Strategic Transmission Options for the Connection of Onshore Renewable Energy Export Projects in Ireland to Great Britain

As of July 2014

Executive Summary

The Irish and UK Governments signed a Memorandum of Understanding in January 2013 to “complete their consideration of how Irish renewable energy resources, onshore and offshore, might be developed to the mutual benefit of Ireland and the UK”. The Governments have since explored the possibility of an Inter-Governmental Agreement to enable the trading of renewable energy between Ireland and Great Britain pre-2020. A number of developers have signed connection agreements with National Grid Electricity Transmission (“National Grid”) to connect their proposed renewable energy projects, located onshore and offshore in Irish territory, to the Great Britain transmission system.

National Grid and EirGrid are the Transmission System Operators for the Great Britain and Ireland transmission systems respectively. In these roles, National Grid and EirGrid have undertaken a high-level technical study to consider how best to connect Irish renewable energy export projects to Great Britain.

Based on preliminary analysis of GB transmission capability and discussions with government and regulatory bodies, a number of transmission designs were analysed for a range of Irish wind export generation capacity volumes. The transmission designs differed in terms of connection configuration, ranging from a radial, direct and exclusive approach through to more co-ordinated connection approaches with the HVDC technology adapted to provide an optimal solution. The radial approach is limited to a maximum of 2.4 GW due to GB transmission system restrictions, while for co-ordinated and integrated approaches a maximum of 4 GW of generation capacity was considered due to technology limitations and GB transmission restrictions.

A high-level cost analysis, which examined the capital costs and operational costs associated with each of the transmission designs was conducted as well as an environmental and technology assessment. The results show that for the volumes of Irish renewable export generation considered, a co-ordinated approach to the transmission development provides for the most efficient and economic design solution.

The study concludes that a co-ordinated approach:

- Enables the timely connection of higher volumes of renewable generation than could be delivered through independently developed radial connections.
- Reduces the overall cost of connection per kW.
- Minimises the environmental impact by reducing the amount of transmission infrastructure, and reduces the number of consents required thereby reducing the risk of consenting delays.
- Provides multiple paths to market.
- Facilitates the transmission of electricity for other purposes including market-to-market interconnection and Great Britain network flows, providing significant benefits to consumers.

1. Introduction

1.1 This National Grid and EirGrid joint report presents the results of a high-level technical analysis that compares a range of transmission designs for connecting specified onshore Irish Wind Export (IWE) volumes to Great Britain. The IWE volumes analysed are generic and are not related to any one generation developer connection application or the National Grid contracted generation background. The aim of this report is to:

a. Provide an understanding of current technological developments and environmental issues that influenced the network transmission designs examined,

b. Present three transmission design options that could be considered for the connection of the anticipated lower IWE volumes than the existing contracted position with National Grid of 10.5[1] GW, and

c. Present the results of a lifetime cost analysis, which compares the transmission capital and operational costs associated with the three transmission design options[2].

1.2 An Energy Trading Grid Group (ETGG)[3] was established by the UK and Irish Governments as part of the programme of work outlined in the Memorandum of Understanding signed in January 2013. The ETGG was a forum for discussing system planning, operation and technical issues around the transmission elements of IWE projects, as well as, where appropriate, consideration of solutions compatible with 2020 delivery in order to inform the relevant decision makers.

1.3 The results included in this report have been shared previously with government and regulatory bodies in both Great Britain and Ireland. This report does not discuss consents, technical standards, ownership or potential operating frameworks, which were outside the scope of this analysis.

1.4 There are regulatory and policy issues, surrounding these types of non-GB generation connections, under consideration by Ofgem through the Integrated Transmission Planning and Regulation (ITPR) project that may affect how some of the transmission designs discussed in the report might ultimately be delivered. These issues are being considered through other work streams and are not covered in depth in this report.

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[1] This was the contracted position at the time this analysis was undertaken.

[2] The cost per kilowatt quoted for each transmission design option is not an absolute cost and can only be used for the purposes of comparison in the context of this report.

[3] Membership of the Irish Energy Trading Grid Group consisted of the Department of Energy and Climate Change (DECC) and the Office of Gas and Electricity Markets (Ofgem) in the UK, the Department of Communications, Energy and Natural Resources (DCENR) and the Commission for Energy Regulation (CER) in Ireland, National Grid, and EirGrid.

2. Background

2.1 As part of the EU Renewables Directive[4] agreed by the European Parliament and the Council of the European Union, a number of co-operation mechanisms[5] were introduced to enable cross-border support of renewable energy. These allow for renewable energy produced in one Member State to contribute towards the target of another Member State.

2.2 Ireland has one of the largest wind energy resources in Europe, which analysis indicates is in excess of its own domestic requirements. The opportunity exists to export renewable energy from Ireland to other Member States, and in the first instance the United Kingdom, under a co-operation mechanism.

2.3 To assess this opportunity, the Irish and UK Governments signed a Memorandum of Understanding in January 2013 to "complete their consideration of how Irish renewable energy resources, onshore and offshore, might be developed to the mutual benefit of Ireland and the UK". The Governments have explored the possibility of an Inter-Governmental Agreement to enable the trading of renewable energy between Ireland and Great Britain pre-2020.

2.4 Several developers have been pursuing plans to build large scale renewable energy projects, both onshore and offshore in Irish territory, with the intention of physically exporting to the Great Britain transmission system. A number of these developers have signed connection agreements with National Grid Electricity Transmission ("National Grid") to connect their generation to the Great Britain transmission system. An indicative representation of this is shown in Figure 1 overleaf.

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[4] EU Renewables Directive (2009/28/EC): http://europa.eu/legislation_summaries/energy/renewable_energy/en0009_en.htm

[5] There are three co-operation mechanisms - Statistical Transfer, Joint Projects and Joint Support Schemes - that allow for renewable energy produced in one Member State to contribute towards the target of another Member State.

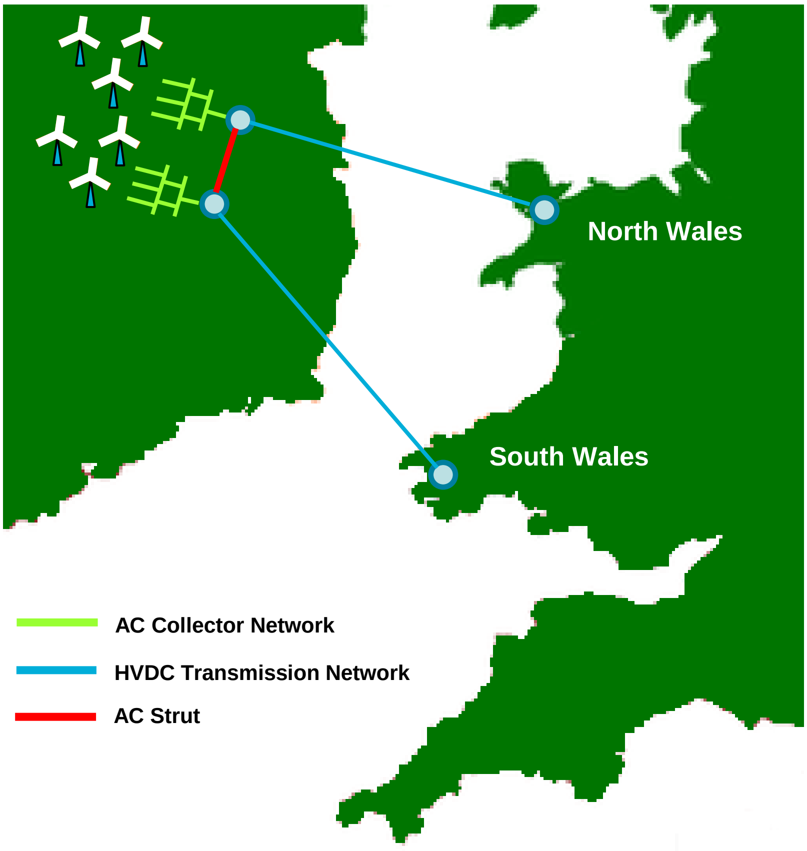

Figure 1: A potential transmission design option for the connection of wind generation in the Irish Midlands to the Great Britain transmission system.

