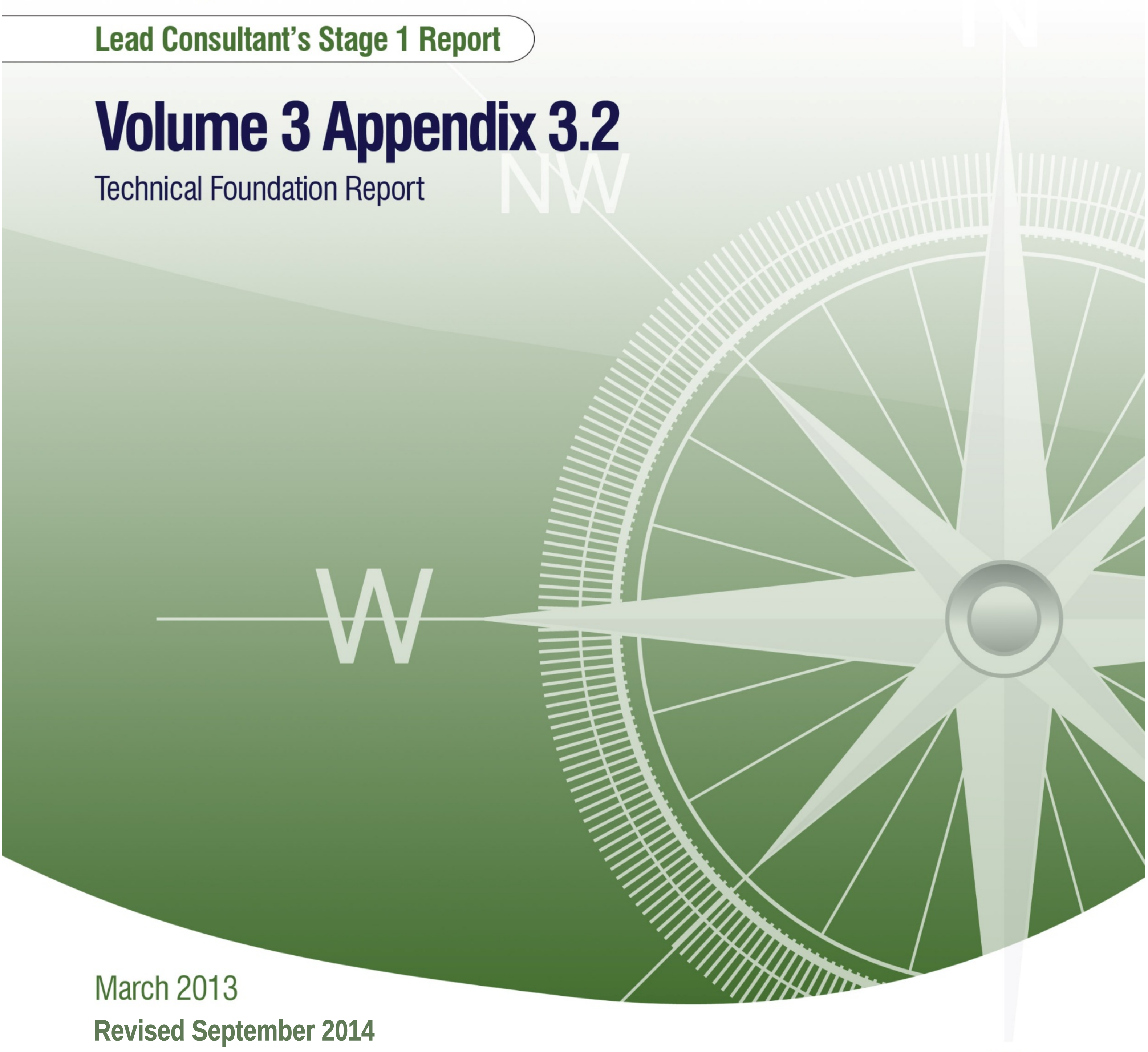
The Grid West Project

EirGrid

Lead Consultant's Stage 1 Report

Volume 3 Appendix 3.2

Technical Foundation Report



March 2013

Revised September 2014

TOBIN Consulting Engineers

URS

DRURY

TECHNICAL FOUNDATION REPORT

PROJECT: **Grid West Project**

CLIENT:

EirGrid Plc
The Oval
160 Shelbourne Road
Ballsbridge
Dublin 4

COMPANY:

TOBIN Consulting Engineers
Block 10-4
Blanchardstown Corporate Park
Dublin 15

www.tobin.ie

DOCUMENT AMENDMENT RECORD

Client: **EirGrid**

Project: **Grid West Project**

Title: **Volume 3 Appendix 3.2 of Stage 1 Report –Technical Foundation Report**

PROJECT NUMBER:				DOCUMENT REF: 6424-B			
B	Amendments from Feedback	GC/BJD	19-09-14	BJD	19-09-14	BJD	19-09-14
A	Final Issue	GC	21-02-13	JS	21-02-13	MG	22-02-13
Revision	**Description & Rationale**	**Originated**	**Date**	**Checked**	**Date**	**Authorised**	**Date**
TOBIN Consulting Engineers							

Errata and Amendments

Page	Section	Amendment
13	3.3	Bullet point relating to “Excavation” and “Backfill” amended with reference to quantities of excavation. Third paragraph amended regarding drainage pattern.
25	5.2.3	Third paragraph of Section 5.2.3 amended; reference to “mountainous” areas removed.
27	5.3	Final paragraph of Section 5.3 amended and typing errors corrected.
38	6.4.1	Footnotes [11] and [12] have been revised with regard to Losses for HVDC lines and cables.
38	6.4.2	Second bullet point has been revised with regard to losses in HVDC systems.
39	6.4.2	Item No. 4 of Section 6.4.2, referring to EirGrid GWTS quantification of losses, has been deleted. Final two paragraphs of Section 6.4.2 have also been deleted.
40	6.5.2	Footnote [14] has been inserted.
49	7	Table 7-1 has been amended - the evaluation of losses for all 4 technologies are now equal and coloured as “light yellow”.
50	7	First two bullet points below “Review of the above matrix shows the following” have been amended to reflect changes to Table 7-1.
51	8	Second last paragraph has been revised.
D-13	D3.3	Wording of the first paragraph of Section D3.9 has been amended.
D-13	D3.3	“Backfill” bullet point revised.
D-24	D4.1	Second bullet point has been revised to read “HDVC overhead lines are not commonly implemented”.
D-26	D4.5	Wording of the first paragraph of Section D4.5 has been amended.
D-26	D4.5	Second paragraph under “Installation Methods” has been revised.
D-27	D4.5	Figure 15 added - “Typical cross section of a high voltage cable construction trench”.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF MAPS

LIST OF FIGURES

LIST OF ANNEXES

ANNEX A:	Reference Documents
ANNEX B:	Review of the Environmental Impact Advantages and Disadvantages of Overhead Lines vs Underground Cables
ANNEX C:	Basis for Cost Comparisons
ANNEX D:	Review of Technologies

EXECUTIVE SUMMARY

The Grid West project is the planning, development and construction of a proposed new 400kV transmission circuit to facilitate the connection of Gate 3 renewable power generated in the vicinity of Bellacorick, County Mayo. The project, which is part of EirGrid's Grid25 strategy, envisages the construction of a new transmission circuit from the Bellacorick area to connect to the existing 220kV grid at either Flagford or Cashla, with a straight line distance of 100km[1] between Bellacorick and Flagford or Cashla.

The Grid West project is currently in the development phase (i.e. pre-construction) leading to an application to the relevant authority for planning consent. As defined by EirGrid's Project Development & Consultation Roadmap, the project is at Stage 1.

Developments in recent years in the transmission of electrical power now allow a number of different technologies to be considered for any project. Historically the majority of land-based transmission projects have utilised conventional alternating current (AC) overhead transmission lines using steel lattice towers and air-insulated outdoor substations. However alternative technologies to be considered by this report include:

- High Voltage Alternating Current (HVAC) Underground Cables (UGC);
- High Voltage Direct Current (HVDC) Overhead Line (OHL);
- HVDC UGC; and
- Substations.

It is recognised in the industry that there is not only one technology or mix of technologies that is appropriate for all projects and that the most appropriate technology must be considered for each project on its own merits.

The objective of this report is to review each of the above alternative technologies, identify the relative advantages and disadvantages of each and then assess these against the requirements of the Grid West project, in order to identify an emerging preferred technology.

In assessing the impact, advantages and disadvantages of each technology, a number of selection criteria have been adopted, following consultation with EirGrid.

