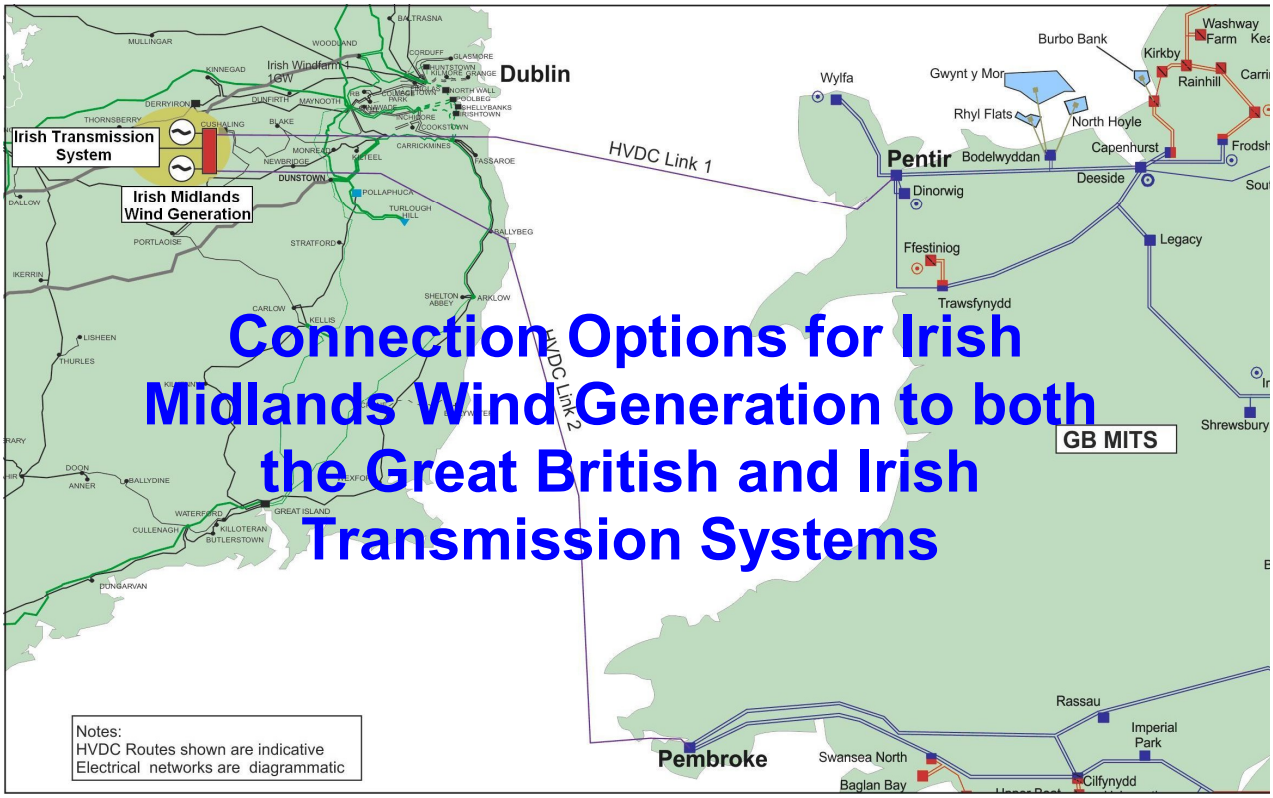

Connection Options for Irish Midlands Wind Generation to both the Great British and Irish Transmission Systems

30th January 2013

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Foreword

National Grid Electricity Transmission is in the process of making and has already made connection offers for large scale renewable energy export projects in Ireland that would access the renewable energy market in Great Britain. In that context, a formal Memorandum of Understanding (MoU) on renewable energy trading between Ireland and the United Kingdom was signed in early 2013 by the two Governments with a view to it leading to a full inter-governmental agreement.

Against this background, National Grid and EirGrid, in our roles as Transmission System Operators (TSOs) for the Great British and Irish transmission systems respectively, have undertaken a joint technical study to consider how best to coordinate the infrastructure associated with the renewable energy projects with network developments in and between both countries. The study examines the design and operation of an integrated network between Great Britain and Ireland and explores the wider network development value provided by one or more connections to the Irish transmission system[1]. It concludes that such an integrated network could provide similar benefits as another East-West Interconnector type project, but at a fraction of the cost.

The successful development of such projects presents technical, regulatory and political challenges that will have to be overcome. However, the delivery of an innovative, efficient, and economic design solution would facilitate greater electricity market integration and result in enhanced competition and lower electricity prices thereby benefitting network customers on both islands as well as the renewable generation developers.

[1] These connections hinge on the successful development of an integrated network of renewable energy export projects in the Midlands of Ireland that are connected to Great Britain.

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Executive Summary

Several developers have proposed the building of large-scale renewable energy export projects in Ireland that would access the market for renewable energy in Great Britain. This study is based on proposed projects that may connect directly to the Great Britain Main Interconnected Transmission System (GB MITS) via two or more High Voltage Direct Current (HVDC) links. Figure 1 shows one such possible connection method for wind generation located in the Irish Midlands.

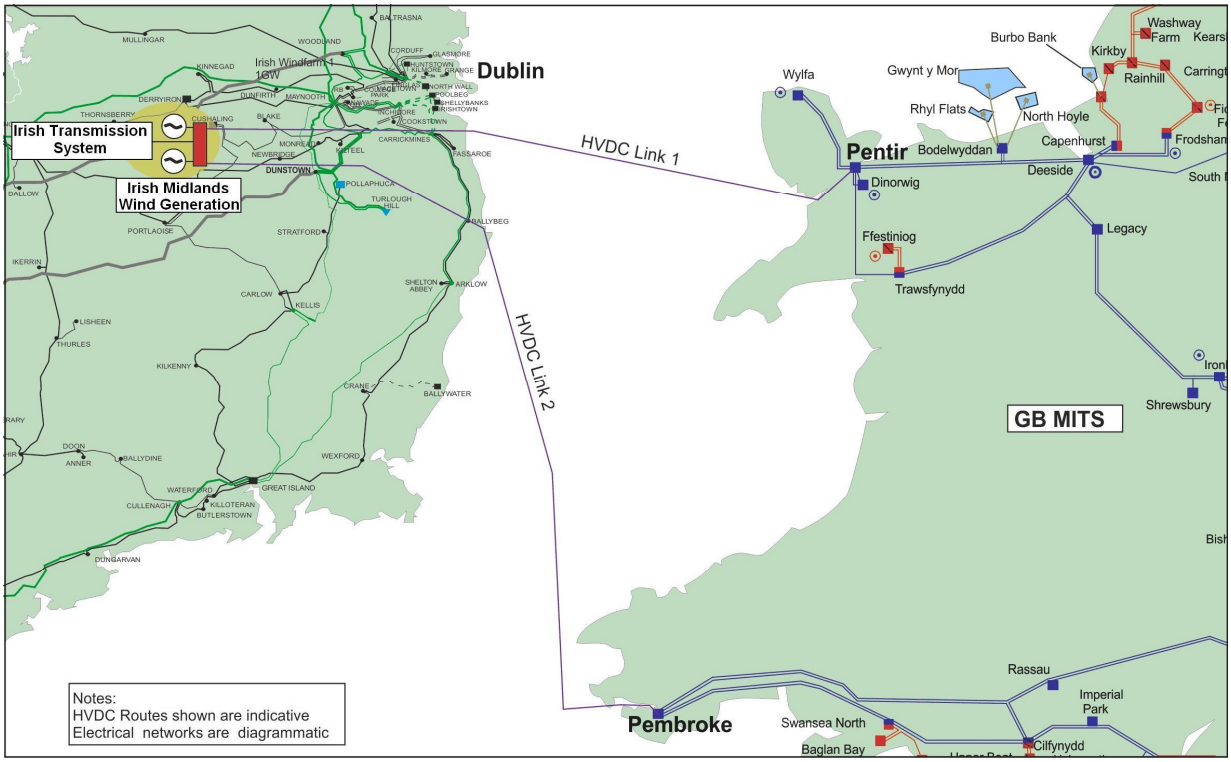

Figure 1: A potential generic connection method for wind generation in the Irish Midlands to the Great Britain and Ireland transmission systems.

National Grid and EirGrid are the Transmission System Operators (TSOs) for the Great Britain and Ireland Transmission Systems respectively. In these roles, a joint study has been undertaken to consider the coordination of the infrastructure associated with the renewable energy projects with network development in and between both islands. In particular, this study examines different connection options[2] from the renewable energy projects in Ireland to the Irish transmission system and compares these to a scenario with no connection. Technical standards, ownership and operating frameworks were outside

[2] This study does not presuppose the regulatory framework under which a connection option would be delivered.

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the scope of the study but it is envisaged that they would need to be agreed by the TSOs. As a starting point, the study has concentrated on a possible 3 GW of wind generation located in the Irish Midlands consistent with existing strategic development of GB MITS. It has also considered to a lesser extent the possible connection of 5 GW of wind generation. A number of potential connection options for this "Integrated with Interconnection"[3] project have been examined in detail, with the studies performed considerate of what is practical, current technical, regulatory and political issues, and the costs and benefits. This integrated planning approach is more robust and efficient to different possible future development scenarios including ensuring connection of future prospective renewable projects both onshore and offshore can be facilitated. The most appropriate sites for connection would be selected and these sites would be made available to all eligible developers and not just for one developer who might under utilise the connection. In addition, co-ordinated development could avoid or defer network reinforcements on both networks and also facilitate cost-effective interconnection between the Irish transmission system and GB MITS.

The Benefits of Interconnection

In particular, the studies focussed on the incremental costs and benefits arising from incorporating one or two connections of 0.5 - 0.7 GW each to the Irish transmission system relative to a scenario with no such connection. Different connection capacity sizes (ranging from 0.5 GW to 1.4 GW) were considered as part of the analysis, while the suitability of four separate potential connection points on the Irish transmission system was examined. In addition, different technologies for connection have been considered. The ability of the Great Britain MITS to accommodate the additional power arising from the interconnection and the increase in additional transmission capacity was also analysed.

The benefits identified and assessed in the study include:

- production cost savings from trading between the two markets,
- the benefit to the Irish transmission system of shared reserve/response,
- reduction in the total generation capacity required to maintain security of supply on the Irish transmission system,

[3] A radial connection approach was deemed inefficient in previous National Grid Electricity Transmission analysis.

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- potential increase in boundary transfer capability on the Great Britain system[4].

For a single 0.5 GW connection (between the 3 GW of Irish Midlands Wind Generation network and the Irish transmission system) for example, the studies show the annual benefits to be £61m p.a. / €75m p.a. with approximately 35% arising from trading, 20% from the sharing of reserve/response, 40% from generation capacity savings, and 5% from an increase in boundary transfer capability on the Great Britain system. The trading benefits accrue to both Great Britain and Ireland. The identified benefits from sharing reserve/response and the provision of generation capacity are those accruing to Ireland only. The benefits accruing to Great Britain from these two aspects have not been assessed but would be lower as the smaller Irish power system would have difficulty in consistently providing comparable levels of reserve and spare generation to Great Britain. These benefits are not available under a direct connection "developer led" approach because there would be no connection to the Irish transmission system. In addition, given the scale of proposed development, there is the potential to reduce the need for infrastructure required for other purposes and reduce consumer costs.

Moreover, the Third Package Directive (2009/72/EC) advocates that "cross-border interconnections should be further developed in order to secure the supply of all energy sources at the most competitive prices to consumers and industry within the Community". Greater interconnection between Great Britain and Ireland would help facilitate implementation of the target model for electricity market integration. This will not only result in enhanced competition and lower electricity prices, but will also facilitate greater renewable energy penetration and increase security of supply on the two islands.

The Cost of Interconnection

The cost of connection to the Irish transmission system is composed of two components; the capital cost of the connection to the Irish substation, and the capital cost of any deep network reinforcements required. The capital cost of the connection to an Irish substation depends on the connection technology employed. Given the short distances involved for this connection, HVDC is likely to be more expensive but may deliver other benefits compared to HVAC, which has certain associated risks that would need further analysis. A range of different connection options and technologies were evaluated based on their

[4] The potential benefits of avoided/deferred investment on the Irish transmission system have not yet been assessed.

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capital costs, their impact on system operation, their complexity, and deliverability.

The preferred technology option is a multi-terminal[5] HVDC connection from the Irish Midlands Wind Generation station to the Great Britain MITS with a single associated AC-DC converter connecting into the Irish system (Network Interconnection Option 20)

In addition, a second new interconnection would also provide clear benefits albeit slightly lower than the benefits provided by the first interconnection. However, the infrastructure costs associated with the increase in power transfer to the GB MITS has not yet been assessed. Further studies are needed to definitively prove the economic case for the second new interconnection. Assuming that there is an economic case, this interconnection could be progressed at a later stage to the first interconnection or alternatively both could be progressed in parallel.

An initial estimate of the timelines required indicates that either option could be progressed so as to align with timescales established by the wind generation project developers. Alternatively, interconnection options could be progressed at a later stage independently of the works associated with the wind generation connection. However, there are technical issues that need to be advanced and regulatory frameworks that need to be developed in order to deliver the recommended concept (or any variation on it) and enable wind generation based in Ireland to successfully connect to the Great Britain MITS.

Developing the Interconnection

Based on the studies performed, the appropriate size for initial connections to the Irish transmission system is 0.5 GW. However, the links could be constructed at a higher capacity (e.g. 0.7 GW) for “future-proofing” at relatively little extra cost. The additional cost of construction of a 0.7 GW link relative to a 0.5 GW link has been used in the capital cost

[5] Multi-terminal HVDC Current Source Conversion (CSC) schemes currently in operation include the 2 GW Quebec – New England system and the 0.3 GW Sardinia–Corsica–Italy system. Planned Multi-terminal HVDC Voltage Source Conversion (VSC) schemes include Kreigers Flak (between Germany and Denmark), Moray Firth Offshore Hub (Scotland), and the Cobra scheme linking the Netherlands and Denmark.

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estimation. Woodland and Dunstown, two 400 kV stations located to the North-West and South-West of Dublin respectively as shown in Figure 2, have been identified as the most appropriate connection points on the Irish transmission system. Once the locations of the specific generation developments are known, further studies would be required to confirm the optimal connection points on the Irish transmission system.

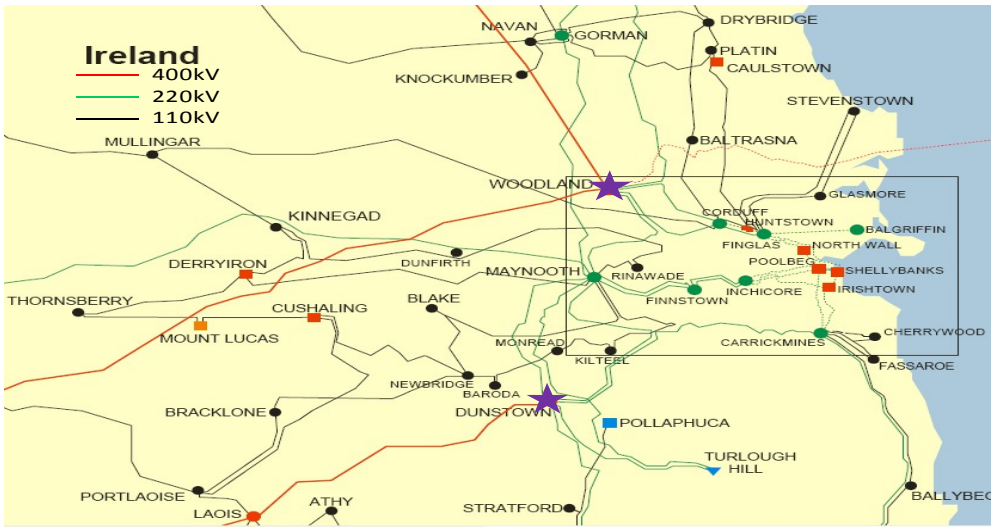

Figure 2: Woodland and Dunstown, the most appropriate connection points on the Irish system.

An interconnector sized at 0.5 GW can be accommodated at both Woodland and Dunstown while the additional power flows from Ireland to Great Britain can be accommodated on the GB MITS without driving a need for new build network reinforcements on either network. However, a number of uprates are required to facilitate the connections on the Irish transmission system, at an estimated total cost of

In addition, a capacity of 0.5 GW aligns with the current maximum in-feed on the Irish system thereby avoiding additional operating constraints (e.g. higher reserve requirement) implicit with a higher in-feed.

In summary, there are significant synergies to be achieved if an optimal integrated network approach is adopted with the potential to convey significant benefits to network customers on both islands as well as developers. To take this forward, there is a requirement for cross-industry technology innovation while developments are also required in the political and regulatory space in order to allow these projects to proceed regardless of the development option chosen. It is important that the next steps are progressed as soon as possible.

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Table of Contents

FOREWORD ..... **I**

EXECUTIVE SUMMARY ..... **II**

1 INTRODUCTION **1**

2 BACKGROUND **4**

2.1 GENERIC GENERATION SCENARIOS 5
2.2 NETWORK INTERCONNECTION OPTIONS 5
2.3 GB AND IRISH TRANSMISSION SYSTEM CONNECTION POINTS 6
2.4 POWER SYSTEM MODELLING METHODOLOGY 6

3 PREFERRED CONNECTION AND NETWORK INFRASTRUCTURE OPTIONS **8**

3.1 NETWORK INTERCONNECTION OPTION 1 (BASE CASE FOR 3 GW NIO) 15
3.2 NETWORK INTERCONNECTION OPTION 8 17
3.3 NETWORK INTERCONNECTION OPTION 9 20
3.4 NETWORK INTERCONNECTION OPTION 9A 23
3.5 NETWORK INTERCONNECTION OPTIONS 11 AND 14 25
3.6 NETWORK INTERCONNECTION OPTIONS 12 AND 15 27
3.7 NETWORK INTERCONNECTION OPTIONS 17 AND 20 29
3.8 NETWORK INTERCONNECTION OPTIONS 18 AND 21 32
3.9 NETWORK INTERCONNECTION OPTION 2 (BASE CASE FOR 5 GW NIO) 34
3.10 NETWORK INTERCONNECTION OPTION 22 36

4 BENEFIT OF NETWORK INTERCONNECTION OPTIONS **38**

4.1 TRADING BENEFIT 38
4.2 GENERATION CAPACITY VALUE 40
4.3 RESPONSE AND RESERVE SHARING VALUE 40
4.4 CONGESTION VALUE 41
4.5 BENEFIT SUMMARY 42

5 NETWORK INTERCONNECTION AND DEEP REINFORCEMENT CAPITAL COSTS **44**

5.1 GB TRANSMISSION CAPITAL COSTS 44
5.2 CAPITAL COST OF CONNECTION TO THE IRISH SYSTEM 47
5.2.1 Network Interconnection Option 8 Capital Costs 47
5.2.2 Network Interconnection Option 9 Capital Costs 47
5.2.3 Network Interconnection Option 11 and 14 Capital Costs 47
5.2.4 Network Interconnection Option 12 and 15 Capital Costs 47
5.2.5 Network Interconnection Option 17, 20 and 22 Capital Costs 47
5.2.6 Network Interconnection Option 18 and 21 Capital Costs 48
5.3 DEEP REINFORCEMENTS ON THE IRISH SYSTEM 48
5.3.1 Summary of Deep Reinforcement Costs on the Irish System 50
5.3.2 Sensitivity Study for 0.7 GW 50

6 COST-BENEFIT ANALYSIS **51**

7 PLANNING AND ENVIRONMENTAL CONSIDERATIONS **54**

7.1 NETWORK BENEFITS TO THE IRISH SYSTEM (AVOIDED/DEFERRED INVESTMENT) 54
7.2 NETWORK BENEFITS TO THE GB MITS (AVOIDED/DEFERRED INVESTMENT) 54
7.3 IRELAND ENVIRONMENTAL AND PLANNING CONSIDERATIONS 54
7.3.1 Planning and Development Acts 2000-2011 54
7.3.2 Exempted Development Status 55
7.3.3 Appropriate Assessment 58
7.3.4 Environmental Impact Assessment Thresholds 60
7.4 UK PLANNING AND ENVIRONMENTAL CONSENT CONSIDERATIONS 60
7.5 PROJECT DELIVERABILITY AND TIMELINES 64
7.5.1 Deep Reinforcement Leadtimes 64

NATIONAL GRID/EIRGRID CONFIDENTIAL

8 OTHER CONSIDERATIONS 65

8.1 VSC HVDC TECHNOLOGY CONSIDERATIONS 65
8.1.1 Cable Technologies 66
8.1.2 Multi Terminal 67
8.2 FACTORS AFFECTING IRISH TRANSMISSION SYSTEM OPERATION 68
8.3 FACTORS AFFECTING THE GREAT BRITAIN MAIN INTERCONNECTED TRANSMISSION SYSTEM OPERATION 72
8.4 FLEXIBILITY 73
8.5 MARKET INTEGRATION 73
8.6 POLITICAL AND REGULATORY FRAMEWORK 74

9 CONCLUSIONS 76

10 RECOMMENDATIONS 79

APPENDIX A – DETAILED SYSTEM MODELLING ANALYSIS RESULTS 82

A.1 EIRGRID NETWORK MODELLING 82
A.1.1 Study Objectives 83
A.1.2 Methodology 84
A.1.3 Assumptions 85
A.1.4 Results 86
A.1.5 Costs 89
A.1.6 Conclusion 90
A.2 NATIONAL GRID NETWORK STUDY THERMAL ANALYSIS 91
A.2.1 Study Assumption and Sensitivities 91
A.2.2 Transmission Reinforcements 92
A.2.3 DC Thermal Results for Connections at Pentir and Pembroke 400 kV 94
A.2.4 Analysis of Increase in Boundary Transfer Capability or Congestion Value 97
A.2.5 Voltage Issues 98
A.2.6 Fault Levels 99
A.2.7 Transient Stability Limits 99
A.2.8 Conclusions 99

APPENDIX B – GB MITS BOUNDARIES 101

B.1 GB MITS TRANSMISSION BOUNDARIES 101

APPENDIX C – RECOMMENDED TOR AND MODELLING 103

APPENDIX D – GLOSSARY OF TERMS 105

APPENDIX E – INTEGRATED VS RADIAL SYNOPSIS 107

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1 Introduction

National Grid is in the process of making and has already made connection offers for large scale renewable energy export projects in Ireland that would access the renewable energy market in Great Britain (predominately connecting at Pentir and Pembroke 400 kV substations). To potentially optimise these connection designs, National Grid and EirGrid, in their roles as Transmission System Operators (TSOs), have undertaken a joint study to compare base case "Integrated"[6] and "Integrated with Interconnection"[7] options to coordinate network developments in and between both countries to inform an optimal integrated network approach[8]. This will also maintain network flexibility and keep options open whilst the necessary regulatory arrangements develop.

In particular, the study specifically explores the wider value provided by an additional connection to the Irish transmission system. The analysis undertaken forms the first step of the investigations that the TSOs would typically go through in transmission planning, although the planning process for such a hybrid network infrastructure has not yet been defined.

This report presents the results of the analysis of twelve different network designs against a 3 GW Irish Midlands Wind Generation[9] scenario, and two different network designs against a 5 GW scenario[10]. Comparisons of network designs incorporating a connection to the Irish transmission system have been made against a base case purely "Integrated" design (one for 3 GW and one for 5 GW) based on benefits, capital costs, impact on system operation, complexity, and deliverability. An overview of the potential benefits arising from incorporating a connection to the Irish transmission system in the overall connection design and which are discussed or assessed in this report is provided below:

- Increase in power trading capability between the Irish and Great British systems

[6] **Integrated** - the connection of Irish Midlands Wind Generation directly to the GB MITS with no connection to the Irish transmission system.
[7] **Integrated with Interconnection** - the connection of Irish Midlands Wind Generation to both the GB and Irish Transmission Systems.
[8] This is the coordination of renewable energy export generation developers and existing Transmission System Operators to deliver the most innovative, efficient and economic design solution.
[9] The renewable energy export generation will be refered to as Irish Midlands Wind Generation throughout the report (see Appendix D for a Glossary of Terms).
[10] Two 5 GW options have been considered for comparison with the 3GW option.

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via the generator connection circuits (over and above that already available on the EWIC and Moyle interconnections)[11].

- Ability to share response and reserve between the GB MITS and the Irish system (up to 0.2 GW).

- A potential increase in boundary transfer on the GB MITS with respect to North to Midlands (B8) and the Midlands to South (B9)[12] and a possible reduction in the level of AC interconnection required between the Irish Midlands Wind Generation collector stations, through the ability to "wheel" power through the Irish transmission system.

- A reduction in the boundary transfers on the GB MITS North Wales exports (NW2, NW3 and NW4) by exporting power through interconnection to the Irish transmission system.

- An ability to reduce congestion on South to North power transfers on the Irish system.

- The coordination of connection works in Ireland to reduce onshore reinforcement works on the GB and Irish transmission systems.

- Increased connectivity (with interconnection to the Irish transmission system) providing greater transmission circuit redundancy to the Irish Midlands Wind Generation.

- Provision of generation capacity to the GB MITS and Irish transmission system.

Section 2 briefly outlines the project background and defines the assumptions used in the study as well as setting out the requirements for the Network Interconnection Options

[11] All network interconnected options to the Irish network provide the capability to exchange power between Great Britain and Ireland. As such, these additional transmission assets achieve the same function as a new Great Britain-Ireland interconnector.
[12] GB MITS boundary diagrams area included in Appendix B.

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(NIO). In Section 3, each NIO is described and "optioneered" to identify the preferred design concept. This is followed by Sections 4 and 5, which detail the measured benefits of the network designs (based on the ENTSO-E 2020 market data), and National Grid and EirGrid indicative capital costs for network connection and infrastructure, respectively. An initial evaluation of the costs and benefits was performed, and the results are presented in Section 6. Environmental and Planning considerations are then briefly described in Section 7. In Section 8, a technical evaluation of the High Voltage Direct Current (HVDC) Voltage Source Converter (VSC) technologies and the potential risks is presented. In addition, this section also outlines other considerations including operational, flexibility, political and regulatory factors. Section 9 presents the main conclusions of the report. Section 10 presents a number of recommendations for next steps to guide the future direction of this project.

