activity, and shares revenues generated (after re-investment in the Centre) with Customers.

Overall Recommendation

Therefore, it is recommended that the Centre continues to be owned and operated by SHE Transmission, in partnership with Scottish Power, National Grid and the ESO; to deliver the 'Future Scope' as described in this Section.

The operational costs of the Centre would be funded through a RIIO-T2 allowance for 2021-26, with revenues generated re-invested or shared with customers.

In our view, this represents both the most cost efficient solution to the end consumer and the solution which most effectively addresses the increasing relevance and potential value in the activity of the Centre over the period.

7) Financial Projections

Operating Cost Projection (2021-26)

Commentary on the Cost Projections

	Commentary
Resource Costs	This covers the staffing costs of the dedicated team at the Centre: ○ Centre Manager; ○ HVDC technically Manager; ○ Lead Simulation Engineer; ○ Simulation Engineers; and ○ Technical Project Officer. And use of resources from SSE's support services.
External Support	Estimated cost of external consultancy support, based on historic usage.
Travel & Expenses	Estimated based on current travel expenses.
Learning and Dissemination	Cost of disseminating knowledge, including: ○ Continuing to host the annual HVDC Operators' Forum; ○ Attending & presenting at conferences; ○ Publications; ○ Hosting training and dissemination events.
Annual Running Costs	Based on current running costs, this covers: ○ Waste collection ○ Water and Electricity ○ Fire system maintenance ○ AV system maintenance ○ AC and LV maintenance ○ Office supplies & furniture ○ Cleaning ○ Grounds maintenance ○ Snow clearing & gritting ○ Web-site fees ○ Pest control ○ Doors and gates maintenance ○ IT hardware maintenance ○ Software maintenance ○ Window cleaning ○ Event Catering
Staff Training	Estimated cost of training centre staff.

Cost Recovery Mechanism

The HVDC Centre is seeking to cover the operating costs through a RIIO-T2 allowance.

These operating costs would be recovered through general system charges, as the running costs of the HVDC Centre would be part of normal operating expenditure for T2. Any over/under spend will be dealt with through the Totex Incentive Mechanism (sharing factor with consumers).

Note: The HVDC Centre asset is not on SHE Transmission's RAV as it was paid for by NIC funding, so is deemed fully paid as all costs and income were put through P&L account not capex.

Revenue (2021-26)

We are expecting to generate revenue over this period, the revenue generated would be re-invested in the HVDC Centre or shared with customers.

It is proposed to use the RIIO-T2 Totex incentive mechanism for any: excess allowance, overspend, revenue generated from TOs/SO and revenues generated from other organisations.

Therefore, it is proposed that, each year, any excess allowance or revenue (after costs and investment in the Centre), are shared between customers and SHE Transmission through the Totex Incentive Mechanism.

This is intended to provide an incentive reward to SHE Transmission for the efficient running of the facility and for the risks associated with operating the Centre.

Purchase of Future Replicas

The HVDC Centre encourages HVDC projects to purchase Replicas as part of their project. Each individual HVDC project would be responsible for the full cost of the Replicas.

The Centre will host such Replicas at the Centre, and would charge the projects for the cost of hosting. However, hosting charges would be kept to a minimum to encourage projects to host their Replicas at the Centre.

8) Impact & Benefit

Progress Against SDRCs (to date)

The following table lists each SDRC in chronological order and details the Project's progress towards their achievement.

SDRC	Description	Status
9.1	**Formal Agreement with Project Partners.**	Completed on time. Formal agreements concluded in 2014.
9.2	**OFTOs and Renewable Developers Event**	Completed on time. The OFTOs and Renewable Generators Event was held in September 2014.
9.3	**Engagement with 1st HVDC Project**	Completed on time. Caithness-Moray Project confirmed the provision and use of Replicas.
9.4	**Complete Design of MTTE Facility**	Completed on time. The Design Development Document and Functional Specification were approved.
9.5	**Establishing HVDC Operators' Forum and Website**	Completed on time. Four HVDC Operators' Forum events have been held. The website (hvdccentre.com) was launched in 2015.
9.6	**Commence Operation of the MTTE**	Completed on time. The facility was formally opened on 26 April 2017.
9.7	**Publishing Studies & Test results**	Completed on time. Reports are published on the Centre's Website.
9.8	**Future Business Model**	Completed on time. By the submission of this document.
9.9	**Second Replicas**	**On Target**

8) Impact & Benefit

Impacts and Benefits Achieved (to date)

The following table lists the specific benefits that the Centre has delivered so far.

