North-South Interconnector Project
Independent Experts Review 2021

Index

Executive Summary

In 2021 a new independent International Expert Commission (IEC2021) has been set up by the Irish Department of the Environment, Climate & Communications (DECC) to undertake a review of the North-South Interconnector (NSIC) project with the following purposes:

- To assess whether the principal findings of the "Independent study to examine the technical feasibility and cost of undergrounding the North-South Interconnector: Update by the International Expert Commission" from October 2018 (IEC2018) remain valid; this Part should take note of the principal findings contained in the 2012 Report by the International Expert Commission (IEC2012);

- To engage with EirGrid and ask to provide a list of conclusions and recommendations set out in previous reports conducted/commissioned by it on the NSIC.

The IEC2021 highlights and confirms that it has drafted this report fully independently and without any conflict of interest with the counterparts.

The IEC2021 has received full collaboration and has had fruitful and open discussion with both parties of DECC and the Transmission System Operator EirGrid.

The IEC2021 has made a detailed review of previous IEC2018/IEC2012 reports and different past studies on NSIC.

The IEC2021 has stated in its conclusions that the set of five alternatives considered by IEC2018 for the implementation of the North-South Interconnector project is the most appropriate, up-to-date, technically feasible and in line with the International Best Practice.

The screening criteria considered by IEC2018, which ruled out the applicability of UGC (underground cable) in HVAC (High Voltage Alternating Current) technology with UGC in excess of 10 km, full HVAC UGC, GIL (Gas Insulated Line) as well as LCC (Line Commutated Converter) technology for HVDC (High Voltage Direct Current) OHL (overhead line), are considered correct based on the International Best Practice, IEC2021 experience and other transmission project pre-feasibility studies.

The IEC2021 agrees on the feasibility of an HVAC OHL option with towers design having a less intrusive visual impact, however it underlines that this would come with higher (up to double) investment costs for such HVAC OHLs with respect to standard HVAC OHL solutions.

The IEC2021 agrees with the conclusion that HVDC UGC, based on VSC (Voltage Source Converter) technology, as embedded VSC-HVDC UGC, and HVAC OHL are the only options to be considered for the NSIC project.

The IEC2021 has acknowledged the considerable effort by EirGrid in estimating the investment costs of implementation for NSIC, including investment cost revision over this decade, and agrees on the investment cost differences of the two alternatives.

The IEC2021 has taken account of the EirGrid concern about operational complexity increase by an embedded HVDC technology application for the NSIC project in the All Island Transmission system context: the HVDC technology is in fact accounted by EirGrid for in the "Shaping our electricity future" project study in a 'non embedded' configuration. On the other hand, EirGrid has gained several years of operational experience with VSC-HVDC technology by EWIC interconnector. On this matter, the IEC2021 believes, also based on the outcomes of technical studies carried on in this decade on NSIC itself and on other projects, that this complexity can now be managed, given the advancements in VSC technology, increase of commissioned VSC applications and operational experiences worldwide: the VSC-HVDC option should not be ruled out for future projects.

The IEC2021 has evaluated some positive and useful elements of the multi-criteria approach applied by EirGrid in the decision-making process of alternatives for NSIC.
In this regard, also given the ongoing NSIC planning stage, the IEC2021 has taken into due account that the final qualitative score of EirGrid multi-criteria table has been the fundament for the decision-making process of Transmission Alternative.
However, while acknowledging the final outcome, IEC2021 is of the opinion that in the future not only qualitative but more quantitative elements and evaluations shall be introduced in the Cost Benefit Analysis for the assessment of Grid Investment Alternatives, as well as the Operational Impact of HVAC & HVDC technologies.

1. Introduction

The present report has been prepared by an independent International Expert Commission (IEC), newly set up in 2021 (hereby IEC2021) by the Irish Department of the Environment, Climate & Communications (DECC) and composed of the experts, Mr. A. L'Abbate and Mr. A. Mansoldo, to undertake a review of the North-South Interconnector (NSIC) project. The review task by the IEC2021 follows the previous review activities, carried out in 2018 and 2012 on NSIC project by other two independent International Expert Commissions (IEC2018 and IEC2012, respectively).
In the following, background and scope of work are briefly introduced.

1.1. Background

The North-South Interconnector (NSIC) has been proposed for development on the island of Ireland in the form of a 138 km 400 kV single circuit overhead line (OHL): this project is critical to improving the efficient operation of the integrated Single Electricity Market of Ireland and Northern Ireland and to increasing security of electricity supply to customers across the island of Ireland. The North-South Interconnector has now been fully approved by the planning authorities in Ireland and Northern Ireland.
Several studies have been carried out on the project, most recently an independent study into the technical feasibility and cost of undergrounding the North-South Interconnector published by the Department of the Environment, Climate and Communications in October 2018.

1.2. Scope of Work

An independent review of work previously carried out in relation to whether the project should be delivered by way of an overhead line or underground cable is now being undertaken. The output of this will be a report structured as follows:

- Part 1: an assessment as to whether the principal findings of the "Independent study to examine the technical feasibility and cost of undergrounding the North-South Interconnector: Update by the International Expert Commission" from October 2018 remain valid. This Part should take note of the principal findings contained in the 2012 Report by the International Expert Commission.

- Part 2: EirGrid will be asked to provide a list of conclusions and recommendations set out in previous reports conducted/commissioned by it on the NSIC.

2. North-South Interconnector project history

A brief history of the North-South Interconnector project is worth initially to account for the decision-making process undertaken by EirGrid starting from 2007. With reference to Figure 1, analyses have been undertaken from the technical and economical point-of-view considering also alternative routes in case of usage of underground technologies.
In particular, as per technical and economic studies it is worth to underline that in 2009 two detailed technical analyses have been carried out on the Irish Transmission system when using UGC technology both HVAC and HVDC.
In addition, costs associated with the implementation of the project in case of AC technology have been calculated both for OHL line and UGC AC technology in 2009.
Also, in 2013 a cost update has been performed based on the 2009 study on economic comparison.

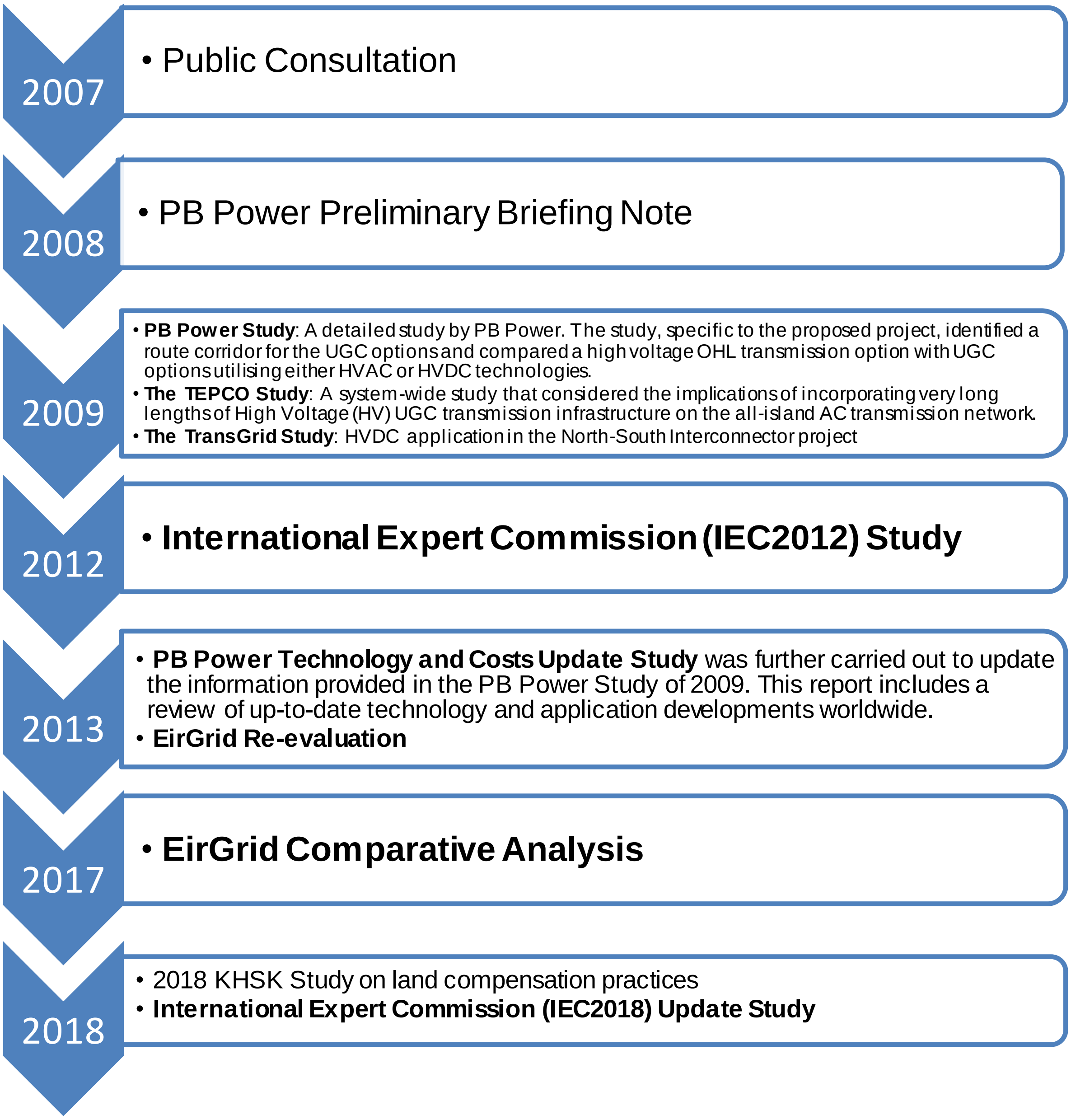

Figure 1. North-South Interconnector project history

Based on the different studies outcomes, including the review on the potential technological options performed by the IEC2012, EirGrid has produced in 2017 a comparative analysis among technologies in order to apply a multi-criteria approach in the decision-making process.
A further economic analysis on land compensation and international practices has been considered and produced in 2018.
Finally, a new 2018 revision has been performed by the IEC2018, where a techno-economic comparison of different technological options has been initially taken into account, including AC, DC underground and the Gas Insulated Line (GIL) technology.