- Operability: whether the technology can be reasonably and practically applied and utilised post completion of the project. There are a number of different technical considerations, including connection to and integration with the existing transmission network which need to be taken into account.
- Maintainability: how practical the maintenance of the circuit will be;

---

[1] The straight-line distance is approximately 100km, however a distance of 130km has been allowed for the physical length of the line in EirGrid technical studies. This is based on experience and allows a provision for the effects of line routing around constraints and accommodation of stakeholder considerations.

- Constructability: how practical the construction of the circuit will be;
- Losses: all transmission systems have inherent losses however these vary from technology to technology. EirGrid has an obligation to ensure that electricity is transmitted in the most economically efficient manner, requiring that losses be minimised;
- Future expansion and flexibility (‘future proofing’): ensuring that the network can be easily upgraded in the future as more power plants connect to the system or new loads need to be connected, while remaining flexible to adapt to changing demands expected to be placed on the network;
- Environmental impact: including, amongst other factors, terrain, ecology, cultural heritage and visual impact;
- Cost: It is commonly possible to engineer any solution, if the cost is not a consideration. However the cost is one of the factors that must be considered in assessing any technical solution, as one of the EirGrid obligations is to provide an economical transmission network to its users and customers;
- Risk to the implementation and consenting of the project: There are risks associated with the adoption of any of the technologies, but the objective must be to minimise these risks.

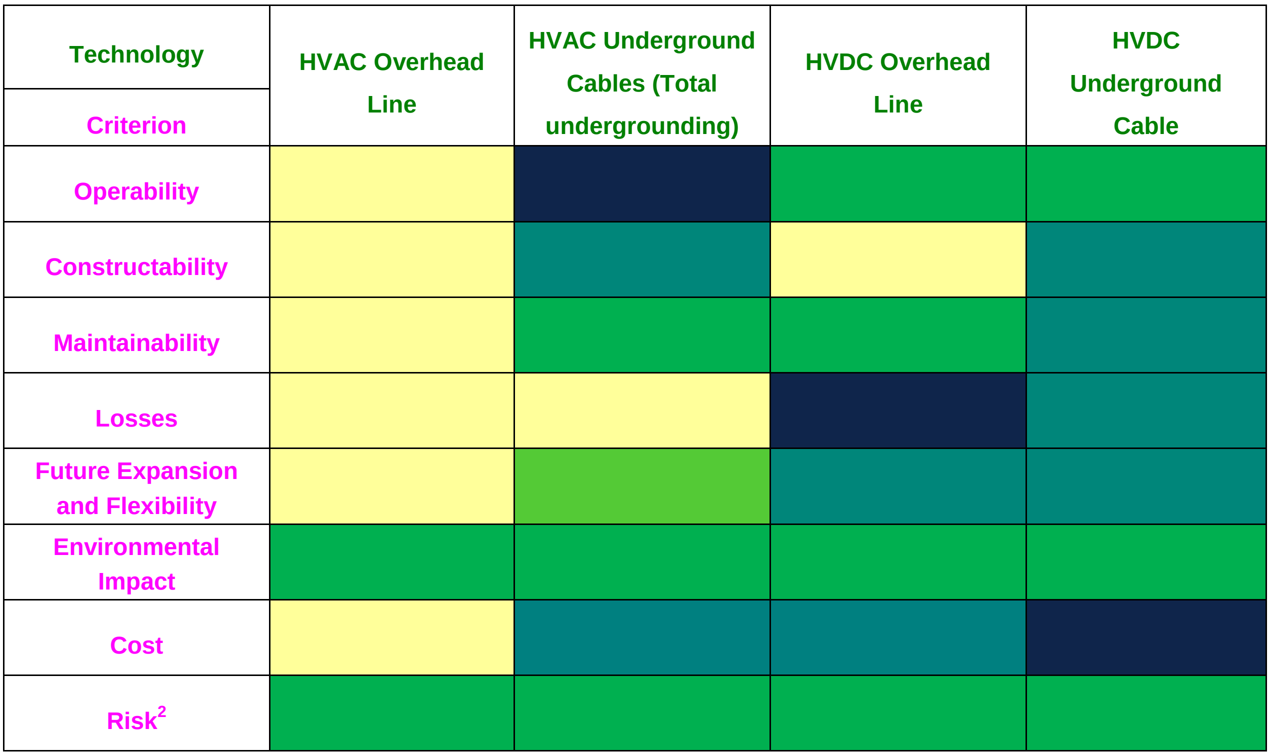
This report presents an analysis of the different technical solutions that could be adopted for the Grid West project. A multi-criteria evaluation methodology is used. This approach is also used for the evaluation of environmental impacts. The impact of each of the above criteria for each of the technologies was assessed and their impact analysed. The analysis is based on qualitative assessment and assigns the same relative weighting to each of the criteria. This technique has allowed a reasonable assessment of the different technologies across a range of potential impacts, and the identification of the technology with the least impact.