2.5 Trading of renewable power in this manner would offer benefits such as enhanced security of supply and improved electricity market integration, as advocated by the EU's Third Energy Package Directive[6].

2.6 The economic tipping point between radial and integrated transmission designs was determined to be 1.2 – 1.5 GW of generation capacity for the connection points considered - see Figure 2 overleaf. The radial approach is limited to a maximum of 2.4 GW[7] due to GB transmission system restrictions against the GB contracted generation background. For co-ordinated or integrated approaches a maximum of 4 GW of generation capacity was considered due to technology limitations and GB transmission restrictions. Each transmission design approach was assessed against the maximum level of generation it can facilitate and a full build out of generation for each approach is assumed.

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[6] EU Third Energy Package Directive: http://ec.europa.eu/energy/gas_electricity/legislation/legislation_en.htm

[7] This assumes that all existing transmission routes on the west coast of England and Wales are reinforced to their full capacity. The radial approach can achieve connection capacities higher than 2.4 GW only by connecting deeper into the GB transmission system at an increased cost.

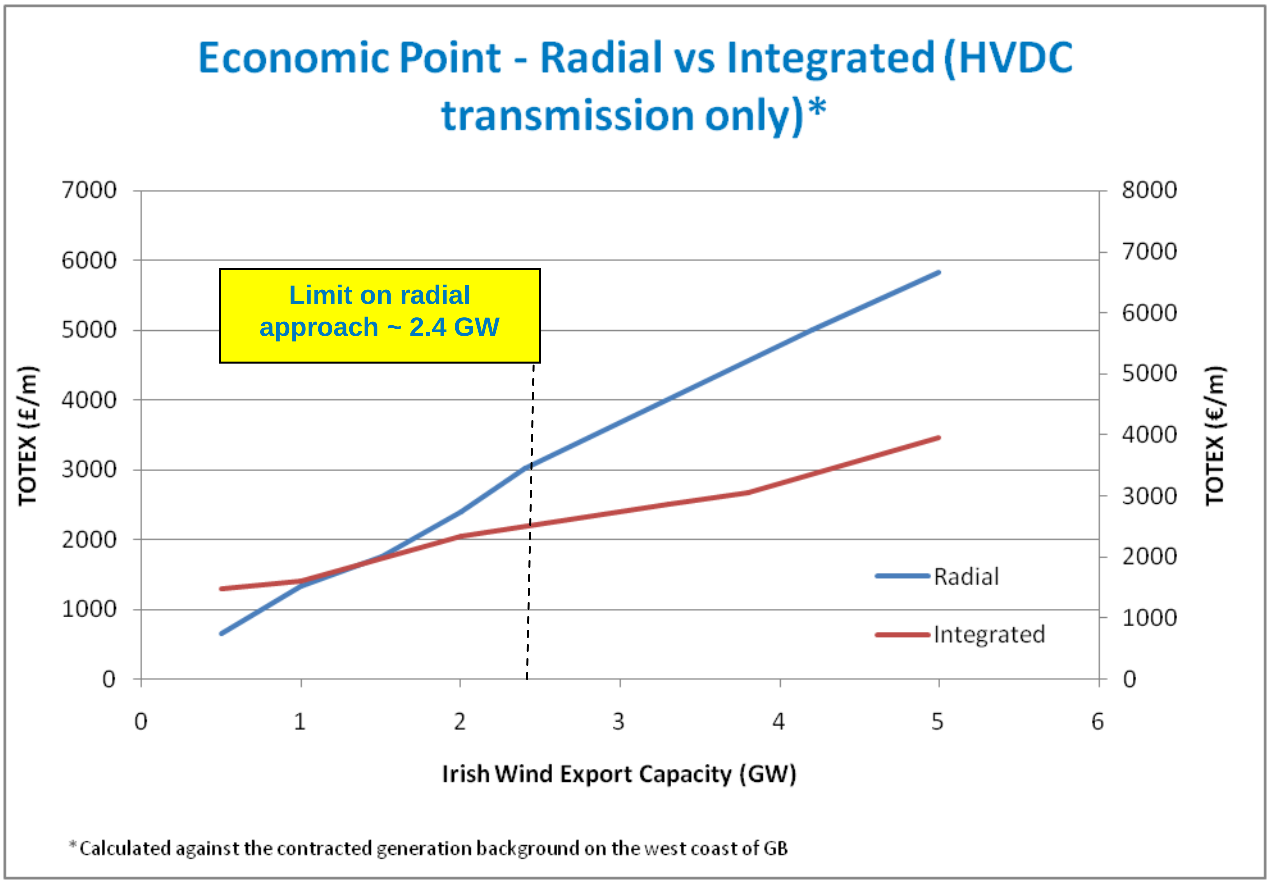

Figure 2: Economic tipping point for Radial versus Integrated / Co-ordinated transmission designs.

2.7 With regard to the treatment of the transmission infrastructure required to connect Irish generation to Great Britain, there are a range of regulatory and policy issues under consideration. Ofgem has consulted on options for the licensing framework and potential regulatory arrangements for transmission assets connecting generation from outside of Great Britain to the Great Britain electricity transmission system. This consultation feeds into the wider work that Ofgem is doing as part of the ITPR project, which is examining whether the system planning and asset delivery arrangements are appropriate to achieving a long-term efficient integrated transmission network - onshore, offshore and cross-border. Ofgem aims to provide further clarity in September 2014[8] on the appropriate regulatory route for non-GB connections as part of its draft conclusions on ITPR.

3. Basis for the Report

3.1 National Grid and EirGrid are the Transmission System Operators (TSOs) for the Great Britain and Ireland transmission systems respectively. In these roles, National Grid and EirGrid have been working together to consider how best to co-ordinate the transmission infrastructure required to connect IWE projects to Great Britain with network developments in and between both

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[8] Ofgem's most recent open letter, dated 23rd May 2014, on the 'Update on the regulation of transmission connecting non-GB generation to the GB transmission system', provided an update on the regulation of transmission connecting non-GB generation to the GB transmission system, following the consultation in November 2013, and the anticipated publication on draft conclusions on ITPR in September: https://www.ofgem.gov.uk/publications-and-updates/update-regulation-transmission-connecting-non-gb-generation-gb-transmission-system

islands. This is consistent with the statutory requirements and licence obligations pertaining to both companies[9].

3.2 National Grid and EirGrid have previously identified benefits to British and Irish consumers through co-ordinating the connection of the Irish renewable export projects to include an interconnection to the Irish transmission system. A joint report concluded that a capital investment of £80m/€100m to enable interconnection would increase market-to-market trading between GB and Ireland and provide estimated annual benefits to consumers of £60m/€75m per annum[10].

3.3 This report examines the transmission infrastructure more holistically to determine the overall optimal design approach for connecting Irish wind generation to Great Britain[11].

4. Analysis Undertaken

4.1 A high-level desktop environmental constraints study was carried out to obtain a strategic understanding of the primary environmental issues likely to influence development of renewable energy trading projects and to examine the development potential from an environmental perspective. The areas of opportunity for wind generation used in the assessment were primarily the areas defined by Local Authorities as "preferred"[12] (or equivalent definition) for the purposes of wind energy generation and/or areas of cut-away peat bog as appropriate. Lands which were constrained from an environmental perspective such as areas covered by nature conservation designations, as well as areas within 500m of domestic dwellings were removed from the analysis. The wind generation potential of the remaining areas was then calculated. The results of the study were used as inputs to the high-level transmission designs and to validate some of the assumptions made.