It is important to note that this type of generation connection does not fit into any existing regulatory framework for either Great Britain or Ireland. There are ongoing discussions with the respective authorities[13] on how this type of generation connection should be treated. At this stage, it is clear that developments in the political and regulatory space will be required if wind generation in Ireland is to successfully connect to the GB MITS.

Overall, this report serves as an initial assessment to begin to understand the extent of the technical and operational issues of potential "Integrated with Interconnection" designs between National Grid and EirGrid. Further work will be required to fully determine and understand all the benefits, costs and risks associated with any preferred Network Interconnection Option.

[13] For National Grid - Department of Energy and Climate Change and Ofgem; for EirGrid – Department of Communications, Energy and Natural Resources and Commission for Energy Regulation.

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2 Background

National Grid have connection offers that have been signed by developers, offers that are currently being considered by developers, while other developers are in the application process with regard to the connection of large-scale renewable energy export projects in Ireland and in the Irish Sea to the GB transmission system. The proposed projects consist of large wind generation developments and other developments in Ireland that could connect directly to the Great Britain transmission system. This generation could be connected either in a radial configuration or as part of a wider integrated network solution.

Previous National Grid Electricity Transmission strategic analysis concluded that there are significant benefits to be achieved with an integrated network over radial connections for the anticipated level of renewable generation in Ireland and the Irish Sea[14]. With an integrated approach, interconnection between projects enables network cables to provide transmission capacity to the onshore transmission owner when under utilised by the renewable generation and this offsets the need for some onshore reinforcements. Also, an integrated network has fewer and higher rated cables than a radial connection, which leads to reduced capital expenditure, greater use of installed network capacity, increased connectivity providing greater transmission circuit availability to the renewable generation and reduced operating costs for the transmission system operator.

This optimised “Integrated” design concept is used as a base case in this analysis and compared to “Integrated with Interconnection” [15] developments with the Irish transmission system. This is conceptually considered as a way to further improve the integrated designs by utilising transmission capacity on low wind days to increase the trading between the two markets.

This study explores network interconnected design options against a generic generation and network scenario, which can be related back to the requested developer connections and are consistent with network development strategies for both National Grid and EirGrid.

[14] A radial connection approach was considered inefficient due to the significant onshore reinforcements required to facilitate such connections, plus the higher overall costs and the reduction in transmission flexibility. A synopsis of the previous analysis is included at Appendix E.

[15] These interconnections hinge on the successful development of an integrated network of renewable energy projects in the Midlands of Ireland that are connected to Great Britain.

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2.1 Generic Generation Scenarios

Three generic wind generation capacity scenarios were envisaged for this joint study and these are listed below:

- High 7GW of connected wind generation
- Medium 5GW of connected wind generation
- Low 3GW of connected wind generation

Due to time constraints and reflecting a likely staged connection of the generation, the initial studies concentrated on the Low scenario. However, some initial comparison work has been conducted for the Medium scenario to identify potential additional benefits. The Medium and High wind generation scenarios will be studied in detail at a future date. It is worth noting that for the Medium and High wind generation scenarios, the prospect of having larger interconnection block sizes might be a possibility (for instance, if there were multiple parallel interconnections to the Irish transmission system) but further study work would be required to determine both the acceptable block size that could be accommodated and also the optimum interconnection points for these larger integrated generation connections.

EirGrid and National Grid have used 2020 generation backgrounds to analyse the impact on their respective transmission systems. The backgrounds were adapted to accommodate the Irish Midlands Wind Generation and the interconnected transfer, plus the potential of significant volumes of wind generation capacity in the Irish Sea.

2.2 Network Interconnection Options

The generic Network Interconnection Option (NIO) configurations considered in the report for comparison are:

- **Integrated** - The connection of Irish Midlands Wind Generation directly to the GB MITS with no connection to the Irish transmission system.

- **Integrated with Interconnection** - The connection of Irish Midlands Wind Generation to both the GB MITS and Irish Transmission System.

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The number of HVDC links considered between Great Britain and the Irish Midlands Wind Generation in Ireland depended on the generation scenario; for 3 GW and 5 GW connections the number of HVDC links assumed was two and three respectively. Each HVDC link was assumed to have a power transfer capacity of 2.5 GW[16].

2.3 GB and Irish Transmission System Connection Points

The optimum HVDC VSC link rating of 2.5 GW and the connection points into the GB transmission system have been assessed by National Grid in a previous internal strategy paper[17]. The NIOs considered here are consistent with this strategy for the 3 GW generation connection scenario and the 5 GW generation connection scenario has assumed a connection of the third HVDC Link into South Wales rather than the South West of England. Both generation connections are dependent on the proposed North to South Wales reinforcement, which is currently proposed to be the Wylfa – Pembroke HVDC VSC Link.

EirGrid considered and studied interconnection into four potential Irish substations at Woodland, Laois (planned station), Maynooth and Dunstown. EirGrid also identified another possible connection point in the south-east of Ireland, Great Island, which could potentially alleviate further reinforcement on the Irish system. Given the distance from the likely location of developer wind generation collector station sites in the midlands, it was excluded from the scope of this study. However, a co-ordinated approach to the cable routing could potentially deliver benefits from avoided investment on the Irish transmission system.

2.4 Power System Modelling Methodology

Power system modelling was restricted to Great Britain, Ireland and Northern Ireland only. DC thermal studies, Plexos market studies and generation adequacy studies have been conducted against a 2020 base case and adjusted as required.

Network Security Studies: PSS/E was used to model the Irish transmission system and DigSilent PowerFactory software was used to model the GB MITS.

[16] The technical issues and risks associated with this HVDC VSC technology are discussed in Section 8.
[17] National Grid, Strategy for connection of new generation in and around Wales, 3 April 2012.

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Market Modelling: A market model for 2020 based on TSO-approved generation forecasts for the ENTSO-E Ten Year Network Development Plan (TYNDP) 2012 was used as the basis for the Plexos studies. Great Britain, Ireland and Northern Ireland were modelled in detail with fixed hourly power flows between Great Britain and the rest of Europe based on the results of a full seventeen-country Pan-European model.

Generation Adequacy Studies: EirGrid's AdCal generation adequacy assessment tool was used to estimate the capacity benefit to the Irish system from one or more connections to the Irish transmission system.

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3 Preferred Connection and Network Infrastructure Options

The Network Interconnection Options (NIOs) considered in this study are described in this section. The study predominantly focuses on 3 GW generation connection options, twelve of which are examined in this section, but also evaluates two 5 GW generation connection options for comparative purposes. Option 1 (a purely "Integrated" design) constitutes the Base Case NIO for comparison with the different "Integrated with Interconnection" 3 GW NIOs that incorporate a connection to the Irish transmission system. The following paragraphs detail the technical assumptions and value definitions that are common across all NIOs.

Network Interconnection Options Assumptions: All NIOs include High Voltage Direct Current (HVDC) Voltage Source Conversion (VSC) links from the Irish Midlands Wind Generation to the GB Main Interconnected Transmission System (MITS) and an AC connection between the Irish Midlands Wind Generation collector stations. The key assumptions are described below:

- **HVDC Link Technology:** The technology for these links was assumed to be 2.5 GW HVDC VSC for all of the NIOs. To date, no VSC link of this rating has been commissioned. However, discussions with manufacturers have indicated that these ratings are achievable with developments to existing technology, mainly with respect to Insulated Gate Bipolar Transistors (IGBTs) and HVDC cables[18]. Additionally, it was assumed that the HVDC VSC links would be instantaneously responsive following a fault contingency and fluctuations in generator outputs.

- **Block sizes of generation connected to make up the 3 GW and 5 GW connections of wind:** It was assumed that wind generation block sizes for each NIO would be 0.5 GW, which has a material impact on Largest Single In-feed Loss / In-feed Loss Risk limits in both networks. The 0.5 GW blocks are based on typical 400/220 kV or 400/110 kV transformers and associated internal wind generator collector radial cable feeder circuit capacities.

[18] It is anticipated that the HVDC cables required for the National Grid Western Link project will be type registered later this year and this will be prior to the decision point to commit to the design concepts presented in this report.

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- **HVAC Network Connections between Wind Collector Stations:** It is assumed that the High Voltage Alternating Current (HVAC) connection transfer capacity does not restrict the required transfer capability for any NIO[19]. Also, due to the likely short distance between the Irish Midlands Wind Generation collector substations, it is assumed that AC transmission equipment will be the most economic and efficient connection technology.

- **Midland Wind Generation Collector Substation Configuration:** It is assumed that intact substation design will limit less probable faults (busbars or couplers) to only the loss of 0.5 GW wind generation block sizes.

GB MITS and Irish Transmission System Contingencies: Respective transmission systems were secured against each TSO's security standards[20]:

- National Grid secure against N-2 and N-D fault contingencies in planning timescales while N-3 studies are carried out for summer background conditions where applicable. For N-2[21] and N-D fault contingencies on the circuits out of North Wales, fast power ramp-up and ramp-down (in stability timescales) is required on the HVDC Link from Wylfa to Pembroke for all generation backgrounds considered.

- EirGrid secure to N-1 fault contingency. The majority of the Irish transmission system is composed of single circuit transmission lines (the exception being the double circuit 275 kV line between Louth in Ireland and Tandragee in Northern Ireland).

Capital Costs: These are estimated, subdivided into National Grid and EirGrid connection costs, and then compared across the different NIOs. The cost of the generation connection

[19] The optimum rating for the HVAC interconnection will be determined in subsequent studies and for HVDC multi-terminal connections HVDC links between Irish Midlands Wind Generation collector stations were not considered.
[20] For National Grid these are the National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS) and for EirGrid these are the Operating Security Standards (OSS) and Electricity Supply Board National Grid Transmission Planning Criteria (ESB NGTPC).
[21] It was understood that the NETS SQSS GSR008 review will remove the requirement to secure against an N-2 fault contingency. However, it was still considered for the modelling of the proposed connection designs in this report.

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and the internal HVAC collector networks are assumed to be the same for all connection options and are therefore not considered in this comparison. The capital costs are presented in both Pounds (£) and Euros €). The exchange rate used throughout the document is £1 to €1.23.

HVDC N-1 Contingencies: In the case of a HVDC fault on either of the point-to-point links or the multi-terminal bussing point the following technical considerations were applied:

- Intertrip/deload to the Irish Midlands Wind Generation and/or the Irish Interconnector is required in some circumstances for the removal of a thermal over-loading on the remaining HVDC Link. For all of the 3 GW connection options, generation will need to be tripped for a fault on either DC Link 1 or 2. The intertrip/de-load requirement will depend on the Irish Midlands Wind Generation output and the import/export to and from the Irish transmission system. The worst case for a single interconnection occurs with a 3 GW Irish Midlands Wind Generation output plus an export from the Irish system to the GB MITS of 0.7 GW, which would require an intertrip/deload of 1.2 GW. Table 3.1 details the intertrip/deload requirements for 100% wind generation (3 GW) and transfer across a new single Irish interconnector of ± 0.5 to ± 0.7 GW:

Serial	Pre Fault Transfer to GB MITS			N-1 OTS[22] Requirement	Generation Tripped Wind Generation - WG New Irish Interconnector - NII
	Irish System	DC Link 1	DC Link 2		
01	0.7 GW	1.2 GW	2.5 GW	1.2 GW	0.5 GW WG + 0.7 GW NII
02	-0.7 GW[23]	-0.2 GW[24]	2.5 GW	0	0
03	0.5 GW	1.0 GW	2.5 GW	1.0 GW	0.5 GW WG + 0.5 GW NII
04	-0.5 GW	0.0 GW	2.5 GW	0	0

Table 3.1 – Operational Tripping Scheme requirements for DC Link 1 or 2 N-1 fault contingencies

- A coordination strategy is required to ramp up power on the remaining intact HVDC link to ensure that the GB MITS does not see an in-feed loss greater than 1.8 GW and the Irish system does not see a loss greater than 0.5 GW.

[22] Operational Tripping Scheme (OTS).
[23] A negative value here denotes power flow into the Irish system.
[24] A negative value here denotes power flow from Pentir to Ireland.

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- Transmission capacity for the Irish Midlands Wind Generation depends on the availability of the HVDC VSC link connections to GB MITS. In the case of a 3 GW wind generation connection, a long term cable fault means that the transmission capacity to GB MITS will need to be reduced to 1.8 GW inclusive of the flow on the interconnection with the Irish transmission system for Infrequent In-feed Loss Risk. Pre-fault it would be constrained to 4.3 GW inclusive of the flow on the interconnection with the Irish system. These constraints exist for both "Integrated" and "Integrated with Interconnection" design concepts.

Option Analysis: A summary table is included to aid in the analysis of each NIO. The table highlights potential areas of risk and also identifies future requirements to refine the NIO. For ease of understanding, it includes a color coded system to indicate the overall viability of a particular design concept. A brief definition of the technical and value considerations used are given below:

- **HVDC Terminals:** HVDC can be used for point-to-point transmission with one sending and one receiving terminal, which is the simplest or configured into a multi-terminal bussing with more than one HVDC cable connecting to a terminal[25], which is more complicated.

- **Operation and Protection:** The ease of operation of the NIO is an important factor to be considered for each design concept. The objective of the protection system is to ensure that the network interconnection configuration operates safely, reliably and efficiently. Faults need to be detected quickly and devices are required to disconnect the faulty elements to ensure the integrity of the network. To ensure satisfactory operation, control of the power flows on both the HVDC links and AC connections is also vital.

- **Control Co-ordination:** This relates to the HVDC control strategy required to set the hierarchy of HVDC links i.e. which link(s) will carry the most power and which

[25] Depending on the development of IGBT technology a multi-terminal connection could limit power flow capacity in some NIO concepts and further optioneering may be required.

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link(s) will be ordered to increase its power level in the event of a fault on a HVDC link.

- **Control System Interaction Study:** A study would need to be undertaken by the manufacturers to examine the interaction between the different HVDC converter stations and any effects such interaction could have on the respective transmission networks.

- **Intertrip/Deload Scheme:** The costs of transmission redundancy exceed the costs of wind curtailment, and consequently an intertrip scheme is used. The intertrip scheme would be negotiated commercially under a connection design agreement with the Irish Midlands Wind Generation developer and, for NIOs incorporating a connection to the Irish transmission system, also with the Irish Interconnection owner/operator. An intertrip scheme may become more difficult to coordinate (possibly 3 different ownership boundaries) with interconnection to the Irish transmission system.

- **Trading Value:** This is the annual reduction in total variable production costs for the Irish and Great Britain systems with additional interconnection.

- **Generator Capacity Value:** This is the annual benefit due to the generation capacity saving that can be realised with additional interconnection (for the same Loss of Load Expectation).

- **Response and Reserve Sharing Value:** This is the annual saving in response/reserve costs arising from the ability of the GB system to provide reserve/response to the Irish system.

- **Congestion Value:** Congestion value is the reduction in constraint costs due to additional transfer capacity across a particular interconnection or boundary. It relates to what could possibly be achieved taking in to account generation and operational criteria. In this case, it is the value to the North Wales Export (NW2, 3 and 4), the North to Midlands (B8) and Midllands to South (B9) boundary transfers.

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- **Wheeling Power:** In the case of NIOs with two connections to the Irish transmission system, this is the ability to transfer power via the Irish transmission system from one Irish Midlands Wind Generation collector station to another i.e. import power into one Irish transmission substation and then export power out of a different substation.

The above considerations have been assessed using Difficulty and Benefit scales to provide a succinct overview of each NIO. The Difficulty and Benefit scales used are defined in Tables 3.2 and 3.3.

Scale of Difficulty	Description
Simple	Minor manageable risks / minor cost risk / minor control coordination issues / minor complexity
Moderate	Some manageable concerns & risks / potential for some cost variance / some control coordination issues / some complexity
Complex	Major concerns & risks / major mitigation required / significant cost risk / potential for significant cost variance / significant control coordination issues / significant complexity

Table 3.2 – Scale of Difficulty for Technical Considerations

Scale of Benefit	Description
High	High value – high benefit to both parties
Medium	Medium value – some benefit to both parties
Low/None	No value or limited to any one party.

Table 3.3 – Scale of Benefit for Value Consideration

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Interconnection Transmission Entry Capacity Available: Initial National Grid DC thermal studies indicate that 0.5 GW of interconnection with the Irish transmission system can be accommodated on the GB MITS. However, there are overloaded circuits with 0.7 GW and above being imported into Great Britain from Ireland (see Appendix A.2). As DC studies are only an approximation, further AC studies will be required to determine the exact reinforcements. The infrastructure costs associated with these reinforcements have not been considered in this study.

EirGrid studies indicate that 0.5 GW of interconnection can be accommodated on the Irish transmission system by uprating a number of lines in the vicinity of the proposed connection points. However, initial studies indicate that additional new build reinforcement is required to accomodate 0.7 GW of interconnection. Further detailed study work would be required to determine the level of new build reinforcement required to accommodate 0.7 GW at each proposed connection point.

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3.1 Network Interconnection Option 1 (Base case for 3 GW NIO)

This option comprises of two point-to-point 2.5 GW HVDC VSC connections from the 1 GW and 2 GW Irish Midlands wind collector stations to Pentir and Pembroke 400 kV substations on the GB MITS i.e. a total of four converter terminals. The 1 GW and 2 GW Irish Midlands Wind Generation collector stations in Ireland are in turn connected via a short HVAC 400 kV or 220 kV cable. This is represented in Figure 3.1 below. This Option 1 (a purely "Integrated" design) constitutes the Base Case for comparison with the different "Integrated with Interconnection" 3 GW NIOs that incorporate a connection to the Irish transmission system.

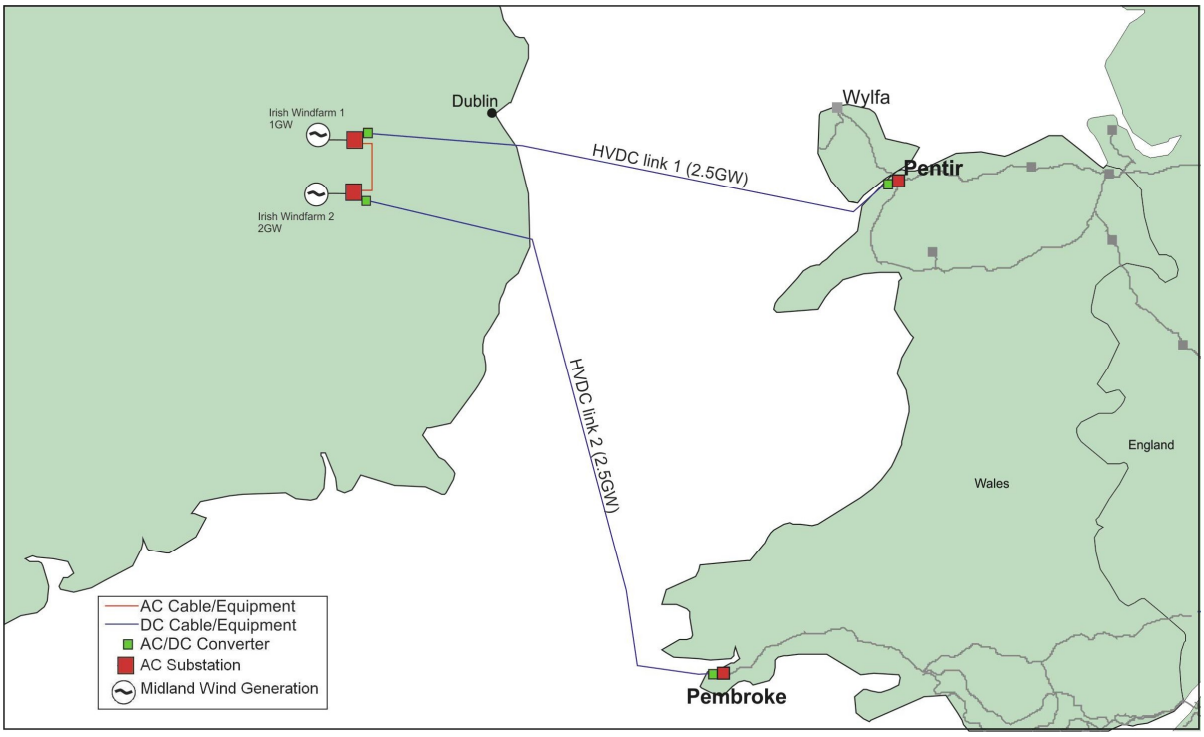

Figure 3.1 – Network Interconnection Option 1 (Base Case for a 3 GW connection)

Key Points for Option 1

- **Trading/Reserve and Response/Generation Capacity Value:** This is purely a generation connection directly into the GB MITS and there is no benefit from these aspects because this concept has no connection to the Irish transmission system.

- **Congestion Value:** There is medium benefit to the GB MITS (see figure 4.2). Over a year it could provide an average capability of approximately 1.2 GW and therefore reduce constraints costs on the NW 2, 3 and 4, B8 and B9.

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Option 1 Summary Table: This summarises the technical and value considerations discussed at the beginning of this chapter for each option.

Serial	Technical and Value Considerations	Difficulty /Value /Requirement
01	Terminals	Point to Point
02	SQSS Requirement (Infeed loss)	Met (with OTS)
03	Operation and Protection	Simple
04	Control Co-ordination	Simple
05	Control system interaction study	Required
06	OTS/Deload Scheme	Required (0.5 GW)
07	Trading Value	None
08	Generator Capacity Value	None
09	Response and Reserve Sharing Value	None
10	Congestion Value	Medium
11	Wheeling Power	None

Table 3.4 – Option 1 Summary

Option Overview: This is a simple generation connection into the GB MITS and it does provide medium congestion benefit to the B8, B9 and NW export boundaries, dependent upon the HVAC connection capacity between the Irish Midlands Wind Generation collector stations and the HVDC Link 2 to Pembroke 400 kV. However, it does not optimise the utilisation of the HVDC Links 1 and 2 and provides no trading value with the Irish transmission system.

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3.2 Network Interconnection Option 8

This option contains two point-to-point 2.5 GW HVDC VSC connections to Pentir and Pembroke 400 kV substations on the GB MITS. These are then connected to 1 GW and 2 GW wind collector stations in Ireland which in turn are connected via a short HVAC 400 or 220 kV cable. So the same as Option1, but additionally there is an interconnection from the Irish Midlands Wind Generation Station 2 (the southern most station in Ireland in Figure 3.2) via a HVAC 220 kV cable link to an Irish transmission system substation with a 0.5 GW to 0.7 GW capacity. This is represented in Figure 3.2 below.

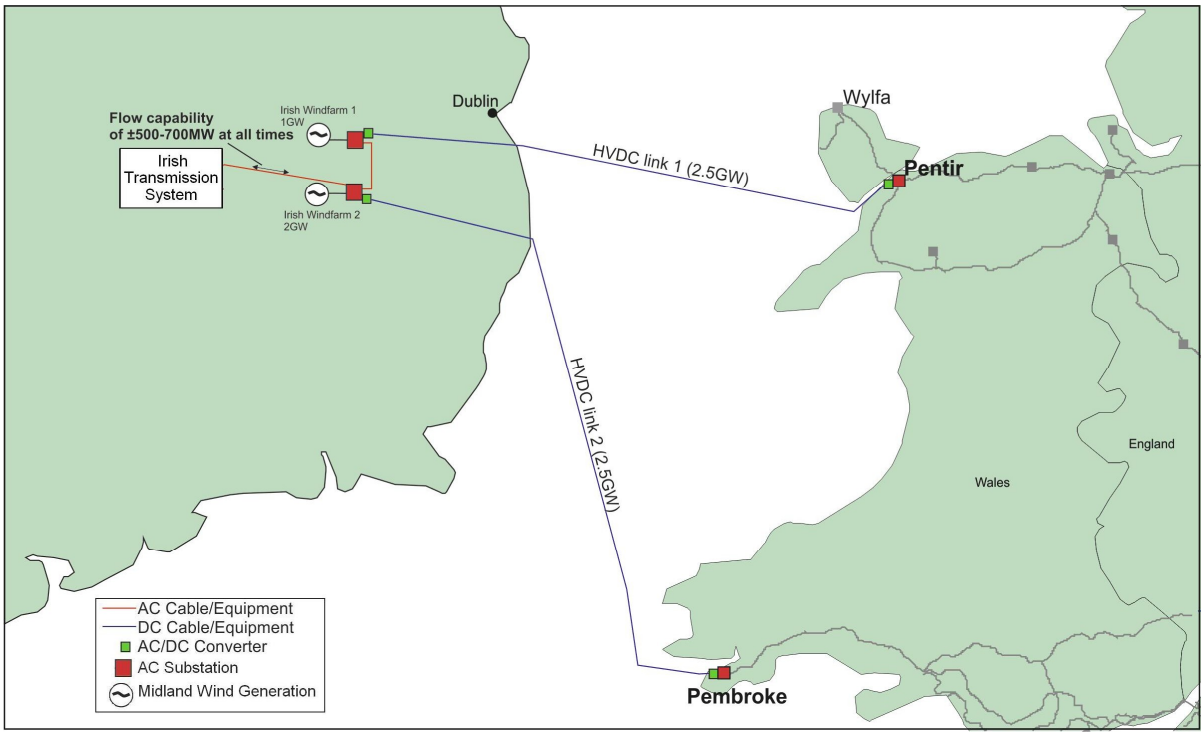

Figure 3.2 - Network Interconnection Option 8

Key Points for Option 8

- **HVAC Interconnection to the Irish Transmission System:** The loading on this circuit will be controlled via the HVDC transfers as they ramp-up and ramp-down according to wind generation outputs and GB and Irish transmission system conditions. The effects of this on the Irish transmission system with respect to frequency and stability have not been confirmed. It would need to be carefully examined and detailed power system modelling would be required.

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- **Congestion Value:** There is medium congestion value for the GB MITS with this option and there is medium value for the Irish transmission system due to the single point HVAC connection (this is dependent on point of connection).

