NORTH-SOUTH 400kV INTERCONNECTION DEVELOPMENT

OUTLINE AND UPDATE OF EIRGRID'S CONSIDERATION OF THE TRANSMISSION TECHNOLOGY OPTIONS AS PRESENTED TO THE INDEPENDENT EXPERT GROUP

DECEMBER 2017

A European Project of Common Interest

EXECUTIVE SUMMARY

The Minister for Communications, Climate Action and Environment has appointed an independent expert group (IEG) to examine the technical feasibility and cost of undergrounding the North-South Interconnector, taking into account the most recent developments in technology and experience gained from existing projects abroad. This report sets out EirGrid's position on these matters.

EirGrid is proposing that the proposed interconnector be implemented by means of a single circuit 400 kV overhead line. The proposed overhead line will be approximately 137 km in length (103 km in Ireland and 34 km in Northern Ireland) and will form a second high capacity tie-line between the networks of Ireland and Northern Ireland. Planning approval for the part of the proposal located in Ireland has been received from An Bord Pleanála. This report replicates and updates the evaluation of the technology options that was submitted to An Bord Pleanála by EirGrid during the planning process.

EirGrid's evaluation of the technology options was carried out in the knowledge that the proposed second North South Interconnector will be of the highest strategic importance for the island of Ireland, with a power carrying capacity equivalent to 23% of the island's peak demand. It will form an internal reinforcement of the single 'all-island' network and will operate like any other transmission circuit in the meshed network.

HVDC technology was considered as an option. It was found that embedding a HVDC circuit into the 'all-island' network and requiring it to operate like an AC circuit would require complex control and communications systems which international experience shows are prone to occasional failure. Such a failure has the potential in the case of the North South Interconnector, to collapse the entire 'all-island' network resulting in a widespread blackout. Taking such a risk is unnecessary when there is a technically superior and lower risk option readily available.

A HVDC underground cable circuit can also be expected to experience more failures that take much longer to repair, than an equivalent HVAC overhead line. The analysis in the case of the North South Interconnector indicates that the HVDC underground cable option would experience one failure every 16 months and be out of service for between 25 to 40 days on each occasion. By contrast the proposed 400 kV overhead line is expected to experience only one fault every 20 years and be out of service for less than two days as a result.

The HVDC underground cable option would also cost many hundreds of millions of euro more than the proposed 400 kV overhead line. A report commissioned by EirGrid (PB Power Report 2013) found that it would cost €817 million and that this would be €670 million more than the proposed overhead line. The latest analysis of cost information from HVDC projects around Europe, including the ALEGrO Project between Belgium and Germany, indicates that the HVDC option would cost in the region of €780 million confirming that PB Power's cost estimate is reasonable.

HVAC underground cable was also considered as an option. It was found that undergrounding a circuit with the length (135 km) and power carrying capacity (1,500 MVA) required of the North South Interconnector using HVAC underground cable over its entire length is not technically feasible.

Partial undergrounding of such a circuit may however be feasible. EirGrid's analysis shows that due to technical limitations associated with HVAC cables the maximum length of the proposed interconnector that could be undergrounded in one continuous length, or in a series of shorter lengths, is approximately 10 km. Partial undergrounding would also add as much as €75 million to the cost of the project. Such additional expenditure can only be justified if it can be proven to be an advantageous and cost effective way of overcoming an environmental or technical constraint to the preferred overhead line.

No section of the proposed route was found where this applies and therefore a solution comprising entirely of 400 kV AC overhead line is proposed.

Table of Contents

1 INTRODUCTION

The Minister for Communications, Climate Action and Environment has appointed an independent expert group (IEG) to examine the technical feasibility and cost of undergrounding the North-South Interconnector, taking into account the most recent developments in technology and experience gained from existing projects abroad.

As part of their scope of work the IEG is expected to consult with EirGrid. This report has been prepared in anticipation of this engagement. It provides a brief introduction to the project in the form of its context and history. It then outlines EirGrid's consideration of the technology options for the North South Interconnector Project, as presented to An Bord Pleanála during the statutory planning process. It also includes any updated information that has come to light since the conclusion of that process.

EirGrid's consideration of the technology options is presented .as follows –

Step 1 is a general consideration of HVDC technology for use on this project, regardless of whether it is implemented using overhead line or underground cable and compares it with a standard HVAC overhead line using a range of environmental, technical and economic criteria.

Step 2 considers the feasibility of undergrounding the interconnector for its entire length using HVAC underground cable and compares this with an equivalent HVAC overhead line.

Step 3 considers the option of implementing the project using HVAC technology, mostly by means of overhead line but with some underground cable. This is known as partial undergrounding.

Step 4 is an assessment of design options for a HVAC overhead line solution.

2 CONTEXT AND HISTORY

EirGrid and SONI are jointly planning a major cross-border electricity transmission development between the existing high-voltage transmission networks of Ireland and Northern Ireland. The proposed interconnection project will link the existing 400 kV substation in Woodland, County Meath with a planned substation in Turleenan, County Tyrone; it will provide a second high capacity electricity interconnector between Ireland and Northern Ireland.

EirGrid holds the licence of Transmissions System Operator (TSO) in Ireland. In this role EirGrid is required by statute:

> "To *operate and ensure the maintenance of and, if necessary, develop a safe, secure, reliable, economical and efficient electricity transmission system, and to explore and develop*

opportunities for interconnection of its system with other systems, in all cases with a view to ensuring that all reasonable demands for electricity are met and having due regard for the environment".

SONI is the licensed TSO in Northern Ireland and is responsible for the planning of the transmission network in that jurisdiction.

ESB owns the transmission network in Ireland and is responsible for its construction in accordance with EirGrid's development plan. NIE fulfils this role in Northern Ireland.

EirGrid and SONI are required by their respective regulators to plan and develop the two transmission systems as if they formed one single transmission network; that is a single 'all-island' transmission network. They are further required to do this in accordance with their respective Transmission System Security and Planning Standards (TSSPS). It is a fundamental principle of these standards that no single loss of an item of transmission plant or equipment shall result in a failure to meet the specified quality of supply standards. Ireland is not alone in basing its security of supply on this underlying principle with other European TSOs[1] and almost all TSOs worldwide basing their network design on this principle.

The necessity for ensuring the continued security of supply of the transmission system cannot be overstated. Reliable electrical power has become a base requirement for society. National and local government, education, healthcare, transport, utilities (gas, water, telecoms, etc.), industry, commerce and domestic consumers all rely on a reliable electricity supply. An interruption to supply quickly escalates, as both geographic scale and duration of the interruption is increased, from an inconvenience (with costly impacts) to an impact on the continued functioning of society.

A total system blackout, regardless of its duration, would cause long-term and potentially permanent damage to society. At the very least it would cause loss of national and global reputation. Such a loss of reputation would impact on location and investment decisions of business and commerce, and the health and wellbeing of the economy. It is internationally recognised that the development of a transmission network takes time and that a resolution to current inadequacies could be expected to take a generation to resolve.

[1] Best exemplified in Section 4 of the European Network of Transmission System Operator's technical criteria: ENTSO-E Cost Benefit Analysis methodology

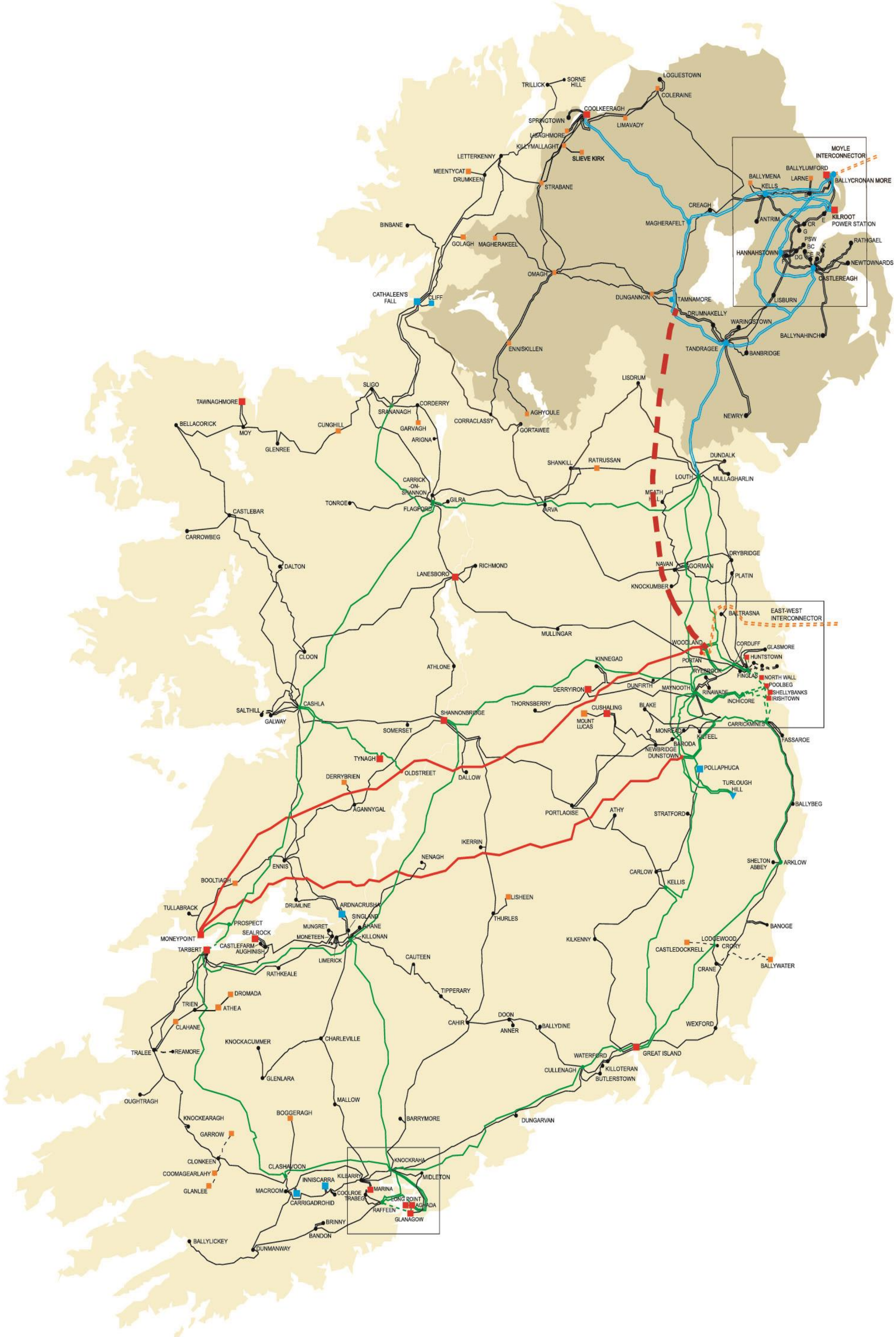

Figure 1: Map Showing Transmission Network and Proposed Interconnector

(The proposed interconnector is indicated in dashed red)

400 kV	220 kV
275 kV	110 kV
DC Interconnector	

Currently there is only one high-capacity tie line connecting the two transmission systems. This is the Louth-Tandragee double circuit 275 kV overhead line with a combined nominal capacity of 1,500 MVA, see Figure 1. Under this arrangement there is a risk that a single event – such as a lightning strike, accidental or deliberate damage to a tower structure, a fire at one of the termination points, or a mal-operation of the complex power system protection schemes - could cause a trip of the existing double circuit 275 kV tie line. In such a scenario, interconnection between the transmission systems of Ireland and Northern Ireland would be lost entirely. In this situation, the transmission systems in Ireland and Northern Ireland would revert to operating independently of each other – this is known as system separation. This could result in loss of load in either or both systems as power transfer and mutual support cannot occur. System separation, depending on the pre-separation interconnector flows, will result in a generation surplus in one system and a deficit in the other. The system with the deficit may be required to disconnect demand customers; the system with the surplus may have difficulty stabilising the system frequency. If such an imbalance is not corrected quickly enough the system could collapse.

Both systems must be capable of dealing with this eventuality and this imposes a limit on the power transfer which the systems can cater for with the existing tie line; in short it imposes a restriction on the usage of the existing tie line. The consequence is that the existing tie line cannot currently be utilised to the full extent of its capacity. In the context of the single 'all-island' transmission network this situation cannot be allowed to continue as it means that the 'all-island' transmission network is not in compliance with the Transmission System Security and Planning Standards. As stated previously these standards are founded on the underlying principle that the loss of a single item of plant or equipment shall not result in a failure to meet the specified quality of supply standards. This is commonly referred to as the 'N – 1' ('N minus 1') criterion where 'N' is the system normal condition and 'minus-1' is the loss of a single item of plant.

To bring the 'all-island' network into compliance with the planning standards it is proposed that a second tie line of similar power carrying capacity to the existing tie line be connected between appropriately robust points on the transmission systems north and south of the .border. It should be of similar power carrying capacity (that is 1,500 MVA) in order to provide the longevity, flexibility, efficiency and economic performance required of a transmission network development. Specifically a capacity of about 1,500 MVA is required for the following reasons –

- The proposed tie lie will form a link between the 400 kV network in Ireland and the double circuit 275 kV network in Northern Ireland. The nominal capacity of the circuits that form these 400 kV and 275 kV networks is 1,500 MVA (275 kV is built with double circuit lines which add to 1500 MVA). Therefore developing a circuit between these existing systems of similar capacity will allow power to flow between each system up to the rated capacity of each system without the need for further reinforcement.

This is in line with the statutory and licence requirements that require that transmission reinforcements should be developed in an efficient and economic manner with due care for the environment. If the proposed tie line was to be built with a lower nominal capacity then it would need to be rebuilt to a higher capacity at a later date, or a third tie line would have to be built, in order to leverage the two jurisdictional high-capacity networks.

- Similarly the nominal capacity of the existing tie line is 1,500 MVA. The proposed development will form a second north-south interconnector and operate in parallel with this existing tie line. A nominal capacity of 1,500 MVA will therefore match that of the existing tie line and provide full 'N-1' security for cross border power flows.
- Studies based on conservative assumptions also show that cross-border power-flows of at least 1,100 MVA would occur on occasion if the capacity limitations currently imposed on the existing tie line were to be withdrawn. In line with best international practice[2] it is prudent to design a new transmission circuit with a margin for future growth and/or an allowance for unforeseen operational conditions or events. In this case that means designing for a capacity of about 1,500 MVA (1,100 MVA plus a margin).

The proposed development is referred to as an 'interconnector' because it will connect between two transmission systems that are subject to different regulatory regimes .and in different jurisdictions. However it will, to all intents and purposes, be a reinforcement of the single 'all-island' transmission network. It will be an embedded circuit in the 'all-island' network and will operate like any other transmission circuit in the meshed network. Its development will eliminate concerns about the sudden and unexpected forced outage of the existing tie line as; in that event, it will provide an adequate alternative path for power flows between Ireland and Northern Ireland. It will effectively remove the existing constraints on such power flows and will provide the following benefits:

- Improve the efficiency of the all-island single electricity market;
- Improve security of supply by providing a reliable high-capacity link between the two parts of the all-island transmission system;
- Support the development of renewable power generation by enhancing the flexible exchange of power flows over a large area of the island; and
- Reinforce the network in the north–east area of Ireland.

In 2007 the project was first brought to the public's attention by means of a structured public consultation. It was immediately apparent that many of those who participated did not favour an overhead line solution and wanted the new transmission circuit to be placed underground.

[2] Based on similar interconnector projects in Europe as set out in the ENTSOE Ten Year Network Development Plan.

Feedback indicated that stakeholders wanted a project-specific and site-specific study of an underground cable option to be carried out in order to ensure a fair and transparent comparison with the overhead line option.

In response to this and in accordance with its requirement to consider alternative solutions EirGrid commissioned and published a number of studies over a period of some six years as follows:

- **The PB Power Preliminary Briefing Note** (Parsons Brinckerhoff, Power Division [PB Power], 2008). A short report, published at an early stage in the project development process, drawing upon generic information to summarise in general terms the technical and cost issues associated with implementing the proposed transmission circuit.

- **The PB Power Study** (PB Power, 2009). A .detailed study by PB Power following the publication of the Preliminary Briefing Note. The study was specific to the proposed project, it identified a route corridor for the UGC options and compared a high voltage OHL transmission option with UGC options utilising either HVAC or HVDC technologies.

- **The TEPCO Study** (TEPCO, 2009). A system-wide study that considered the implications, for transmission system reliability and stability, of incorporating very long lengths, and large quantities, of High Voltage (HV) UGC transmission infrastructure on the all-island AC transmission network. The study was performed by Tokyo Electric Power Company of Japan (TEPCO) who, as owner and operator of the world's longest existing UGC circuit operating at a voltage of 400 kV or above, is uniquely placed to bring its specific experience to bear on the subject.

- **The TransGrid Study** (TransGrid, 2009). A system wide study that considered the implications for transmission system reliability and stability of incorporating HVDC circuits into the integrated all-island AC transmission network. This study was performed by TransGrid Solutions of Winnipeg, Canada, a consultancy with extensive international experience in the evaluation of HVDC technology. The study included an examination of the viability of using this technology for a second north-south interconnector.

- **The PB Power Technology and Costs Update** (PB Power, April 2013 and Supplementary Note July 2013). A report summarising the results of a further study carried out to update the information provided in the *PB Power Study* of 2009. This report includes a review of up-to-date technology and application developments worldwide. It also draws upon information and conclusions published within a number of recent relevant studies (including the Government-commissioned IEC Report of 2012) into the subject of transmission technology options. A key output from the updated study has been to provide up-to-date comparative costs for the identified options.

During this same period the Government of Ireland commissioned and published two independent technical reports:

- **The Ecofys Study** (Department of Communications, Energy and Natural Resources (DCENR) 2008). A *Study on the Comparative Merits of Overhead Electricity Transmission Lines Versus Underground Cables*, carried out by Ecofys on behalf of the Department of Communications, Energy and Natural Resources.

- **The International Expert Commission (IEC) Report** (2012). A review of the case for, and cost of, undergrounding all or part of the Meath–Tyrone 400 kV line (subsequently known as the North-South 400 kV Interconnection Development).

Other reports of interest at this time were:

- **Denmark's Strategy for the Development of its 400 kV Network**[3] – (*Technical Report on the Future Expansion and Undergrounding of the Electricity Transmission Grid –: Summary – April 2008* and the *Cable Action Plan: 132-150 kV Grids – March 2009)*. The first report considers the long-term strategy for the development of the electricity transmission network in Denmark. Six 'Expansion Principles' were considered. These ranged from 'Expansion Principle A - complete undergrounding' to 'Expansion Principle F - no further expansion of the grid'. Subsequently the mid-range strategy known as 'Expansion Principle C' was adopted. The second report, the *Cable Action Plan* outlines how and over what period this strategy will be implemented. Note: The Danish strategy and its implementation[4] are discussed later in Section 5.4.

- **Askon Report**[5] (*Study on the Comparative Merits of Overhead Lines and Underground Cables as 400 kV Transmission Lines for the North-South Interconnector Project* (2008) commissioned by North East Pylon Pressure (NEPP)).

- **Cigré**[6] **Technical Brochure 379 - *Update of Service Experience of HV Underground and Submarine Cable Systems,*** *ISBN 978 -2-85873-066-7* (April 2009). The study collected and analysed data relating to the installed quantities of underground and submarine cable systems rated at 60 kV and above together with the service experience and the performance of existing underground and submarine cable systems.

[3] Available at www.Energinet.dk.
[4] In November 2016 the Danish Ministry of Energy, Utilities and Climate announced that all future 400 kV circuits would be realised using overhead lines.
[5] This report is not publically available but can be obtained from NEPP, refer to www.nepp.ie for further information.
[6] The technical brochure is available from Cigré. Cigré is an acronym in the French language for 'The International Council on Large Electric Systems'.

- **UK Electricity Transmission Costing Study (2012**)[7]. This study was performed on behalf of the UK Department of Climate Change (DECC) with the purpose of informing the Infrastructure Planning Commission in regard to the costs of feasible transmission options.

In 2013 EirGrid consulted the public on two other 400 kV projects, namely the Grid West project and the Grid Link project. During the course of this consultation stakeholders questioned how EirGrid could carry out a fair and transparent comparative analysis of the technology options for those two projects. As a result, in January 2014 Ireland's Minister for Communications, Energy and Natural Resources appointed an Independent Expert Panel (IEP) to:

"decide terms of reference for comprehensive, route-specific studies of fully undergrounded options for both Grid Link and Grid West. The panel will be required to ensure that the studies are complete, objective, and comparable to similar studies of overhead options for the two projects, and will report to the Minister in that regard"[8].

In addition, the IEP was tasked with providing an opinion to the minister on -

"the compatibility of the methodologies to be employed on the GW and GL projects with what has already been done (i.e. up to 2 May 2014, being the date the Panel decided to examine the N/S project) on the North South Transmission Line project"[9].