The outcomes of the different studies commissioned and published by EirGrid over the years are summarised in the following sections, taking into due account the key aspects and recommendations highlighted by EirGrid.

2.1. PB Power Preliminary Briefing Note 2008

In 2008 PB Power prepared a short report, published at an early stage in the project development process, to summarise in general terms the technical and cost issues associated with implementing the proposed transmission circuit.
Table 1 reports the key elements of the report as highlighted by EirGrid.

Table 1. Key elements of PB Power Preliminary Briefing Note 2008

Report Title	Context of Report	Main Findings / Observations of Report
***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.

2.2. PB Power Study 2009

A detailed study was prepared by PB Power following the publication of its 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.

Table 2 reports the key elements of the study as highlighted by EirGrid.

Table 2. Key elements of PB Power Study 2009

Report Title	Context of Report	Main Findings / Observations of Report
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.
		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.

In addition, several other important elements can be extracted from the PB Power Study 2009 and highlighted, as reported in the following.

Excerpts about conclusions HVAC UGC vs. HVAC OHL

"240. Robust reliability statistics for transmission OHL and UGC are difficult to obtain for a number of reasons. However, overhead lines are susceptible to environmental effects and thus normally exhibit fault rates higher than those of cable circuits. An underground cable circuit is thus normally more reliable than its equivalent overhead line.

241. However, average repair times for cables are much higher than those for OHL, being measured in weeks rather than hours. From European statistics, availability over the long term of 140 km OHL would be expected to be around 99.8% pa compared to 90.3% for the same length of UGC. Two such UGC circuits in parallel (as could be chosen if the UGC

installation comprised 2 cores per phase) would be expected to achieve 99.1% between them.

242. Thus, even a double circuit UGC performance would not match that of the single circuit OHL, having an expected unavailability of 0.9%, that is, 4.5 times worse than the 0.2% unavailability of the OHL.

243. System security all over Europe relies upon the relatively high availabilities provided by OHL networks. The introduction of significant quantities of UGC in strategic transmission routes may thus compromise system security to the extent that additional circuits may need to be built.

244. Significant reactive compensation would be required for the Project if an UGC solution was to be chosen. Many alternative designs are practicable, but the assumptions of this report allow for relatively small compensator installations at each of the three substations and at three intermediate locations along the 140 km route. This approach would facilitate transport into locations remote from major roads and would tend to reduce the cost of cable insulation (because peak operating voltages along the circuit would be lower). In addition, it would simplify any strategic spares strategy for this important part of the installation.

245. The additional capacitance added to any system by UGC would have the effect of lowering the frequencies at which the system resonates. System resonance can result in equipment damage, so detailed design would need to ensure that appropriate solutions are included within the Project design. There is a potential impact on a total UGC project cost of up to 2% or 3%.

246. OHL produces power frequency electric fields which are relatively stable in time. The proposed OHL would produce a maximum field strength of around 8.3 kV/m, which is lower than the European and Irish adopted ICNIRP Basic Restriction guideline limit of 9 kV/m. The field strength would drop to about one tenth of its maximum at about 35 m from the centreline of the OHL.

247. Both OHL and UGC produce power frequency magnetic fields whose strengths would be directly proportional to the electrical load being carried at any instant. The magnetic fields from the OHL and the UGC would have maximum strengths (at full load) of around 48μT and 68μT respectively. These are both much lower than the European and Irish adopted ICNIRP Basic Restriction guideline limit of 360μT. Under normal circumstances the maximum magnetic field strengths to be found near the circuit would be much lower than these maxima, since the circuit would only run at full load under emergency conditions. Moving away from the centreline of the circuit, the OHL and UGC field strengths would have dropped to one tenth of their values at around 45 m and 8 m respectively.

248. Long UGC installations can have a negative impact upon system complexity, due to the introduction of circuit ancillary equipment, including reactive compensation and associated protection systems.

249. OHL is seen to be much more flexible over the long term than UGC. Upgrades to OHL current carrying capacity or circuit voltage, and modifications to the system topology, would be at lower cost and would require shorter outages than would be the case for UGC."

Excerpts about Conclusions on HVDC Technology

"311. Successful application HVDC transmission within a meshed all-island network would depend upon a considerable amount of HVAC equipment and a sizeable converter station installation at each of its connecting points to the HVAC network

312. Complex control algorithms would be required to allow it to respond appropriately to the conditions of the existing AC network. For this, and for other reasons, an HVDC solution would introduce more system complexity than an HVAC OHL.

313. HVDC terminal stations would require more planned maintenance outages than their HVAC equivalents. In addition to any equipment failures, system operators would need to plan for around 18 days each year when the HVDC bipole link would be running at 50% capacity, and around a further 2 days each year when it would not operate.

314. The proposed Project would double the Northern Ireland - Republic of Ireland interconnector capacity so, during any period when the Project connection is out of service, the available interconnector transfer capacity would be halved. In this circumstance the significant annual maintenance periods of HVDC would represent an operational disadvantage.
315. A new and substantial strategic spares holding of HVDC equipment would probably need to be established to maintain the quoted availability.
316. For these technical reasons HVDC is not recommended over the proposed OHL connection."

2.3. TEPCO Study 2009

A detailed analysis was conducted as 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) that, as owner and operator of one of the world's longest existing HVAC UGC circuits operating at a voltage of 400 kV or above, is uniquely placed to bring its specific experience to bear on the subject. It considers different combinations of HVAC OHL and HVAC UGC options.
Table 3 reports the key elements of the study as highlighted by EirGrid.

Table 3. Key elements of TEPCO Study 2009

Report Title	Context of Report	Main Findings / Observations of Report
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.

In addition, some detailed and important elements can be extracted from the TEPCO Study 2009 and highlighted, as reported in the following.

Excerpts on HVAC UGC performance

"The results of this thorough study concluded that with regards to the long cable network an attention must be paid to lower frequency phenomena such as temporary and steady-state overvoltages. The slow-front overvoltage is not a concern for the safe operation of the network because of the decay in the cable and large capacitance of the cable. For example, dominant frequency components contained in the energisation overvoltage are not determined by the propagation time of the overvoltage as it is often discussed in the textbooks that deal with surge analysis. They are rather determined by parallel resonance frequencies and are often very low due to the compensation.

Severe overvoltages were found in the parallel resonance overvoltage analysis in studies Part 1 and Part 2. Both of them exceeded the withstand overvoltage of a typical 400 kV surge arrester. The magnitude of the overvoltage found in Part 1 is at a level in which there is no solution except from operational countermeasures. In contrast, manufacturers will be able to develop a surge arrester that can withstand the overvoltages found in Part 2. It will, however, lead to higher protective levels ensured by the surge arrester, which may affect the insulation design of other equipment. These additional costs need to be evaluated by manufacturers. Finally, it will of course affect the total insulation coordination studied by the utilities.

[..]
Generally speaking, temporary overvoltages, such as the resonance overvoltages and the overvoltages caused by load shedding are low probability phenomenon. Only certain, particular network operating conditions can yield such a severe overvoltage that they would lead to equipment failure. Evaluating a low-probability high-consequence risk is difficult but must be done when installing cables. The risks may be avoided via carefully prepared operational countermeasures, but unfortunately it will be a major burden for system analysts."

2.4. TransGrid Study 2009

A detailed analysis was conducted as 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 between Republic of Ireland (RoI) and Northern Ireland (NI).
Table 4 reports the key elements of the study as highlighted by EirGrid.

Table 4. Key elements of TransGrid Study 2009

Report Title	Context of Report	Main Findings / Observations of Report
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.

It is important to highlight that the analyses carried out in the TransGrid Study 2009 regarded different scenarios and cases: considering the NSIC, the studied Scenario 2/Scenario 3 compared a 400 kV HVAC line, a three-terminal line-commutated converter (LCC) HVDC system and a three-terminal voltage source converter (VSC) HVDC system, to connect Northern Ireland to the Republic of Ireland with terminals at Turleenan, mid Cavan and Woodland. The scheme was then the one connecting three substations/terminals, with an intermediate substation/terminal.