4.2 Due to the length of cables required (upwards of 250 km) to connect such projects to Great Britain, High Voltage Direct Current (HVDC) transmission technology is the only possible

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[9] Transmission of electricity in Great Britain and Ireland requires permission by a licence granted under Section 6(1)(b) of the Electricity Act 1989 ("the Electricity Act") in Great Britain, and granted under the Electricity Regulation Act, 1999 (as amended) and Regulation 8 of Statutory Instrument 445 of 2000 in Ireland. National Grid and EirGrid have been granted transmission licence(s) and are therefore bound by the legal obligations, which are primarily set out in the Electricity Act and the transmission licence in Great Britain and the Transmission System Operator Licence granted to EirGrid by the Commission for Energy Regulation and as deriving under the Electricity Regulation Act, 1999 (as amended) and Regulation 8 of Statutory Instrument 445 of 2000. National Grid is the operator of the high voltage transmission system for Great Britain and its offshore waters, which is known as the National Electricity Transmission System (the "Transmission System"), and is the owner of the high voltage transmission system in England and Wales. EirGrid is the operator of the electricity transmission system in the Republic of Ireland.

[10] "Connecting Wind Generation in Ireland to the Transmission Systems of Great Britain and Ireland", February 2013: http://www.eirgrid.com/media/ExportingRenewableEnergy-JointStudybyEirGridandNationalGrid(Feb%202013).pdf

[11] The results of this analysis are based on an assessment of the GB and Irish future energy markets and it will need to be reassessed as these energy markets develop.

[12] From their websites, it would appear that some developers are considering locating turbines in areas outside of the ones being considered here. These areas have not been included in our current assessment.

solution[13]. Therefore, a review of HVDC technologies that could be used to connect Irish renewable generation to Great Britain was also conducted. The conclusions from this review have been used to inform decisions on transmission designs which could be achievable in 2020 timescales.

4.3 Three transmission design options[14] were analysed for IWE volume scenarios of 2.4 GW and 4 GW based on analysis and discussions with ETGG members. The IWE generation volume that could connect to the GB transmission system is influenced by two factors:

a. The design approach adopted, for example a radial approach or co-ordinated approach, and

b. The spare enduring export capability[15], based on the National Grid contracted generation background at the time of the study at the assumed connection points of the transmission system on the west coast of Great Britain, and the relevant design criteria[16] of the GB National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS)[17].

4.4 The GB transmission system connection points (Pentir, Pembroke and Alverdiscott) used are those previously determined in the analysis conducted for the existing contracted IWE projects with National Grid. It has been assumed these connection points remain optimal for the volumes of generation considered in this report[18].

4.5 The three IWE transmission design options examined consisted of the Alternating Current (AC) Collector Network and the HVDC Transmission Network components only; Figure 3 provides a visual representation of these components and the other main components that comprise an entire IWE project. The key components are as follows:

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[13] Notwithstanding other technical issues which might dictate the use of other technologies for short transmission distances, with increasing lengths Alternating Current (AC) underground cables absorb more of the usable electricity to the point that, at distances above approximately 80km – 100km, little useful power can be transmitted. This is an electrical characteristic of AC cables as a result of capacitance between the conductor and earth.

[14] It was not within the scope of this analysis to consider all possible transmission design options.

[15] Spare Enduring Export Capability is the power transfer that is available immediately out of the connection point following all planned local and wider transmission reinforcements and the connection of local contracted generation.

[16] Chapter 2 of the National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS) requires National Grid to design generation connections such that with two circuits unavailable (referred to as n-2 fault/outage conditions), due to a combination of a fault (e.g. lightning strike) and/or an outage (planned maintenance), there will be no loss of generation in-feed greater than 1.8 GW. It also further requires National Grid to design generation connections such that for n-2 fault/outage conditions there shall be no unacceptable overloading of the remaining transmission circuits. It has been assumed that IWE generation will be constrained following loss of one in-feed either for fault or outage conditions.

[17] The GB NETS SQSS establish a co-ordinated set of criteria and methodologies that Transmission Licensees use in the planning and operation of the National Electricity Transmission System. National Grid is the Administrator for the SQSS and along with other Transmission Licensees maintains the Standard itself. All changes are subject to Industry Consultation and approval by Ofgem.

[18] This may require a re-assessment depending on the volume of IWE generation that may be agreed between the Irish and UK Governments.

a. Generator Network – this is typically operated at or below 110 kV in Ireland and connects the wind farms to 220 kV substations for transmission onwards on the AC Collector Network.

b. AC Collector Network – this is the transmission network that consists of all the underground cables[19] and substations from the 220 kV substation to the 400 kV substation that is assumed to be co-located next to the HVDC converter station. The voltage is stepped up to 220 kV and finally 400 kV to facilitate higher power transfers and lower transmission losses.

c. AC Struts – These underground AC cables, located in Ireland and assumed to operate at 400 kV, would facilitate the flow of power between HVDC links to the GB transmission system as part of an integrated design. AC Struts are designed to provide transmission redundancy and resilience in the event of a fault or outage on one of the HVDC cables to Great Britain. They may also provide a route for GB transmission system flows potentially avoiding GB network reinforcements[20].

d. HVDC Transmission Network – Once power has been collected at the 400kV substations it is converted from AC to DC at a converter station and the bulk power is transferred via HVDC cables to Great Britain. Power is then converted back to AC at another converter station before entering the GB transmission system.

e. Irish and GB Transmission Systems – These are the respective and existing national AC transmission systems.

f. Interconnection to the Irish transmission system – This is the connection from the Irish transmission system to the HVDC Transmission Network, which provides power transfer capability between the Irish and GB transmission systems.

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[19] For the purpose of this study it has been assumed only underground cables would be used in Ireland and this is consistent with developer proposals.

[20] The use of the IWE transmission network to transfer power between Pentir, Pembroke and Alverdiscott during times of low generation may offset the need for additional reinforcements on the GB transmission system.