In May/June 2014 EirGrid prepared and submitted reports[10] to the IEP, at its request, describing the extent of, and the methodology applied to, the comparative analysis of the UGC and OHL options for the North South Interconnector project. In July 2014 the IEP .announced that, in its opinion, the work completed to date on the North-South 400 kV Interconnection Development is compatible with the terms of reference to be employed on the Grid West and Grid Link projects:

"Having considered and discussed all of the material, the Panel is unanimously of the opinion that, in all material respects, what has already been done on the N/S project is compatible with the methodologies now being employed on the GW and GL projects. While the Panel acknowledges that no two grid infrastructure projects are identical, and that some non-comparabilities are likely to arise when assessing the potential environmental impacts, technical efficacy and cost factors, the Panel is of the opinion that no material differences in the methodologies arise.[11]*"*

In June 2015 EirGrid submitted to An Bord Pleanála an application for planning approval for the part of the proposed development located in Ireland. SONI had previously submitted an application for

[7] Available at http://www.theiet.org/factfiles/transmission-report.cfm.
[8] http://www.dccae.gov.ie/news-and-media/en-ie/Pages/PressRelease/Minister-Rabbitte-responds-to-Grid-Link-public-consultation.aspx.
[9] http://www.dccae.gov.ie/news-and-media/en-ie/Pages/PressRelease/Statement-by-the-Independent-Expert-Panel.aspx.
[10] Report to the Independent Expert Panel Date: 29/05/2014 & Addendum Date: 19/06/2014 available at http://www.eirgridnorthsouthinterconnector.ie/media/Appendix%203%20Report%20to%20the%20Independent%20Expert%20Panel%2029-5-2014%20Add%2019-6-2014.pdf.
[11] http://www.dccae.gov.ie/news-and-media/en-ie/Pages/PressRelease/Statement-by-the-Independent-Expert-Panel.aspx

approval of the part of the proposed development located in Northern Ireland to the competent authorities in that jurisdiction. The overall proposed development consists of an approximately 137 km long 400 kV single circuit overhead line, It will connect the 400 kV substation at Woodland in County Meath to a proposed new 400kV/275kV substation at Turleenan in County Tyrone, where connection will be made to an existing 275 kV double circuit overhead line, see **Figure 1**.

EirGrid included an Environmental Impact Statement (EIS) as part of its application to An Bord Pleanála. The Environmental Impact Assessment Directive requires that an EIS shall contain "[*a]n outline of the main alternatives studied by the developer and an indication of the main reasons for his or her choice, taking into account the effects on the environment*". EirGrid's outline of its consideration of alternatives can be found in Chapter 4 of Volume 3B of the EIS. This includes a consideration of alternative transmission technologies in particular overhead line transmission versus underground cable transmission.

In December 2016 the Inspector appointed by An Bord Pleanála to consider and make recommendations on the application for planning approval having considered the EIS and the many submissions, both written and verbal, received from third party stakeholders concluded on the matter of alternative transmission technologies at page 180 of her report as follows:

> *"I accept that different projects require different solutions. EirGrid accepts that the DC option is feasible, but rejects it on the grounds of technical and cost considerations. Having regard to the significant technological advances made and which continue to be made in technology, the Board may wish to seek specific expert opinion on the current feasibility of integrating a HVDC system into the existing AC meshed network. However, having taken into considerations all of the arguments made, the strategic importance of the proposed interconnector as part of the all-island transmission network, the lack of existing strong interconnection between Ireland and Northern Ireland and the overwhelming need for reliability and security of supply, on balance it would appear that the technology currently best suited to satisfy the requirements of the proposed North-South Interconnector development is an overhead high voltage alternating current power line*."

The Inspector then went on to recommend to the board members of An Bord Pleanála that approval be granted for the proposed North-South 400kV Interconnection Development. The Board unanimously accepted that recommendation and granted planning approval on 21 December 2016.

Subsequently a group opposed to the proposed development appealed to the High Court to overturn that decision. One of their stated grounds was that a proper consideration of the technical alternatives had not been undertaken. On 22 August 2017 in his decision to refuse the application the judge stated in regard to the consideration of the alternatives that -

"[I]t is difficult in the confines of a judgement to do justice to the exhaustive consideration of alternatives that has been undertaken by EirGrid, as assessed thereafter by the inspector. Suffice it for the court to note that in its consideration of alternatives, EirGrid has clearly gone above what the EIA Directive requires".

NOTE: This document hereafter replicates the case made by EirGrid to An Bord Pleanála in the 2015 EIS and at the oral hearing in 2016 for its choice of 400 kV AC overhead line as the preferred technology for implementing a second high-capacity North South electricity interconnector. No new opinion or information is presented here that was not presented to An Bord Pleanála other than information in response to new arguments that have been put forward since publication of the inspector's report or where new information of relevance has come to light.

Where such new information is presented later in this document it is done so in this format (in a text box) so that it is clearly distinguishable from what went before.

3 EIRGRID'S METHODOLOGY FOR COMPARING THE TECHNOLOGY OPTIONS

In assessing technological options for the design and construction of the proposed interconnection infrastructure, it is necessary to acknowledge the need for a technical solution that ensures a transmission system that, although connecting two separately-owned systems within two separate jurisdictions, will be operated as an integrated transmission system and which will service a single integrated market in which operational constraints are minimised.

It is also a requirement of this development that the new interconnector connects between appropriately robust points on the transmission networks north and south of the border and that it be physically remote from the existing north-south interconnector.

The technological options were therefore considered against a number of key performance objectives which must be achieved regardless of the particular option that is actually employed. The objectives and / or design criteria identified for the proposed development are:-

a) Comply with all relevant safety standards;

b) Comply with all system reliability and security standards;

c) Provide an environmentally acceptable and cost-effective solution;

d) Have a power carrying capacity in the region of 1,500MVA, and connect between appropriately robust points on the transmission networks north and south of the border;

e) Facilitate future reinforcement of the local transmission network in the north-east area;

f) Facilitate future grid connections and reinforcements; and

g) Comply with 'Good Utility Practice'[12] or 'best international practice'.

Criteria 'a', 'b' and 'c' derive from EirGrid's statutory and regulatory obligations. Criteria 'd' and 'e' are specific objectives identified for this development. The reason for the 1,500 MVA capacity is explained in Section 2 above. Criteria 'f' and 'g' are general objectives that are applicable to all reinforcements and extensions to the transmission network.

[12]In the context of this report the terms 'Good Utility Practice' and 'best international practice' are interchangeable. The term 'Good Utility Practice' is widely recognised and adopted as a policy, either voluntarily or by regulation, within the industry. The principle behind good utility practice is that electric utilities will adopt the practices and methods of a significant portion of utilities within a specified geographic boundary. In the case of EirGrid the relevant utilities are the 41 members of ENTSO-E (European Network of Transmission System Operators for Electricity) that are drawn from 34 countries in Western Europe.

It should also be noted that compliance with good utility practice does not preclude the use of innovative practices, methods or technologies; however, when such innovative practices, methods or technologies are under consideration, the accompanying risk of failure and consequence of such failure must also be considered.

As stated previously, the Government-appointed Independent Expert Panel reviewed this methodology and concluded that its application by EirGrid in the case of this project was compatible "*in all material respects*" with the methodology that it had specified for the comparative analysis of underground cable and overhead line options for other transmission projects.

4 HIGH-VOLTAGE DIRECT CURRENT (HVDC) AS AN ALTERNATIVE TO HIGH-VOLTAGE ALTERNATING CURRENT (HVAC)

There are several technological options by which a transmission circuit of the capacity required for the proposed development could, in theory, be implemented. Some of these options utilise AC technology while others utilise DC technology.

Until relatively recently, DC technology was only used for high-capacity electricity transmission in circumstances where it was the only technically feasible or cost-effective option. However, during consultations associated with transmission projects (including this proposed development) stakeholders have suggested that DC technology should be used not because of any technical, operational or cost advantage that might accrue, but rather because it is seen as a way of facilitating the undergrounding of the proposed development.

The first step in the in-depth consideration of the technological options that are potentially feasible for this development is to carry out a general evaluation of HVDC technology, as an alternative to the standard HVAC technology, regardless of whether the scheme is to be implemented using OHL, UGC or a combination of both.

The existing electricity transmission system in Ireland is, as in every other country in the world, a HVAC (or AC) system. Any new transmission project that utilises HVAC would therefore be an extension of the existing technology.

HVDC is an alternative method of transmitting electricity. HVDC technology is mostly used to transmit bulk power from one point to another over long distances where HVAC is not technically and / or environmentally acceptable (e.g. a long (> 50 km) high-capacity submarine cable).

HVDC can also be the most cost effective option for very long transmission circuits. **Figure 2** illustrates graphically how the cost differential of HVDC UGC, HVDC OHL, HVAC UGC and HVAC OHL varies with circuit length. The HVDC options start at a cost disadvantage to any HVAC option due to the relatively high cost of the converter stations at the terminals. However as the circuit length increases, the difference in cost declines until eventually a break-even point is reached and thereafter the HVDC option becomes the most cost-effective. For example in the graph below the cost break-even point for the HVDC OHL (dashed green) option versus the HVAC OHL (solid blue) option occurs when the circuit length is in the region of 600-800km; whereas in the case of the HVDC UGC (dashed purple) option the break-even point with HVAC UGC (solid red) is in the region of 80–120 km. On the graph the curve representing the HVDC UGC (dashed purple) option and the curve representing the HVAC OHL (solid blue) option do not intersect within the 0 to 1,000 km, range thus indicating that under these circumstances a HVDC UGC would never be more cost-effective than a HVAC OHL option. In addition the graph would suggest that the breakeven or crossover point between these options would occur at some circuit length far in excess of 1,000 km, a distance that is of no relevance for a country the size of Ireland.

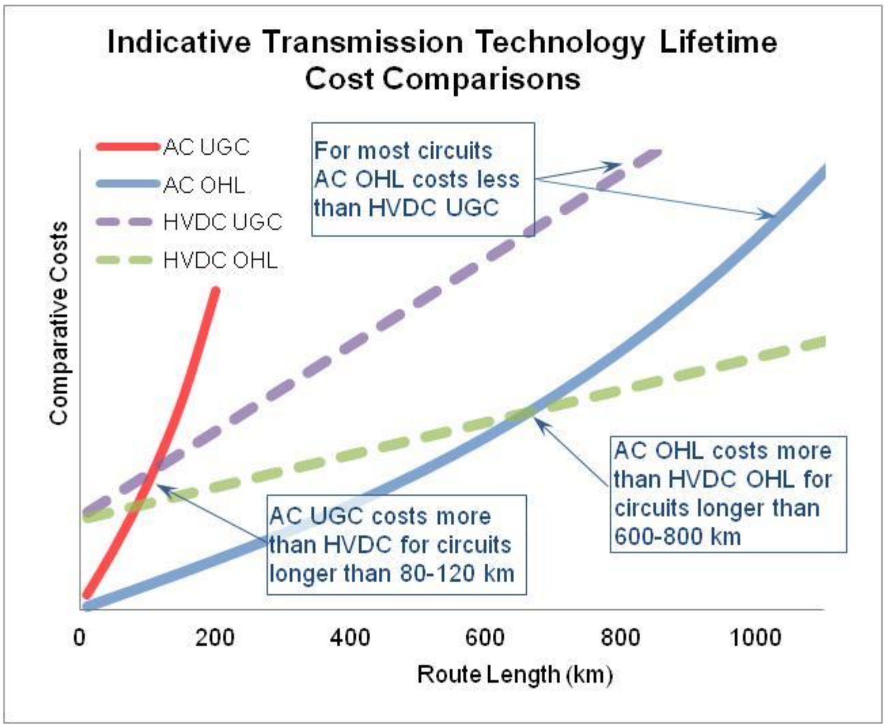

Figure .2: Comparison of HV Transmission Options – Cost versus Circuit Length

(Source: Parsons Brinckerhoff, incl. *Electricity Transmission Costing Study* 2012)

HVDC is also used for linking independently operated (asynchronous) HVAC systems (e.g. an interconnector such as EirGrid's East West Interconnector) where it is impossible or undesirable to link such systems using a standard HVAC circuit.

Inserting a HVDC circuit between any two points in a HVAC network would require the HVAC electricity to be converted into HVDC electricity at one end, transmitted through cable or OHL to the other end, where it would be converted back from DC to AC, and then transmitted back into the HVAC network. This is inefficient (unless the HVDC circuit is very long) and costly (in terms of the requirement for converter stations) but it is technically feasible.

There are two main HVDC converter station technologies – Current Source Converters (CSC) also known as Line Commutated Converters (LCC) and the emerging Voltage Source Converters (VSC). Both can be applied in combination with OHL and UGC.

VSC DC is considered a more flexible technology than LCC DC as it can be less difficult to integrate into an AC grid. This VSC DC technology continues to develop with converter stations becoming more efficient, reliable and compact; these advances were specifically referred to in the findings of the IEC Report.

4.1 COMPARATIVE ASSESSMENT OF HVDC AND HVAC FOR THIS PROJECT (2012/2015)

Following the publication of the *IEC Report* in 2012 EirGrid reviewed its own comparative assessment of a UGC VSC HVDC circuit[13] versus a standard high voltage OHL AC circuit for the implementation of the proposed development against the previously identified project objectives / design criteria. The findings were described in the 2015 EIS as follows:-

a) Comply with all relevant safety standards;

Both options are equally compliant. In the case of this criterion EirGrid does not see any difference in the two technology options.

b) Comply with all system reliability and security standards;

The proposed development as part of the 400 kV network will form a necessary extension of the backbone of the 'all-island' transmission network, and is required in order to enable the two networks, north and south, to operate as if they were one network. It will be an integral part of the 'all-island' meshed network, and as such the power flow (quantity and direction) in the circuit is required to react instantaneously to dynamic system changes. These occur due to rises and falls in system demand and sudden and unplanned changes in system configuration due to unplanned outages of other circuits or generators. If the proposed interconnector is a standard AC circuit then the power flow will react naturally and instantaneously, without any input from a control system or human operator, to such dynamic changes to the system. The power flow on a HVDC circuit on the other hand will not react naturally to such changes. The DC circuit will only react if prompted to do so by a controller. However, a human operator would not be able to react quickly enough, so the control would have to be by means of a computerised control system.

[13] The IEC disregarded DC OHL in its report (page 18) on the basis that the cost of a DC OHL option would be similar to a DC UGC option if the cables were to be installed under optimum conditions (as described in point c below). While this is debatable it can be said that from a technical and operational perspective there is no difference between DC OHL and DC UGC other than the fact that the time required to repair a fault on a DC UGC would be considerably longer (many weeks longer) than that required to repair a fault on a DC OHL.

The control system for the HVDC option is required to react correctly within milliseconds of its detection of the sudden system change if it is to prevent instability and even blackout of the entire system. To do this, the control system must first be able to detect that an event has occurred, even though it may have occurred at some remote location, assess its impact and then respond appropriately. It has been speculated that it might be possible to programme all possible events and their impact on the HVAC system (like a simulator) into the control system, so that by only monitoring the local system conditions the control system would be able to determine what has occurred, even if the event is remote. However with so many different variables, this does not seem possible. Instead the practice is for the HVDC control system to monitor what is happening at the remote locations via a network of communications links.

Such a communication system would be extensive with communication paths required over several hundred kilometres between remote stations. Communication links to keys stations across Ireland and Northern Ireland would be required. At each remote station a local data acquisition system would be required to monitor local conditions, process the data and transmit the relevant information back to the central control system at the HVDC converter station. The HVDC control system would then need to translate the incoming information into the appropriate response and control all the electronic components in effectively real time to respond. This would require bespoke control system software and algorithms. In order to do this the control system in one HVDC converter station must also communicate with its partner control system in the HVDC converter station at the other end of the HVDC scheme. . This would also require c.135 km of communication circuits, either incorporated into the HVDC cables directly or installed as a separate communications cable.

Every component in this communications chain and complex control system would need to work flawlessly every second of every year of the expected 50 year life of the project to avoid the risk of a system wide blackout. This flawless operation would need to continue through on-going weather conditions, maintenance, third party intervention, accidental and malicious damage or any other condition that may impact on this system and its operation. The software for the controller would also need to be programmed for every conceivable material situation, correctly interpreting these situations through 50 years of development and change in the transmission system and/or be updated with new equally flawless software during this time period.

Given the scale and importance of the North South interconnector to the all-island transmission network, a mal-operation of the control system can even have serious implications when the transmission system is in normal operation. If the mal-operation was to cause a sudden step change in power flow through the HVDC circuit or a sudden reversal in direction of that power flow this is also capable of initiating a network blackout. This level of risk is unusual by international standards. Typically the power carrying capacity of HVDC circuits are much smaller proportionally to total system demand than would be the case for the North South Interconnector, and therefore the mal-operation of those HVDC schemes presents a proportionally smaller risk to security of supply. This is expanded on further under criterion (g).

As stated previously the overarching principle in the design of the transmission network is that no single item of plant of equipment should present a risk to security of supply. The complex control system and communications system required for the HVDC option would present a continuous risk to security of supply of the greatest consequence throughout its lifetime. This is, in and of itself, sufficient reason to conclude that while the HVDC solution may be feasible to build it is not acceptable. The available published international experience of the performance of HVDC control and protection schemes supports this conclusion.

While there is little published information available on the performance of control systems associated with VSC HVDC technology, there is information available from China on the performance of similar control and protection schemes for CSC (or LCC) HVDC schemes. Unsurprisingly this shows that control failures do occur. For example, one study of the performance of all HVDC schemes in China over the period 2006 to 2012 shows a failure rate of around one per annum and of these failures half were due to a mal-operation of that scheme's control and protection system.

References:

1. A survey of the reliability of HVDC system throughout the world during 2011-12', B4-117. Cigré 2014;
2. 'The operation statistics and analysis of HVDC transmission systems in state grid corporation of China 2006-2012', B4-106, Cigré 2014;
3. 'The reliability of HVDC projects in SGCC and the operation experience', B4-109, Cigré 2012

In conclusion the control system required for the HVDC option would be bespoke and very complex, and would therefore introduce the very real risk of mal-operation. Analysis of the risk of mal-operation of the computerised system controlling the operation of a HVDC north-south interconnector has shown that this could (due to its relatively high-capacity and strategic location within the network) result in the collapse of the entire 'all-island' electricity system. Taking such a risk is unnecessary when there is a technically superior (for this type of application) and less risky option readily available.

In addition to the above it is worth noting that the durations of fault repairs and maintenance of a HVDC scheme are much greater than those of a standard HVAC overhead line. It can therefore be expected that a HVAC OHL will have a much better level of availability than an equivalent HVDC scheme. This is supported by system statistics.

In April 2009 Cigré[14] published the results of the most comprehensive study of UGC reliability carried out to date. This study was based on the results of a survey of 73 utilities from around the world. Of interest is the information received on the performance of 1,388km of XLPE cable with a voltage rating in the range 220 kV to 500 kV. While these statistics were derived from the experience with AC cables, given the similarity in installation methods and depth of burial of AC and DC cables their susceptibility to third party damage is considered to be similar. In addition, as HVDC places a much greater level of stress on the XLPE insulation than is the case with a comparable HVAC cable, it is reasonable to conclude that HVDC XLPE cables have a greater rate of failure of the insulation than comparable HVAC cables. The foregoing would therefore suggest that if the failure rate for HVAC XLPE cables as determined by the Cigré study is applied to HVDC XLPE land cables it would give an optimistic result.

Applying the HVAC XLPE fault rates to the length of HVDC cable (2 x 135 km) that would be required for the proposed development gives a projected fault rate of about one fault every 19 months. The Cigré study also found that the average time taken to repair a fault on a 400 kV XLPE cable is 25 days if the cable is direct buried and 45 days if installed in a tunnel. A direct buried cable is however ten times more likely to be damaged due to external factors than a cable installed in a tunnel the study concluded. Similar repair times and experience can be expected for HVDC land cables.

Another factor that has an impact on the level of availability of a HVDC scheme is the reliability of the converter stations at each end of the circuit, bearing in mind that they are not required in the case of the HVAC OHL option. Internationally publically available information on the reliability of HVDC VSC converters is however sparse. PSC Consultants[15] has provided information on the performance of the Cross Sound and Murraylink schemes. This showed a 'non-availability' for service rate for these HVDC schemes of 3% and 4% per annum respectively during the period 2003 to 2009. A review of the stated reasons for each outage shows that they were exclusively related to the converters and were either scheduled or forced outages of the converter stations. On this basis these statistics can be considered to provide converter station outage rates.

EirGrid's own statistics for the East West Interconnector shows an average non-availability rate of 5.5% (of which 4.5% forced and 1.0% planned) over its first three full years of service (October 2013 to September 2016), while last year (2016/2017) the unavailability rate was much worse at 26% due to forced outages of a converter station. Like the Cross Sound and Murraylink statistics,

[14] Cigré Technical Brochure 379 - *Update of Service Experience of HV Underground and Submarine Cable Systems, ISBN 978 - 2-85873-066-7* (April 2009).
[15] Sourced at: http://www.eirgridgroup.com/site-files/library/EirGrid/Grid-West-HVDC-Technology-Review-Report-PSC.pdf

all of the outages contributing to these non-availability rates were either forced or scheduled outages of the converter stations, none were due to problems with the HVDC cables.

Combining the expected outage rates of the converter stations with the expected outage rates of the 135 km of underground cables results in a much poorer level of availability for service than that of the 400 kV AC OHL option.