In addition, some further elements and important details can be extracted from the TransGrid Study 2009 regarding in particular Scenario 2 and highlighted, as reported in the following.

Excerpts on technological options performance comparison

"One thing to note about the contingency analysis is that power flow case 2.2 (summer peak 1500 MW RoI-NI) in particular had many diverged power flow cases especially in the AC option load flow (see the excerpt in Table 5). The LCC option had fewer diverged cases than the AC option and the VSC had by far the fewest of all. After investigation into the particular contingencies that had difficulty in converging, it is thought that power flow case 2.2 may have a lack of reactive power support and hence many "blown up" solutions in the contingency analysis. "Blown up" refers to diverged power flow solutions. For this reason it is difficult to assess exactly what is happening in the blown up solutions and whether or not real voltage violations/collapse exist, or whether it is simply a solution convergence problem. Because this problem is occurring mainly in the AC option of power flow case 2.2, mitigation options were not specifically investigated because it is a base case issue. However it should be noted that the HVDC options, particularly the VSC option, show improvement in solution convergence, possibly because the VSC option provides AC voltage control with a significant range of reactive power support. Several of these contingencies were tested in dynamics and were found to be stable."

Table 5. Excerpt from TransGrid Study 2009 on diverged power flow cases in Scenario 2

CONTINGENCY	AC Option	LCC Option	VSC Option
Scenario 2.1			
none			
Scenario 2.2			
DUBLINBP	Blown up	Blown up	-
IKERRIN_T	Blown up	Blown up	Blown up
AGHADA-CAHIR 380	Blown up	-	-
DUNSTOWN-LAOIS 380	Blown up	Blown up	-
FLAGFORD-CAVAN 380	Blown up	Blown up	-
LAOIS-WMD_400 380	Blown up	Blown up	-
CAVAN-WOODLAND 380	Blown up	-	-
MONEYPOINT-OLDSTREET 380	Blown up	Blown up	-
MONEYPOINT-WMD_400 380	Blown up	Blown up	-
WOODLAND-OLDSTREET 380	Blown up	Blown up	-
BALLYCRONAN 275	Iteration limit exceeded	Blown up	-
CASHLA-FLAGFORD 220	Iteration limit exceeded	-	-
CASHLA-PROSPECT 220	Iteration limit exceeded	-	-
CARRICKM-CHARLESLAND 220	Blown up	Blown up	-
DUNSTOWN-TURLOUGH 220	Blown up	-	-
CAVAN-FLAGFORD 220	Blown up	-	-
FLAGFORD-SRANANAGH 220	Blown up	-	-
FINNSTOW-MAYNOOTH 220	Blown up	-	-
INCHICOR-POOLBEG 220	Blown up	-	-
MAYNOOTH-KINNEGAD 220	Blown up	-	-
PROSPECT-TARBERT 220	Iteration limit exceeded	-	-
SHANNONB-WMD 220	Blown up	-	-
CAHIR-KILL HILL 110	Blown up	Blown up	Blown up
KILL HILL-THURLES 110	Blown up	Blown up	Blown up
CUNGHILL-OUNAGH 110	Iteration limit exceeded	-	-
CUNGHILL-SLIGO 110	Iteration limit exceeded	-	-
LANESBOR-MULLINGA 110	Blown up	-	-
LOUTH-RATRUSSA 110	Iteration limit exceeded	-	-
LOUTH CAP 110	Iteration limit exceeded	-	-
NAVAN CAP 110	Iteration limit exceeded	-	-
RATHKEAL-TARBERT 110	Iteration limit exceeded	-	-
THORNSBE-MOUNT LUCAS 110	Iteration limit exceeded	Blown up	-
FLAGFORD 3WDG TRANSFORMER	Blown up	-	-
TURLEENAN-MID CAVAN 380	Blown up	-	-
CHARLESLAND 3WDG TRANSFORMER	Blown up	Blown up	-
CHARLESLAND 3WDG TRANSFORMER	Blown up	Blown up	-
FINGLAS 3WGD TRANSFORMER	Iteration limit exceeded	-	-
FINGLAS 3WGD TRANSFORMER	Blown up	-	-
IRISHTOWN-DUBLIN BAY 220	Blown up	Blown up	-
ATHLONE TRANSFORMER 110	Iteration limit exceeded	-	-
ATHLONE TRANSFORMER 110	Iteration limit exceeded	-	-
SALTHILL TRANSFORMER 110	Iteration limit exceeded	-	-
TULLABRA TRANSFORMER 110	Iteration limit exceeded	-	-
MAGH_TAMN	Iteration limit exceeded	-	-
LOUTH-CAVAN 220	-	Iteration limit exceeded	-
Scenario 2.3			
LOUTH-RATRUSSA 110	-	-	Iteration limit exceeded
Scenario 2.4			
BELLACORICK-CASTLEBE 110	Iteration limit exceeded	Iteration limit exceeded	-

(*) Note that a "-" in the table indicates a converged power flow solution for the particular contingency.

2.5. IEC2012 Review Study

A review study, published in 2012[1], was conducted by the independent International Expert Commission (IEC), appointed by the Irish Government and recalled as IEC2012. In its report, **the IEC2012 did not recommend any solution as such. However, the IEC2012 recommended against fully undergrounding using an HVAC cable solution. The IEC2012 noted that, if the option is to underground the connection along the whole, or main part of the route, with the technology available at the time, the best solution would be a voltage source converter (VSC)-based HVDC solution combined with cross-linked polyethylene (XLPE) cables**. The IEC2012 also stated that the best cable route is the one that may follow existing infrastructures such as highway tunnels or railroads, or through farmlands, as the width of the HVDC cables trajectory is rather smaller than the one needed for HVAC cables. In difficult terrain for undergrounding, another option could be the use of HVDC OHL.

[1] The study was carried out in the second half of 2011.

The IEC2012 additionally stressed that an HVAC overhead line 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 rather than the classical steel lattice towers, at least for part of the route.

Moreover, several other important elements can be extracted from the IEC2012 review study and highlighted, as reported in the following.

Excerpts about TransGrid Study 2009

"The Studies show that the HVAC (OHL) and HVDC options are all technically feasible and each option could be integrated into the network provided that relevant protection, control and telecommunication systems for these HVDC technologies and their interactions are sufficiently robust to maintain the safety, reliability and security of the Irish Network."

"VSC-HVDC technology is technically feasible and has "improved dynamic voltage performances" compared to the HVAC (OHL) alternative. Adding STATCOM to the HVAC (OHL) alternative as suggested by TransGrid Study 2009 would add significant costs since the cost of a STATCOM is half the cost of the complete HVDC converter. This would add dynamic capabilities and not the possibility for load sharing among parallel lines[2]."

"Based on the selected power flows and contingencies that were studied, there are no significant technical advantages identified for the use of HVDC transmission instead of HVAC transmission for the North-South Interconnector[3]."

"A meshed HVAC network with embedded HVDC circuits can impose an added complexity to future network planning and expansion."

"Both HVDC options could be designed with a controller to monitor the phase angle difference between the two systems when the double circuit Louth-Tandragee lines are out-of-service in order to further adjust the HVDC power transfer to minimise the angle difference between North and South."

Excerpts about technical alternatives

"New technical options can offer more attractive overhead and underground solutions. The traditional HVAC overhead line has undergone significant technical development in recent years; some achievements are:

- Reduced visual impact
- Increase capacity per line
- Possibilities to reduce number of pylons
- Possibilities to reduce EMF

HVAC cables[4] are technically possible, but they have never been found attractive for long distance, high power transmission.

[2] This is a limitation for HVAC solution that can never have the operational advantages of a VSC-HVDC solution.

[3] Scenarios are very limited and they can only stress the technical differences. Techno/economic requires a more comprehensive approach and modelling activity.

[4] HVAC (XLPE/Oil filled) cables.

GIL transmission is also technically possible, but it has not been found to be an attractive solution for any project with similar length as the Meath-Tyrone Project.

VSC-HVDC has seen significant developments over the last years:

- Converter losses significantly reduced
- Higher voltage and capacity commercially introduced
- Large number of contracts under execution with significant distance of underground cables included
- HVDC breakers under development enabling construction of DC grids
- Multiple EU suppliers can today offer the technology with ratings suitable for the Meath-Tyrone Project"

Excerpts about international benchmark

"The benchmark projects have been carefully selected to cover projects with similar data as found in the Meath-Tyrone project, and representing different technical solutions including:

- 100% HVAC OHL
- Partly UGC, partly OHL, HVAC technology
- Partly UGC, partly OHL, HVDC technology
- 100% HVDC UGC

All projects have one thing in common - the technical solution has very recently been decided - and they thus represent the state of the art of industrial practices.

For HVAC connections, the solution by underground cables is only used for limited distances.

For **HVDC lines, undergrounding with cables is today a realistic solution**. VSC-HVDC is used in most subsea projects, although LCC-HVDC is still interesting for point-to-point subsea connections. Overhead lines are used also for HVDC in difficult terrain or when an existing right-of-way is reused.