Option 8 Summary Table: This summarises the technical and value considerations discussed at the beginning of this chapter for this option:

Serial	Technical and Value Considerations	Difficulty /Value /Requirement
01	Terminals	Point to Point
02	SQSS Requirement (Infeed loss)	Met (with OTS)
03	Operation and Protection	Complex
04	Control Co-ordination	Moderate
05	Control system interaction study	Required
06	OTS/Deload Scheme	Required (1.0 GW)
07	Trading Value	Medium (0.7 GW)
08	Generator Capacity Value	Medium
09	Response and Reserve Sharing Value	Low
10	Congestion Value	Medium
11	Wheeling Power	None

Table 3.5 – Option 8 Summary

Option Overview: The HVAC interconnection links the southern 2 GW Irish Midlands Wind Generation station directly to the Irish transmission system. It is the cheapest interconnection option considered. However, it is not an agreed preferred design concept at this stage due to operational issues. In particular, this connection option would potentially drive the non-synchronous penetration of the Irish power system higher than could safely or prudently be operated. It would also expose the Irish power system to large frequency fluctuations due to the fluctuating output of the wind generation, exacerbating the frequency control issue in Ireland and Northern Ireland. To alleviate this, the DC link flows would need to exactly match the wind output, which may not be technically possible. There are also concerns

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over what would happen during a fault on the DC links to GB MITS, and whether a fault in Great Britain would lead to some or all of the exported wind generation being fed into the Irish system. There are potential difficulties in studying all of the ramifications of the AC connection if multiple vendors are involved, who may be unwilling to share their electromagnetic transient models or dynamic models of their equipment. This option could be a possibility in the future but would require significant study analysis to assess the technical challenges and risks identified.

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3.3 Network Interconnection Option 9

This option is very similar to Option 8. However, there is an additional interconnection from the Irish Midlands Wind Generation Station 1 (the northern most wind station in Ireland on the graphic shown in Figure 3.3) via a HVAC 400 or 220 kV cable link to a separate Irish transmission substation with another 0.5 GW to 0.7 GW transfer capacity i.e. there are two HVAC interconnections to the Irish transmission System creating a meshed AC network between Stations 1 and 2. This is represented in Figure 3.3 below:

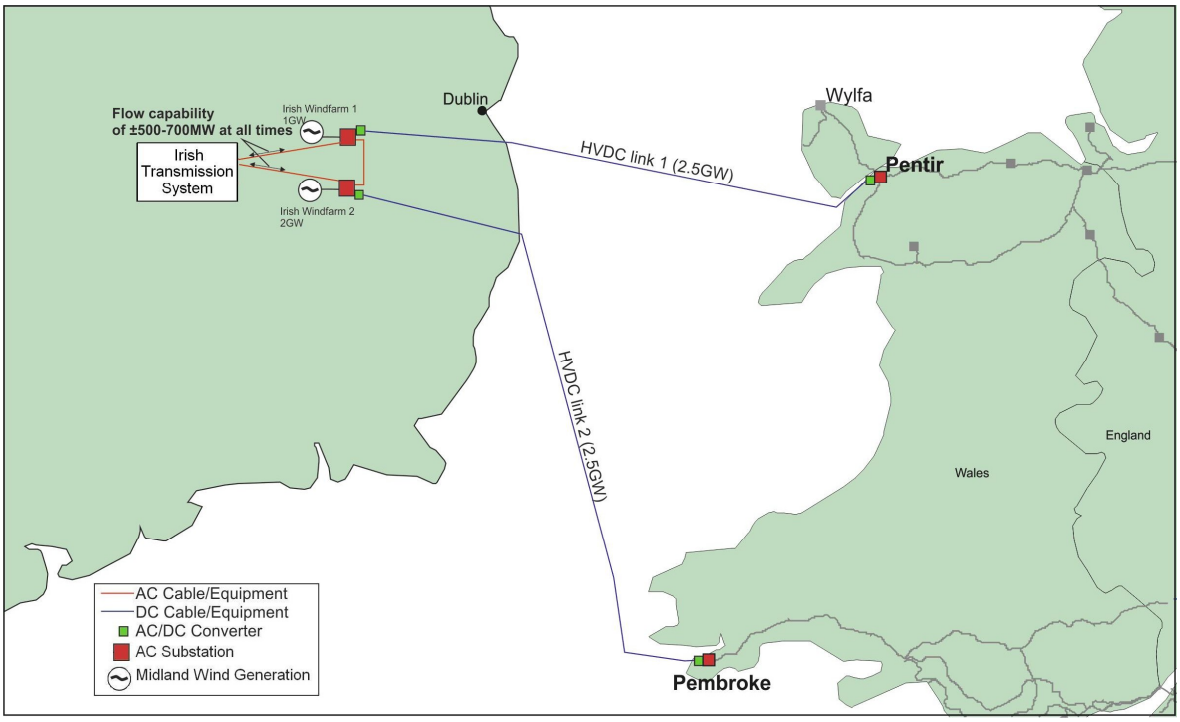

Figure 3.3 – Network Interconnection Option 9

Key Points for Option 9

- **HVAC Interconnection to the Irish Transmission System:** The power transfer on these circuits will be difficult for the system operators to control and will depend on Irish transmission system conditions, relative transmission circuit impedances and the HVDC Link 1 and 2 transfers as they ramp-up and ramp-down according to the wind generation outputs. Quad-Boosters could be used to assist in controlling the interconnection circuit loading. The effect of this connection option on the Irish transmission system with respect to frequency and stability has not been confirmed. It would need to be carefully examined and detailed power system modelling would be required.

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- **Trading Value:** This connection ensures that there is a potential 1.0 – 1.4 GW import and 1.0 - 1.3 GW[26] export capacity available (depending on circuit sharing) for trading between the Irish transmission system and GB MITS at all times.

Option 9 Summary Table: This summarises the technical and value considerations discussed at the beginning of this chapter for this option:

Serial	Technical and Value Considerations	Difficulty /Value /Requirement
01	Terminals	Point to Point
02	SQSS Requirement (Infeed loss)	Met (with OTS)
03	Operation and Protection	Complex
04	Control Co-ordination	Moderate
05	Control system interaction study	Required
06	OTS/Deload Scheme	Required (1.8 GW)
07	Trading Value	Medium (up to 1.4 GW)
08	Generator Capacity Value	High
09	Response and Reserve Sharing Value	Low
10	Congestion Value	Medium
11	Wheeling Power	Medium

Table 3.6 – Option 9 Summary

Option Overview: The two HVAC connections link the 3 GW of Irish Midlands Wind Generation directly to the Irish transmission system creating a meshed network and making it more difficult for EirGrid to manage with regard to power transfer, frequency and stability issues. Although the potential capacity for trading and congestion is of high value the actual capability is unclear and has been assessed as a medium value. It is the cheapest double connection option. However, it is not a preferred design concept due to the operational issues. In particular, this option would

[26] The maximum export from the Irish transmission system is limited to 1.3 GW when the Irish Midlands Wind Generation is at its maximum output of 3 GW because the boundary capability across the 2 HVDC Links is limited to 4.3 GW due to Infrequent Infeed Loss Risk (i.e. limit is determined by IILR + 1 x HVDC Link Capacity = 1.8 GW + 2.5 GW = 4.3 GW)

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potentially drive the non-synchronous penetration of the Irish power system higher than could safely or prudently be operated. It would also expose the Irish power system to large frequency fluctuations due to the fluctuating output of the wind generation, exacerbating the frequency control issue in Ireland and Northern Ireland. To alleviate this, the DC link flows would need to exactly match the wind output, which may not be technically possible. There are also concerns over what would happen during a fault on the DC links to GB MITS, and whether a fault in Great Britain would lead to some or all of the exported wind generation being fed into the Irish system. There are potential difficulties in studying all of the ramifications of the double AC connection if multiple vendors are involved, who may be unwilling to share their electromagnetic transient models or dynamic models of their equipment. This option could be a possibility in the future but would require significant study analysis to assess the technical challenges and risks identified.

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3.4 Network Interconnection Option 9a

This NIO is almost identical to Option 9. However, in this NIO the Irish Midlands Wind Generation stations would connect directly to the 400 kV substations on the Irish transmission system (potentially at Woodland and Dunstown sites) via HVAC 400 kV or 220 kV links. HVDC VSC converter stations would be built at the two Irish 400 kV substation sites to export the Irish Midlands Wind Generation output directly to the GB MITS. The HVAC connection between the Irish Midlands Wind Generation collector stations would form part of the Irish transmission system and could be coordinated with Irish network reinforcements (possibly the Dublin Ring) to provide the necessary transfer capacity between the two stations.

Additional Points for Option 9a

- **Operational Issues:** This option would potentially drive the non-synchronous penetration of the Irish power system higher than could safely or prudently be operated. It would also expose the Irish power system to large frequency fluctuations due to the fluctuating output of the wind generation, exacerbating the frequency control issue in Ireland and Northern Ireland. To alleviate this, the DC link flows would need to exactly match the wind output, which may not be technically possible. There are also concerns over what would happen during a fault on the DC links to GB MITS, and whether a fault in Great Britain would lead to some or all of the exported wind generation being fed into the Irish system. There are potential difficulties in studying all of the ramifications of the AC connection if multiple vendors are involved, who may be unwilling to share their electromagnetic transient models or dynamic models of their equipment.

- **Capital Costs:** At this stage, costs have not been estimated for this option due to a multitude of factors that cannot easily be quantified at this time. However, it is deemed likely that there would be an overall saving because of the coordination of generator developer works with Irish network reinforcements.

Option Overview: This option could be a possibility in the future but would require significant study analysis to assess the technical challenges and risks identifed. Early

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commercial liasion between EirGrid, the generation developer and National Grid would be required to establish a connection agreement.

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3.5 Network Interconnection Options 11 and 14

These options contain three point-to-point HVDC Links; two 2.5 GW HVDC VSC connections to Pentir and Pembroke 400 kV substations on the GB MITS plus a back-to-back 0.5 GW to 0.7 GW HVDC converter connecting the Irish Midlands southern wind station 2 to the Irish transmission system i.e. a total of six converter terminals. For Option 14 only, this would operate at 0.3 to 0.5 GW trading transfer plus 0.2 GW reserve. This is represented in Figure 3.4 below:

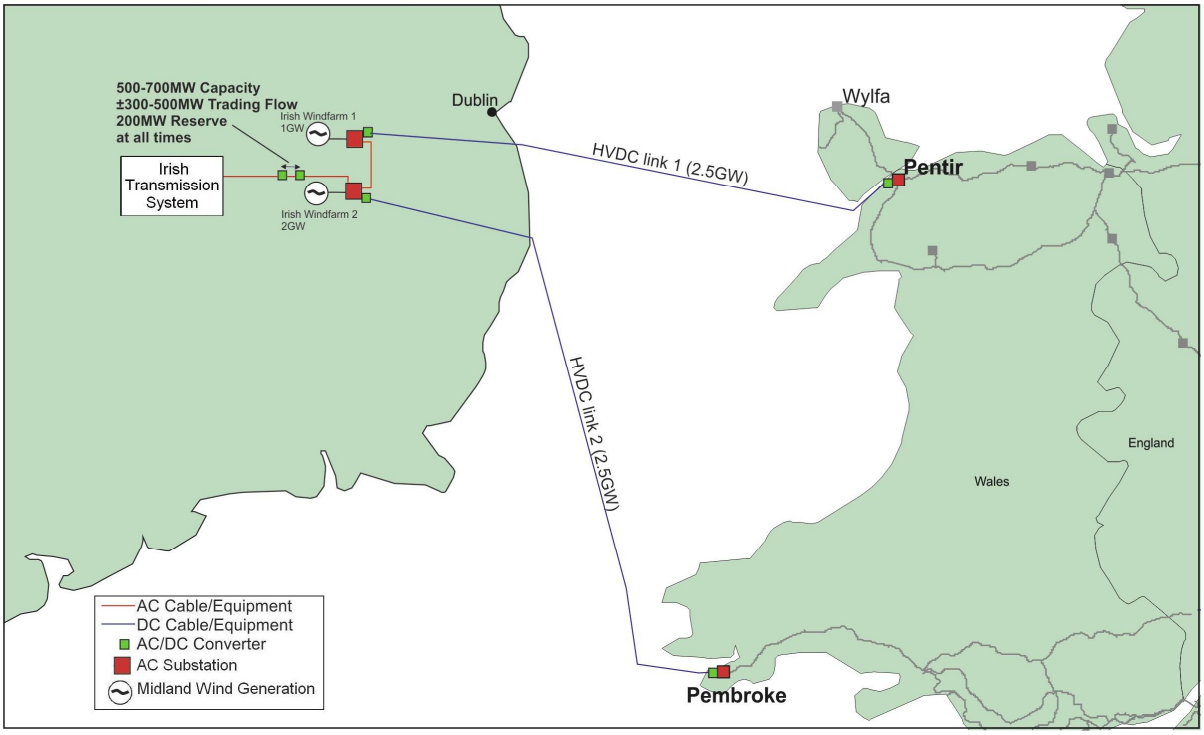

Figure 3.4 –Network Interconnection Options 11 and 14

Key Points for Options 11 and 14

- **HVDC Interconnection to the Irish Transmission System:** This provides control of the power transfer import or export to and from the Irish transmission system. However, the key difficulty with this NIO is the complex control coordination required with the point-to-point HVDC Links 1 and 2 to the GB MITS.

- **Trading/Response and Reserve Sharing Value:** Option 11 provides a trading benefit only whereas Option 14 provides a reduced trading benefit plus a response and reserve sharing benefit.

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Options 11 and 14 Summary Table: This summarises the technical and value considerations discussed at the beginning of this chapter for these options:

Serial	Technical and Value Considerations	Option 11 Difficulty/Value /Requirement	Option 14 Difficulty/Value /Requirement
01	Terminals	Point to Point	Point to Point
02	SQSS Requirement (Infeed loss)	Met (with OTS)	Met (with OTS)
03	Operation and Protection	Moderate	Moderate
04	Control Co-ordination	Complex	Complex
05	Control system interaction study	Required	Required
06	OTS/Deload Scheme	Required (1.2 GW)	Required (1.2 GW)
07	Trading Value	Medium (0.7 GW)	Medium (0.5 GW)
08	Generator Capacity Value	Medium	Medium
09	Response and Reserve Sharing Value	Low	Medium
10	Congestion Value	Medium	Medium
11	Wheeling Power	None	None

Table 3.7 – Option 11 and 14 Summary

Options Overview: These are not preferred NIOs due to the control coordination complexity of the HVAC Irish Midlands Wind Generation system being islanded between the HVDC links to the Irish transmission system and GB MITS.

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3.6 Network Interconnection Options 12 and 15

These options contain four point-to-point HVDC Links; two 2.5 GW HVDC VSC connections to Pentir and Pembroke 400 kV substations on the GB MITS plus two back-to-back 0.5 GW to 0.7 GW HVDC converter stations connecting the Irish Midlands Wind Generation stations 1 and 2 (northern and southern wind stations on the graphic in Figure 3.5) to the Irish transmission system i.e. a total of eight converter terminals. For Option 15 only, this would operate at 0.6 to 1.0 GW trading transfer plus 0.4 GW reserve. This is represented in Figure 3.5 below.

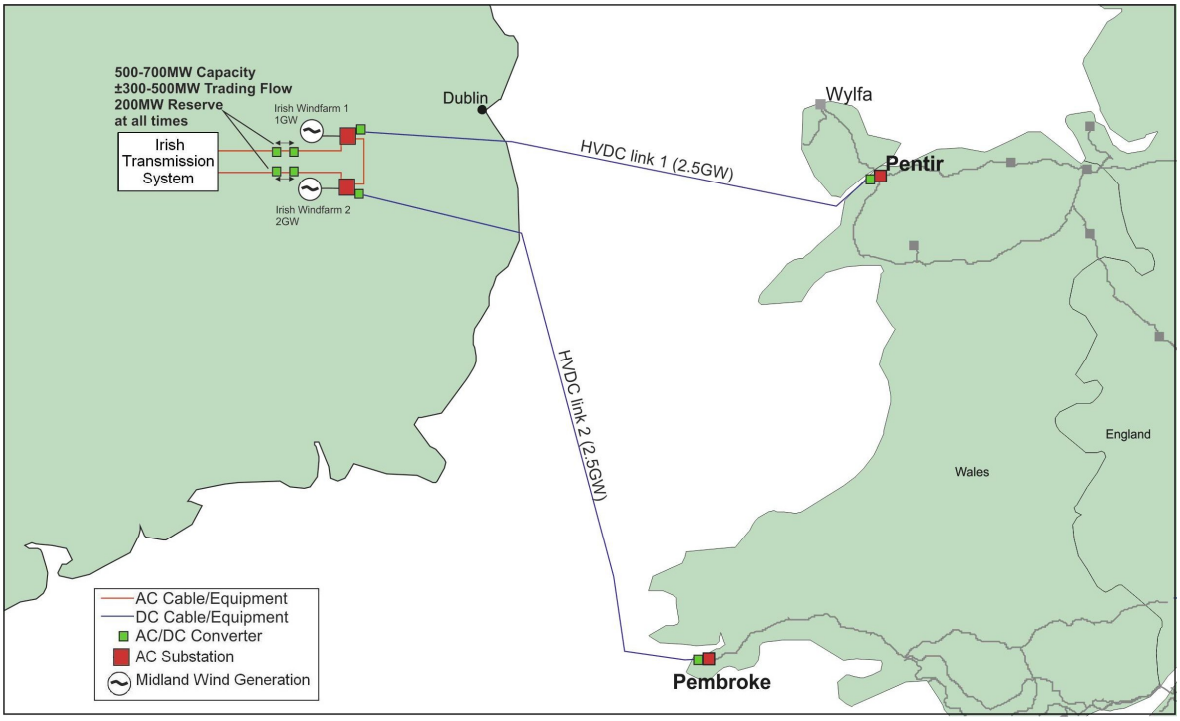

Figure 3.5 – Network Interconnection Options 12 and 15

Key Points for Options 12 and 15

- **HVDC Interconnection to the Irish Transmission System:** These two HVDC links provide control of the power transfer import or export to and from the Irish transmission system. Again, the key difficulty with this NIO is the complex control coordination hierarchical issues between the point-to-point HVDC Links 1 and 2 to the GB MITS and the two HVDC interconnections with the Irish transmission system.
- **Trading/Response and Reserve Value:** These connections ensure that there is a trading capacity of 1.0 – 1.4 GW import and 1.0 - 1.3 GW export with a response

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and reserve sharing capability of up to 0.4 GW (for Option 15 only) available between the Irish transmission system and GB MITS at all times.

- **Congestion Value:** Both of these connections provide a high congestion value to both the GB and Irish transmission systems, and also the double interconnection allows the system operators to wheel power.

Options 12 and 15 Summary Table: This summarises the technical and value considerations discussed at the beginning of this chapter for these options:

Serial	Technical and Value Considerations	Option 12 Difficulty/Value /Requirement	Option 15 Difficulty/Value /Requirement
01	Terminals	Point to Point	Point to Point
02	SQSS Requirement (Infeed loss)	Met (with OTS)	Met (with OTS)
03	Operation and Protection	Moderate	Moderate
04	Control Co-ordination	Complex	Complex
05	Control system interaction study	Required	Required
06	OTS/Deload Scheme	Required (1.8 GW)	Required (1.8 GW)
07	Trading Value	High (1.4 GW)	High (1.0 GW)
08	Generator Capacity Value	High	High
09	Response and Reserve Sharing Value	Low	High
10	Congestion Value	High	High
11	Wheeling Power	High	High

Table 3.8 – Option 12 and 15 Summary

Options Overview: There is an increased congestion benefit with two HVDC links connected through to two separate Irish transmission system substations. However, these are still not preferred NIOs due to the control coordination complexity of the HVAC Irish Midlands Wind Generation system being islanded between the HVDC Links to the Irish transmission system and GB MITS.

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3.7 Network Interconnection Options 17 and 20

These options contain a multi-terminal HVDC VSC bussing connection at the Irish Midlands Wind 2 HVDC converter station, from which there are HVDC links connecting to converter stations at Pembroke 400 kV substation and to the Irish transmission system. There are two 2.5 GW HVDC VSC cable links to the GB MITS and one 0.5 to 0.7 GW cable connection to the Irish transmission system (for Option 20 only, this would operate at 0.3 to 0.5 GW trading transfer plus 0.2 GW reserve). The two Irish Midlands Wind Generation stations are connected via a short HVAC 400 or 220 kV cable. This is represented in Figure 3.6 below.

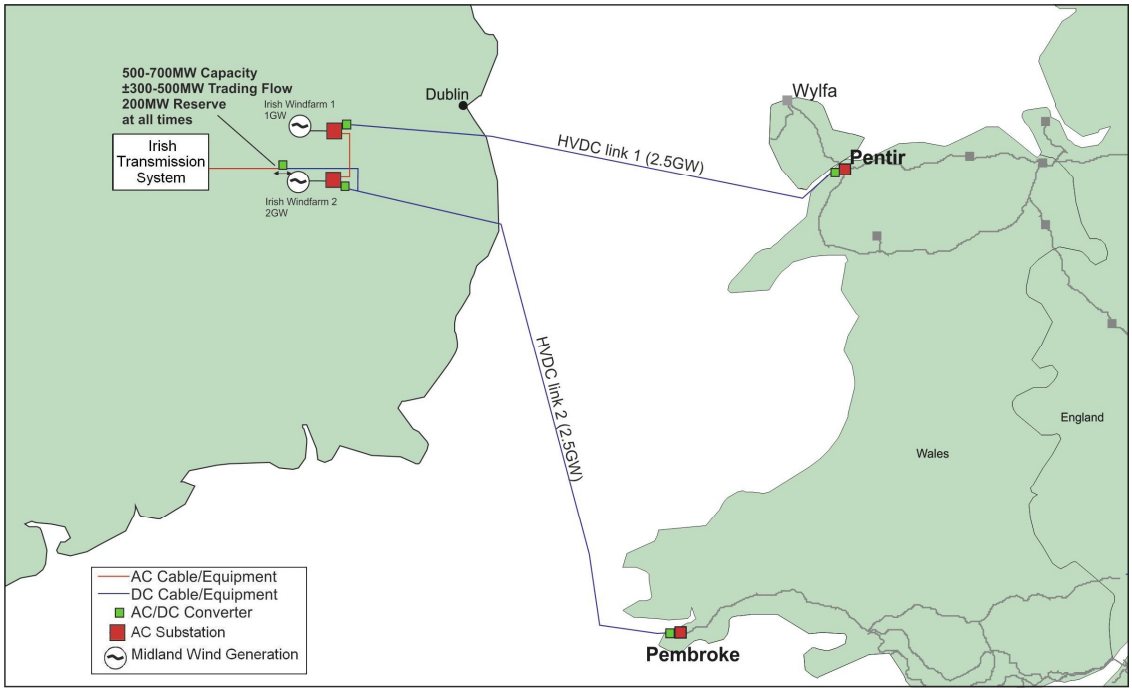

Figure 3.6 – Network Interconnection Options 17 and 20

Key Points for Options 17 and 20

- **HVDC Interconnection to the Irish Transmission System:** The single multi-terminal HVDC link provides control of the power transfer import or export to and from the Irish transmission system. A possible disadvantage to this multi-terminal connection is a reduction in the transfer capacity to Pembroke. This is due to the existing current limitation of the IGBT power electronic components of a VSC HVDC converter station.

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- **Trading/Response and Reserve Value:** These connections ensure that there is a trading capacity of 0.5 - 0.7 GW with a response and reserve sharing capacity of up to 0.2 GW (for Option 20 only) available between the Irish transmission system and GB MITS at all times.

- **Congestion Value:** Both of these connections provide a moderate congestion value to the GB MITS and Irish transmission system.

Options 17 and 20 Summary Table: This summarises the technical and value considerations discussed at the beginning of this chapter for these options:

Serial	Technical and Value Considerations	Option 17 Difficulty/Value /Requirement	Option 20 Difficulty/Value /Requirement
01	Terminals	Multi-Terminal/ Point-to-Point	Multi-terminal/ Point-to-Point
02	SQSS Requirement (Infeed loss)	Met (with OTS)	Met (with OTS)
03	Operation and Protection	Moderate	Moderate
04	Control Co-ordination	Moderate	Moderate
05	Control system interaction study	Required	Required
06	OTS/Deload Scheme	Required (1.2 GW)	Required (1.2 GW)
07	Trading Value	Medium (0.7 GW)	Medium (0.5 GW)
08	Generator Capacity Value	Medium	Medium
09	Response and Reserve Sharing Value	Low	Medium
10	Congestion Value	Medium	Medium
11	Wheeling Power	None	None

Table 3.9 – Option 17 and 20 Summary

Options Overview: The multi-terminal HVDC bussing point reduces the number of converter stations required and reduces the complexity of the control co-ordination and protection. However, it may reduce the HVDC power transfer capacity to Pembroke. There is a moderate congestion benefit with one HVDC link connected to

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the Irish Transmission System substation and the complexity risk in this design is moderate. **Overall, Option 20 is the preferred design solution**.

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3.8 Network Interconnection Options 18 and 21

These options contain two multi-terminal HVDC VSC bussing connections, two converter terminals connecting to the GB MITS at Pentir and Pembroke 400 kV substations and two converter terminals connecting to the Irish transmission system i.e. a total of six converter terminals. There are two 2.5 GW HVDC VSC Links to the GB MITS and two 0.5 to 0.7 GW HVDC VSC connections to the Irish Transmission System (for Option 21 only, these would each operate at 0.3 to 0.5 GW trading transfer plus 0.2 GW reserve). The Irish Midlands Wind Generation stations are connected via a HVAC 400 or 220 kV cable. This is represented in Figure 3.7.