There are 439 km of existing 400 kV OHLs in Ireland. This length of 400 kV OHL is too small a sample for determining meaningful performance statistics. Meaningful statistics can, however, be obtained by considering the fault statistics of the combined quantity (approximately 2,245 km) of 400 kV, 275 kV and 220 kV OHLs under EirGrid's control[16]. Taking the fault statistics of this existing 2,245 km of OHL for the period 2004 to 2012, gives a projected fault rate for the proposed (approximately 140 km long) 400 kV OHL of one permanent fault (that is a fault that requires repairs before the OHL can be returned to service) every 20 years. The statistics also show that the average duration that a 400 kV / 275 kV / 220 kV OHL circuit will be out of service for repair after a fault is less than two days. This is summarised in **Table 1**.

Table 1: Summary of Comparative OHL and UGC Statistics

UGC and OHL	Projected Fault Rate for N-S Interconnector	Average Time to Repair
HVDC UGC – directly buried cable (statistics based on 1,388 km of XLPE cable with a voltage rating in the range 220 kV to 500 kV) **Source:** Cigré Technical Brochure 379	1 fault every 19 months (cable only)	25 to 40 days
OHL (statistics based on 2,245km of 220 kV, 275 kV and 400 kV OHL in Ireland) **Source:** EirGrid (2004 – 2012)	1 fault (permanent fault requiring repairs) every 20 years	Less than 2 days

The comparative analysis therefore indicates that the HVAC OHL option would have a far better level of availability for service than the HVDC option. This comparative performance must always be a factor when a TSO is considering transmission options particularly when the circuit in question is to be a backbone circuit of the transmission network and therefore of the highest strategic importance.

[16] This is reasonable compromise because the existing 220 kV and 275 kV OHLs are of similar design and experience similar operating conditions to that of the existing 400 kV OHLs.

From the above EirGrid has determined that under the heading of 'comply with all system reliability and security standards', a standard HVAC circuit is preferable to a HVDC circuit for the specific characteristics of the proposed development.

c) Provide an environmentally acceptable and cost effective solution;

Both the DC UGC option and the AC OHL option can be installed in such a way as to be environmentally acceptable. It is the cost difference therefore which will be the deciding factor in the case of this criterion.

The IEC estimated that the standard AC OHL circuit would cost €167 million whereas the DC UGC alternative would cost €500 million. That is a difference of €333 million. The PB Power Technology and Costs Update Report (July 2013),[17] on the other hand, found that the standard AC OHL circuit would cost €140 million whereas the DC UGC alternative would cost €810 million (see Table 3-2, page 3 of the Supplementary Note). That is a difference of €670 million.

This significant variation between the cost estimates in the IEC Report and the PB Power Update Report for the DC option can be explained as follows. Both reports agree that the converter stations will cost approximately €300 million (that is €150 million each). The cost difference arises in the difference in cost per km for the DC UGC connecting between the two converter stations.

The IEC assumes optimum conditions are available for the installation of the DC cables. By 'optimum conditions' they mean that the cables will be installed in the wide soft margin of a major road for almost the entire length and that the cables will be installed side by side in a single 3 metre wide trench (**Figures `2** and **3** are extracted from the IEC Report and were included in that report for the purpose of illustrating the assumptions that formed the basis for the UGC cost estimate). This results in a cost per km of €1.36 million for 140km[18] giving a total cable cost of €190 million.

[17] The *Supplementary Note* of July 2013 to the *PB Power Technology and Costs Update Report* of April 2013 revise the comparative cost estimates by excluding any provision for the intermediate substation near Kingscourt (refer to summary details of report in Table A in the appendix). This results in the PB estimates being directly comparable with those of the IEC as the IEC also excluded any provision for the intermediate substation.
[18] The IEC assumed that the route for UGC would be 140km in length whereas PB Power identified a route for UGC and measured it at 135km in length.

Figure 3: Wide Soft Margin of a Major Road

(Source: IEC Report p. 46)

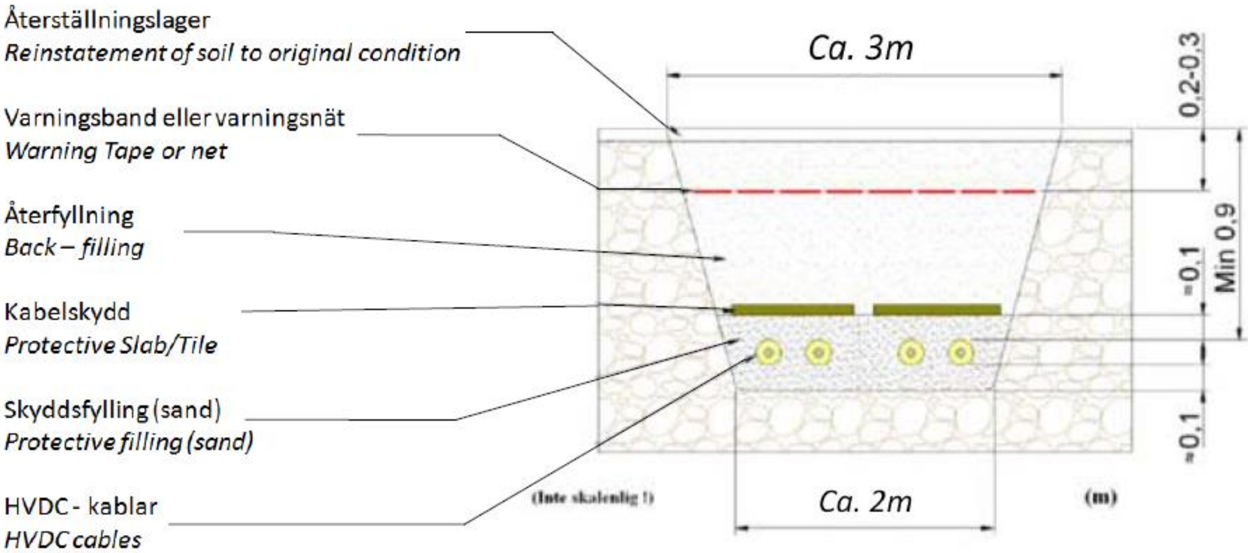

Figure 4: Section through cable trench for two parallel HVDC circuits

(Source: IEC Report (p. 46) with translation to English by EirGrid)

The PB Power estimate is based on the assumption that the DC cables will be installed along a route across country through farmland in the corridor identified in the PB Power Report of 2009. This results in a cost per km of €3.76 million for 135km giving a total cable cost of €508 million.

In EirGrid's view, the IEC estimate is understated. A long major road, with a wide soft margin, linking Batterstown in County Meath to Turleenan in County Tyrone does not exist. Instead the roads in the five counties to be traversed are generally narrow and winding. The IEC recognises that installing cables under such roads would result in a higher cost per km than the €1.36 million previously indicated. It is also the case that due to the winding nature of the roads that any route that follows the public roads will be longer than a more direct cross country route.

In its consideration of the DC option EirGrid accepted the costing approach adopted by PB Power for the following reasons:

- It will allow the two pairs of DC cables that would be required for such a scheme to be installed in two separate trenches that are sufficiently far apart (> 5 metres) that it reduces the likelihood, to a level that can be considered to be negligible, of a single event causing damage to both sets of cables at the same time. This will result in a significantly better level of service availability and as a result improved security of supply.

- It will result in a shorter more direct route.

- It will avoid extensive road closures and the considerable disruption to local communities that that entails.

Installing cables along a cross country route would likely however result in a greater environmental impact than that of any option that involves their installation under or adjacent to public roads.

However no matter which approach is assumed for routing the DC UGC, across country or under public roads, the implementation costs of the proposed AC OHL are significantly less than that of the DC technology options.

Life cycle costs should also be considered in any comprehensive economic assessment of the technology options. These would include the cost of electrical losses, operation and maintenance costs, including the cost of retaining any necessary specialist repair teams and strategic spares and ultimately the cost of decommissioning.

The PB Power Report (April 2013) considered these costs and found as follows –

Table 2: Summary of Comparison of Life Cycle Costs

Option	Life Cycle Cost Present Value (€M)	Difference (€M)
HVAC OHL	55	Base case
HVAC UGC	90	35
HVDC UGC	110	55

Source: Table on p36 of PB Power Report (2013)

From this it can be seen that life cycle cost of the HVDC option further increases the present value cost over that of the proposed HVAC OHL.

It should be noted that specialist repair teams are not required in the case of the OHL option as this is standard technology in widespread use in Ireland. Specialist repair teams are required to repair HVAC and HVDC underground cables of the type required here however the practice in such cases is to rely on the manufacturer of the cable to provide the repair team. This is a factor in the length of the average time it takes to repair such cables. Provision is made for these costs in O&M portion of the cost estimate.

Specialist repair teams are required to repair HVDC converter stations and again it would be the practice in such cases to rely on the manufacturer of the converter station equipment to provide the repair team. Provision is made for these costs in O&M portion of the cost estimate.

In the case of the DC UGC option it is noted in Section 3.4.4 of PB Power 2013 that provision has not been made for the cost of holding strategic spares. This cost would be considerable but its estimation was considered to be beyond the scope of the study.

The IEC also considered life cycle costs and in Chapter 8 noted that at full load (1,500 MW) the losses on the proposed overhead line would exceed those on the HVDC option while at low loads (below 500 MW) the reverse would be the case. The average life cycle load on the overhead line will however be well below its full capacity. This is because in order to comply with the 'N-1' criterion the typical daily peak load must be less than 750 MW and the average operating load will then be significantly lower than this. PB Power assumed an average operating load of 500 MW for its calculations of the cost of losses which is a conservative assumption (meaning it is on the high side).

The IEC went on to conclude in regard to life cycle costs that they are difficult to estimate and are in any case “rather irrelevant”. They did not therefore include any provision for these in their comparative economic assessment. EirGrid does not agree with this and indeed it is not the practice among European TSOs to ignore life cycle costs when comparing options for transmission developments.

d) Have a power carrying capacity in the region of 1,500MW, and connect between appropriately robust points on the transmission networks north and south of the border;

Both technology options are equal under this criterion.

e) Facilitate reinforcement of the local transmission network in the north-east area

Both technology options are equal under this criterion as the presence of the interconnector will provide reinforcement to the area by increasing interconnection between Ireland and Northern Ireland. The ability to tap into the new circuit along the route is dealt with separately under item (f) below.

f) Facilitate future grid connections and reinforcements

All circuits forming a meshed transmission network have the potential to be ‘tapped’ into at an intermediate point to provide a new grid connection or reinforcement sometime in the future. It is envisaged that the circuit that forms the proposed development will require an intermediate substation in the vicinity of Kingscourt at some future point in time (although not now expected to be required for at least a decade), and others (where and when they will be required cannot be predicted at this juncture) are probable. The facilitation of future grid connections and reinforcements is therefore an important consideration of the technology choice.

As stated previously, a DC circuit does not naturally integrate within an AC network and a consequence of this is that a DC circuit embedded in an AC network would not facilitate future grid connections and reinforcements. If the north-south interconnector were to be developed using HVDC technology, then the cost of the planned ‘tap in’ to the circuit near Kingscourt, based on the estimates of the IEC, would be in of the region of €150 million more than the cost of tapping into an equivalent AC circuit. This is due to the requirement for new converter station(s). It would in all likelihood make uneconomic the plan to further reinforce the north-east area by developing a new substation near Kingscourt. Consequently that reinforcement would have to be achieved by some other means, such as the building of new AC transmission lines into the area.

In addition to the excessive cost of tapping into a DC circuit, the only practical way of tapping into such a circuit would result in the creation of a ‘multi-terminal’ DC circuit (i.e. a DC circuit with more than two terminals). A multi-terminal DC circuit would require an even more complex control system than a two terminal circuit, thus increasing what is already considered to be an unacceptable risk of mal-operation.

The poor facilitation of future grid connections and reinforcements presented by the DC option makes the use of HVDC technology less preferred than a standard AC circuit when compared against this criterion for the implementation of the proposed development.

g) Comply with good utility practice

There are no working examples in the world[19] of a DC circuit embedded in a small and isolated AC transmission network, such as that on the island of Ireland. The examples of planned DC interconnectors in Europe that were identified in the IEC Report (that is the proposed France-Spain Interconnector and the proposed Norway–Sweden Interconnector) are not comparable with the proposed interconnector. The electricity networks in those four countries are much larger (six times larger in the case of Norway-Sweden and almost 20 times larger in the case of France-Spain) and stronger than those on the island of Ireland and they already have multiple AC interconnections with each other.

The risk of failure, and the consequence of failure, is an important factor in deciding whether the embedding of a DC circuit in an interconnected network is, or is not, good practice. There is currently only one interconnector between Ireland and Northern Ireland and these two networks are required to merge into each other and to operate as if they were one network. The proposed development, with a power carrying capacity of 1,500MW, will become the 'backbone' of this 'all-island' network.

By contrast the proposed France / Spain and Norway / Sweden DC Interconnectors are upgrades in cross border power transfer capacity between networks that are already highly interconnected[20] with each other. Also unlike the network on the island of Ireland the Norway / Sweden and France / Spain networks form part of a wider continental network and have multiple interconnections (both synchronous and non-synchronous) with other third party countries. In addition **Table 3** illustrates that the power carrying capacity of the proposed north south interconnector relative to the combined 'all-island' system demand is far greater than the comparable figure in the case of the proposed France / Spain and Norway / Sweden Interconnectors. The North South Interconnector would have the capacity to carry 23.8% of the 'all-island' peak demand whereas the comparable figures for the France / Spain and Norway / Sweden Interconnectors are 2.9% and 1.4% respectively and that this in turn results in the north south interconnector having a far greater level of strategic importance than those proposed interconnectors.

[19] There are a few working examples in the world (December 2013) of a DC circuit embedded in an AC transmission network however these networks are not representative of the small and isolated AC transmission network on the island of Ireland. The closest comparable scheme is probably the 1,400MW Kii Channel project in Japan which uses OHL and submarine cable. Although an island network, Japan represents a much larger generation and load base than Ireland.

[20] There are five existing AC transmission interconnectors between Norway / Sweden, four between France / Spain and one between Ireland / Northern Ireland.

Table 3: Comparison of Interconnected Networks and the Relative Importance of Proposed Interconnectors

Interconnected Countries	Power Carrying Capacity of Proposed Interconnectors	Combined System Peak Demand[21]	Capacity of Proposed Interconnectors as a % of Peak Demand
Ireland - Northern Ireland	2 X 750 MW	6,311 MW	23.8%
Norway – Sweden	2 X 720 MW	49,643 MW	2.9%
France – Spain	2 X 1,000 MW	145,625 MW	1.4%

The capacity of the proposed North-South Interconnector relative to the 'all-island' system peak demand together with the relatively limited level of interconnection with each other and with third party networks means that the North-South Interconnector will have a far greater level of strategic importance to Ireland

The strategic importance of the proposed new France /Spain and Norway / Sweden DC interconnectors will be far less critical to the overall system security of their combined networks than the proposed north south interconnector will be to the 'all-island' network. These proposed DC interconnectors are therefore not representative of a DC circuit embedded in a small and isolated AC transmission network, such as that on the island of Ireland.

It is on this basis that implementing the proposed development using HVDC technology would not be considered as complying with 'good utility practice' or complying with 'good international practice'.

[21] The annual instantaneous peak loads were obtained from the Entso-e website. The instantaneous peak loads for the respective pairs of networks did not occur at the same time (although they were within days of each other). The combined figures are therefore a slight over statement of the actual combined instantaneous system peak demand.

Different project objectives or drivers result in different project solutions and no two projects are the same

Internationally, the best practice methodology amongst Transmission System Operators for assessing options for transmission projects is to use multi-criteria analysis. It is useful to consider therefore why some TSOs have concluded that a HVDC solution is the most beneficial technology to apply for their particular project and why that is not the case for the North South Interconnector Project.

In recent years HVDC has become increasingly popular for broader applications in the transmission system due to the advancement of semiconductor devices. There are two AC/DC converter types used for HVDC: Current Source Converters (CSC) and Voltage Source Converters (VSC). CSC is a long established converter technology for bulk power transmission, 'point-to-point' over long distances. For applications where short distances are involved or smaller amounts of power are being transferred, CSC becomes infeasible due to the significant amount of reactive power compensation required to maintain stable converter operation.

The latest HVDC technology, 'VSC', offers further benefits when compared with CSC and this has been instrumental in the large increase in the number of HVDC projects in recent years. VSC technology can facilitate connections to weak AC systems (such as intermittent renewable energy resources), comes with ease of power flow reversal and a 'blackstart' capability.

VSC also provides the ability to independently control real and reactive power. A potential benefit of this is greater control of energy transfer, which allows greater management of energy markets and network constraints. It was primarily this ability which resulted in the developers of the ALEGrO link between Germany and Belgium selecting HVDC as their preferred solution over the standard AC option.

The modular multilevel converter, which is the topology of choice for VSCs today, requires little to no filtering thanks to the modular structure producing output power with an almost harmonic free AC waveform. This reduces both converter footprint and power lost in the conversion process from AC to DC and vice versa.

Another benefit of HVDC is that the distance over which it can transfer power efficiently is not nearly as limited as that of HVAC. HVDC OHLs and UGCs are cheaper per km to install than the equivalent HVAC OHLs and UGCs. There is however a large initial setup cost associated with the AC/DC converter stations, resulting in a cost breakeven distance when comparing HVAC and HVDC technologies. For cable projects which have distances in excess of around 80 to 120 km (dependant on environmental constraints) HVDC becomes the economical solution - for example the 180 km Murraylink UGC connecting South Australia with Victoria. For overhead lines the breakeven point increases to over 700 km, such as the 1,060 km HVDC link in China between Three Gorges hydropower plant and Shanghai.

HVDC can also be used to interconnect two asynchronous AC networks, as each AC/DC converter terminal can adapt to the voltage and frequency of the AC system it is connected to, as is the case with the East West Interconnector and the Moyle interconnector between the islands of Ireland and Great Britain. This also allows the HVDC link to act as a 'firewall' between the two AC systems, where the HVDC link blocks disturbances originating in one system from propagating to the other. An example of where this ability was an important deciding factor is the Caprivi HVDC link between Namibia and Zambia. For this project an overhead line HVDC option was chosen as the use of HVAC would pose the risk of 50 Hz resonance on the respective AC networks.

HVDC was thoroughly evaluated as a technology option for the North South Interconnector (NSI) development. It was evaluated alongside HVAC alternatives. The options considered were required to meet specific network reinforcement needs. The NSI is required to form a second high capacity tie-line between the networks of Ireland and Northern Ireland. The NSI will be embedded in an existing synchronous AC system with the aim of increasing security of supply across the 'all-island' electricity network.

The use of HVDC for the NSI is technically feasible but it is not an acceptable solution. The most significant difference from a technology perspective is that using HVDC technology would not remove the risk of system collapse for the loss of the existing 275kV interconnector. This is because of the HVDC technology's firewall capability, which means that the HVDC option, unlike the HVAC solution, will not respond inherently and automatically to increase its power flow to compensate for the loss of the 275kV interconnector. Instead it would require a bespoke and complex system to tell it what to do and such a system requires an extensive communication network in order to function properly. This poses a serious risk to security of supply in the case of the NSI as a failure of the control system to operate correctly, for example due an internal fault (hardware, software or programming error), a fault on the extensive communications network or a malicious intrusion by a hacker, has the potential to cause a system wide blackout.

The HVDC option would facilitate the use of UGC without the need for reactive power compensation, however, the cost of laying, operating and maintaining UGC circuits (whether AC or DC) is significantly more than the corresponding HVAC OHL solution.

Facilitating future grid connections on a HVDC system would require a multi-terminal HVDC (MTDC) system. An MTDC grid is where three or more HVDC terminals are connected to form a DC grid. The main technological barrier to MTDC is the lack of a commercially available DC circuit breaker, which must be able to act in a matter of milliseconds to break a DC fault current. At present there are two examples of MTDC grids in China, both of which have AC/DC converter terminals with a relatively small capacity of less than 400 MW. Thus, given the overall size of the Chinese grid, in the event of a DC-side fault the entire MTDC grid can be disconnected. This would not be feasible for the NSI, as the ability to facilitate future grid connections is lost due to the lack of available DC side protection devices.

The NSI is a land based circuit, 135km in length, and is needed as an internal reinforcement in a synchronous network. As such it neither needs, nor materially benefits from the properties and abilities of HVDC technology that have been identified above and in fact it is the very presence of some of the these that means that the HVDC option is not acceptable for this project.

There are many examples of transmission projects in the world, some of which have been discussed above, where this is not the case. For most of these the HVDC option was found to provide significant benefits while at the same time it was found that the HVAC option was not even technically feasible and therefore the choice between HVDC and HVAC was easy and obvious. Examples of such projects include EWIC, Moyle and ALEGrO.

In those few cases where there was a real technology choice to be made and HVDC was chosen it was because the properties and abilities identified above provided benefits which swung the balance in favour of the HVDC option. That does not arise in the case of the NSI project. Consequently the use of HVDC for the NSI project was assessed as not being the preferred technology option to satisfy the specific reinforcement criteria of the NSI.