It is already clear from the list of projects that there is not one "right" solution. Each project must be decided on its own merits considering specific local conditions."

Excerpts about some observations relevant for the Meath-Tyrone Project based on the reference projects

"The reference projects with similar technical data as Meath-Tyrone have demonstrated that an underground HVAC cable alternative or a classic LCC-HVDC solution is not attractive. The solutions chosen are:

- 100% HVAC OHL
- Hybrid HVAC with OHL and limited distance HVAC UGC
- Hybrid solution with HVAC OHL + VSC-HVDC UGC and partly VSC-HVDC OHL
- 100% VSC-HVDC UGC

The reference cases illustrate that the "best" solution is different in each case.

The HVAC OHL is a natural choice in difficult terrain whereas partly or fully undergrounding has been chosen in other cases.

From a certain distance onwards, and if full undergrounding is chosen, the best option is VSC-HVDC solution. The distance relevant to Meath-Tyrone Project certainly falls within this range. Due to a much more compact cable system, this alternative offers more options to install the cable as compared to an AC cable and the installation costs are crucial for the overall project costs. It should be possible to find good reference material in built and planned projects particularly in Germany and Sweden. The terrains studied in these projects appear to be relevant to the conditions found in Ireland."

Excerpts about losses

"Losses for VSC-HVDC have been significantly reduced compared to state of the art when previous studies were made. The HVAC OHL has the lowest losses at low load, whereas the VSC-HVDC and the HVAC cable alternatives have lower losses than the HVAC OHL at high load."

This can be noted by representing in a diagram the variation of power losses (in MW, vertical axis) with the power transfer (in MW, horizontal axis) of the three technological options, such as HVAC OHL, HVAC UGC, VSC-HVDC UGC, for a 1400 MW rating (see Figure 2).

"The VSC-HVDC option offers an opportunity to reduce the losses in the connected AC grids in both ends due to better voltage control and the capability to optimize the load flow between the HVDC connection and the parallel AC lines. This opportunity is difficult to quantify without detailed studies. The losses at low load (below 500 MW) in the VSC-HVDC system can also be reduced by operating one set of converters and keeping the second pair in standby. This will reduce the losses with up to 2 MW."

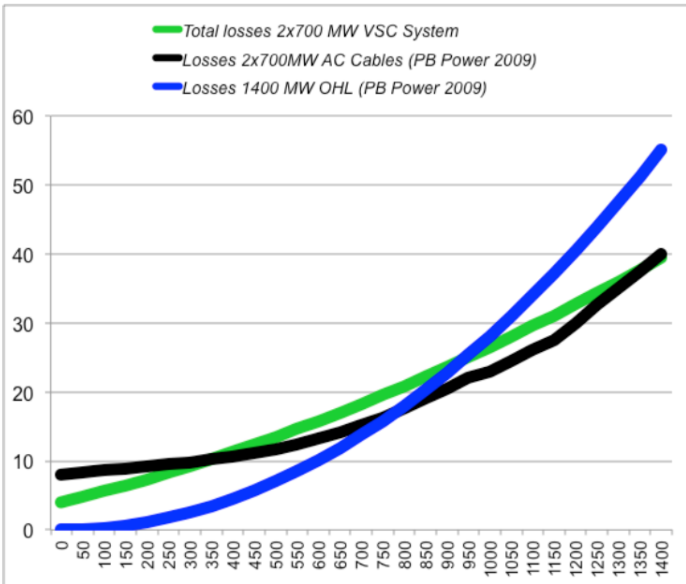

Figure 2. Comparison of losses for VSC-HVDC UGC, HVAC UGC, HVAC OHL

"Operational costs for different alternatives are related to losses. They depend on the power flowing through the link. This is an assessment outside of the scope of this report. All alternatives have different characteristics but are rather close making the assessments of lowest "life cycle losses" rather irrelevant, certainly when considering that prices of energy is very difficult to estimate over the say 60 years of lifetime."

Excerpts from the Executive Summary - 1

"Given the fast technological and market developments over the last years, some of the conclusions drawn in reports on the Meath-Tyrone project reflect the technology status as available a couple of years ago, using information available at the time.

Examples are the development of VSC HVDC technology and its deployment in transmission projects and the introduction of new tower designs for overhead lines. Given these major changes in the market it appears relevant to look at near-term trends, i.e. systems that can be bought off the shelf.

Detailed studies were made before the final solution was defined in each of these cases and these experiences are of great value for the Meath-Tyrone project. Examples are:

- Overhead lines can be rendered more acceptable by using new tower designs, new conductor types and other measures to reduce the visual impact and in some cases also reduce EMF. Short distances may also be covered using underground AC cables.
- When considering undergrounding, AC cables are not the best choice when longer connections are to be covered. DC technology becomes a viable option as the cable itself is comparable in cost to an advanced overhead line, while major steps forward are seen in both costs and losses in the converter stations.

The Commission is not recommending any solution as such. However, it recommends against fully undergrounding using an AC cable solution.

If the option is to underground the connection along the whole, or main part of the route, with today's technology the best solution is a VSC-HVDC solution combined with XLPE cables. The best cable route is most likely following existing infrastructure such as large freeways or railroads, or through farmland as the width of the trajectory is far less than that needed for the AC cables. In difficult terrain for undergrounding DC overhead lines can be used.

The Commission wants to stress that an (AC) overhead line 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 classic steel lattice towers now proposed.

For cost estimations, values found in real projects under execution are the most reliable source, although the high market activity and large fluctuations in key cost parameters such as metal prices can have a major influence that may be different given the technical option chosen."

Comments by the IEC2021 - 1

The IEC2021 fully agrees on the above statements by the IEC2012. The IEC2021 has however to stress that the expected OHL costs can nowadays be increased also significantly with new towers design having a less intrusive visual impact: in fact, this would come with higher (up to double) investment costs for such HVAC OHLs with respect to standard HVAC OHL solutions.

Excerpts from the Executive Summary - 2

"Operational costs for different alternatives, e.g. losses, will depend upon the power flowing through the link. This is an assessment outside the scope of this report. All alternatives have different characteristics, but are rather close making the assessment of lowest "life cycle losses" rather irrelevant, certainly when considering that price of energy is very difficult to estimate over say 60 years of life of the project."

Comments by the IEC2021 - 2

The IEC2021 agrees only partially on the above statements by the IEC2012: since the losses depend on system lines loadings, as the IEC2012 correctly points out, the IEC2021 believes that a more detailed analysis should be carried out to assess the system lines loadings and the correlated losses so to compare the different alternatives. A system study should then be conducted before stating that such assessment might be rather irrelevant. The loadings can be in fact determined by different situations, such as: market conditions; network topology and operational conditions; physical power flows repartition; reliability/availability of lines; system control and remedial actions. Moreover, the IEC2021 has to highlight that operational costs cannot be limited to losses only, but there are several other aspects and cost elements that shall be taken into account to fully assess the operational impact on system economics: reliability/availability, system generation and dispatch costs, renewable overgeneration costs, CO2 emissions costs. All these elements shall then be included in the picture and evaluated by appropriate techno-economic analyses and optimisation studies, to be conducted in line with ENTSO-E CBA guidelines. In addition, given the fundamental benefit of controllability brought by VSC-HVDC options, system flexibility impact on operational costs shall be duly analysed by appropriate optimisation tools as well and included in the assessment towards the comparison of the different alternatives for NSIC project.
Finally, given the uncertainty on the prices of fuels, metal and energy over say 60 years of life of the NSIC project, as the IEC2012 correctly points out, sensitivity analyses on those parameters shall be also conducted to compare the impact of the different alternatives for NSIC project.

2.6. PB Power Technology and Costs Update 2013

In April 2013, PB Power prepared a report summarising the results of a further analysis carried out to update the information that PB Power provided in its previous study of 2009. This new report by PB Power has included a review of up-to-date technology and application developments worldwide. It has also drawn upon information and conclusions published within a number of previous relevant studies (including the IEC2012 review report) 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.
Table 6 reports the key elements of the study as highlighted by EirGrid.

Table 6. Key elements of PB Power Technology and Costs Update 2013

Report Title	Context of Report	Main Findings / Observations of Report
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.

The key outcome of the study is that the 400 kV HVAC OHL option for the NSIC project is still the most economically convenient one in terms of lower level of investment expense, followed in the order by the 400 kV HVAC UGC and the HVDC UGC solutions.
Given that in its further analyses EirGrid decided to defer the previously proposed intermediate substation to be located by Kingscourt, PB Power was additionally tasked to prepare a Supplementary Note and provide an indication of the impact of such deferment on the NSIC project

investment cost.
Table 7 reports the key elements of such Supplementary Note as highlighted by EirGrid.

Table 7. Key elements of PB Power Technology and Costs Update 2013 – Supplementary Note

Report Title	Context of Report	Main Findings / Observations of Report
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.