Project/Activity	Impact
EPC Testing and commission support for the CM project	The Centre was able to undertake this testing on the Replicas, without which the CM project would have been delayed (by circa 3 months). Commissioning support, ensured there was no delaying the commissioning timescales.
Control Room training	The Centre enabled the control room team to train and practice the operation of the Caithness-Moray link, this ensured a smoother and safer adoption of the scheme.
Maximising HVDC for Black Start (Scottish Government)	Will lead to a reduction in cost of Black Start services, a more stable system, and a reduction in the time to restore the system.
Stability Pathfinder (National Grid ESO)	The HVDC centre has provided modelling expertise to the GBESO both to support its tender evaluation and provide insights surrounding its tests and requirements.
NSL Protection Study (Scottish Power & National Grid)	This critical study will ensure that the AC protection will be suitable for purpose following connection of the NSL link. Alternatives would be; not to connect/ delay connection ahead of connection, connect at risk of cascade event leading to disconnection (see value of lost load calculations above) or
Eastern Link Project Support (TOs)	Providing technical advice to the project team, to help define the appropriate technology.
PROMOTioN	Providing efficient design of future offshore wind (and an income for the HVDC Centre).
Demonstrated multi-terminal multivendor interoperability.	We have demonstrated how multi-terminal schemes can operate with multiple vendors (and submitted a paper to the CIGRE session on this).
Training Course Delivery	Increasing industry skills (particularly focused on TOs and ESO).
HVDC Operators' Forum	Ensuring that lessons are learnt across the industry.
Converter Models (University of Strathclyde)	Developing open-source detailed converter models.
Stability assessment (University of Strathclyde)	Stability assessment and mitigation of HVDC converter interactions: Impedance modelling of HVDC converters for system stability studies.
Black Start Protection Coordination (EPRI)	Coordination of AC network protection during grid energization from HVDC schemes: Assess suitability for existing AC protection for Black start from HVDC.
Grid Code Compliance (Cardiff University)	Improving Grid Code Compliance of existing and upcoming HVDC Schemes in GB: Assess and test HVDC Grid Code compliance using simulation and experimental tools.

8) Impact & Benefit

Future Impact and Benefits

Over the RIIO-T2 period, the HVDC Centre will provide support to HVDC projects that plan to connect to the GB grid, de-risking project delivery and ensuring the stability of the network.

Specific impacts and benefits will be:

Project/Activity	Impact/Benefits
Support NIA/NIC innovation projects	Both HVDC related and other NIA and NIC projects could benefit from the modelling (and Hardware-in-the-loop) capabilities of the Centre to de-risk the deployment of innovation projects.
Manage the delivery of an HVDC innovation (NIA) programme	The Centre will oversee the delivery of an HVDC focused NIA funded innovation project, ensuing that the project meets the needs of TOs and HVDC projects.
Maintain a library of HVDC models	To enable to de-risking of future developments, the Centre will maintain a library of HVDC models.
Engage with industry groups (e.g. OFTOs Working Group, Grid Code Export Working Group, CIGRE B4, etc)	Provide leadership and TOs/ESO perspective to various HVDC related working groups.
Host industry events at the Centre	Host events at the Centre for: Transmission Licensees, Innovation Projects (NIA/NIC) and other HVDC-related events (e.g. IET events)
Support the Moyle Interconnector	Provide a range of support to Moyle's plans to replace their control systems (hardware & software), connecting South Ayrshire to Northern Ireland completing in 2022.
Support the Shetland Island link	Extension to the Caithness-Moray project. Since this will form a multi-terminal, the first of its kind in GB, the testing of the Shetland hardware will be undertaken at the Centre. The proposed multi-terminal extension of the Caithness-Moray link to Shetland will require testing against the detailed model of the Shetland network to avoid adverse effects on the AC and DC networks.
Support Interconnector Projects: NSL, NorthConnect, Aquind interconnector, Viking Link, Greenlink interconnector	Providing support as requested, including: Network integration, bespoke control verification (such as black start related), enhanced FST, hosting replicas, commissioning support, operational support etc.
Support the Dogger Bank windfarm project	Offshore windfarm has situated its converter stations between Beverley and Cottingham, connecting to the substation at Creyke Beck. The project aims to begin commencing construction in 2022 (comprising multiple DC links). As the first offshore HVDC connected windfarm, the Centre may support detailed analysis for both the design and commissioning phases.
Support the Eastern HVDC project	Proposes two separate HVDC links, one connecting Peterhead to Hawthorn Pit/ Cottam/Drax commission in 2026, and the other connecting Torness with Hawthorn Pit/ Cottam/Drax which will be under construction in 2026. Centre activities expected to be similar to Shetland Island link, noting the scale of these projects may encompass larger across- GB simulation encompassing