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4.1.1 Summary of the multi-criteria assessment

The comparative assessment of the HVDC VSC (OHL or UGC) option and the standard AC OHL option, which included regard for the findings of the IEC report, is outlined above (i.e. points 'a' to 'g') and a summary of same is shown in **Table 4**. The overall conclusion is that the DC option is least preferred, primarily on the basis of cost effectiveness, its poor ability to facilitate future grid connections and because it would not be considered as complying with 'best international practice'.

Table 4: Overview AC versus DC - Strategic Constraints of Potential AC and DC Transmission Options

Points	Description	AC OHL	DC (UGC or OHL)
	Comply with EirGrid's Statutory and Regulatory Obligations		
a)	Safety	***	***
b)	Reliability and security	***	**
c)	Cost effectiveness	***	*
	Due regard to the environment	**	**
	Meet the Specific Needs of the Project		
d)	1500MW capacity and appropriately strong points of interconnection	***	***
e)	Reinforce the North-East transmission network	***	***
	Meet the General Objectives for All Projects of this Type		
f)	Facilitate future grid connections and reinforcements	***	*
g)	Good Technical Solution – Be 'best international practice' with proven technology	***	*

***	Preferred, limited impact, acceptable
**	Some impact, some difficulty
*	Least preferred, major impact, unacceptable

4.2 2017 UPDATE ON COST OF THE HVDC OPTION

Cost experience from recent HVDC schemes in Europe (including the ALEGrO Project) and their comparison with published cost estimates for the HVDC options identified for the North South Interconnector Project

Using the most recent cost information from VSC HVDC schemes in Europe should provide a good base for the estimate of the costs for the North – South Interconnector. However, this requires care as schemes can be very different in their topologies (monopoles, twin monopoles, bi-poles), their transmission systems (overhead line, underground cable, submarine cable), and the topography of the routes. Simple comparisons of total scheme prices or ratios of price per power rating (€/MW) may be misleading. It is essential to de-couple the major price aspects of an HVDC scheme as much as is possible to ensure that any extrapolation to the North – South Interconnector is valid. Individual extrapolated figures can be re-combined for a more realistic estimate.

The major scheme components are,

- AC land cables, including installation, between converter stations and the grid connection points. This is potentially negligible for NSI, but is significant for some schemes where this distance could be 5 – 15km.
- Converter stations at both ends, normally ordered as one package
- DC underground cables including installation, which are very relevant to NSI
- DC submarine cables, including installation, which are not relevant to NSI

For some schemes the land and sea cables may be different contracts. For long sea (and land) cables the contracts may be split between different suppliers to manage manufacturing capacity issues and to reduce risks associated with design and/or manufacturing defects.

HVDC Converter Station Costs

Published price information on some recent VSC HVDC schemes is summarised in **Table 5**. In most cases these are symmetrical monopole schemes at the same DC voltage as would be required by NSI. One scheme uses a bi-pole topology, with a much higher DC voltage (North Sea Link).

Table 5: Converter Prices for recent HVDC Projects

Project	Power rating (MW)	DC voltage (kV)	Converter Price (€m)	Price/Power Ratio (€m/MW)
France - Italy	2 x 600	±320	300	0.25
Alegro	1000	±320	273	0.27
IFA 2 (2017)	1000	±320	270	0.27
North Sea Link (2016)	1400	±525	410	0.29

This data suggests that a price/power ratio of 0.27 would be an appropriate basis for an estimate of the cost of the converter stations needed for a VSC HVDC link for the NSI scheme**. This would give a converter cost of €405m for the 2 x 750 MW NSI HVDC option.**

The International Expert Commission (IEC) Report (2012) indicates a converter station price of €310m for 2 x 700 MW. Scaling this figure to 2 x 750 MW would indicate a price of €332m. This gives a price/power ratio of 0.22, which is below recent project contract prices. The variation in scheme prices since 2011 means that the estimate in the IEC Report can no longer be relied upon as it is too low based on today's experience.

The PB report of 2013 used a price of €445m for three converter stations (including the intermediate station near Kingscourt); each rated at 2 x 720 MW. Scaling this price for two stations of 2 x 750 MW gives a price of €309m, that is a price/power ratio of 0.21. The costs estimate in the 2013 PB Power Report for the converter stations is therefore also too low based on today's experience.

Underground cable costs

Most published information on the price of cables is a total figure including manufacture and installation, with no indication of the relative prices for each component. Similarly where a scheme comprises land and sea cables it is rare that a spilt of the prices for each length is given. Hence some care is needed in comparing cable prices. For symmetrical monopole and some bi-pole schemes only two cables are needed (+ve and –ve), hence only one installation campaign is needed. For a twin monopole scheme (such as would be required for the NSI project), with two pairs of cables, two separate installation campaigns may be needed.

Table 6: Underground Cable Prices for recent HVDC Projects

Project	Power (MW)	DC voltage (kV)	Distance (km)	No of cables	Cable length (km)	Price (€m)	Price/ distance (€/km)
France – Italy	2 x 600	±320	190 land	4	760	200	0.26
Alegro	1000	±320	90 land	2	180	125	0.69
IFA 2	1000	±320	245 Land 25 Sea 220	2	490	350	0.71
North Sea Link	1400	±525	480 sea 250 sea	2 2	960 500	472 340	0.49 0.68

As indicated there is much more variability on the price of cables than converter stations, due to the very specific conditions for installation of the cables. Thus in ideal conditions, such as the France – Italy project, where the cable is laid in the verge alongside a straight motorway the price/length ratio may be quite low. In more difficult laying conditions the price may be significantly higher. For the shorter Alegro cable the price/km ratio is much higher which may reflect the difficulty of the route. For IFA 2 no split between land and sea cables is available. NSL is split between two manufacturers, the higher price/km ratio relating to the Norwegian section through a fjord and overland.

Experience suggests that long land cables are more expensive than long sea cables, despite the high costs associated with chartering cable laying vessels. The difficulties encountered on land with multiple cable joints, through narrow country roads, multiple planning jurisdictions, land ownerships, etc. can add significantly to the cost.

Based on this analysis a price of €0.7m/km would be appropriate for the NSI project. This will require four cables of 135 km length, i.e. 540km of installed cable giving an **estimated underground cable price for the scheme of €378m.** This is at variance with the IEC report, which estimated the cable price as €190m for 560km of cable, i.e. a ratio of €0.34m/km. The PB report of 2013 quoted a cable price of €508m, significantly higher than the figure of €378m. However this is based on a detailed review of the potential cable route traversing the countryside and identifying the different types of terrain to be traversed and the number and extent of rivers and roads that have to be crossed.

Summary of Cost Update

The foregoing is summarised in the following table.

Table 7: Summary of HVDC Cost Update

Item	IEC (2012)	PB Power (2013)	Update based on recent (2017) projects
Converter Stations	€310 million	€309 million	€405 million
Underground Cables	€190 million	€508 million	€378 million
Total	**€500 million**	**€817 million**	**€783 million**

Both the IEC and PB Power underestimated the cost of the converter stations. This may be due to the prices quoted in the market at that time being based on 'loss leaders'. With a more mature market now in place the prices being quoted today are likely to be more realistic and therefore sustainable.

The cost of installing the underground cable is very much influenced by the conditions encountered along the route. Only PB Power has identified and assessed a route for an underground cable. PB Power's estimate for the underground cables is therefore likely to be the most robust.

4.3 UPDATE ON ADVANCES IN HVDC TECHNOLOGY

Update on advances in VSC-HVDC Technology since publication of the IEC Report in 2012.

Section 4.3 of the International Expert Commission (IEC) Report provides a brief summary of the then (late 2011) 'state of the art' of HVDC technology with particular emphasis on the VSC version of the technology. The IEC Report also provided some predictions as to how this technology might develop in the future. The report characterised the development of HVDC systems under six topics. Comments on the present position of these topics, after an interval of five years, is presented below -

IGBT (Insulated Gate Bipolar Transistors) switching devices

IGBTs are the basic building block of a VSC HVDC converter station. In 2012 the "state of the art" was a 3.3kV device which could switch about 1500A and these would have been suitable for the proposed interconnector rating (2 x 750 MW at ±320kV). Indeed they could handle up to 1,000 MW at ±320kV. One manufacturer (ABB) had an IGBT which could switch up to 2,000 A.

In 2017 the situation is unchanged with suppliers still using the same range of devices, although 4.5kV rated devices are available, but with the same current ratings. There is now significant operational experience of using these IGBTs at power ratings up to 1,000 MW at ±320kV.

Efficiency of VSC HVDC Schemes

The IEC noted that efficiencies had improved over the years from 1.9% losses to less than 1%. This suggested that efficiencies would continue to improve in the future however five years later that has not materialised. Today a figure of 1% station losses is still typically quoted by manufacturers for VSC schemes. This figure is dominated by the conduction, i.e. on-state, losses of the IGBT devices, with transformer and auxiliary power losses making up the balance.

Some marginal improvement in this loss figure may be anticipated by enhanced designs of converter valves or different switching patterns of the IGBT devices. However, for any present economic evaluation of a HVDC option a figure of 1% should be used.

The use of a new generation of switching devices based on silicon carbide rather than silicon should reduce valve losses, but these devices are still at the low power (industrial drives) end of the market. The future use if silicon carbide devices would not be a "one for one" replacement of present IGBTs, but would instead require major development activity by the manufacturers.

Size of converter station buildings

The size of converter buildings has not reduced much since 2012. The modular nature of the converter valves (made up of IGBTs) does allow a trade-off between the height of the valve structure and its length. Typically a ±320kV valve hall would be 20 – 22m in height. By removing 1 tier (say out of 4 tiers) of power modules the height could be reduced to 18 – 20m but at the trade-off of increasing the building footprint as the building length would have to increase by 25%.

Excavating the site to partially submerge the building, say by 2m could further reduce the height of the building in the landscape, but with the expense of additional civil works and potentially removal and disposal of large quantities soil from the site.

HVDC XLPE cables

The IEC noted that HVDC plastic extruded (XPLE) cables are cheaper than comparable HVAC underground cables. This is correct on a metre for metre basis but the resulting saving does not always offset the very high cost of the converter stations required at each end of a HVDC scheme. Converters are not required in the case of a comparable HVAC scheme. Figure 2 in Section 4 above indicates a breakeven distance of 80/120 km for HVDC UGC and HVAC UGC. Figure 2 does not find a breakeven distance for HVDC UGC and HVAC OHL suggesting that if it does occur it is in excess of 1,000 km.

HVDC XPLE cables are now the industry standard at ±320kV and are offered by a number of suppliers. There is more experience of XPLE for land cables than for sea cables, but there are many schemes in construction using XPLE for land and sea cables.

Mass Impregnated (MI) cables are still being used for higher voltage VSC schemes above 400kV, although designs of XLPE for 525kV and 640kV have been launched by manufacturers.

500kV VSC schemes

The 500kV Skagerrak 4 scheme between Norway and Denmark has entered commercial service and represents the current state of the art.

The NSL link between the UK and Norway is in construction at 525kV and will become the next step for VSC technology.

HVDC circuit breakers

The IEC noted that HVDC circuit breakers are "under development and are expected to be commercially available on the market in 2013". It was suggested that the availability of HVDC circuit breakers would lead to the development of HVDC meshed networks. This would be similar to the way HVAC circuit breakers enabled the development of the meshed networks that make up today's transmission grids.

The introduction of HVDC circuit breakers however has not materialised. HVDC circuit breakers have been developed by two European based manufacturers (ABB and GE - formerly Alstom). Although launched several years ago, these devices are still in the testing laboratories and no commercial unit has entered service or been ordered. No suitable European application, e.g. a multi-terminal system or overhead line project, has been developed which would benefit from such a device.

In China C-EPRI has developed a HVDC circuit breaker which is also in the test laboratory. A 500kV version of this device will be installed in a multi-terminal VSC HVDC scheme near Beijing in the near future.

HVDC manufacturers

The IEC report mentioned three European manufacturers with VSC HVDC capability. These were ABB, Siemens and General Electric. GE is a USA-based company, but its HVDC business is in Europe (UK).

All of these manufacturers have VSC projects in service and in construction. These are mostly at voltages up to 320kV, with some at 400kV (Siemens in construction), 500kV (ABB in operation) and 525kV (ABB in construction).

Since the publication of the IEC report three Chinese manufacturers have developed VSC technology and placed schemes into service (but only in China) at voltages up to 320kV. These are GEIRI/C-EPRI, NR Electric and RXPE.

These Chinese companies now have European offices and are actively tendering for HVDC projects outside of China.

HVDC Cable manufacturers

At the time of the publication of the IEC report there were three European cable manufacturers with the potential capability to manufacture XLPE underground cables although not all had done so at a voltage of 320kV. These were ABB, Prysmian and Nexans.

In 2017 the cable market looks slightly different with the following manufacturers being active for European VSC HVDC projects,

- NKT (which has acquired ABB's cable business);
- Prysmian;
- Nexans;
- Silec (part of the General Cable group) and
- Sumitomo (formerly trading as J-Power).

Future developments beyond 2017

Beyond 2017 most development activity in the field of VSC HVDC is aimed at increasing power ratings towards 2,000 – 3,000 MW, to allow it "compete" with the classic LCC HVDC technology for bulk power transfer. Marginal improvements may be anticipated in the next five – 10 year timeframe, but no radical technological changes are foreseen, which would significantly reduce the price or improve the functionality of converter stations.

4.4 2017 UPDATE ON USAGE OF HVDC TRANSMISSION IN EUROPE

Recent announcements in respect of the ALEGrO Project, a HVDC UGC interconnector between Belgium and Germany have prompted proponents of the UGC option to again question the technical arguments presented by EirGrid against the use of similar technology for the proposed North South Interconnector.

Similar questions were raised previously in respect of other land-based HVDC projects, specifically the France/Spain and the Norway/Sweden interconnectors. This was addressed in the 2012/2015 comparative assessment (refer to Table 3 in Section 4.1) and the same arguments apply, although in the case of the Belgium/Germany interconnector they are even more stark.

The Belgium/Germany interconnector will have a capacity of 1,000 MW. The Ireland/Northern Ireland interconnector will be 50% larger at 1,500 MW. Germany and Belgium are at the centre of the massive and highly interconnected continental European super grid. In comparison the network on the island of Ireland is tiny and isolated.

The Belgium/Germany interconnector will be of relatively minor importance within the overall massive continental grid. By contrast the North South Interconnector will be of the highest strategic importance for the island of Ireland. The Table below (modelled on Table 3 in Section 4.1 above) gives an indication of the relative importance of these interconnectors to their respective networks.

Interconnected Countries	Power Carrying Capacity of Proposed Interconnectors	Combined System Peak Demand	Capacity of Proposed Interconnectors as a % of Peak Demand
Ireland - Northern Ireland	2 X 750 MW	6,311 MW	23.8%
Belgium – Germany	1 X 1,000 MW	400,607 MW	0.2%

The difference between the capacity of the proposed interconnectors as a % of their respective network's peak demand gives an indication of the magnitude of the difference in their relative importance. The Table above suggests that the North South Interconnector will be almost 120 times (23.8/0.2) more important to the all-island network than the Belgium/Germany interconnector will be to the continental European grid. The importance of the proposed circuits to system security and stability determines the level of risk that can be tolerated by their respective developers.

When planning extensions to the transmission network the TSO must consider the level of risk that is tolerable. This involves a consideration of the likelihood of a failure and the consequence of that failure. HVDC schemes are known to fail. Complex control schemes, such as would be required for a HVDC circuit embedded in an AC network are prone to mal-operation. EirGrid and SONI have first-hand experience of a mal-operation of the control and protection scheme for the existing Louth-Tandragee 275kV interconnector triggering a mal-operation of the control scheme for the Moyle HVDC Interconnector resulting in an extensive automatic load shedding event.

Clearly the developers of the Belgium/Germany interconnector have determined that the risk to system security and stability of implementing the proposed interconnector using HVDC technology is acceptable. As indicated above, the strategic importance of the North South Interconnector is far greater to Ireland and Northern Ireland than the ALEGrO interconnector is to Belgium and Germany. In fact EirGrid and SONI have determined that the North South Interconnector is of the highest strategic importance. If implemented using HVDC technology, a failure of its control scheme would have the potential to bring down the entire network resulting in an all-island blackout. Such risk taking is unacceptable particularly when there is a very reliable and less costly option readily available.

The acceptably of implementing the North South Interconnector using HVDC was raised at the oral hearing in 2016 and the Inspector concluded (page 180) –

> *"having taken into considerations all of the arguments made, the strategic importance of the proposed interconnector as part of the all-island transmission network, the lack of existing strong interconnection between Ireland and Northern Ireland and the overwhelming need for reliability and security of supply, on balance it would appear that the technology currently best suited to satisfy the requirements of the proposed North-South Interconnector development is an overhead high voltage alternating current power line".*

And at page 187 –

> *"it is my opinion that as a critical element of the transmission system between Ireland and Northern Ireland, it has been demonstrated that an overhead line option presents less risk for system security, reliability and availability than a DC option".*

Proponents of the UGC option have noted that there are plans in place for the installation of thousands of kilometres of HVDC UGC across Europe and they claim that this is evidence that implementing the North South project using similar technology would not be out of step with ‘good utility practice’.

This is however a misunderstanding or misrepresentation of the facts. The European ten year network development plan (TYNDP) published by ENTSOE (European Network of Transmission System Operators for Electricity) identifies all of the major extensions and upgrades to the transmission grids that are planned for the following ten years across Europe. The 2014 plan shows that 44,500 km of new high voltage circuits are planned. The table below shows this 44,500 km broken down into AC and DC technology and how much of each is planned to be implemented by means of overhead lines, underground cables and submarine cables.

Table 8: Planned Quantities of OHL, UGC and Submarine Cable in Europe ENTSOE TYNDP 2014

Technology Type	HVAC (km)	HVDC (km)	Total (km)
Overhead Line	18,000	4,500	22,500
Underground Cable	500	1,000	1,500
Submarine	2,000	17,500	19,500
Total	**20,500**	**24,000**	**44,500**

From **Table 8** it can be seen that underground cables, whether AC or DC, account for only 3.4% (1,500 km) of the planned extensions. HVDC projects are becoming more prevalent in Europe with such projects now making up 54% (24,000 km) of the planned extensions. This is mainly being driven by a relatively small number of very long submarine projects which in total account for 73% (17,500 km) of all of the HVDC extensions. These long submarine cables cannot be implemented using AC technology so HVDC is the only feasible option. In the case of the AC projects 88% (18,000 km) are planned as overhead lines with only 2.4% (500 km) planned as underground cable, the balance comprising multiple short submarine cables. It can be seen therefore that the proposal to implement the North South Interconnector using HVAC overhead line is in accordance with the practice applied across Europe.

4.5 HVDC OFFSHORE SUBMARINE CABLED OPTION

During public consultation some stakeholders suggested that consideration be given to an offshore cable, i.e. a submarine cable off the east coast, for linking the two transmission networks on the island of Ireland. This suggestion was made without specifying whether the submarine cable would utilise AC or DC technology. The DC submarine option is considered here while the AC submarine option is considered later in **Section 5.3.**

There are numerous examples of long high capacity DC submarine cables in Europe so this option is potentially feasible. However, all of the disadvantages of the 'on-land' DC option vis-à-vis a standard AC transmission technology option identified above apply in the case of the sub-sea DC option. In addition to those disadvantages the following also applies.

For any on-land UGC option there is a concern about the relatively long time it takes to find and repair faults. In the case of the undersea options the time to repair will be significantly greater than for the equivalent on land option. Reference can be made to the example of the six months that it took to repair a fault on the NorNed[22] HVDC cable during commissioning in 2007 / 2008. Much of the delay was due to poor weather conditions during the winter months and the resulting concerns for health and safety of repair crews. For this reason a DC submarine cable off the east coast is considered to be even less preferred when rated against the criterion of 'Reliability and Security' than an on-land DC cable.

The circuits required for the proposed development must connect into the existing transmission grid at appropriately strong points north and south of the border. In the case of the undersea option long on-land cables are required to reach the coast (in excess of 40km from Woodland to the coast). An entirely on-land cabled option can take a more direct cross country route and as a result be considerably shorter and by implication less expensive than its undersea equivalent. For this reason a DC submarine cable, is considered to be even less preferred when rated against the criterion of 'Cost Effectiveness' than an on-land DC cable.

EirGrid's overall conclusion on the HVDC offshore submarine option is that it is not acceptable for this development and merits no further consideration.

[22] NorNed is a HVDC undersea interconnector between Norway and the Netherlands. It was first put into service in May 2008.

4.6 OVERALL CONCLUSION ON HIGH-VOLTAGE DIRECT CURRENT (HVDC) AS AN ALTERNATIVE TO HIGH-VOLTAGE ALTERNATING CURRENT (HVAC)

EirGrid's consideration of the option of using HVDC technology for implementing the proposed interconnector is supported by the findings of the PB Power Study (2009, April 2013 and July 2013) and the TransGrid Study (see summaries of these studies in **Table A** in the **Appendix**). In addition consideration has been given to the findings of the International Expert Commission (see summary of IEC Report in **Table B** in the **Appendix**).

The overall consideration found that any DC option whether implemented using UGC, OHL or off-shore submarine cable would not facilitate the future development of the transmission network as well as any AC option. Nor would the DC option be considered as complying with 'best international practice'.

