Project Code/Version No:
SSEEN01/1.0

Electricity Network Innovation Competition Full Submission Pro-forma

Section 1: Project Summary

1.1 Project Title:

Multi-Terminal Test Environment (MTTE) for HVDC Systems

1.2 Funding Licensee:

Scottish Hydro Electric Transmission plc (SHE Transmission)

1.3 Project Summary:

SHE Transmission together with National Grid Electricity Transmission Limited (NGET) and Scottish Power Transmission Limited (SPT) is proposing to establish a collaborative facility which will enable the planning, development and testing of high voltage direct current (HVDC) transmission solutions in GB.

This facility is known as the Multi-Terminal Test Environment (MTTE); it will house: a real-time simulator system (which simulates HVDC schemes), IT infrastructure and accommodation for replica HVDC control panels.

The anticipated proliferation of HVDC systems in GB during RIIO-T1 and beyond is largely being driven by the increasing penetration of renewable generation. To date, there is limited experience in GB of the design, construction and operation of HVDC systems.

To maximise the benefits of the significant expected investment in HVDC systems in GB, there is a need to:

- 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.

The MTTE will contribute to achieving these aims, which are intended to reduce the risks, costs and time-to-deployment of HVDC systems for GB transmission Customers.

1.4 Funding

1.4.3 NIC Funding Request (£k): £ 11,815

1.4.4 Network Licensee Contribution (£k): N/A

1.4.5 External Funding - excluding from NICs/LCNF (£k): N/A

1.4.6 Total Project cost (£k): £ 13,978

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Section 1: Project Summary continued

1.5 Cross industry ventures: If your Project is one part of a wider cross industry venture please complete the following section. A cross industry venture consists of two or more Projects which are interlinked with one Project requesting funding from the Electricity Network Innovation Competition (NIC) and the other Project(s) applying for funding from the Gas NIC and/or Low Carbon Networks (LCN) Fund.

1.5.1 Funding requested from the LCN Fund or Gas NIC (£k, please state which other competition):
The Project does not intend to request funding from the LCN Fund or Gas NIC.

1.5.2 Please confirm if the Electricity NIC Project could proceed in absence of funding being awarded for the LCN Fund or Gas NIC Project:
Not Applicable

☐ **YES – the Project would proceed in the absence of funding for the interlinked Project**

☐ **NO – the Project would not proceed in the absence of funding for the interlinked Project**

1.6 List of Project Partners, External Funders and Project Supporters:

Project Partners: National Grid Electricity Transmission (NGET) & Scottish Power Transmission Ltd (SPT)

External Partners: Scottish Enterprise .

Project Supporters: ABB, Aberdeen City Council, Alstom, Siemens, Power Network Demonstration Centre (PNDC), Electric Power Research Institute (EPRI), University of Aberdeen Imperial College London, University of Manchester, University of Nottingham, University of Southampton, University of Strathclyde and University of Warwick.

1.7 Timescale

1.7.1 Project Start Date:	**1.7.2 Project End Date:**
6th January 2014	31st March 2021

1.8 Project Manager Contact Details

1.8.1 Contact Name & Job Title: Frank Clifton Project Development Manager	**1.8.3 Contact Address:** Future Networks SSE Power Distribution Inveralmond House 200 Dunkeld Road Perth PH1 3AQ
1.8.2 Email & Telephone Number: frank.clifton@sse.com 01738 456 237	

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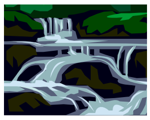
Section 2: Project Description

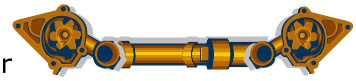
This section should be between 8 and 10 pages.

2.1 Technical Context

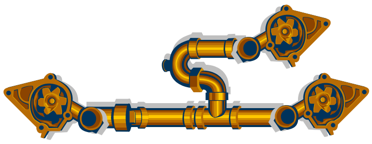
The MTTE will enable the planning, development and testing of High Voltage Direct Current (HVDC) transmission solutions in GB. HVDC transmission systems use Direct Current to reduce electrical losses over long distances. The difference between AC and DC can be illustrated by the analogous difference between water flow down a river and down a pipe:



- AC can be thought of as a river; whatever flows into one end will flow to the other without the need to control it.
- DC can be thought of as a pipe with a pump at each end (the pumps represent the converter stations).



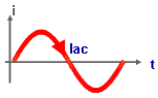
- The pump at one end must pump exactly the same amount of water/power as the pump at the other end, or the pipe will burst (i.e. they are controlled, and need to interact with each other to maintain equal flow).



- Now consider a 3rd terminal (connecting a 3rd pipe with another pump); coordinating the infeed pumps to be exactly the same as the outflow (for every millisecond) requires complex and fast control.

Glossary of technical terms

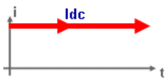
This section provides explanations of the key technical terms used throughout this document; they are presented in alphabetical order.



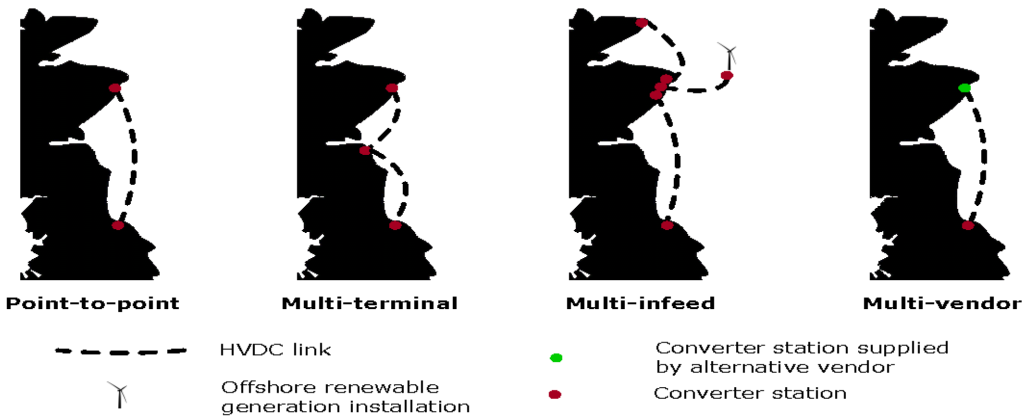
- **AC:** The GB transmission network currently transmits alternating current (AC) at standardised high voltages, i.e. 132kV, 275kV & 400kV, known as High Voltage AC. This dominance of AC systems is due to the relative simplicity of stepping AC voltage up and down and of isolating faults, as well as the relatively low cost of AC network components e.g. transformers and circuit breakers.
- **Adverse Control Interactions:** These occur when the reactions of control systems in different converter stations act to amplify an issue rather than damp it, potentially leading to the HVDC system tripping.
- **Control interactions:** The control systems in converter stations manage the operation of individual components (on the scale of milliseconds) through control interactions which are tuned to maximise power flow, minimise losses and be resilient to fluctuations.
- **Control panels:** The control systems in converter stations operate on computer racks known as control panels.
- **Converter station:** A converter station is required at each end of an HVDC link to convert the power from AC to DC, and at the other end from DC back to AC. Converter stations generally use either Line Commutated Converters (LCC) or Voltage Source Converter (VSC) technology. Each converter station is a large, complex and expensive facility; converter costs are dependent on their rating and range between £55m-£180m each, which includes extensive protection and control systems.

Project Description cont.

- **Factory Acceptance Testing (FAT):** Before an HVDC system is commissioned, the vendor undertakes factory acceptance testing of the associated control systems through a large number of scenarios (typically over a 3-6 month period).
- **HVDC:** High Voltage Direct Current (HVDC) transmission systems use Direct Current to reduce electrical losses over long distances, where AC systems are impractical. HVDC technologies vary between manufacturers, and there is a lack of standardisation (e.g. no standard voltages).



- **In proximity:** A situation in which converter stations interact electrically, regardless of whether they are geographically located next to each other, potentially causing complex control interactions.
- **Multi-infeed:** Co-location of multiple HVDC terminals such that the associated converter stations are located next to each other, potentially causing complex control interactions. This situation is also known as Co-located Converters.
- **Multi-terminal:** A multi-terminal HVDC system includes 3 or more terminals.
- **Multi-vendor:** Typically all of the converter stations in an HVDC system are provided by the same supplier; multi-vendor refers to HVDC systems including converter stations from different suppliers.



- **Other active controlled equipment:** Devices in the transmission network such as static VAR compensators (SVCs), static synchronous compensators (STATCOMs) and wind turbines which use complex software to control power flow that can lead to control interactions.
- **Point-to-point:** Almost all existing HVDC links directly connect from one location to another, which can be described as a point-to-point link.
- **Replica Control Panels:** The control systems for a converter station are within computer racks known as control panels. Replica control panels are an exact replica of these computer racks.
- **RTS:** A real time simulator (RTS) is a computer model capable of simulating the behaviour of HVDC converter stations in real time, enabling the use of real hardware (e.g. control panels). An RTS capable of modelling complex multi-terminal HVDC systems would require significant computer processing power.
- **Terminal:** Point at which a HVDC link terminates; normally a converter station.

Project Description cont.

2.2 Project Context

The growth in renewable generation in GB

The UK Government has set an ambitious target for the deployment of renewable energy generation capacity over the next decade. By 2020, the Government expects that 15% of the UK's energy needs will be met from renewable sources, with around 30% of electricity generation coming from renewable sources, as indicated in the UK's Carbon Plan.

The need for new infrastructure – a new breed of Transmission Network

Significant expansion will be required across GB's transmission infrastructure to facilitate the expected increase in renewable generation over the next decade and beyond. A number of transmission projects are in development or construction to deliver this new transmission capacity, including reinforcement of existing lines as well as the construction of new assets. For instance, we anticipate that an investment of £3-5 billion in SHE Transmission's network will be required, depending upon the timing and scale of renewable generation deployment. NGET and SPT also have significant infrastructure investment plans.

In a number of instances of the new transmission infrastructure planned for GB, the use of conventional Alternating Current (AC) systems is not expected to offer a viable solution. In particular, HVAC systems become impractical for transmission links over longer subsea distances due to electrical losses incurred as a result of cable charging currents. In these cases, High Voltage Direct Current (HVDC) systems are the preferred solution. A report by SKM to Ofgem ("Review of Worldwide Experience of Voltage Source Converters High Voltage Direct Current Technology Installations", 25 March 2013) indicates that HVDC systems are a widely accepted solution for subsea transmission distances in excess of 60-70km. A key example in GB is SHE Transmission's planned link from Caithness to Moray, where a subsea cable presents a more practical and effective option than the longer and more challenging onshore route. This project is currently subject to Ofgem assessment in accordance with the Strategic Wider Works process as part of RIIO- T1.

The future role for HVDC systems in GB

In National Grid's Electricity Ten Year Statement (November 2012), three 'UK Future Energy Scenarios' are considered: Slow Progression, Gone Green and Accelerated Growth, and the anticipated HVDC links required for each scenario from 2015 to 2030 are mapped, as shown in the diagrams below and in Appendix I. Under all scenarios there is expected to be a significant number of new HVDC links in GB (excluding international interconnectors):

- 20 new HVDC links in the 'Slow Progression' scenario;
- 37 new HVDC links in the 'Gone Green' scenario; and
- 45 new HVDC links in the 'Accelerated Growth' scenario.

While these projects will each be subject to a detailed needs case analysis, the overall portfolio of potential HVDC projects in GB represents a significant potential investment for the Transmission System Owners (TOs) and Offshore Transmission Owners (OFTOs).

There are only 4 existing HVDC links currently connected to the GB network, and all are point-to-point international interconnectors.

However, the 'Electricity Ten Year Statement 2012' identifies a number of multi-terminal and/or multi-infeed HVDC systems which offer the potential to reduce costs and enhance system performance in comparison with the exclusive use of point-to-point systems. As identified in SKM's report (referenced above), to date, there is limited international experience in the design, construction and operation of these multi-terminal and multi-infeed systems. As a result, the planned developments present a new range of challenges and risks for GB TOs/OFTOs.

The overall portfolio of potential HVDC projects in GB represents a large investment and significant operational challenge for the TOs and OFTOs. The MTTE will play a key role in ensuring that that this portfolio of HVDC projects can be proven, validated, and ultimately constructed and operated successfully.

2.3 The Problems

There are a number of problems currently preventing the more widespread adoption of more complex HVDC systems. These problems, along with the method through which they will be addressed by the MTTE for the benefit of the transmission system, are summarised below and discussed further in Appendix III.

- **Transmission Planning of HVDC schemes:** As the number of HVDC and other active devices increase, future network planning and development will become ever more complex. Furthermore, there is a lack of appropriate tools to model and understand the detailed impact of complex HVDC systems on the existing network and simulate future HVDC expansion scenarios.
- **Requirements Specification of HVDC schemes:** The novelty of multi-terminal, multi-vendor and multi-infeed HVDC systems limits the ability to specify detailed requirements and negotiate technical details.
- **Multi-Terminal HVDC schemes**: Multi-terminal HVDC offers the potential of multiple connections at a substantially lower cost with more security than point-to-point. However the complexity of multi-terminal HVDC introduces additional risks and uncertainly on the impacts.
- **Competition and Multi-Vendor HVDC:** The market for HVDC systems is dominated by a small number of large suppliers. There is limited interoperability and standardisation between the suppliers' preferred designs, especially in the control and protection systems. This situation both limits competition between the existing suppliers and hinders the potential for new entrants to the market. Resulting in a high-risk for multi-vendor HVDC schemes and a lack of confidence in regulation of power flow and system stability. Furthermore, there is currently no facility to undertake acceptable testing of multi-vendor schemes; or for schemes in close proximity which could cause adverse control interactions (for which individual vendors factory acceptance testing is not adequate). It is also widely recognised that significant work is required in the development of common standards for HVDC. Whilst CIGRE/CENELEC have begun to tackle the issue, a substantial workload remains, which the MTTE will help inform.
- **Control interactions between multi-terminal, co-located and electrically connected converters, and with other active controlled equipment:** The interaction between two or more HVDC converter stations on the same system, at the same location or in close electrical proximity can introduce the risk of adverse control interactions and impacts on the AC network. This risk is

exacerbated where converters are supplied from different manufacturers (with their different power electronic technologies and different control and protection systems). These issues will need to be anticipated and resolved in this diverse environment to avoid unacceptable impacts on network security. Coupled to this there are an ever increasing number of other controlled devices being connected to the network which could again cause adverse interactions with HVDC systems. The TOs as network owners have an obligation to identify and manage any issues to ensure the integrity and security of the GB network.

- **Train Transmission Planning and Operational Engineers:** The TOs and OFTOs have limited experience in the design and operation of HVDC systems (and no experience of multi-terminal or multi-infeed operation). The control and protection systems are absolutely critical to the secure and reliable operation of these systems. There is therefore expected to be a significant skills gap which needs to be addressed on the operation of HVDC systems. Furthermore, training is usually only provided when an HVDC link is commissioned, and future engineers do not have a system to be trained on.
- **Post commissioning scenario planning and operational optimisation:** There is limited experience in the operation of HVDC systems amongst the GB TOs. This will result in the TOs operating the system in a prudent configuration in order to ensure system security. However, as experience and knowledge of the operating conditions develops, the systems can be optimised to improve network efficiency and reduce losses. This could currently be undertaken on the live system, which restricts the ability to optimise, takes longer and comes with an additional risk to the Network; or could be undertaken in less sophisticated models which do not accurately represent the system. The scenario planning would also include contingency and emergency planning.
- **Model New HVDC Technologies:** As new HVDC technologies emerge (e.g. circuit breakers, DC-DC converters etc.) there is currently no independent facility to test and demonstrate their operation and control, or their specific use as part of GB HVDC schemes. Therefore, the use of new technologies on the GB network introduces unknown risks due to a lack of knowledge on their operation, control and interactions.

2.4 The Method

SHE Transmission (together with NGET & SPT) is proposing to establish a collaborative facility which will enable the planning, development and testing of complex High Voltage Direct Current (HVDC) transmission solutions in GB. Explanation is provided below.

Establish the MTTE Facility

MTTE intends to allow the TOs to close the HVDC knowledge gap and reduce the risks, to allow these projects to proceed and to ensure that they can be successfully delivered. A "point-to-point" solution procured from an established vendor currently represents the least risk option for delivering a successful project. The introduction of further connections - either multi-terminal or multi-infeed - will add a further layer of complexity which the MTTE would address.

The MTTE facility will include:

- The site & building.

Project Description cont.

- A Real Time Simulator (RTS) system which can simulate multiple aspects of HVDC systems, along with the AC network; with the ability to 'plug-in' control panels from vendors. The RTS will have the scope to be increased in future if required.
- IT infrastructure and accommodation for replica control panels.
- Expert resource to model and simulate HVDC schemes.
- Development of a programme of scenarios and trials that will provide a robust framework against which to model and test planned HVDC systems to maintain system security and reliability (some network modelling will be undertaken on the RTS systems prior to the MTTE opening).
- The delivery of the programme of the studies and test.
- Operational processes and procedures including:
    - Establishing the management/governance model to allow access for all GB Transmission License Holders; and
    - Developing background IP protection arrangements that are acceptable to ensure the participation of vendors.
- The learning from the MTTE will be used to inform the development of new specifications and requirements for the TOs and OFTOs to use for the design and operation of HVDC systems. This will also be used to inform evolving standards such as the HVDC Grid Code being developed by ENTSo-E on behalf of ACER and work being undertaken by CIGRE/CENELEC.

Facilitate Transmission Planning of HVDC schemes

The MTTE will allow a much more robust set of scenarios to be analysed within the project development timeframe to ensure that the existing assets are properly utilised and any new extensions are fully investigated. For example, this could be used to model the impact of a new renewable connection which may have a different "load profile" from existing profiles.

The MTTE will be able to model complex HVDC schemes (and the associated AC network) under a comprehensive range of operating conditions to ensure the optimum balance or security, efficiency and reliability. Network Licensees will be able to:

- Test and study the control, protection, interaction and operational issues associated with the DC and AC systems; and
- Assess the impact of planned HVDC systems alongside future expansions.

Further information on the range of studies and analysis proposed for the MTTE is included in Appendix V.

Improve Requirements Specification of HVDC schemes

The MTTE will provide an environment, skills and tools to model the details of HVDC systems, which will enable more accurate specification of the requirements, which is expected to reduce the risks and ensure value for money on HVDC schemes.

Facilitate Multi-Terminal Solutions

The MTTE will provide an environment, skills and tools to model the complex multi-terminal HVDC systems, with studies performed quickly and efficiently in a safe simulated environment. The incorporation of replica control panels of HVDC links will improve the accuracy and therefore confidence in the results of the studies performed.

Facilitating Competition and Multi-Vendor HVDC schemes

The MTTE will enable the control and protection systems from different suppliers to be tested with each other, to demonstrate their interoperability; utilising replica control panels. It also provides a facility where new entrants to the market can model and test their systems.The MTTE will also be able to undertake Acceptance Testing of multi-vendor HVDC systems and/or electrically connected systems (e.g. co-located).

De-risk control interactions between multi-terminal, co-located and electrically connected converters, and with other active controlled equipment

The MTTE will enable the testing of control interactions in a safe environment, to mitigate the risk of adverse control interaction in the live system. This will ensure that any adverse impacts are identified and managed to maintain system security and reliability. This can be done in an environment which does not compromise system security or have the potential for adverse Customer impact.

Transmission Planning will use the MTTE to understand the control interactions with generation control systems. The impact of the connection of offshore renewable projects can be simulated prior to construction.

This will give the TOs the ability to move confidently toward multi-terminal solutions by reducing the risks associated with their control interactions.

Train and Develop Transmission Planning and Operational Engineers

The MTTE provides a facility to train staff on the operation of the system, during the lifetime of the scheme, in a 'safe' simulated environment, with access to replica control panels identical to those in operation.

System Optimisation – Reducing Losses and Improving Efficiency

The use of replica equipment combined with the functionality of the MTTE will help to give TOs the information required to optimise the performance of the HVDC systems. It will enable the running of multiple scenarios (e.g. changing various control parameters) to optimise the performance of the overall network as well as the HVDC scheme, within a safe simulated environment.

Model New HVDC Technologies

The MTTE will offer a facility for the TOs/OFTOs to study and assess the impact of future developments in HVDC technology as they are brought to market, by providing a suitably robust simulation environment to fully assess new equipment. This will reduce the risks and provide confidence in the deployment of such technology to allow TOs/OFTOs (and hence Customers) to benefit from the new technology, and potentially more competition.

2.5 The Trials

The MTTE facility will include the necessary IT and control equipment to allow the TOs to study the interaction of HVDC systems with the existing AC grid. It will utilise the replica control panels and simulators of the proposed HVDC systems to ensure that their integration and interaction with the grid can be studied and modelled in detail. This will provide the ability to validate the performance of vendors' equipment against the requirements identified by the TOs. Most notably this can be done in a manner that does not risk damage to real assets such as DC cables and convertors while pushing the operational envelope of DC cables and associated plant.

There will also be the opportunity to study and develop scenarios for the future expansion of HVDC systems. Therefore, the MTTE will be developed with the functionality to allow testing of future vendor supplied control equipment.

The MTTE will be used to deliver a series of trials and simulations to:

- Develop the AC system model: An AC system model will be developed to enable a range of potential system states to be simulated. This will include low fault levels, phase unbalance, a number of AC and DC fault scenarios, local and inter-area oscillations, low system inertia and others. This will also include modelling of the interaction with other "active" devices such as wind turbines etc. which are becoming an ever more significant element of the generation mix.
- Develop a test programme: A test programme will be developed for evaluating the response of the different proprietary protection and control systems under a comprehensive range of operating conditions. This will be developed to support the portfolio of HVDC projects being developed across the GB network.
- Commission and test proprietary protection and control systems: Following delivery, the protection and control systems will be connected to the RTS and commissioned. Tests will be performed in accordance with the developed test programme.

The studies and trials to be performed on the MTTE will check both steady state and dynamic operation of multiple HVDC controllers connected to a common AC transmission network. Modelled scenarios could include a variety of scheme types, such as multi-infeed, multi-terminal, embedded HVDC, and HVDC schemes in close proximity to other controlled devices e.g. wind turbines.

Multi-terminal configurations may be assumed only to be based on VSC multi-level topologies. The role of the MTTE is to check that the HVDC system operates correctly and predictably in order to ensure the following:

- The stations operate within their designed parameters;
- The control system behaves as anticipated by the vendor from digital studies;
- The protection system responds as anticipated by the vendor;
- The scheme meets the requirements of the national Grid Code;
- The steady state behaviour of the station complies with the requirements;
- The dynamic behaviour of the station complies with the Customer's requirements; and
- The controller maintains system stability following system perturbations.