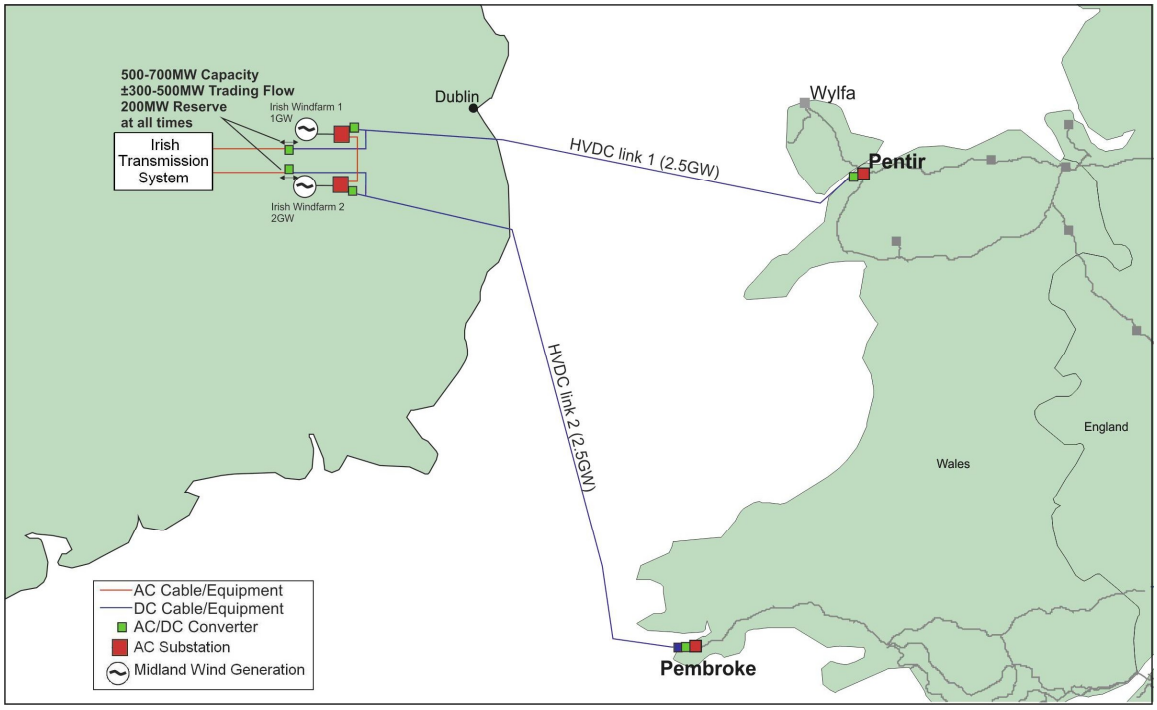

Figure 3.7 – Network Interconnection Options 18 and 21

Key Points for Options 18 and 21

- **HVDC Interconnection to the Irish Transmission System:** The two HVDC links provide control of the power transfer import or export to and from the Irish transmission system. The operational strategy for control coordination with these NIOs is less complex than NIOs with multiple point-to-point terminals. A possible disadvantage to this multi-terminal connection is a reduction in the transfer capability to Pentir and Pembroke due to the existing current limitation with the IGBT power electronic components.

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- **Trading/Response and Reserve Value:** These connections ensure that there is a trading capacity of 1.0 – 1.4 GW import and 1.0 - 1.3 GW export with a response and reserve capacity of up to 0.4 GW (for Option 21 only) available between the Irish Transmission System and GB MITS at all times.

- **Congestion Value:** Both of these connections provide a high congestion value to both the GB MITS and Irish Transmission System.

Options 18 and 21 Summary Table: This summarises the technical and value considerations discussed at the beginning of this chapter for these options:

Serial	Technical and Value Considerations	Option 18 Difficult/Value /Requirement	Option 21 Difficult/Value /Requirement
01	Terminals	Multi-Terminal	Multi-terminal
02	SQSS Requirement (Infeed loss)	Met (with OTS)	Met (with OTS)
03	Control and Protection	Moderate	Moderate
04	Control Co-ordination	Moderate	Moderate
05	Control system interaction study	Required	Required
06	OTS/Deload Scheme	Required (1.8 GW)	Required (1.8 GW)
07	Trading Value	High (1.4 GW)	High (1.0 GW)
08	Generator Capacity Value	High	High
09	Response and Reserve Sharing Value	Low	High
10	Congestion Value	High	High
11	Wheeling Power	High	High

Table 3.10 – Network Interconnection Options 18 and 21

Options Overview: The multi-terminal HVDC bussing points reduce the number of converter stations required and equally reduce the complexity of the control co-ordination and protection. However, it could reduce the HVDC link power transfer capacity to Pentir and Pembroke. This option still maintains the increased congestion benefit arising from having two HVDC links connected to two separate Irish transmission system substations.

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3.9 Network Interconnection Option 2 (Base case for 5 GW NIO)

This option contains three point-to-point 2.5 GW HVDC VSC connections; one to Pentir and two to Pembroke 400 kV substations on the GB MITS[27] giving a total of six converter terminals. These are then connected to one 1 GW and two 2 GW Irish Midlands Wind Generation collector stations and connected to each other via two short HVAC 400 or 220 kV cable links. This is represented in Figure 3.8 below. This Option 2 (a purely "Integrated" design) constitutes the Base Case for comparison to the different "Integrated with Interconnection" 5 GW NIOs that incorporate a connection to the Irish transmission system.

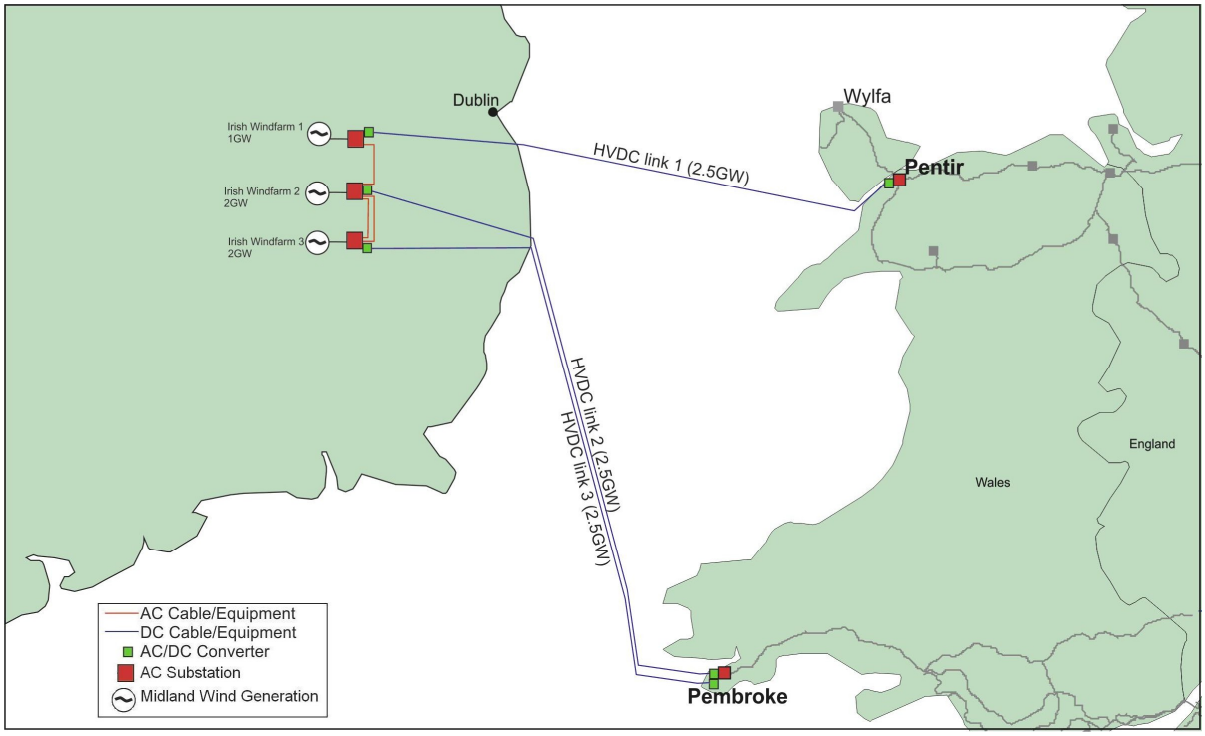

Figure 3.8 – Network Interconnection Option 2

Key Points for Option 2

- **Trading/Reserve and Response/Generation Capacity Value:** This is purely a generation connection direct into the GB MITS and there is no benefit in these aspects because there is no connection to the Irish transmission system.

[27] This is consistent with the current thinking from National Grid. The alternative connection point for the third HVDC Link would be in to the South West of England.

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- **Congestion Value:** There is more benefit to the GB MITS compared to NIO 1, but it is still limited by the total Irish Midlands Wind Generation load factor and the capacity of the HVDC Links 2 and 3 to Pembroke 400 kV.

Option 2 Summary Table: This summarises the technical and value considerations discussed at the beginning of this chapter for each option:

Serial	Technical and Value Considerations	Difficulty /Value /Requirement
01	Terminals	Point to Point
02	SQSS Requirement (Infeed loss)	Met
03	Control and Protection	Simple
04	Control Co-ordination	Simple
05	Control system interaction study	Required
06	OTS/Deload Scheme	Not Required
07	Trading Value	None
08	Generator Capacity Value	None
09	Response and Reserve Sharing Value	None
10	Congestion Value	High
11	Wheeling Power	None

Table 3.11 – Option 2 Summary

Options Overview: The two HVDC Links to Pembroke 400 kV station increase the ability to cycle power from Pentir 400 kV station to Pembroke 400 kV station leading to a greater congestion value. There is no trading/response and reserve/generation capacity benefit and no co-ordination of reinforcement.

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3.10 Network Interconnection Option 22

This 5 GW option contains a multi-terminal HVDC VSC bussing connection at the central Irish Midland Wind Generation collector station 2. There are three point-to-point terminal connections to the GB MITS (one at Pentir and two at Pembroke 400 kV substations) and one multi-terminal connection to the Irish transmission system giving a total of seven converters. There are three 2.5 GW HVDC VSC cable links to the GB MITS and one 0.5 to 0.7 GW cable connection to the Irish Transmission System (which could also operate at 0.3 to 0.5 GW trading transfer plus 0.2 GW reserve). The three Irish Midlands Wind Generation stations (1-2-2 GW split) are connected via short HVAC 400 or 220 kV cable links. This is represented in Figure 3.9 below.

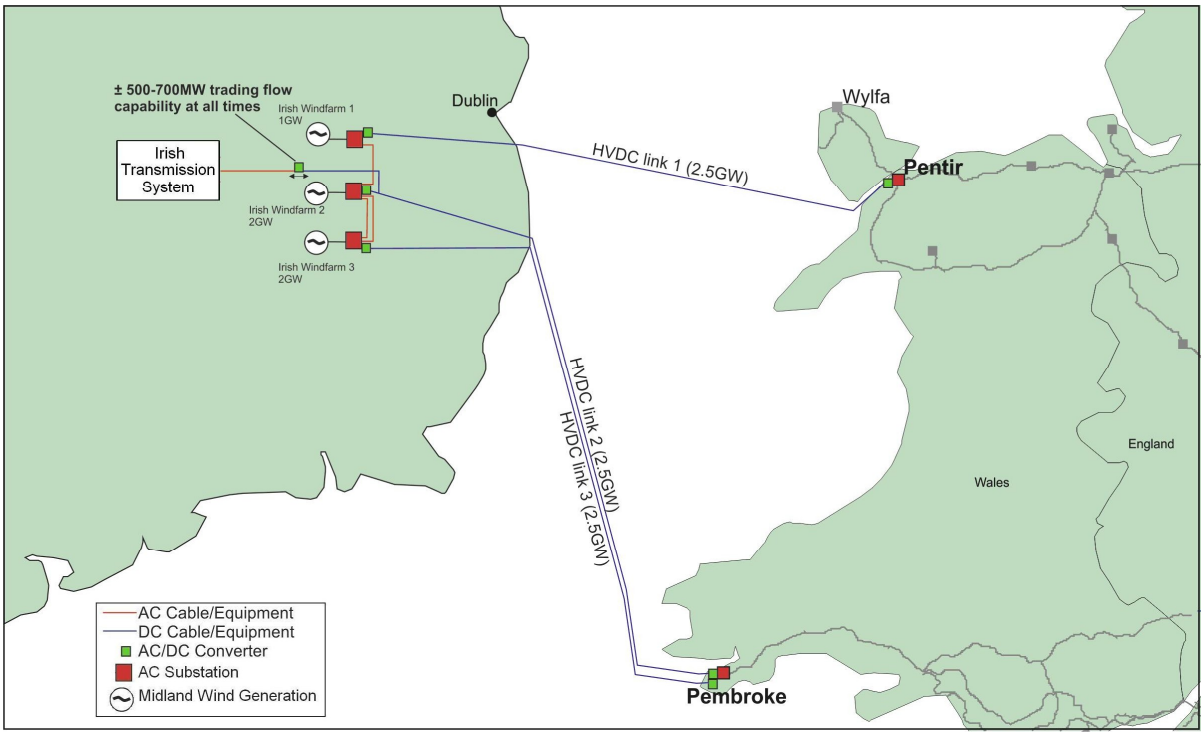

Figure 3.9 – 5 GW Network Interconnection Option 22

Key Points for Option 22

- **HVDC Interconnection to the Irish Transmission System:** The one multi-terminal HVDC connection provides control of the power transfer import or export to and from the Irish transmission system. There maybe a reduction in power transfer capacity on the HVDC Link 2 to GB MITS due to this multi-terminal connection. With regard to the three Irish Midlands Wind Generation stations, the optimal connection point for the Irish interconnector has yet to be determined.

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- **Trading/Response and Reserve Value:** This connection ensures that there is a trading capacity of 0.5 - 0.7 GW with a response and reserve capacity of up to 0.2 GW available between Irish Transmission System and GB MITS.

- **Congestion Value:** This connection provides a high congestion value to the GB MITS due to the additional HVDC Link 3 into Pembroke 400 kV station.

Option 22 Summary Table: This summarises the technical and value considerations discussed at the beginning of this chapter for each option.

Serial	Technical and Value Considerations	Difficulty /Value /Requirement
01	Terminals	Multi-terminal/ Point-to-Point
02	SQSS Requirement (Infeed loss)	Met (with OTS)
03	Control and Protection	Moderate
04	Control Co-ordination	Moderate
05	Control system interaction study	Required
06	OTS/Deload Scheme	Required (0.7 GW)
07	Trading Value	Medium (0.7 GW)
08	Generator Capacity Value	Medium
09	Response and Reserve Sharing Value	Medium
10	Congestion Value	High
11	Wheeling Power	None

Table 3.12 – Network Interconnection Option 22 Summary

Options Overview: The two HVDC Links to Pembroke 400 kV station increase the ability to cycle power from Pentir 400 kV station to Pembroke 400 kV station leading to a greater congestion value. The multi-terminal HVDC bussing point reduces the number of converter stations required and reduces the complexity of the control co-ordination and protection. There is a high congestion benefit with one HVDC link connected to the Irish transmission system substation and the complexity risk in this design is moderate.

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4 Benefit of Network Interconnection Options

In this section, the potential benefits arising from the various Network Interconnection Options (NIOs) are detailed and quantified. The benefits identified and assessed in the study include production cost savings from trading between the two markets, sharing of reserve/response and a reduction in the total generation capacity required to maintain security of supply on the Irish system. The benefits accruing to Great Britain from these latter two aspects have not been assessed, but would be lower as the smaller Irish power system would have difficulty in consistently providing comparable levels of reserve and spare generation to Great Britain. A potential increase in boundary transfer capability and associated constraint saving on the Great Britain MITS was also assessed.

4.1 Trading Benefit

The Plexos market modelling tool was employed to assess the potential trading benefits arising from new interconnection between Ireland and Great Britain. Plexos is an hourly chronological Monte Carlo generation production cost modelling simulation program, used to determine power system performance and cost. The cost minimised within the Plexos market model is the sum of the generation fuel cost, Variable Operation and Maintenance (VOM) cost and CO_2 cost.

The market model employed was based on a pan-European model created and developed by the ENTSO-E Regional Group North Seas (RGNS) for the development of the 2012 Ten-Year Network Development Plan (TYNDP). In preparation of the TYNDP 2012, three different generation/demand scenarios were modelled by ENTSO-E RGNS for 2020. For this study, the “Scenario B with Nuclear Phase-out” scenario, which captures the impact of the nuclear phase-out plans of Germany and Switzerland (announced in summer 2011) was used. This was selected as it was the latest ENTSO-E forecast and considered the most likely outcome.

A single node representation was used for Great Britain, Ireland and Northern Ireland with internal transmission constraints within each market area not modelled. The only transmission constraints modelled relate to the interconnection transfer capacities linking the market areas as illustrated in Figure 4.1. The interaction between Great Britain and the

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rest of Europe was modelled using fixed hourly power flows, which were based on the results of a full seventeen-country pan-European model.

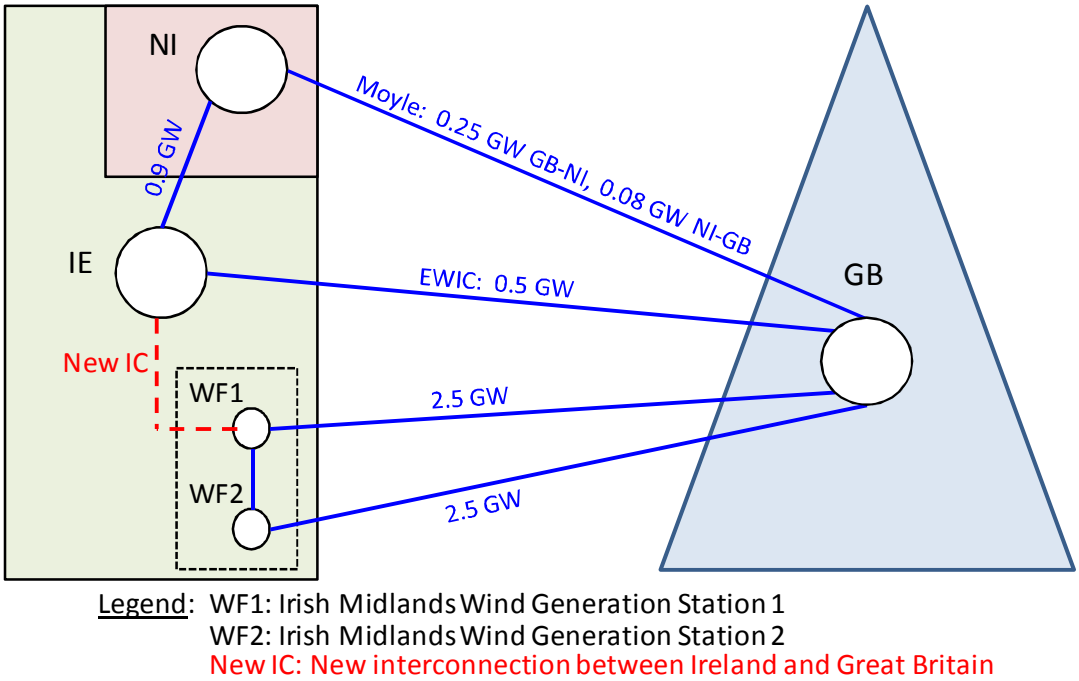

Figure 4.1 – Single node representation of Ireland (IE), Northern Ireland (NI) and Great Britain (GB) as used in the Plexos market model.

The trading benefits arising from new interconnection between Great Britain and Ireland (represented graphically in Figure 4.1 by the connection from the Ireland (IE) node to Irish Midlands Wind Generation Station 1 (WF1)) have been determined for a number of different interconnection trading capacity scenarios. The trading capacity scenarios and the associated annual trading benefits are detailed in Table 4.1. The analysis focussed on production costs rather than on marginal prices. However, it was observed that there was a reduction in average system marginal prices in Ireland.

Interconnection Trading Capacity	Annual Trading Benefit (£m p.a. / €m p.a.)
1 x 0.35 GW = 0.35 GW	£21m / €26m
1 x 0.5 GW = 0.5 GW	£28m / €35m
1 x 0.7 GW = 0.7 GW	£35m / €43m
2 x 0.5 GW = 1.0 GW	£43m / €53m
2 x 0.7 GW = 1.4 GW	£49m / €60m

Table 4.1: Annual trading benefits for different trading capacity scenarios

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4.2 Generation Capacity Value

Generation adequacy studies were carried out to estimate the annual capacity benefit to the Irish system from one or two connections to the Irish transmission system. The study year examined was 2020. New interconnection capacity between Ireland and Great Britain was added to the model in blocks of 0.5 GW and Open Cycle Gas Turbines (OCGTs) on the Irish system were then removed to achieve the original system adequacy value (in Loss-of-Load Expectation (LOLE) terms).

The results show that there are substantial capacity benefits to the island of Ireland from each additional 0.5 GW interconnector: 0.4 GW for a single new interconnector and 0.3 GW for a second new interconnector. This benefit is dependent on efficient market coupling being in place so that power can flow when it is required.

In the All-Island Single Electricity Market (SEM)[28], there is a Capacity Payment Mechanism (CPM) which values generation capacity at the cost of connecting a least-cost, technically acceptable generator known as the Best New Entrant. The Best New Entrant generator is selected annually by the Commission for Energy Regulation (CER) and is typically a medium-size OCGT. Generation capacity is valued at 63.56 £/(kW x year) or 78.18 €/(kW x year) for 2013. On this basis, the annual capacity benefit arising from a single new 0.5 GW interconnector would be £25 p.a. / €31m p.a. while the annual capacity benefit arising from two new 0.5 GW interconnectors would be £45 p.a. / €55m p.a.

4.3 Response and Reserve Sharing Value

The Plexos market modelling tool was used to assess the benefits to the Irish system of increased reserve and response sharing on the new interconnection using the same Plexos market model as was used to estimate the trading benefit. The estimated annual benefit to Ireland is up to £12m p.a. / €15m p.a. depending on the amount of reserve and response deemed acceptable to be provided from a single source i.e. the new interconnection.

[28] The Single Electricity Market (SEM) is the wholesale electricity market operating in the Republic of Ireland and Northern Ireland. It is a gross mandatory pool market that operates with dual currencies.

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4.5 Benefit Summary

The table below summarises the potential benefits for a range of interconnection trading capacities, which can be related back to the different NIOs considered in Section 3. The benefits presented are the annual benefits arising from trading, the sharing of reserve and response to the Irish system, the provision of generation capacity to the Irish system, and a congestion value to the GB MITS.

Interconnection Trading Capacity	Annual Average Congestion Value to GB[31] (£m/€m p.a.)	Generation Capacity Value to Ireland (£m/€m p.a.)	Reserve and Response Value to Ireland (£m/€m p.a.)	Annual Trading Value (£m/€m p.a.)	Total Annual Benefit (£m/€m p.a.)
0.35 GW	£2.5m/€3.1m	£25m/€31m	£12m/€15m	£21m/€26m	£61m/€75m
0.5 GW	£2.5m/€3.1m	£25m/€31m	£12m/€15m	£28m/€35m	£68m/€84m
0.7 GW	£2.5m/€3.1m	£35m/€43m	£12m/€15m	£35m/€43m	£85m/€104m
1.0 GW	£2.5m/€3.1m	£45m/€55m	£12m/€15m	£43m/€53m	£103m/€126m
1.4 GW	£2.5m/€3.1m	£45m/€55m	£12m/€15m	£49m/€60m	£109m/€133m

Figure 4.5 – Benefit Summary for Various Interconnection Trading Capacities

[31] Estimated value based on £2/kW saving across the B8, B9 and NW 2, 3 and 4 boundaries.

These results have clearly identified significant potential total benefits for both a single and double interconnection to the Irish transmission system. Further analysis is required to quantify other additional benefits not yet assessed due to time and resources. These benefits include:

- Sharing of reserve/response for the GB MITS.
- Reduction in the total generation capacity required to maintain security of supply on the GB MITS.
- The potential congestion benefits of avoided or deferred investment on the Irish transmission system.
- The ability to 'wheel' power through the Irish transmission system, in the case of a double interconnection this may reduce the level of AC interconnection required between the Irish Midlands Wind Generation collector stations.

Some of these may be substantial (specifically the congestion benefit to the Irish transmission system), but further work would be required to quantify the scale of these benefits.

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5 Network Interconnection and Deep Reinforcement Capital Costs

An overview of the estimated costs for the 3 GW and 5 GW Network Interconnection Options (NIOs) is presented in Table 5.1 and Figure 5.1 overleaf. The costs for each NIO are for the total works inclusive (where applicable) of the cost of the interconnection from the Irish Midlands Wind Generation to one (or both, depending on the option) of the Woodland 400kV and Dunstown 400kV substations on the Irish system.

[32] These costs have been extracted from an internal National Grid strategy paper, Strategy for connection of new generation in and around Wales, 3 April 2012.

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Note 1: Costs bourne by the Generator have been omitted in the costing analysis as Generator costs will remain the same regardless of network interconnection option and therefore will have no impact on option selection.
Note 2: All costs are project costs and as such include estimates for planning, construction, etc.
Note 3: Costs based on exchange rate of £1 = €1.23 (04/12/12).

	Equipment Detail	Costs	3 GW Options											5 GW Option	
			1	8	9	11	12	14	15	17	18	20	21	2	22
nationalgrid															
EIRGRID															
Total TSO Costs															

* According to estimations based on Western HVDC Project
** Cost estimations taken from West Coast Strategy Paper, April 2012

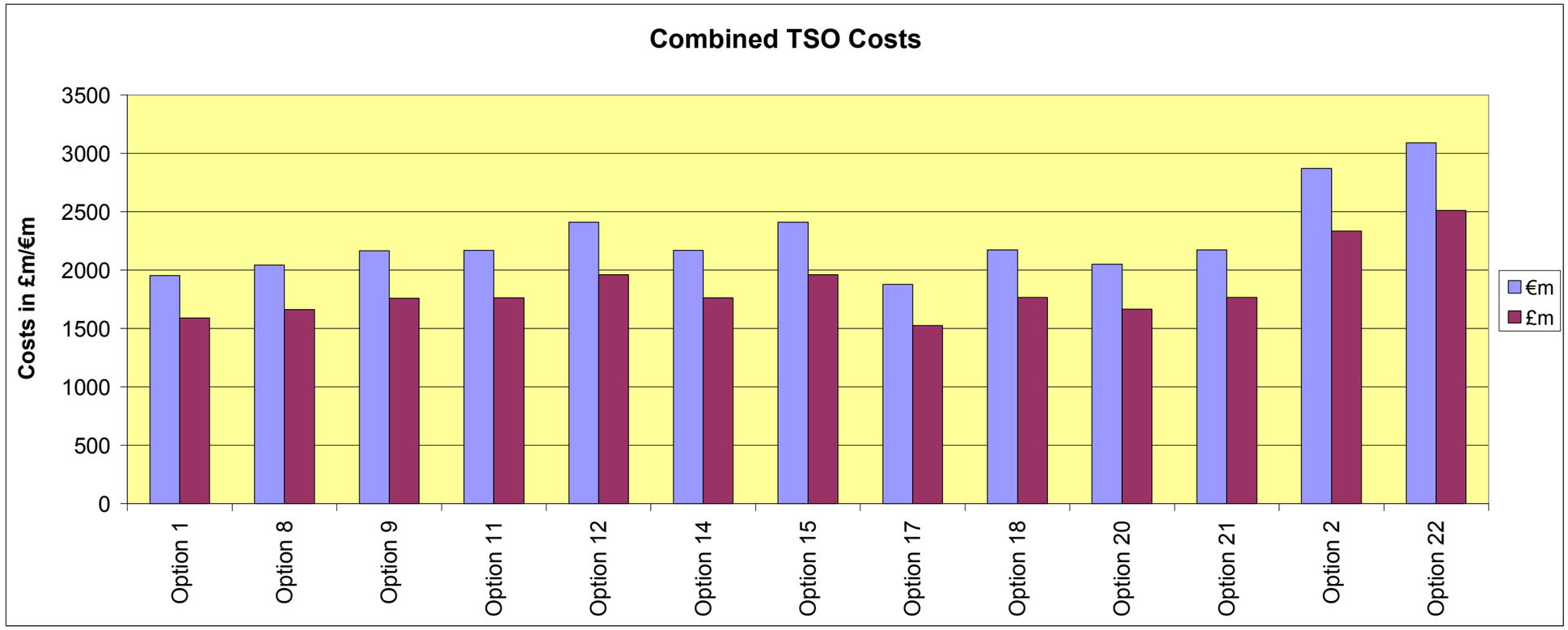

Table and Figure 5.1 – Overview of Estimated Total Costs

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5.3 Deep Reinforcements on the Irish System

Network studies were performed to analyse the capability of the Irish transmission system to import/export generation to/from Great Britain at either one or two separate connection points on the Irish transmission system. The network studies were performed using PSSE's Transmission Interchange Limits Calculations (TLTG) DC load flow tool. The four Extra High Voltage (EHV) stations closest to the likely location of the Irish Midlands Wind Generation were examined in detail: the Woodland, Laois (planned station) and Dunstown 400kV stations and the 220kV Maynooth station.