The key outcome of the Supplementary Note is that the 400 kV HVAC OHL option for the NSIC project remains the most economically convenient one in terms of lower level of investment expense, followed in the order by the HVDC UGC 400 kV and the HVAC UGC solutions. The deferment of the intermediate substation allows a saving in investment in all three options, with the HVDC solution presenting the largest expense reduction; however, this does not change the fact that the 400 kV HVAC OHL option is still the most economically convenient one in terms of investment level.

2.7. EirGrid Final Re-evaluation Report 2013

In April 2013 EirGrid published a Final Re-evaluation Report for public consultation.
This resulted from a comprehensive re-evaluation of the North-South 400 kV Interconnection Development Project undertaken by EirGrid. The re-evaluation process included a review of a previous application to An Bord Pleanála[5] for planning approval of what was then referred to as the Meath-Tyrone 400 kV Interconnection Development: the goal of this review consisted in verifying whether the purpose, content, conclusions, and rationale related to that previous application remain valid towards the preparation of a new application for approval of the North-South 400 kV Interconnection Development Project (otherwise referred to as the North-South Interconnector Project).
As part of this review process, EirGrid published a Preliminary Re-evaluation Report in May 2011, which concluded with the identification of an indicative OHL path within an emerging preferred route corridor. The Preliminary Report was the subject of a period of consultation.

The Final Re-evaluation Report updated the consideration of OHL and UGC based on the findings of the IEC2012 review study and the PB Power Technology and Costs Update 2013. EirGrid's

[5] An Bord Pleanála is the Irish Planning Appeals Board.

comparative analysis of OHL and UGC options in the Final Re-evaluation Report is based on the methodology, whose elements can be also extracted and highlighted, as reported in the following, with comments by the IEC2021.

Excerpts - 1

"The first step in the analysis was to carry out a general evaluation of HVDC technology, as an alternative to the standard HVAC technology regardless of whether the HVDC scheme is to be implemented using OHL, UGC or a combination of both. **The overall findings of this analysis were that any DC option whether implemented using UGC, OHL or offshore submarine cable would not facilitate the future development of the transmission network**. 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. 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 be-spoke control system. The risk of failure, and the consequence of failure, must be a factor in the consideration of any technical alternative. Introducing a complex and be-spoke control system into the operation of a strategically important part of the „all-island" transmission network brings with it considerable risk for system security and stability. Such risk taking is unnecessary in the case of this proposed development as there is a technically superior and less risky option readily available**. As a result of all of the foregoing EirGrid concluded that any option using HVDC technology is not an appropriate or acceptable option for implementing the proposed interconnector."

Comments by the IEC2021 - 1

The IEC2021 has taken account of the EirGrid concern about operational complexity and risk increase by an embedded HVDC technology application for the NSIC project in the Irish all-island transmission system context, given the specific role of the NSIC and considering the limited experience with similar embedded HVDC solutions at the time of the Final Re-evaluation Report by EirGrid (2013). The IEC2021 understands that the concern is related to a loss of the 275 kV double circuit Louth-Tandragee OHL and the power flow re-routing to a HVDC link instead of a HVAC tie.

Excerpts - 2

"Having eliminated all HVDC options, the next step in the analysis was to compare an entirely undergrounded 400 kV AC option with a 400 kV AC OHL. The conclusions of this analysis were that **undergrounding a 400 kV circuit of the length (c. 135 km) required for the NSIC Project using AC UGC would not be in compliance with good utility practice and in addition would cost substantially more than the OHL option**. **As a result, the entirely undergrounded option, using 400 kV AC UGC, was eliminated from further consideration**. This conclusion was supported by the findings of the International Expert Commission (IEC)."

Comments by the IEC2021 - 2

The IEC2021 agrees with the above statements by EirGrid.

Excerpts - 3

"Although the entirely undergrounded AC option was eliminated, as consistent with the findings of the IEC report, the option of using a hybrid AC solution, i.e. a combination of AC UGC and AC OHL, commonly referred to as „partial undergrounding", remained an option for consideration. Indeed, the IEC found in this regard that partial undergrounding is technically feasible but within limitations on the cumulative length of the UGC sections. The next step in the comparative analysis was therefore to consider the option of undergrounding part of the proposed development using AC UGC but within these recognised constraints. The analysis showed that in the case of the North-South Interconnector Project **partial undergrounding is feasible but only if the length to be undergrounded is restricted, for technical and operation reason, to less than approximately 10 km in one continuous length or an accumulation of shorter lengths**; and the cost premium of using the short length(s) of UGC is an environmentally advantageous and cost-effective way of overcoming an environmental or technical constraint to the preferred OHL. Following consultation and engagement with the relevant planning authorities, prescribed and non prescribed bodies, and the general public including where possible landowners, EirGrid concluded however that there was no section of the preferred OHL route where the above applies and is therefore proposing that the entire 400 kV circuit be implemented using 400 kV AC OHL."

Comments by the IEC2021 - 3

The IEC2021 agrees with the above statements by EirGrid regarding partial HVAC undergrounding. The IEC2021 recalls that the exclusion of VSC-HVDC solution for NSIC has been due to the limited experience with similar embedded HVDC solutions at the time of the Final Re-evaluation Report by EirGrid (2013), notwithstanding the evaluations made by TransGrid (2009) and by the IEC2012 (2012). The situation has however evolved over the years in terms of technological progress and further implemented embedded HVDC solutions.

Excerpts – 4

"In its Terms of Reference, the IEP (Independent Expert Panel) specified a number of technical criteria against which the alternatives for GW (Grid West) and GL (Grid Link) shall be compared. These are:
a. Compliance with all relevant safety standards;

b. Compliance with system reliability and security standards;

c. The average failure rates during normal operation, average repair times and availabilities of the main elements of each option;

d. The expected impact on reliability of supply or unavailability of the development;

e. Implementation timelines, including procurement and availability of key equipment and resources;

f. The extent to which future reinforcement of, and/or connection to, the transmission network is facilitated;

g. The risk associated with use of any untried technology solution that would be required as part of a development option; and

h. Compliance with good utility practice."

[..]

"Good Utility Practice means any of the practices, methods and acts engaged in or approved by a significant portion of the electric utility industry in Europe during the relevant time period, or any of the practices, methods and acts which, in the exercise of reasonable judgment in light of the facts known at the time the decision was made, could have been expected to accomplish the desired result of the lowest reasonable cost consistent with good business practices, reliability, safety and expedition. Good Utility Practice is not intended to be limited to the optimum practice, method or act to the exclusion of all others, but rather to be acceptable practices, methods, or acts generally accepted in the ENTSO-E region and consistently adhered to by EirGrid."

Comments by the IEC2021 - 4

The IEC2021 fully agrees with the above statements.

Excerpts – 5

"In its Terms of Reference, the IEP specified a number of technical criteria against which the alternatives for GW and GL shall be compared. These are:

a. Project pre-engineering costs, including costs of evaluation of route, line technology and substation options;

b. Project implementation costs including:

- cost of procurement, installation and commissioning of overhead line and/or underground cable for the required continuous pre-fault, continuous post-fault and short-term post-fault ratings;
- costs of substations including procurement, installation and commissioning of required protection and control equipment and any equipment necessary for compliance with relevant technical standards;
- all relevant civil works for construction, including: for access to sites; for any necessary river/road/rail crossings or diversions, any tunnels necessary for any sections of underground cable, and for towers plus their foundations for sections of overhead line; and for post-construction restoration;
- Third Party Payments (wayleaves, community gain, rates etc);
- Interest During Construction; and
- the costs of any environmental monitoring deemed necessary to mitigate the impact of the development during construction or on-going operation.

c. Project life cycle costs (including Losses, Operation & Maintenance, Decommissioning and the costs of retaining any necessary specialist repair teams);

d. The expected costs to operation of the Single Electricity Market arising from unavailability of the development; and

e. Estimates of the range of uncertainty attaching to all of the cost components under all options."

Comments by the IEC2021 - 5

The IEC2021 fully agrees with the above statements concerning costs under a., b., e. categories, whereas has a broader view concerning costs under c., d. categories. In fact, the IEC2021 believes that a more detailed analysis with respect to the one taken as reference should be carried out to assess the system losses so to compare the different alternatives.
Moreover, the IEC2021 has to highlight that the operational costs cannot be limited to losses only, but there are several other aspects and cost elements that shall be taken into account to fully assess the operational impact on system economics: reliability/availability, system generation and dispatch costs, renewable overgeneration costs, CO_2 emissions costs. All these elements shall then be included in the picture and evaluated by appropriate techno-economic analyses and optimisation studies, to be conducted in line with ENTSO-E CBA guidelines. In addition, given the fundamental benefit of controllability brought by HVDC options, system flexibility impact on operational costs shall be duly analysed by appropriate optimisation tools as well and included in the assessment.

Excerpts – 6

"Three technical alternatives were set out and evaluated, namely:

- AC OHL
- AC UGC
- DC (OHL & UGC)

For this comparative evaluation of technological alternatives, regard was given to all relevant studies, to current international best practice, to feedback received during public consultation, and to the extensive experience and expertise of EirGrid and NIE in respect of transmission infrastructure design, construction and operation."