In this report these criteria are assessed at a high level. It is recognised that much more detailed development and design is needed to fully identify the impact. It is necessary to undertake an assessment of this nature at this early stage, to allow the further development of the planning application, including the route corridor selection, environmental impact assessment and stakeholder/landowner engagement. For example the route for an underground cable would be subject to different engineering and environmental constraints as for an overhead line, which would affect the route corridor selection. However as with any development project, subsequent activities may require this analysis to be re-assessed, if new information or factors arise.

The resultant analysis matrix is shown on the following page.

Review of this matrix below shows that high voltage alternating current overhead line (HVAC OHL) offers the most acceptable technical solution when assessed against the selection criteria adopted, and is thus the emerging preferred technology to be adopted for Grid West at this stage of the project. This result validates the conclusion reached by EirGrid in its preceding reports.

However certain issues pertaining to conventional overhead lines, such as visual impact, may weigh against the identification of this technology as a preferred solution. Therefore, ways in which such issues can be resolved while maintaining the use of the technology – and gaining from its inherent advantages - may offer a reasonable balance between EirGrid's obligations under its statute and the acceptance of the scheme by stakeholders and the public. Some risk would remain in adopting alternative designs as there is still the potential for public opposition given that, in the case of low impact transmission towers for example, no agreed international standard has emerged for such alternatives.



Technology	HVAC Overhead Line	HVAC Underground Cables (Total undergrounding)	HVDC Overhead Line	HVDC Underground Cable
Criterion				
Operability	🟨	⬛	🟢	🟢
Constructability	🟨	🟦	🟨	🟦
Maintainability	🟨	🟢	🟢	🟦
Losses	🟨	🟨	⬛	🟦
Future Expansion and Flexibility	🟨	🟩	🟦	🟦
Environmental Impact	🟢	🟢	🟢	🟢
Cost	🟨	🟦	🟦	⬛
Risk[2]	🟢	🟢	🟢	🟢

Key	
🟨 **Light Yellow**	Preferred, very limited impact, no difficulty, fully acceptable,
🟩 **Green**	Limited impact, limited difficulty, acceptable
🟢 **Dark Green**	Some impact some difficulty, limited acceptability
🟦 **Aqua**	High impact, difficult, poor acceptability
⬛ **Dark Blue**	Least preferred, major impact, high difficulty, unacceptable

The research and analysis carried out for this report also demonstrates that a total underground HVAC cable solution is not appropriate for the Grid West project. It also shows that the HVDC technology is not preferred, mainly because of increased losses, greater operational difficulties, increased maintenance requirements, higher cost and limitations in future expansion and flexibility to adapt to future changing requirements.

---

[2] Risk Analysis is made against the mitigated risk

With respect to substation technology, both air-insulated switchgear (AIS) and gas-insulated switchgear (GIS) are well proven technologies and have been implemented successfully in Ireland and around the world. Both technologies offer advantages depending on the application and the selected substation site. The key disadvantage of AIS is the significantly larger footprint required, but this technology does have advantages in terms of cost, maintainability and future expansion over GIS. GIS has a clear advantage when there are space constraints. It is also housed in a building, which assists in reducing the visual impact. In the case of the Grid West project, the final selection of technology is likely to be influenced by the availability of land and ability to screen potential visual impact and will thus be determined during the development of the project. The report proposes that given that as the project is only in the first Stage of EirGrid's Project Development & Consultation Roadmap, both technologies be taken forward into the substation site identification and evaluation process.

It is important that the selection of the preferred technology be made as early as practicable and appropriate in the project, as this enables the project to proceed to the next stages. In particular, the selection of the least constrained route corridor, which is the major activity in Stage 1, has been based on use of HVAC OHL technology as identified in this report. However, as with any development project, subsequent activities may require this analysis to be reviewed, if new information or factors arise.