8) Impact & Benefit

Project/Activity	Impact/Benefits
	many of the above and existing HVDC projects also. The Eastern HVDC interconnector capacity will result in more than 50% of the overall circuit capacity between Scotland and England being HVDC in nature. It is critical that this transmission boundary with a range of known historic stability considerations is considered in sufficient detail with HVDC performance appropriately defined to maintain system security and reliability.
Facilitating sharing accurate models between suppliers/ TOs/ESO	This limits interaction investigations and the ability to manage the associated risks. A neutral environment where suitably detailed/open models can be integrated with a similarly detailed model of the GB system is required.
Modelling and analysing adverse AC system interactions (e.g. system resonances)	Requiring relevant network modelling and HVDC control detail to be brought together to ensure the TO and ESO can respectively design, plan and operate networks appropriately.
Modelling and analysing adverse interactions with other HVDC systems (or FACTS devices)	We understand from our liaison with HVDC owners, the ESO and TOs, that converter control interactions have already been evidenced within the GB network. These interactions require specific detailed modelling, however neither the TOs, the ESO, nor the developers have the ability to analyse the performance of HVDC at this level within the context of the GB network that they are connected. Requiring TOs to ensure the performance and behaviour of HVDC control is taken into account when designing and optimising the operation of other devices used to support network capacity and security.
Modelling and analysing adverse interactions with existing users	Requiring TOs and the ESO to ensure the design, planning and operation of new HVDC does not lead to mechanical or other impacts upon existing synchronous generation and other already connected Users.
Real-time (RTDS) simulation support for HVDC schemes	Using RTDS to provide: Providing technical advice/support, Enhanced FST, Procurement, installation and commissioning of Replicas, Compliance demonstration support, Hosting Replicas, Commissioning support and Operational Support.
Network protection coordination testing	Requiring the TOs to quantify in detail the effect of HVDC during a fault condition to ensure protection functions appropriately without risk of non-operation, slow operation or increased network depletion following a fault. The SO and TOs cannot allow HVDC interconnectors to connect to the Grid unless they are satisfied that their own network protection scheme will not be compromised. This can require the detailed testing of multiple vendor supplied models, together with the dynamic network model and real protection relays (as is the case for NSL protection coordination study that the Centre has been commissioned to undertake).
Demonstrating and testing multi-terminal and multi-vendor HVDC systems	Requiring new standards, specifications and analysis of DC systems by TOs and others developing and delivering such designs.
Supporting the definition of standards and interoperability requirements	Requiring manufacturer specific HVDC solutions to be understood in detail and limiting the extent to which any one manufacturer can understand its risk of interaction with another design.

8) Impact & Benefit

Project/Activity	Impact/Benefits
Delivering seminars and training to increasing capabilities, in GB, for HVDC integration modelling and analysis	The Centre will enhance it training provision (for details of planned events, refer to hvdccentre.com). Requiring training and capability development across the industry across a range of analysis platforms and with respect to particular forms of new interaction, together with control room training in operating in this evolving environment.

Measurable Outcomes

The following measurable outcomes would be reported to Ofgem:

Total value of work undertaken

The HVDC Centre would provide Ofgem with a breakdown of the work carried out for the TOs and the ESO, and the associated cost of the work had it been charged for.

Benefits calculation

This would provide Ofgem with the financial benefits that the Centre has delivered through working with the TOs and the ESO on HVDC projects. These range between the reduction of constraint costs or delivering efficient outage planning.

9) Conclusion

Conclusion

The HVDC Centre has become a world-leading Centre of HVDC expertise and is providing critical support to projects in GB and the security of the GB network; directly benefiting customers.

Need

The period 2021-26 will see a huge investment in HVDC schemes in GB; the most concentrated development of HVDC in the world. Such extensive development poses significant risks to the reliable operation, control and resilience of the GB network.

In order to mitigate these risks an independent testing facility that can host detailed models (and control/ protection hardware) from multiple suppliers and from TOs/ESO is required. It must have the expertise (and technology infrastructure) to undertake specialist studies; along with the credibility that ensures the results can be relied upon.

Evolution

As a result of the NIC funding to develop a world-class facility, combined with hiring subject matter experts together with the experience of delivering high-profile project-critical studies; we now have an internationally recognised HVDC Centre of excellence - which is ideally positioned to support GB's HVDC plans.

Engagement

The Centre sees a key role in bringing together and facilitating engagement and knowledge exchange on HVDC in GB.

Governance

Over the 2021-26 period, the Centre plans to maintain similar governance arrangements, and similar Ofgem oversight as with the MTTE project.

Impact

Over the RIIO-T2 period, the HVDC Centre will be able to provide support to all the HVDC projects that plan to connect to the GB grid, de-risking project delivery and ensuring the stability of the network, and delivering substantial financial benefits.

Cost

The HVDC Centre is seeking to cover the operating costs through a RIIO-T2 allowance. Revenues generated will be re-invested in the HVDC Centre and shared with customers.

Recommended Option

Whilst the Centre is a GB facility that supports all HVDC schemes connecting to the GB Grid, SHE Transmission is considered the appropriate TO, to take the responsibility for the facility for the next price control period, on behalf of all the transmission licensees and the system operator.

The enhanced 'Future Scope', provides the optimal level of support for the next period.

In our view, this represents both the most cost efficient solution to the end consumer and the solution which most effectively addresses the increasing relevance and potential value in the activity of the Centre over the period.

Overall Conclusion

The National HVDC Centre has grown to become a critical component of the GB electricity infrastructure; which ensures the integrity and security of the GB electricity network, while enabling the delivery of the ambitious plans and the continued de-risking of HVDC schemes envisaged across the period 2021-2026.

The Centre will, subject to Ofgem agreement to these pragmatic plans, continue to de-risk the deployment of the increasing volumes and complexity of GB connected HVDC schemes planned in 2021-26, to mitigate their delivery risk while ensuring the integrity and security of the GB electricity network.

Future Business Model – February 2020