While the cost of the DC options (UGC or OHL) would be comparable with an AC UGC option they would all be significantly more expensive to implement than the proposed 400 kV AC OHL option, €670 million more according to the findings of the *PB Power Technology and Cost Update* (July 2013) and €333 million according to the findings of the IEC Report.

In addition the proposed interconnector is required to be an integral part of the 'all-island' AC transmission network and will therefore be required to operate like any other AC circuit within the network. It is possible, in theory at least, to embed a DC circuit into an AC transmission network and make it operate like an AC circuit; however this would require a complex and bespoke control system. The risk of failure, and the consequence of failure, must be a factor in the consideration of any technological option. A complex and bespoke control system brings with it considerable risk of failure. The proposed interconnector will form the backbone of the 'all-island' transmission network and will therefore be of the highest strategic importance. If implemented using HVDC technology there is the potential that a failure of its complex control system would collapse the entire 'all-island' transmission network. This is an unnecessary risk to take in the case of this proposed development when there is a technically superior and less risky option readily available. Therefore even if the excessive cost was not a sufficient reason for rejecting the HVDC option, which it is, the HVDC option is not acceptable due to the risk it presents for system security and stability.

As a result of all of the foregoing it was concluded that any option using HVDC technology is not an appropriate or acceptable option for implementing the proposed interconnector.

5 CONSIDERATION OF HIGH VOLTAGE ALTERNATING CURRENT (HVAC) OPTIONS

The use of HVDC technology whether implemented by OHL or UGC, on-land or off-shore, has been discounted above. All further consideration and comparison of OHL and UGC is therefore restricted to HVAC technology particularly at the 380 kV / 400 kV level.

Most proponents of the underground cable option now accept EirGrid's position that the proposed interconnector cannot be implemented using HVAC UGC as the distance from Woodland to Turleenan is too great. **Section 5** is included here however for the sake of completeness and also as a lead in to the subsequent section (**Section 6)** that addresses the issue of partial undergrounding of AC transmission circuits.

5.1 HIGH VOLTAGE AC OVERHEAD LINE (OHL)

Over 98% of the on land Extra High Voltage (EHV - 315 kV to 500 kV) electricity transmission network in Europe is of HVAC OHL construction. For comparative purposes the extent of the 380 kV / 400 kV network in 10 Western European countries including Ireland, is shown in **Table 9**.

Table 9: Extent of the 380 kV / 400kV AC OHL and UGC Installations in Western Europe [23]

Country	Overhead Line (km)	Underground Cable (km)	% Cable
Belgium	1,335	0	0.00%
France	21,361	3	0.01%
Germany	20,237	70	0.34%
Great Britain	11,979	229	1.91%
Ireland	439	0	0.00%
Netherlands	2,061	30	1.43%
Portugal	2,236	0	0.00%
Spain	19,567	55	0.28%
Sweden	10,700	8	0.07%
Switzerland	1,780	8	0.45%

(Source: *ENTSO-E Statistical Yearbook* 2011)

[23] Denmark is deliberately excluded from Table 9 as it is a special case and is discussed in greater detail in **Section 5.4.**

400 kV OHL technology conventionally utilises steel lattice towers to support the electricity conductors. As the construction of a 400 kV OHL requires limited civil works with a simple mechanical construction, it is very cost effective compared to an equivalent UGC system which has a more complicated construction and design.

400 kV OHLs have a high level of availability for service, that is, most faults are temporary and automatically cleared without impacting the integrity of the transmission network, and the permanent or persistent faults can be located easily and quickly repaired. Where there is a temporary fault (e.g. a lightning strike), restoration can occur within a number of seconds. In the case of permanent faults, restoration times are on average, less than 48 hours[24].

Compared to equivalent UGCs, 400 kV OHLs result in a relatively low physical impact to the land they cross (limited to the tower locations and land within the OHL corridor). It is a very flexible technology which can be routed and constructed in a wide variety of topographies. With longer spans it can also be constructed to pass over waterways or obstacles.

HVAC OHL technology is considered international best practice and is a proven technical solution for transmission of high-voltage electricity. It is the technology around which the transmission network in Ireland has been developed to date. It is EirGrid's position, based upon professional and technical expertise, extensive experience, and international best practice that, on the grounds of achieving an overall balance between environmental, economic and technical objectives, the approach to the establishment and routing of high voltage transmission circuits in rural areas will normally be best achieved through an OHL construction methodology

5.2 HIGH VOLTAGE AC UNDERGROUND CABLE (UGC).

High voltage UGC technology involves installation of specialised insulated cables under the ground. The cables can either be direct buried or placed within ducts / concrete trenches or tunnels. Direct burial installation requires the use of heavy equipment along the entire length of the route, not only for excavation but also for the transport and installation of the cables. However, it does not require the level of civil engineering required by cut and cover tunnels and deep bore tunnelling type installations. Cable tunnels in contrast to cable trenches are very costly to build and are normally used over short distances and typically only in densely developed urban areas where lack of space precludes the use of OHLs and direct buried cables.

The installation of direct buried UGC is highly dependent on soil type. There are two main influences: excavation and backfill. Trenching for UGC requires the excavation of significant

[24] Refer to **Section 5.5.**

quantities of soil. The suitability of the excavated soil as a backfill material and its thermal resistivity are important considerations. Special techniques such as directional drilling are also used for crossings under roads, railways and waterways resulting in a reduced disturbance to the surrounding environment.

In terms of reliability of UGCs, reference is made to the most comprehensive study to date carried out by Cigré *Update of Service Experience of HV Underground and Cable Systems, ISBN 978 -2-85873-066-7* (2009). This study was based on the results of a survey of 73 utilities from around the world. The study found, that once located, the average time taken to repair a fault on a 400 kV XLPE cable (a cable type which would be considered for the proposed interconnector) is 25 days if the cable is direct buried, and 45 days if installed in a tunnel. On the basis of potential for prolonged unplanned circuit outages, 400 kV OHLs are therefore considered to have a better service availability than equivalent UGCs (this is discussed in greater detail in **Section 5.5**).

Long term reliability is also considered to be an issue. The expectation and international experience is that as an UGC gets older, it becomes less reliable. This is principally due to deterioration of the material used in the manufacture of the cable and the long term impact of electrical and thermal stresses over the operational life of the cable.

In relation to the use of UGC for HVAC transmission, the high capacitance of the cable presents design and operational difficulties. The most notable of these is the risk of temporary high voltages within the network which exceed the rating of the cable and can cause critical failure of either the cable equipment or transmission assets in a wider area. The TEPCO report and subsequent internal analysis has shown that equipment ratings could be exceeded.

The IEC Report recommended against using a total HVAC UGC solution for this particular project advising that *"AC cables are technically possible, but have never been found attractive for long distance, high power transmission"* and *"For AC connections, the solution by underground cables is only used for limited distances".* In fact, there are no 400 kV HVAC UGC in the world that approach the length required for the proposed development.

One of the main advantages of installing UGCs is the reduction in landscape and visual impacts associated with the OHL option. However installing buried cables across the country side introduces environmental issues specific to that technology, e.g. potential impact on archaeology as a result of excavation works and permanent loss of habitat due to removal of hedgerows.

Because of their higher cost and lower level of availability for service, high voltage transmission cables are generally only used in urban areas or wherever a constraint has been identified such that no alternative exists other than to use a cable. In Europe some examples of circumstances where such cables have been used would be:

- In densely populated areas and where no alternative exists;
- In congested areas of infrastructure where no alternative exists;
- Where it is necessary to cross water and no alternative exists; and
- Where no alternative exists but to route through an environmentally sensitive area and undergrounding is deemed to be less of an impact on the environment.

5.3 UNDERGROUNDING THE ENTIRE INTERCONNECTOR USING AC UGC

EirGrid considered the option of undergrounding the proposed development using AC UGC and concluded that the entirely undergrounded AC option would not be an acceptable solution as:

- It would not be the least cost technically and environmentally acceptable solution; and
- Its use would not be in compliance with good utility practice.

Some stakeholders who participated in the public consultation disagreed with EirGrid's conclusion, and referenced, either directly or indirectly, the Askon Report (*Study on the Comparative Merits of Overhead Lines and Underground Cables as 400 kV Transmission Lines for the North-South Interconnector Project)* which was commissioned by North East Pylon Pressure (NEPP) in support of their contention that the development should be undergrounded.

The IEC reviewed the Askon Report as part of its review of the proposed development. The IEC Report stated that, while the author of the Askon Report, Professor Noack *"is well known in the industry for his work on lightning protection and overvoltages"* the "*Commission, is however, not aware of his expertise in grid development, grid operation, economic aspects and undergrounding*". The IEC then went on to state that it had found "*several questionable statements*" in the Askon Report. The more significant of these were:–

- The IEC does not agree with the Askon Report when it states that long 400 kV AC UGC "*are not really a problem and that experience is there".* The IEC found that there are no 400 kV UGC circuits in the world that approach the length required for the proposed interconnector and that this is because of sound technical reasons;
- The analysis by Askon of the reliability of AC UGC circuits is not valid as it "*is not backed up by actual data"; and*
- The costs estimates for AC UGC in the Askon Report are significantly understated as insufficient provision is made for the cost of installation.

Overall, the IEC concluded that the findings of the Askon Report "*are not consistent with industrial practice for other projects in Europe"* that are similar in size and form to the proposed development and which "*have been executed, are under construction or are in planning".* The IEC Report goes on to make only one recommendation and that is that the proposed development should not be implemented using the entirely undergrounded AC cable option.

The position of the IEC regarding the Askon Report is consistent with EirGrid's position on that report. EirGrid concurs with the recommendation of the IEC that the proposed development should not be implemented using the entirely undergrounded AC cable option.

Undergrounding the entire interconnector, approximately 135km in length, using AC UGC is therefore eliminated from further consideration for this development.

It is stated in **Section 4.5** that during public consultation some stakeholders suggested that consideration be given to an offshore cable that is a submarine cable off the east coast, for linking the two transmission networks on the island of Ireland. As an AC offshore option would require an even longer length of AC cable than the approximately 135km length of the on land option it is also eliminated from further consideration for this development.

5.4 HIGH VOLTAGE AC XPLE UGC AND EXTENT OF ITS USE

Although the entirely undergrounded AC option was eliminated, the option of using a hybrid AC solution, i.e. a combination of AC UGC and AC OHL, commonly referred to, and herein after referred to, as 'partial undergrounding', remains an option for consideration. Indeed the IEC found in this regard that the partial undergrounding is technically feasible but within limitations on the cumulative length of the UGC sections. It is appropriate therefore that consideration continues to be given to the use of high-voltage AC UGC for this development but within these recognised constraints.

XLPE (cross linked polyethylene) insulated cable is the 'state of the art' for HVAC UGC in the world today. EirGrid adopted the use of high voltage XLPE cable at an early stage in its commercial development. The first 110 kV XLPE cable in Ireland was installed in 1978. The first 220 kV XLPE cable in Ireland was installed in 1984. The installation of long lengths (greater than 1000 metres) of 400 kV XLPE UGC only became possible in the late 1990s with the development of a suitable cable joint for connecting lengths of such cable together.

In the period 1997 to 2009, 11 significant 380 kV / 400 kV XLPE projects[25] (i.e. projects that involved a circuit length in excess of 2km) were completed in Europe. The longest of these was the 20km long Elstree - St John's Wood 400 kV cable project in London. This cable is installed in a three metre diameter air conditioned tunnel. The combined circuit length of these 11 European 'projects of significance' amounts to approximately 196km[26], and they have a combined single phase cable length of some 640km. It should be noted that a minimum of three single phase cables is required per circuit.

If the proposed development was to be implemented in its entirety using 400 kV XLPE cable, it would require approximately 810km (2 X 3 X 135km[27]) of single phase cable. This means that this single project would require more 400 kV XPLE cable to be installed in Ireland (in one circuit) than has been installed throughout Europe during the period 1997 to 2009. It appears, based on an analysis of reports (Europacable, Cigré T&D World[28]) of major EHV (extra-high voltage - in the range 315 kV to 500 kV) UGC projects carried out across the world in the fifteen year period up to 2012, that if the proposed interconnector was to be implemented entirely using UGC, there would be more EHV XLPE cable installed on the island of Ireland than in all of mainland Europe or in North America.

In contrast to the relatively small quantity of EHV UGC that has been installed in Europe during the period 1997 to 2009, it is interesting to note that in the period 2000 to 2009 over 10,000km of EHV OHL was installed in mainland Europe (17 member states of UCTE[29]). The reason for this overwhelming preference among UCTE members for OHL can be clearly understood in a letter[30], dated 14 January 2008, from the Secretary General of the UCTE to APG (the Austrian Power Grid Company) wherein it states:

> "*For the time being 400 kV AC cable systems cannot compete with overhead power lines in the transmission grid. Using cables for lines in interconnected operation (400 kV backbone) presents serious technical, financial and environmental drawbacks.*"

and

> "*UCTE therefore recognizes overhead power lines as the most reliable and most secure technical solution for transmitting electricity over long distances. Furthermore based on different studies within UCTE an overhead line is the more efficient and more economical way for the transportation of electricity compared with underground cables at the 400 kV leve*l".

[25] Entso-e & Europacable Joint paper to EU Commission: *Feasibility and technical aspects of partial undergrounding of extra high voltage power transmission lines*, December 2010, available at http://ec.europa.eu/energy.
[26] In the case of some of these projects the circuits consisted of two cables per phase giving a total of six single phase cables per circuit.
[27] The distance of 135 km is derived from the length of the route identified by PB Power in its 2009 report. The requirement for two cables per phase is also identified by PB Power in that report. There are three phases in the AC system.
[28] Transmission and Distribution World magazine, available at http://www.tdworld.com
[29] UCTE is an association of Transmission System Operators from mainland Europe (excluding Scandinavia and the countries of the former USSR). UCTE is now a part of ENTSO-E. The data was obtained from the UCTE Statistical Yearbooks 2000 and 2009.
[30] Available at http://www.eirgridprojects.com/projects/northsouth400kvinterconnectiondevelopment/projectactivity/2008/

This overwhelming preference for OHL among European utilities is expected to continue into the future. In this regard, the *Ten Year Network Development Plan (TYNDP)* 2012[31] issued by ENTSO-E (European Network of Transmission System Operators for Electricity) indicates that in the period covered by the TYNDP, a further 28,400km of new EHV (i.e. greater than 330 kV) AC OHL is planned to be installed in Europe while during the same period only 420km, in predominantly short lengths, of 400 kV AC UGC is planned (p 62). The reason for the preference for 400 kV OHL is explained in the TYNDP (p 81) as follows:

> "*New 400 kV AC OHL projects are in technical, economic, and ecological terms the most efficient solution for long distance electricity transmission. Indeed, such reinforcements integrate straightforwardly into the existing grid since this technology has been the standard for a long time*".

It is clear therefore that the electricity utilities of Europe still consider the use of OHL for 400 kV circuits to be best practice, and that 400 kV UGC is only used in very limited situations and only over relatively short lengths. The installation of 270km (2 X 135km) of 400 kV UGC in Ireland in one project, or even in a multiple of different projects, could not be described as complying with good utility practice.

During public consultation it has often been stated by stakeholders that the strategy adopted by Denmark for the undergrounding of its transmission grid should be considered as the standard for what constitutes 'best international practice'. EirGrid does not agree and instead considers 'best international practice' to be the practices, methods and acts engaged in or approved by a significant portion of the electric utility industry in Europe' and not just the practice in a single European country. The practices in a broad range of European countries with regard to the undergrounding of 400 kV transmission circuits are set out above.

Notwithstanding the fact that the practice in Denmark is not the determinant for what constitutes 'best international practice' it is useful to consider the Danish strategy. In 2009 a plan[32] was published in Denmark for the undergrounding of the entire 132 kV / 150 kV grid over a period extending to 2040. The plan for the 400 kV grid is however quite different. Even though there appears to be a national desire and a willingness to pay for the undergrounding of the entire 400 kV grid, it was determined that it was not achievable due to the technical difficulties, uncertainties and risks associated with the installation of long lengths of 400 kV UGC.

[31] Available at https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2012/.
[32] Energinet.dk - Cable Action Plan: 132 - 150 kV Grids - March 2009.

The technical difficulties and risks associated with the installation of long 400 kV UGC are explained in a technical report[33] published by the committee set up by the Danish Government to develop the strategy for the undergrounding of the transmission grid. At page 19 it states:

> *"When a 400 kV cable is disconnected, the large energy volumes stored in the cable and the cable substations will oscillate and cause overvoltage. The installation of long cables or a large number of short 400 kV cables increases the risk of such phenomena becoming a serious problem. The over voltages may become very large with the ensuing risk of other components being disconnected. This increases the risk of power failures."*

It was as a result of these concerns that the Danish committee recommended that those 400 kV circuits that form the backbone of the transmission grid should not be undergrounded, as to do so would carry too high a risk for system security and stability. Based on this, it was decided that the required increase in interconnection capacity with Germany would be achieved by constructing a new double circuit 400 kV OHL. That line is now complete and in service since December 2014.

It is clear therefore that new 400 kV OHLs are being, and will be, constructed in Denmark. The map of Denmark at **Figure 5** shows the planned extent of 400 kV grid by 2030. The proposed new OHLs can be seen on this map as solid orange lines.

[33] Technical Report on the Future Expansion and Undergrounding of the Electricity Transmission Grid – Summary – April 2008www.energienet.dk.

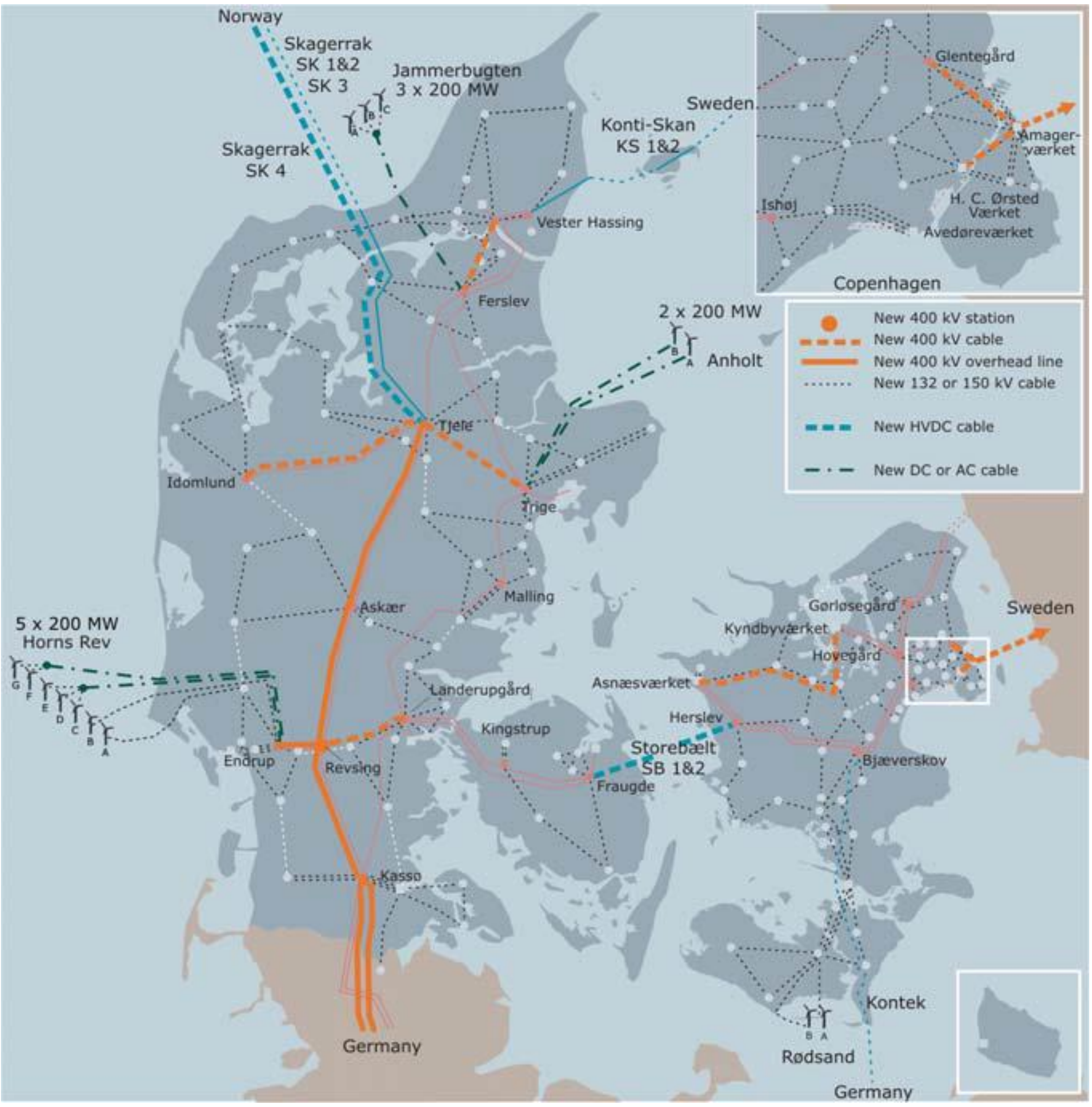

Figure 5: Planned 400 kV Infrastructure for the Danish Transmission Network

(Source: *Technical Report on the Future Expansion and Undergrounding of the Electricity Transmission Grid – Summary* – April 2008)

The longest AC UGC in the world, with a voltage rating greater than or equal to 380 kV, is a 40km long cable in Tokyo, Japan. Denmark aspires to having the longest such UGC in the world. However recognising the technical difficulties, uncertainties and risks associated with such long 400 kV UGC, a research and development programme has been instituted, in cooperation with Danish universities which, it is hoped, will conclude with the installation and testing of a long length (between 40km and 60km) of 400 kV UGC. The Technical Report states (p.8) that "if *targeted efforts are made, these tests can be implemented within 6 – 10 years"*. If successful, plans will proceed to underground all future "*non-vital backbone"* 400 kV circuits. The 400 kV circuits proposed for undergrounding over the following decades can be seen on **Figure 5** as dashed orange lines.