This list is not exhaustive and does not include all of the possible permutations of multi-infeed or multi-terminal scenarios; these would be determined on a project by project basis.

A key part of the MTTE development programme will be to ensure that the models and trials are valid and representative of the actual systems. Our engagement with vendors and academia and research organisation will support this validation (refer to Section 4.6 for more details).

2.6 The Solutions

By addressing the problems identified above, the MTTE will enable and facilitate the following future network solutions:

- Multi-Terminal Transmission schemes (e.g. 3 , 4 or 5 terminal HVDC systems);including generation connections if appropriate;
- Extensions to HVDC schemes (e.g. adding 3rd, 4th or 5th terminals to schemes);
- Multi-vendor schemes (where different manufactures supply the converter stations at different terminals); and
- Multi-infeed and Converters in electric proximity (providing confidence of the integration between converters, and other active controlled devices).

2.7 Technical Description of the Project

The MTTE will create a new facility for the testing and proving of HVDC systems for use by the GB TOs/OFTOs. The key elements required for the facility are shown below (Figure 2.1)

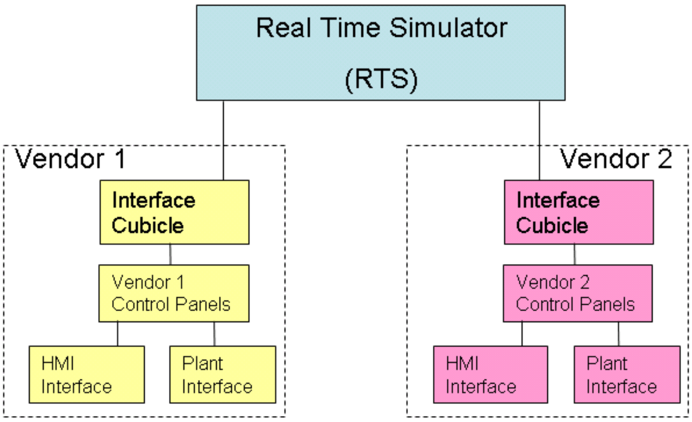


Figure 2.1 The key elements making up the MTTE facility

Real Time Simulator

The heart of the MTTE will be the Real Time Simulator (RTS). The RTS is purpose built to allow the user to investigate the effects of disturbances on power system equipment and networks to prevent outages or complete failure.

The RTS is a combination of advanced computer hardware and comprehensive software. Power system networks are created using electrical components from component model libraries. The RTS emulates the power system (AC and DC side) and the converter operation. Due to computational restrictions, the AC network is normally modelled as a reduced network; this configuration has been developed from the full country model and has the same dynamic response.

Modelling will cover all details of control signal interface as well as the sensor outputs which are supplied to the controllers. The standard manufacturers' control racks are directly connected to RTS in the same way they would be connected to the actual HVDC system.

The RTS will work in continuous, sustained real time and can thus solve power system equations fast enough to realistically represent conditions in the actual network. Because the solution is real time, the simulator can be connected directly to replica power system control and protective relay equipment.

A user interface is required for the RTS facility, which enables the RTS users to build the model of the AC network and converters and to run the simulations, and including assistive tools such as graphical models of system components.

Interface Cubicles

Additional hardware is required to interface the RTS processors to the vendor's controller. The interface cubicle will be required to convert the control signals from the hardware controller to the RTS.

Vendors Hardware Controllers

In their own facilities, vendors perform FAT on their controllers, as final proof of the hardware and software, prior to shipment to the site. This requires the full cubicle suite to be assembled, plus all of the AC and DC side interface cubicles; this can be a significant quantity of cubicles (Figure 2.2). For a point-to-point link both HVDC terminals need to be represented, with a model of the DC transmission medium in between them.

Figure 2.2 Cubicle suite as required for FAT on vendors hardware controllers [Source: Alstom Grid]

For the MTTE it is anticipated that a considerably reduced cubicle suite would be used, without duplication and with limited interface requirements. This could be as simple as a single control cubicle plus an interface cubicle. Clearly some testing could not be performed, but the main aim of the MTTE is to test interactions between vendors' controllers, rather than prove individual items of equipment – a task which is already performed by industry.

MTTE Facilities

The MTTE will also need to provide the necessary building and support services to house the replica control panels and RTS in a secure and safe environment. The intention is to secure these panels for long term use by the TOs. A key requirement for the MTTE is to ensure that vendors equipment is protected in a secure environment with appropriate levels of physical and IT security to protect each supplier's Intellectual Property.

2.9 Changes since ISP

We have continued to develop the MTTE concept since the ISP. This has allowed us to begin to more clearly identify the issues and problems which the MTTE will help to address. This has resulted in a more comprehensive set of requirements for the MTTE which has allowed us to better define the costs and programme for the project.

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Section 3: Project Business Case

This section should be between 3 and 6 pages.

3.1 Business Case Context

Our core purpose within SHE Transmission is to provide the energy people need in a reliable and sustainable way. More specifically, SHE Transmission's statutory duties as a transmission licensee are:

- To ensure the development and maintenance of an efficient, coordinated and economical system of electricity transmission;
- To facilitate competition in the supply and generation of electricity; and
- To have due regard for preservation of amenity.

The drive toward a low carbon electricity sector and in particular the growth in renewable generation has created a wide range of challenges for the Transmission network and the wider electricity sector. These challenges are placing an increasing, and urgent, demand on Transmission Owners (TOs) to provide the capacity required for renewable energy generation.

This capacity will require new infrastructure to be constructed to meet these new demands, and building the required infrastructure will be a demanding task requiring considerable investment.

We also set out our asset management policy which seeks to balance three main factors: cost, risk and performance. Our aim is to achieve satisfactory network performance at an acceptable risk and within the constraints of efficient cost. Across all of our activities, safety issues are given overall priority.

The high cost, complexity, novelty and risks associated with the construction of HVDC systems will present the TOs with an unprecedented set of challenges. Furthermore, as the number of HVDC scheme connected to the network increases, the potential for adverse interaction between them also increases (which has the potential to add cost and risk to future infrastructure projects).

Our ultimate stakeholder is the GB electricity consumer; people who pay electricity bills have a legitimate interest in how they are made up. Given that transmission costs are a contributor to energy bills, it is important that we minimise the cost of developing and running our transmission network.

3.2 Integration with SHE Transmission Business Plan

To deliver our core purpose in these challenging times we recognise that innovation is a necessity. At SHE Transmission we believe that "innovation with a purpose" is central to our strategy and this makes a substantial contribution to providing the energy people need in a reliable and sustainable way. In our Innovation Strategy (published in January 2012) we have committed to seven high-level innovation objectives which have identified through analysis of our stakeholder views.

The MTTE project will deliver learning which will contribute directly to the delivery of these objectives:

- "Accelerating network development and connections including the integration of increasing amounts of renewable generation" - by helping to better inform the future development of HVDC schemes.
- "Minimising the cost of providing network capacity" – by supporting the Transmission Operators to move toward commissioning multi-terminal or multi-

vendor solutions.

- "Maximising the use of existing assets to deliver capacity and speed connection" – the more advanced modelling work done at MTTE is expected to enable greater utilisation of network assets (both AC and DC).
- "Maintaining and improving network performance" – the MTTE will provide TOs with additional knowledge to ensure optimum performance of HVDC systems and the associated AC system. This will allow the TOs to maximise efficiency and reduce losses whilst maintaining systems security and stability.
- "Providing more accurate information on the short and long term asset condition information to allow more informed decision making" – the knowledge garnered for MTTE will help provide better informed plans for development of the transmission system.
- "Remaining at the forefront of innovation to maintain our record of providing the highest standards of service at the lowest possible cost" – the knowledge from the MTTE will help SHE Transmission and the other TOs assess the potential impact of new 'active' devices including future HVDC systems on the network prior to their implementation.

We are confident that the MTTE project will complement and support the SHE Transmission Innovation Strategy and allow us to continue to meet our core objective of providing the energy people need in a reliable and sustainable way. The MTTE will also be able to be used by the other Transmission License holders to ensure that all GB Customers can benefit.

3.3 Motivation for Multi-Terminal Test Environment

Whilst HVDC offers a precise and controllable means of transmitting electrical energy over long distances, the predicted increase in the number of HVDC systems will present the TOs with a new range of challenges and risks. These systems are characterised by very high capital costs and there is limited experience in their design and specification amongst the TOs and OFTOs. Further to this, the market place is dominated by a small number of very large suppliers each of which utilise bespoke technology.

The HVDC projects currently proposed by TOs are largely based around 'point-to-point' solutions provided by a single vendor. This approach should allow these projects to proceed within an acceptable level of risk and cost. The move to multi-terminal, multi-infeed or multi-vendor solutions offers the potential to reduce the costs associated with these projects in the longer term. However, across the world there is very limited experience of these systems and their development would present a significant new challenge to TOs.

As identified in National Grid's Ten Year Statement (2012), there is the potential for an increasing number of HVDC systems to be connected to the GB network in the future. As the number of these systems increase so do the number of potential adverse interactions with other HVDC systems, the existing AC system and other controlled devices on the AC system. Therefore, the TOs will need to thoroughly understand and investigate these issues in order to maintain network security and reliability.

3.4 Benefits from MTTE

Benefits for Customers

It is Customers, both today and tomorrow, that will ultimately fund the investment in HVDC infrastructure through transmission charges. Therefore, the ability of the MTTE to reduce

Project Business Case cont.

the costs and risk associated with the development of HVDC systems will directly benefit Customers.

Benefits for Transmission Licensees

The MTTE project will deliver the following benefits for Transmission Licensees (both TOs & OFTOs), which would flow through to benefits to our Customers:

- **Support Transmission Planning of HVDC schemes:** Improved transmission planning of complex HVDC schemes will enable the optimisation of their performance, reduced risks and provide value for money for our Customers, together with more confidence in transmission planning decisions and their impact on the Network.
- **Improve Specification of HVDC schemes:** The MTTE will enable the detailed investigation of complex HVDC schemes to more accurately specify the requirement, which is expected to reduce the risks and ensure value for money for our Customers, and will provide confidence in their specification and impacts.
- **Facilitate Multi-Terminal Solutions:** The move to a multi-terminal solutions for HVDC systems offers the potential to reduce project costs by reducing the number of converter stations when compared with separate point-to-point solution (with an associated significant cost saving). The MTTE will allow a greater range of simulations to be carried out to identify potential adverse interactions and allow TOs to develop optimum operating strategies. The ability of the MTTE to utilise replicas of the actual control equipment will provide the ability to test the operation of the system prior to final commissioning and provide further confidence.
- **Facilitate Competition and Multi-Vendor HVDC schemes**: The MTTE's ability to undertake multi-vendor interoperability testing will facilitate more competition in the HVDC market, provide confidence in multi-vendor compatibility, and therefore enable multi-vendor HVDC schemes. This will reduce the risk of such schemes and reduce their costs, which are ultimately borne by our Customers. The TOs will be able to carry out elements of pre-commissioning testing at the MTTE to complement the vendors Factory Acceptance Testing. The ability of the MTTE to carry out simulations using hardware rather than software models will allow a greater range of tests and simulations to be carried out. This should shorten and de-risk the commissioning period for projects, whilst reducing risk of potential adverse control interactions.
- **De-risk control interactions between multi-terminal, co-located and electrically connected converters, and with other active controlled equipment:** The MTTE and the use of replica control equipment will allow a much broader and representative range of analysis to be undertaken. This will allow the TOs to be proactive and address issues in advance as the network develops. Feedback from other projects in Europe such as Borwin1 suggests that these additional models and simulations are essential to maintaining grid stability. This will result in a reduced risk of adverse control interactions between active controlled devices and HVDC systems, reducing the risk of generation constraints (saving Customer money), and improving system reliability. This reduced risk will provide confidence in developing these complex schemes, providing more flexibility to optimise future grid development.

Project Business Case cont.

- **Allow HVDC systems to be operated at, or close to, their optimal configuration from the outset.** This is a key benefit, something that took AC systems several decades to achieve with benefits in the form of relative improved resilience, reduced losses, greater transfer levels. The MTTE will allow the interaction between the HVDC and existing AC networks to be carefully studied and new operational scenarios can be modelled to allow system performance to be optimised.
- **Train Transmission Planning and Operational Engineers:** The MTTE provides an off-line 'safe' facility in which to train engineers in a simulated environment, and will be used to help develop the staff required to manage these new, highly complex assets. This will provide improved training for engineers throughout asset lifetime, with a greater pool of expertise to be drawn upon, and enable training on 'real-life' scenarios which will reduce the risk and time to undertake these actives on the live system.
- **Undertake post commissioning scenario planning and operational optimisation:** The use of replica equipment combined with the functionality of the MTTE will help to give TOs the information required to optimise the performance of the HVDC systems. Resulting in improve network efficiency and reduce losses, along with better informed grid operation decisions.
- **Model New HVDC Technologies:** There will be an increasing number of new active devices and HVDC equipment available to the GB network in the coming years. The MTTE will allow these devices to be simulated in advance of their connection to identify any adverse interactions. This is particularly important where large scale renewable projects are developed in stages; these projects may extend over a number of years and there is no guarantee that all of the turbines will be of the same design. Therefore, the MTTE will mitigate the risks that advances or changes in technology cause adverse impacts on the Network. This will provide confidence in the use of new technology, and the associated benefits of deploying it on the Network, at a reduced risk.

The MTTE is expected to reduce risk across all HVDC projects in GB, especially those with a multi-terminal element, as shown in Figure 3.1.

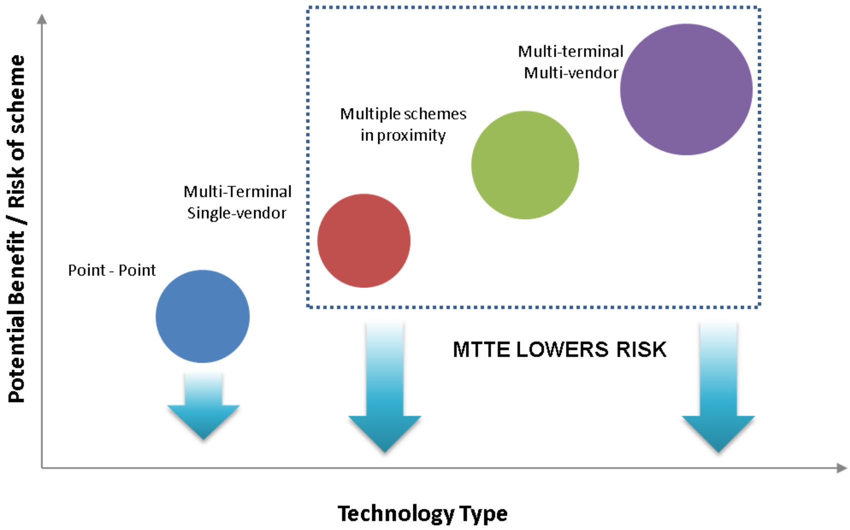

Figure 3.1The MTTE will reduce the level of risk associated with all HVDC projects in GB, especially those with a multi-terminal element. Note: the indicated benefit/risk levels are representative only.

Financial Benefits of MTTE

TNEI Services Ltd (TNEI) has produced a report for Scottish Enterprise on the background to and the benefits of the MTTE. As part of this work, TNEI has investigated the European market and comparative industries to evaluate the potential financial benefits of the MTTE.

Their report concludes that:

- The MTTE will encourage competition (both new entrants, and facilitating multi-vendor solution), and this is likely to drive down costs.
- The MTTE will assist in de-risking future HVDC solutions by mitigating technical risks, and that this will reduce the cost of risk for individual projects.
- The MTTE will increase reliability and availability of HVDC links by enabling operational issues to be solved more quickly and mitigating operational risks, leading to a reduction in constraint costs (e.g. Borwin Alpha suffered from significant delays during the commissioning stage).

To estimate the financial benefit of the MTTE, we also need to estimate the total planned expenditure on HVDC infrastructure in GB. We will consider the period from 2015 to 2030. In National Grid's Electricity Ten Year Statement (2012), they consider 3 scenarios: Slow Progression, Gone Green and Accelerated Growth; for the purposes of this submission we will consider the 'Slow Progression' and 'Gone Green' to assess the potential financial benefits, [refer to Appendix I for an extract of the Gone Green scenario]. Based on these scenarios, National Grid is anticipating the following new HVDC links between 2015 and 2030:

	Slow Progression Scenario	Gone Green Scenario	Accelerated Growth
Point-to-point HVDC Links	20	37	45
Multi-infeed or Multi-Terminal Locations*	7	14	18
New International HVDC Interconnectors	2	4	6
Total (Point-to-Point + Interconnectors)	22	41	51

Table 3.2 Anticipated proliferation of HVDC infrastructure between 2015 and 2030 in the three UK Future Energy Scenarios considered in National Grid's Electricity Ten Year Statement 2012

*Number of locations where multiple new links terminate at the same location, and therefore either:

- There will be co-located converter stations (i.e. multi-infeed), with the associated complex interactions and risks; or
- There is an opportunity to have a multi-terminal system (e.g. instead of 2 point-to-point links requiring 4 converter stations, a multi-terminal solution would only need 3 converter stations).

Project Business Case cont.

Rationalised System Designs

In addition, the MTTE will facilitate the move to more multi-terminal HVDC schemes. This can be thought of as 2 point-to-point links (requiring 4 converters) being replaced by one 3 terminal system (requiring only 3 converters). There are obviously a large number of factors which need to be considered before TOs will have the confidence to make this change. However the outputs from MTTE will inform and contribute toward this process.

System Optimisation

The MTTE will allow the interaction between the HVDC and existing AC networks to be carefully studied and new operational scenarios can be modelled to allow system performance to be optimised. This could lead to reduced losses and increased efficiency for both the DC and AC networks, both of which will lead to reduced costs.

All of the above will lead to reduced costs for all GB Transmission Customers.

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Section 4: Evaluation Criteria

This section should be between 8 and 10 pages.

4.1 Accelerating the development of a low carbon energy sector through the MTTE

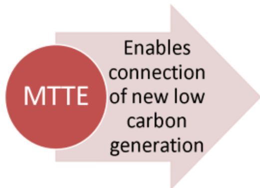
High voltage direct current (HVDC) transmission systems will play a critical role in developing future capability to connect the large renewable generation resource available in remote or offshore areas in GB. The use of HVDC cables will be essential because high voltage alternating current (AC) cables become impractical for sub-sea cables longer than 60-70km.

Seven new HVDC links are currently planned by GB TOs. Pending regulatory approval for these projects, at least two of these schemes are anticipated to involve multi-terminal interfaces, including the possible extension of the Caithness-Moray HVDC link from Caithness to Shetland as well as the Eastern HVDC link. The use of multi-terminal HVDC converter arrangements is expected to reduce overall system costs and losses compared to using a number of separate point-to-point.

The MTTE will accelerate the deployment of multi-terminal HVDC systems by helping to establish investment-level confidence in the systems for TOs/OFTOs and Ofgem. This will contribute to the development of the low carbon energy sector, which forms a key aspect of the UK Government's Carbon Plan:

> *"Over the next decade we need to continue reducing electricity generation through increasing the use of...generation from renewable sources. Alongside this, we will prepare for the rapid decarbonisation required in the 2020s and 2030s by supporting the demonstration and deployment of the major low carbon technologies that we will need on the way to 2050."*
>
> *p.9, 'The Carbon Plan: Delivering our low carbon future', Department of Energy and Climate Change, 2011*

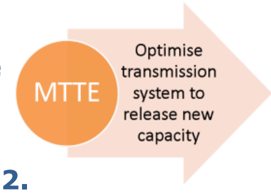
The contribution of the MTTE project to this evaluation criterion is summarised in Table 4.1



MTTE capability	Assessment of the feasibility and performance of multi-terminal and/or multi-vendor HVDC systems, providing investment-level confidence to accelerate the deployment of these systems.
Counterfactual case	The risks and uncertainties associated with multi-terminal and/or multi-vendor HVDC systems could delay or restrict the deployment of those systems in RIIO-T1 and beyond, potentially delaying the availability of connections for new renewable generation capacity.
Low carbon benefit of MTTE	The MTTE will contribute to enabling the connection of multiple renewable energy sources in GB during RIIO-T1 and beyond, supporting the delivery of the UK Government's Carbon Plan.

Table 4.1 Accelerating the development of a low carbon energy sector through the MTTE: Enabling the connection of new low carbon generation through optimised HVDC infrastructure

The MTTE will also facilitate the development of the low carbon energy sector by providing a robust case for TOs to accelerate the creation of new renewable generation capacity on the AC transmission system.



This contribution from the MTTE project is summarised in Table 4.2.

MTTE capability	Assessment and optimisation of the control, protection, interaction and operational issues associated with HVDC and AC systems, in a realistic simulated environment.
Counterfactual case	Power flow optimisation by TOs in HVDC and the associated AC systems would take place heuristically over a longer period during live operation of those systems, delaying the release of any additional renewable generation capacity and entailing sub-optimal conservative operating regimes over a longer period.
Low carbon benefit of MTTE	Provision of evidence to enable TOs to expand the capacity available to connect renewable generation on the existing AC transmission system.

Table 4.2 Accelerating the development of a low carbon energy sector through the MTTE: Optimising transmission system performance to release capacity to connect low carbon generation

While the contributions from the MTTE project summarised in Table 4.2 will not release network capacity directly, they will be a key enabler of multi-terminal and multi-vendor HVDC developments in GB. There is currently limited international experience of multi-terminal HVDC systems; they present a new range of challenges and risks. The MTTE offers a collaborative facility for GB Transmission Licensees to address these challenges and risks, enabling the delivery of cost-effective transmission system capacity to connect planned offshore renewable generation in GB.

4.2 Delivering value for money for electricity transmission Customers through the MTTE

The outputs of the MTTE would impact on the operations of all of the GB TOs, since each of the TOs are currently planning to develop large-scale HVDC links in GB (e.g. the Western HVDC Link is being built by NGET and SPT; and SHE Transmission, SPT and NGET are developing the Eastern HVDC Link Project).

The MTTE outputs would also impact on the operation of GB OFTOs, since they will own and operate offshore transmission infrastructure connecting new offshore renewable generation projects; a large proportion of this infrastructure will be based on HVDC technology or affected by other HVDC transmission infrastructure.