1 OBJECTIVES

The West of Ireland, and County Mayo in particular, has significant potential for the development of renewable generation, particularly wind and ocean energy (tidal/wave). Under the Gate 3 Group Processing Approach EirGrid has issued connection offers to a number of wind farm developments in the Bellacorick area which, in total, will allow the connection of 647MW of wind energy. As part of the EirGrid Grid25 strategy to develop the Irish electricity transmission system, EirGrid is planning a new Extra High Voltage (EHV) electricity transmission line from the Bellacorick area to connect to the existing EHV grid at either Flagford or Cashla. This project is designated the Grid West project and forms the first phase of developments to allow the export of renewable energy from the Bellacorick area and promote development in the region.

The Grid West project is currently in the development stage, leading to an application for planning consent to the relevant planning authority. EirGrid has appointed engineering and environmental consultants, TOBIN Consulting Engineers in association with URS and Drury, to develop this project and prepare the planning application.

EirGrid, as the Transmission System Operator (TSO), has undertaken a considerable amount of work in developing the project to date. It has completed a study of the requirements for the Grid West project, Grid West Initial Technical Studies (GWITS) as included as Appendix 3.1, which sets out the main conclusions of this study which are as follows:

- Subject to reinforcements, the existing 110kV network will be able to export 170MW of the total 647MW of renewable connection offers. These reinforcements are currently in progress and ongoing.
- The balance of 477MW can be exported to the grid by a new higher voltage transmission circuit.
- The study found that the preferred solution, taking into account initial high level technical, environmental and cost considerations, is a single circuit, 400kV overhead transmission line approximately 100km[3] direct route length from Bellacorick to existing 220kV grid substations at either Flagford or Cashla.
- The study found that, having regard to technical requirements, the new circuit could be connected at either Flagford or Cashla. Therefore, both options remain open for further study (to be completed in this current phase of the project).

In the development of a new electrical power transmission project, it is necessary to make fundamental decisions as to the most appropriate technology to be used. Historically the majority of land-based transmission projects have utilised conventional alternating current (AC) overhead transmission lines (OHL) using steel lattice towers and air-insulated outdoor substations. However technical advances in

---

[3] The straight-line distance is approximately 100km, however a distance of 130km has been allowed for the physical length of the line in EirGrid technical studies. This is based on experience and allows a provision for the effects of line routing around constraints and accommodation of stakeholder considerations.

recent years now allows greater consideration of alternative technologies to be considered. These technologies include:

- For transmission lines
  - Underground high voltage alternating current (HVAC) cables;
  - High voltage direct current (HVDC) OHL; and
  - HVDC underground cables.

- For substations
  - Air-insulated switchgear (AIS); and
  - Gas insulated switchgear (GIS), both indoor and outdoor.

It is recognised in the industry that there is not only one technology or mix of technologies that is appropriate for all projects and that each technology must be considered on its own merits for any particular project.

The objective of this report is to review and assess each of the above alternative technologies, identify the advantages and disadvantages of each and then assess these against existing technologies and the requirements of the Grid West project, in order to identify an emerging preferred technology for the project. This process will then validate or contest the conclusion reached by the Grid West Initial Technical Studies that HVAC OHL technology is the preferred technology for the Grid West project.

This report does not challenge the Grid25[4] strategy. The selection of the single circuit 400kV HVAC line in the GWTS has been made in accordance with the Grid25 strategy. However, the Grid25 Strategy states that EirGrid will '*examine the potential for using HVDC technology for appropriate applications….*'. As the Grid West project is primarily for the export of renewable generation and HVDC is being increasingly used in Europe for this application, the use of HVDC has been reviewed.

In assessing the advantages and disadvantages, a number of aspects need to be considered. These include:

- Technical application: whether the technology can be reasonably and practically applied and utilised for the project. There are a number of different technical considerations, including the connection to and integration with the existing transmission network, ease of construction, operation and maintenance.

- Land use: current and future land use and geotechnical conditions.

---

[4] Grid25: A Strategy for the Development of Ireland's Electricity Grid for a Sustainable and Competitive Future, (2009). EirGrid Publication (see Bibliography)

- Environmental impact including effects on terrain, ecology, cultural heritage, water resources and geology.

- Visual impact: Recent high voltage transmission projects throughout Europe have attracted strong public opposition, most commonly to the visual impact of overhead power lines. Means of minimising this visual impact need to be considered, including the use of underground cables and lower visual impact designs.