The *Denmark Cable Action Plan*[34] envisages that the expansion of the 400 kV network will proceed as shown in **Table 10.** From this it can be seen that (assuming the technical uncertainties mentioned in the previous paragraph are resolved) approximately 55% (290km) of the expansion will be achieved by means of 400 kV OHLs and the remaining 45% (240km) by 400 kV UGC.

Table 10: Denmark 400 kV Network Expansion Plan

Year	400 kV Overhead Line	400 kV Underground Cable
2009	1,270 km	80 km
2030	1,560 km	320 km

While the new interconnector with Germany was implemented by means of a double circuit 400 kV overhead line (commissioned in 2014) the plans for the further expansion of the Danish 400 kV network using 400 kV underground cable as set out in the Denmark Cable Action Plan of March 2009 were contingent on the results of a research and development programme carried out in cooperation with Danish universities. It was hoped that these studies would conclude with the installation and testing of a 60 km long cable as a test case and if successful all future "non-vital" 400 kV circuits would then be undergrounded.

The results of the technical studies however did not support the undergrounding of long 400 kV AC cables and the undergrounding of the 60 km circuit did not progress. Following which in November 2016 the Danish Ministry of Energy, Utilities and Climate announced that all future 400 kV circuits would be realised using overhead lines.

[34] Energinet.dk - *Cable Action Plan: 132 - 150 kV Grids* - March 2009.

5.5 RELIABILITY STATISTICS FOR HIGH-VOLTAGE AC UGC AND OHL

From a transmission adequacy point of view the availability for service, or more correctly the lack of availability for service, of a transmission circuit is a more important measure of reliability than simple 'failure rate'. A circuit's 'availability' is derived from the expected failure rate and the average time it takes to repair a fault.

The vast majority of faults on transmission OHLs are transient in nature. Most of these are caused by lightning; the lightning does not cause any damage; the fault only exists as long as the lightning exists. The protection systems for the OHLs are designed to trip the line when a fault occurs and, based on the assumption that the fault is transient, will automatically switch the line back into service within one second. If the fault is not transient but a 'permanent' fault then the OHL will re-trip and the line will remain out of service until repair crews can find and repair the fault.

In the case of transmission UGCs however almost every failure can be assumed to be a permanent fault as usually the very act of failing results in an explosion at the point of failure which destroys a section of the cable.

As the time it takes to repair a 400 kV UGC is much greater than the time to repair a 400 kV OHL it can be expected that such an OHL will have a much better level of availability for service than an equivalent UGC and this is supported by system statistics.

In April 2009, Cigré[35] published the results of the most comprehensive study of UGC reliability carried out to date. This study was based on the results of a survey of 73 utilities from around the world. Of interest is the information received on the performance of 1,388km of XLPE cable with a voltage rating in the range 220 kV to 500 kV. Applying the calculated fault rates of this 1,388km of installed cable, to the length of cable[36] (2 x 135 km) that would be required for the proposed development, gives a projected fault rate of 'one fault per annum'.

In addition, the Cigré study found that the average time taken to repair a fault on a 400 kV XLPE cable is 25 days if the cable is direct buried, and 45 days if installed in a tunnel. A direct buried cable is, however, ten times more likely to be damaged due to external factors than a cable installed in a tunnel the study concluded.

Consider the 'fault rate' and 'average time to repair' of an equivalent OHL. There are 439km of existing 400 kV OHLs in Ireland. This length of 400 kV OHL is too small a sample for determining meaningful performance statistics. Meaningful statistics can, however, be obtained by considering

[35] Cigré Technical Brochure 379 - *Update of Service Experience of HV Underground and Submarine Cable Systems, ISBN 978 - 2-85873-066-7* (April 2009).
[36] The distance of 135km is derived from the length of the route identified by PB Power in its 2009 report. The requirement for two cables per phase is also identified by PB Power in that report.

the fault statistics of the combined quantity (approximately 2,245km) of 400 kV, 275 kV and 220 kV OHLs under EirGrid's control[37]. Taking the fault statistics of this existing 2,245km of OHL for the period 2004 to 2012, gives a projected fault rate for the proposed (approximately 140 km long) 400 kV OHL of one permanent fault (that is a fault that requires repairs before the OHL can be returned to service) every 20 years.

The statistics also show that the average duration that a 400 kV / 275 kV / 220 kV OHL circuit will be out of service for repair after a fault is considerably less than that of an equivalent UGC circuit - less than two days in the case of OHLs, and 25 days in the case of a 400 kV UGC. This is summarised in **Table 11**.

Table 11: Summary of Comparative OHL and UGC Statistics

UGC and OHL	Projected Fault Rate for N-S Interconnector	Average Time to Repair
UGC – directly buried cable (statistics based on 1,388 km of XLPE cable with a voltage rating in the range 220 kV to 500 kV) **Source:** Cigré Technical Brochure 379	1 fault per annum	25 days
OHL (statistics based on 2,245km of 220 kV, 275 kV and 400 kV OHL in Ireland) **Source:** EirGrid (2004 – 2012)	1 fault (permanent fault requiring repairs) every 20 years	Less than 2 days

The comparative analysis indicates that OHLs have a substantially better level of availability for service than UGCs. This result is consistent with the findings of the independent Ecofys Report[38] in which the 'availability' (the term Forced Outage Rate is used in the report) of OHLs was found to be at least ten times (at least one order of magnitude) better than that of UGCs. This comparative performance must always be a factor when a TSO is considering UGC particularly when the circuit in question is to be a backbone circuit of the transmission network and therefore of the highest strategic importance[39].

[37] This is reasonable compromise because the existing 220 kV and 275 kV OHLs are of similar design and experience similar operating conditions to that of the existing 400 kV OHLs.
[38] *Study on the Comparative Merits of Overhead Electricity Transmission Lines Versus Underground Cables*, carried out by Ecofys on behalf of the Department of Communications, Energy and Natural Resources and available at www.dcenr.gov.ie.
[39] Refer to **Section 5.4** for the impact that this consideration had on the Government approved plan for the extension of the transmission grid in Denmark.

5.6 THE WORLD'S LONGEST HIGH VOLTAGE AC XPLE CABLE CIRCUITS

The longest high voltage AC XLPE cables operating in the world today are submarine cables. The longest is the 105km long 90 kV 40MW interconnector from Great Britain to the Isle of Man. The record for the longest HVAC cable in the world is likely to be broken when the proposed 125km[40] long 220 kV and 200MW interconnector between the islands of Sicily and Malta is commissioned. These long cables are radial connections and as such they do not form part of a meshed transmission network, unlike the proposed development. They also have a much lower power carrying capacity than that which is required of the proposed interconnector (i.e. 1,500MW). The environmental impacts of UGC, the technical difficulties of UGC, and the cost of UGC increase rapidly with increase in voltage rating and power carrying capacity. These examples of long HV undersea cables are therefore in no way comparable with the requirements of the proposed development.

The longest 'on-land' AC XLPE cable circuit, with rated voltage of 400 kV or higher, operating in the world today is a 40km double circuit cable in Tokyo, Japan. These 500 kV, 900MW cables were commissioned in 2000. The longest such cable in Europe, at 20km, is the Elstree - St John's Wood 400 kV 1,600MW circuit in London, which was commissioned in 2005. Unlike the long undersea cables, these cables have power carrying capacities, and voltage ratings, that are comparable with that of the proposed interconnector: There, however, the similarities end, in that:-

- The cables in London and Tokyo are installed under the streets and buildings of two of the largest cities in the world. Both of these cable circuits are installed in air conditioned tunnels. The proposed development would traverse open farm land in the main;

- The proposed interconnector UGC route (as identified by PB Power) is about 135km in length. The cables in London and Tokyo are a fraction of this length. The technical difficulties associated with long lengths of EHV UGC increase with increase in circuit length; and

- The transmission networks in Great Britain and Japan are orders of magnitude bigger and therefore unlike Ireland are far better able to accommodate such long lengths of EHV UGC.

One of the project objectives / design criteria for the proposed interconnector, as stated in **Section 3**, is that it will have a power carrying capacity in the region of 1,500MW and connect between appropriately robust points on the transmission networks north and south of the border. To try to achieve this using an entirely UGC option would require the installation of two circa 135km-long UGC circuits. It is clear from the above that no country in the world has ever implemented such a

[40] The circuit consists of 100km of submarine cable plus 25km of on-land UGC.

project, or anything comparable. It is also evident from ENTSO-E's *Ten Year Network Development Plan 2010-2020* that there are no plans to install anything comparable in Europe in the next ten years.

It is concluded therefore that to implement the proposed interconnector using long lengths of high voltage AC UGC would not comply with good utility practice.[41]

5.7 COST COMPARISON OF AC UGC AND AC OHL

Capital Costs

Three separate comparative studies of UGC versus OHL were carried out in Ireland during the period 2008 / 2009 as follows:

- Askon Report (commissioned by North East Pylon Pressure (NEPP)),
- Ecofys Report (commissioned by the DCENR) and
- PB Power Report (commissioned by EirGrid / NIE) supplemented by the *PB Power Technical and Costs Update* (April and July 2013).

The studies found that the capital cost of UGC ranged from three to eight times that of an equivalent OHL[42].

The most up to date site specific comparative cost estimate available for this development can be found in the *PB Power Update Report, Supplementary Note* of July 2013. This report found that the AC UGC option would cost €740 million more than the proposed 400 kV OHL.

Life Cycle Costs

In some of the written and oral submissions presented by observers during the planning application process, it was acknowledged that the capital cost of UGC was much greater than that of OHL. It was, however, asserted in these submissions that UGC is more efficient than OHL and that over its life cycle a UGC would incur lower electrical losses and, therefore, lower operating costs than an equivalent OHL. It was further stated that if the cost of the two technologies were compared over a typical life cycle, then UGC might well prove to be the more cost effective option.

[41] The term 'good utility practice' is defined in this context in a footnote in **Section 3.**

[42] Note: As these studies were only interested in calculating the cost differential between the options, they did not include in their estimates provision for project costs that are common to all options. Their cost estimates for each option cannot therefore be considered as 'whole of project' cost estimates.

These assertions are incorrect as they are based on a misunderstanding of transmission networks operation. UGCs and OHLs have different electrical characteristics with the result that a lightly-loaded UGC (typically less than 50% loaded) will have higher electrical losses than an equivalent lightly-loaded OHL, while a heavily-loaded UGC (typically greater than 50% loaded) will have lower losses than a heavily-loaded OHL. This is well illustrated in the graph in **Figure 6** which compares the energy losses of a 400 kV OHL 1,500 MVA circuit with two 400 kV UGC alternatives (2 X 1,200 mm² and 2 X 1,600 mm² aluminium cables) of comparable capacity. The breakeven point (crossover point) for the 1,200 mm² UGC (in comparison with the OHL) is 900 MVA while the comparable breakeven point for the 1,600 mm² UGC is lower at 840 MVA.

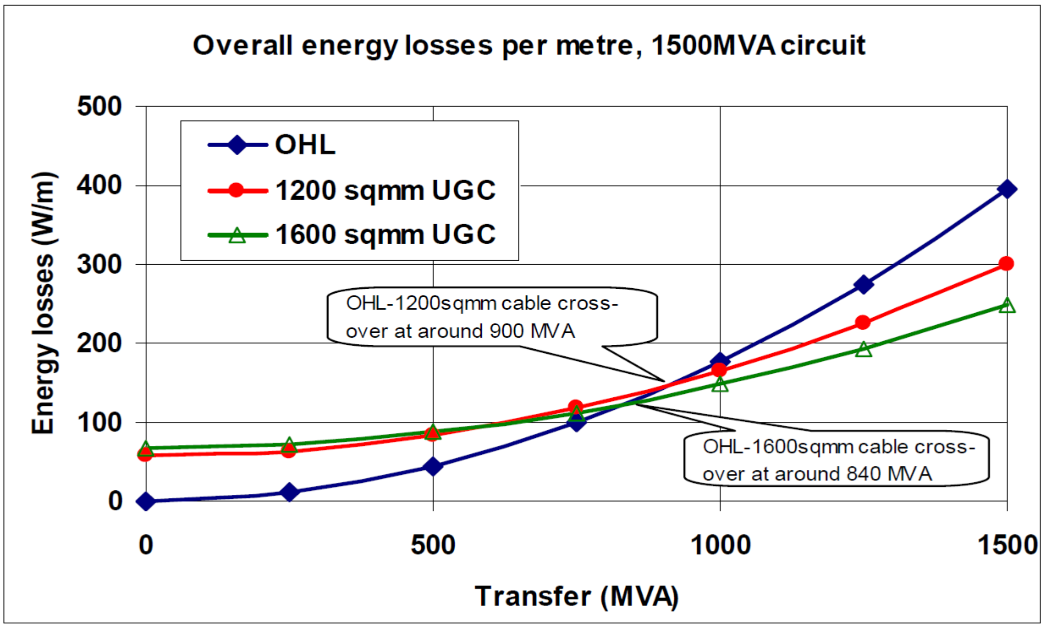

Figure 6: Comparison of Energy Losses for OHL and UGC

(Source: Figure 3-7 *PB Power Report* (2009))

Circuits in a meshed transmission network are required, under normal system conditions, to have a contingency capacity. In other words, they are required to have sufficient spare capacity to cater for the sudden loss of another circuit on the network. In practice, this means that transmission circuits, and particularly backbone circuits, typically operate at less than 50% of their power-carrying capacity. Therefore, OHL transmission circuits incur lower electrical losses than equivalent UGC transmission circuits during their lifetime. This is confirmed, in the case of the transmission networks of mainland western Europe, in the letter from the Secretary General of UCTE (as previously referenced), dated 14 January 2008 to the Austrian Power Grid Company (APG), in which it was stated that, "*based on different studies within UCTE an overhead line is the more efficient and more economic way for the transportation of electricity compared with underground cables at the 400 kV level*".

The average energy transfer on the proposed interconnector, over its lifetime, is expected to be less than 33% of its nominal power carrying capacity. This is on the basis that the peak load on the circuit (under normal system conditions) should not exceed 50% of capacity[43]. It is therefore the case that using OHL for the new interconnector will incur lower electrical losses than using equivalent UGC alternative.

The *PB Power Update Report* of 2013 estimated that over its lifetime the cost of operating and maintaining the proposed 400 kV OHL would be €55 million while the comparable cost for the UGC option would be €90 million. This estimate was based on an assumed average loading of 33% of capacity (500MVA).

6 PARTIAL UNDERGROUNDING OF AC TRANSMISSION CIRCUITS

6.1 BACKGROUND TO PARTIAL UNDERGROUNDING

'Partial undergrounding' is the term used to describe the undergrounding of a short section, or short sections, of a long transmission circuit that is comprised predominantly of OHL.

As the use of any HVDC technology, whether OHL or UGC, is not an appropriate or acceptable option for this development (refer to **Section 4.6**), the following consideration of partial undergrounding is restricted to high voltage AC technology and has little or no relevance to HVDC technology.

Partial undergrounding of 110 kV circuits is common practice in Ireland. There are no examples of partial undergrounding at the 400 kV level in Ireland, however there are numerous examples elsewhere in Europe. Partial undergrounding of 400 kV AC circuits is therefore technically feasible.

[43] See Section 9.2.2 of the Ecofys Report (summarised in Table B in the **Appendix**) for further discussion on this point.

6.2 CONSIDERATION OF PARTIAL UNDERGROUNDING FOR THIS DEVELOPMENT

When considering partial undergrounding for a 400 kV project, it is essential to understand the environmental, technical and cost implications of such a development. These issues are assessed in general terms in a joint position paper prepared by Europacable and ENTSO-E that was submitted to the European Commission in December 2010 (*Feasibility and Technical Aspects of Partial Undergrounding of Extra High Voltage Power Transmission Lines* (December 2010)). The joint paper "*merges the experience European Transmission System Operators (TSOs) have gained with the inclusion of underground EHV cables into their transmission networks over many years with the technical expertise of the leading XLPE EHV cable systems manufacturers in Europe*". The implications, for the proposed interconnector are considered below.

6.2.1 Partial Undergrounding – Environmental Issues

The size of the AC UGCs required for the proposed interconnector would be such that they could not be installed under public roads or under the disused railway line, as these roads and railways are not sufficiently wide. The only practical option would be to install the cables directly across farmland. This would have the following environmental implications:

- The construction effort associated with the installation of the UGC section would be considerably greater than that of the OHL. The UGC would require a construction swathe of 20 to 22 metres, as wide as a dual carriageway[44], to be cut through the countryside. This would result in much greater disruption to farming and other activities during the construction phase than would arise from the construction of the OHL.

[44] High Quality Dual Carriageway as defined by the National Roads Authority.

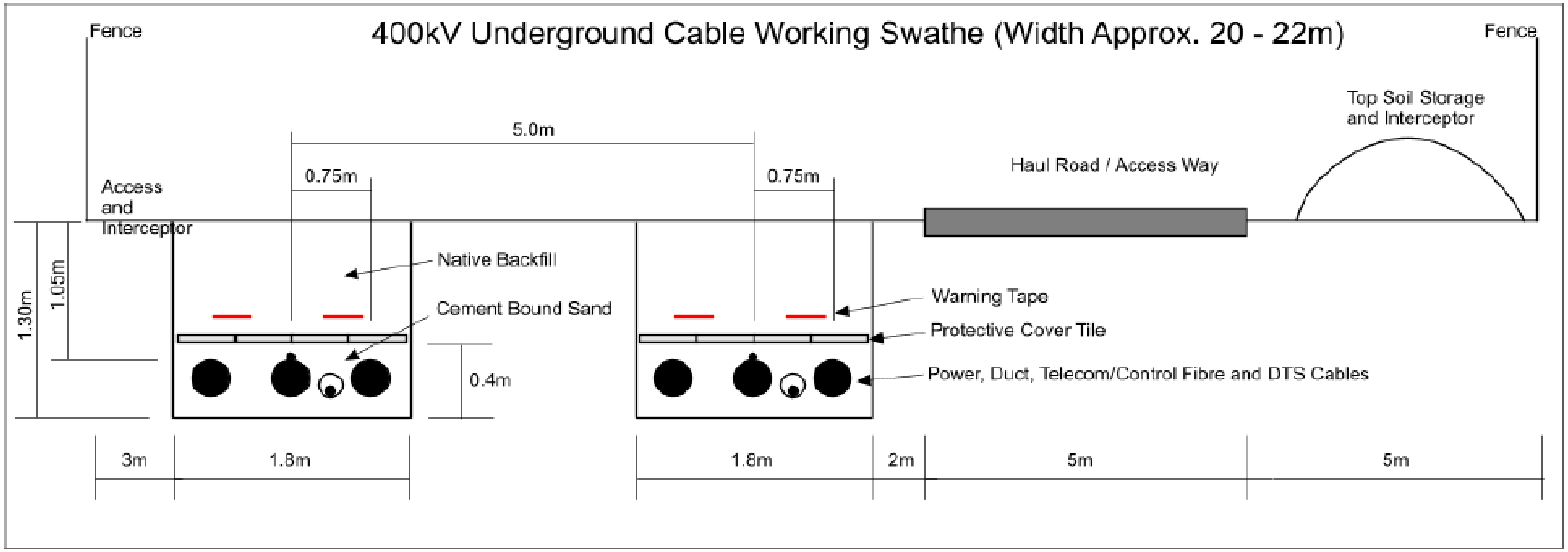

Figure 7: 400 kV Single Circuit, Two Trench, Working Swathe

(Source: Figure 7.1(b) *PB Power Report* (2009))

- The UGC construction swathe would cut through every hedgerow in its path, leaving a permanent gap. The hedgerow would not be allowed to re-establish itself as deep rooted vegetation cannot be permitted to grow in proximity to UGCs.

Figure 8: Photographs of a 400 kV Double Circuit Cable Being Installed Cross-Country

(**Note:** The first photograph shows the construction swathe with one trench and the haul road, the second photograph shows the construction swathe with two open trenches and haul road in the centre – Source National Grid Company, UK.)

- This is unlike the case of the OHL where in many cases the OHL will over sail hedgerows without unduly interfering with them. Where a tower is positioned straddling a hedgerow, a section of the hedgerow will be removed during construction, but it can be allowed to re-establish itself afterwards (see **Figure 9**), and management of the hedgerow thereafter will be required only to prevent its interference with the OHL.