The studies indicate that Dunstown and Woodland, two 400kV stations located to the North-West and South-West of Dublin respectively as shown in Figure 5.2, are the optimal connection points on the Irish system.

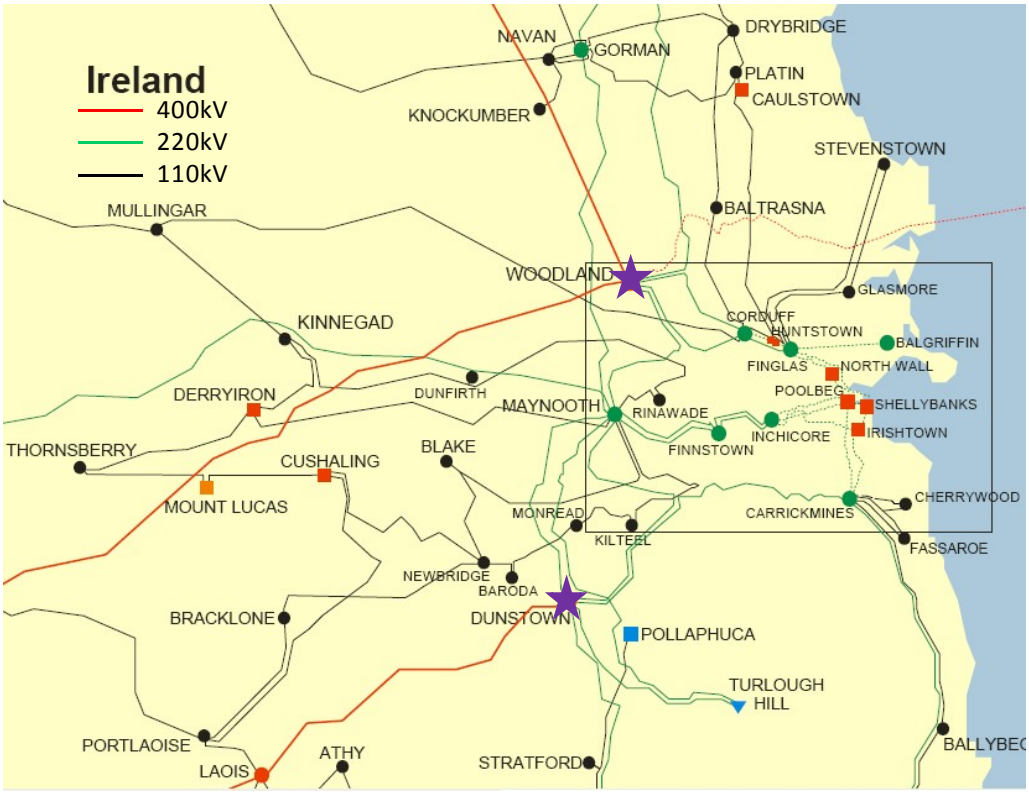

Figure 5.2: Woodland and Dunstown, the most appropriate connection points on the Irish system.

To achieve an import/export capability of 0.5 GW at Dunstown and/or Woodland 400 kV stations the following reinforcements are required:

1. Uprating of Corduff - Finglas 220 kV Overhead Lines (OHL) 1 and 2
2. Uprating of Corduff - Woodland 220 kV OHL 1 and 2
3. Uprating of Maynooth - Woodland 220 kV OHL
4. Uprating of Laois - Portlaoise 110 kV OHL (Laois is a new station planned for connection in 2015)

A cost estimate for these reinforcements was derived using information from Price Review 3[33]

Table 5.2: Price Review 3 Estimated Costs

The resulting reinforcement costs are shown in Table 5.3. The deep reinforcement cost of this project is estimated to be

Reinforcements	Length (km)	Uprate Cost per km	Total
Corduff - Finglas 220 kV 1	3.7		
Corduff - Finglas 220 kV 2	3.7		
Corduff -Woodland 220 kV 1	18.4		
Corduff - Woodland 220 kV 2	17.8		
Maynooth - Woodland 220 kV	22.3		
Laois - Portlaoise 110 kV	9.66		
Total	**75.56**		

Table 5.3: Total Cost of Required Deep Reinforcements

[33] CER Transmission and Distribution Price Review 2009

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5.3.1 Summary of Deep Reinforcement Costs on the Irish System

The study identified the need to uprate five 220 kV lines (totalling 66 km in length) and one 110 kV line (9.7 km in length) in order to achieve 0.5 GW import/export at a single node and 1000 MW import/export at two nodes (0.5 GW each at Dunstown and Woodland 400 kV stations).

The total cost of these reinforcements is It is assumed that the AC-DC converter will be sufficiently compensated to deal with any voltage issues at the connection point.

5.3.2 Sensitivity Study for 0.7 GW

A sensitivity study was performed to examine an increase in the transfer capability into the Irish transmission system from 0.5 GW to 0.7 GW for a single connection configuration at the same four stations (i.e. the Woodland, Laois and Dunstown 400kV stations and the 220kV Maynooth station). The results indicate that the uprating of a number of lines in the vicinity of the connection points is insufficient and further new build reinforcement is required to reach the 0.7 GW target. However, further detailed study work would be required to determine the level of new build reinforcement required to accommodate 0.7 GW at each proposed connection point. The additional infrastructure costs associated with the reinforcements required to increase the interconnection capacity from 0.5 GW to 0.7 GW have not been considered in this study.

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6 Cost-Benefit Analysis

For the 3 GW wind generation scenario, the Base Case Network Interconnection Option (NIO) is an "Integrated" development option with direct connection of the Irish Midlands Wind Generation to the GB MITS and no interconnection to the Irish transmission system (Option 1). The estimated cost of this option is £1.690bn / €2.079bn, excluding the cost of the wind turbines and the wind generator's internal collector network. This "Integrated" connection approach provides additional benefits over and above a set of radial direct connections to the GB MITS (a summary is provided in Appendix E).

This study focussed on performing an initial evaluation of the incremental costs and benefits arising from incorporating one or two connections to the Irish transmission system relative to the above Base Case NIO with no such connection. These "Integrated with Interconnection" NIOs provide the capability to exchange power between Great Britain and Ireland, and hence the connection to the Irish transmission system effectively fulfils the same function as a new interconnector between the two islands.

A wide range of possible interconnection options to the Irish transmission system were examined. Some were ruled out for technical or risk reasons. The remaining options were analysed to quantify the range of possible benefits such as production cost savings from trading between the two markets, the benefit to the Irish system of shared reserve/response, a reduction in the total generation capacity required to maintain security of supply on the Irish system, and an increase in boundary transfer capability on the Great Britain system. The benefits accruing to Great Britain from sharing reserve/response and the reduction in the total generation capacity required to maintain security of supply have not been assessed. Similarly, the potential benefits of avoided/deferred investment on the Irish transmission system have not yet been quantified. These benefits were described in detail in Section 4. Any additional cost incurred by each option was also estimated and presented in Section 5. The additional costs are composed of the capital cost of the connection to the substation on the Irish transmission system, and the capital cost of any deep network reinforcements required on the Irish system. These additional costs and benefits were then assessed against the Base Case Option 1 to determine the incremental net benefits, if any.

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Based on the evaluation of the incremental costs and benefits, the most promising NIO is Option 20, which consists of a multi-terminal HVDC connection from the Irish Midlands Wind Generation station to the Great Britain MITS with a single associated AC-DC converter connecting into the Irish system. Table 6.1 details the range of incremental annual benefits and incremental total (non-annualised) capital costs for this option. The preferred interconnection option would provide the same benefits as, for example, another East-West Interconnector-style interconnection project would produce but at a fraction of the cost

Based on the capital costs and annual benefits in Table 6.1, this option has a payback on capital costs of less than two years[34] and the benefits will endure for the remaining asset lifetime.

Incremental Costs and Benefits for Option 20		
Incremental Annual Benefits (£m p.a. / €m p.a.)	£61m p.a. / €75m p.a.	• Assumed to be operated at 0.5 GW capacity • Values are annualised benefits
Incremental Total Capital Costs (£m / €m)		• Values are total costs (non-annualised)

Table 6.1 – Incremental costs and benefits for Option 20, the most promising NIO.

In addition, a second new interconnection based on the same technology (i.e. the configuration in NIO option 21) would also provide clear benefits albeit slightly lower than the benefits that would be provided by the first interconnection. Also, there is a requirement for reinforcement works for imports greater them 0.5 GW to the GB MITS and the infrastructure costs associated with this increase in power transfer have not been assessed in this report. Further studies are needed to definitively prove the economic case for the second new interconnection. Assuming that there is an economic case, this

[34] Monthly Benefit = Annual Benefit/12 = £5.08m

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interconnection could be progressed at a later stage to the first interconnection or alternatively both could be progressed in parallel.

Based on the studies performed, the initial appropriate size for each connection to the Irish system is 0.5 GW. However, the links could be constructed at a higher capacity (e.g. 0.7 GW) for “future-proofing” at relatively little extra cost. The additional cost of construction of a 0.7 GW link relative to a 0.5 GW link has been used to estimate the capital cost shown in Table 6.1.

Finally, a full and detailed Cost Benefit Analysis is required to definitively ascertain the total benefits associated with the preferred NIO and to include the additional benefits not assessed to date. This subsequent analysis should also consider a variety of generation scenarios over longer timescales to provide increased robustness to these results.

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7 Planning and Environmental Considerations

7.1 Network benefits to the Irish system (avoided/deferred investment)

The "Integrated with Interconnection" options with two connections to the Irish transmission system have the potential to defer reinforcements in the Dublin region by facilitating the transfer of power between Dunstown and Woodland 400kV substations, the assumed connection points. While there is a need for network reinforcement in the Dublin region, the level and nature of reinforcement required has not yet been determined. Therefore, at this stage, it is not possible to assess the potential benefits until a decision is made on the Dublin reinforcement project. A decision is expected in Q2 2013.

EirGrid also identified another possible connection point in the south-east of Ireland, Great Island, which could potentially alleviate further reinforcement on the Irish system. Given the distance from the likely location of developer wind generation collector station sites in the midlands, it was excluded from the scope of this study. However, a co-ordinated approach to the cable routing could potentially deliver benefits from avoided investment on the Irish transmission system.

7.2 Network benefits to the GB MITS (avoided/deferred investment)

National Grid has identified the requirement to reinforce the GB MITS between North and South Wales. All "Integrated" or "Integrated with Interconnection" design concepts presented in this report would provide an increase in transfer capability / congestion benefit on critical system boundaries associated with these reinforcements. The extent of this congestion benefit and the avoidance or deferral of other works has not been fully determined and National Grid plans to develop schemes for a North to South Wales reinforcement from 2014.

7.3 Ireland Environmental and Planning Considerations

7.3.1 Planning and Development Acts 2000-2011

Under Section 182A of the Planning and Development Acts 2000-2011 "transmission" in relation to electricity is construed as meaning the transportation of electricity by means of (a) a high voltage line where the voltage would be 110 kilovolts or more, or (b) an

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interconnector, whether ownership of the interconnector will be vested in the undertaker or not. Therefore it is likely that An Bord Pleanála would deem the proposed development to fall within the scope of this section, and accordingly would be made to the Strategic Infrastructure Division (SID) of An Bord Pleanála (ABP).

7.3.2 Exempted Development Status

The current planning legislation makes provision for certain works to be exempted development (i.e. development which does not require a prior grant of development consent); this depends on the specific nature of the works involved. Of equal relevance, however, certain works will required to occur within, adjacent to, or close to, designated areas (e.g. candidate Special Areas of Conservation (cSACs) or Special Protection Areas (SPAs).

Exemption from a legal requirement to obtain prior statutory consent for certain works relevant to electricity infrastructure provision is conferred by several Classes set down in Schedule 2 of the Planning and Development Regulations 2001 (as amended). Specifically, the Class of exemption which applies to the undergrounding of cables is Class 26, which states as constituting exempted development:

> *"the carrying out by any electricity undertaking of development consisting of the laying underground of mains, pipes, cables or other apparatus for the purposes of the undertaking"*

Any Class of exemption is subject to the qualification that no works would contravene the provisions of Article 9 of the same Regulations. For clarity, it should be noted that there is no "blanket" exemption for UGC; it must meet certain site-specific tests. However, if it is proposed to construct an UGC, and provided the "Article 9" tests were passed, then Class 26 exemption could normally be relied upon, and in the past this was not generally difficult to surmount.

A significant amendment has occurred to the Article 9 restrictions on exemptions, with the publication of the Planning & Development (Amendment)(No. 2) Regulations 2011 (13th

NATIONAL GRID/EIRGRID CONFIDENTIAL

September 2011). Along with other additions/amendments to Article 9, the amended Regulations add the following category:

> *"(viiB) comprise development in relation to which a planning authority or An Bord Pleanála is the competent authority in relation to appropriate assessment and the development would require an appropriate assessment because it would be likely to have a significant effect on the integrity of a European site,"*

This has serious implications for UGC and exempted development, given the complexity of the Appropriate Assessment (AA) process. Appropriate Assessment derives from the European Habitats Directive, which seeks to ensure that there is no adverse impact arising from a proposed development upon the integrity of a designated site – commonly known as Natura 2000 sites (or Natura sites). The new provision within Article 9 thereby concerns all development within, adjacent to, proximate to or possibly more distant from, designated Natura 2000 sites, and is based upon the **potential** to impact upon that site, rather than any residual impact arising following the application of mitigation measures.

The key element of this is that the "competent authority" (An Bord Pleanála – ABP in the case of Strategic Infrastructure Development - SID) is the body who carries out the assessment, not the applicant. Therefore, while EirGrid and its consultants can prepare reports which conclude that there is no impact upon a European Site, and thereby hold that UGC are exempted development in a particular instance, the competent authority has the Statutory obligation to carry out the process of screening for AA, and the actual AA if it considers this is required, and may come to a different conclusion. If an application has been submitted for development, but excludes UGC on the consideration it is exempted development, for example proposing a substation, but not a UGC to link to a wind collector stations, it is likely that the competent authority will return the application as incomplete; probably more serious, from a cost and time perspective, ABP might see fit to Grant Approval for what is proposed in the application, but exclude the UGC element, meaning this requires a separate application to the SID, with a separate pre-application and application process.

This issue has been raised by An Bord Pleanála during pre-application in respect of a particular SID project since September 2011 when this provision commenced in the Statutory Regulations. It should be noted that the implications of this is not restricted to

NATIONAL GRID/EIRGRID CONFIDENTIAL

works being proposed by EirGrid, but also to ESB Networks, and the Independent Power Producers (IPPs).

Line uprates, while potentially exempt under the Planning and Development Act 2000 (as amended), since September 2011, with the enactment of section 17 of the Environment (Miscellaneous Provisions) Act 2011, a new provision has been added to the legislation governing exempted development, whereby development shall not be exempted development if an Appropriate Assessment (AA) of the development is required (it has been the case for many years that development shall not be exempted development if an Environmental Impact Assessment (EIA) of the development is required). Thus, in the event that an AA of the up-rating of existing transmission lines, or in respect of minor works, is required, those works would not be exempt from the requirement to obtain statutory consent.

In addition, certain works may comprise a "notifiable action or Activity Requiring Consent" to the NPWS of the Department of Arts Heritage and the Gaeltacht (DAHG), by virtue of their siting within a designated Natural Heritage Area (NHA).

Therefore, a number of different legislative codes are in force regarding transmission development – including that relating to Planning and Development, and also relating to implementing the European Habitats Directive. These are outlined below.

Section 4(1)(g) of the Planning and Development Act 2000 (as amended) specifies as exempted development:

> *"development consisting of the carrying out by any local authority or statutory undertaker of any works for the purpose of inspecting, repairing, renewing, altering or removing any sewers, mains, pipes, cables, overhead wires, or other apparatus, including the excavation of any street or other land for that purpose".*

Section 4(1)(h) may also be relevant, confirming that exempted development also includes:

> *"development consisting of the carrying out of works for the maintenance, improvement or other alteration of any structure, being works which affect only the*

NATIONAL GRID/EIRGRID CONFIDENTIAL

interior of the structure or which do not materially affect the external appearance of the structure so as to render the appearance inconsistent with the character of the structure or of neighbouring structures";

7.3.3 Appropriate Assessment

Guidance is provided by the National Parks and Wildlife Service (NPWS) publication *'Appropriate Assessment of Plans and Projects in Ireland: Guidance for Local Authorities',* 2009. In summary, the key relevant points to note are:

- Natura 2000 sites include Special Areas of Conservation (SACs), Special Protection Areas (SPAs), candidate SACs (cSACs) and proposed SPAs (pSPAs) but not Natural Heritage Areas (NHAs) or proposed NHAs (pNHAs);
- It is the decision of the competent authority (An Bord Pleanála in this instance) whether or not to carry out Stage 2 AA. This follows a Stage 1 Screening for AA, also carried out by the competent authority;
- AA must be carried out if it cannot be excluded, on the basis of objective information, that the project will have a significant effect on the integrity of that site, either individually or in combination with other plans or projects;
- In accordance with the precautionary principle, where doubt exists about the risk of a significant effect, an AA must be carried out;
- AA is an impact assessment process, and a Natura Impact Statement (NIS) – i.e. a statement of the likely and possible impacts of the plan or project on a Natura 2000 site must be prepared;
- AA is a four stage process: Stage one - Screening for AA; Stage 2 – AA; Stage 3 - Alternative Solutions; and Stage 4 – Imperative Reasons of Public Importance (IROPI);
- A Stage 1 Screening Report can come to three possible recommendations/ conclusions: (a) AA is not required; (b) no potential or significant effects/AA not required; and (c) significant effects are certain, likely or uncertain.
- If the Stage 1 Screening concludes with (c) then rejection of the project or AA (Stage 2) follows; it is usually the latter;
- If the Stage 1 screening concludes with (a) or (b) then AA may not necessarily follow but this is within the remit of the competent authority to determine.

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Therefore, even if the Stage 1 Screening carried out by ABP finds that no potential environmental impact exists, there is still a risk that An Bord Pleanála may carry out a Stage 2 AA. If this is the case then the cable loses its exempted development status. All this can obviously only occur when the application has been submitted, and ABP undertakes the AA Screening process.

It is prudent and current practice, for EirGrid's consultants to prepare and submit with the application an AA Stage 1 Screening Report with an application, and an NIS if the Stage 1 Screening cannot rule out potential impacts arising, but these are merely tools which hopefully will assist the competent authority in carrying out its statutory functions. The Board's process in carrying out its statutory functions in this regard is obviously irrespective of any conclusions that EirGrid and its Consultants might arrive at in carrying out its own reports.

In summary for all projects, including uprate projects, a Stage 1 Screening Appropriate Assessment is required to be conducted to determine if there is any potential for significant impacts on designated Natura 2000 sites (comprising SACs, cSACs, SPAs and pSPAs). This may need to be informed by a site survey to determine if any qualifying features are likely to be impacted by the project. If the outcome of the Stage 1 Screening Appropriate Assessment is that no significant impacts are likely then a Stage 2 Appropriate Assessment is not required and the project remains exempt for planning purposes. If the outcome of the Stage 1 Screening Appropriate Assessment is that a Stage 2 Appropriate Assessment is required (a Natura Impact Statement is prepared) as significant impacts could not be ruled out at Stage 1 Screening then the project becomes de-exempt and a planning application must be made to the relevant planning authority.

In tandem with this process, all projects are examined to determine if there is any potential for them to impact on NHAs (nationally designated sites). If the project has the potential to impact on NHAs, then consent from the Minister is required for the works. It is worth noting that this process does not apply to proposed NHAs.

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7.3.4 Environmental Impact Assessment Thresholds

The legislation pertaining to the requirement for an EIA for various types of developments is the Planning and Development Acts 2000 – 2011 (incorporating the Planning and Development Regulations 2001 – 2011). With regard to the requirement, or otherwise, for an Environmental Impact Assessment (EIA), this is required for classes of development prescribed by Article 93 and Schedule 5 of the Planning and Development Regulations 2001-2011. Where EIA is required, the developer must submit an Environmental Impact Statement (EIS) with the application for planning permission/planning approval.

Item 20 of Part 1 of Schedule 5 states that the threshold for an EIA in respect of electricity transmission infrastructure comprises:

'*Construction of overhead electrical power lines with a voltage of 220 kV or more and a length of more than 15 kilometres*'.

Item 3 of Part 2 of Schedule 5 refers to the 'Energy Industry' and section (b) states:

'Industrial installations for carrying gas, steam and hot water with a potential heat output of 300 Megawatts or more, or transmission of electrical energy by overhead cables not included in Part 1 of this Schedule, where the voltage would be 200 Kilovolts or more'.

If a proposed development does not meet this statutory threshold in terms of voltage, and an EIS is not automatically required in respect of the proposal. However, by virtue of the provisions of section 182A(5) and/or Article 103 of the Planning and Development Regulations 2001-2011, An Bord Pleanála, where it considers that the development is likely to have significant effects on the environment, shall require the applicant to submit an EIS.

7.4 UK Planning and Environmental Consent Considerations

Under its duty in the Electricity Act 1989 to facilitate competition in the supply and generation of electricity, National Grid has a statutory obligation to offer connection facilities to any new or proposed power station or plant, including offering connections to a local distribution company or major industry that requires a high voltage electricity supply.

NATIONAL GRID/EIRGRID CONFIDENTIAL

Therefore, proposals for a new electricity generation project may also involve transmission works away from the power station site, such as new overhead lines or HVDC Links, modifications to existing lines or new development at substations. These transmission works may be the responsibility of National Grid, the distribution companies or the generator itself depending upon the particular circumstances of each case.

Consents, Rights and Permissions

When National Grid needs to build new energy infrastructure, such as gas or CCS pipelines, overhead electric lines and above ground installations such as substations or compressor stations, a number of consents or approvals may be required from different permitting bodies. The number and type of consents required depends on the type of infrastructure and where it is located, including whether it is onshore or offshore.

Certain types of energy infrastructure fall within the categories of Nationally Significant Infrastructure Projects (NSIPs) which require a Development Consent Order (DCO) under the Planning Act 2008. As required by the amendments under the Localism Act 2011, applications for DCOs are determined by the Planning Inspectorate and the Secretary of State for Energy and Climate Change (the Secretary of State). For National Grid, NSIPs can include new high voltage overhead lines in England and Wales (except those crossing land that we occupy or control or certain minor works which are exempt)

Where transmission infrastructure is needed to connect just one customer and where that customer's project is also an NSIP in its own right (e.g. a new onshore electricity generating station over 50MW or offshore generating station over 100MW), it is possible and may be appropriate where timescales coincide, for the transmission network reinforcements to form part of the customer's DCO application. Conversely, where National Grid has an NSIP proposal that is needed for a variety of reasons (not just to meet the needs of a single customer) or involves network reinforcements in advance of anticipated future energy developments, it will often be necessary for National Grid to apply separately for a DCO for its works. In such circumstances National Grid will endeavour to synchronise its pre-application consultations and DCO application with the customers we are connecting.

NATIONAL GRID/EIRGRID CONFIDENTIAL

For offshore infrastructure a new consenting and licensing regime was introduced in 2011 by the Marine and Coastal Access Act 2009. Inshore (from Mean High Water to 12 nautical miles) and offshore (12 to 200 nautical miles) the Marine Management Organisation, National Assembly Wales, Marine Scotland and the Department of the Environment for Northern Ireland are the marine planning authorities for their respective territorial waters. Within those areas a licence might be needed for activities in or over the sea, or on or under the sea bed. This can include the installation of cables, pipelines and overhead lines or investigatory work such as intrusive surveys. Depending on the nature of the proposals there may also be overlaps with other consenting regimes, particularly where infrastructure comes ashore.

Where offshore proposals are NSIP development, consent for the offshore elements in addition to any onshore NSIP elements will be needed under the Planning Act 2008.

Other types of new energy infrastructure might require planning permission from local planning authorities. Examples can include new substations, sealing end compounds or AC/DC converter stations on our electricity network or new compressor stations, pressure reduction installations, block valves and other above ground installations on our gas transportation or proposed CCS pipeline networks. Major extensions to those sorts of sites and temporary construction accesses onto classified roads may also need planning permission. Where such works are in England and are needed in connection with a proposed NSIP, it may be possible to incorporate them into a DCO application as “associated development”. In Wales, separate applications for planning permission to local planning authorities are required as planning is a devolved matter.

Under the Town & Country Planning (General Permitted Development) Order 1995, certain works on the electricity network may be “permitted development” and can be undertaken without first needing to apply for planning permission. This can include the installation of additional plant and equipment at operational sites and extensions to existing buildings, subject to certain limitations.

Installation of underground electricity cables is also permitted development and does not require either consent under the Planning Act or local planning permission, although the

NATIONAL GRID/EIRGRID CONFIDENTIAL

sealing end compound(s) at the point of transition between overhead lines and underground cables may require planning permission from the local planning authority.