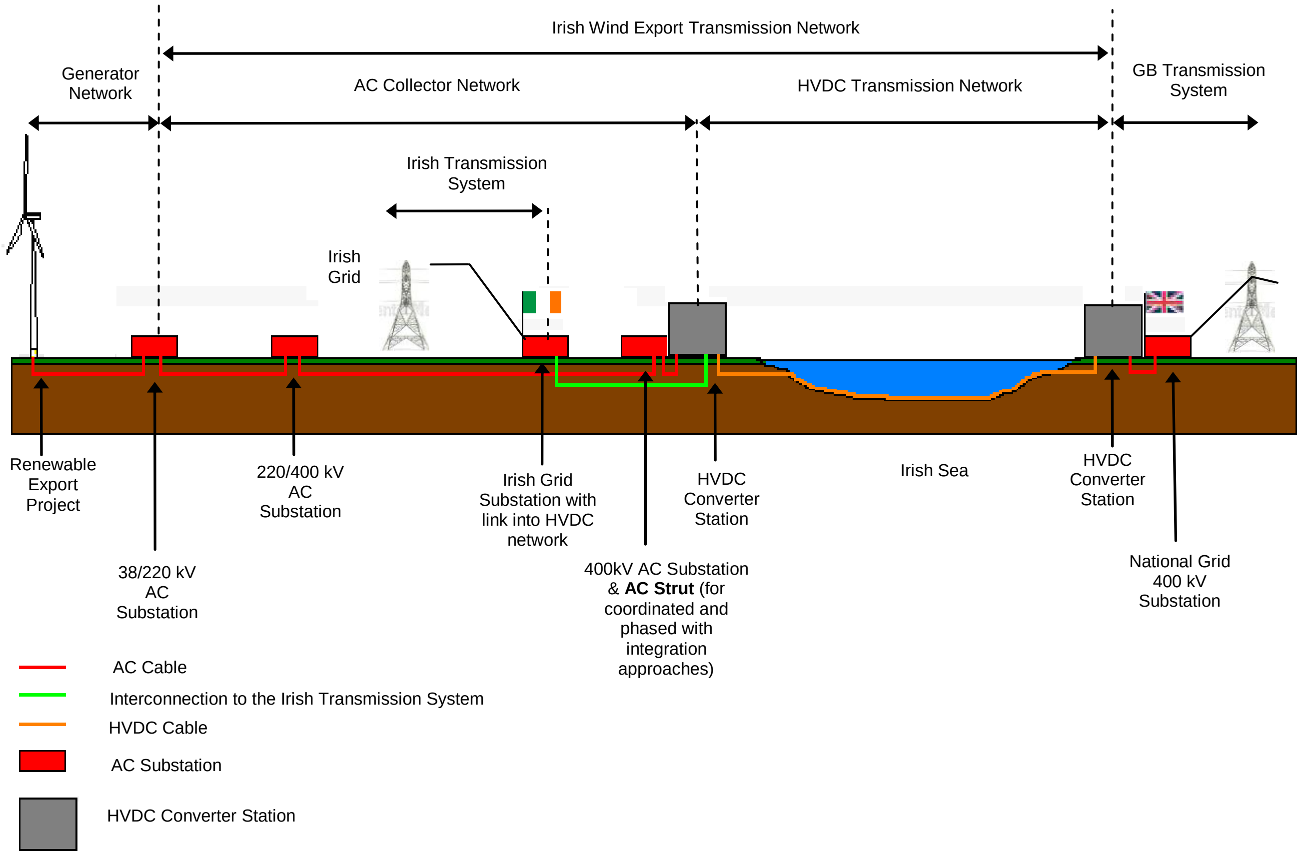

Figure 3: Diagram of IWE transmission network component parts.

4.6 The strategy employed considered volumes of generation in the contracted background and connection dates reflecting the GB Gone Green Scenario[21] 2013. Under the Gone Green scenario there is an anticipated delay in the connection of some of the contracted GB generation to the GB west coast connection points; this creates an opportunity for co-ordinated and phased connection approaches of IWE generation to capitalise on potential temporary spare transmission capability on the GB transmission system. This could allow a higher IWE volume to connect until approximately 2025. However, by 2025 all of the relevant non-IWE GB contracted generation is assumed to have connected requiring further infrastructure works to be delivered to ensure firm capacity for the IWE generation.

4.7 For each transmission design, a high-level cost analysis was undertaken to determine the optimum economic solution. Both the capital costs and the operational costs[22] associated with each network design were estimated for comparison purposes over an assumed lifetime of 20 years. The capital costs include estimated costs for the AC collector network, HVDC transmission

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[21] Each year National Grid publishes the UK Future Energy Scenarios (UK FES) document which provides detailed analysis of credible future energy scenarios. These scenarios are used for a range of modelling activities including detailed network analysis which enables National Grid to identify strategic electricity network investment requirements for the future. One of the scenarios “Gone Green” has been designed to meet the UK environmental targets with 15% of all energy from renewable sources including contributions from IWE projects by 2020. More information on the FES is available at http://www2.nationalgrid.com/uk/Industry-information/Future-of-Energy/

[22] Operation and maintenance cost, cost of transmission losses and the GB onshore transmission reinforcement cost were not included in this analysis.

networks and interconnection to the Irish transmission system[23].

4.8 The Spackman approach has been used in the cost analysis of the potential transmission network solutions to find their Present Value (PV). This approach was promoted by the Joint Regulators Group[24] in its Technical Paper "Discounting for CBAs involving private investment, but public benefit", where a firm finances the investment but the benefits mainly accrue to consumers or the wider public. Using this approach the cost of financing the assets is added to the actual cost of the assets. The financing costs are based on National Grid's post-tax Weighted Average Cost of Capital (WACC) of 4.55%[25]. The WACC is used to convert the capital costs into annual costs and a flat annuity is assumed over the lifetime of the asset. These annual costs are then discounted at HM Treasury's recommended Social Time Preference Rate (STPR) of 3.5%.

4.9 The operational costs examined include:

a. The cost of constrained/lost energy as a result of transmission faults and/or outages. The cost of constrained energy is assumed to be £110/MWh (€129/MWh)[26] and an availability rate of 95%[27] has been applied equally to all HVDC transmission networks regardless of rating.

b. The reduction in market-to-market trading benefits, estimated at approximately £7.7m (€9m) per year. This reduction occurs when capacity is not always available on the IWE transmission networks to enable trading between the two electricity markets.

4.10 As with the capital costs, the STPR discount rate of 3.5% was used to discount the operational costs. Electrical transmission losses and annual maintenance costs have been excluded as they have been deemed similar across all transmission design options on a per kW basis.

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[23] Capital Costs are based on The IET, PB/CCI Electricity Transmission Costing Study (http://www.theiet.org/factfiles/transmission-report.cfm) and National Grid's 2013 Electricity Ten Year Statement (http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Electricity-Ten-Year-Statement/).

[24] The Joint Regulators Group is an association of the UK's economic and competition regulators.

[25] It should be noted that the WACC will vary depending on who is constructing the project and the regulatory and financial arrangements underpinning renewable energy trading. A higher WACC value will result in higher financing costs.

[26] The cost of constrained energy consists of an assumed £50/MWh (€58/MWh) for lost wind farm revenue plus an assumed £60/MWh (€70/MWh) for replacement energy.

[27] There is little published information on reliability and availability of VSC HVDC converters reflecting the still comparatively limited service experience. A 95% availability rate was assumed for the purposes of this analysis.

5 Transmission Approaches

5.1 Three different transmission design approaches, outlined below, were considered for the connection of IWE generation. Common across all designs is a 0.5 GW[28] HVDC interconnection to the Irish transmission system, which facilitates market-to-market trading flows as well as providing other benefits. While some transmission design options could accommodate more than one interconnection to the Irish transmission system, using a single 0.5 GW interconnection ensures that the results of the cost analysis are directly comparable for all of the transmission design options examined.

Radial Approach: A radial connection approach consists of one or more direct point-to-point connections from the independent AC collector networks and HVDC converter stations in Ireland to HVDC converter stations in GB. It assumes that all constituent parts of individual generation developer projects are built independently with no integration of their AC collector networks or HVDC transmission networks. The generation developers are assumed to act independently and develop their projects to meet the 2020 target. This approach allows for the connection of a maximum of 2.4 GW of IWE generation due to the criteria specified in the GB NETS SQSS and the contracted generation background.

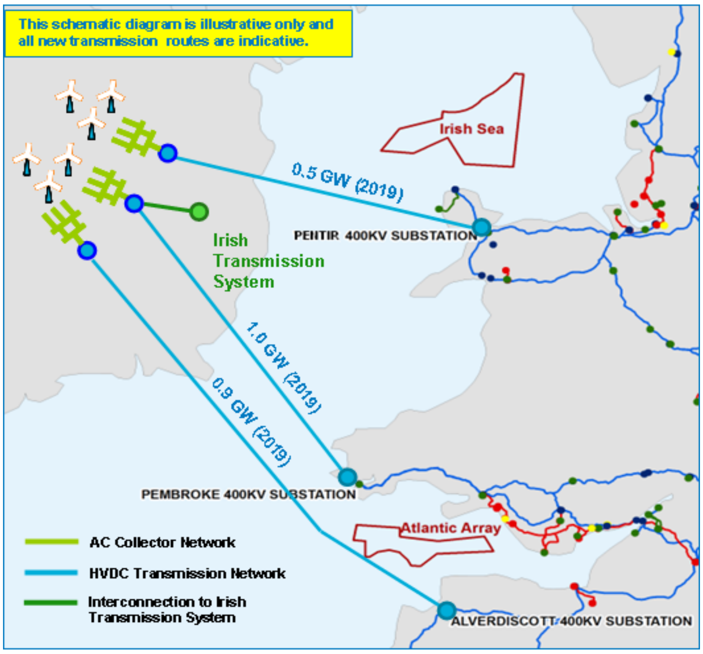
This schematic diagram is illustrative only and all new transmission routes are indicative.