Figure 9: Photograph of a Tower Straddling a Hedgerow with Vegetation Re-established

- Two underground chambers would be constructed approximately every 650m along the UGC route to accommodate the 400 kV cable joints. At these locations two inspection enclosures, either underground chambers accessed via a surface manhole or above ground kiosks similar to that shown in **Figure 10** are required.

Figure 10: Photograph of Above Ground Inspection Kiosks for UGC

(Source: PB Power (2009) Report, page A6 11)

- No buildings are permitted within a UGC reserve[45]. Buildings can, and have been, constructed below high voltage OHLs, most notably in the UK.

[45] Note: This applies where the cables are buried directly into the ground. If the cables are installed in a tunnel, and can be accessed via the tunnel, then buildings and other infrastructure can be constructed above, provided there is sufficient clearance.

- It would be necessary to have a substation at every location where the 400 kV circuit changes from OHL to UGC. Where a substation is required solely for the purpose of accommodating a transition from UGC to OHL, it is known as a ‘transition station’ or as a ‘sealing end compound’. A typical 400 kV transition station has the same appearance as a small 400 kV substation. It would require a land take of about one-half of a hectare. It would consist of an inner compound enclosing the live equipment and a small building, with a buffer strip around the compound to accommodate an earth berm, and / or vegetation, for screening and an access road.

Figure 11: Example of a 400 kV Underground Cable to Overhead Line Transition Station

(Source: 380-kV-Salzburgleitung Auswirkungen der möglichen (Teil) Verkabelung des Abschnittes Tauern-Salzach neu - Gutachten im Auftrag von Energie-Control GmbH Wien – Professor B. R. Oswald)

6.2.2 Partial Undergrounding – Technical Issues

Inserting a section of UGC into an OHL circuit will have a negative effect on the reliability performance of the overall circuit. The latest performance statistics (refer to **Section 5.5)** confirm that, on a kilometre for kilometre basis, 400 kV OHLs have a much better service availability record than 400 kV UGCs.

The risk to transmission system stability associated with the installation of a long length of EHV UGC exists, regardless of whether that long length of cable forms an entire UGC circuit, a single section of partial undergrounding, or is made up of multiple shorter sections of UGC within a single hybrid OHL / UG circuit. As a result, some utilities have set down the maximum permissible length of EHV UGC that can be installed on their transmission system whether installed as a single UGC circuit or as part of a hybrid UGC / OHL circuit and the maximum permissible cumulative length of EHV UGC on the system. In the Netherlands, for example, the maximum permissible length of a single 400 kV UGC is 20km. It is also the case that the longest 400 kV UGC in Europe is a 20km cable installed in an air conditioned tunnel in London.

When considering what should be the maximum permitted length of 400 kV UGC on the island of Ireland, EirGrid and SONI must take account of the accompanying risk of failure and consequence of such failure. The transmission system on the island of Ireland is much smaller than that on the island of Great Britain and, of course, much smaller than that of mainland Europe, to which the system in Netherlands is connected. The transmission system in Ireland is therefore able to accommodate much shorter lengths of 400 kV UGC than is the case in Great Britain or the Netherlands, for example. The Transmission System Operator (TSO) and the Transmission System Owner (TAOs) in Ireland are also much smaller than their counterparts in Great Britain and the Netherlands and must, therefore, carry correspondingly smaller risk.

Based on the present extent and configuration of the Irish network, EirGrid considers that the maximum length of 400 kV UGC that would be technically feasible to install as part of the proposed development (inclusive of that part of the interconnector located in Northern Ireland) is approximately 10km[46], whether installed in one continuous length or in an accumulation of shorter lengths. However, there are a number of environmental factors and costs issues which must also be considered in any appraisal of the technological option of partial undergrounding.

[46] Notwithstanding the earlier discussion about larger European countries being capable of accommodating longer lengths of 400 kV UGC than can be accommodated on the island of Ireland the practice in mainland Europe seems to be to also limit the maximum length of 380/400 kV partial UGC to approximately 10km e.g. the Randstad Project in the Netherlands, the Stevin Project in Belgium and the Wesel-Meppen Project in Germany..

6.2.3 Partial Undergrounding – Cost Issues

The *PB Power Technology and Costs Update Report*[47] of July 2013 (see **Table A** in the appendix) contains the most up-to-date detailed site specific cost comparison of UGC and OHL for the proposed interconnector. The Update Report found (Table 8-16 on page 27) that AC UGC would cost on average €5.4 million per km more to install than the AC OHL.

At least one, and potentially two, transitions stations are required for each section of the circuit that is undergrounded. Depending upon the length of an underground section (and therefore the facilities required at each end), transition stations could add an additional €5 - €15 million (approximately) per installation.

Unlike OHL, long sections of UGC would require electrical compensation equipment to be installed along its route to counteract the effects of the underground cable on the transmission network; a 10km section of UGC would require around 0.5 hectares of land to accommodate such equipment. The costs for this transition station compensation equipment are included in the overall cost estimate updates for the AC UGC option but may not be required for short sections of partial undergrounding - hence the spread in estimated costs. Likewise, the land-take of the transition station for a short section of undergrounding which would not require the installation of reactive compensation equipment could be reduced to around 0.3 hectares.

6.2.4 Conclusion on Partial Undergrounding for the Proposed Interconnector

Partial undergrounding is feasible if:

- The length to be undergrounded is restricted, for technical and operational reason, to less than approximately 10km in one continuous length or an accumulation of shorter lengths; and

- The cost of using the short length(s) of UGC can be proven to be an environmentally advantageous and cost-effective way of overcoming an otherwise unavoidable environmental or technical constraint to the preferred OHL.

Neither EirGrid nor SONI has identified any section of the route of the proposed development where the above applies and are therefore proposing that the entire 400 kV circuit be implemented using 400 kV AC OHL.

[47] Cavan-Tyrone and Meath-Cavan 400 kV Transmission Circuits: Technology and Costs Update – Addendum to the 2009 Report and Supplementary Note – July 2013 by Parsons Brinckerhoff.

7 OVERHEAD LINE (OHL) DESIGN CONSIDERATIONS

7.1 OPERATING VOLTAGE AND CIRCUIT CONFIGURATION

As stated earlier the appropriate nominal capacity for the proposed interconnector is approximately 1,500MVA. It is concluded in **Section 4.6** that the only technological option that provides an acceptable method for achieving the strategic and specific objectives of the proposed interconnector is AC OHL. Based on the foregoing, consideration is now given to the configuration of such an AC OHL development.

The EHV transmission network of the Northern Ireland system although operated at 275 kV, is constructed to a 400 kV standard. These 275 kV double circuits OHL comprise the most robust part of the Northern Ireland network. In Ireland, the 400 kV network extends between the Moneypoint Generation Station in County Clare, and Woodland Substation in County Meath, and Dunstown Substation in County Kildare (both within the Greater Dublin Area), again comprising the most robust part of the transmission network in Ireland. It is entirely appropriate that an interconnection development with a nominal capacity of 1,500MW[48] provide interconnection between the 'most robust parts' of the respective networks namely the existing Woodland 400 kV Substation in County Meath and a proposed new substation adjacent to the existing double circuit 275 kV OHL in County Tyrone (Turleenan) see **Figure 12**.

Consideration has been given to constructing the proposed Interconnector using a double circuit design of 275 kV, matching existing circuit operation in Northern Ireland, thereby meeting minimum technical requirements in the short term. However, such an alternative would have no longer-term or lifetime cost saving in comparison with a single circuit 400 kV option. The 400 kV option will result in better voltage performance and reduced power losses.

[48] The capacity of an OHL is determined by the maximum permitted operating temperature of its electricity conductors (wires). While the maximum operating temperature is mostly influenced by the quantity of electrical current passing through the wires, the ambient temperature and ambient weather conditions are also important factors. In Ireland therefore, OHL have a 'winter rating' based on average winter weather conditions and a 'summer rating' based on average summer conditions. The 'nominal capacity' of an OHL is a rounded off figure, somewhere between the higher 'winter rating' and the lower 'summer rating' and is only used for comparative purposes. As stated previously MVA (megavolt-amperes) is the technically correct unit of measurement for describing the capacity of transmission circuits however in this context and in this document MW is interchangeable with MVA.

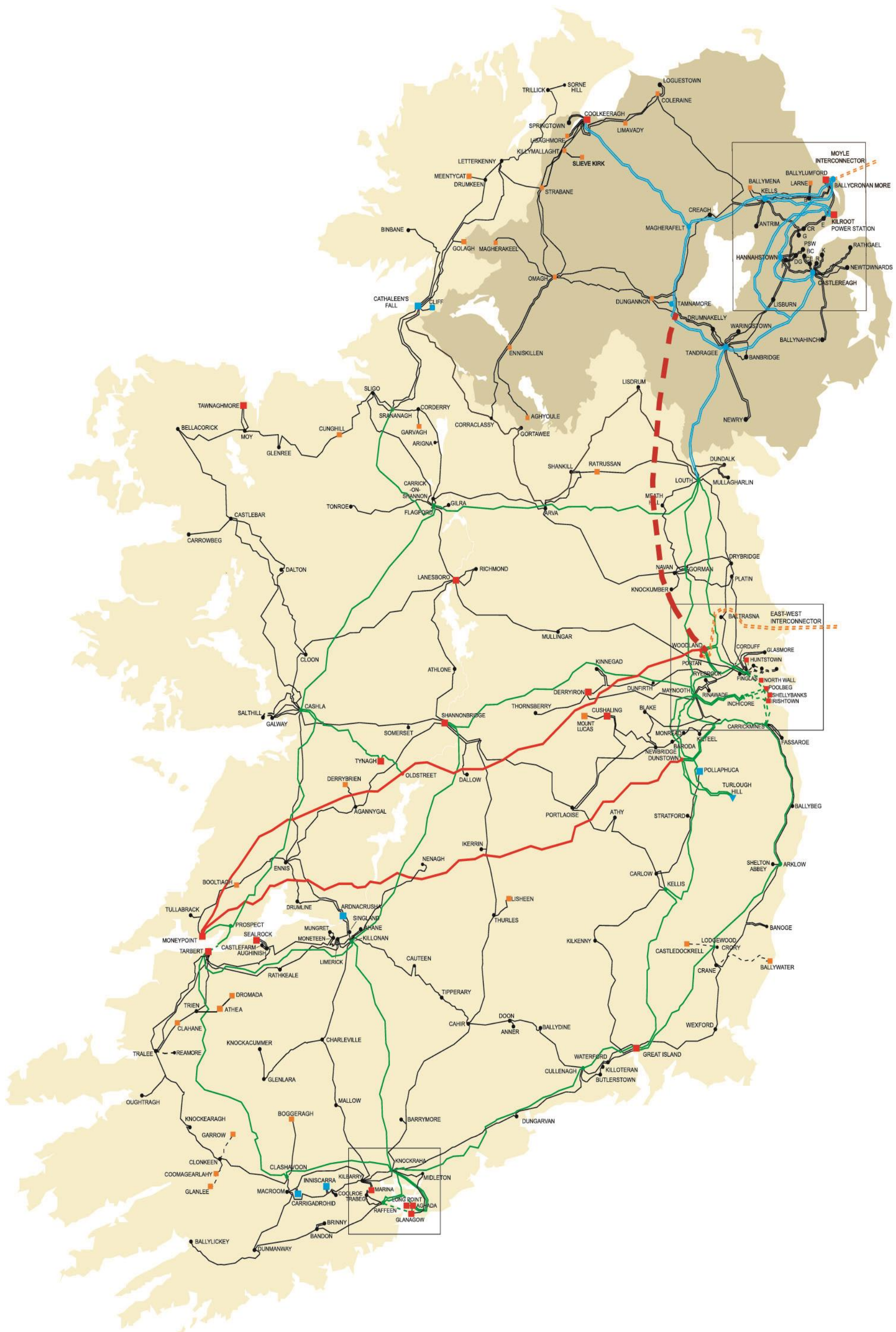

Figure 12: Map Showing Transmission Network and Proposed Interconnector

(The proposed interconnector is indicated in dashed red)

400 kV	220 kV
275 kV	110 kV
DC Interconnector	

The circuit design and operating voltage are both important variables which determine the eventual size, scale, and ultimately, appearance of the support structures that would need to be constructed to facilitate an overhead transmission line. These variables therefore have a direct influence on potential landscape and visual impacts arising from the proposed OHL. It is acknowledged that the scale of a single circuit 400 kV OHL is likely to have a greater environmental impact than a single circuit 275 kV OHL. However, a single circuit 275 kV OHL would not be able to deliver the required 1,500MVA capacity. The towers required for the double circuit 275 kV line that would be necessary in order to deliver the required 1,500MVA capacity would be taller (see **Figure 13**) and likely to therefore have a greater visual impact than those required for a single circuit 400 kV OHL. There would effectively be no difference between the two options in terms of land requirements.

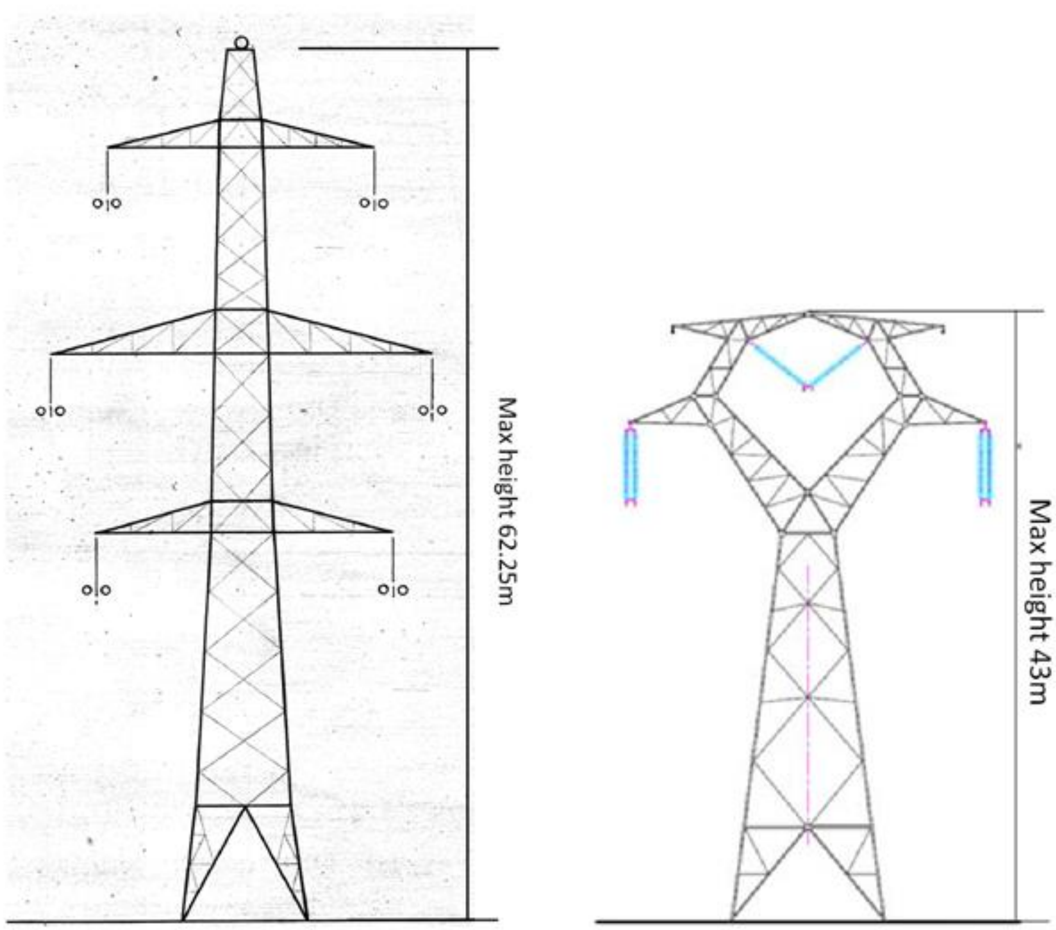

Figure 13: Outline Drawing of a 275 kV Double Circuit Tower and 400 kV IVI Tower

(Not to be scaled **-** for illustrative purposes only)

Overall, having regard to these factors, and including due consideration of environmental impact, EirGrid and SONI jointly determined that a 400 kV single circuit arrangement represented the most appropriate selection for the proposed Interconnector. This conclusion was accepted by both of the relevant regulatory authorities (CER and NIAUR).

7.2 400 KV SINGLE CIRCUIT SUPPORT STRUCTURE: TYPE SELECTION AND DESIGN

The type and design of support structure that is chosen has implications for the maximum achievable span length, angles of deviation and clearance requirements over obstacles (all of which need to be in accordance with the current EirGrid / ESB standards and specifications, which in turn are based on best international practice). Therefore support structure design is an important consideration for the detailed line design process.

7.2.1 Background to Support Structure Selection

In considering alternative designs for the 400 kV OHL support structures, EirGrid commissioned a variety of studies which looked at a range of issues from visual impact on the landscape to electrical considerations. The studies evaluated a range of designs that included a number of lattice steel structures, wooden structures and steel monopole structures. A summarisation of these studies can be found in the *EirGrid / NIE Meath-Tyrone 400 kV Interconnection Development: Tower Outline Evaluation and Selection Report* (October 2009). This report reviews the methods and results of the previous studies.

The studies concluded that wooden structures would not be technically feasible for 400 kV OHLs in Ireland due to the heavy mechanical loading requirements and electrical clearance requirements. Steel monopole designs were found to be technically feasible with some benefits such as a small footprint requiring a reduced corridor width and relatively short construction duration when compared with traditional lattice steel structures. Due to these benefits a steel monopole design has already been used in Ireland to good effect for a 110 kV OHL running through an urban area in Cork (refer to **Figure 14**).

Figure 14: 110 kV Monopole Overhead Line in Cork

On balance however the studies found that for a 400 kV OHL, located in a rural setting in Ireland, a lattice steel structure is preferred. This was on the basis that while monopole designs are sometimes preferred in urban and suburban areas due to a combination of their reduced visual impact and reduced corridor width; the same advantages would not apply for a 400 kV OHL in an entirely rural setting. At 400 kV the superstructure of the monopole design would be a large dense visually intrusive steel pole with a diameter of up to six metres at its base. In addition due to the shorter maximum span that can typically be achieved with a monopole design a greater number of structures are required per kilometre than is the case with the lattice steel design.

Having identified lattice steel as the preferred design for the support structures for the proposed 400 kV OHL, a range of designs was considered in consultation with a designer / manufacturer of lattice steel structures. This resulted in four options being advanced for detailed comparative assessment. These were the classic or standard 401 type structure as used in the mid-1980s for the existing 400 kV OHLs in Ireland and the modern designs of the IVI type, VVV type and inverted delta type (refer to **Figure 15**).

For many stakeholders the visual impact of the proposed development was a significant concern. In recognition of this, a visual assessment report which looked at delivering a reduced visual impact of a 400 kV OHL on the landscape was commissioned by EirGrid from AECOM. The four alternative lattice steel tower designs were subject to a comparative visual impact appraisal and ranked in order of preference.

The four options are illustrated in **Figure 15.** The preferred tower type represents a balance between landscape and visual impacts and technical requirements.

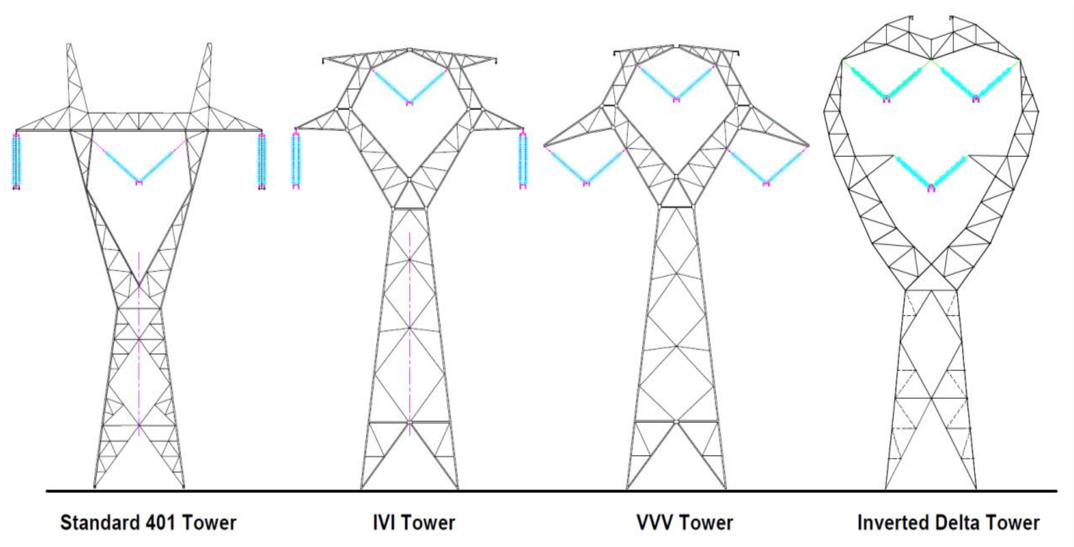

Figure 15: Outline Drawings of Lattice Steel Towers (not to scale)

All of the tower designs were symmetrical in form, with similar weight, footprint and finish. The span lengths were also the same, thereby resulting in a similar frequency of supports along a length of OHL. They also have a similar capacity for flexible routing. The overall height of the towers is also similar with the exception of the Inverted Delta tower type which is some 2.5m taller than the other alternatives.