This cross-sector applicability of the MTTE outputs offers economies of scale for transmission Customers. Furthermore, the MTTE will deliver value for Customers both during the 4-years of operation and over the lifetime of the MTTE once the viability and effectiveness of the MTTE has been demonstrated. In addition to these broad benefits, the MTTE will deliver value for money to transmission Customers in several specific respects which are discussed in Tables 4.3, 4.4 and 4.5 below.

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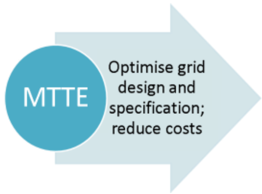
Evaluation Criteria cont.

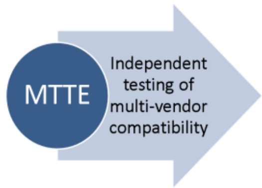
The first specific source of value is the provision of improved information for stakeholders such as TOs and Ofgem about the design and specification of future HVDC transmission systems in GB. This is discussed in Table 4.3.



MTTE capability	Assessment of the control, protection, interaction and operational issues associated with future multi-terminal and/or multi-vendor HVDC transmission systems in a wider range of operational scenarios than would be accessible during conventional commissioning tests.
Counterfactual case	Future multi-terminal HVDC development in GB will be informed by limited experience of a small number of traditional point-to-point HVDC links. This could limit the ability of TOs to specify detailed requirements and negotiate technical details with suppliers. An understanding of the operational characteristics of HVDC systems will be gained in GB by gradually increasing the operational envelope of live assets while protecting the integrity of HVDC assets such as cables.
Value provided by MTTE	Simulation of a wide range of operational scenarios for future HVDC systems in GB, leading to cost efficiencies through optimised specification and design.

Table 4.3 Delivering value for money through the MTTE: Optimised planning and specification of future HVDC systems in GB

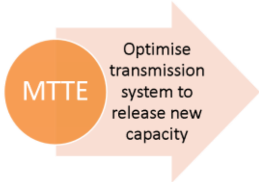
The second specific source of value is the potential to enable cost savings through the implementation of HVDC system elements from multiple vendors. This is discussed in Table 4.4.



MTTE capability	Independent demonstration and evaluation of the compatibility between HVDC control systems provided by different vendors.
Counterfactual case	Uncertainty over the compatibility between HVDC control systems provided by different vendors may prohibit the development of multi-terminal HVDC systems.
Value provided by MTTE	Contribution to enabling the procurement of different elements of HVDC schemes from multiple vendors, potentially leading to cost efficiencies (the TNEI report summarised in Appendix XII confirms the potential for multi-vendor cost efficiencies).

Table 4.4 Delivering value for money through the MTTE: Facilitating multi-vendor HVDC solutions in GB

The MTTE will also contribute to optimising the performance of new HVDC network capacity in GB. This specific source of value is discussed in Table 4.5.



MTTE capability	Provision of information to support performance optimisation of HVDC systems in GB, including their interaction with AC systems.
Counterfactual case	Performance optimisation of HVDC systems and the associated AC systems would be heuristic, taking place over a longer time period.
Value provided by MTTE	Potential cost efficiencies through reduced losses and increased HVDC asset utilisation. For example, potential HVDC links in northern Scotland with a common terminal could be transmitting energy produced by different renewable energy sources with widely varying output characteristics, necessitating a conservative operational approach for the HVDC links. Using the MTTE to understand the possible HVDC system interactions could facilitate operational approaches that would increase the level of HVDC asset utilisation.

Table 4.5 Delivering value for money through the MTTE: Optimising the performance of HVDC systems in GB

Further details about the motivation and benefits of the MTTE are provided in Section 3 of this document.

The value attributable to the transmission system versus elsewhere

All of the activity in the MTTE will result in benefits to Transmission Customers, as described in Section 3.4. In particular:

- Improved transmission system planning involving complex HVDC systems at the MTTE will enable optimisation of their performance from the outset, potentially in the form of improved resilience, reduced losses and greater transfer levels, leading to cost savings for Customers;
- Detailed simulation of HVDC system performance at the MTTE will enable TOs to more accurately specify requirements for future HVDC systems, which is expected to ensure value for money in procuring those systems; and
- The MTTE will facilitate the move to multi-terminal HVDC schemes in GB, which could reduce project costs by reducing the number of converter stations when compared with separate point-to-point solution(s).

A report prepared by TNEI for Scottish Enterprise (and summarised in Appendix XII of this document) confirms the potential ability of the MTTE to deliver cost savings for transmission Customers in these areas.

The outputs from the MTTE will also be of interest to other stakeholders, such as renewable developers, research organisations, academia and manufacturers. However, any additional work specifically commissioned by these groups, will be subject to reaching suitable commercial arrangements.

Delivering the MTTE at a competitive cost

We have selected project participants using the following approach:

- Leveraging our existing framework agreements with potential suppliers to ensure value for money;

- We intend to implement formal collaboration agreements with the three main European HVDC equipment suppliers at an early stage of the MTTE project; and
- We will adopt a competitive tendering process, ensuring value particularly for the major cost items (i.e. RTS system and civil costs).

4.3 Generating knowledge for all Network Licensees at the MTTE

The GB Transmission Network Licensees comprise the 3 Transmission Owners (TOs) together with the Offshore Transmission Owners (OFTOs), and the System Operator, NETSO. At present there are four HVDC schemes in operation in GB, each an interconnector, with one more embedded scheme in construction and many more at the planning stage. The geographical nature of GB implies close proximity between much of the associated infrastructure and hence the need for co-operation and coordination between the TOs/NETSO in planning and operating this infrastructure.

There is a need for a facility such as the MTTE to provide a focus for the investigation of the interactions which will be encountered in the future where there likely to be a significant number of HVDC schemes connected to the GB network (further details about this need are provided in Sections 2.2 and 2.3). Although the MTTE is driven by SHE Transmission in the first instance due to the large number of potential HVDC schemes in its area, all of the TOs will be able to use the MTTE facility and ultimately benefit from the work of the MTTE. Experience from Manitoba, Canada and elsewhere in the world has shown that the conjunction of HVDC converter stations (such as those planned in the northeast of Scotland), testing and simulation facilities (such as the MTTE), and cooperation with manufacturers and academic institutions creates a strong centre of excellence. This effect encourages detailed investigation of the phenomena related to HVDC systems and promotes innovation in new control and protection techniques.

The testing of manufacturers' control and protection systems in the MTTE will require the protection of manufacturers' background intellectual property rights. This will be assured by the operating protocols implemented in the MTTE facility. However, the wider knowledge gained from the study of the operation of multiple HVDC converters in close proximity on the AC network will be shared among the stakeholders of the MTTE.

4.4 The innovative nature of the MTTE and the need for an NIC project

The innovative nature of the MTTE

The proposed MTTE is a highly innovative facility with sophisticated testing and simulation capability. Centres such as, the Manitoba HVDC Research Centre and the Institut de recherche d'Hydro-Québec in Canada, have demonstrated how HVDC facilities can de-risk and facilitate the development of HVDC (in Canada).

The key benefit of the MTTE compared to similar work underway across the world is its tailoring and dedication to the needs of the GB Transmission System and its future development. This focus on modelling the interaction between the GB Network and future HVDC systems will provide essential confidence in the validity of the results for TOs and for Ofgem. The MTTE would provide the GB TOs with a dedicated, openly accessible and long term source of learning in relation to HVDC and the associated AC transmission systems.

The Electric Power Research Institute (EPRI) in the U.S. also has a broad HVDC Transmission research programme*. Our consultation with research and development organisations such as the Power Networks Demonstration Centre (PNDC) and EPRI supports our conclusion that the capabilities of the MTTE would be unique and innovative.

**Further details about the EPRI's HVDC Transmission (Program 162) are available at http://portfolio.epri.com/ProgramTab.aspx?sId=pdu&rId=263&pId=7558*

As described in detail in Section 2.4, the main innovative aspects of the MTTE include:

- The capability to test accurate replicas of hardware;
- The capability to study multiple HVDC converters in close proximity (multi-infeed condition) and multiple HVDC converters connected on the DC side (multi-terminal condition);
- The capability to enable study of any part of the GB network, and the impacts and interactions of HVDC schemes; and
- The ability to use MTTE for long term operational planning and optimisation of the GB Transmission Network.

The need for NIC funding to develop the MTTE

We selected the MTTE for submission for NIC funding due to its close alignment with the objectives of the SHE Transmission Innovation Strategy* and with the requirements identified in the NIC governance document. We held a number of internal workshops to identify, score and prioritise potential NIC projects and undertook significant external engagement to ensure that it aligned with the needs of the GB Transmission Operators as well as other industry stakeholders.

** p.3-4, 'Our Innovation Strategy', Scottish Hydro Electric Transmission Limited, 2012. Available at http://www.ssepd.co.uk/uploadedFiles/Controls/Lists/Resources/Compliance_report(1)/RIIOT1_2011_SHETL_InnovationStrategy_v290711.pdf*

The MTTE will facilitate the planning and simulation of HVDC systems in order to establish investment-level confidence in the design, control and operation of future multi-terminal and/or multi-vendor HVDC schemes in GB and in their interaction with the existing Transmission Network. Without the MTTE, it will be very difficult for TOs to move away from the better-understood, lower-risk, though potentially sub-optimal option of single-vendor point-to-point HVDC solutions.

The MTTE is a collaborative facility which would provide a valuable resource for all Transmission Licensees across a range of proposed future HVDC developments in GB. This approach will avoid the requirement for each individual HVDC project to replicate the proposed functionality of the MTTE on a project-by-project basis, providing substantial economies of scale for GB transmission Customers. The collaborative nature of the MTTE will also enable all Licensees to benefit from the knowledge gained from multiple projects in a shorter timeframe than if this work was done on an individual project basis.

Achieving these economies of scale requires funding and investment beyond that required to achieve the same outputs for a single HVDC project in isolation. It would be very challenging for any single proposed HVDC project (e.g. the Eastern HVDC Link) to justify establishing an equivalent to the MTTE at a sufficiently early stage and with sufficient functionality to adequately inform the project. In addition, the uncertainty that affects large infrastructure projects such as HVDC links means that TOs are not in a position to provide the upfront funding required for a facility such as the MTTE.

As a result of these factors, we believe that the costs, risks and benefits of the MTTE should be spread across the Transmission Licensees and HVDC projects, and that the NIC provides an appropriate mechanism to do this. There are also a number of commercial and technical risks associated with the project [refer to Appendix X for details], which makes innovation funding appropriate.

4.5 The involvement of other partners and external funding in the MTTE

A summary of the roles, benefits and contributions of partners in the MTTE project is provided below.

Transmission licensees (SP Transmission, National Grid Electricity Transmission and Offshore Transmission Owners (OFTOs))

- **Role** The licensees, along with any combined HVDC project teams (e.g. the Eastern HVDC Link project team), will be able to commission studies by operational MTTE staff, and can provide replica control panels from their HVDC links to the MTTE. During the NIC-funded period of operation (i.e. the first four years) the licensees would agree the programme of work for the MTTE through the collaborative management structure. The roles of SPT and NGET will be formalised through collaboration agreements.
- **Benefit to Partner** The licensees will be able to de-risk their grid development strategies by understanding the impact of HVDC developments on the wider network. They will be better equipped to accurately specify HVDC schemes, de-risking the procurement process.

Benefits for Offshore Transmission Operators

- Much of the above will also be of benefit to Offshore Transmission Operators in the design of the infrastructure for connecting the renewable generation to the GB Network. From National Grid's Ten Year Forecast ['Electricity Ten Year Statement 2012'] there are a number of potential OFTO connections which could be developed as multi-terminal solutions.

GB System Operator (NETSO)

- **Role** Able to commission studies by operational MTTE staff.
- **Benefit to Partner** Outputs from the MTTE will improve the NETSO's understanding, control and operation of GB's current and planned HVDC infrastructure.
- **Contribution** Project development and ongoing involvement in the MTTE management structure.

Interconnector owners

- **Role** Able to commission studies by operational MTTE staff.
- **Benefit to Partner** Implementation of recommendations and other outputs from the MTTE would reduce the risks of adverse control interactions and harmonic instability of HVDC interconnectors. The outputs could also enable optimisation of interconnector performance (i.e. relating to power flow and reduced losses).

Renewable energy generation developers

- **Role** Able to commission studies by operational MTTE staff.
- **Benefit to Partner** Studies undertaken in the MTTE could inform the needs cases and specifications for HVDC links that would enable the associated offshore renewable generation projects to proceed. Where this enables the HVDC infrastructure to be delivered at a lower cost, this would reduce the cost of the infrastructure to the OFTOs which would flow as a benefit to transmission Customers. In addition, implementation of recommendations and other outputs from the MTTE could reduce the risks of adverse control interactions and harmonic instability for HVDC links to offshore renewable generation.
- Larger scale offshore windfarm developments will use HVDC within the windfarm networks. The design and configuration of these systems can be studied and optimised in the MTTE. Suitable access arrangements and charges will be put in place to ensure that generators pay an appropriate cost for use of the MTTE.

Main HVDC vendors

- **Role** The European HVDC market is currently dominated by three main suppliers. Our consultation with them has established their intent to participate in the development of the MTTE (refer to Appendix VII for more details).
- **Benefit to Partner** The testing and modelling work at the MTTE will facilitate the progression to multi-vendor HVDC schemes in GB, and enable the participating suppliers to supply those multi-vendor schemes

Other participants in the energy supply chain

- **Role** Other suppliers may want to use the MTTE to test the control interactions of their equipment (e.g. generator turbine control systems, HVDC breakers, converter stations from emerging suppliers). This testing could increase diversity and competition in the HVDC equipment supply market, which will ultimately benefit transmission Customers.
- **Benefit to Partner** Access to a unique specialised testing facility.

Research & development organisations

- **Role** R&D organisations including the PNDC and EPRI have expressed their interest in collaborating in the development and subsequent operation of the MTTE and potentially in commissioning MTTE studies.
- **Benefit to Partner** The primary benefit of collaboration between the MTTE and R&D organisations would be the exchange of relevant knowledge, guidance and expertise.

Academia

- **Role (1)** The MTTE requires expertise to develop and validate the simulation models of both HVDC components and the AC Network, and intends to engage with a consortium of academic institutions (with leading HVDC expertise) to deliver this.

- **Role (2)** In addition, there is an opportunity for our academic partners to utilise the MTTE to undertake HVDC research which is useful to the Network Licensees, and help develop the expertise within the MTTE. This will be dependent on reaching suitable agreements to avoid compromising the other MTTE activities.
- **Benefit to Partner** The participating academic institutions will benefit from access to the MTTE's Real Time Simulator capability, which could support PhD-level work.
- **Contribution** In response to our Request for Information (RFI), each academic institution proposed in-kind contributions to the MTTE.

Scottish Enterprise

- **Role** As part of its objective to promote Scotland as a hub of expertise in offshore renewables, Scottish Enterprise have commissioned a study to help them gain a greater understanding of the role of HVDC in the future..
- **Benefit to Partner** Scottish Enterprise has engaged TNEI Services to estimate the benefit to the Scottish economy of encouraging greater HVDC expertise and development activity in Scotland.

Local Authority

- **Role** We have commenced discussions with local authorities of potential locations for the MTTE.
- **Benefit to Partner** Local job creation and indirect benefits of attracting a community of expertise to the area.

The MTTE has been developed to ensure that the benefits delivered are relevant to GB Transmission License Holders either TOs or OFTOs. This is to ensure that best value is achieved from this use of Customers' money.

Other stakeholders (such as renewable developers) will only be able to access the MTTE subject to agreeing suitable commercial arrangements. This will ensure best value for GB Customers.

4.6 The relevance of the MTTE

Our duties as a Transmission Licensee include:

- The development and maintenance of an efficient, coordinated and economical system of electricity transmission;
- Facilitating competition in the supply and generation of electricity; and
- Having due regard for preservation of amenity.

We believe that focussed, purposeful innovation is central to performing these duties effectively. The MTTE demonstrates this benefit of innovation.

The primary area of business planning which would benefit from the MTTE is the increasing requirement for SHE Transmission and the other GB TOs to provide network capacity for new renewable energy generation, which is being driven by the move to a low carbon electricity sector in GB*. Over the coming decade we expect to significantly expand our transmission network to facilitate the growth of renewable generation in the north of Scotland. The use of multi-terminal HVDC systems could form an important part of this expansion in our network and of similar investments undertaken by other GB TOs.

The learning generated by the MTTE will provide an essential step change in enabling SHE Transmission and the other TOs to assess the potential impact of future HVDC systems on the network prior to implementation, and to account for this impact in business planning. This benefit is particularly valuable given the high cost, complexity and novelty currently associated with the construction of multiple HVDC systems in GB. In addition, the improved information available from the MTTE about both short and long-term HVDC asset condition will support better informed transmission system planning. The MTTE will also provide TOs with additional knowledge to ensure optimum performance of HVDC systems and the associated AC system. The outputs from MTTE are expected to allow TOs to increase efficiency and reduce losses whist maintaining system security and stability.

These benefits of the MTTE for our business planning will feed through to accelerate the cost-effective integration of increasing amounts of renewable generation in GB.

**The UK Government's Carbon Plan suggests that 60–80 GW of new electricity capacity will need to be built by 2030, with renewable electricity potentially providing 35-50GW by 2030, representing a major expansion in the UK's renewable electricity generation capacity. See p.72-73, 'The Carbon Plan: Delivering our low carbon future', Department of Energy and Climate Change, 2011.*

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Section 5: Knowledge dissemination

This section should be between 3 and 5 pages.

☐ Please cross the box if the Network Licensee does not intend to conform to the default IPR requirements.

5.1 Introduction

Effectively capturing and disseminating learning, both internally and externally, is a critical aspect of innovation projects undertaken by SHE Transmission. In order to achieve this in innovation projects, we adopt clear learning objectives supported by established knowledge management principles and procedures. The following subsections discuss our approach to this process in the case of the MTTE project.

5.2 Clear learning objectives for the MTTE project

SHE Transmission takes a structured approach to learning capture by setting high level learning objectives, supported by a detailed breakdown of interim steps required to fulfil each objective. The following learning objectives have been set for the MTTE project:

- **Support Transmission Planning of HVDC schemes**: The MTTE will produce analysis and reports on the development scenarios investigated, and will share these the other TOs/OFTOs to increase the understanding of the impact of HVDC development scenarios on the existing network. In addition, the models developed will be shared with Network Licensees.
- **Improve Requirement Specification of HVDC schemes**: The MTTE will produce analysis and reports advising Network Licensees on the specification of HVDC schemes, and these will share these with the other TOs/OFTOs to increase the understanding of specifying requirements for HVDC schemes.
- **Facilitate Multi-Terminal HVDC solutions:** The MTTE will produce analysis and reports on the Multi-terminal scenarios, and will share these with the other TOs/OFTOs to increase the understanding of Multi-Terminal HVDC.
- **Facilitate Competition and Multi-Vendor HVDC schemes**: The MTTE will produce reports on multi-vendor compatibility to inform the development of HVDC standards and interoperability. Acceptance testing reports will also be produced.
- **De-risk Control interactions between co-located and electrically connected converters, and with other active controlled equipment**: The MTTE will produce reports on the impact of planned HVDC systems, providing detail on any control interactions with converter stations in close proximity and active controlled equipment. These reports will be shared with all Licensees to improve sector-wide understanding of the associated issues. This would include reports on the integration of generators into HVDC networks and the associated risk of adverse control interactions and their control protocols and strategies.
- **Train Transmission Planning and Operational Engineers**: The MTTE will produce training material which will be available to all Transmission Licensees.
- **Undertake Post commissioning scenario planning and operational optimisation**: The MTTE will produce recommendation reports on specific HVDC schemes to enable optimisation which will be shared with all Licensees.

Knowledge dissemination continued

- **Model New HVDC Technologies**: The MTTE will produce analysis and reports on the performance, impact and interactions of new HVDC technologies or active controlled devices in accurately simulated GB situations and their suitability for specific applications / locations.

Appendix III provides details about the specific activities at the MTTE that will contribute to the achievement of each of these learning objectives.

5.3 Reapplication of experience

SHE Transmission staff are aware of the need to learn from previous research; literature reviews plus stakeholder consultation will be part of the development of detailed studies to achieve the learning objectives above. This will help ensure that the MTTE outputs generate new learning; where necessary, studies and learning objectives may be refined to ensure the project builds on current knowledge rather than reproducing it.

5.4 Continual learning capture

The capture of formal technical learning - relating to the objectives above - will be supplemented by reflection on the process of project delivery in order to identify lessons learned. The project team will build a schedule of lessons learned reviews into the detailed project plan, and will refine this schedule during the course of the project. Findings from lessons learned reviews will be validated by SHE Transmission's internal Project Review Board and disseminated to relevant groups as set out below.

5.5 Targeted communication

We recognise that different groups will have different interests in the learning generated by the MTTE and that dissemination is most effective when the messages and methods are tailored to the audiences' needs. Our dissemination will focus on the following groups, using the methods outlined below:

GB Transmission Owners (TOs) and Offshore Transmission Owners (OFTOs)

GB TOs are the primary audience for learning from the MTTE project because they operate the existing AC grid and over time, will procure, own and operate an increasing number of HVDC systems in various configurations. Learning outcomes from the MTTE will help them to understand how multiple HVDC systems will perform individually, interact with each other and what their combined impacts will be on the AC grid. Results from modelling the impacts of different HVDC options and testing different manufacturers' systems will enable informed procurement and operational decisions. The project will enable TOs to build on each others' learning and work towards specifying consistent requirements in a standardised way.

Similarly, OFTOs will be interested in the results from studies relating to their own HVDC systems, and systems they may choose to procure. Both groups will be interested in the opportunities for learning through evaluating the impacts of potential changes or extensions to existing HVDC systems.

Knowledge dissemination continued

National Electricity Transmission System Operator (NETSO)

National Grid is the TSO for GB as well as a TO. In its role as TSO, National Grid will be interested in MTTE learning from a number of perspectives, including understanding network availability, optimisation, performance and redundancy, asset life and future scenarios relating to HVDC systems.

Developers of standards and network codes

Test results from the MTTE will provide a valuable input to inform the process of standards development, by identifying parameters to which systems will need to conform. The key groups to communicate with here are CENELEC (European Committee for Electrotechnical Standardization), the IEC (International Electrotechnical Commission), CIGRE (International Council on Large Electrical Systems, specifically its Study Committee B4 HVDC and Power Electronics) and ENTSO-E (European Network of Transmission System Operators for Electricity, responsible for developing HVDC network codes).