Figure 4: Radial Transmission Design.

The key aspects of this approach are:

- Three VSC HVDC links are required to provide 2.4 GW of IWE capacity, connecting to north Wales, south Wales and the south west of England. The links have been sized based on the GB onshore enduring export capabilities at Pentir (0.5 GW), Pembroke (1.0 GW) and Alverdiscott (0.9 GW).
- This is a direct and exclusive connection that provides a firm capacity of 2.4 GW for IWE generation, but reduced benefits from market-to-market interconnection and no GB network flow capability.

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[28] The costs and benefits of interconnection were examined in a previous National Grid-EirGrid joint study and published in the report ”Connecting Wind Generation in Ireland to the Transmission Systems of Great Britain and Ireland”, February 2013: http://www.eirgrid.com/media/ExportingRenewableEnergy-JointStudybyEirGridandNationalGrid(Feb%202013).pdf.

Phased with Integration Approach: A phased with integration connection approach assumes that there is a phased build-up of IWE generation, with point-to-point connections from independent AC collector networks and HVDC converter stations in Ireland to HVDC converter stations in Great Britain assumed to be delivered in a phased manner in 2019, 2022 and 2025. It is assumed that AC Struts are in place by 2025 to integrate between the HDVC converter stations; this creates a multi-purpose network, facilitating market-to-market interconnection and GB network flows.

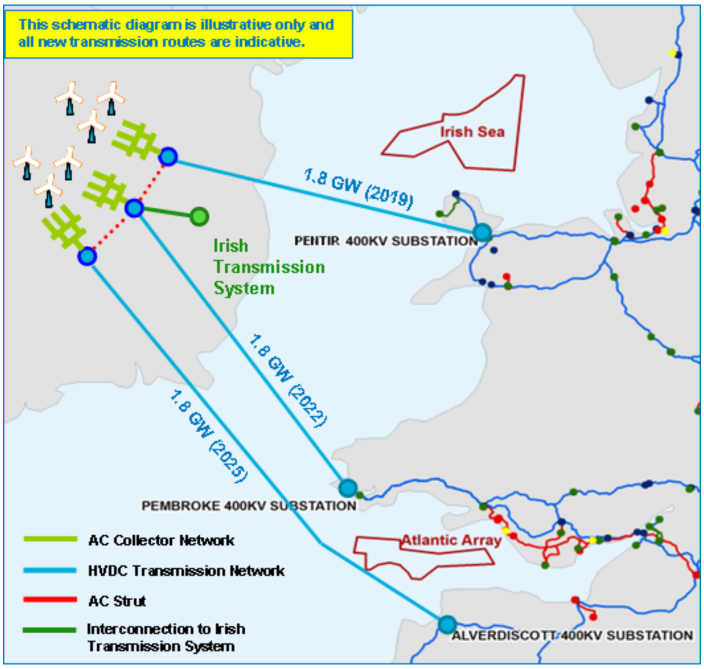

Figure 5: Phased with Integration Transmission Design.

The key aspects of this approach are:

- 3 x 1.8[29] GW VSC HVDC links are required to provide 4 GW of IWE capacity, connecting to north Wales, south Wales and the south west of England.
- GB generation sensitivities mean that only 2.4 GW enduring export capability is available post-2025. However, the remaining 1.6 GW of IWE generation would be firm following the assumed completion of the AC Struts in 2025, integrating all three HVDC links[30].
- There is increased transmission asset stranding risk; however, this could be managed through incremental development.

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[29] GB NETS SQSS standards require that no loss of generator infeed greater than 1.8 GW be permitted, which dictates a maximum point-to-point connection rating of 1.8 GW.

[30] Using similar AC struts would not provide for 4 GW of firm access in the Radial Approach due to the much smaller capacity HVDC cables assumed in that connection approach.

Co-ordinated Approach: A co-ordinated design approach assumes collaboration at every level of transmission, meaning the AC collector networks and the HVDC transmission networks are co-ordinated and optimally designed to accommodate the generation from all developers. This design also enables the assets to be used for multiple purposes such as market-to-market interconnection and GB network flows. Parallel high capacity HVDC links are used to optimise these benefits. This approach allows for the connection of 4 GW of IWE generation.

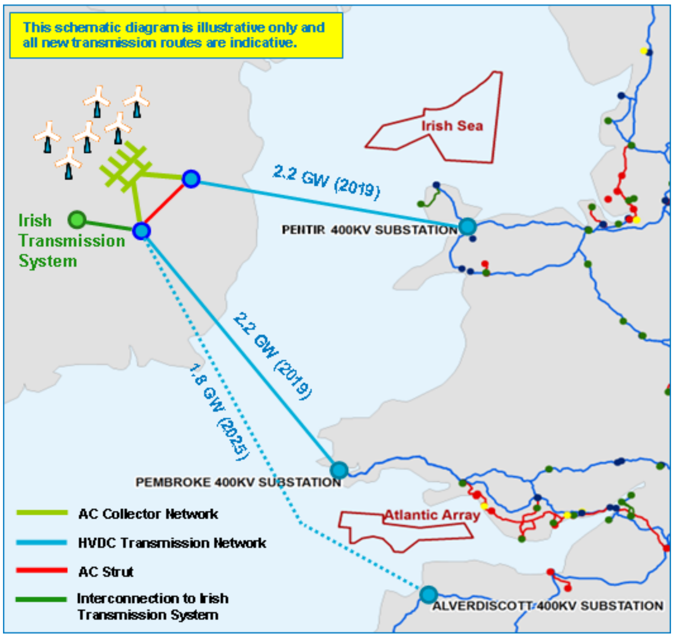

Figure 6: Co-ordinated Transmission Design.

The key aspects of this approach are:

- 2 x 2.2 GW VSC HVDC links provide 4 GW of IWE generation connection capacity, connecting to north Wales and south Wales (one of the two HVDC links is limited to 1.8 GW in operation due to loss-of-largest-infeed risk in NETS SQSS).

- GB contracted generation in north Wales (including Celtic Array and project Horizon) means that only a capacity of 2.7 GW is available post 2025. The remaining 1.3 GW of IWE generation would therefore be non-firm, until a third HVDC link is connected to the south west of England. The cost of this third link is included in the analysis.

- However, if the contracted position were to change, 4 GW of firm capacity may be available for IWE generation using just two HVDC links, one to north Wales and one to south Wales.

- There is increased transmission asset stranding risk; however, this could be managed through incremental development.

6. Environmental Assessment Results

6.1 The desktop environmental constraints study[31] conducted for this report identified that:

a. There is a wind resource available for potential generation capacity of up to 5 GW within the defined study area - see Figure 7 (the study area encompassed counties that the Irish midlands developers have listed publicly as the areas in which they propose to develop projects for export to Great Britain. Offshore projects and projects with elements of storage were not examined as part of the study).

b. There is no substantial difference between the potential wind generation locations identified in the study to the areas under consideration by developers. While the potential wind generation locations identified in this study may differ from specific locations being considered by developers, they are located within the same general area and therefore this should not have a significant impact on the high-level transmission designs considered in this report.