The resulting matrix by EirGrid is represented in

Table 8.

Table 8. Multi-criteria matrix by EirGrid

Objective	Description	Technical Options		
		AC Overhead	AC Underground	DC
1	**Comply with EirGrid's Statutory and Regulatory Obligations**			
1.1	Safety	* * *	* * *	* * *
1.2	Reliability and security	* * *	* *	* *
1.3	Cost effectiveness	* * *	*	*
1.4	Due regard for the environment	* *	* *	* *
2	**Meet the Specific Objectives of this Project**			
2.1	1500 MVA Capacity and appropriately strong points of interconnection	* * *	* * *	* *
2.2	Reinforce the North East transmission network	* * *	* * *	* * *
3	**Meet the General Objectives for all projects of this type**			
3.1	Facilitate future grid connections and reinforcements	* * *	* * *	*
3.2	Good Technical Solution - Be 'best international practice' with proven technology	* * *	*	*

Acceptable for this project	* * *
A concern for this project	* *
Unacceptable for this project	*

Comments by the IEC2021 - 6

Table 8, which has been produced by EirGrid after evaluation of the study process undertaken between 2009 and 2014, tends to use a multi-criteria approach where pros and cons of examined alternatives for the NSIC project - AC OHL, AC UGC and DC (OHL & UGC) options - have been estimated. The IEC2021 highlights that the multi-criteria approach shown in

Table 8 is based on a qualitative evaluation only.
Moreover, the IEC2021 is of the opinion that for objective 1.3 (Cost effectiveness) in

Table 8 the evaluation for the DC OHL option has to be distinguished as less conservative for a categorisation as "A concern for this project" (**) since it has to be differentiated by the one for the DC UGC option that is categorised as "Unacceptable for this project" (*) in

Table 8.
Furthermore, the IEC2021 believes that for objective 1.4 (Due regard for the environment) in

Table 8 the evaluation for the AC UGC option shall be more promising for a categorisation as "Acceptable for this project" (***) and not as "A concern for this project" (**) in

Table 8.
Also, the IEC2021 remarks that for objective 2.1 (1500 MVA Capacity and appropriately strong points of interconnection) in

Table 8 the evaluation for the DC option could be updated for a categorisation as "Acceptable for this project" (***) and not as "A concern for this project" (**) in

Table 8, given today's progress advance of HVDC technology.
Finally, the IEC2021 needs to highlight that the criteria in

Table 8 shall be further developed and extended to explicitly include some missing elements (such as those ones related to network losses, social welfare, RES integration, CO_2 emissions) with respect to the CBA guidelines methodology, firstly adopted by ENTSO-E **in 2013**, based on a quantitative assessment.

Excerpts on TransGrid Study 2009 evaluation by EirGrid – 1

"There are no working examples in the world 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."

Comments by the IEC2021 on TransGrid Study 2009 evaluation by EirGrid - 1

The IEC2021 can agree on these statements by EirGrid. The IEC2021 is also aware that, at the time of that evaluation by EirGrid (2013), there were very few cases of DC embedded applications in AC grids. The situation has however evolved over the years after 2013.

Excerpts on TransGrid Study 2009 evaluation by EirGrid – 2

"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 1,500 MW, will become the 'backbone' of this 'all-island' network."

Comments by the IEC2021 on TransGrid Study 2009 evaluation by EirGrid - 2

The IEC2021 acknowledges the risk of failure due to an embedded (and crucial) DC link and the concern expressed by EirGrid in 2013 evaluation, even if such DC solution can be considered as technically feasible.

Excerpts on TransGrid Study 2009 evaluation by EirGrid – 3

"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 losses, 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."

Comments by the IEC2021 on TransGrid Study 2009 evaluation by EirGrid - 3

The IEC2021 agrees only partially on the above statements by EirGrid, as a technical comparison of the two technologies (HVAC and HVDC) performed in TransGrid Study 2009 has shown that, in terms of flexibility and dynamic control, the VSC-HVDC option performs much better than the HVAC solution. In fact, as also reported in section 2.4, TransGrid Study 2009 refers for the power flow (summer peak case, 1500 MW transit along RoI-NI corridor) in the contingency analysis to many diverged results, especially with the AC OHL option, while the "LCC option had fewer diverged cases than the AC option, and the VSC had by far the fewest of all" (see also Table 5). Also, the IEC2021 highlights the need to carry out a fully-fledged techno-economic comparison of the two technologies (HVAC and HVDC, both LCC and VSC) and of the different options (OHL, UGC) and to factor in the flexibility of the HVDC solution.

2.8. EirGrid Outline and Update on the Options 2017

The findings from the various previous studies and reviews were discussed and updated in the

'Outline and Update of EirGrid's consideration of the Transmission Technology Options as presented to the Independent Expert Group' report submitted by EirGrid to the DECC in December 2017. This report summarised EirGrid's positions on NSIC project options: several elements of EirGrid's positions have been already illustrated in previous sections **Error! Reference source not found.**-**Error! Reference source not found.**.
Some key conclusions can be extracted from EirGrid 2017 report and reported as in the following.

Excerpts from the Executive Summary

"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."

2.9. KHSK Report on Land Compensation 2018

Under request by DECC, in 2018 KHSK prepared a report to carry out a comprehensive study about the land compensation mechanism to owners of properties in the vicinity of transmission infrastructure developments. In particular, it was asked in the study, among others, to answer the question whether any difference is obtained in these externalities if the infrastructure is performed with OHL or with UGC technology.
The report also considered international benchmarking and other TSOs practices on this matter.
The conclusions of the report did not fully clarify any difference in compensations and cost

associated to the use of OHL or UGC.
Moreover, several other elements can be extracted from KHSK 2018 report and highlighted, as reported in the following, with comments by the IEC2021.

Excerpts from the Executive Summary

"3. [..] Two conclusions are important. The first is that there is no scientific basis for a claim that transmission lines cause health problems. **The second is that there is limited evidence from numerous analyses of sales prices that transmission lines depress the value of the land over which they pass**.

4. This second finding is important as it greatly weakens the argument that there are environmental or lasting perceived negatives associated with the construction of new infrastructure although these issues may appear important before and for a time after the infrastructure is constructed.

5. In relation to the payment of compensation, the main finding of this report is that there is **considerable variation in the approaches that are used by TSOs to compensate land owners** and in the levels of compensation that are paid. Indeed, it would not be meaningful to try to summarise the information given the extent of the differences.

6. Payments for direct impacts on property are often assessed against a published scale and the basis for this compensation is not contentious. However, **arbitration is often required to arrive at an actual agreed payment**.

7. One important point that emerges is that provisions in the legal framework in each country, particularly in relation to private property rights and the formal rights of electricity operators, are the key determinants of the approaches to compensation that are seen. These vary hugely. Approaches have been designed in response to these provisions rather than against objective strategic criteria.

8. Some types of compensation are provided by all TSOs. These include payments for damages to land or crops and the usual practice is to try to restore damage before offering 100% compensation for losses. A similar approach is taken with respect to loss of crops, but there are a lot of differences in practices regarding how to do this.

[..]
10. **The concept of national interest is important in many countries and where a project is defined as such the TSO often has considerable powers to act**. [..]

11. **It is very rare to specifically compensate for issues such as visual intrusion, noise or health as the potential for these impacts is usually not recognised in law. It is more common to compensate for loss of value in a property on the assumption that these impacts will be captured into the value**.

[..]

13. There is huge variation in relation to how to compensate for loss of land but the use of valuers or agreement with national farmer representative organisations are common approaches. Many countries also have detailed laws to guide valuations.

14. **Compensation is usually paid as a lump sum irrespective of its basis**. The exception is a minority of cases where there are recurring annual payments to reflect loss of earning potential, overhang or leases.

[..]

16. **Some TSOs have developed community benefit (gain sharing) schemes but the practice is still not widespread**. Most of these schemes have little or no legislative basis and are often viewed as a way to address local opposition.

Comments by the IEC2021

The IEC2021 believes that the matter of land compensation can play a role in the determination of the final infrastructure costs, and for this reason a possible compensation differentiation for a power system infrastructure based on OHL or on UGC shall be taken into account in the economic analysis.

2.10. IEC2018 Review Study

A new review study, published in 2018, was conducted by the independent International Expert Commission (IEC), appointed by the Irish Government and recalled as IEC2018, to update the IEC2012 findings. In its report, the IEC2018 considered the different alternatives for NSIC project, based on:

1. a HVAC connection entirely made up of overhead line (OHL);
2. a HVAC connection comprising a combination of OHL and underground cable (UGC);
3. an undergrounded HVAC connection using a 'gas insulated line' (GIL);
4. a HVDC connection entirely made up of OHL;
5. a HVDC connection of which at least some of the connection uses underground cable, perhaps all of it underground.

In its findings, the IEC2018 practically confirmed the main outcomes of IEC2012 review study, stating that the two feasible, possible options for the NSIC project are based on HVAC OHL and VSC-HVDC UGC solutions.
The IEC2018 stated that its overall finding is that, from a techno-economic point of view, an HVAC OHL is the most beneficial way of meeting the need for enhanced power transfer capability between the Republic of Ireland and Northern Ireland.