Academics

Academic involvement in the development and execution of the MTTE work programme will ensure that the adopted methodology is robust and that the results have validity. Learning from the project will in turn influence the direction of applied and fundamental HVDC research as potential problems and areas for improvement in current technology are identified by MTTE studies.

Generators

Generators connecting to the grid via HVDC systems will be interested in the requirements and development of standards for HVDC systems, since they are responsible for ensuring their equipment meets these specifications.

Vendors

For HVDC Vendors to offer commercial products meeting the GB network operators' needs, they need to receive specific requirements communicated in a clear way. Learning - in the form of refined requirements to be used in the procurement process - is therefore of significant interest to suppliers. In addition, suppliers will be able to use learning from MTTE test programmes to evaluate and validate their products' performance under a range of operating conditions, including interactions with other systems.

Government and Regulators

While not a primary target audience for learning, a general overview of the outcomes from the MTTE test programme, in particular the standards developed, will be of interest to policy makers and Ofgem. This is because validated results regarding the performance and impacts of HVDC systems will give these groups improved confidence to approve plans put forward by network operators.

5.6 Dissemination methods

We know that dissemination brings the most benefits to all parties when it is interactive rather than one-way, and that personal communication and direct experience are some of the most powerful tools for sharing/assimilating learning. Our proposed methods reflect these principles:

HVDC Operators' Forum

An operators' forum will be set up to provide a platform for knowledge exchange between relevant GB network licensees. All TOs and OFTOs will be entitled to membership for the duration of the project. It will be run in a similar way to the Energy Storage Operators Forum scheme managed by EA Technology Ltd. and will build on Scottish and Southern Energy Power Distribution Limited (SSEPD)'s experience of delivering and participating in knowledge sharing activities for network innovation projects [SSEPD is the holding company of SHE Transmission].

Regular events, with space for formal and informal discussions, will create an environment conducive to open exchange and will allow personal contacts to be built up, promoting knowledge sharing beyond events.

For members, the forum will offer:

- At least 3 events per year, each consisting of a minimum one day programme of talks/interactive sessions and/or site visits with practical demonstrations and an evening meal. Events may feature input from 'guests' with relevant specialist knowledge. At least one event per year will include an opportunity for knowledge exchange with suppliers.
- All published outputs from the MTTE test programme
- The opportunity to request specific studies/tests based on their interests
- Access to a secure online area of the project website which will host:
    - Broadcast of talks from events as live webcasts;
    - Multimedia and written outputs from events including notes on discussions;
    - Monthly updates on project progress (development of centre and studies);
    - Knowledge assets from programme of studies to fulfil learning objectives; and
    - An online discussion area.

Events

The MTTE Centre will host a launch event in early 2017 and an annual showcase in each subsequent year to provide all stakeholders with an overview of the facilities and key learning from the development and execution of the detailed studies. The last event will also launch the next phase of the centre's operation, as a commercial entity. Additional presentations will be made at other suitable conferences and trade events including the NIC annual conference.

Website

A website will be created for the MTTE project. As well as the secure area for HVDC Operators' Forum members (see above), this will have a public-facing area to provide general information about the project, centre and non-confidential knowledge assets, including academic papers and presentations.

Knowledge dissemination continued

Training

Dissemination through training is an important aspect of SHE Transmission's innovation projects. The MTTE project will include development of hands-on training activities and supporting resources (e.g. procedures, work instructions, models and e-learning courses) for:

- System planners: modelling and testing potential and proposed systems/scenarios;
- Control room staff: software focussed - system operation, witness testing procedures; and
- Operational units: hardware focussed - field operation and maintenance.

Training in these areas will also be delivered via HVDC placements offered through SSEPD's existing development programmes for students, graduates and trainee engineers. The centre will also enable academic partners to offer PhD studentships on HVDC topics, although they will be responsible for sourcing studentship funding.

Participation in HVDC standards development groups

We will disseminate learning from the MTTE test programme by active participation in the activities of relevant HVDC working groups and committees in GB. Sharing learning via these established channels will ensure the learning is incorporated in international standards and can ultimately be accessed by industry participants worldwide.

5.7 IPR Arrangements

The project will conform to the default IPR arrangements. It is not expected that this project will generate Relevant Foreground IPR which it would be appropriate to protect through registration, other than copyright.

Dissemination for this project has been planned to meet the twin requirements of providing access to learning to all interested parties above, while protecting the background IPR of suppliers providing replica control panels for use in the centre.

Relevant foreground IPR will consist of:

- Results of modelling studies and tests published as papers; and
- Requirements which can be used in the specification of HVDC systems.

All relevant network licensees will be able to access publications detailing this IPR. Suppliers will be provided with access to publications detailing the results of studies involving their own systems. Background IPR relating to individual HVDC control systems will not be needed to utilise this Foreground IPR. Background IPR will therefore be retained by suppliers. The physical arrangement of suppliers' equipment within the MTTE centre, the design of the IT system architecture and the centre's operational procedures will have control measures built-in to protect the security of background IPR. Suppliers will be consulted on these measures, which will also be independently assured.

Subject to reaching suitable commercial arrangements third parties will be able to commission and fund work at the MTTE. These commercial arrangements will include for IPR and will be outwith the default IPR arrangements.

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Section 6: Project Readiness

This section should be between 5 and 8 pages.

Requested level of protection require against cost over-runs (%):

0%

Requested level of protection against Direct Benefits that they wish to apply for (%):

Default: 50%

6.1 Project Readiness Summary

Overall the MTTE is poised to start, with all of the key stakeholders ready to participate, the resources and project framework in place, and the project planning at an advanced stage.

The MTTE project will be delivered using SSE's Major Projects Governance Framework (tailored for Innovation projects), with the Innovation Steering Board as the Project Board and Stewart Reid (Future Networks Manager) as the Project Director.

6.2 Project Start

The MTTE project has already started; it has passed Gate 0 and Gate 1 as defined in the Governance Framework. Key roles within the delivery team have already been filled and we are fully prepared for the transition to full project delivery upon award of NIC funding.

The MTTE project is supported at every level within SHE Transmission. The project board includes members of the senior management team including Mark Mathieson (Managing Director of Networks), each of whom is actively committed to the successful delivery of the project.

The project team includes:

- Project Director: Stewart Reid (Future Networks Manager)
- Project Development & Stakeholder Engagement: Frank Clifton
- Project Manager: Simon Marshall (HVDC R&D Lead for SHE Transmission)
- IT & RTS Lead: Henrik Magnusson
- Business Analysis: Casey Bauchope
- Building & Facilities Lead: Peter Lodge
- Recruitment & Training Lead: Sarah Anderson
- MTTE Work Programme Lead: Roddy Wilson
- Learning & Dissemination Lead: Jenny Rogers
- MTTE Operations Lead: Andrew Robertson
- Legal: Debbie Harding
- Regulation: Beverley Grubb
- Finance: Steve Kennedy/ Davina Button
- Corporate Affairs: Greig Clarke
- Procurement & Commercial: Carl Lappin
- NGET Lead: Paul Coventry
- SPT Lead: James Yu

The availability of the above resources to start in January 2014 has been agreed.

The project team will primarily be based in SHE Transmission's offices in Perth.

Based on this, we do not anticipate any issue with starting the project on schedule.

6.3 Cost Estimates

We adopted the following process to ensure that the cost estimates included in this proposal are robust:

- The functional requirements were defined with input from across the project partners (e.g. this included identifying the specific studies and activities that SHE Transmission, NGET, SPT and other Network Licensees would perform in the MTTE).
- Based on the functional requirements, the technical and non-technical requirements were developed (in consultation with SHE Transmission's IT department and Major Projects construction specialists, together with external RTS system suppliers).
- We costed each element of the technical and non-technical requirements based on internal experience or external quotations.

6.4 Minimising cost overruns

The MTTE project costs fall into three main categories:

- Resourcing - which includes internal resource, external support and MTTE staffing costs;
- IT - including RTS system;
- Building and facilities; and
- HVDC Control and Protection Equipment.

Our approach to minimising cost overruns in each of these categories is discussed below.

Resourcing

- External support will be capped, to ensure that there is no overspend.
- The MTTE will recruit up to 5 FTEs, and their costs have been benchmarked with similarly skilled roles.

IT

- For IT costs, we have sought quotes from the RTS suppliers to ensure that we have robust estimates.
- For the IT infrastructure costs, we have undertaken a detailed review of these requirements and estimated the associated costs based on experience of similar projects. The majority of these would then be supplied through SHE Transmission's IT framework contracts, which increases cost certainty.

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Project Readiness continued

Site/Building

- Facilities / Operation – we have included appropriate costs for utilities, security, IT support etc.

HVDC Control Panels

- Based on estimates received from expert advisors we have estimated the costs of the control panels required in order for the MTTE to deliver its initial objectives.

6.5 Benefits Estimates

We have adopted the following process to estimate the benefits of the project:

- Within the internal project team, we estimated the potential benefits.
- We identified the limitations of our own estimates and asked Scottish Enterprise to engage with external consultants to provide an independent view of the potential benefits.
- We then sense-checked these with the MTTE project partners and validated them with our external technical advisor.
- Since the benefits are mostly indirect, they are considered accurate to with +/-50%.
- In general we have taken a very prudent view in estimating the potential benefits that the MTTE will enable. However, even in the worst-case scenario of maximum cost and minimum benefits, the project still has a strong business case.

6.6 Minimising shortfalls in direct benefits

Given the nature of the project benefits, there are no direct benefits.

6.7 Quality Plan

All information contained in this proposal (incl the Appendices) has gone through the following process to assure validity and accuracy:

- Peer review;
- External expert review;
- Internal management review; and
- Partner review (NGET & SPT).

6.8 Impact of Lower Renewables Take-Up

The benefits of this project are based on the central assumption that GB Transmission Licensees will invest in HVDC technologies over the coming years. Given the number of planned GB HVDC projects this is considered a safe assumption.

However, if planned offshore renewables are not constructed, then that will lessen the needs cases for future HVDC projects, and if these projects do not proceed, then that would erode the anticipated benefits from the MTTE.

6.9 Process for Suspending the Project

The project will be managed through a gated project management process, and at each Gate the project feasibility and risks will be reviewed and a decision taken on whether to proceed.

Furthermore, the regular Risk Review workshops may escalate a significant risk or issue that requires a decision on the feasibility of the project.

Any resulting proposed change to the project or request to suspend the project would then be submitted to Ofgem for approval.

6.10 Cross-Sector

This project is not part of a cross-sector project.

6.11 Collaboration Agreements

The MTTE project is a collaborative project with the other TOs (i.e. National Grid Electricity Transmission and Scottish Power Transmission) but is being led by SHE Transmission.

The three TOs have been collaborating on jointly developing the NIC proposals through a series of meetings and workshops. This has provided a valuable forum to share ideas and help ensure that the projects being developed will benefit each of the TOs.

We have endeavoured to engage will all active participants in the HVDC marketplace, confirming that there is significant interest in this proposal, and have held a number of collaborative workshops with the potential partners to develop the project scope.

It is our intention to develop a formal Collaboration Agreement with SPT and NGET for the delivery and operation of the MTTE project.

Supply Chain / Manufacturers

We have engaged with a number of the established and emerging manufacturers to ensure that they are supportive of the project and will engage with the facility should it go ahead.

Academic Partners

As identified previously, the MTTE intends to work with a number of academic partners who have knowledge and expertise in HVDC to help deliver the programme and support the development of the simulation models. Suitable commercial arrangements will be required to be put in place to formalise these working arrangements. Working together the three TOs have engaged with a broad cross-section of the academic community to identify the appropriate level of support for the project.

Other Stakeholder Organisations

We have also engaged with a number of organisations who have a wider interest in this area, these include:

- CIGRE: To discuss working with the Cigre B4 working groups;
- EPRI: Who are providing advice and support to develop the project, with the potential of using the centre for future research projects; and
- PNDC: Who are providing advice and support (especially relevant given their recent experience building a collaborative centre), with the potential for future collaboration.

Network Licensees:

- As our project partners, National Grid (NGET) and Scottish Power Transmission (SPT) have provided Letters of Support which described their commitment and engagement to the project [refer to Appendix VII].

Vendors Engagement:

- The success of this project is dependent on the engagement with the HVDC Vendors. We have held discussions with the three of the main suppliers of HVDC technology (ABB, Alstom & Siemens), and also with potential new entrants to the market

6.12 Project Plan

A detailed project plan can be found in Appendix IX, and an overview is provided below:

The MTTE project deliver will be managed using SSE's Major Projects Governance Framework (a mandatory requirement for projects of this size within SSE).

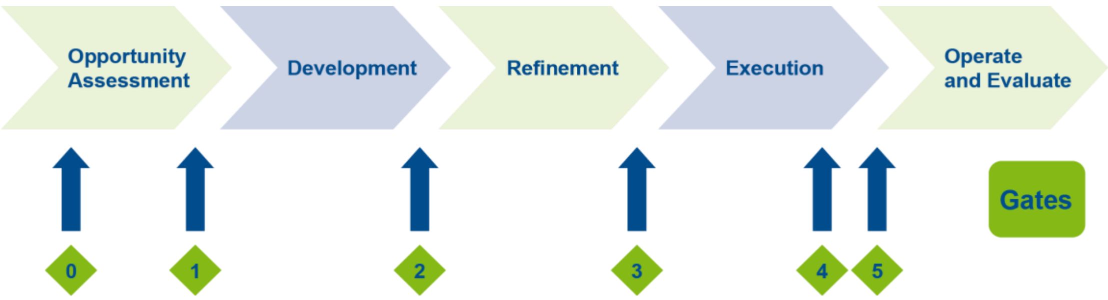

Figure 6.1 SSE Major Projects Governance: Gate Process

Project Readiness continued

The process has five phases with gate keeping as the project moves through the phases. The purpose of the gates is to ensure transparency, scrutiny and appropriate approval on project development and required deliverables. Clarity on project risks, as well as benefits will assist with business decision making.

Phase 1: Opportunity Assessment

The phase was completed and the gate passed, prior to submitting the Initial Screening Process for the MTTE.

Deliverables: Business Strategy and Regulatory fit Analysis, Cost Estimate Classification 0, Business Case, Conceptual Design and Signed-off ISP for the NIC.

Phase 2: Development

The project is currently in this phase where the project is being further assessed and defined.

Deliverables: Preliminary Site Feasibility Study, Cost Estimate Classification 1, Business Case, Project Development Plan, Governance, Development Resource Review, Project Safety Health and Environment Review, Environmental Requirements, Design Development, Technology Overview, Risk Management and Signed-off NIC Full submission document

Phase 3: Refinement (Design)

In this phase the design of the MTTE will be fully developed.

Deliverables: Health and Safety Plan, Environmental Requirements, Cost Estimate Classification 2, Business Case, Project Development, Contract and Procurement Strategy, Planning Permission and Land Options, Governance, Refinement Resource Review, Detailed Site Feasibility, Design Development Document, Risk Management Plan, Quality Management and Lessons Learned

Phase 4: Execution (Build)

In this phase the MTTE will be constructed and commissioned.

Deliverables: Health and Safety Plan, Cost Estimate Classification 3, Business Case, Operation Plan, Resource Review, Risk Management Plan, Quality Management, Lessons Learned and Testing & Commissioning Plan

Phase 5: Operate and Evaluate

4 years of operations to undertake the programme of activity within the MTTE.

This phase will conclude with the NIC project being formally closed down, the MTTE is intended to be subsequently run as a self-sustaining operation, funded by its partners and use of the facility.

Deliverables: Health and Safety Plan, Resource Review, Quality Plan, Project Handover Plan, Lessons Learned and Concluding Report

Project Gates

Six gates exist as shown in Figure 6.1, where project development, definition and key deliverables are assessed to ensure the project benefits and opportunities are being fully exploited and project risks are understood, mitigated and controlled. At each gate the deliverables are reviewed and approved by accountable individuals and teams.

Workstreams

A number of workstreams will run across the project phases:

- IT & RTS (including the RTS system, replica control panels and associate IT infrastructure);
- Building & Facilities (focusing on the building);
- Recruitment & Training;
- MTTE Work Programme (Programming study activity, coordinating pre-commission model development, and academic support);
- MTTE Operations (incl operational processes and procedures, and management structure);
- Learning & Dissemination; and
- Project management,
- Project Development & Stakeholder Engagement

Each workstream will have a workstream lead who is responsible of the delivery of the output of the workstream within each phase, coordinated by the project manager.

6.13 MTTE Organisation Model

SHE Transmission undertook a consultation with our project partners and stakeholders to understand the requirements of the MTTE organisation model. We also sought the advice of EPRI and TNEI on the organisation models of other demonstration and test centres around the world, to learn from their experience. Finally we engaged with our Legal and Regulation teams on the proposed models.

Based on these discussions we agreed that the MTTE organisation model should be based on the following principles; that the MTTE should:

- Be the long term 'home' of replica control panels provided by suppliers of HVDC projects (subject to suitable commercial agreement for each project);
- Protect the background IP of Suppliers' equipment;
- Be collaborative, and focused on delivering value to Transmission Licensees and their Customers;
- Draw on the expertise of the academic community; and

- Be able to be self-sustaining after the funded operation.

Based on the information available at present, we have decided that the MTTE organisation should be a SHE Transmission owned and operated entity, managed by a joint management team.

This enables SHE Transmission to make firm commitments to suppliers on the use and IP protection of their equipment, while ensuring the collaboration of the Partners.

6.14 Management Structure of the MTTE

The management structure of the MTTE is designed to ensure that the centre is a collaboration between the Project Partners, it will comprise:

- Senior Responsible Owner for the Centre, who will be ultimately responsible for the centre: Future Networks Manager (Stewart Reid).
- A core management team of the MTTE partners, to provide strategic direction and management oversight for the centre: comprising representatives of Transmission Licensees, bound by collaboration agreements.
- The management team will work with the stakeholders group, comprising: academic partners, related research centres, suppliers, renewables companies.
- The centre will employ a MTTE Manager, responsible for the day-to-day management and operation of the centre, who reports to the management team.
- The MTTE will employ RTS Specialist Engineers (approximately 4 FTEs) as experts in RTS simulations, to build and maintain the models, and lead the studies/tests, and who will report to the MTTE Manager.

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Section 7: Regulatory issues

This section should be between 1 and 3 pages.

☐ Please cross the box if the Project may require any derogations, consents or changes to the regulatory arrangements.

The MTTE Project will not require any derogations, exemptions or changes to the regulatory arrangements.

7.1 Strategic Wider Works

SHE Transmission is currently investigating, developing and investing in a number of large capital projects during the RIIO-T1 price control period that are anticipated to utilise HVDC technology. Due to the uncertainty associated with these projects, they are funded through the Strategic Wider Works process.

As such, funding for these projects to proceed does not form part of our base allowances and will be subject to assessment and determination by the Authority. Whilst we envisage a strong interaction between MTTE and these projects during the development, construction and operation of the assets, these projects are dependent on the outcome of the Strategic Wider Works process. One of these projects that will utilise HVDC technology, the Caithness-Moray project, is currently being assessed by Ofgem, with further projects at different stages in the assessment process.

7.2 European Network Codes

There are currently a number of network codes being developed by the ENTSO-E, on behalf of ACER, that will apply throughout the EU. One of the codes currently under development is the Network Code on HVDC Connections. It is currently anticipated that this Code will be submitted to ACER for approval by 1 May 2014. As such, the first version of this Code will be finalised prior to learning from MTTE being available and may create opportunities for MTTE to assess implications of components of the Code on the GB transmission system.

As with other Network Codes, we would expect that the Code will incorporate a modification process and anticipate learning from MTTE being used by the GB TOs to inform future versions of the Code more fully.

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Section 8: Customer impacts

This section should be between 2 and 4 pages.

No interaction is planned or expected with Customers or Customers' premises as part of this Project.

No other Customer impacts are planned or expected as part of this Project.

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Section 9: Successful Delivery Reward Criteria

This section should be between 2 and 5 pages.

The following section describes the success criteria for the project, the completion of which are key milestones and indicators of the overall success of the project.

Progress against these criteria will be monitored and reported on during project delivery.

Criteria 9.1

Formal Agreement with Project partners.

The success of this project will be crucially dependent on the involvement of Transmission Licensees and of the vendors. Therefore, an early indication of success of the project is the establishment of formal collaboration agreements with the project partners and suppliers.

Evidence:

Signed collaboration agreements with key project partners NGET and SPT by end of May 2014.

Criteria 9.2

Complete Design of MTTE Facility

The completed design of the MTTE facility, both technical design and physical design, is a key milestone for the project, and will be consolidated within the Design Development Documents. The detailed design will adhere to the requirements defined in the requirements specification.

Evidence:

Design development document and requirements specification for the MTTE facility signed-off SHE Transmission, NGET and SPT by end of May 2015.

Criteria 9.3

Design, Build and Publish Internet Site

A key component of our knowledge and dissemination plans is the utilisation of the MTTE Members Website, which provides a secure area to share these outputs with Transmission Licensees. Therefore, a key success criterion is the set-up and publishing of the MTTE members' website.

Evidence:

Establishment of the MTTE members' website by end of August 2015.

Criteria 9.4

Completion of Building Works

The completion of the site civil works and the construction of the building will represent a major milestone for the project. This date will be defined in the project plan and achieving this date will be a significant indication that the project is on track to achieve its final in-service date. Take-over will be subject to the approval of SSEPD's construction department and any relevant oversight from local government planning authorities. The snagging list will progressively be reduced to zero items, but this does not prevent the project proceeding to the next stage - the installation of equipment.

Evidence:

Completion of building works to allow the start of installation of the IT infrastructure by end of February 2017.

Criteria 9.5

Installation, Testing & Commissioning of the RTS and IT Infrastructure

The successful installation, testing and commission of the RTS and IT infrastructure of the MTTE are key to the facility's success. The testing and commissioning requirements would be developed during the design phase, to ensure that the facility meets the project requirements.

Evidence:

Installation, Testing & Commissioning and formal acceptance of the RTS and IT Infrastructure by the Project Director by end of April 2017.

Criteria 9.6

Commence Operation of the MTTE

With 9.4 and 9.5, the MTTE will be built, and the IT/RTS infrastructure commissioned. However the MTTE will also need to be resourced, with the management structure in place, processes and procedures agreed, data sets of the AC network received (from NETSO) and the plan of studies and tests agreed.