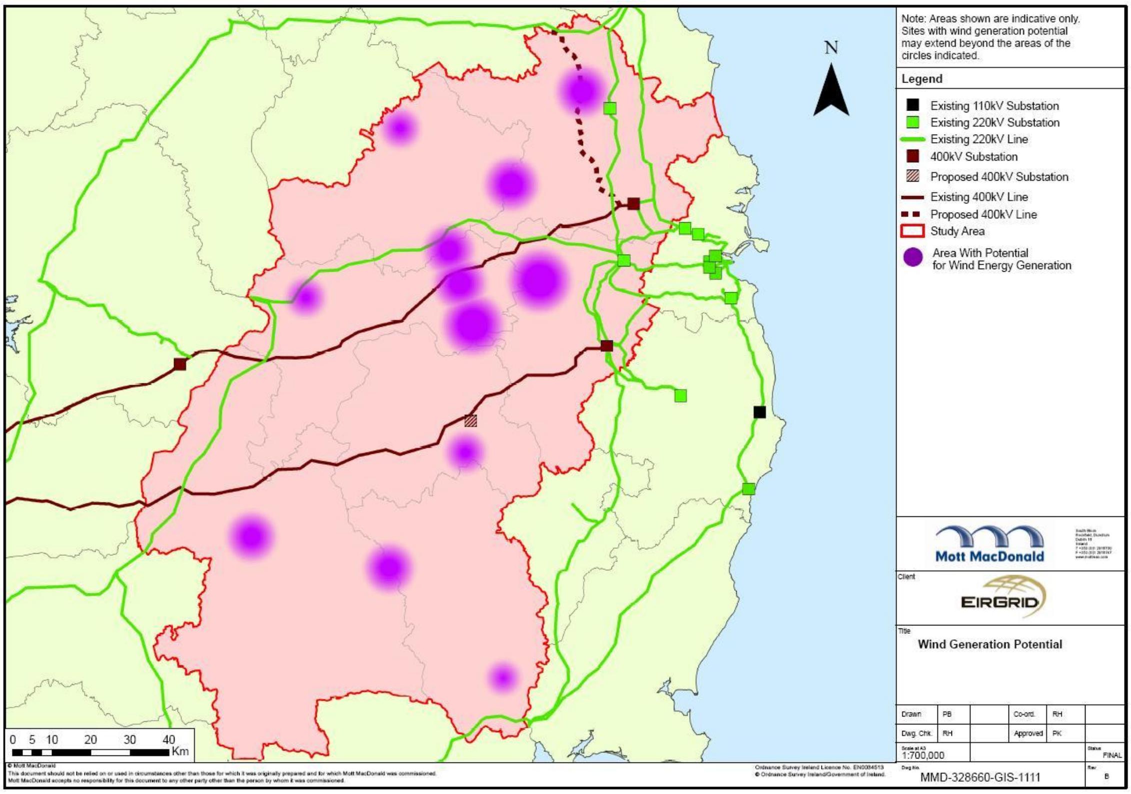

Figure 7: Assessment of wind generation potential within the study area in Ireland.

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[31] Note: This high-level analysis of the study area was conducted by EirGrid for the purpose of assessing possible energy export transmission needs in the future. It is entirely without prejudice to the workings of the planning system (local authorities and An Bord Pleanála) and to the separate policy for renewable electricity currently being developed by the Department of Communications, Energy and Natural Resources in Ireland.

c. Louth, South Wicklow and North Wexford offer the best opportunities for landfall of cables in Ireland, with limited opportunities elsewhere.

d. Four broad feasible underground cable transmission corridors exist for transmission infrastructure to connect the wind generation in the Irish midlands to landfall locations along the Irish coastline – see Figure 8 below.

6.2 The results of the desktop environmental study were used as inputs to the high-level transmission designs to validate some of the assumptions made.

6.3 The existing potential GB transmission system connection points at Pentir, Pembroke and Alverdiscott[32] on the west coast of England and Wales were assumed to be suitable from an environmental perspective; however, further detailed environmental analysis would be required to confirm this assumption.

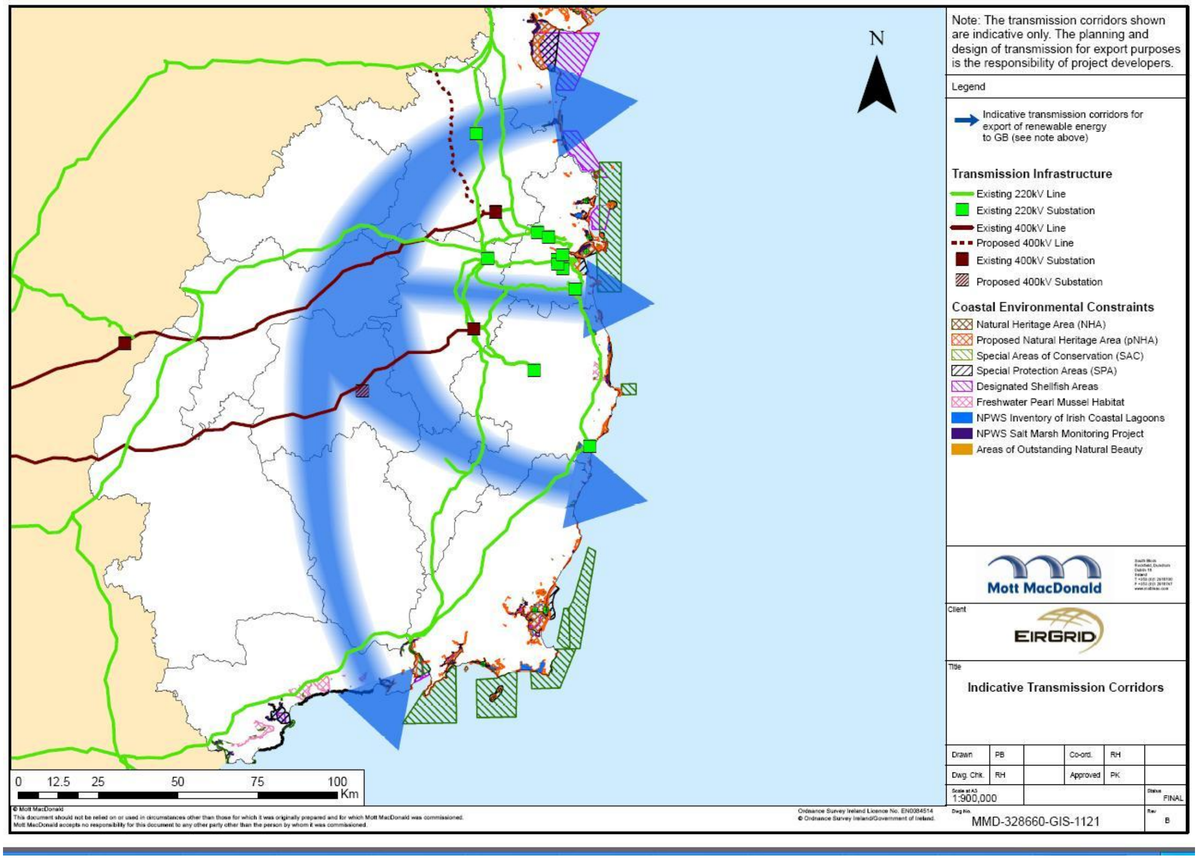

Figure 8: Indicative underground cable transmission corridors identified for connecting potential wind generation areas to potential landfall locations for cables on the east and south-east coasts of Ireland.

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[32] These are the current optimal connection points to the GB transmission system due to enduring export capability and proximity to the coast line and this has been assumed to be extant for the purposes of this analysis; these connection points could be subject to change depending on generation background changes and GB transmission system developments.

7. HVDC Technology Assessment Results

7.1 A technology assessment was conducted in two parts; firstly an examination of the two available High Voltage Direct Current (HVDC) technologies and secondly an assessment of available HVDC technology capacity within the IWE project timescales.

7.2 The relevant features of the two types of HVDC technology - Voltage Source Converter (VSC) and Line Commutated Converter (LCC) - are as follows:

a. LCC has difficulty operating when connected to a weak AC system, such as the IWE AC Collector Network. The strength of the AC system is important for stable operation of LCC as faults and disturbances on the AC system may cause failure of the conversion technology resulting in interruption to the power transmission.

b. LCC converters are not able to operate continuously at low levels of power, typically less than 10% of the rated power transmission capacity, which may occur during extended periods of low wind.

c. VSC technology does not require a source voltage from the AC system and therefore it can operate when connected to a weak AC system.

d. VSC is able to operate continuously at any level of power flow within its rating.