Temporary or permanent culverts, outfalls and other drainage works may require planning permission and formal consents from the Environment Agency. Such approvals may relate to river crossings and other works affecting watercourses. Under local bye laws, there could be approvals required from local drainage boards and under other legislation there can be a variety of secondary consents needed. With the agreement of the relevant consenting bodies, secondary consents or approvals may also be included in a DCO application as “ancillary matters”.

In addition to these primary and secondary consents, where new onshore infrastructure crosses land that National Grid does not own or occupy, the agreement of the relevant landowners is required. In most cases where rights to install, operate, inspect, maintain and repair are needed, we will seek to agree an easement with the landowner.

Amenity Responsibilities

As a responsible business, National Grid integrates environmental considerations into all its activities. There is in place an environmental management system certified to ISO 14001, where performance against clear environmental objectives and targets is regularly monitored and reported publicly in its Environmental Performance Indicators.

Under Section 38 and Section 9 of the Electricity Act 1989, National Grid has a duty to:

> "have regard to the desirability of preserving natural beauty, of conserving flora, fauna and geological or physiographical features of special interest and of protecting sites, buildings and objects of architectural, historic or archaeological interest; and shall do what it reasonably can to mitigate any effect which the proposals would have on the natural beauty of the countryside or on such flora, fauna, features, sites, buildings or objects."

Under the provisions of the Planning Act 2008 National Grid also has a duty to consult and engage with communities and stakeholders. In meeting these duties, National Grid has defined ten commitments to underpin its aspiration to engage positively with stakeholders and communities and to meet amenity responsibilities when undertaking electricity works.

NATIONAL GRID/EIRGRID CONFIDENTIAL

These commitments are described in its combined Stakeholder, Community and Amenity Policy document[35].

National Grid also has particular responsibilities with regards to National Parks, Areas of Outstanding Natural Beauty (AONBs) and Sites of Special Scientific Interest (SSSIs). The special protection afforded to these areas is always recognised when planning new transmission infrastructure.

A small proportion of the existing GB transmission infrastructure is located within these designated areas. National Grid aims to ensure that all staff and contractors:

- Are aware of the location of these sensitive areas.
- Carry out the appropriate consultations.
- Plan works with appropriate mitigation to minimise the impact of our works.

7.5 Project Deliverability and Timelines

It is expected that the design concepts presented in this report would not impact on the timelines of any current renewable generation developer in Ireland.

7.5.1 Deep Reinforcement Leadtimes

The lead time to carry out the required line uprates to facilitate interconnection to the Irish transmission system can range from 18 months to 3 years. The two main factors affecting leadtimes would be the projected traffic of the outage work programme and the availability of ESB Networks staff. However the 220 kV circuits to be uprated are all in close proximity and this may complicate the outage planning programme and possibly extend the lead time.

[35] National Grid Stakeholder, Community and Amenity Policy: http://www.nationalgrid.com/uk/LandandDevelopment/SC/Responsibilities/sched9/schedule+9.htm

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8 Other Considerations

8.1 VSC HVDC Technology Considerations

Voltage Source Conversion (VSC) High Voltage Direct Current (HVDC) is the latest development in the field of HVDC technology and its main difference with Current Source Conversion (CSC) technology is that VSC converter stations are able to form their own AC voltage waveform and act as a true voltage source. This gives total flexibility regarding the location of the converters in the AC system since the requirements for the short circuit capacity of the connected AC network is low, enabling VSC HVDC systems to be connected to very weak AC systems. Therefore VSC HVDC can connect remote electrical islands such as offshore generation or in this case onshore wind generation on the island of Ireland without the need for additional equipment.

VSC HVDC technology has the capability to control both real and reactive power rapidly and independently of each other. The converter station can operate over a whole region of differing real and reactive power, unlike the CSC HVDC converter which can only provide discrete amounts of reactive power. This helps to keep the voltage and frequency of the associated AC system stable. The key technology that enables VSC HVDC converter stations to produce a voltage waveform is the high power Insulated Gate Bipolar Transistor (IGBT)[36] which unlike the thyristors used in the CSC systems are self commutated, i.e. they can be switched on and off rapidly (up to 2000 times per second) to modulate a voltage waveform. Some key technology considerations are highlighted by ENTSO-E's offshore technology paper[37] and are summarised below.

At present the power handling capability of the largest available VSC HVDC converter module is 1.0 GW at ±300kV, however capabilities of 1.110 GW may well be possible in the immediate future for single converter Cross Linked Polyethylene (XLPE) insulated bipole pairs operating at ±300kV. For CSC HVDC the power handling capability is planned to be 2.2 GW with Mass Impregnated (MI) bipole pairs operating at ±600 kV[38]; the limitation for the power handling capability is due to the MI cable. To achieve the 2.5 GW power handling capacity for the NIO considered in this report further VSC HVDC

[36] To date, the present maximum current that can flow on an IGBT is 1.8 kA.
[37] Offshore Transmission Technology, ENTSO-E, November 2011.
[38] 600 kV technology has not been type registered to date.

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technology development will be essential, specifically with regard to the current carrying capability of the IGBT and to a lesser extent cable development.

8.1.1 Cable Technologies

Subsea cable systems are required for offshore transmission. AC cables are limited to a distance of approximately 50 km due to capacitive charging in the cables which reduces their ability to transfer real power. For this reason AC subsea cables have not been considered as a possible connection technology for this project. This is not the case with DC transmission, where a charging current only occurs during the instant of switching on or off and therefore has no effect on the transfer capability of the cable.

With VSC transmission, only one DC polarity is allowed and therefore the cable does not need to be designed for polarity reversal unlike its CSC counterpart. This greatly simplifies the cable design, leading to cheaper and lighter cables. HVDC cables are described by their insulation type. For this project Mass Impregnated (MI) Paper and Cross Linked Polyethylene (XLPE) cables will be considered; please note, capital costs in this report have been calculated assuming the use of MI cables

Mass Impregnated Paper: MI insulation is made by winding kraft paper around the conductor until the required insulation thickness is achieved. The cable is then placed in a vacuum chamber and heated to remove any air and moisture. A viscous oil is introduced which impregnates the paper, increasing the electrical strength of the insulation. A recent development uses Polypropylene Laminated Papers (PLP), where thin layers of plastic are laminated to the paper layers, allowing the cable to operate at higher temperatures and therefore higher current ratings.

Mass Impregnated cables have been used in HVDC applications since the 1950's and it is therefore a very mature technology. Currently the highest installed rating, 0.66 GW/Cable operating at ±500 kV, is for the Neptune project in the US. Although, current MI cables are actually capable of transferring 1.0 GW/pole.

As previously mentioned PLP is an emerging technology which allows the cable to operate at a higher temperature and therefore increase power transfer. It is believed that voltages up to 650 kV and 1.5 GW transfers will be available with this technology.

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Technology Risks: MI cables are a proven technology for high powered subsea transmission. The risk lies with the supply chain, with only three manufacturers of MI cables in Europe: ABB (cable factory in Karlskrona, Sweden), Prysmian (cable factory in Naples, Italy) and Nexans (cable factory in Halden, Norway). With increasing demand for subsea cables, it is likely bottlenecks will develop which could have major impacts on projects. Supply and installation lead times for MI cables is in the region of 2-3 years.

For higher cable voltages, such as 600 kV or more, there is currently only one manufacturer which increases the risk associated with this technology even further.

Cross Linked Polyethylene: Extruded XLPE insulated cables are made by extruding the polymer over the cable core and they have only been on the HVDC market for the last ten years. To date the East West Interconnector has the maximum installed rating of 0.25 GW/cable operating at ±200 kV. However the market is capable of supplying XLPE cables up to 320kV, with transfers of 0.5 GW/cable. There are not perceived to be any barriers to achieving voltages greater than 320kV should there be a demand for them. 500kV cables could be developed within the next 5 years offering transfer capacities of 1.0 GW/cable.

Technology Risks: As the use of XLPE for HVDC applications is relatively new there is a risk that some failure may occur during the cable's lifetime. Plus, there is also a risk that voltage levels will not reach their expected levels, which may have an impact on this project.

8.1.2 Multi Terminal

In a Multi Terminal configuration there are three or more terminals. Worldwide there are currently two multi-terminal systems in operation, both based on CSC HVDC technology with a further project in India scheduled to be operational by 2015. There is however a major constraint with regards to CSC multi-terminal configurations and that is the need to change the converter polarity to reverse power flow. This limits the multi-terminal system to essentially deliver power in one direction only. This issue can be overcome through the use of VSC HVDC, where the power flows can be changed by controlling the firing angle of the power electronic devices within the VSC converter. However, it should be noted that no such system has been implemented to date. It appears that there are no major barriers

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for the manufacturers to overcome, particularly with the announcement that DC circuit breakers will be made available (although there has been no commercial implementation of this technology as yet), and it is estimated that VSC multi-terminal systems will be on the market within the next few years.

In fact, there are a number of projects that are planning to use VSC muti-terminal systems. The 1.6 GW Kreigers Flak project plans to connect wind generators in the Baltic Sea to the transmission networks of Germany and Denmark through the use of multi-terminal VSC. The Moray Firth Offshore Hub is planned by Scottish Hydro Electric Transmission Ltd to act as a multi-terminal switching station on the Blackhillock to Caithness link for future wind generator connections and to increase transmission capacity. A HVDC link between the Netherlands and Denmark, known as the Cobra cable, is also proposed with the possibility of a multi-terminal hub to allow for the future connection of offshore wind generators. All three of these projects are EU co-financed technology demonstration projects for offshore grids and receive funding from the European Energy Programme for Recovery (EEPR). Although initial timescales indicated that all three EEPR projects would be in operation by 2016, it is now believed that 2018 is a more realistic date[39]. A further onshore VSC multi-terminal project is also planned to reinforce the connection between Sweden and Norway, phase one is due for completion in 2014.

Technology Risk: At present there is no multi-terminal VSC HVDC in operation despite its technical feasibility. Performance under fault requires significant discussions with manufacturers and studies to fully understand any implications. One of the biggest risks with a multi-terminal configuration is that it would be manufacturer specific meaning all equipment and control systems would be provided by a single supplier, although there is currently a working group looking at DC Grid standards. There may also be significant competition for manufacturing and construction capacity.

8.2 Factors Affecting Irish Transmission System Operation

EirGrid's Facilitation of Renewables study from 2010 examined many of the challenges that would be faced by a TSO when operating the power system with very large amounts

[39] Report from the commission to the European Parliament and the council on the implementation of the European Energy Programme for Recovery, European Commission, August 2012.

NATIONAL GRID/EIRGRID CONFIDENTIAL

of wind relative to the size of the system. Based on the results of that study, a qualitative breakdown of some of the different challenges is given here and summarised in Table 8.1.

Operational Complexity: All of the options will increase the operational complexity of the Irish transmission system (apart from Options 1 and 2). In particular, Options 8 and 9 would represent a step-change in operational complexity, with an extremely large wind generator (relative to the overall demand on the Irish system) being AC-connected to the Irish system. This increase in complexity would occur in many different domains including management of wind variability, transient stability, voltage and frequency control, and in particular the provision of operating reserve. This additional AC-connected intermittent generation, coupled with the predicted levels of renewable generation already under development, would increase the non-synchronous penetration levels to far beyond what the Facilitation of Renewable study has deemed to be permissible. The other options, in which there is HVDC connection to the Irish Transmission System would also increase operational complexity, but not to the same extent as the AC connection.

Steady-State Voltage Control: Displacement of conventional generators by wind makes control of voltage more difficult, because conventional generators traditionally have far superior reactive power capabilities compared with wind turbines. The co-ordination and central control of numerous small sources of reactive power providers has proven to be difficult thus far when interactions with the distribution system are taken into account. With HVDC interconnection, the provision of statcom-type modes at the converter station would be of benefit to voltage control in the vicinity of the connection point.

Transient Stability: HVDC interconnection could help transient stability by providing fast dynamic reactive support during faults. However, both HVDC and AC-connected wind generation will appear as asynchronous sources to the Irish system, and so will make the Irish power system appear electrically lighter and less transiently stable. The Facilitation of Renewables studies showed that synchronous condensers or wind generation with fast dynamic reactive power provision could help to mitigate this. It is not clear whether the various options would expose the Irish power system to large uncontrolled flows during N-1 contingencies or due to converter blocking at the GB side. This would need careful study for all options under consideration.

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Voltage Stability: As for steady-state voltage control, for HVDC interconnection options, the provision of statcom-like modes at the converter station would help voltage stability on the Irish power system. Depending on the wind turbine technology used, an AC connection could have a positive or a negative effect on voltage stability and the impact of this would need to be carefully studied.

Frequency Control: With a large AC-connected wind generators, the Irish system could see a much increased level of frequency fluctuations due to the inherent variability of the wind output, and would have a significant impact on Dispatch Balancing Costs. This would be particularly evident at high wind output. Possible mitigation strategies would include placing wind generators in an active power control mode, so that they produce a relatively constant output. Another option would be for the HVDC controller to modulate the DC flow in exact correspondence with the wind generators fluctuating output. However, in this case, the wind fluctuations would appear at the GB MITS transmission system connection point.

Reserve: Increased interconnection with the GB MITS system could provide additional reserve sources, helping security of supply in Ireland.

Existing Wind Connections: At present, the Irish power system can accommodate up to 50% non-synchronous generation. Beyond this value, existing wind generators are curtailed. The appearance of a substantial amount of extra non-synchronous generation, whether it be through AC or DC connection, has the potential to significantly impact the curtailment of existing wind generation in Ireland. The treatment of wind generation on an AC island relative to priority dispatch generation in Ireland would require careful consideration.

System Non-Synchronous Penetration (SNSP): Ireland currently has a 50% non-synchronous generation limit, i.e. no more than 50% of the generation should come from non-synchronous sources such as wind or HVDC interconnection. This is calculated as SNSP = (Wind + HVDC Imports)/(Demand + HVDC Exports). In the case of an AC-connected wind generator, the entire wind generation would appear in the calculation of the SNSP value for Ireland, whereas with a HVDC interconnection, only the instantaneous HVDC flow into Ireland would serve to increase the SNSP value. Consequently, the AC

NATIONAL GRID/EIRGRID CONFIDENTIAL

interconnection would push the operation of the system into an area that the Facilitation of Renewables study deemed to be unsafe.

Options	Operational Complexity	Steady-state Voltage Control	Transient Stability	Voltage Stability	Frequency Control	Reserve	Impact on Existing Wind Connections	SNSP
1-2 No Electrical Connection	0	0	0	0	0	0	0	0
8-9 AC Connection	--	--	---	-	---	+	---	---
11, 12, 14, 15 Back-Back HVDC	-	+	-	+	+	+	-	-
17, 18, 20, 21 Multi-terminal HVDC	-	+	-	+	+	+	-	-

'+' : EirGrid Operations believe that these scenarios will help operate the power system more securely.
'-' : EirGrid Operations believe that these scenarios may cause operational difficulties, but should be manageable.
'--' or '---' : EirGrid Operations believe that these scenarios will present significant challenges and will need further consideration.

Table 8.1 – Summary of factors affecting Irish transmission system operation.

EirGrid Operations are of the view that Options 11, 12, 14 and 15 would be best in terms of buffering the Irish grid from the variability of the wind, and from faults on the Great Britain MITS. Options 17, 18, 20 and 21, which are effectively multi-terminal HVDC schemes, would also be viewed positively and would give the best controllability of the proposed wind generation.

In general, AC connected wind generation could degrade the stability of the Irish power system for high wind power levels, and impose significant extra curtailment on the existing wind generators in Ireland. HVDC connections would also serve to increase the SNSP value if energy was being imported into Ireland, which could also impose extra curtailment

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on Irish wind generation. However, HVDC connections would provide an electrical buffer between the proposed wind generator, and potentially buffer against faults on the GB MITS.

HVDC schemes generally offer very good control – particularly with ramping services, blackstart services, and can help with voltage control and system damping. There are open questions on how any new HVDC scheme would interact with the existing interconnectors, harmonics levels, and sub-synchronous torsional interactions. It would be wise to study all these areas well before any contracts are signed.

EirGrid Operations have serious concerns about the ability of the TSOs to both operate and study the various options under consideration. For example, there are potential difficulties in carrying out EMT studies to guarantee that the wind turbines and HVDC controllers would behave in unison to maintain a stable AC island, particularly with different vendors / Intellectual Property issues.

8.3 Factors Affecting the Great Britain Main Interconnected Transmission System Operation

For National Grid, "Integrated with Interconnection" design solutions would primarily provide another trade link with the Irish transmission system. Exports and imports over this link will be dictated by the respective price of power in each country and during periods of high wind it is very likely that power will be exported from Ireland to Great Britain on all three interconnectors (Moyle, EWIC and the proposed "Integrated with Interconnection" link with Irish Midlands Wind Generation).

Operational Complexity: This additional interconnection with the Irish transmission system would expose the National Electricity Transmission System Operator (NETSO) to increased exports into North and South Wales during period of high wind generation output (generally in the winter months). The implications of this are:

- **A Possible Reduced Usage of Response and Reserve from Pumped Storage.** Dinorwig and Ffestinog provide significant support to the NETSO in frequency control. The location of the new interconnection may result in increased

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generation constraints on the North Wales export boundaries during periods of high wind output in order to secure capacity for response from Pumped Storage. Alternatively, response could be held elsewhere on the system during these peak export periods therefore reducing the usage of pumped storage.

- **Additional OTS/Deload Requirement.** With an "Integrated" only connection of 3 GW of Irish Midlands Wind Generation via two HVDC Links at 2.5 GW there is a requirement on the fault contingency of one HVDC Link to reduce the Irish Midlands Wind Generation output by 0.5 GW. With an "Integrated with Interconnection" connection, there would be a requirement to increase this depending on the level of export from the Irish transmission system. EirGrid would likely be able to accommodate up to 0.5 GW of a reduction in power transfer although further studies would be required to confirm the exact level of reduction that can be achieved.

Wheeling Power: EirGrid has assessed the ability to wheel power between two 400 kV substations for a double NIO. The benefit to the NETSO is an ability to wheel up to 0.5 GW through the Irish transmission system although exactly when and how this would be achieved has not been determined. However, it does provide additional capacity between the wind generator collector stations and therefore between Pentir and Pembroke.

8.4 Flexibility

In terms of the connection options being proposed, the HVDC options offer the most flexibility for future development beyond this project, while delivering the maximum benefit to the Irish and Great British systems in terms of increased interconnection.

The proposed network would need to be constructed to the Grid Code standards and the appropriate Irish electrical (ESB) standards to future-proof for incorporation into the main Irish transmission system, due to for example a permanent HVDC cable failure, or a change in the regulatory system or policy landscape in Great Britain.

8.5 Market Integration

The Third Package Directive (2009/72/EC) advocates that "cross-border interconnections should be further developed in order to secure the supply of all energy sources at the most

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competitive prices to consumers and industry within the Community". Greater interconnection between Great Britain and Ireland would help facilitate implementation of the target model for electricity market integration. This will not only result in enhanced competition and lower electricity prices, but will also facilitate greater renewable energy penetration and increase security of supply on the two islands.

8.6 Political and Regulatory Framework

This type of generation connection does not fit into any existing category for either the National Grid or EirGrid; there are ongoing discussions with the respective authorities to provide direction on how to treat this type of generation connection. At this stage, it is clear that political and new regulatory developments or the adaptation of existing regimes will be required if wind generation based in Ireland is to successfully connect to the GB MITS. For this to happen, the following issues will require resolution:

- A decision is required by the UK government as to whether it is possible to access the GB renewable subsidy scheme if the wind generation is not based on land in GB or within GB waters.

- An intergovernmental agreement between the two countries.

- A decision as to which, if any, regulatory regime will apply to the infrastructure connecting Irish Wind to the GB MITS. Three options are seemingly open in this regard: (i) classification as GB MITS / Irish Transmission System, (ii) as offshore transmission or (iii) as an interconnector[40].

- A decision on how the costs associated with the infrastructure to connect Irish Midlands Wind Generation will be recovered, plus the separation of ownership of transmission assets from generation assets in order to comply with the Third Package Directive (2009/72/EC).

[40] Each has its difficulties. Classification as transmission, GB and Irish, raises the issue of asset ownership outside of the franchise of the existing licensees and who should pay for such infrastructure, particularly if these assets are not then interconnected to the Irish transmission system. It does not appear possible to seek a classification under the offshore regime as the project is neither in GB waters nor offshore. Classification as an interconnector typically assumes the connection of two markets or member states – it is not clear whether Irish wind may be able to seek exemptions to elements of the interconnector requirements.

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Initially, a decision on whether to allow access to existing subsidy schemes will be required in order to determine whether to proceed with the new or adapted regulatory development.

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9 Conclusions

Based on an initial evaluation of the costs and benefits it would appear that there are significant synergies to be achieved if an optimal integrated network approach is adopted with the potential to convey significant benefits to network customers on both islands as well as developers. This approach would require cross-industry technology innovation. In addition, there are developments required in the political and regulatory space in order to allow these projects to proceed regardless of the options chosen. It is important that this work is progressed as soon as possible.

The Base Case Network Interconnection Options (NIO) are “Integrated” developments with direct connection of the Irish Midlands Wind Generation to the GB MITS and no connection to the Irish transmission system (Option 1 for 3 GW and Option 2 for 5 GW). These “Integrated” approaches provide additional benefits over and above multi-radial direct connection design solutions. With regard to capital costs, National Grid has already determined in a separate study that for a fully “Integrated” design (inclusive of all current connection offers) there are significant savings relative to a radial design, which are in the order of over £1bn / €1.23bn. A synopsis of this study is provided in Appendix E.

To optimise this integrated approach further, a wide range of possible network interconnection options to the Irish transmission system were then examined. Some were ruled out for technical or risk reasons. The remaining options were analysed to quantify the range of possible benefits such as production cost savings from trading between the two markets, the benefit to the Irish system of shared reserve/response, a reduction in the total generation capacity required to maintain security of supply on the Irish system, and a potential increase in boundary transfer capability on the Great Britain MITS. The benefits accruing to Great Britain from sharing reserve/response and the reduction in the total generation capacity required to maintain security of supply have not been assessed. Similarly, the potential benefits of avoided/deferred investment on the Irish transmission system have not yet been quantified. Any additional cost incurred by each option was also estimated. The additional costs are composed of the capital cost of the connection to the substation on the Irish transmission system, and the capital cost of any deep network reinforcements required on the Irish system. These additional costs and benefits were then

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assessed against the Base Case Option 1 (for the 3 GW wind generation scenario) to determine the incremental net benefits, if any.

Based on the evaluation of the incremental costs and benefits, the most promising NIO is Option 20, which consists of a multi-terminal HVDC connection from the Irish Midlands Wind Generation station to the Great Britain MITS with a single associated AC-DC converter connecting into the Irish system. Table 9.1 details the range of incremental annual benefits and incremental total (non-annualised) capital costs for this option. The preferred interconnection option would provide the same benefits as, for example, another East-West Interconnector-style interconnection project would produce but at a fraction of the cost

This option has a payback on capital costs of less than two years and the benefits will endure for the remaining asset lifetime

Incremental Costs and Benefits for Option 20		
Incremental Annual Benefits (£m p.a. / €m p.a.)	£61m p.a / €75m p.a.	• Assumed to be operated at 0.5 GW capacity • Values are annualised benefits
Incremental Total Capital Costs (£m / €m)		• Values are total costs (non-annualised)

Table 9.1 – Incremental costs and benefits for Option 20, the most promising NIO for the 3 GW wind generation scenario.

In addition, a second new interconnection based on the same technology (i.e. the configuration in NIO 21) would also provide clear benefits albeit slightly lower than the benefits provided by the first interconnection. Also, there is a requirement for reinforcement works for imports greater them 0.5 GW to the GB MITS and the infrastructure costs associated with this increase in power transfer have not been assessed in this report. Further studies are needed to definitively prove the economic case for the second new interconnection. Assuming that there is an economic case, this

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interconnection could be progressed at a later stage to the first interconnection or alternatively both could be progressed in parallel.

Based on the studies performed, the initial appropriate size for each connection to the Irish system is 0.5 GW. However, the links could be constructed at a higher capacity (e.g. 0.7 GW) for “future-proofing” at relatively little extra cost. The additional cost of construction of a 0.7 GW link relative to a 0.5 GW link has been used to estimate the capital cost shown in Table 9.1. Woodland and Dunstown, two 400 kV stations located to the North-West and South-West of Dublin respectively, have been identified as the most appropriate connection points on the Irish system. An initial estimate of the timelines required indicate that either one or two interconnections could be progressed in a manner that would not impact on the timelines envisaged by the wind generation project developers. However, there are technical challenges to be overcome in order to be able to deliver this solution.

Finally, the initial judgement on a 5 GW Irish Midlands Wind Generation connection (with three 2.5 GW HVDC VSC Links to the GB MITS) suggests there will be an increase in congestion value to the GB MITS. While not studied explicitly, it is likely that the incremental benefits of connecting to the Irish transmission system in the 5 GW wind generation scenario would be similar to those determined for the 3GW wind generation scenario.

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10 Recommendations

This report has investigated the technical issues, capital costs and benefits associated with a variety of Network Interconnection Options (NIOs) for connecting wind generation located in the Irish Midlands to GB MITS. In particular, the study focussed on performing an initial evaluation of the incremental costs and benefits arising from incorporating one or two connections to the Irish transmission system relative to a Base Case NIO with no such connection. The report has also highlighted the need for political and regulatory guidance on the connection of renewable generation in Ireland to the GB MITS and the necessity of further development in HVDC VSC technology. The results of the studies performed show that there are significant potential benefits, for consumers on both islands and generation developers, which warrant further investigation and development work on the "Integrated with Interconnection" design concepts. The recommendations for how this work can be progressed are outlined below in two consecutive steps.

First Steps:

- National Grid and EirGrid should consult with their respective Government Departments and Electricity Market Regulators to ensure that all further work undertaken is informed by and consistent with emerging initiatives on renewable energy exports from Ireland to Great Britain.

- Concurrently, an engagement process with generation developers should be established as soon as possible. National Grid and EirGrid could use this process to brief them on the co-ordinated development plan, to listen to and consider their viewpoints and agreed a collaborative way forward.

Second Steps:

- On the confirmation of an inter-governmental initiative on renewable energy exports from Ireland to Great Britain, applications for funding should be submitted by National Grid and EirGrid to their respective Electricity Market Regulators to finance this next step of this co-ordinated development process.