The main difference in the visual appearance of the towers, and consequently their ability to more or less successfully be accommodated into the landscape, was related to specific design features, density, outline complexity and phasing arrangements. The 401 design features were such that a relatively denser and more complex structure was created, although the phasing arrangement was relatively compact and simple. Tower designs IVI and VVV followed a relatively similar structure, although the phasing arrangement and design density was more complex in tower VVV than IVI, increasing the former’s visual prominence in the landscape. The increased height of the Inverted

Delta tower combined with its greater width and bulk creates the most substantial and visually prominent form out of all the structures.

Tower design alternative IVI had the lowest appraisal score (that is the best score) which was supported by a more qualitative analysis undertaken, including the use of photomontages. For these reasons it was considered to have the lowest visual impact in comparison with the other tower alternatives. As such, tower design alternative IVI was considered as the preferred tower type for the proposed development.

Additional studies examined matters such as foundation design, electrical parameters, insulation coordination and manufacturing processes.

From the results of each study, the following conclusions were made:

- Following the visual impact evaluation performed by AECOM it was considered that the IVI tower design visually imposes least on the landscape.
- It was considered that the costs of the cold formed tower compared to that of its hot rolled counterpart would be higher due to the limited availability of manufactures of this style of tower.
- Visually it was considered that the composite insulator type would have a lesser impact to that of glass insulators and given the comparative cost of both materials be the recommended insulator material to be used.
- Following a foundation study on each of the tower designs the small variation of the size and load of each foundation does not constitute preference of any design.
- In an electrical study performed by SAE Power Lines it was found that from an electrical performance perspective there is not much difference between the four lattice steel options.

From all the studies it was considered that the tower design that would most satisfy all required criteria is a hot rolled steel IVI tower with composite insulators. Accordingly, this tower was adopted as the support structure design for the proposed development.

7.2.2 Review and Confirmation of the Selection of a Single Circuit Support Structure for the Proposed Development

EirGrid reviewed the pre 2009 studies and concluded that the lattice steel structure known as the ‘IVI Tower’ shall be put forward as the emerging preferred option.

It was also noted that in a report by the Government appointed IEC[49] it was concluded that while a high voltage AC OHL *“still offers significantly lower investment costs than any underground alternative”* it “*could also be made more attractive by investing slightly more in new tower designs than the classical steel lattice towers now proposed*[50]”. The IEC also identified that it may be possible to “*reduce the visual impact of traditional lattice steel towers”* by “*painting the steel dark green or another colour somewhat matching the terrain around. This method is efficient to reduce the visibility as most people will see the tower with nature as a background.”* On the basis of the findings of the IEC Report, EirGrid committed to giving further consideration to alternative structures before finalising its preferred project solution.

7.2.3 Re-evaluation of Feasible Alternative Tower Overhead Line Structures

Separately to, and independent of, the proposed development, EirGrid had commissioned the consultants Atkins (with LSTC as sub-consultants) to develop conceptual 400 kV and 110 kV steel monopole designs. In the course of this study, Atkins identified a conceptual design for a single circuit 400 kV steel monopole that is potentially suitable for use on the Irish transmission system.

[49] Available at www.dcenr.gov.ie.
[50] EirGrid considers the Type 401 tower to be the ‘classical’ or ‘traditional’ design for a 400 kV single circuit lattice steel tower. The Type 401 was never proposed for this development instead the modern IVI design with lower visual impact is the preferred option.

Figure 164: 'Atkins' Monopole Design and Proposed IVI Lattice Tower

EirGrid asked ESBI to carry out a comparative assessment of the 'Atkins' monopole versus the IVI tower specifically for use on this proposed development. In addition, as the option was raised by the IEC in its report, EirGrid requested that ESBI comment on the effectiveness of the painting of galvanised steel OHL structures as a visual impact mitigation measure in the Irish landscape in general and for this proposed development in particular.

ESBI concluded that, in general, the 400 kV monopole design identified by Atkins is technically feasible for use on the Irish transmission system, including for use on the proposed development. However, following a comparative assessment of the Atkins monopole versus the IVI tower for use specifically on the proposed development ESBI found that:

- A monopole design may provide some advantages over a traditional lattice steel design when set in an urban or semi-urban landscape. This proposed development however is set entirely within a rural landscape and in such circumstances it is not clear that the Atkins monopole design would provide any advantages over that of the IVI tower design.
- It is considered that due to the nature and size of the monopole structures (which are of similar heights to IVI towers), and the requirement for about 25% more structures in the case of the monopole design, there may be increased visibility.

- The construction effort and consequently the environmental impact of the construction, is considerably greater in the case of the monopoles due to a combination of the larger size and weight of the steel members, the larger foundations and the greater number of structures required.

- The monopole design will be more costly to implement in comparison with the IVI design in terms of raw materials and number of individual structures.

- The programme for delivery of the proposed development will be six to eight months longer if a monopole design is used as opposed to an IVI tower design.

Accordingly, it was recommended that the IVI tower be adopted by EirGrid as the preferred structure for the proposed development.

It was noted that it was technically feasible for a development that consisted primarily of IVI towers to insert monopoles in very specific and localised areas where doing so would result in a lesser impact than that of the IVI towers.

It was also noted that the painting of towers as a camouflage effect and the use of specially treated non-shiny ‘shadow’ conductor can be a mitigation measure in specific situations.

8 CONCLUSIONS

The proposed second North South Interconnector will be of the highest strategic importance for the island of Ireland with a power carrying capacity equivalent to 23% of the island’s peak demand. It will form an internal reinforcement of the single ‘all-island’ network and will operate like any other transmission circuit in the meshed network.

It is on this basis that EirGrid considered the technology options for implementing the proposed development and concluded as follows:

- HVDC technology is not an acceptable option for the specific nature, extent, and intended function of the proposed development.

- Even the use of the latest VSC HVDC technology is not acceptable because it would introduce the very real risk that a mal-operation of its control system could cause a collapse of the entire 'all-island' network resulting in an all island blackout. Taking such a risk is unnecessary when there is a technically superior and lower risk option readily available.

- Implementing the development using VSC HVDC would also be significantly more expensive than a standard AC solution, €670 million more according to the PB Power Report.

For these reasons, EirGrid is proposing a standard HVAC solution and concluded in this regard as follows:

- Undergrounding the entire North South Interconnector by means of HVAC underground cable is not technically feasible as the distance (c. 135 km) is too great. EirGrid's analysis shows that the maximum length of 400 kV AC underground cable that could be accommodated is about 10 km.

- Partial undergrounding may be feasible, but only if the length of underground cable to be installed is relatively short; and where the cost of using the short length of underground cable can be proven to be an advantageous and cost effective way of overcoming an environmental or technical constraint to the preferred overhead line; and where it can be confirmed that the use of underground cable does not exceed the transmission system's capacity to accommodate such cables.

EirGrid is obliged, within the terms of its licence and statutory obligations as TSO, to develop the transmission system using least cost, technically and environmentally acceptable solutions. Based on all of the above and in order to comply with its licence conditions and statutory obligations, EirGrid is proposing that the development is entirely comprised of 400 kV overhead line.

A single circuit 400 kV overhead line is the best technical solution for this development and would be significantly less costly than any underground cable alternative.

EirGrid considered a number of options for the design of the proposed 400 kV single circuit overhead line and concluded that the preferred support structure is the lattice steel structure known as the 'IVI' tower.

APPENDIX

Table A - Reports on Alternative Transmission Technologies Commissioned by EirGrid

Report Title	Context of Report	Main Findings / Observations of Report
Table A1 ***PB Power Preliminary Briefing Note -*** *Island of Ireland Cavan-Tyrone and Meath - Cavan 400 kV projects Preliminary Briefing Note Overhead and Underground Energy Transmission Options* Prepared by Parsons Brinckerhoff this was issued as an interim report **February 2008**	The *Preliminary Briefing Note* sets out a comparative overview of the technical and economic issues arising in respect of OHL and UGC transmission infrastructure options, with particular reference to the proposed Tyrone to Cavan element of the proposed interconnector. The document notes that both OHL and UGC technologies are proven in service, but includes a number of observations. The Briefing Note focused primarily on HVAC technology. The document did not include a review of HVDC technology because, at this early stage in the project, it appeared that the high land-take and high costs of terminal stations would not offer any benefits over the AC solutions.	UGC technology has not yet been tried anywhere in the world for an appropriate transmission infrastructure circuit approaching the route length of that proposed. HVAC OHL technology accounts for over 99% of Extra High Voltage (EHV) transmission infrastructure worldwide as it is considered to represent the best balance from an economic, technical and environmental perspective. UGC technology is noted to play an important role in urban and congested areas, or where site specific environmental constraints occur, for example within an area of outstanding scenic beauty. UGC technology is significantly more expensive than OHL technology. There can be considerable variation in cost ratios dependent upon the terrain and the circumstances. The Briefing Note stated that further work would be undertaken to examine the specific feasibility issues relevant to the prospect of undergrounding the proposed interconnector.

Report Title	Context of Report	Main Findings / Observations of Report
Table A2 **The PB Power Study -** *Cavan-Tyrone and Meath-Cavan 400 kV Transmission Circuits Comparison of high-voltage transmission options: Alternating current overhead and underground, and direct current underground* Prepared by Parsons Brinckerhoff **February 2009**	This study considers use of alternative technologies for the proposed interconnector. It makes two sets of comparisons: • HVAC UGC as an alternative to the proposed HVAC OHL; and • HVDC UGC as an alternative to the proposed 400 kV HVAC technology. In each case the comparison of the technologies addresses routing feasibility, high-level environmental considerations, and the installation and cost differences that would be associated with the alternatives.	HVAC OHL transmission is the most widely used method of bulk power transfer in Europe and represents the lowest cost technically feasible approach to establishing and maintaining a secure electrical power grid. Global transmission development activity suggests that this preference by utilities for the use of OHLs is likely to persist into the future. The longest XLPE transmission cable (in the range 380 kV to 500 kV) is 40km and runs in a tunnel. If implemented using AC UGC the proposed interconnector would be the longest such cable circuit worldwide at approximately 135km. HVAC OHLs are susceptible to environmental effects and thus normally exhibit fault rates higher than those of UGC circuits. However, average repair times of UGC are much higher than those of OHL. High voltage UGC has the capacity to inflict considerable short term (construction period) and long term operational negative impact on the environment - however, mitigation measures can be put in place. Both high voltage OHL and UGC produce power frequency magnetic fields whose strengths would be directly proportional to the electrical load being carried at any instant. The insertion of a HVDC transmission circuit into the HVAC transmission network would introduce more system complexity than an HVAC OHL. Cost estimates for each option were calculated. The construction cost estimate for the UGC option was calculated by firstly identifying a potential route for the UGC alternative from County Meath to County Tyrone**;** then identifying the different types of landscape along this route as well as all rivers and roads that would have to be crossed; then calculating a cost per km per landscape type, a cost per major and per minor river and road crossing and using this data to build up a cost for installing UGC along the entire route.

Report Title	Context of Report	Main Findings / Observations of Report
		The cost of the OHL option was calculated by estimating a cost per km for 400 kV OHL (based on PB Power's international experience) and multiplying this by the length of the OHL in kilometres. Whole–of-project cost estimates (construction and lifetime running costs) for high voltage AC and DC UGC compared to 400 kV OHL shows OHL to be significantly more cost effective.
Table A3 **The TEPCO Technical Study** *Assessment of the Technical Issues relating to Significant Amounts of EHV Underground Cable in the All-Island Electricity Transmission System* Prepared by Tokyo Electrical Power Company of Japan (TEPCO) **November 2009**	EirGrid commissioned TEPCO to undertake a system-wide study that considers the implications, for transmission system reliability and stability, of incorporating very long lengths, and large quantities, of HV UGC transmission infrastructure on the AC transmission network of the island of Ireland. The Study was carried out in 3 parts: Part 1: Evaluation of the potential impact on the all-island transmission system of significant lengths of EHV UGC, either individually or in aggregate. Part 2: Feasibility study on the 400 kV Woodland – Kingscourt – Turleenan line as AC UGC for the entire length. Part 3: Feasibility study of the 400 kV Woodland – Kingscourt – Turleenan line as mixed OHL / UGC.	The study concludes: Part 1: Identified a potential for the occurrence of 'severe' Temporary Overvoltage's (TOVs) which would exceed the withstand capability of the installed equipment. The Study concludes that the magnitude of these TOV's is such that there are no technical solutions currently available to mitigate this risk and the only option available would be to use operational counter measures. Part 2: To achieve the required 1,500MW capacity, the optimum UGC solution is a 400 kV double circuit 1,400mm^2 aluminium cable - requiring a total of 2,600MVArs (1,300MVArs per circuit) of reactive compensation would be required at the proposed terminal points and an additional reactive compensation installation approximately half-way between Turleenan and Moyhill (Kingscourt). Part 3: No significant TOVs were identified for the mixed OHL / UGC. However, further detailed studies relating to the particular positions and lengths of cable sections in order to determine the measures that may be taken to ensure safety and stability from the overall circuit would be necessary.

Report Title	Context of Report	Main Findings / Observations of Report
Table A4 **The TransGrid Study** - *Investigating the Impact of HVDC Scheme in the Irish Transmission Network* Prepared by TransGrid solutions Inc. of Canada **October 2009**	The study involved a technical comparison of HVAC OHL versus HVDC UGC and one section dealt in particular with the proposed Meath-Tyrone 400 kV Interconnection Development.	There are no working examples in the world of a multi-terminal HVDC scheme, embedded in a meshed AC network as would be required for the proposed Meath-Tyrone Interconnection Development. Such a scheme is however in theory at least, technically feasible. Having carried out a technical comparison of HVDC versus HVAC technology for this proposed development it was found that there are no significant reasons to select HVDC over HVAC. The AC option showed significantly lower loses, fewer overloads in the Louth / Tandragee / Turleenan area, a stronger system at the Moyle Interconnector terminal and a less complex control and protection scheme. Embedding a HVDC circuit in a meshed AC network "*can impose an added complexity to future network planning and expansion. For instance when planning the system it is difficult and expensive to tap into an existing HVDC circuit whereas an AC circuit can be easily tapped to serve new load or build a new AC station and lines.*" A technical comparison of the two technologies (HVAC and HVDC) concluded that, for the scenarios and contingencies studied, there were no significant technical advantages identified for the use of a HVDC circuit in place of the HVAC circuit proposed.

Report Title	Context of Report	Main Findings / Observations of Report
Table A5 **The PB Power Technology and Cost Update -** *Comparison of High Voltage Transmission Options: Alternating Current Overhead and Underground and Direct Current Underground* [This is an addendum to the 2009 PB Power Study and should be read in conjunction with that 2009 report] **April 2013**	EirGrid and NIE requested PB Power to update their 2009 report to take account of scientific advances in the development of new, feasible transmission technologies, and also to review the cost estimates for practical transmission configurations. The updated PB Power Report does not revisit the landscape aspects and most of the technical aspects as these remain unchanged. The *PB Power Electricity Transmission Costing Study* published in 2012 by the UK Department of Energy and Climate was used as a source of information for the technology and cost update.	The most cost effective solution for the proposed scheme would be a 400 kV AC OHL, estimated to cost around €165 million to construct A 400 kV AC UGC is estimated to cost €935 million, or over 5.7 times as much as an equivalent OHL to construct, and would also cost significantly more than an OHL to operate and maintain over its lifetime. A HVDC UGC is estimated to cost €1,005 million, or 6 times as much as an equivalent 400 kV AC OHL to construct, and twice as much as an OHL to operate and maintain over its lifetime.

Report Title	Context of Report	Main Findings / Observations of Report
Table A6 **The PB Power Technology and Cost Update –** Cavan-Tyrone & Meath-Cavan 400 kV Transmission Circuits Technology and costs Update**.** *Supplementary Note to the April 2013 Addendum* **July 2013**	In April 2013 EirGrid published its *Final Re-evaluation Report* and at the same time announced its decision to defer the previously proposed intermediate substation near Kingscourt, Co. Cavan. A consequence of the deferment of this substation, regardless of which technology option is chosen, is that it would reduce the initial investment required to develop the interconnector so EirGrid requested PB to provide, in a supplementary note, an indication of the impact of the deferment on the initial investment.	The most cost effective technology option remains a 400 kV AC OHL, estimated to cost around €140 million. With the deferment of Kingscourt, 400 kV AC UGC becomes the most costly option, estimated at around €880 million, or €740 million more than the equivalent AC OHL. The deferment of Kingscourt has little or no impact on the cost differential with the AC OHL as similar costs are deferred in the case of both options. The deferment of the substation near Kingscourt will however have a significant impact on the initial investment required to develop the HVDC option. This is due to the very high cost of HVDC converters, and the fact that, with the deferment, converters would only be required initially at Turleenan and Woodland not Kingscourt. Under this scenario, the HVDC option, at an estimated cost of around €810 million, is no longer the most costly option. It is still, however, €670 million more costly than the least cost option, the 400 kV AC OHL. The initial investment cost of the HVDC option is reduced, due to the deferment of the substation near Kingscourt, by around €160 million (€970M - €810M), whilst the initial investment costs of the two AC options are only reduced by around €20 - €25 million. The disparity of the effects on the AC and HVDC options highlights one major disadvantage of the HVDC option for the Ireland N-S Link. This is that, if the N-S Link is developed using HVDC technology, future 'tap-ins' to the circuit for the substation near Kingscourt and / or for some other (as yet unknown) requirement at some other location along the route, will be many times more expensive than tapping into an AC circuit.

Table B - Reports Commissioned by Government on Alternative Transmission Technologies

Report Title	Context of Report	Main Findings / Observations of Report
Table B1 **The Ecofys Study -** *Study on the Comparative Merits of Overhead Electricity Transmission Lines versus Underground Cables* Prepared by Department of Communications, Energy and Natural Resources (DCENR) **May 2008**	The aim of the study was to provide the best available professional advice on the relative merits of constructing and operating OHL compared to UGC, having regard to technical characteristics, reliability, operation and maintenance factors, environmental impact, possible health issues, and cost.	Globally the vast majority (approximately 99.5%) of UGC is generally used in areas of high population density or high land values – generally urban areas - where it is difficult to find suitable OHL routes. International experience shows that extra high voltage (EHV) UGC is generally not used for any great distance, e.g. the longest such UGC is in Tokyo and is only 40km in length. Whilst decisions may be taken to underground lower voltage networks of distribution systems, this is not normally applied to the higher voltage networks of transmission systems, as the technology involved is substantially different and more demanding. Both EHV UGC and OHL are found to have an environmental impact but these impacts are different for the different technologies, and in most cases mitigation measures are available, e.g. UGC has a greater impact on water resources and soils and geology, whereas OHL has a greater impact on Landscape and Visual and Communities. The study distinguishes between the perceived health risks associated with Electro-Magnetic Fields (EMF) and actual health risks associated with EMF and cites the International Commission of Non-Ionising Radiation Protection (ICNIRP) recommendation. The study concludes that the construction and operation of an EHV UGC in Ireland with a length of 100km would not be backed by worldwide experience. Mitigation measures are proposed to reduce the potential impact of the planned Interconnector on the environment.

Report Title	Context of Report	Main Findings / Observations of Report
Table B2 **The IEC Report** - *Meath- Tyrone Report Review by the International Expert Commission* August – November 2011. *(A review of the case for, and cost of undergrounding all or part of the Meath-Tyrone 400 kV Interconnection Development*.) Prepared by Normark B., et al. **November 2011**	In July 2011 the Minister for Communications, Energy and Natural Resources appointed the IEC to:- Examine the case for, and cost of, undergrounding all or part of the Meath–Tyrone 400 kV line (now known as the North-South 400 kV Interconnection Development); Review expert literature already available both in Ireland and internationally in relation to undergrounding high voltage [HV] power lines; Consider the route or routes proposed by; and Consult with EirGrid, the North East Pylon Pressure Committee and the County Monaghan Anti-Pylon Committee, and other bodies / organisations.	The main findings of the report are as follows:- Based on an analysis of a number of different high capacity transmission projects in Europe, it is clear "*that there is no single "right" solution. Each project must be judged on its own merits and hybrid solutions, i.e. combining different technologies, have been applied in many cases, for instance partially undergrounding a link. A specific technical solution must be derived accounting for local conditions*"; There have been advances in transmission technology in recent years, examples being "*the development of VSC HVDC technology and its deployment in transmission projects and the introduction of new tower designs for overhead lines*"; The only recommendation the IEC made was "*against fully undergrounding using an AC cable solution*"; While the report does not recommend that the interconnector be undergrounded it does find that if the interconnector has to be undergrounded for all, or a significant portion, of its length then with today's technology the best solution would be "*a VSC HVDC solution combined with XLPE cables*"; and The report concludes that a high voltage AC OHL solution for the proposed interconnector still offers "*significantly lower investment costs than any underground alternative and could also be made more attractive by investing slightly more in new tower designs than the classical steel lattice towers now proposed".*