Moreover, several other important elements can be extracted from the IEC2018 review study and highlighted, as reported in the following.

Excerpts from the Executive Summary - 1

"Since 2011, no major new technologies have emerged from the laboratory in a state of readiness for commercial deployment. However, a number of examples of HVDC 'embedded' within an AC system and avoiding the electrical problems associated with long high voltage AC underground cables are either under development or have entered operation. Particular attention is therefore paid to 'embedded' HVDC.
A number of projects in Europe that make significant use of the main alternatives to conventional overhead lines are described in order that these alternatives may be better understood. They include three 'embedded' HVDC projects and two that are planned to use novel OHL tower designs.
An update is presented of the Commission's own, earlier estimate of the cost of developing North-South as HVDC with underground cables as an alternative to an AC development with overhead line. It can be concluded that the costs for both key alternatives, AC overhead line and HVDC underground cables, have gone up. However, the cost relation is still the same: the HVDC option is more than three times more expensive."

Comments by the IEC2021 - 1

The IEC2021 agrees with these statements by the IEC2018 and has to highlight that further embedded HVDC projects in Europe, based on LCC or VSC technology, especially for underground, but also undersea cable implementation, have been developed in the latest years or are under ongoing development towards a more widespread application of such option by European TSOs.

Excerpts from the Executive Summary - 2

“The Commission’s new review of the technical options for enhancing the power transfer capability between the Republic of Ireland and Northern Ireland has concluded that:

- Complete AC undergrounding is not viable; partial undergrounding is possible but with a limited total length of undergrounded sections.
- AC overhead line is viable; it would be possible to build the interconnection using new tower designs that are less visually intrusive but at an extra cost.
- A gas-insulated line (GIL) to cover the entire length would be extremely expensive and is, as yet, unproven anywhere in the world. Partial undergrounding using GIL would also be very expensive.
- The only viable means by which a high voltage interconnection of significant length could be completely undergrounded would be through use of an embedded HVDC link.

Embedded HVDC is not yet common worldwide but operational experience does exist and, within a few years, there will be at least four examples in Europe of comparable size.

Although the Commission regards it as a credible option, there are a number of aspects of the potential use of embedded HVDC in the context of enhancing the interconnection between Northern Ireland and the Republic that would require careful consideration. Among these issues is that a number of parties with which the Commission has consulted have expressed the need for economic development in the areas through which the planned North-South interconnector passes. They have pointed specifically to the possibility of attracting investment in new industrial or commercial facilities that have a need for significant amounts of electrical energy, in particular data centres. However, development of a North-South interconnector as embedded HVDC system would not achieve this.

Strictly limited partial undergrounding of an AC interconnection is possible but the Commission’s understanding is that further planning enquiries would be necessary delaying commissioning of a new interconnector by, we understand, at least two years with an annual constraint cost of, according to the transmission system operator in Ireland, EirGrid, between 13 M€ and 20 M€ in the early years. Based on current central estimates, adoption of an embedded HVDC alternative would delay commissioning of a new interconnector by at least 5 years and would add approximately 120 M€ of additional constraint costs to the extra cost of building the link as HVDC compared with the currently planned AC OHL. The Commission’s own estimate of the extra capital cost of 1 × 1GW voltage source converter (VSC) based embedded HVDC for a North-South interconnection compared with the planned 400kV AC OHL is 270 M€ giving an estimated total extra cost of 390 M€ or, with 2 × 700MW, 570 M€.”

Comments by the IEC2021 - 2

The IEC2021 can generally agree on most of these statements by the IEC2018.
In the following subsection, the IEC2021 provides a more detailed argumentation on those statements by the IEC2018.

2.10.1. Conclusions on IEC2018 review outcomes

In this subsection, the IEC2021 intends to detail its evaluation of the IEC2018 review outcomes.
The revision made by the IEC2018 has been issued with the following examined set of alternatives for the NSIC project:

- 1. a HVAC connection entirely made up of overhead line (OHL);

- 2. a HVAC connection comprising a combination of OHL and underground cable (UGC);
- 3. an undergrounded HVAC connection using a 'gas insulated line' (GIL);
- 4. a HVDC connection entirely made up of OHL;
- 5. a HVDC connection of which at least some of the connection uses underground cable, perhaps all of it underground.

First, the IEC2021 wants to point out that **the set of Candidate Transmission technology chosen by the IEC2018 is comprehensive enough to come to a conclusion about the best techno-economic options available in the market to implement the NSIC project**.
Specific comments and evaluations made by the IEC2021 on IEC2018 review conclusions are highlighted in the following.

Conclusion n.1

The IEC2018 stated in its review:
Complete AC undergrounding is not viable; partial undergrounding is possible but with a limited total length of undergrounded sections.

The IEC2021 fully agrees on this statement. More investigation has been done in recent years and further studies are currently in progress also by other TSOs in Europe on long HVAC UGC applications to show evidence about the impact of long HVAC UGCs in HV and EHV grids. In Europe there have been so far no long HVAC UGCs installations at EHV level for the length of 138 km as for NSIC project. Recent HVAC UGC projects have been implemented in Denmark (at 230 kV level for an underground track of 60 km) and in Germany (at 155 kV level for an underground length of 30 km).
This depends on the need for reactive compensation as well as by limitations due to technical constraints when operating switching procedures in proximity of NSIC. The IEC2021 confirms the critical aspects correctly highlighted by the IEC2018 in its review report.
The IEC2021 is well aware about the dependency of the feasibility of HVAC UGCs on the power system strength and is in line with IEC2018 position that long HVAC UGCs, in particular at EHV level like the NSIC, can put the transmission system at risk. The value of maximum 10 km for partial HVAC undergrounding at 400 kV is a fair conclusion considering the Irish All-Island transmission stiffness, in particular in the expected connection nodes of Woodland and Turleenan, as found in other applications in the All-Island transmission grid.

Conclusion n.2

The IEC2018 stated in its review:
AC overhead line is viable; it would be possible to build the interconnection using new tower designs that are less visually intrusive but at an extra cost.

The IEC2021 fully agrees on this statement. Other TSOs in Europe have gone through some recent projects leading to the installation of new HVAC OHLs with a more acceptable and less intrusive tower design which fulfils EMF reduction constraints as well as aesthetic and environmental impact improvements. This has been the case of new tower design in Italy and in the Netherlands, for example.
The IEC2021 has however to stress that the expected OHL costs can significantly be increased with towers design having a less intrusive visual impact: in fact, this would come with higher (up to double) investment costs for such HVAC OHLs with respect to standard HVAC OHL solutions.

Conclusion n.3

The IEC2018 stated in its review:
A gas-insulated line (GIL) to cover the entire length would be extremely expensive and is, as yet, unproven anywhere in the world. Partial undergrounding using GIL would also be very expensive.

The IEC2021 fully agrees with this statement. Gas-insulated technology has been on the market for many years now and it has mostly addressed switchgears and substations (GIS) installation so far. GIL technology has some interesting potentials at system impact, such as low reactance, limited or absent compensation needs, high power capacity transport ability. However, it is not yet proven for long distances (above 10 km) at transmission level in Europe; also, the environmental impact overall can be dramatic if GIL installation is not properly undergrounded or contained in large trenches, not to be visible in the neighboring.
As of today, GIL is considered an option to be used where service tunnels are available, i.e. integrated in tunnel structures combining the corridors of energy and transport (for vehicles and railways): this is the case of the GIL project along the Brenner Pass Tunnel across the Italy-Austria energy and transport corridor.

Conclusion n.4

The IEC2018 stated in its review:
The only viable means by which a high voltage interconnection of significant length could be completely undergrounded would be through use of an embedded HVDC link.

The IEC2021 welcomes this statement, in which in practice the conclusion about the five options initially proposed for the NSIC project has been narrowed down to the only two feasible alternatives: a HVAC OHL and a fully undergrounded embedded HVDC cable. The IEC2021 also agrees that the implementation of embedded HVDC shall be better based on VSC technology, concluding that **embedded VSC-HVDC UGC and HVAC OHL are the only options to be considered for the NSIC project**.
The embedded VSC-HVDC UGC option has been and will be applied by different TSOs in Europe, as important alternative to the construction of HVAC OHLs: more examples can be taken as reference, such as the (completed or under construction) projects across the France-Spain, Italy-France, Germany-Belgium ties. Further embedded HVDC UGC projects under development in Germany (across 3 long north-south axes) could be based on VSC technology.
Some of these projects have been thoroughly described by IEC2018 in its review.

Conclusion n.5

The IEC2018 stated in its review:
Although the Commission regards it as a credible option**, there are a number of aspects of the potential use of embedded HVDC in the context of enhancing the interconnection between Northern Ireland and the Republic that would require careful consideration. Among these issues is that a number of parties with which the Commission has consulted have expressed the need for economic development in the areas through which the planned North-South interconnector passes. They have pointed specifically to the possibility of attracting investment in new industrial or commercial facilities that have a need for significant amounts of electrical energy, in particular data centres. **However, development of a North-South interconnector as embedded HVDC system would not achieve this.