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- Other potential sources of funding should also be explored. For the interconnection to the Irish transmission system, an application could be considered for funding under the Connecting Europe Facility as a designated Project of Common Interest (PCI), under the European Energy Infrastructure Package[41]. In addition, INTER-REG grant funding could be investigated.

- Considering the output from the first step developer engagement process, National Grid and EirGrid should establish a single purpose cross-company project team[42] with respective engineering, commercial and legal expertise to deliver an all-party agreed design solution. This team could be coordinated by National Grid and EirGrid (under an agreed Memorandum of Understanding or potentially as part of a Joint Venture) with inputs from developers, manufacturers and other interested parties. Some outline Terms of Reference are included in Appendix C. To ensure respective Government targets and timelines envisaged by the wind generation developers are not impacted upon, the cross-company project team should be established as soon as reasonably possible. An initial estimation of the required timeframe for completion of this design work is one year[43].

- National Grid and EirGrid should consider how best to develop cross-company liaison with manufacturers in order to focus the development of HVDC technologies to meet the envisaged timescales. For example, the two companies could initiate a multi-party group that would meet regularly and which would serve as a forum to discuss the key developments required and drive progress.

It is clear that the timeframe for the renewable energy export projects is tight and challenging. Therefore, the first step recommendations need to be progressed in earnest

[41] PCI status aims to facilitate investments of pan-European interest by providing support with achieving regulatory status, limiting the planning consent process to a maximum of 4 years 3 months and initial funding mechanisms.

[42] This aims to deliver the strategic coordination of National Grid / Generation Developers / EirGrid since the development of generation projects and the location of their infrastructure could affect the costs and benefits of this "Integrated with Interconnection" strategy. N.B. There is potential to optimise these NIOs by coordinating the routes of the HVDC VSC Links between GB MITS and the Irish transmission system and the location of the wind generation collector stations (and hence the HVDC converter stations) with the Irish transmission system.

[43] This is subject to alignment with the developer project timelines and is mindful of the HVDC VSC lead times.

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to ensure the delivery of an innovative, efficient and economic design solution for the benefit of network customers on both islands as well as the generation developers.

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Appendix A – Detailed System Modelling Analysis Results

A.1 EirGrid Network Modelling

Network studies were performed to analyse the capability of the Irish system to import and export generation to/from National Grid at either one or two separate connection points.

The study was divided into two sections. The first section sought to identify which of the strong robust substations (Woodland, Laois (planned), Maynooth and Dunstown) in the general vicinity of the likely Irish Midlands Wind Generation location would be suitable connection points for a Single Node Connection Configuration. The suitability of each connection point was judged on the level of deep reinforcements required at each node and the notional distance from the wind collection stations.

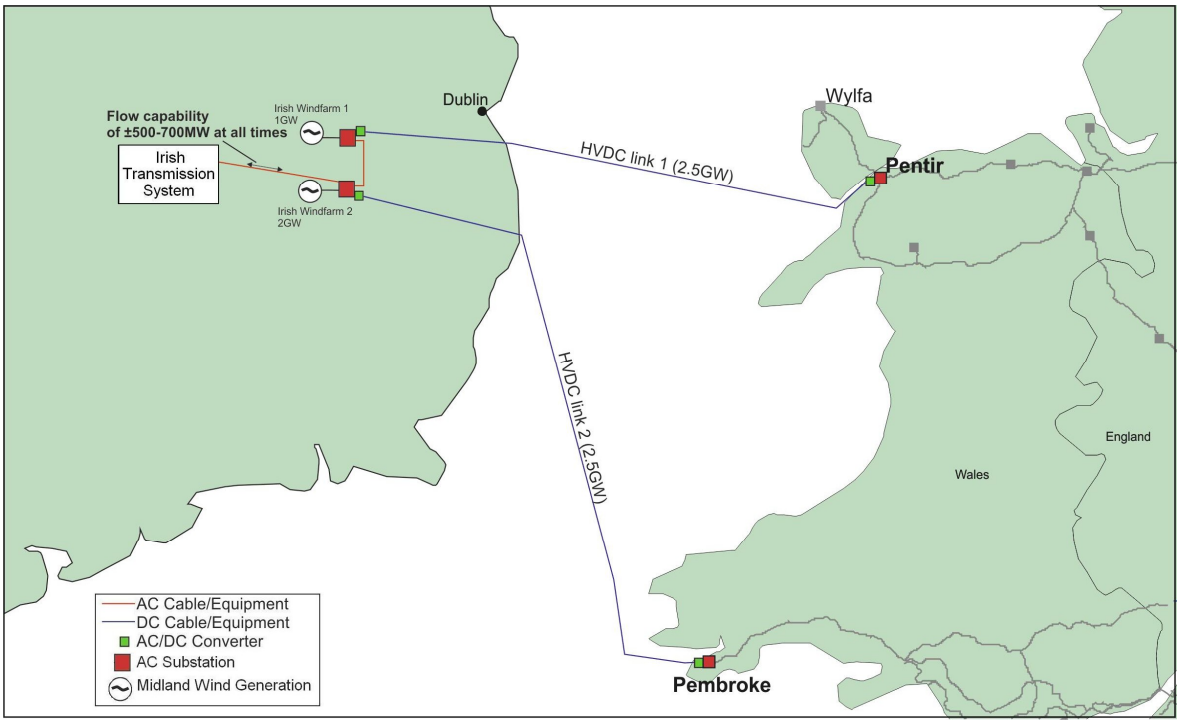

Figure A.1: Connection Configuration 1 for TLTG Study

The second part of the study sought to identify which pairing of nodes would be best suited for a Double Node Connection configuration. This study took into account the results of the Single Node Connection Study. The study sought to identify the full import and export capability of each node pairing configuration and also investigate the configurations' ability to "wheel" power from one node to another via the EirGrid system.

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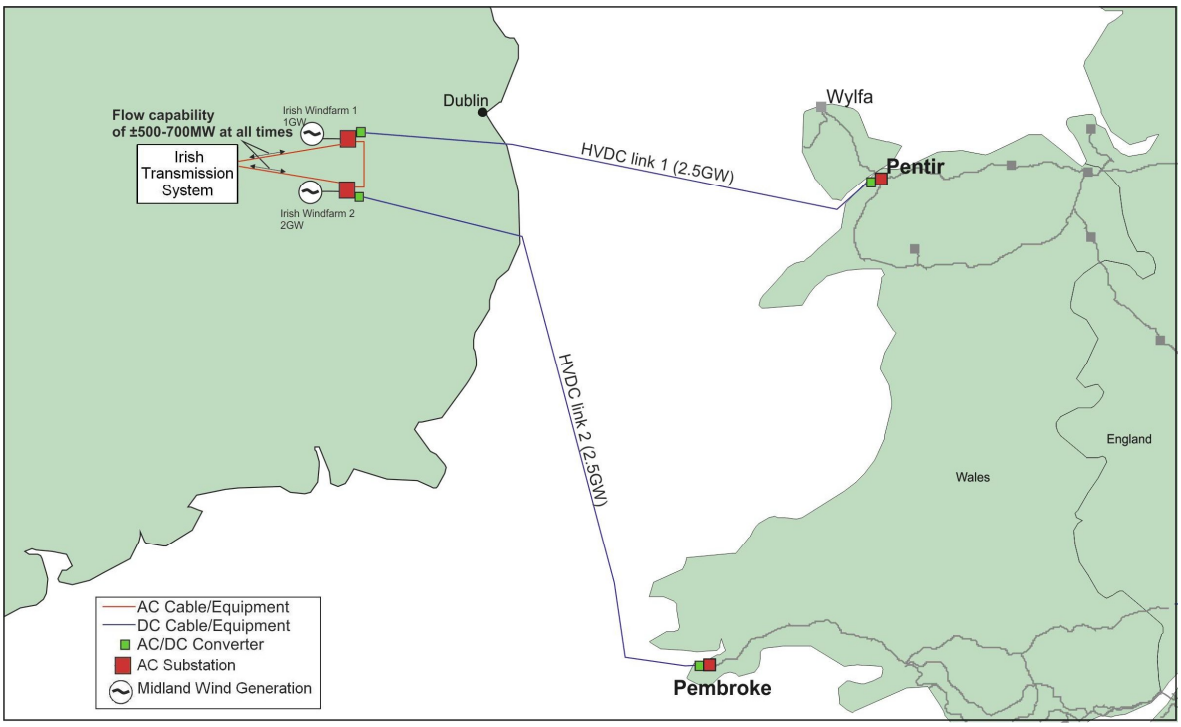

Figure A.2: Connection Configuration 2 for TLTG study

A.1.1 Study Objectives

The objective of this study was to examine the capacity at four transmission stations to accommodate interconnection to GB via one or more "tapped" connections to the transmission infrastructure to be built for the Irish Midlands Wind Generation development. Specifically the study aimed to answer the following questions:

1. What are the limiting elements of infrastructure on the transmission network when importing or exporting 0.5 GW from Maynooth 220 kV station and what additional reinforcements are required?
2. What are the limiting elements of infrastructure on the transmission network when importing or exporting 0.5 GW from Dunstown 400 kV station and what additional reinforcements are required?
3. What are the limiting elements of infrastructure on the transmission network when importing or exporting 0.5 GW from Woodland 400 kV station and what additional reinforcements are required?
4. What are the limiting elements of infrastructure on the transmission network when importing or exporting 0.5 GW from the planned Laois 400 kV station and what additional reinforcements are required?

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5. Using results from questions 1-4 and further analysis, what is the most optimum pairing of the studied nodes to:
    - Ensure a 1.0 GW import/export capacity between EirGrid Transmission System and GB MITS?
    - Ensure a 0.5 GW loop flow (in at one node and out at the other) through the EirGrid system can be accommodated?

Figure A.3: Map of Study Nodes

A.1.2 Methodology

Capacity Calculation

To calculate the capacity of the transmission system to accommodate the proposed "tapping" at either of the four nodes, PSSE's Transmission Interchange Limits Calculations (TLTG) tool was used. TLTG is a DC load flow tool that incrementally adds generation (or demand) at a selected node, and reduces (or increases) generation in other parts of the system by the same amount until a level of generation (or demand) is reached that puts the system outside acceptable N-1 standards.

PROMOD generation dispatch was used to determine the demand level for each hour of the study year (2020). From the 8760 hours of generation dispatches provided, several

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hours were then selected for TLTG analysis, which were considered to represent the most onerous cases for the import or export of power.

Treatment of Limitations

Following the discovery of a limiting infrastructure this is then (if possible) uprated and the TLTG is re-run until the level of generation (or demand) places the system outside N-1 standards again. This is repeated until the import/export target is achieved or until a new unplanned piece of infrastructure is required.

The studies are repeated for different areas in which the generation is increased or decreased during the TLTG process. These areas were as follows:

- Dublin
- Munster
- North-West

A.1.3 Assumptions

In general, the assumptions on system demand levels, generation and grid will match the general assumptions used in network studies as encapsulated in the *All-Island Transmission Forecast Statement 2012-2018*. Assumptions specific to the study are detailed below.

Study Period

The years of the study were:

- 2020, the first year that the interconnector would be expected to connect, and

Network

The following *Grid**25*** projects will be assumed to be in place by 2020:

- Grid Link; a Knockraha – Great Island – Dunstown 400 kV line,
- Grid West; a Bellacorick – Flagford 400 kV line,
- North South interconnector; a Turleenan – Woodland 400 kV line,
- Moneypoint – North Kerry 400 kV,
- RIDP – a 275 / 220 kV reinforcement of Northern Ireland and Donegal

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A number of circuit uprates that are expected to be completed by 2020 were assumed. The Dublin Ring Project which does not have capital approval was not included in the base case for the study.

Generation

The amount of wind generation in the 2020 cases was that which is required to meet Ireland's 40% renewable target for 2020.

The PROMOD generation dispatch produces 8760 relevant study cases. Several hours with challenging generation profiles and demand levels were selected for the TLTG studies (High Wind, High Thermal, High Dublin High Wind etc.)

Moneypoint coal fired generators were assumed to still be connected and fully operational in 2020. The offshore wind generation of Oriel and Kish Banks and the Ballakelly CCGT were not modelled.

Demand

The demand on the system of Ireland was determined by the PROMOD dispatch selected.

Study Cases

The study cases selected for the TLTG from the 8760 PROMOD dispatches were as follows:

1. Summer Peak 70% Wind, High Dublin Generation
2. Summer Peak 66 % Wind, Low Dublin Generation
3. Summer Peak 23% Wind, Evenly spread thermal Generation
4. Summer Peak 0% Wind, High Dublin Generation
5. Summer Peak 0% Wind, Low Dublin Generation

A.1.4 Results

Single In feed

The single in feed TLTG study required the following overhead lines be uprated corresponding to the four connection points in order for a 0.5 GW import export capability.

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Connection Point 1: Dunstown			
Limiting Circuit	**Length (km)**	**Summer/Winter Rating (MVA)**	**Solution**
Import			
Limiting Circuit	*Length (km)*	*Summer/Winter Rating (MVA)*	*Solution*
Corduff – Finglas 220 kV 1	3.7	431/518	Uprate
Corduff – Finglas 220 kV 2	3.7	431/518	Uprate
Corduff –Woodland 220 kV 1	18.4	431/519	Uprate
Corduff – Woodland 220 kV 2	17.8	431/520	Uprate
Laois – Portlaoise 110 kV	9.66	107/126	Uprate
Export			
Maynooth – Woodland 220 kV	22.3	431/518	Uprate

Table A.1: Dunstown Connection Results

Connection Point 2: Laois			
Limiting Circuit	**Length (km)**	**Summer/Winter Rating (MVA)**	**Solution**
Import			
Corduff – Finglas 220 kV 1	3.7	431/518	Uprate
Corduff – Finglas 220 kV 2	3.7	431/518	Uprate
Corduff –Woodland 220 kV 1	18.4	431/519	Uprate
Corduff – Woodland 220 kV 2	17.8	431/520	Uprate
Laois – Portlaoise 110 kV	9.66	107/126	
Export			
Maynooth – Woodland 220 kV	22.3	431/518	Uprate

Table A.2: Laois Connection Results

Connection Point 3: Maynooth			
Limiting Circuit	**Length (km)**	**Summer/Winter Rating (MVA)**	**Solution**
Import			
Corduff – Finglas 220 kV 1	3.7	431/518	Uprate
Corduff – Finglas 220 kV 2	3.7	431/518	Uprate
Corduff –Woodland 220 kV 1	18.4	431/519	Uprate
Corduff – Woodland 220 kV 2	17.8	431/520	Uprate
Export			
Maynooth – Woodland 220 kV	22.3	431/518	Uprate

Table A.3: Maynooth Connection Results

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Connection Point 4: Woodland			
Limiting Circuit	**Length (km)**	**Summer/Winter Rating (MVA)**	**Solution**
Import			
Corduff – Finglas 220 kV 1	3.7	431/518	Uprate
Corduff – Finglas 220 kV 2	3.7	431/518	Uprate
Corduff –Woodland 220 kV 1	18.4	431/519	Uprate
Corduff – Woodland 220 kV 2	17.8	431/520	Uprate
Maynooth – Woodland 220 kV	22.3	431/518	Uprate
Export			
0.5 GW Export Achieved			

Table A.4: Woodland Connection Results

The results in Tables A.1 – A. 4 indicate that similar overloads occurred across the four nodes during the study. These overloads are known problems on the network. The capacity of these lines can be increased by uprating the lines without any need for new infrastructure developments.

Double In Feed Configuration

Based on the likely cable routing, the preferred substations selected for the Double In Feed Connection Configuration analysis were Dunstown and Woodland.

Wheeling Power

TLTG analysis was used to import power from one node and export from the other. The studies showed that no further reinforcements were required to "wheel" 0.5 GW of power between the Dunstown and Woodland 400 kV nodes provided the required uprates from the single in feed section are in place.

Dunstown In – Woodland Out			
Wheeling MW	**Limiting Circuit**	**Length (km)**	**Summer/Winter Rating (MVA)**
521 √	Dunstown – Maynooth 220 kV	30.55	431/518
Woodland In – Dunstown Out			
Wheeling MW	**Limiting Circuit**	**Length (km)**	**Summer/Winter Rating (MVA)**
797 √	Poolbeg – Carrickmines PST 220 kV	14.5	267/267

Table A.5: Wheeling of Power between Dunstown and Woodland

Dunstown – Woodland Exporting

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The studies showed that no further reinforcements were required to export 1.0 GW of power out of the Dunstown and Woodland 400 kV nodes provided the required uprates from the single in feed section are in place.

Woodland and Dunstown Exporting			
Exported MW	**Limiting Circuit**	**Length (km)**	**Summer/Winter Rating (MVA)**
1148 √	Finnstown – Inchicore 220 kV 2	10.62	646/776

Table A.6: Dunstown and Woodland 1.0 GW Export Results

Dunstown – Woodland Importing

The studies showed that no further reinforcements were required to import 1.0 GW of power out of the Dunstown and Woodland 400 kV nodes provided the required uprates from the single in feed section are in place and that a minimum of 0.3 GW of Dublin generation is maintained.

Woodland and Dunstown Importing			
Imported MW	**Limiting Circuit**	**Length (km)**	**Summer/Winter Rating (MVA)**
1019 √	Dunstown – Maynooth 220 kV	30.55	431/518

Table A.7: Dunstown and Woodland 1.0 GW Import Results

Note: Overloading of the Maynooth – Finnstown – Inchicore 220 kV corridor and of the uprated Woodland – Corduff – Finglas 220 kV corridor occurs during periods of high wind and low Dublin generation. In a number of incidences the TLTG when importing at the selected nodes will in turn decrease Dublin generation causing the mentioned overloads. Due to the low likelihood of the situation and the low price of generation in Dublin these overloads were not deemed realistic and not associated with the project.

A.1.5 Costs

To achieve an import/export capability of 0.5 GW at Dunstown and/or Woodland 400 kV stations the following reinforcements are required:

1. Uprating of Corduff - Finglas 220 kV OverHead Line (OHL) 1 and 2
2. Uprating of Corduff - Woodland 220 kV OHL 1 and 2
3. Uprating of Maynooth - Woodland 220 kV OHL

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4. Uprating of Laois - Portlaoise 110 kV OHL (Laois is a new station planned for connection in 2015)

A cost estimate for these reinforcements was derived using information from Price Review 3[44]. Table A.8 shows the Price Review 3 estimated costs employed.

110kV Uprating	Total Cost (per Km)
110kV line uprated to HTLS equivalent of 187 MVA	
220kV Uprating	
220kV line uprated from 600 ACSR Curlew to HTLS equivalent of 646 MVA	

Table A.8: Price Review 3 Estimated Costs

The resulting reinforcement costs are shown in Table A.9. The deep reinforcement cost of this project is estimated to be

Reinforcements	Length (km)	Uprate Cost per km	Total
Corduff – Finglas 220 kV 1	3.7		
Corduff – Finglas 220 kV 2	3.7		
Corduff –Woodland 220 kV 1	18.4		
Corduff – Woodland 220 kV 2	17.8		
Maynooth – Woodland 220 kV	22.3		
Laois – Portlaoise 110 kV	9.66		
Total	**75.56**		

Table A.9: Total Cost of Required Deep Reinforcements

A.1.6 Conclusion

The TLTG study identified the need to uprate five 220 kV lines (66 km) and one 110 kV line (9.7 km) in order to achieve the targets set out of 0.5 GW import/export at a single node and 1.0 GW import/export at two nodes (0.5 GW each at Dunstown and Woodland 400 kV stations).

[44] CER Transmission and Distribution Price Review 2009

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The total cost of these reinforcements is It should be noted that these uprates are being investigated whether or not this interconnection proceeds. It is assumed that any station upgrade work necessary will be progressed in any event and that the AC-DC converter will be sufficiently compensated to deal with any voltage issues at the connection points.

A.2

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3 GW Irish Windfram Connection