When all of these are in place, the MTTE will be able to commence operations, therefore this is a key milestone and measure of success of the project.

Evidence:

Commencement of MTTE Operations by end of May 2017.

Successful Delivery Reward Criteria continued

Criteria 9.7

Publishing Studies & Test results

The key outputs from the MTTE are the reports on specific scenarios which are completed within the MTTE, which will be disseminated to transmission licensees. Therefore, a key success criterion is the publishing of studies or test reports on the MTTE members' website.

Evidence:

Publishing the first set of reports on a specific Transmission Licensee led project, on the MTTE website by end of March 2018.

Criteria 9.8

Project Close

The project is seeking NIC funding to fund the establishment of the facility together with supporting the first 4 years of operation. The project close will consolidate all of the learning developed over this time, and proposed the future of the facility.

Evidence:

Project close-down by end of March 2021.

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Section 10: List of Appendices

This submission is supported by the following appendices:

Appendix I	**Maps & Network Diagrams - The Proliferation of HVDC in GB:** Extracts from National Grid's Electricity Ten Year Statement showing how HVDC is expected to grow in GB.
Appendix II	**Technical Context of the MTTE:** Provides a summary of HVDC technologies to contextualise the MTTE.
Appendix III	**Problems, Methods, Outcomes & Benefits:** Shows how the MTTE will address the HVDC challenges to deliver the Outcomes & Benefits.
Appendix IV	**RTS, Replica Cubicles and IT Infrastructure Requirements:** Summary of the requirements of the Real Time Simulator (RTS), vendors' replica control & protection cubicles, and the IT infrastructure.
Appendix V	**MTTE Tests & Studies:** Technical description of the studies and test which will be undertaken within the MTTE.
Appendix VI	**Site and Building:** The location and layout of the MTTE.
Appendix VII	**Project Partners:** Describes how the MTTE will bring together the range of stakeholders and project partners.
Appendix VIII	**Project Governance Structure:** Provides an overview of the proposed project structure.
Appendix IX	**Project Plan:** Describes the timings of the project phases, milestones and outputs.
Appendix X	**Risk Register:** Describes the risks that have been identified, together with the impact and mitigation actions.
Appendix XI	**Mitigation & Contingency Plans:** Shows the detailed mitigation measures for the higher-factor risks.
Appendix XVI	**List of Figures & Tables**

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Appendix I – Maps & Network Diagrams

The Proliferation of HVDC in GB

In National Grid's Electricity Ten Year Statement (November 2012), three scenarios are considered: Slow Progression, Gone Green and Accelerated Growth, and the anticipated HVDC links required for each scenario from 2015 to 2030 are mapped.

Under all scenarios there is expected to be a significant number of new HVDC links in GB:

- 20 new HVDC links in the 'Slow Progression' scenario;
- 37 new HVDC links in the 'Gone Green' scenario; and
- 45 new HVDC links in the 'Accelerated Growth' scenario.

In addition, the expected construction of new international HVDC connectors adds further complexity to GB's HVDC development scenario. Such international links are expected to be vital in ensuring energy security for GB alongside a low carbon electricity supply, the scenarios anticipate:

- 2 new HVDC International Interconnectors in the 'Slow Progression' scenario;
- 4 new HVDC International Interconnectors links in the 'Gone Green' scenario; and
- 6 new HVDC International Interconnectors links in the 'Accelerated Growth' scenario.

There are only 4 existing HVDC links currently connected to the GB network, and all are point-to point international interconnectors.

To illustrate this anticipate proliferation of HVDC in GB between 2015 and 2030, Figure 10.1 has been extracted from National Grid's 'Gone Green' scenario.

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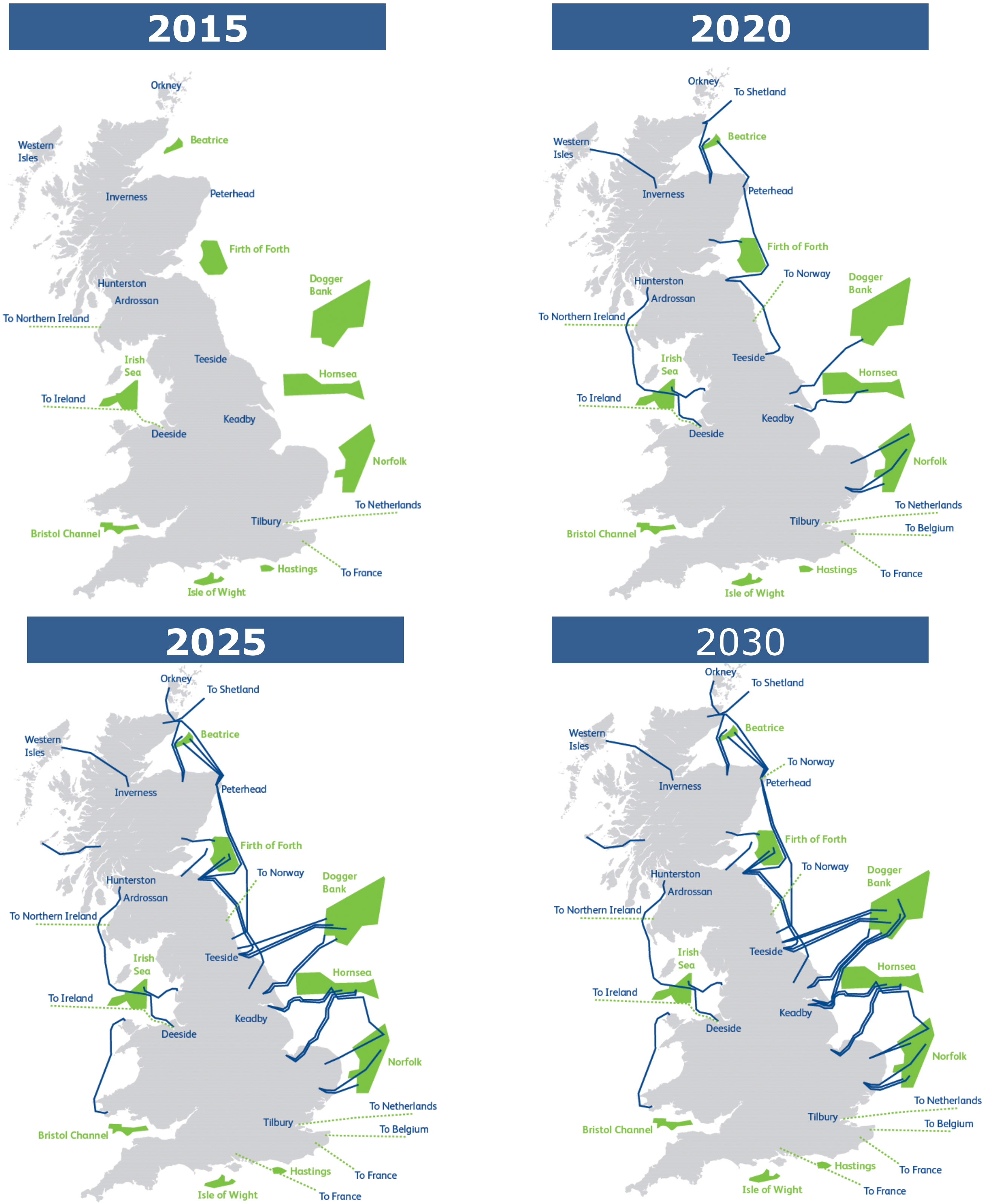

'Gone Green' transmission scenario (2015, 2020, 2025 & 2030), showing only HVDC systems and offshore wind projects for clarity. Adapted from National Grid Electricity Ten Year Statement, November 2012

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Appendix II – Technical Context of the MTTE

As of mid-2013, the GB transmission system includes four operational HVDC schemes (Table 10.1).

Table 10.1 Operational HVDC schemes in the GB transmission system

Interconnector Rating	Interconnector name	Geographical location
2000MW	Cross Channel	UK – France
2 x 250MW	Moyle	Scotland – N. Ireland
1000MW	Britned	UK – Netherlands
500MW	East – West	Ireland – UK

In addition, there is one new HVDC scheme under construction (Table).

Table 10.2 HVDC schemes under construction in the GB transmission system

Interconnector Rating	Interconnector name	Geographical location
2000MW	Western Link	Scotland – Wales embedded link

With the exception of the East – West Interconnector, all of these schemes are based on conventional **line commutated converter (LCC) technology**. The concept of LCC technology is shown in Figure A2.1. The schemes in Table 10.1 and Table 10.2 are considerably more complicated than Figure A2.1, but the key aspects of the technology are illustrated.

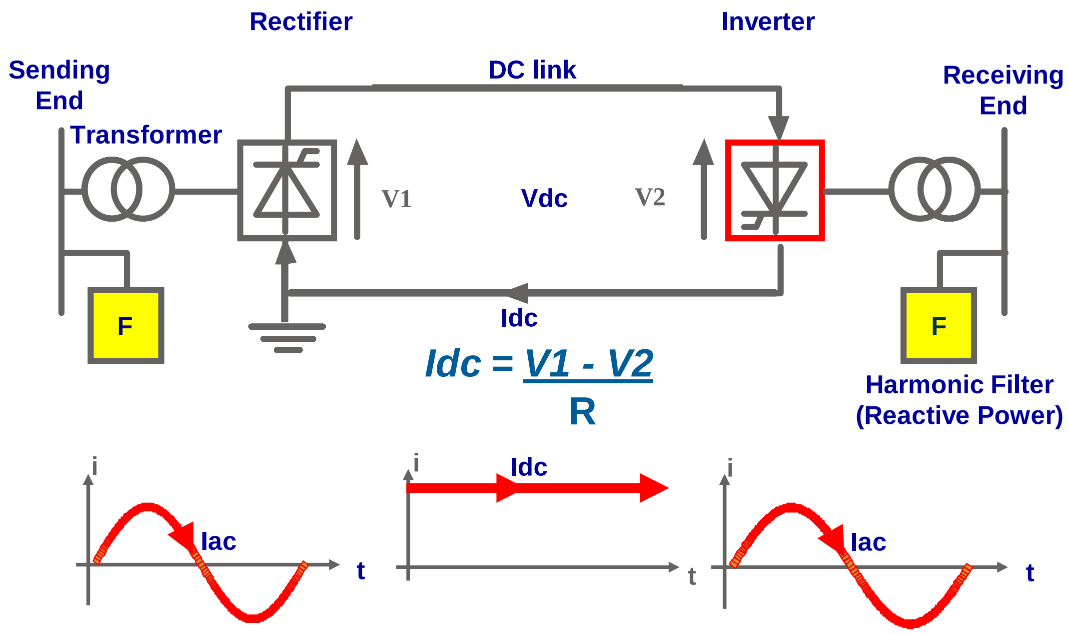

Figure A2.1. Simplified LCC HVDC circuit.

The alternating current (Iac) at the sending end system is converted to a DC current (Idc) via a power electronic rectifier and transmitted via a DC link to the remote station, where a power electronic inverter re-converts back to alternating current (Iac) to be supplied to the receiving end system.

The technology requires the presence of an AC voltage source at both sending and receiving end systems to operate. In addition, the AC and DC systems should be relatively strong (in terms of short circuit level) relative to the power transmitted in the DC link.

It is an inherent function of LCC technology that it absorbs reactive power from the AC network, which has to be compensated by the installation of high voltage capacitor banks at both sending and receiving end systems. The process of converting AC current to DC current generates harmonic distortion, which needs to be filtered at the point of connection to the AC networks. The capacitor banks installed to provide reactive power compensation may also be configured to filter the harmonic distortion, minimising the amount of equipment required. These harmonic filter (reactive power) banks are switched in and out as the power transmitted through the link is increased or decreased.

Power flow is controlled by changing the levels of DC voltage at the rectifier (V1) and inverter (V2) stations. The resistance (R) of the DC transmission link, whether overhead line or submarine/underground cable, is a constant value. Reversing the direction of power flow in the DC link requires a change of polarity of the two converter stations, since the power electronic devices used for LCC technology – high power thyristors – can conduct current in only one direction.

LCC is a mature technology offering high power transmission levels (7200MW at ±800kV is the state of the art) and low converter station losses (around 0.75% of scheme rating). It has been extensively used throughout the world for many power transmission applications.

The East – West interconnector (see Table) uses the more modern **voltage source converter (VSC) technology**. Most of the planned HVDC schemes shown in Appendix 1 are expected to be based on VSC technology. The basic concept of a VSC scheme is shown in Figure A2.2.

Figure A2.2. Simplified VSC HVDC Circuit

A capacitor bank, charged to a DC voltage of U_{C1} is used as a momentary source of energy storage between the DC and AC systems. A power electronic converter at Station 1 inverts the DC voltage to create a controlled AC voltage on the secondary side of the transformer which connects to AC Network 1. A similar operation occurs at

Station 2, where the DC voltage U_{C2} is inverted to create a controlled AC voltage on the secondary side of the transformer connected to AC Network 2. Power flow between the two stations is achieved by controlling the relative magnitudes of the DC voltages (U_{C1}, U_{C2}) in the same way as in an LCC scheme. However, because the output voltage at each converter is controlled relative to the voltage on the AC network, the reactive power (Q) interchange between the VSC converter and the AC network can also be controlled. Depending on the converter output voltage the VSC scheme can absorb or generate reactive power, independent of the level of real power flow between the stations. The two converter stations are able to control their reactive power (Q_1, Q_2) independently. This essentially makes the VSC converters independent of the strength of the AC network.

Because the DC voltage (U_{C1}, U_{C2}) is initially created by simple rectifier action from one of the AC networks, it is not an essential function of VSC technology that both AC networks are present during operation, which is a fundamental difference to the LCC technology. This means that VSC technology is able to operate into a passive network i.e. one without an indigenous source of generation, or can "black start" an AC network. This makes VSC ideal for connection to island loads and it is the only realistic HVDC technology for connection to wind farms, which are intermittent sources of generation.

In the latest generation of VSC technology, known as **modular multi-level converter (MMC)**, the output voltage from the converter is a synthesised sinusoidal waveform, composed of hundreds of small steps of DC voltage. The DC capacitor shown in Figure A2.2 is effectively segmented into hundreds of sub-modules, each of which is switched on or off, by a power electronic switch. The concept is illustrated in Figure A2.3, although only 6 steps are shown for simplicity.

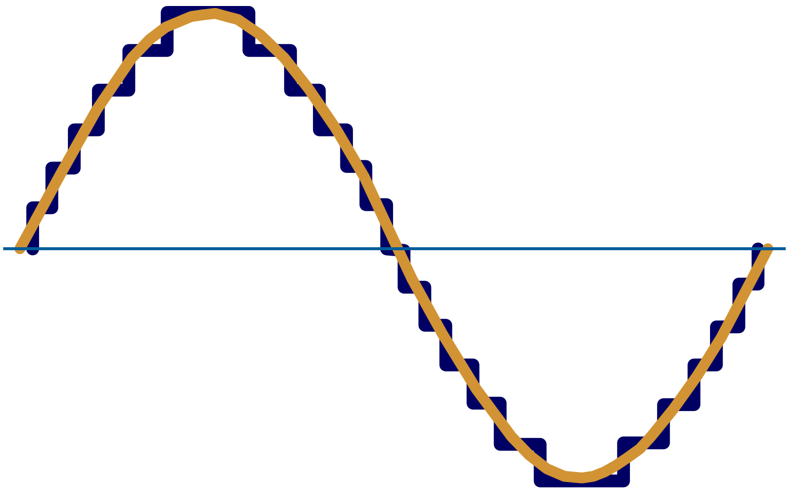

Figure A2.3 Output voltage from a MMC VSC scheme

As the output voltage is a virtually perfect sinusoidal waveform, it is anticipated that no harmonic filters, or only a small filter bank, will be required for the schemes anticipated for future UK projects. Note that the East – West HVDC scheme uses an earlier generation of VSC technology, using Pulse Width Modulation (PWM) control and does have harmonic filters installed on both sides of the interface transformer.

A key feature of VSC technology is that the power electronic devices used – high power transistors – can conduct current in both directions and therefore reversal of power flow can be achieved without requiring voltage polarity reversal. This can have a beneficial impact on the choice of cable technology used for off-shore schemes and interconnectors.

VSC technology has been developed since the late 1990's; a limited number of schemes are in service, with an upper limit on ratings of 500MW at ±200kV representing the state of the art. There is only one MMC scheme in operation, although there are many under construction, at ratings up to 1000MW and ±320kV. Converter station operating losses have reduced considerably since the inception of VSC technology and are now around 1% of scheme power rating. As no high voltage filter (reactive power) banks are required, the MMC VSC station is much more compact than a LCC station of the same power rating, hence ideal for installation on an off-shore platform.

On the GB transmission network there will be, installed in the near future, multiple HVDC links of different technologies (LCC, PWM VSC and MMC VSC), supplied by different manufacturers and in many cases installed in close proximity to each other. Potential adverse control interactions between these multiple controlled HVDC devices and with other controlled devices on the networks, including SVCs, STATCOMs and wind turbine generators (WTG), represents a significant risk to the stability and security of the GB transmission network. The proposed MTTE, as described in this document, represents a unique facility to study such interactions, anticipate potential problems and propose solutions.

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Appendix III – Problems, Methods, Outcomes & Benefits

The MTTE project will be a key enabler of planned HVDC systems in GB. The methods through which the MTTE project will address the key challenges and provide associated benefits and learning outcomes are described in the summary format in the diagram below; and in detail in the following table.

The Problems, Methods, Outcomes & Benefits of the MTTE, all fall under the following categories:

- Support Transmission Planning of HVDC schemes;
- Improve Requirements Specification of HVDC schemes by TOs;
- Facilitate Multi-Terminal HVDC Solutions;
- Facilitate Competition and Multi-Vendor HVDC schemes;
- De-risk control interactions between multi-terminal, co-located and electrically connected converters, and with other active controlled equipment;
- Train and Develop Transmission Planning and Operational Engineers;
- Undertake post commissioning scenario planning and operational optimisation; and
- Model New HVDC Technologies.

Problem Statement	MTTE Method / Activity	Learning Outcome	Benefit
Network planning is increasingly complex & there is a lack of HVDC modelling tools;	RTS can model complex HVDC scenarios and test their interaction and impacts.	Disseminated reports on development scenarios and their impacts; shared RTS models.	Improved planning; scheme optimisation; reduced risks; reduced costs; informed decisions.
Difficulty in specifying multi-terminal / multi- infeed / multi-vendor HVDC systems	Detailed modelling will allow more accurate specification of HVDC scheme requirements	Analysis and reports advising on the specification of HVDC schemes; disseminated for learning.	Accurate requirements definition: reduces the risks & provides value for money to customers.
The complexity of multi- terminal HVDC introduces risk and uncertainty of the impacts of such schemes on the network	MTTE: The environment, skills and tools to model complex HVDC efficiently and accurately	Analysis / reports on multi-terminal scenarios (for dissemination) to increase MT understanding	Facilitates the move to multi-terminal, with the associated lower cost.
Limited inter-operability / standardisation between HVDC suppliers' systems; limited competition / restrictions on new market entrants	Test control & protection systems from different suppliers in order to ensure compatability.	Reports on multi-vendor compatability to inform development of HVDC standards	Facilitates competition; provides confidence in compatability; enables multi-vendor schemes.
No facility exists to undertake acceptable testing of multi-vendor HVDC, multi-infeed or schemes in close proximity	MTTE enables Acceptance Testing of complex HVDC e.g. multi-vendor to be performed	Acceptance test reports	Shortens and de-risks project commissioning periods, reduces risk of adverse interactions.
Risk of adverse control interactions due to co-located/electrically connected HVDC converters	Test / identify all interactions using RTS capability; mitigate risk of live interactions.	Reports on impacts of planned HVDC & any control interactions with converter stations etc	Improved analysis means issues can be addressed in advance, helping maintain grid stability.
Risk of adverse interactions between controlled devices - e.g. wind turbines and HVDC converters	Simulate & predict active control interactions e.g. wind farms	Reports on integration of generators etc into HVDC systems; risks and control strategies.	Reduced risk of adverse interactions due to active controlled equipment.
Limited experience within TOs & OFTOs in HVDC design & operation; particular skills gap in more complex systems e.g. multi-infeed	MTTE: Train on replica control panels & realistic network simulation; develop skills	MTTE will allow simulated operational training, and disseminate training material.	Improved training particularly, 'real-life' scenarios prior to live implementation.
HVDC training is only provided on commissioned schemes; there is thus a lack of a system on which to train future engineers.	MTTE provides a simulated environment to train engiineers on HVDC assets.	Training materials disseminated to all Transmission Licensees	Asset life-time training, reduced risks, improved training quality and experience.
Limited experience in HVDC scheme operation amongst TOs & limited scheme optimisation ability	MTTE simulations - with replica panels - will facilitate safe & efficient optimisation	Recommendations to TOs on specific HVDC schemes, allowing optimisation.	Helps facilitate HVDC scheme optimisation; improve network efficiency, reduce losses.
No facility currently exists to test integration of new HVDC devices	MTTE allows assessment of future HVDC technologies as they are brought to market	Reports, analysis, simulation on new HVDC technologies; impacts / interactions etc	Risks and adverse interactions can be identified before live deployment.

Figure 10.5 MTTE problem input to benefit output table

Table 10.3 The Problems, Methods, Outcomes & Benefits of the MTTE; detailed version

Area	Problem Statement	Method to Address the Problem	Learning Outcome	Benefit
Transmission Planning of HVDC schemes	Future network planning and development will become increasingly complex as the numbers of HVDC links and other active devices increase. In addition, there is a lack of appropriate tools to model and understand the detailed impact of complex HVDC systems on the existing network and simulate future HVDC expansion scenarios.	The MTTE will allow a much more robust set of scenarios to be analysed within the project development timeframe to ensure that the existing assets are properly utilised and any new extensions are fully investigated. For example this could be used to model the impact of a new renewable connection which may have a different "load profile" from existing profile. The MTTE will be able to model complex HVDC schemes (and the associated AC network) under a comprehensive range of operating conditions to ensure the optimum balance or security, efficiency and reliability. Network Licensees will be able to: • Test and study the control, protection, interaction and operational issues associated with the DC and AC systems. • Assess the impact of planned HVDC systems alongside future expansions to the Grid.	The MTTE will produce analysis and reports on the development scenarios investigated, and will share these with the other TOs/OFTOs to increase the understanding of the impact of HVDC development scenarios on the existing network. In addition, the models developed will be shared with Network Licensees.	Improved transmission planning of complex HVDC schemes will enable the optimisation of their performance, reduced risks and provide value for money for our customers, together with more confidence in transmission planning decisions and their impact on the Network.
Requirement Specification of HVDC schemes	The novelty of multi-terminal, multi-vendor and multi-infeed HVDC systems limits the ability to specify detailed requirements and negotiate technical details.	The MTTE will provide an environment, skills and tools to model the details of HVDC system, which will enable more accurate specification of the requirements, which is expected to reduce the risks and ensure value for money on HVDC schemes.	The MTTE will produce analysis and reports advising Network Licensees on the specification of HVDC schemes. These will be shared with the other TOs/OFTOs to increase the understanding of specifying HVDC schemes.	The MTTE will enable the detailed investigation of complex HVDC schemes to more accurately specify the requirement, which is expected to reduce the risks and ensure value for money for our customers, and will provide confidence in their specification and impacts.