7.3 VSC HVDC technology is therefore well suited for wind connections[33] and is the most appropriate HVDC technology for connecting IWE generation to GB; it essentially consist of two main components[34], cables and converters, and these respective technology aspects are discussed below:

a. The main competing cable types are Mass Impregnated (MI) and Cross-Linked Polyethylene (XLPE). The former can deliver greater capacity (with voltages circa 600 kV) and is a more mature and established technology, whereas XLPE is still developing with lower capacity (with voltages circa 320 kV) but quicker installation timescales[35].

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[33] The use of HVDC transmission for connection of wind generation is described in CIGRE WG B4.39, 'Integration of large scale wind generation using HVDC and power electronics'.

[34] Other HVDC components not considered here are: converter transformers; HVAC switchgear; HVDC switchgear; AC filters and DC filters.

[35] Generally, it is considered jointing of XLPE cables is more straightforward and requires less time than MI cables. However, MI cables have a longer and more well-proven history in joint reliability and robustness **-** Potential Use of Submarine or Underground Cables for Long Distance Electricity Transmission in Manitoba (2011, 98) 'For example, there is evidence that DC MI cable joints have performed very well, whereas failures have occurred for AC XLPE cable joints.'.

b. The converter characteristic limiting the overall power transfer of this technology is the current-carrying capability of the Insulated Gate Bipolar Transistor (IGBT) modules used in the converter valves. Presently, IGBT current-carrying capability is in the region of 1.8 kA, with a number of suppliers[36] currently developing IGBT solutions in excess of 2 kA.

7.4 The above two components' future capacities were assessed and the results are presented below:

a. IGBT developments are expected to achieve a 2 kA rating by 2016[36].

b. The highest power rating expected for MI cables with VSC HVDC technology within the IWE project timescales, considering the above IGBT rating of 2 kA combined with a voltage level of 600 kV, is ~2.4 GW[37].

c. The highest power rating expected for XLPE cables with VSC HVDC technology within the IWE project timescales, considering the above IGBT rating of 2 kA combined with a voltage level of 320 kV, is ~1.3 GW[36].

7.5 These results were used to determine the technology adopted for each of the transmission design approaches; XLPE cable technology was assumed for lower capacity links up to 1 GW in the radial approach and MI cable technology was assumed in the 'co-ordinated' and 'phased with integration' approaches.

8. Cost Assessment Results

8.1 For each transmission design, an estimated total lifetime cost has been calculated consisting of the sum of the:

a. Initial capital cost of developing, procuring, installing and commissioning the new transmission assets, and

b. The operational costs that are expected to be incurred during the lifetime of these new transmission assets.

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[36] SKM report on "Review of Worldwide Voltage Source Converter (VSC) High Voltage Direct Current (HVDC) Technology Installations" (2013): https://www.ofgem.gov.uk/ofgem-publications/52726/skmreviewofvschvdc.pdf.

[37] This assumes that a full-bridge bipolar configuration is used.

8.2 These costs were calculated to Present Values as of 2018[38], with the first year of capital outlay occurring in 2019 across all options. A high-level summary of the results of the lifetime cost analysis on a £/kW and €/kW[39] basis are presented in Table 1 and these results are shown graphically in Figure 9. These calculations are time sensitive and would need to be reassessed as both the GB and Irish energy markets and generation backgrounds develop.

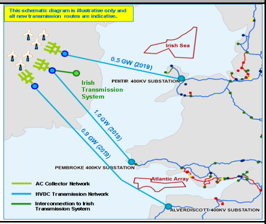
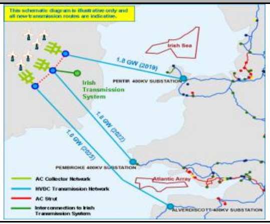
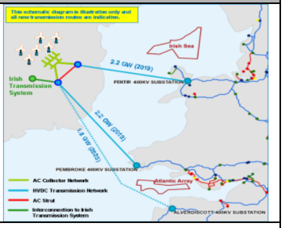
Transmission Design Options (Maximum generation capacity permitted)	**Radial (2.4 GW)**	**Phased with Integration (4.0 GW)**	**Co-ordinated (4.0 GW)**
			
Present Value of Assets over 20 years (cost/kW)	£2,879 m (£1,199) €3,368 m (€1,403 m)	£4,489 m (£1,122) €5,252 m (€1,313)	£4,242 m (£1,061) €4,963 m (€1,241)
Present Value of Constrained Energy and Lost Trading Benefit over 20 years (cost/kW)	£765 m (£319) €895 m (€373)	£367 m (£92) €429 m (€107)	£192 m (£48) €225 m (€56)
Lifetime Cost of Network Option	£3,644 m €4,263 m	£4,856 m €5,681 m	£4,434 m €5,188 m
Lifetime Cost of Network Option in £/kW and €/kW	**£1,518** **€1,776**	**£1,214** **€1,420**	**£1,109** **€1,297**

Table 1: Summary of the lifetime cost analysis.

8.3 The total cost and cost per kilowatt have been calculated for each transmission option. The latter provides a reasonable comparable figure between the respective approaches for the different volumes of generation considered; however, it is recognised that this does not completely eliminate the difference in the economy of scale, i.e. the difference in cost per kilowatt between radial and co-ordinated or integrated designs would be less if designed for the same lower volume of generation.

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[38] The price base for the cost assumptions is 2013 costs. No adjustments have been made to account for the impact of inflation. IWE transmission network capital outlay is assumed to occur in the year of commissioning. No cost distribution curves have been applied.

[39] An exchange rate of £1 = €1.17 has been assumed for this study.

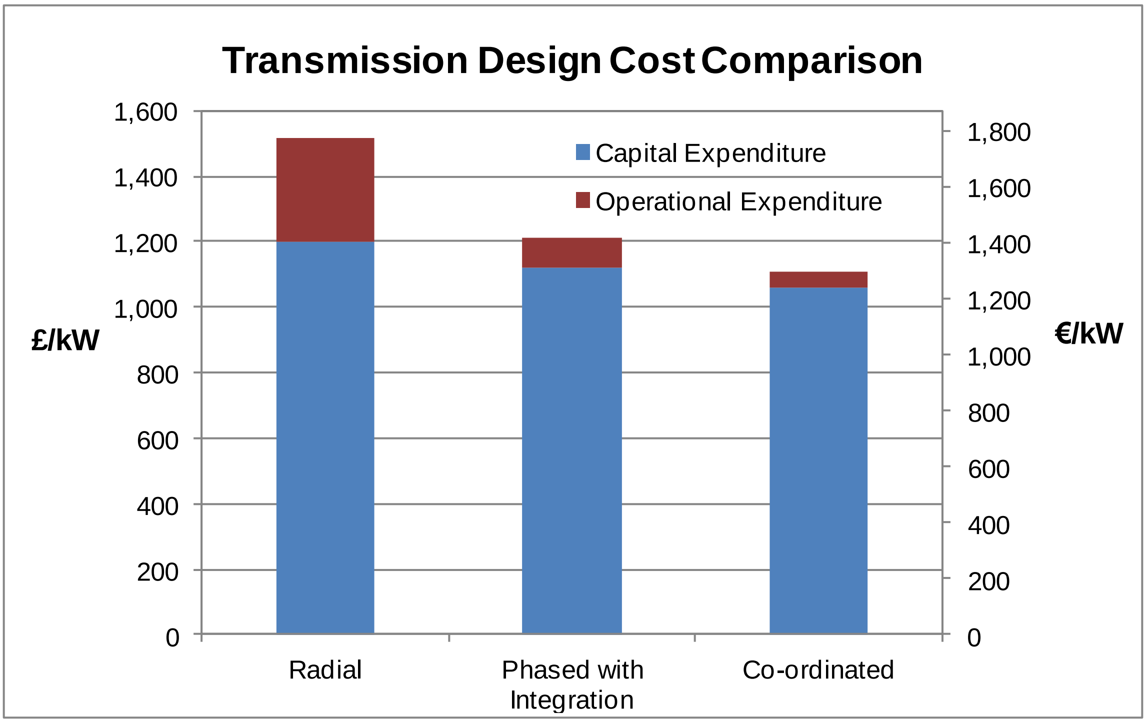


Figure 9: Summary of lifetime cost assessment.