Serial	Fault Contingency	Remaining Circuit Post-Fault Power Flows	Intact Power Flow MW(%)	Winter Ratings Used	Post-Fault Loading (no action)/Overload MW	Post-Fault Loading (no action)/Overload % Loading	Critical Boundary Transfer MW (Boundary) Pre-Fault	Critical Boundary Transfer MW (Boundary) Post-Fault	Post-Action - Power Flows following the these Actions: Post-Fault Loading MVA (%)	Post-Action: Wylfa (2.5 GW) MW	Post-Action: to 500MW Pentir to Pembroke)	Dinorwig Response	Thermally Compliant + within Stability	Comments
Generation Sensitivity 01: Wylfa 3.6 GW; Irish Sea at 70% (including Codling Park). EirGrid Interconnection at float.														
Intact	Prefault tap change to position 22 on Stocksbrige QB (Nominally 20)													
1	Trawsfynydd - Treuddyn Tee Double Circuit	Daines - Macclesfield	2002(83.4)	2400	3392.7	141.3	7504 (NW2)	4579 (NW2)	2387.9 (99.5)	2500MW with pre fault loading of 0MW	500 MW transfer into Pembroke post-fault	None	YES	Stocksbridge QB operated at tap position 30 (Max in timescales). Pentwortham QB unchanged at tap 18.
		Pentir - Connah's Quay***	2647(69.3)	3820	3949.2	103.4			2480.6 (64.9)					
		Connah's Quay - Daines **	2240.2(72.3)	3100	4004.1	129.2			2843 (91.7)					
		Bredbury - Stalybridge	845.4(77.5)	1090	1154.8	105.9			952.7 (87.4)					
		Lister Drive - Birkenhead	372.5(49.7)	750	767.7	102.4			505.6(67.4)					
		Daines - South Manchester	685.3(82.1)	835	901.8	108.0			752.1 (90.1)					
		Penworthham - Padiham	1931.3(89.0)	2170	2514.1	115.8			2136 (98.44)					
2	Pentir - Trawsfynydd Double Circuit	Pentir - Connah's Quay ***	2647(69.3)	3820	3912.8	102.4	7504 (NW2)	6366 (NW2)	3374.3 (88.3)	600MW w th pre-fault loading of	500 MW transfer into Pembroke	None	YES	Stability limit is more onerous than the thermal limit for this
3	Pentir - Connah's Quay Double Circuit	Pentir - Trawsfynydd ***	1251.9(44.7)	2800	3453	136.7	7504 (NW2)	5180 (NW2)	2514.5 (99.5)	1500MW with pre fault loading of 0MW	500 MW transfer into Pembroke post-fault	197MW (50% of lost generation)	YES	197MW of response provided by Dinorwig on loss of Gwent Y Mor Wind Farm.
		Trawsfynydd - Treuddyn Tee ***	1314(42.4)	3100	3572.2	115.0			2616.7 (84.4)					
4	Pentir - Connah's Quay Double Circuit	Pentir - Trawsfynydd ***	1251.9(44.7)	2800	3368.9	133.4	7504 (NW2)	5186 (NW2)	2524.3 (99.9)	1300MW with pre fault loading of 0MW	500 MW transfer into Pembroke post-fault	None	YES	No Dinorwig response provided, loss of generation picked up by Sizewell (394MW)
		Trawsfynydd - Treuddyn Tee ***	1314(42.4)	3100	3479.8	112.2			2619.8 (84.5)					
5	Pembroke - Swansea North (A804 & A80L)	Pembroke - Swansea North (A80M)	1112.3 (40)	2780	2215.2	79.7	4433 (SW1)	4433 (SW1)	n/a	n/a	n/a	None	YES	No issues
		Pembroke - Swansea North (A80N)	1113.7 (40.1)	2780	2217.9	79.8								
Generation Sensitivity 01: Wylfa 3.6 GW; Irish Sea at 70% (including Codling Park). EirGrid Interconnection at 500MW.														
Intact	Prefault tap change to position 22 on Stocksbrige QB (Nominally 20), 500MW from EirGrid into Pembroke													
6	Trawsfynydd - Treuddyn Tee Double Circuit	Daines - Macclesfield	2007.8(83.6)	2400	3417.2	142.4	7504 (NW2)	5068 (NW2)	2462(102.3) *see comments	2500MW with pre fault loading of 0MW	No capacity	None	YES	Stocksbridge QB operated at tap position 35 (Max). Circuit still overloaded however enhanced winter rating is
7	Pentir - Trawsfynydd Double Circuit	Pentir - Connah's Quay ***	2648.8(69.3)	3820.0	3912.8	102.4	7504 (NW2)	6366 (NW2)	3374.4(88.3)	fault loading of 0MW	No capacity	None	YES	Stability limit is more onerous than the thermal limit for this
8	Pentir - Connah's Quay Double Circuit	Pentir - Trawsfynydd ***	1250.3(44.6)	2800	3452.9	136.7	7504 (NW2)	5180 (NW2)	2514.3(89.7)	2000MW with pre fault loading of 0MW	No capacity	197MW (50% of lost generation)	YES	197MW of response provided by Dinorwig on loss of Gwent Y Mor Wind Farm.
		Trawsfynydd - Treuddyn Tee ***	1306(42.1)	3100	3572	115.2			2616.7(84.4)					
9	Pentir - Connah's Quay Double Circuit	Pentir - Trawsfynydd ***	1250.3(44.6)	2800	3367.4	133.3	7504 (NW2)	5184 (NW2)	2523(90.1)	1800MW with pre fault loading of 0MW	No capacity	None	YES	No Dinorwig response provided, loss of generation picked up by Sizewell (394MW)
		Trawsfynydd - Treuddyn Tee ***	1306(42.1)	3100	3478.3	112.2			2618.5(84.5)					
10	Pembroke - Swansea North (A804 & A80L)	Pembroke - Swansea North (A80M)	1237.7 (44.5)	2780	2465.1	88.7	4933 (SW1)	4933 (SW1)	n/a	n/a	No capacity	None	YES	No issues
		Pembroke - Swansea North (A80N)	1239.3 (44.6)	2780	2468.0	88.8								
Generation Sensitivity 01: Wylfa 3.6 GW; Irish Sea at 70% (including Codling Park). EirGrid Interconnection at 700MW.														
Intact	Prefault tap change to position 24 on Stocksbrige QB (Nominally 20) with Wylfa link loaded at 150MW. 500MW from EirGrid into Pembroke and 200MW into Pentir.													
11	Trawsfynydd - Treuddyn Tee Double Circuit	Daines - Macclesfield	1987.8(82.8)	2400	3372.1	140.5	7553 (NW2)	5227 (NW2)	2519.1(104.9)	2500MW with pre fault loading of 150MW	No capacity	None	NO	Circu ts overloaded with Wylfa at 2.5GW and stocksbridge QB at tap 35. Pentwortham QB unchanged at tap 18. Overload on the Penwortham - Padium tha
		Connah's Quay - Daines **	2258(72.9)	3100	4015.9	129.6			3098 (99.9)					
		Bredbury - Stalybridge	890.6 (81.7)	1090	1199.1	110			1086.4(99.7)					
		Daines - South Manchester	698.4 (83.6)	835	914	109.5			805.7(96.5)					
		Birkenhead - Lister Drive	384.2(51.2)	750	777.9	103.7			578.9(77.2)					
		Penworthham - Padiham	1965.9(90.6)	2170	2546.7	117.4			2280.4(105.1)					
12	Pentir - Trawsfynydd Double Circuit	Pentir - Connah's Quay ***	2665.2(69.8)	3820	3937.4	103.1	7553 (NW2)	6366 (NW2)	3374.1(88.3)	1300 MW with pre-fault loading of 150 MW	No capacity	None	YES	Stability limit is more onerous than the thermal limit for this fault. (6.4GW North Wales 2)
		Connah's Quay - Legacy ***	970.2(43.9)	2210	2197.8	99.5			1957.1(88.6)					
13	Pentir - Connah's Quay Double Circuit	Pentir - Trawsfynydd ***	1258.9(49.8)	2800	3477.1	137.7	7553 (NW2)	5182 (NW2)	2514.6 (99.56)	2200MW with pre fault loading of 150MW	No capacity	197MW (50% of lost generation)	YES	197MW of response provided by Dinorwig on loss of Gwent Y Mor Wind Farm.
		Trawsfynydd - Treuddyn Tee ***	1320.6(42.6)	3100	3596.8	116.0			2616.7 (84.4)					
14	Pentir - Connah's Quay Double Circuit	Pentir - Trawsfynydd ***	1258.9(49.8)	2800	3391	134.3	7553 (NW2)	5184 (NW2)	2523 (99.9)	2000 MW with pre-fault loading of 150 MW	No capacity	None	YES	No Dinorwig response provided, loss of generation picked up by Sizewell (394MW)
		Trawsfynydd - Treuddyn Tee ***	1320.6(42.6)	3100	3502.2	112.9			2618.4 (84.5)					
15	Pembroke - Swansea North (A804 & A80L)	Pembroke - Swansea North (A80M)	1275.4(45.9)	2780	2540.0	91.4	5083 (SW1)	5083 (SW1)	n/a	pre-fault loading of 150 MW	No capacity	None	YES	No issues
		Pembroke - Swansea North (A80N)	1276.9(45.9)	2780	2543.2	91.5								
Generation Sensitivity 01: Wylfa 3.6 GW; Irish Sea at 70% (including Codling Park). EirGrid Interconnection at 1000MW.														
Intact	Prefault tap change to position 24 on Stocksbrige QB (Nominally 20) with Wylfa link loaded to 500MW. 500MW from EirGrid into Pembroke and 500MW from EirGrid into Pentir.													
16	Trawsfynydd - Treuddyn Tee Double Circuit	Daines - Macclesfield	2015.5(83.9)	2400	3400.4	141.7	7504 (NW2)	5557 (NW2)	2604.9 (108.5)	2500Mw w th pre-fault loading of 500MW	No capacity	None	NO	Stocksbridge QB operated at tap position 35 (Max in timescales). Circuits in red require uprating. Overload on the Penwortham - Padium that cannot be resolved with the QBs, further study required.
		Pentir - Connah's Quay***	2650.1(69.3)	3820	3950	103.4			2970.6 (77.7)					
		Connah's Quay - Daines **	2258.7(72.8)	3100	3998.9	129.0			3211(103.6)					
		Bredbury - Stalybridge	876.9(80.3)	1090	1182	108.5			1123 (103)					
		Lister Drive - Birkenhead	381.9(50.9)	750	771.7	102.9			607.4 (81)					
		Daines - South Manchester	696(83.3)	835	909.7	108.9			824.7 (98.8)					
		Penworthham - Padiham	1956.3(90.1)	2170	2531.3	116.6			2328 (107.3)					
17	Pentir - Trawsfynydd Double Circuit	Pentir - Connah's Quay ***	2650.1(69.4)	3820	3912	102.3	7504 (NW2)	6269 (NW2)	3325.9 (87)	1500MW w th pre fault loading of	No capacity	None	YES	Stability limit is more onerous than the thermal limit for this
18	Pentir - Connah's Quay Double Circuit	Pentir - Trawsfynydd ***	1240.9(44.2)	2800	3452.9	136.7	7504 (NW2)	5180 (NW2)	2514.6 (99.6)	2500MW with pre fault loading of 500MW	No capacity	197MW (50% of lost generation)	YES	197MW of response provided by Dinorwig on loss of Gwent Y Mor Wind Farm.
		Trawsfynydd - Treuddyn Tee ***	1302(42.0)	3100	3572.8	114.2			2616.7 (84.4)					
19	Pentir - Connah's Quay Double Circuit	Pentir - Trawsfynydd ***	1249.1(44.6)	2800	3367.6	133.4	7504 (NW2)	5184 (NW2)	2523.1 (99.9)	2300MW with pre fault loading of 500MW	No capacity	None	YES	No Dinorwig response provided, loss of generation picked up by Sizewell (394MW)
		Trawsfynydd - Treuddyn Tee ***	1311.1(42.2)	3100	3478.4	112.2			2618.5 (84.5)					
20	Pembroke - Swansea North (A804 & A80L)	Pembroke - Swansea North (A80M)		2780	2714.9	97.7	5433 (SW1)	5433 (SW1)	n/a	pre-fault loading of 500 MW	No capacity	None	YES	No issues
		Pembroke - Swansea North (A80N)		2780	2718.3	97.8								
Generation Sensitivity 02: Wylfa 3.6 GW; Irish Sea at 100%. EirGrid Interconnection at 500MW.														
21	Trawsfynydd - Connah's Quay - Legacy DC	Daines - Macclesfield	2012.4 (83.8)	2400	3357.5	139.9	7511 (NW2)	5956 (NW2)	2679 (111.6)	2500 MW with a pre-fault loading of 900 MW	500 MW Interconnection into Pembroke pre-fault	None	NO	Stocksbridge QB operated at tap position 35 (Max in timescales). Circuit upratings needed on all those listed here. N.B. The Western Link has not been pulled back and there is a overload on the Penwortham - Padium that cannot be resolved with the QBs
		Connah's Quay - Daines 1	2271.5 (73.3)	3100	3973.8	128.2			3337 (107.6)					
		Connah's Quay - Daines 2	2256 (72.8)	3100	3959	127.7			3321 (107.1)					
		Daines - South Manchester 1	703.7 (84.3)	835	914.9	109.6			853 (102.2)					
		Stalybridge - Bredbury	905.0 (83.0)	1090	1209.8	111.0			1198 (109.8)					
		Gwynt-y-Mor - Connah's Quay 1	2657.9 (69.6)	3820	3954	103.5			3170 (83.0)					
		Daines - Cellarhead	1953.2 (63.0)	3100	3533.6	114.0			3013 (97.2)					
		Padium - Penwortham	1926.8 (88.8)	2170	2484.1	114.5			2255.7 (104.0)					
		Birkenhead - Lister Drive	387.2 (51.6)	750	765.6	102.1			640 (85.3)					
22	Pentir - Gwynt-y-Mor - Connah's Quay DC	Pentir - Trawsfynydd	1245.0 (49.3)	**2800	3392.9	134.3	7511 (NW2)	5956 (NW2)	2642.4 (104.6)	2500 MW with a pre-fault loading of 900 MW	500 MW Interconnection into Pembroke pre-fault	None	NO	Pentir - Trawsfynydd Glaslyn cables need to be balanced to maximise the capability through this route. Dinorwig sensitivity has not be applied.
		Pentir - Four Crosses - Trawsfynydd	1332.5 (47.6)	**2800	3565.1	127.3			2785.1 (99.5)					
		Trawsfynydd - Treuddyn Tee 1	1307.3 (42.2)	3100	3505.3	113.1			2741.1 (88.42)					
		Trawsfynydd - Treuddyn Tee 2	1301.0 (42.0)	3100	3476.1	112.1			2712.19 (87.5)					
23	Pentir - Trawsfynydd Pentir - Four Crosses - Trawsfynydd	Gwynt-y-Mor - Connah's Quay 1	2657.9 (69.6)	3820	3916.6	102.5	7511 (NW2)	6402 (NW2)	3392 (88.8)	1971 MW with a pre-fault loading of 900MW	500 MW Interconnection into Pembroke pre-fault		YES	Stability limit is more onerous than the thermal limit for this fault.
		Gwynt-y-Mor - Connah's Quay 2	2276.1 (59.6)	3820	3532.2	92.5			3009.5 (78.8)					
24	Pembroke - Swansea North DC	Pembroke - Swansea North 1	1467.5 (52.8)	2780	2922.7	105.1	5842 (SW1)	5542 (SW1)	2772.6 (99.7)	Pulled back to 600 MW with a pre-fault loading of 900 MW	500 MW Interconnection into Pembroke pre-fault	None	YES	Stability limit is 6.6 GW for the 4 circuits out of Pembroke.
		Pembroke - Swansea North 2	1465.7 (52.7)	2780	2919.0	105.0			2769.1 (99.6)					
Generation Scenario 03: 1 x Wylfa 1.2 GW removed; Irish Sea at 70% (including Codling Park). EirGrid Interconnection at 500 MW.														
25	Trawsfynydd - Connah's Quay - Legacy DC	Daines - Macclesfield	1899.4 (79.1)	2400	3179.7	132.5	9310 (NW4)	7410 (NW4)	2389.3 (99.55)	1900 MW with no pre-fault loading.	500 MW Interconnection into Pembroke pre-fault	None	YES	Stocksbridge QB operated at tap position 35 (Max in timescales).
		Connah's Quay - Daines 1	1994.4 (64.3)	3100	3616.6	116.7			2861.9 (92.3)					
		Connah's Quay - Daines 2	1979.4 (63.9)	3100	3601.5	116.2			2846.1 (91.8)					
		Daines - South Manchester 1	644.9 (77.2)	835	845.1	101.2			770.6 (92.3)					
		Penwortham - Padium	1802.4 (83.1)	2170	2324.0	107.1			2158.3 (99.5)					
		Daines - Cellarhead	1913.3 (61.7)	3100	3418.8	110.3			2801.5 (90.37)					
26	Pentir - Gwynt-y-Mor - Connah's Quay DC	Pentir - Trawsfynydd	1060.7 (42.0)	2800**	2828.5	112.0	6338 (NW2)	5185 (NW2)	2523.6 (99.9)	650 MW with no pre-fault loading.	500 MW Interconnection into Pembroke pre-fault	None	YES	Gwynt-y-Mor generation is disconnected on this fault.
		Pentir - Four Crosses - Trawsfynydd	1140.9 (40.7)	2800**	2978.5	106.4			2661.6 (95.1)					
27	Pentir - Trawsfynydd Pentir - Four Crosses - Trawsfynydd	Gwynt-y-Mor - Connah's Quay 1	2258.6 (59.1)	3820	3333.7	87.3	6338 (NW2)	6338 (NW2)	3333.7 (87.3)	No post fault action required.	500 MW Interconnection into Pembroke pre-fault	None	YES	
		Gwynt-y-Mor - Connah's Quay 2	1877.9 (49.2)	3820	2950.9	77.3			2950.9 (77.3)					No issues.
28	Pembroke - Swansea North DC	Pembroke - Swansea North 1	1240.9 (44.6)	2780	2472.3	88.9	4940 (SW1)	4940 (SW1)	2472.3 (88.9)	No post fault action required.	500 MW Interconnection into Pembroke pre-fault	None	YES	
		Pembroke - Swansea North 2	1239.3 (44.6)	2780	2468.2	88.8			2468.2 (88.8)					No issues.

* This is the loading on the Four Crosses - Trawsfynydd section of the circuit.

** The Glaslyn Estuary cables have been doubled in this studied and the 6hr ratings of 1400MVA for a 84% pre-fault loading have been used; this cable also has a high cyclic rating. The new cable was modelled as 2000mm^2 400kV XLPE cable.

*** Most heavily loadeded circuit.

Table A .11 DC Thermal Study Results for North and South Wales

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Appendix B – GB MITS Boundaries

B.1 GB MITS Transmission Boundaries

The figures below give a geographic and in some instances a schematic representation of the Great Britain Main Interconnected Transmission System (GB MITS) boundaries discussed in the report.

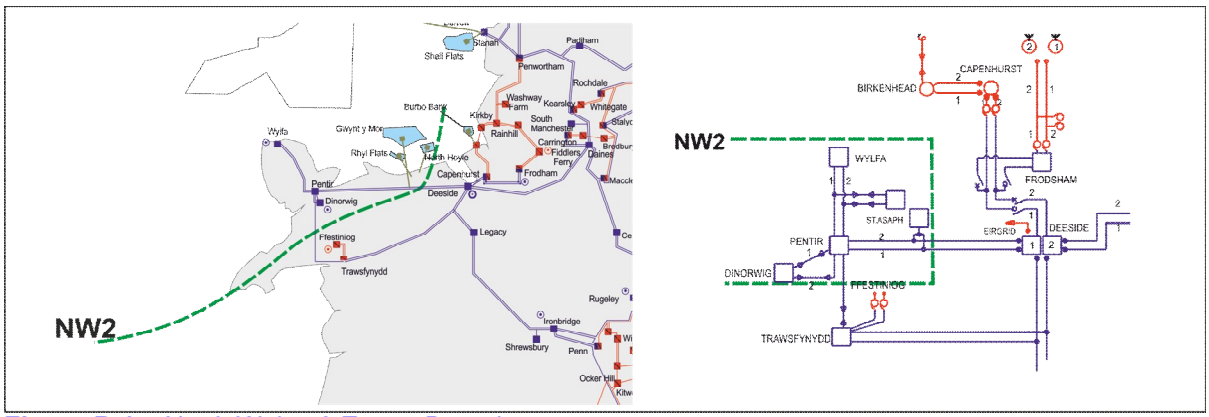

Figure B.1 – North Wales 2 Export Boundary

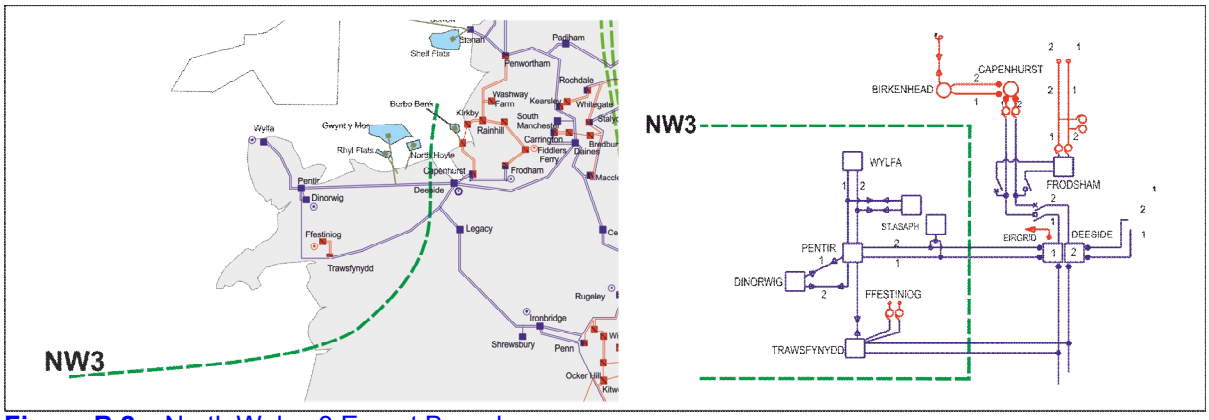

Figure B.2 – North Wales 3 Export Boundary

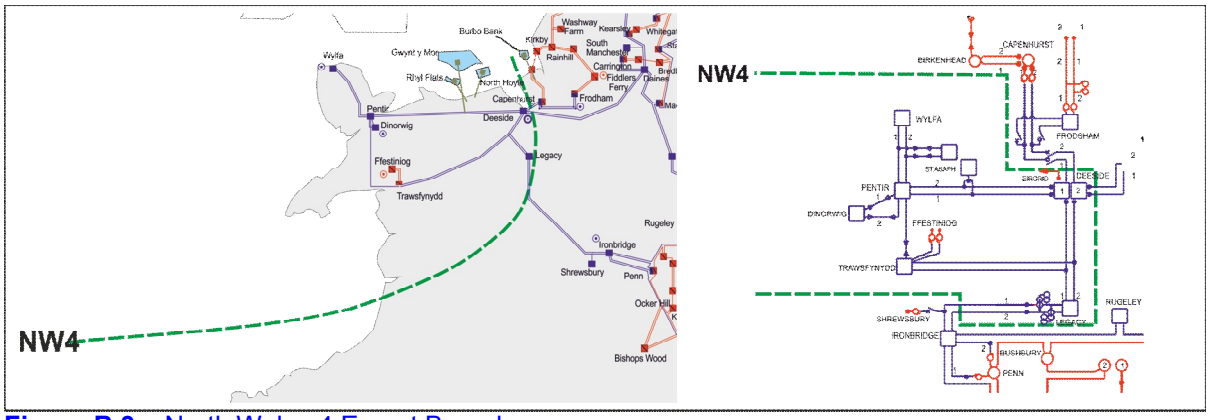

Figure B.3 – North Wales 4 Export Boundary

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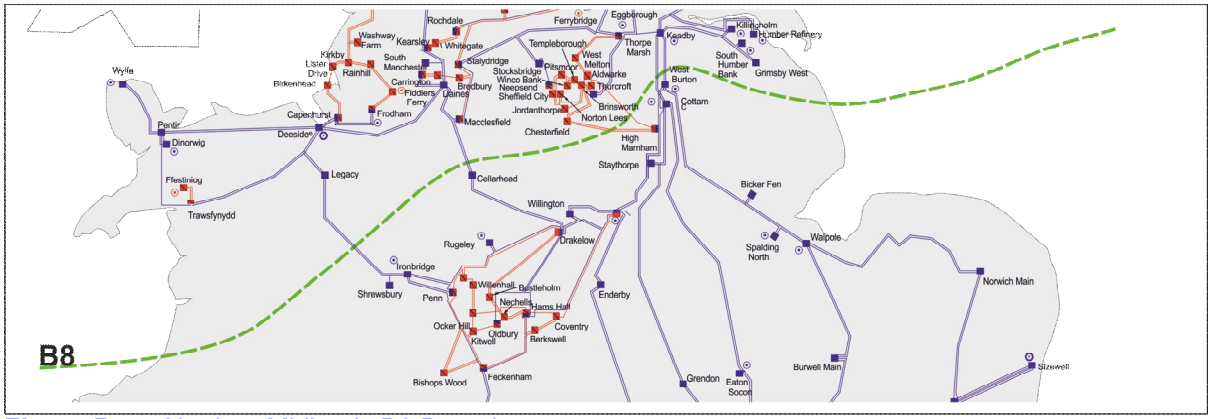

Figure B.4 – North to Midlands B8 Boundary

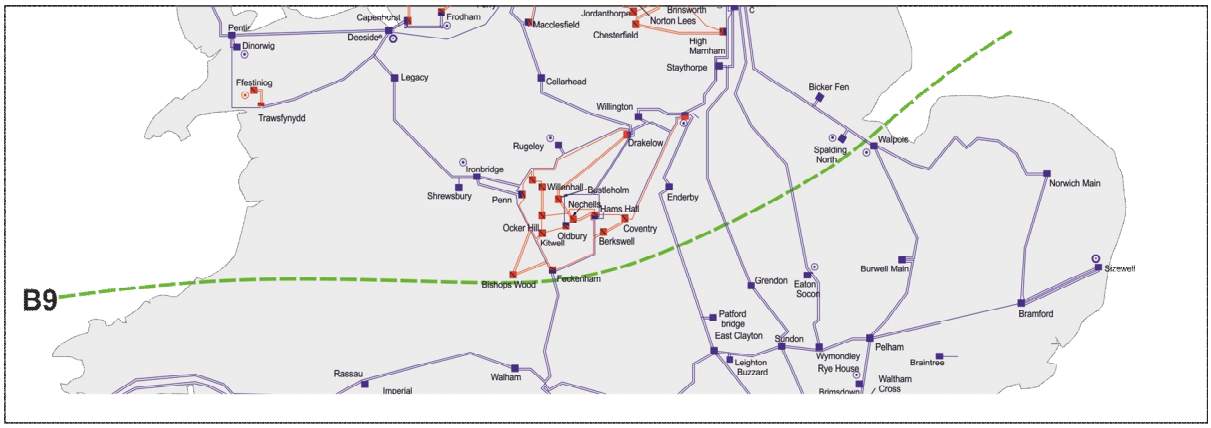

Figure B.5 –Midlands to South B9 Boundary

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Appendix C – Recommended TOR and Modelling

Cross-Company Project Team Outline Terms Of Reference and Tasks

On initial formation of a single purpose cross-company project team the following outline tasks or terms of reference should be considered and developed:

- Establish a list of tasks and allocate to a timeline (consider overlap with the customer project timelines; this has to be monitored and agreed and will influence the size/composition of the team. The initial assumption is that a one year period will be required for completing the work).
- Determine the team composition and the number of personnel required to meet the timelines.
- Review the work done to date (e.g. is further analysis required on options, consider technical implications, other options not yet examined).
- Consider Network Interconnection Options (NIOs) for higher levels of generation (>3GW) i.e. 5 and 7 GW.
- Identify further detailed study requirements (more detailed, additional studies e.g. short circuit and transient stability). A list of some of the studies identified to date is presented overleaf.
- Assess the impact of political and regulatory issues: a decision on whether it is possible for Irish wind generation to access the GB renewable subsidy scheme; an intergovernmental agreement between GB and Ireland; a decision as to which regulatory regime will apply to the infrastructure connecting Irish wind generation to the GB MITS; a decision on how the costs associated with the infrastructure to connect Irish Wind generation will be recovered.
- A full and detailed Cost Benefit Analysis is required to ascertain the total operational/market value of preferred NIOs. The outcomes of the Cost Benefit Analysis should be broken down into constituent values to provide complete clarity to respective authorities.

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Detailed Modelling Requirements

A considerable number of further studies will be required to examine the implications of this project for the safe, secure and reliable operation of the GB MITS and the Irish transmission system. The studies will include:

- Transient stability analysis including effects of clearance times, SNSP and credible HVDC response.
- Fault level analysis and effects on protection – Max and min fault infeed.
- Transient loss of largest infeed / outfeed due to faults on the proposed connection.
- Load flow and Contingency Analysis – Peak and Off-Peak.
- Voltage stability analysis.
- Full EMT type analysis showing expected response of HVDC system to faults.
- PSCAD-type simulation – This may be problematic as realistic models are unlikely to be made available.
- Harmonic analysis of proposed AC and of DC systems, particularly with regard to interference with existing telecoms infrastructure.
- HVDC Ramping requirements – max allowable ramp up and down rate of HVDC Links to GB MITS and new interconnection to the Irish transmission system.
- HVDC Power Reversal requirements.
- SSR and SSTI Studies.
- Small-signal stability analysis.
- Analysis of new requirements for NCC / EMS for each connection type.
- Analysis of the effect of the proposals on existing Irish wind generation and market function.
- Control Coordination Studies.
- Study of appropriate metrics for wind security analysis (SNSP etc)

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Appendix D – Glossary of Terms

Capacity vs Capability	Capacity is the maximum amount of MW that can be transferred on a boundary (i.e. a sum of all the circuit ratings) and capability is the transferred that can be actually achieved against a specific generation/ demand profile.
Irish Midlands Wind Generation	Irish Midlands Wind Generation refers to possible 3 GW or 5 GW wind generation projects located in the Irish Midlands that would access the market for renewable energy in Great Britain. These renewable energy export projects are generic and not specific to any one generation developer connection application.
Single Electricity Market (SEM)	The Single Electricity Market (SEM) is the wholesale electricity market operating in the Republic of Ireland and Northern Ireland. It is a gross mandatory pool market that operates with dual currencies.
Capacity Payment Mechanism	In the Single Electricity Market, there is a Capacity Payment Mechanism which values generation capacity at the cost of connecting a least-cost technically acceptable generator known as the Best New Entrant. Payments are made to all generators based on their availability to run.
Loss of Load Expectation	Loss of Load Expectation (LOLE) is the mathematical expectation of the number of hours in the year during which the available generation plant will be inadequate to meet the instantaneous demand. The use of LOLE to assess generation adequacy is an internationally accepted practice.

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Integrated	The connection of Irish Midlands Wind Generation directly to the GB MITS.
Integrated with Interconnection	The connection of Irish Midlands Wind Generation directly to the GB and Irish Transmission Systems.
Optimal Integrated Network	This is the most innovative, efficient and economic network design solution, delivered by the co-ordination of renewable energy export generation developers with existing Transmission System Operators.

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Appendix E – Integrated vs Radial Synopsis

National Grid has conducted extensive analysis of integrated versus radial strategies for the connection of 'offshore generation'[48] on the west coast of Great Britain. This Appendix aims to provide a synopsis of this analysis.

Whilst 'offshore generation' could be connected radially, significant onshore reinforcement, including new circuits would be required. An optimised radial connection strategy would involve a new circuit in either South Wales or North Wales, and the Pembroke-Wylfa link to distribute power between North and South Wales following faults. There is substantial benefit in the development of an integrated offshore network covering the Irish Sea and parts of Ireland, which can be conceptually thought of as an extension of the GB transmission system. An integrated approach of providing network interconnection between generation developers justifies the use of higher rated HVDC links whose capacity is shared amongst the generators. It provides the optimum solution to accommodate large volumes of renewable 'offshore generation'. As part of the integrated solution it is still necessary to build the Wylfa – Pembroke HVDC link in order to provide increased network flexibility, facilitating the early connection of additional generation, whilst avoiding some onshore reinforcement.

[48] 'Offshore Generation' in this context is generation development not on the island of Great Britain, it includes Irish Sea developments and onshore developments in Ireland.
[49] These estimated costs have been extracted from the National Grid strategy paper, Strategy for Connection of Wind Generation from Ireland and Irish Waters.

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