Facilitate Multi-Terminal Solutions	Multi-terminal HVDC offers the potential of multiple connections at a substantially lower cost with more security than point-to-point. However the complexity of multi-terminal HVDC introduces additional risks and uncertainly on the impacts.	The MTTE will provide an environment, skills and tools to model the complex multi-terminal HVDC systems, with studies performed quickly and efficiently in a safe simulated environment. The incorporation of replica control panels of HVDC links will improve the accuracy and therefore confidence in the results of the studies performed.	The MTTE will produce analysis and reports on the Multi-terminal scenarios, and will share these with the other TOs/OFTOs to increase the understanding of Multi-Terminal HVDC.	The move to a multi-terminal solutions for HVDC systems offers the potential to reduce project costs by reducing the number of converter stations when compared with separate point-to-point solution (with an associated significant cost saving). The MTTE will allow a greater range of simulations to be carried out to identify potential adverse interactions and allow TOs to develop optimum operating strategies. The ability of the MTTE to utilise replicas of the actual control equipment will provide the ability to test the operation of the system prior to final commissioning and provide further confidence.
Competition and Multi-Vendor HVDC	The market for HVDC systems is dominated by a small number of large suppliers. There is limited interoperability and standardisation between the suppliers' preferred designs, especially in the control and protection systems. This situation both limits competition between the existing suppliers and hinders the potential for new entrants to the market. Resulting in a high-risk for multi-vendor HVDC schemes and a lack of confidence in regulation of power flow and system stability. Furthermore, there is currently no facility to undertake acceptable testing of multi-vendor schemes; or for schemes in close proximity which could cause adverse control interactions. It is also widely recognised that significant work needs to be undertaken in the development of common standards for HVDC. Whilst CIGRE/CENELEC have begun to tackle the issue, a substantial workload remains, which the MTTE will inform.	The MTTE will enable the control and protection systems from different suppliers to be tested with each other, to demonstrate their interoperability, utilising replica control panels. It also provides a facility where new entrants to the market can model and test their systems. The MTTE will also be able to undertake Acceptance Testing of multi-vendor HVDC systems and/or electrically connected systems (e.g. co-located).	The MTTE will produce reports on multi-vendor compatibility to inform the development of HVDC standards and interoperability. Acceptance testing reports will also be produced.	The MTTE ability to undertake multi-vendor interoperability testing will facilitate more competition in the HVDC market, provide confidence in multi-vendor compatibility, and therefore enable multi-vendor HVDC schemes. This will reduce the risk of such schemes and reducing their costs, which are ultimately borne by our customers. The TOs will be able to carry out elements of pre-commissioning testing at the MTTE to complement the vendors Factory Acceptance Testing. The ability of the MTTE to carry out simulations using hardware rather than software models will allow a greater range of tests and simulations to be carried out. This should shorten and de-risk the commissioning period for projects, whilst reducing risk of potential adverse control interactions.

Control interactions between multi-terminal, co-located and electrically connected converters, and with other active controlled equipment	The interaction between two or more HVDC converter stations on the same system, at the same location or in close electrical proximity can introduce the risk of adverse control interactions and impacts on the AC network. This risk is exacerbated where converters are supplied from different manufacturers (with their different power electronic technologies and different control and protection systems). These issues will need to be anticipated and resolved in this diverse environment, to avoid unacceptable impacts on network security. Coupled to this there are an ever increasing number of other controlled devices (e.g. STATCOMs, SVCs, TCAC, Series capacitors, wind turbines) being connected to the network which could again cause adverse interactions with HVDC systems. The TOs as network owners have an obligation to identify and manage any issues to ensure the integrity and security of the GB network.	The MTTE will enable the testing of control interactions in a safe environment, to mitigate the risk of adverse control interaction in the live system (which could lead to system outages). This will ensure that any adverse impacts are identified and managed to maintain system security and reliability. Transmission Planning will use the MTTE to understand the control interactions with generation control systems. The impact of the connection of offshore renewable projects can be simulated prior to construction. This will give the TOs the ability to move confidently toward multi-vendor solutions by reducing the risks associated with their control interactions.	Reports on the impact of planned HVDC systems, providing detail on any control interactions with converter stations in close proximity and active controlled equipment. These reports will be shared with all Licensees to improve sector-wide understanding of the associated issues. This would include reports on the integration of generators into HVDC networks and the associated risk of adverse control interactions and their control protocols and strategies.	The MTTE and the use of replica control equipment will allow a much broader and representative range of analysis to be undertaken. This will allow the TOs to be proactive and address issues in advance as the network develops. Feedback from other projects in Europe such as Borwin1 suggests that these additional models and simulations are essential to maintaining grid stability. This will result in a reduced risk of adverse control interactions between active controlled devices and HVDC systems, reducing the risk of generation constraints (saving customer money), and improving system reliability.
Train Transmission Planning and Operational Engineers	The TOs and OFTOs have limited personnel with experience in the design and operation of HVDC systems, and little or no experience of multi-terminal, multi-infeed or multi-vendor HVDC operation. As a result, there is likely to be an associated skills gap. In addition, training is usually only provided when an HVDC link is commissioned, and future engineers do not have a system to be trained on.	The MTTE will provide a simulated environment in which to train the engineers and other staff required to operate and manage complex new HVDC assets, including access to replica control panels identical to those in operation.	The MTTE will produce training material which will be available to all Transmission Licensees	Provision of improved training for an expanded pool of TO and OFTO personnel throughout the lifetime of HVDC assets, including exposure to 'real-life' scenarios prior to implementation on live HVDC systems.

Post-commissioning planning and optimisation	There is limited experience in the operation of HVDC systems among GB TOs. The scope to optimise operation on the live system (to improve efficiency and reduce losses) would be restricted, take longer and present operational risk. The alternative of optimisation using more primitive models would also be limited since they do not accurately represent the system.	The use of replica HVDC equipment combined with the functionality of the MTTE will help to give TOs the information required to optimise the performance of the HVDC systems. It will enable simulation of multiple scenarios (e.g. changing various control parameters) to optimise given HVDC schemes within a safe simulated environment.	The MTTE will produce recommendation reports on specific HVDC schemes to enable optimisation which will be shared with all Licensees.	The MTTE will provide TOs with information that will contribute to optimising the performance of HVDC systems. This will result in improved network efficiency and reduce losses, along with better-informed operational decisions.
Model New HVDC Technologies	There will be an increasing number of new HVDC equipment and active devices available to the GB transmission system in the coming years (e.g. circuit breakers, DC-DC converters etc). There is currently no independent facility to test and demonstrate the operation and control of these new technologies, or their specific use as part of GB HVDC schemes. This presents a level of risk for Licensees.	The MTTE will offer a facility for the TOs/OFTOs to assess the impact of future developments in HVDC technology as they are brought to market, by providing a suitably robust simulation environment to fully assess new equipment. This will reduce the risks and provide confidence in the deployment of such technology to allow TOs/OFTOs (and hence customers) to benefit from the new technology and potentially from increased competition in technology supply.	The MTTE will produce analysis and reports on the performance, impact and interactions of new HVDC technologies or active controlled devices in accurately simulated GB situations and their suitability for specific applications / locations.	The MTTE will allow emerging HVDC technology and active devices to be simulated in advance of their connection to identify any adverse interactions. This is particularly important where large-scale renewable projects are developed in stages; these projects may extend over a number of years and there is no guarantee that all of the turbines will be of the same design. This capability will reduce the risk of advancing or changing technology causing adverse network impacts, increasing confidence in its use.

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Appendix IV – RTS, Replica Cubicles and IT Infrastructure Requirements

This appendix provides a summary of the requirements of the Real Time Simulator (RTS), vendors' replica control & protection cubicles, and the IT infrastructure.

Real Time Simulator (RTS) Requirements

Figure 10.7 shows a simplified diagram of the concept for the MTTE. A Real Time Simulator (RTS) is used to provide the computational facility, which will be used to study the operation of multiple HVDC controllers provided by multiple HVDC vendors. For simplicity only two controllers are illustrated.

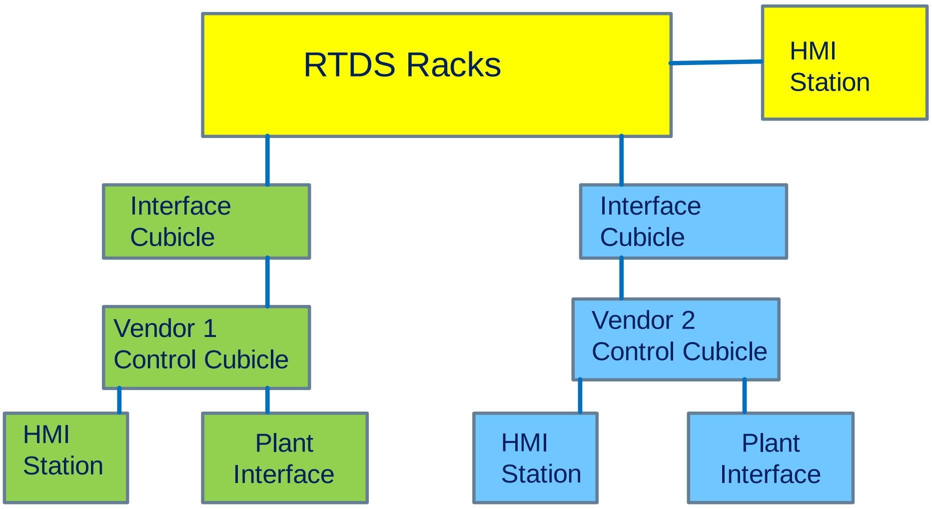

Figure 10.6 Simplified MTTE concept diagram, showing the interaction between the main RTS facilities and the HVDC vendors. For simplicity, only 2 vendors / controllers are illustrated.

The complexity of the tasks to be undertaken at the MTTE places a variety of requirements on the RTS system installed. In general, the RTS equipment must be capable of expansion or up-grade to ensure that the processing power is sufficient for the future applications to be studied.

More specifically, the RTS must be able to model the following key parts of the overall system under study:

- The AC network, normally implemented as a reduced network, which has been developed from the full network model and has been shown to have the same steady state and dynamic response as the full model. The reduced network is likely to consist of 10 busses from the point of connection of the HVDC station(s). This model shall include transmission lines, transformers (including tap-changers), equivalent load representations, and equivalent generator representation.
- The HVDC power electronic valve in terms of its individual switched elements, which maybe of the following types.
    - A LCC bi-pole valve configuration; this means two 6 – pulse bridges, with each valve in the 6 – pulse bridge being switched once per fundamental frequency cycle, i.e. at 60° (3.33ms) intervals.

  - A VSC using a PWM controlled 2 – level bridge, where each valve is switched at a frequency of typically 1000 - 1600Hz,
  - A VSC MMC bridge which may have many hundreds of sub-modules per valve, each individually switched, at time intervals down to 10 – 30us.
- In the initial stages, the RTS may also need to model the control and protection system of the HVDC controller, in the absence of vendor's hardware. This could be a generic HVDC control scheme, based on those available in commercial analysis tools such as PACAD and PSS/E, or a generic control system embedded in the RTS suppliers system.
- For the initial MTTE installation it is expected that two HVDC links (rectifier plus inverter) can be modelled simultaneously, potentially at one location in a multi-infeed configuration. The remote AC systems will be modelled by simple inductance/resistance equivalents.
- Multi-terminal HVDC schemes consisting of 3, 4 or 5 terminals.
- SVC (TCR + TSC) and STATCOM devices, based on standard generic models will be available within the supplied RTS facility.
- Wind turbine generators, based on standard generic models including both DFIG and full converter designs will be available within the supplied RTS facility.
- Detailed generator models as required for the evaluation of Sub-synchronous Torsional Interactions (SSTI), which may be induced by adjacent HVDC converter stations.

Replica control and protection cubicle requirements

Background

In their own laboratory facilities, HVDC manufacturers perform Factory Acceptance tests (FAT), sometimes called Factory System Tests (FST), on their controllers, as final validation of the control and protection hardware and software, prior to shipment to the site. This requires the installation of the full cubicle suite to be assembled in the FAT laboratory, for connection to a Real Time Simulator (RTS). This requires the full duplicated controllers, plus all of the AC side and DC side interface cubicles. For a full HVDC bi-pole scheme this can be a significant quantity of cubicles. For a point to point link the controllers for both HVDC terminals need to be installed.

The cost associated with the full suite of controllers for an HVDC scheme can be quite considerable, as it takes into account the following,

1. The capital cost of the control and protection cubicle hardware
2. The cost of the engineering studies performed in the development of the control and protection algorithms
3. The costs associated with the engineering of the control system architecture
4. The engineering cost associated with the generation of the control and protection software
5. The cost of electrical testing of the control cubicles
6. The cost of testing of the software modules
7. The costs associated with the Intellectual Property of the manufacturer
8. The recoveries applied to the costs, including contributions to R&D, marketing, profit etc, to achieve a selling price to the customer.

The control and protection system for an HVDC scheme as delivered and commissioned for the customer can represent 5 - 8% of the total cost of the project.

MTTE Requirement

For the MTTE it is anticipated that a "replica" control and protection suite would be installed in the facility for investigations of the behaviour of multi-infeed and multi-terminal HVDC schemes. A considerably reduced cubicle suite would be required for the MTTE, as the prime role is to test functionality, particularly in the presence of other controllers, and not the hardware itself. It is anticipated that prior to the use of a replica of the controller in the MTTE facility, the full control and protection suite of cubicles would have been subject to a full FAT sequence as part of a contract delivery. While the MTTE facility could perform the FAT, this is not its prime role.

In commercial HVDC projects it is normal practice to provide 100% redundancy of control and protection equipment. For the MTTE this is not required. In the event of equipment malfunction the test would be curtailed, the problem resolved and the test re-started. Proving of duplicate control and protection functions, control lane auto-changeover, loss of power supplies, etc. is not a requirement of the MTTE facility. Due to the importance of protection of a valuable asset such as an HVDC converter station, in some cases protection functions are quadruplicated to avoid risk to the equipment of spurious operation of protection functions. Such a degree of design redundancy is not a requirement of the MTTE. Any inadvertent operation of the protection system, such as spurious operation or lack of operation can be resolved and the testing resumed.

A key feature of the operation of the HVDC control and protection system is the interface with the station plant. The controller requires a number of analogue signals (current, voltage, frequency, temperature, etc) and digital signals (breaker status, disconnector status, protection status, etc.) to operate the HVDC scheme. The protection aspect of the controller, which is a significant part of the operating software, is highly dependent on receiving such signals. A facility is required to simulate these signals so that the controller is able to operate correctly. This facility would be specific to the individual vendor's controller and would need to be provided by each vendor, whose controller was under test. Ideally once installed such an interface facility would be suitably flexible for continued use on many tests on controllers, although possibly specific to each manufacturer.

An interface cubicle to provide suitable signals to the representation of the power electronic converter implemented in the RTS is required. This needs to receive signals from the main control and protection cubicle and issue the relevant signals to the "power electronics". The normal contract level of redundancy, typically duplication of equipment/communication paths from the controller to the power electronics is not required for the MTTE. Any loss of firing signals can be resolved and testing re-started.

The security levels in the design of the replica controllers are not the same as those required to achieve the levels of reliability and availability of a commercial HVDC scheme.

Proposed Controller Requirements

Expert assessment indicates that the main control and protection system could be housed in a single replica cubicle. This would include a single control lane and potentially a single protection lane, although it may be that manufacturer's "standard" solution includes duplicated protection lanes and "re-engineering" the cubicle may not prove economic. An HMI station to operate the control system is anticipated.

An interface cubicle to represent the analogue and digital signal from the external converter station is anticipated. A cubicle (or cubicles) to house the firing controls for the power electronics is anticipated.

The sketch below indicates the expected arrangement of cubicles for one pole of the converter station.

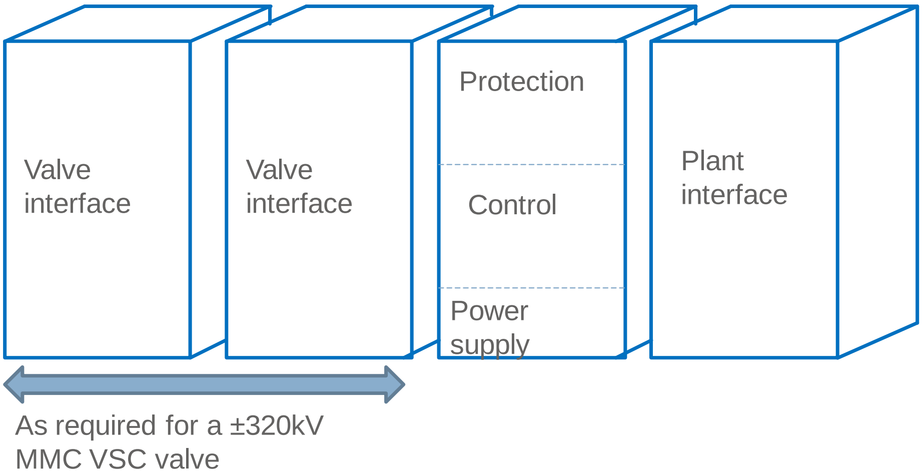

Figure 10.7 RTS cubicle arrangement concept for one pole of an MMC VSC HVDC link. The main control and protection systems could be housed in a single replica cubicle (as illustrated). A plant interface cubicle to represent the analogue/digital signals from the external converter station is anticipated. The HMI is not shown.

IT Infrastructure Requirements

Complex IT systems are at the heart of the MTTE operation, and it is vital that these systems are properly designed in order to provide the functionality required to make the MTTE a success. This functionality encompasses both the computing power to run the complex RTS systems, and the associated aspects of data communication, storage and security.

Non Functional requirements

- **Model security:** Where vendor's software models are used in the MTTE, it is essential that IP is maintained in order to preserve the competitive nature of the market; a configuration management and control process will be required in order to fulfil this requirement
- **Network security**: Access to MTTE computer networks will need to be restricted to protect against external cyber security threats; this may lead to a requirement to segregate the networks and control access.
- **Wide area network:** Facilities will be required for a secure communications / data transfer over the internet connection; for example, simulation results may need to be accessed remotely. It is also possible that remote access to control and run simulations may be incorporated.

Proposed infrastructure

The proposed network implementation for the MTTE comprises 3 Networks – 2 physical networks and a virtual network to be used as an internet-facing external network (Figure 10.8)

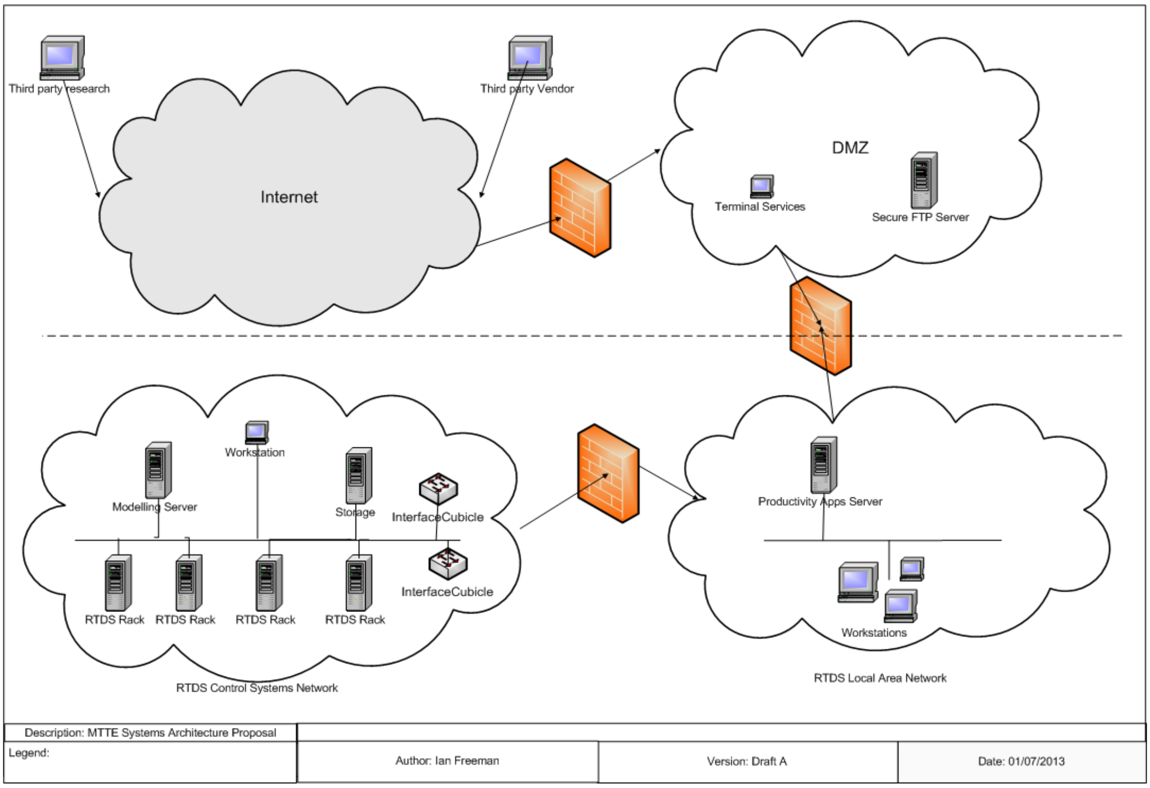

Figure 10.8 The proposed network implementation for the MTTE, comprising 3 networks - 2 physical networks and an internet facing external network

The Control Systems network is used for the installation of the RTS and provides the core network, allowing software models of the Converter Control systems or physical control panels - residing in separate rooms - to be connected to the RTS. This will be a fibre optic network in order to meet the requirements of the simulation and control panel connectivity. It is a segregated high availability and highly secure network. The network includes storage capacity for the models used on the RTS systems.