8.4 The following provides a summary of the results of the cost assessment:

a. A co-ordinated design approach is the lowest cost approach for both capital and operational expenditure due to the higher capacity transmission links and the redundancy and resilience of the network.

b. The capital costs are highest on a per kilowatt basis for the radial approach because it assumes that all component parts of the transmission network connecting to the Great Britain transmission system are built independently and there is no integration of the AC collector networks in Ireland or collaboration on VSC HVDC links to Great Britain.

c. Operational costs for the radial approach are significantly higher than for the other two approaches. This is because for the loss of a HVDC transmission link there is no alternative route for the generation to the GB transmission system i.e. there is no transmission redundancy and resilience.

9. Appraisal of Results

9.1 An appraisal of the cost, environmental and technology assessments for each of the three transmission network design options is summarised at a high level in Table 2.

9.2 For each of the three assessments carried out, the transmission options were scored against a scale ranging from green (high benefit), through yellow (moderate benefit) to amber (low benefit). The transmission design options were gauged to give an overall ranking. The appraisal shows that the co-ordinated approach is the preferred option across the three assessment areas.

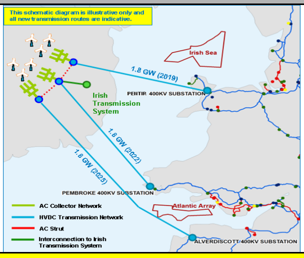
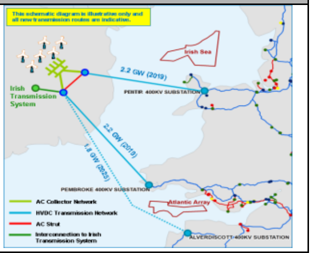
Appraisal of Results	**Radial (2.4 GW)**	**Phased with Integration (4.0 GW)**	**Co-ordinated (4.0 GW)**
			
Lifetime Cost of Transmission Option (£/kW) / (€/kW)	• **Highest cost option** • **1,518 £/kW , 1,776 €/kW**	• **Median cost option** • **1,214 £/kW , 1,420 €/kW**	• **Lowest cost option** • **1,109 £/kW , 1,297 €/kW** • **Cost would be substantially lower if the 3rd cable is not required.**
Environmental Impact	• **3 HVDC cables provide only 2.4GW of connection capacity** • **No co-ordination on AC collector networks => 3 separate networks**	• **3 HVDC cables provide higher 4GW of connection capacity** • **AC Struts may not be required to provide higher 4 GW connection capacity.** • **No co-ordination on AC collector networks => 3 separate networks**	• **2 (possibly 3) HVDC cables provide higher 4GW connection capacity** • **Co-ordination optimises AC collector network to minimise the environmental impact**
Technology	• **All XLPE HVDC cables with capacities equal to or less than 1GW** • **VSC converters with these ratings currently available**[40]	• **All MI HVDC cables with capacities of 1.8GW (MI is more mature than XLPE)** • **VSC converters with these ratings currently available**[39] • **AC Struts use standard AC cable technology**	• **VSC converters with these ratings expected available by 2016**[39] • **All MI HVDC cables (MI is more mature than XLPE)** • **AC Struts use standard AC cable technology**
Overall Ranking	**3**	**2**	**1**

Table 2: Appraisal of results.

9.3 From an economic and environmental perspective, a co-ordinated AC Collector Network with fewer larger VSC HVDC cables is more efficient and more cost effective for higher levels of generation than a direct and exclusive radial approach with independent AC collector networks and a higher number of smaller capacity cables. With regard to the co-ordinated approach, there is risk in stretching the technology boundaries of either cable capacity or IGBT current rating; however, appropriate risk management techniques and suitable mitigation strategies would reduce this to an acceptable level.

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[40] SKM report on "Review of Worldwide Voltage Source Converter (VSC) High Voltage Direct Current (HVDC) Technology Installations" (2013): https://www.ofgem.gov.uk/ofgem-publications/52726/skmreviewofvschvdc.pdf.

10. Conclusions

10.1 National Grid and EirGrid have undertaken a high-level technical study to consider how best to connect Irish renewable energy projects to Great Britain. Three transmission design options were analysed for IWE volumes of 2.4 GW and 4 GW. The transmission designs differed in terms of connection configuration, ranging from a radial connection approach through to more integrated and co-ordinated connection approaches. For each transmission design, the VSC HVDC technology employed was adapted to provide an optimal solution.

10.2 A high-level cost analysis, which examined the capital costs and operational costs associated with each of the transmission designs was conducted as well as an environmental and technology assessment. Based on the results of these assessments, the transmission designs have been ranked in order from most optimal to least optimal – see Table 3.

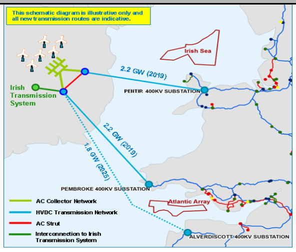
Transmission Design Approach	**Co-ordinated**	**Phased with Integration**	**Radial**
			
Ranking	**1**	**2**	**3**

Table 3: Ranking of the most economic and efficient approaches.

10.3 The results show that a co-ordinated approach is the most economic and efficient solution, for the 2.4 GW and 4 GW wind volume scenarios examined, as it facilitates a more optimal transmission design. An added benefit of this transmission design is that it would reduce overall project risk relative to a direct and exclusive radial connection solution by providing multiple paths to market resulting in greater transmission redundancy and resilience. It also provides additional benefits to consumers by enabling the development of a network that can provide for the transmission of electricity for other purposes including market-to-market interconnection and Great Britain network flows[41]. A co-ordinated transmission solution would also enable a larger amount of IWE generation to connect to the Great Britain transmission system in the period to 2020 and beyond.

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[41] Potential to use the new network to transfer power between Pentir, Pembroke and Alverdiscott during times of low generation and hence offset the need for additional reinforcements on the GB MITS.

10.4 In summary, the study concludes that a co-ordinated approach:

- Enables the timely connection of higher volumes of renewable generation than could be delivered through independently developed radial connections.
- Reduces the overall cost of connection per kW.
- Minimises the environmental impact by reducing the amount of transmission infrastructure, and reduces the number of consents required thereby reducing the risk of consenting delays.
- Provides multiple paths to market.
- Facilitates the transmission of electricity for other purposes including market-to-market interconnection and Great Britain network flows, providing significant benefits to British and Irish consumers.

11. A Look Forward

11.1 Ofgem has consulted on the development of the regulatory framework for the connection of non-Great Britain generation projects to Great Britain. In May 2014, Ofgem released an update on its work noting that it will continue to consider the regulation of these connections as part of the ITPR project and it expects to publish draft conclusions on ITPR in September this year.

11.2 The Irish and UK Governments have held discussions on all the matters required to enable renewable energy exports from Ireland to Great Britain within the EU's 2020 timeframe. It is clear that greater regulatory certainty and developments in the policy frameworks are required before Irish renewable export generation projects can be progressed, with 2020 delivery unlikely given project lead times.

11.3 However, in the context of a European Internal Market and greater integration, greater trade in renewable energy between Britain and Ireland is likely in the post-2020 scenario.

11.4 The analysis has shown that for the volumes of Irish renewable export generation considered, a co-ordinated approach to the transmission development provides for the most efficient and economic design solution while simultaneously providing additional benefits to Irish and British consumers through enabling multi-purpose use of the infrastructure.

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