The IEC2018 considers the embedded VSC-HVDC solution as a potentially feasible option to be applied for the NSIC project. However, an element is introduced here among the decision-making criteria which was considered only in the earlier history for NSIC analysis.
The IEC2021 understands that reference here is to the initial NSIC project conceptual design which had foreseen an intermediate substation, in Kingscourt, which would have facilitated the area development through the Louth-Flagford right-of-way reinforcements.

However, the intermediate substation option has been cancelled in 2012 and the presented NSIC project did not foresee this option anymore.
The updated situation should have been evaluated by the IEC2018.

Conclusion n.6

The IEC2018 stated in its review:
*Based on current central estimates, **adoption of an embedded HVDC alternative would delay commissioning of a new interconnector by at least 5 years and would add approximately 120 M€ of*** additional ***constraint costs to the extra cost of building the link as HVDC compared with the currently planned AC OHL**. The Commission's own estimate of the extra capital cost of 1 × 1GW voltage source converter (VSC) based embedded HVDC for a North-South interconnection compared with the planned 400kV AC OHL is 270 M€ giving an estimated total extra cost of 390 M€ or, with 2 × 700MW, 570 M€.*

The IEC2021 welcomes the estimation of congestion cost within the CBA application for the comparison of transmission alternatives. This evaluation shall be conducted in line with the ENTSO-E CBA guidelines. The IEC2021 wants to stress further that a level of 120 MEuro congestion costs represents quite a large amount: this shows the importance of the full inclusion of Operating Costs/Benefits and Investments Costs to be considered within the CBA. In fact, during the lifetime of a project, the cash flow using a NPV approach may provide benefits in the same order of magnitude of the investment costs.
It is therefore of paramount importance to factor in these elements and in particular to estimate if there is any difference when using HVAC OHL or the more expensive VSC-HVDC UGC technology.

It is understood that this estimated delay of 5 years is due to the installation of VSC-HVDC UGC option with respect to the planned HVAC OHL. The IEC2021 believes that this approach, introduced at this stage, would cause drawbacks in the future as it is likely that every major transmission project shall incorporate these extra costs when dealing with OHL vs. UGC. Based on IEC2021 experience, an estimation made at the beginning of the planning stage for the NSIC project could provide a much higher delay for HVAC OHL, e.g. 10-15 years against 5 years highlighted above for VSC-HVDC UGC.
Since the delay by international best practice is recognised but not much accounted for when comparing transmission alternatives, the IEC2021 does not consider this statement as relevant for an updated cost estimation of VSC-HVDC UGC vs. HVAC OHL. The IEC2021 agrees on the estimation made by the IEC2018 for the additional costs needed for the VSC-HVDC UGC alternative with respect to the planned 400 kV HVAC OHL option.

3. Final outcomes and recommendations

The IEC2021 has stated in its conclusions that the set of five alternatives considered by IEC2018 for the implementation of the North-South Interconnector project is the most appropriate, up-to-date, technically feasible and in line with the International Best Practice.

The screening criteria considered by IEC2018, which ruled out the applicability of UGC (underground cable) in HVAC (High Voltage Alternating Current) technology with UGC in excess of 10 km, full HVAC UGC, GIL (Gas Insulated Line) as well as LCC (Line Commutated Converter) technology for HVDC (High Voltage Direct Current) OHL (overhead line), are considered correct based on the International Best Practice, IEC2021 experience and other transmission project pre-feasibility studies.

The IEC2021 agrees on the feasibility of an HVAC OHL option with towers design having a less intrusive visual impact, however it underlines that this would come with higher (up to double) investment costs for such HVAC OHLs with respect to standard HVAC OHL solutions.

The IEC2021 agrees with the conclusion that HVDC UGC, based on VSC (Voltage Source Converter) technology, as embedded VSC-HVDC UGC, and HVAC OHL are the only options to be considered for the NSIC project.

The IEC2021 has acknowledged the considerable effort by EirGrid in estimating the investment costs of implementation for NSIC, including investment cost revision over this decade, and agrees on the investment cost differences of the two alternatives.

The IEC2021 has taken account of the EirGrid concern about operational complexity increase by an embedded HVDC technology application for the NSIC project in the All Island Transmission system context: the HVDC technology is in fact accounted by EirGrid for in the "Shaping our electricity future" project study in a 'non embedded' configuration. On the other hand, EirGrid has gained several years of operational experience with VSC-HVDC technology by EWIC interconnector. On this matter, the IEC2021 believes, also based on the outcomes of technical studies carried on in this decade on NSIC itself and on other projects, that this complexity can now be managed, given the advancements in VSC technology, increase of commissioned VSC applications and operational experiences worldwide: the VSC-HVDC option should not be ruled out for future projects.

The IEC2021 has evaluated some positive and useful elements of the multi-criteria approach applied by EirGrid in the decision-making process of alternatives for NSIC.
In this regard, also given the ongoing NSIC planning stage, the IEC2021 has taken into due account that the final qualitative score of EirGrid multi-criteria table has been the fundament for the decision-making process of Transmission Alternative.
However, while acknowledging the final outcome, IEC2021 is of the opinion that in the future not only qualitative but more quantitative elements and evaluations shall be introduced in the Cost Benefit Analysis for the assessment of Grid Investment Alternatives, as well as the Operational Impact of HVAC & HVDC technologies, in line with ENTSO-E CBA guidelines.

4. References

1. Public Consultation, 2007.
2. PB Power Note, 2008.
3. PB Power, "Cavan-Tyrone and Meath-Cavan 400 kV transmission circuits comparison of high voltage transmission options: alternating current overhead and underground, and direct current underground", 2009.
4. TEPCO, "Assessment of the Technical Issues relating to Significant Amounts of EHV Underground Cable in the All-island Electricity Transmission System", 2009.
5. TransGrid, "Investigating the Impact of HVdc Schemes in the Irish Transmission Network", 2009
6. IEC2012, "Meath-Tyrone Review by the International Expert Commission", 2011-2012.
7. PB Power, "Technology and Costs update", 2013.
8. EirGrid, "North-South 400 kV Interconnection Development - Final Re-evaluation Report", 2013.
9. EirGrid, "Report to Independent Expert Panel", 2014.
10. EirGrid, "North-South 400 kV Interconnection Development - Outline and Update of EirGrid's consideration of the Transmission Technology Options as presented to Independent Expert Group", 2017.
11. KHSK, "International Practice in the Approach to and Levels of Compensation of Property Owners in Proximity to High-Voltage Transmission Lines", 2018.
12. IEC2018, "Independent study to examine the technical feasibility and cost of undergrounding the North-South Interconnector", Update by the International Expert Commission", 2018.
13. EirGrid, https://www.eirgridgroup.com/the-grid/public-engagement/
14. EirGrid, https://www.eirgridgroup.com/about/in-the-community/community-fund/
15. CIGRE Joint Working Group B4/C1/C4-604, "Influence of embedded HVDC transmission on system security and AC network performance", CIGRE Technical Brochure 536, 2013.
16. ENTSO-E, "2nd ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects", 2017.

17. European Commission, “Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management”, 2015. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015R1222&qid=1669694877010
18. ENTSO-E, “Ten-Year Network Development Plan (TYNDP) 2016”, 2016. http://tyndp.entsoe.eu/
19. ENTSO-E, “Scenario Outlook and Adequacy Forecasts (SO&AF)”. https://www.entsoe.eu/publications/system-development-reports/
20. ENTSO-E, “Ten-Year Network Development Plan (TYNDP) 2018”, 2018. https://tyndp.entsoe.eu/
21. ENTSO-E, “Ten-Year Network Development Plan (TYNDP) 2020”, 2020. http://tyndp.entsoe.eu/
22. CIGRE Working Group B1.57, “Update of service experience of HV underground and submarine cable systems”, CIGRE Technical Brochure 815, 2020.
23. Calmara Neto, M.Schilling, A.M. leite da Silva, M. Silveira, A.M.Rei, “On uncertainties of reliability indices”, paper C1_301, CIGRE 2010.
24. ICF, “Overview of the Potential for Undergrounding the Electricity Networks in Europe”, 2003.
25. J.B. Beddard, “Factors Affecting the Reliability of VSC-HVDC for the Connection of Offshore Windfarms”, Univ. of Manchester, 2014.
26. Amprion, Underground AC cables on land. https://www.amprion.net/Transmission-System/Technology/Underground-cable/Underground-AC-cables.html
27. G. Pedrazzoli, G. Rinzo, “Longest HVAC Cable Systems: A Review”, Proc. of IEEE EEEIC Conference 2018, 2018.
28. CIGRE Working Group B1.47, “Implementation of long AC HV and EHV cable systems”, CIGRE Technical Brochure 680, 2017.
29. R. Benato et al., “Italy-Austria GIL in the new planned railway galleries Fortezza-Innsbruck under Brenner Pass”, paper B1-304, CIGRE 2006.
30. CIGRE Working Group B3/B1.09, “Application of Long High Capacity Gas-Insulated Lines in Structures”, CIGRE Technical Brochure 351, 2008.