The Local Area Network is used for the connection of the application server and connectivity to the virtual network. Firewalls are installed to ensure segregation between each of the network areas.

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Appendix V: MTTE Tests & Studies

This Appendix is a technical description of the studies and tests which will be undertaken within the MTTE.

The MTTE will be use to conduct detailed test and studies for a range of purposes, including: assessing transmission planning options, supporting the development of project specifications, and assessing the impact on new renewables connections. For each of these a range of studies would be required to assess the impacts of various scenarios, and this appendix describes this range of studies. The MTTE will also be able to facilitate acceptance testing of multi-vendor HVDC links in an independent facility.

The below list illustrates the types of study which may be performed in the MTTE to check both steady state and dynamic operation of multiple HVDC controllers, connected to a common AC transmission network. This is not intended to be a comprehensive list, but an indication of the range of studies which can be performed. Such studies would include the following scheme arrangements:

- Multi-infeed conditions where two or more HVDC converter stations are at the same connection point on the AC network, or are in close proximity;
- Multi-terminal conditions, where the scheme involves three or more terminals, some of which are connected to a common AC network, or where all terminals are connected to independent AC networks;
- Embedded HVDC links in the interconnected AC network - which may impact on the above systems; and
- HVDC schemes in close proximity to other controlled devices on the network, such as SVCs, STATCOMs, TCSCs, and Wind Turbine Generators.

It is assumed that the MTTE will have the capability of studying the following HVDC configurations:

- LCC converters, operating in asymmetrical monopole or bi-pole modes;
- VSC converters, based on a 2 – level topology operating as a symmetrical monopole;
- VSC converters, based on multi-level topology operating as a symmetrical monopole; and
- VSC converters, based on multi-level topology operating in asymmetrical monopole or bi-pole modes.

Multi-infeed conditions may be any combination of the above configurations. Multi-terminal configuration may be assumed only to be based on VSC multi-level topologies.

In the following (non exhaustive) list of studies the aim is always to check on correct and understandable operation of the HVDC system to ensure the following:

- The stations operate within their designed parameters;
- The control system behaves as anticipated by the vendor from digital studies;
- The protection system responds as anticipated by the vendor;
- The scheme meets the requirements of the national Grid Code;
- The steady state behaviour of the station complies with the customer’s requirements;

- The dynamic behaviour of the station complies with the customer's requirements;
- The controller maintains system stability following system perturbations; and
- Converters maintain stable operation over the designed range of short circuit levels.

This Appendix does not attempt to list out all of the possible permutations of multi-infeed or multi-terminal scenarios, these would be determined on a study by study basis. The aim is to give a view of the types of investigations which can be performed in the MTTE.

A list of the analogue and digital signals to be recorded is not given here. It can be assumed that all primary signals (voltage, current, frequency, etc.) and computed signals (power, reactive power, etc) are available for display at any point in the electrical circuits. Any digital signals available from the control system (breaker status, mode change, etc.) can be displayed.

1 Energisation of the converter stations

1.1 Energisation of the rectifier with the converter blocked and the DC system isolated, including switching of filters as required
1.2 Energisation of the inverter with the converter blocked and the DC system isolated, including switching of filters as required
1.3 Energisation of the rectifier with the converter blocked and the DC system connected, including switching of filters as required
1.4 Energisation of the inverter with the converter blocked and the DC system connected, including switching of filters as required
1.5 De-blocking of the converters and ramping power to the minimum power flow setting
1.6 Ramping of power from minimum to maximum level, including filter switching, with halts at intermediate power levels; different ramp rates will be investigated
1.7 Reduction of power from maximum to minimum level, including filter switching, with halts at intermediate power levels; different ramp rates will be investigated
1.8 Power reversal from maximum import to maximum export
1.9 Repeat of the above sequence with a second converter in parallel operation

2 Step responses

2.1 Step changes in active power level
2.2 Step changes in reactive power level
2.3 Step changes in DC voltage reference level
2.4 Step change in AC voltage reference level
2.5 Repeat of the above sequence with a second converter in parallel operation

3 AC fault responses at each terminal

3.1 Single phase fault to ground at terminal (protection zone 1)
3.2 Single phase fault to ground in protection zone 2
3.3 Single phase fault to ground in zone 1, unsuccessful reclose
3.4 Single phase fault to ground in zone 2, unsuccessful reclose
3.5 Three phase fault to ground at terminal (protection zone 1)
3.6 Three phase fault to ground in protection zone 2
3.7 Three phase fault to ground in zone 1, unsuccessful reclose
3.8 Three phase fault to ground in zone 2, unsuccessful reclose
3.9 Repeat of the above sequence with a second converter in parallel operation

4 DC fault response at each terminal

4.1 DC fault close to rectifier station
4.2 DC fault close to inverter station
4.3 DC fault at mid-point of transmission circuit
4.4 Repeat of the above sequence with a second converter in parallel operation

5 AC fault ride through

5.1 Reduction of AC bus voltage to 15%
5.2 Reduction of AC bus voltage to 30%
5.3 Reduction of AC bus voltage to 50%
5.4 Reduction of AC bus voltage to 80%
5.5 Repeat of the above sequence with a second converter in parallel operation

6 Inverter station trip

6.1 Trip of the inverter station, power flow from A to B
6.2 Trip of the inverter station, power flow from B to A
6.3 Repeat of the above sequence with a second converter in parallel operation

7 System switching events

7.1 Switching in of an adjacent transmission line
7.2 Switching out of an adjacent transmission line
7.3 Operation of (pre-determined) power run-back in response to line switching
7.4 Energisation of an adjacent grid transformer
7.5 Repeat of the above sequence with a second converter in parallel operation

8 Converter station fault responses

8.1 Single phase to ground fault on the AC bus, transformer secondary side
8.2 Single phase to ground fault within the Valve Hall
8.3 Flash-over within the power electronic structure
8.4 Pole to ground fault in the DC yard on valve side of smoothing reactor
8.5 Protective trip of an AC harmonic filter
8.6 Repeat of the above sequence with a second converter in parallel operation

9 Multi-terminal operation

9.1 Trip off one converter and check that other converters remain in stable operation; re-dispatch power flow
9.2 Repeat 9.1 for each converter in turn.
9.3 Trip of one pole of a converter (assuming a three-wire bi-pole) and check other converters remain in stable operation and re-dispatch power flow
9.4 Repeat 9.1 and 9.3 with no telecommunications between terminals

10 Sub-synchronous Oscillations

10.1 Check that the HVDC controller provides positive damping at the characteristic torsional frequencies of the shafts of nearby generators
10.2 Check the impact of a second converter in parallel operation

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Appendix VI – MTTE location and layout

MTTE location

A number of locations have identified and evaluation for the location of the MTTE, with specific site being considered, based on the criteria below.

- Proximity of transport links (including international airport accessibility)
- Location-linked funding opportunities
- Availability of suitable building/site (with space for expansion)
- Proximity to SHE Transmission , SPT and NGET engineers that are likely to use the facility
- Proximity to academic institution partners
- Communication links
- Proximity to planned HVDC converter stations

A final discussion on the site of the MTTE will be agreed following detailed discussion with our partners.

MTTE layout

An indicative floor plan and external building views for the MTTE are shown in Figure , which includes the following main elements of the MTTE:

- Six replica control rooms (RCRs), which will be secure facilities to house replica control and interface cubicles supplied by vendors (including work station(s) and display screen(s)). We anticipate that between two and three of the RCRs shown will initially house replica control cubicles from the first HVDC project; a further three of these RCRs will accommodate control panels supplied by other vendors for future projects. These rooms will have appropriate levels of physical and IT security to protect the IP of the equipment manufacturers.
- The main RTS room comprising the main RTS processors and any additional items required to operate the system within a climate controlled, secure facility. This lab will be capable of accommodating future expansion in the RTS capability.
- An RTS control room which will house the work-stations and screens needed to operate the RTS facility and will therefore provide the capability to operate the overall MTTE system.
- Meeting and training facilities as well as offices for permanent and temporary staff.
- Catering and other essential facilities.

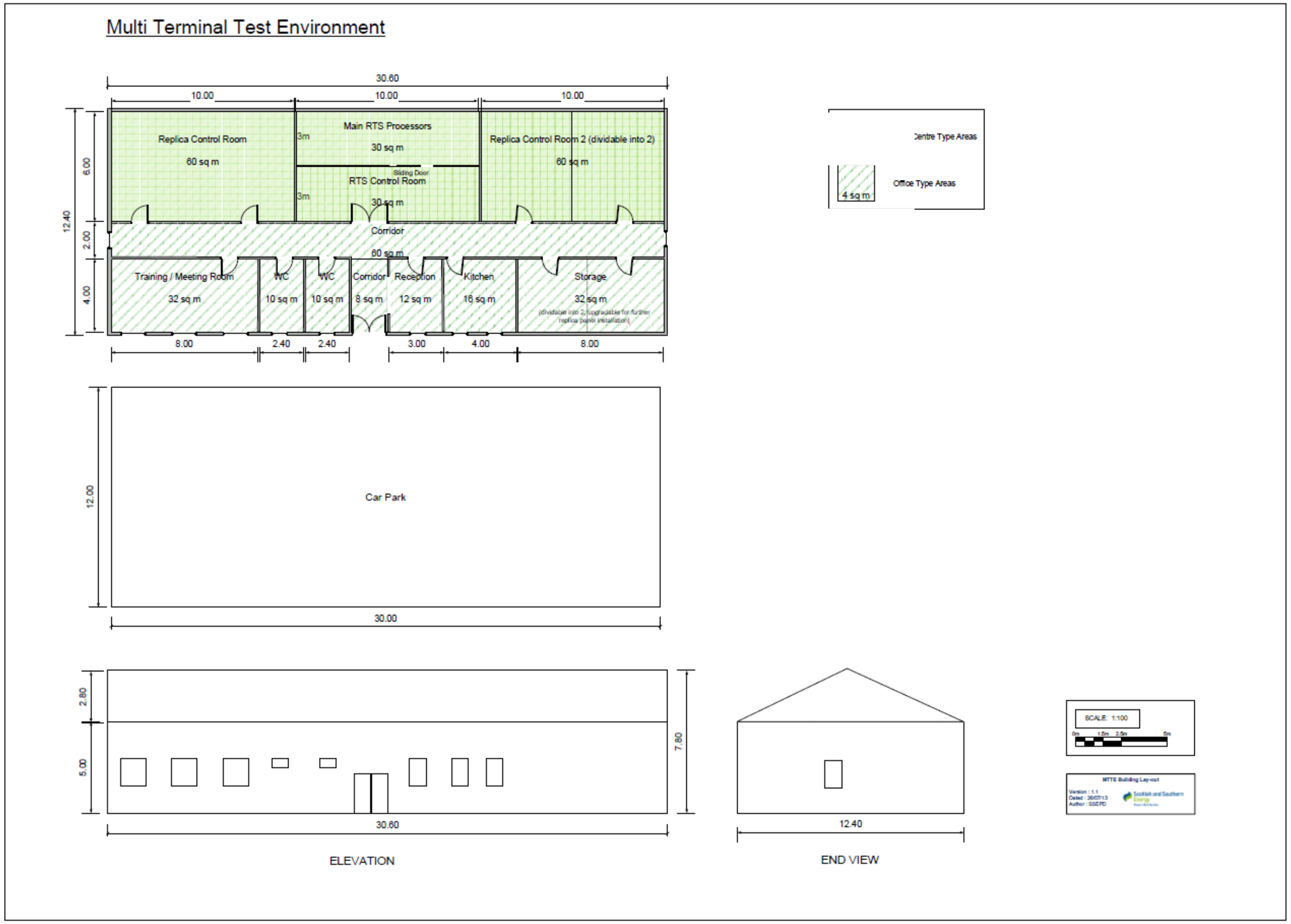

Figure 10.9 Indicative MTTE floor plan and external building views

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Appendix VII – Project Partners

The MTTE is a collaborative project, bringing together a wide range of stakeholders. This appendix describes their respective roles in the project and our selection processes.

Transmissions System Owners & Operator

HVDC System Vendors

R&D Organisations

RTS System Suppliers

External Expertise

Partners

Academia

Stakeholder Roles

Table 10.4 Stakeholder roles in the MTTE

Stakeholder	Role
Transmission Licensees (SP Transmission, National Grid Electricity Transmission, Offshore Transmission Owners (OFTOs))	SPT, NGET & the OFTOs, along with any combined project teams (e.g. the Eastern HVDC Link Project Team), will have access to run studies in the MTTE, and their HVDC projects can provide replica control panels to the MTTE. They can also use the centre to train staff on their control systems. During the NIC-funded period of operation (i.e. the first four years) the licensees would agree the programme of work for the MTTE through the collaborative management structure. The roles of SPT and NGET will be formalised through a Collaboration Agreement.
National Grid National Electricity Transmission System Operator (NETSO**)**	Able to commission studies, including grid development scenarios. May provide RTS models for testing in more complex scenarios - e.g. multi terminal - using MTTE technology.
Interconnector owners Subject to agreeing suitable commercial arrangements	Inter connector owners will be able to commission studies, in order to optimise the management of their assets. Use the MTTE for training new engineers using replicas of their own control equipment.
Renewable energy generation developers – Subject to agreeing suitable commercial arrangements	Able to commission studies. May supply details of planned projects so that impacts of different project development scenarios can be assessed. Can use MTTE to investigate interactions of generation equipment with different transmission system options, and therefore make more informed decisions.
Main HVDC vendors – Subject to agreeing suitable commercial arrangements	Our consultation with them has established their intent to participate in the MTTE.
Other participants in the energy supply chain Subject to agreeing suitable commercial arrangements	Other suppliers may want to use the MTTE to test the control interaction of their equipment (e.g. generator turbine control systems, HVDC breakers, converter stations from emerging suppliers). This will provide confidence in equipment compatibility and identify equipment requiring further refinement.
Research & development organisations (e.g. PNDC & EPRI Subject to agreeing suitable commercial arrangements)	R&D organisations including the PNDC and the EPRI have expressed interest in collaborating in the development and subsequent operation of the MTTE and potentially in commissioning MTTE studies subject to suitable commercial arrangements
Academia and other external expertise	The MTTE intends to form a consortium of academic institutions with leading HVDC expertise to support the MTTE. The process adopted for selecting academic partners is described later in this Appendix.

Stakeholder	Role
Scottish Enterprise	As part of its objective to promote Scotland as a hub of expertise in offshore renewables, have commissioned a report on the role that HVDC may play .
Local Authority	We are collaborating with local authorities to identify potential MTTE locations.
RTS Suppliers	Supply, install, test and maintain the RTS system to the developed specification, which will fulfil the MTTE functional requirements.

Selection Processes

Since there are limited partners in certain stakeholders categories, selection processes are required in order to select those partners who can provide greatest benefit and best value to the MTTE project.

Academic Partners

Our process to select academic institutions for MTTE collaboration has included the following steps:

- Research was carried out to identify institutions with HVDC research expertise that align with the MTTE.
- A set of questions was developed covering key topics and allowing universities to express their HVDC expertise and willingness to commit to the MTTE.
- These questions were issued to the institutions identified in a Request for Information (RFI)
- The responses were analysed and scored according to their alignment with MTTE goals, and the benefits which they are able to bring to the project.

RTS Suppliers

The role of the RTS supplier within the MTTE project is to provide RTS simulators and associated equipment, install this equipment into the MTTE, test the functionality of the equipment and provide ongoing maintenance throughout the MTTE lifetime (including supporting the integration of vendor provided replica control panels).

The selection process for the RTS suppliers is as follows:

- A comprehensive industry review was carried out to identify suppliers capable of supplying the simulation equipment required for the MTTE;
- A set of MTTE functional requirements was developed by SHE Transmission through collaboration with external technical consultants;
- The functional requirements were developed into a Request for Quote (RFQ) which was issued to the identified suppliers;
- RFQ responses will be used to refine the project technical specification, provide assurance of technical feasibility and refine costs;
- Once the project specifications are fully refined, a formal Request for Tender process will be undertaken to ensure value for money.

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Letters of Support from National Grid and Scottish Power

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SP ENERGY NETWORKS

To: Stewart A Reid
Future Networks Manager
SSE Power Distribution
200 Dunkeld Road
Perth, Scotland
PH1 3AQ

01-August-2013

Dear Stewart:

Re: Scottish Hydro Electric Transmission plc:
Multi Terminal Testing Environment for HVDC System (MTTE)

Scottish Power Transmission Ltd (SPT) is pleased to be a proposed partner for the **Scottish Hydro Electric Transmission MTTE** project under Network Innovation Competition.

The three GB transmission operators are tasked under their licence and STC to develop an efficient, coordinated and economic transmission system. This obligation sits in a background of challenging renewable generation targets that have triggered significant transmission infrastructure reinforcements. The drive on sustainable development has led to the application of a significant number of HVDC link projects for both infrastructure and renewable generation connections.

The sustainable and economic development of HVDC networks requires a multi-terminal configuration capability and this leads to the need for a multi-vendor market place and the opportunity to deliver significant procurement savings.

The MTTE project will facilitate the development and evolution of new industry standards that are required to facilitate and manage the technology development risks in a multi-vendor market.

The East Coast HVDC Link project has identified a multi-terminal link as a solution to a network reinforcement need. The availability of the MTTE could play a significant role in this testing of control systems and be a suitable home for a replica control system.

SPT are committed to provide the resources that we have agreed to support the MTTE project starting in January 2014.

Yours sincerely

J Sutherland

Jim Sutherland

Engineering Director, SP Energy Networks

New Alderston House, Dove Wynd, Strathclyde Business Park, Bellshill ML4 3FF
Telephone 0141 614 0008
www.scottishpower.com

Scottish Power Energy Networks Holdings Limited
Registered Office: New Alderston House, Dove Wynd, Strathclyde Business Park, Bellshill ML4 3FF.

P1281 July 12

nationalgrid

National Grid House
Warwick Technology Park
Gallows Hill, Warwick
CV34 6DA

Frank Clifton
Scottish Hydro Electric Transmission
Inveralmond House
200 Dunkeld Road
Perth
PH1 3AQ

Jon Fenn
Head of Network Engineering

www.nationalgrid.com

7th August 2013.

Dear Frank,

Scottish Hydro Electric Transmission Ltd Multi Terminal Test Environment (MTTE) Project.

National Grid is pleased to be a proposed partner for the Scottish Hydro Electric Transmission MTTE project. Projects such as this are an important part of how we respond to network changes, possibly paving the way for national benefits and savings.

By 2020 the GB electricity transmission system will have evolved to connect extensive renewable generation. Beyond 2020 the demands on the UK on electricity networks will dramatically increase with increasing levels of wind generation, increasingly off shore, and greater interconnection with other Northern European Countries.

HVDC systems will feature significantly in the development of off shore networks. It is vital that Transmission Companies understand the implications of integrating these complex systems with the existing on shore HVAC networks, and demonstrate how they will interact with each other on multi-terminal multi vendor HVDC systems. The MTTE project will provide valuable fundamental understanding to support this.

National Grid intends to provide the resources that we have agreed will be needed to support the MTTE project from the England & Wales TO in the event that the MTTE project succeeds in securing NIC funding, starting in April 2014.

Yours sincerely

DoA JON FENN

Jon Fenn
Head of Network Engineering

National Grid plc
Registered Office: 1-3 Strand, London WC2N 5EH
Registered in England and Wales, No 4031152

Appendix VIII – Governance

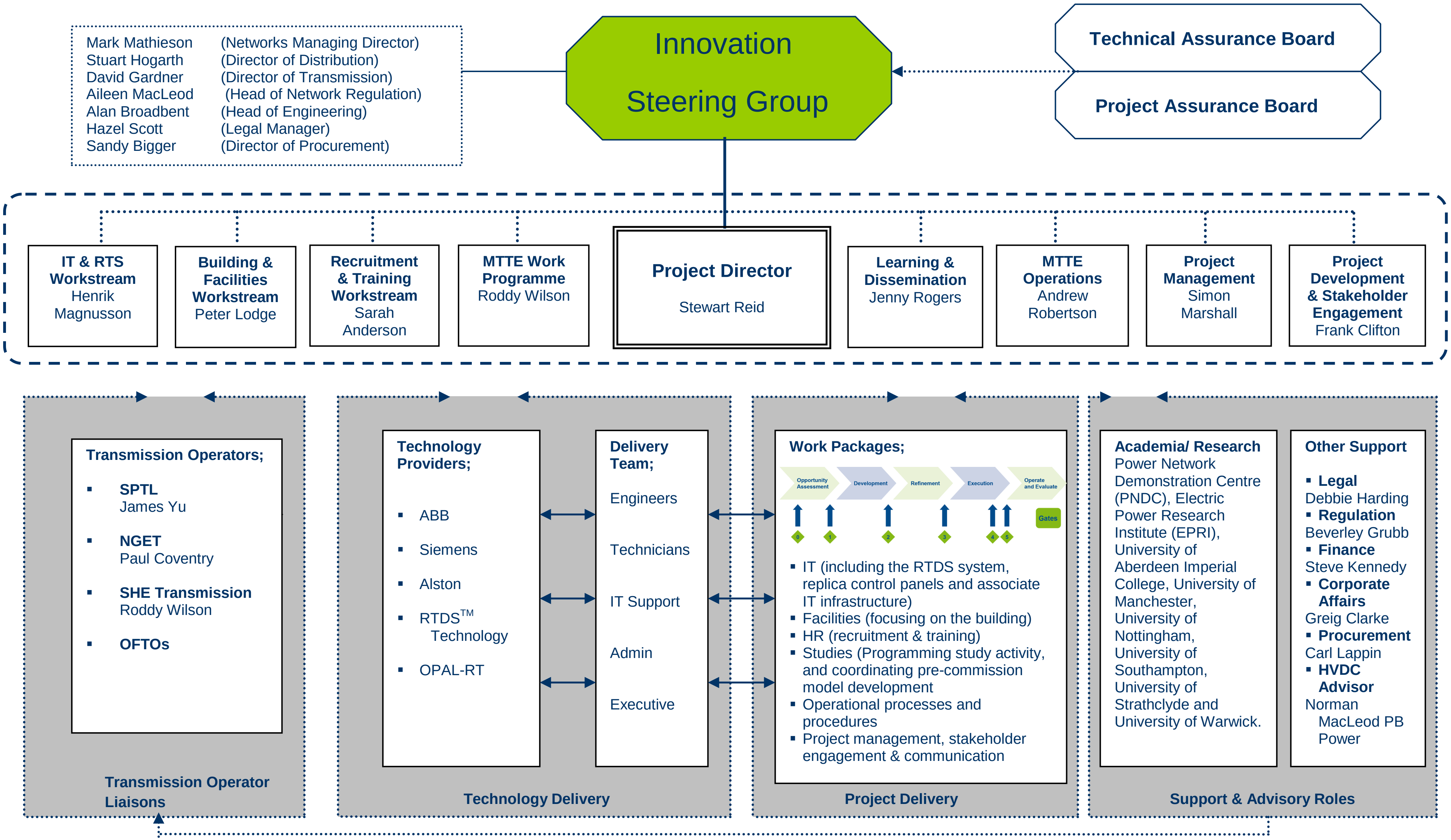

Figure 10.10 Project governance diagram, showing all project participants

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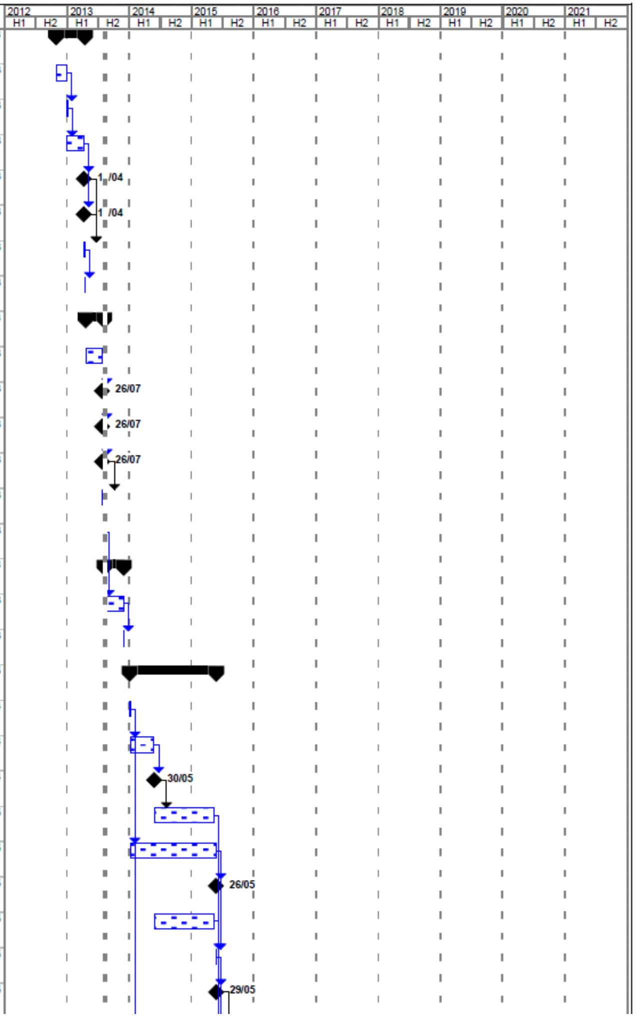
Appendix IX Project Plan: Describes the timings of the project phases, milestones and outputs.

ID	Task Name	Duration	Start	Finish
1	**Phase 1: Opportunity Assessment (Initial Submission)**	**122 days**	**Thu 01/11/12**	**Fri 19/04/13**
2	Review NIC Potential Projects (incl with NGET and SPEN)	45 days	Thu 01/11/12	Wed 02/01/13
3	Gate 0: Approval to develop the ISP for the MTTE	1 day	Thu 03/01/13	Thu 03/01/13
4	Develop MTTE Concept and ISP Document	70 days	Fri 04/01/13	Thu 11/04/13
5	Deliverables: Business Strategy and Regulatory fit Analysis, Cost Estimate Classification 0, Business C	0 days	Thu 11/04/13	Thu 11/04/13
6	Output: MTTE ISP for the NIC	0 days	Thu 11/04/13	Thu 11/04/13
7	Gate 1: Approval to Submit the ISP for the MTTE	1 day	Mon 15/04/13	Mon 15/04/13
8	Submit MTTE ISP to Ofgem	1 day	Fri 19/04/13	Fri 19/04/13
9	**Phase 2: Development (Full Submission)**	**80 days?**	**Mon 22/04/13**	**Fri 09/08/13**
10	Develop MTTE Project and Full Submission Document	70 days?	Mon 22/04/13	Fri 26/07/13
11	Deliverables: Preliminary Site Feasibility Study, Cost Estimate Classification 1, Business Case, Project [	0 days	Fri 26/07/13	Fri 26/07/13
12	Deliverables (2): Environmental Requirements, Design Development, Technology Overview & Risk Man	0 days	Fri 26/07/13	Fri 26/07/13
13	Output: Full Submission NIC Document (incl Appendices and supporting information) for the MTTE	0 days	Fri 26/07/13	Fri 26/07/13
14	Gate 2: Approval to Submit the ISP for the MTTE	10 days	Mon 29/07/13	Fri 09/08/13
15	Submit MTTE Full Submission to Ofgem	1 day?	Fri 09/08/13	Fri 09/08/13
16	**Phase 2.5: NIC Process & Decision**	**81 days**	**Mon 12/08/13**	**Sat 30/11/13**
17	Post-submission work with Ofgem to answer questions, and engage with Expert Review Panel to refine/	80 days	Mon 12/08/13	Fri 29/11/13
18	Ofgem announce funding decision	1 day	Sat 30/11/13	Sat 30/11/13
19	**Phase 3: Refinement (Design)**	**364 days**	**Mon 06/01/14**	**Fri 29/05/15**
20	Project Kick-off workshop	2 days	Mon 06/01/14	Tue 07/01/14
21	Develop Collaboration Agreements with Project Partners.	100 days	Wed 08/01/14	Tue 27/05/14
22	**SDRC: Signing-up Project Partners**	0 days	Fri 30/05/14	Fri 30/05/14
23	Develop Programme of Work, for the MTTE Studies & Test	250 days	Fri 30/05/14	Thu 14/05/15
24	Develop MTTE Design	360 days	Wed 08/01/14	Tue 26/05/15
25	Deliverables: Health and Safety Plan, Environmental Requirements, Cost Estimate Classification 2, Bus	0 days	Tue 26/05/15	Tue 26/05/15
26	Design & Build MTTE Internet Site	250 days	Mon 02/06/14	Fri 15/05/15
27	Gate 3: Approve MTTE Design	1 day	Wed 27/05/15	Wed 27/05/15
28	**SDRC: Complete Design of MTTE Facility**	0 days	Fri 29/05/15	Fri 29/05/15



29	**Pre-MTTE RTS Programme**	**760 days**	**Wed 08/01/14**	**Tue 06/12/16**
30	Design and Specify RTS System Requirements	80 days	Wed 08/01/14	Tue 29/04/14
31	Procure RTS System (Tender Process)	80 days	Wed 30/04/14	Tue 19/08/14
32	Establish Programme of RTS Activity prior to MTTE Opening	160 days	Wed 08/01/14	Tue 19/08/14
33	Run RTS Programme	600 days	Wed 20/08/14	Tue 06/12/16
34	**Phase 4: Execution (Build)**	**511 days**	**Fri 15/05/15**	**Fri 28/04/17**
35	Stage Kick-off Workshop	2 days	Fri 29/05/15	Mon 01/06/15
36	Refine Programme of Work, for the MTTE Studies & Test	400 days	Fri 15/05/15	Thu 24/11/16
37	Publish MTTE Internet Site	20 days	Thu 28/05/15	Wed 24/06/15
38	**SDRC: Design, Build and Publish Internet Site**	0 days	Mon 31/08/15	Mon 31/08/15
39	Develop operational processes and procedures	400 days	Tue 02/06/15	Mon 12/12/16
40	Recruitment & Training	420 days	Tue 02/06/15	Mon 09/01/17
41	**Building Works**	**458 days**	**Fri 29/05/15**	**Tue 28/02/17**
42	Run Tender process for Building works	60 days	Fri 29/05/15	Thu 20/08/15
43	Build MTTE Facility	350 days	Wed 28/10/15	Tue 28/02/17
44	**SDRC: Completion of Building Works**	0 days	Tue 28/02/17	Tue 28/02/17
45	**RTS & IT Infrastructure**	**43 days**	**Wed 01/03/17**	**Fri 28/04/17**
46	Install & Test RTS System	40 days	Wed 01/03/17	Tue 25/04/17
47	Install & Test IT Infrastructure	40 days	Mon 06/03/17	Fri 28/04/17
48	**SDRC: Installation, Testing & Commissioning of the RTDS and IT Infrastructure**	0 days	Fri 28/04/17	Fri 28/04/17
49	Deliverables: Health and Safety Plan, Cost Estimate Classification 3, Business Case, Operation Plan, R	0 days	Tue 25/04/17	Tue 25/04/17
50	**Phase 5: Operate and Evaluate**	**1022 days**	**Mon 01/05/17**	**Wed 31/03/21**
51	Stage Kick-off Workshop	2 days	Mon 01/05/17	Tue 02/05/17
52	**SDRC: Commence Operation of the MTTE**	**0 days**	**Wed 31/05/17**	**Wed 31/05/17**
53	MTTE Programme Work	1000 days	Wed 31/05/17	Tue 30/03/21
54	Deliverables: Health and Safety Plan, Resource Review, Quality Plan, Project Handover Plan, Lessons L	0 days	Tue 30/03/21	Tue 30/03/21
55	**SDRC: Publishing Studies & Test results**	0 days	Fri 30/03/18	Fri 30/03/18
56	Evaluate and Close down NIC Project	0 days	Tue 30/03/21	Tue 30/03/21
57	**SDRC: Project Close**	0 days	Wed 31/03/21	Wed 31/03/21

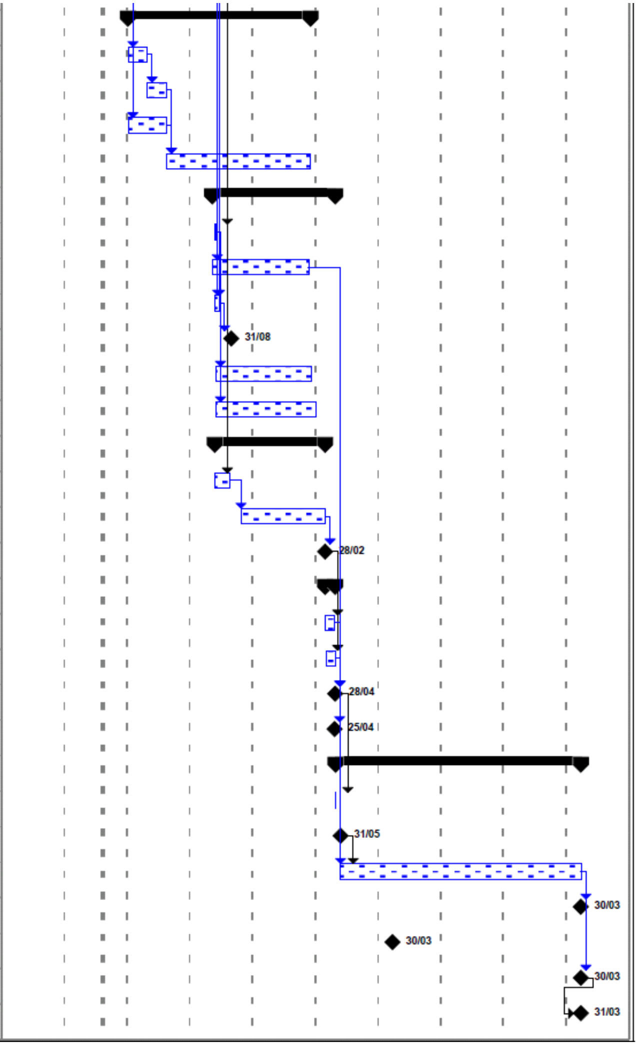


Figure 10.11 Project plan, describing the timings of the project phases, milestones and outputs

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Appendix X – Risk Register

The Risk Management Process for the MTTE is designed to address all of the relevant activities described in the 'risk house of control' shown. It is aligned with SSE's Business Risk and Internal Control Policy Framework.

This process will help to ensure that the required standards and considerations of both risks, and opportunities, are being followed. Additionally, the Risk Management Process allows for all the project level risks to be consolidated and therefore regularly and systematically reported, considered, and managed at a group level.

Risk Review Workshops shall be held during the project, which are used to identify new Risk and plan their mitigations.

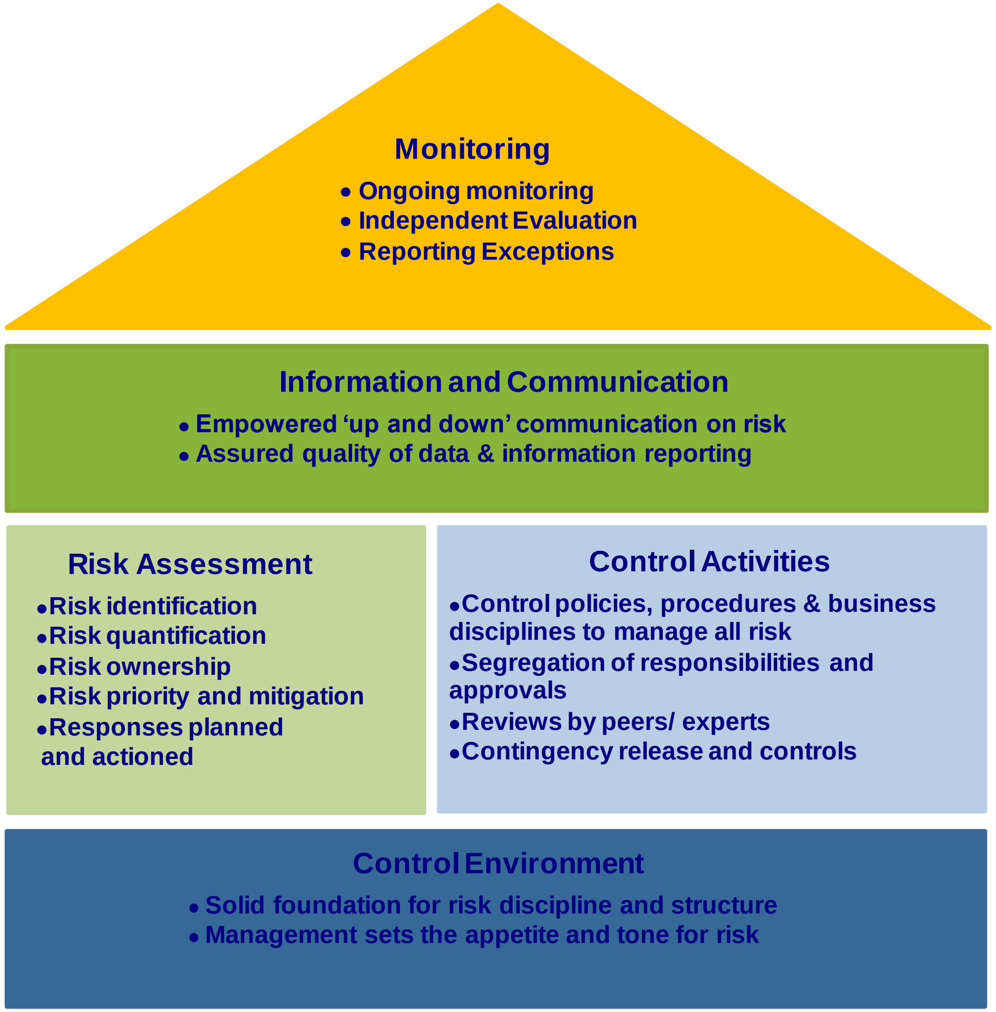

Figure 10.12 SSE 'risk house of control'

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The following table shows an extract from the project's risk register.

Table 10.8 – MTTE project risk log

Ref	Category	Title	Description	Severity or Impact				Likelihood	Risk Factor	Impact of Risk	Mitigation actions
				P	R	O	F				
R001	Collaboration	Loss of Transmission Operator partners	TOs do not sign-up to the collaboration agreement	0	0	3	3	**2**	**6**	Reduced GB-wide MTTE benefits	Agree Memorandums of Understanding with TOs about participation, followed by collaboration agreements.
R002	Collaboration	Loss of vendor partners	Vendors do not agree to participate in the project	0	0	3	3	**2**	**6**	This would impact on the ability of the MTTE to test and demonstrate multi-vender operations.	Obtain statements of support from vendors, followed by collaboration agreements.
R003	Financial	Failure of bid	The project fails to secure NIC funding	0	0	0	3	**3**	**9**	Project unlikely to proceed without NIC funding, although alternative funding would be considered.	None
R004	Financial	Incorrect cost estimates	The estimated costs are substantially different than actual costs.	0	0	3	3	**1**	**3**	Potential project funding gap, requiring alternative funding or a reduction in scope.	Major project cost estimates are based on authoritative suppler quotes;

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Ref	Category	Title	Description	Severity or Impact				Likelihood	Risk Factor	Impact of Risk	Mitigation actions
				P	R	O	F				
R005	Learning and Dissemination	Poor uptake of MTTE outputs	Low uptake of learning outcomes from MTTE	0	2	0	0	**2**	**4**	Reduction in benefit of the MTTE	Application of established knowledge management procedures.
R006	Project Management	Delayed MTTE opening	Opening of the MTTE is delayed due to unforeseen circumstances	0	0	2	3	**1**	**3**	A short delay could entail reputational damage but would not significantly reduce the benefits.	The project will be managed in accordance with SSEPD's Major Projects Governance Framework.
R007	Project Management	Commercial failure of MTTE	A sustainable business model is not achieved for the MTTE	0	0	3	3	**2**	**6**	MTTE would be closed or taken over by a single TO, with the objective to recover investment.	Self-sustaining commercial model developed with project partners from the outset.
R008	Resourcing	Failure to recruit or loss of critical operational staff	Failure to recruit or retain essential skilled personnel	0	0	2	2	**4**	**8**	Quality/quantity of studies performed in the MTTE would be reduced.	Collaboration with vendors and academia to negotiate resourcing.
R009	Resourcing	Insufficient resources for project delivery	Unavailable skills and training impact on project delivery	0	0	1	1	**1**	**1**	Delays in resourcing project team would delay project delivery	Key project team resources have already been identified and have committed to the project.
R010	Resourcing	Discontinuity in project team	Lack of continuity in the project team resource during project	0	0	1	0	**3**	**3**	Potential negative impact on project delivery.	None identified

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Ref	Category	Title	Description	Severity or Impact				Likelihood	Risk Factor	Impact of Risk	Mitigation actions
				P	R	O	F				
R012	Technical	Cancellation of multi-terminal HVDC in GB	The two planned multi-terminal links in GB are cancelled; no other multi-terminal links in GB go ahead.	0	0	3	3	**2**	**6**	Reduced MTTE benefit. However, MTTE outputs also applicable to point-to-point HVDC links.	The project has no control over this risk.
R013	Technical	Unsuitability of multi-terminal HVDC for GB	MTTE demonstrates that multi-terminal or multi-vendor HVDC is not feasible for GB.	0	0	0	1	**1**	**1**	Considered to be a benefit, since it could save significant capital spend.	The limited multi-terminal and multi-vendor links in operation globally confirm their technical feasibility
R014	Technical	Failure to interface with control panels	Failed interfacing between the RTS system and the replica control panels supplied by vendors.	0	0	1	1	**1**	**1**	Functionality and corresponding outputs of the MTTE would be limited.	Vendors currently test equipment using an RTS system and suitable interfaces, which will also be supplied to MTTE.
R015	Technical	RTS Failure	RTS system unable to simulate more complex future 5-terminal HVDC systems	0	0	2	1	**1**	**2**	Limitation on the studies undertaken by the MTTE	RTS tender process will detail the required modelling capability

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Appendix XI – Mitigation & Contingency Plans

The following Table shows the mitigation measures which we would adopt for the seven risks in described in the Risk Register which have a risk factor of 6 or above.

Table 10.6 MTTE project risk mitigation measures

Ref	Risk	Immediate Actions	Interim Measures	Long Term Recovery
R001	Collaboration - Loss of Transmission Operator partners - TOs do not sign-up to the collaboration agreement	Assess impact on overall project delivery	Identify alternative partners if impact is sustained	Review possible modifications to commercial agreements with TO partners
R002	Collaboration - Loss of vendor partners - Vendors do not agree to participate in the project	Assess impact on overall project delivery; Continue modelling tasks at MTTE while other contingency measures are taken	Identify alternative technology vendors / seek specialist support as required	Review possible modifications to commercial agreements with vendors; Review alternative technologies - identify where equipment specification can be widened
R003	Financial - Failure of bid - The project fails to secure NIC funding	Inform project partners; Review project scope; Suspend pending orders	Lessons learnt exercise; Modify agreements with project partners; Source alternative resources to continue the project.	Continue contribution and assistance with other NIC initiatives as appropriate
R007	Project Management - Commercial failure of MTTE - A sustainable business model is not achieved for the MTTE	Review MTTE schedule of work	Develop remedial plan	Review possible modifications to MTTE commercial model

Ref	Risk	Immediate Actions	Interim Measures	Long Term Recovery
R008	Resourcing – Failure to recruit or loss of critical operational staff – Failure to recruit or retain essential skilled personnel	Assess impact and escalate with affected partner organisation(s) as appropriate. Identify tasks which could be placed at risk.	Assess if task or role can be supported by SHE Transmission or another partner. If impact is sustained, consider if work schedule can be amended without affecting overall deliverables.	Completion or cancellation of specific tasks - cancellation only with consent from relevant stakeholders.
R011	Technical - Failure to secure Caithness-Moray HVDC replica control panels - CM project does not supply replica control panels to the MTTE, or the use of the panels is contractually limited.	Assess significance to delivery of outputs and discuss alternative programme phasing with project partners.	Modify MTTE work programme if necessary to ensure continued value	Review possible modifications to commercial agreements with CM project.
R012	Technical - Cancellation of multi-terminal HVDC in GB - The two planned multi-terminal links in GB are cancelled; no other multi-terminal links in GB go ahead.	Immediately review MTTE schedule of work	Develop remedial plan	Modify scope of works undertaken at MTTE to ensure relevance to HVDC links which do proceed in GB

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Appendix XVI – List of Figures & Tables

Pro-forma Figures

Appendices Figures & Tables

Figures

Tables