- EMF: electric and magnetic fields (EMF) associated with high voltage power transmission need to be considered as part of the Grid West project. The different technologies have differing levels of EMF associated with them. However the magnetic fields at ground level for all the technologies in this report are typically an order of magnitude lower than the accepted maximum exposure levels recommended by the International Commission on Non-Ionizing Radiation Protection ICNIRP, *ICNIRP guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz – 100 kHz).* A separate report has been prepared on EMF for the Grid West project and therefore EMF is not considered further in this report.

- Future proofing: ensuring that the network can be easily uprated in the future should more power plant (generation) and consumers (demand) need to be connected to the system.

- Cost: It is commonly possible to engineer any solution, if the cost is not a consideration. However the cost is one of the factors that must be considered in assessing any technical solution, as one of EirGrid obligations is to provide a cost-effective solution to grid connection applicants and the end users of the energy.

The technique used in this report is to identify a number of appropriate selection criteria, assess the impact of each of the technologies against each of the criteria and then analyse the impacts to identify the technology which, for the Grid West project, is emerging preferred and, therefore, to be taken forward to the next stage of the project.

In the next stage of the project the identification of the possible route corridors for the new transmission circuit and the sites for the required substations will be carried out. These corridors will then be subject to extensive and ongoing consultation. As part of the process it will be essential to keep the technology selection under review, so that if other factors emerge during the corridor/site selection process and/or the consultation process that affect the selection of the technology, the process will be repeated or revisited.

For substations, both AIS and GIS are well proven technologies and have been implemented successfully around the world and in Ireland. Both technologies offer advantages depending on the application and the selected substation site. The key disadvantage of AIS is the significantly larger footprint area required, but this technology does have advantages in terms of cost, maintainability and future expansion over GIS. GIS has a clear advantage when there are space constraints but can also be housed in a building, which assists in reducing the visual impact. However for the Grid West project, the final selection of technology is likely to be influenced by the availability of land and will thus be determined during the design development of the project. For this reason the selection of the substation technology is not analysed further in this report, although further technical details are provided in Annex D, as it will be considered at later stages of the project.

It is important that the selection of the technology be made at this early stage in the project, as it has a major impact on all the following activities leading to the submission of the application for planning consent. In particular the selection of the preferred corridor/route, which is the first major activity, will be influenced by the technology selected. For example, the route for an OHL may be significantly different to that for an UGC. However it is important that the technology is identified only as the preferred technology until such time as the comprehensive environmental impact assessment and consultation has been completed. If these reveal any significant changes to the assumptions or analysis carried out in this report, then the technology selection will be revisited.

2 METHODOLOGY

The multi-criteria evaluation methodology used in this report to select the emerging preferred technology can be summarised as:

- Identify the particular requirements of the project, where these can be specifically set out.

- Identify the potential technologies that could be used for the project.

- Identify a range of selection criteria that influence the selection of the technology. It is important that this range is broadly inclusive and does not place too much prominence on one particular criterion, but also not so detailed as to exceed the level of information available at this early stage.

- Identify the impact of each criterion for each technology in the context of the project requirements.

- Analyse the different technologies against each criteria to identify the technology that is the most preferred or minimises the impact and therefore is indicated as the preferred technology. This is done by way of a matrix where the impact of each criteria is assessed on a five point, colour coded scale. Evaluation of this matrix will allow the preferred technology to be identified, based on the identified selection criteria.

This early selection requirement implies that the selection cannot be based on fully developed designs for each technology. It needs to use a range of both generic data, such as cost data, general characteristics, such as ability to integrate with the existing grid, and a range of criteria that can be satisfactorily assessed on a qualitative basis, such as the operational (operability) characteristics and maintenance (maintainability) requirements. The methodology has been adopted to allow assessment/comparison of these different criteria.

The criteria selected need to consider all issues that affect the selection of the technology. There are a large number that can be considered covering the range of technical, environmental, cost, risk and other factors. It is considered important that the criteria provide a reasonable balance between technical and non-technical criteria. Following discussions within the TOBIN/URS team and with EirGrid, the following criteria were agreed:

- Operability;
- Maintainability;
- Constructability;
- Losses;
- Future expansion and flexibility (Future-proofing);
- Environmental impact;
- Investment costs; and
- Risk to project implementation, including consenting risk.

Many other factors were discussed including, importantly, health and safety. Following the discussion it was considered that all the potential technologies would meet health and safety requirements and standards in their design and, therefore, are generally similar and that including health and safety as a selection criterion would not facilitate the selection process.

This methodology is analogous to the methodology utilised to assess the emerging preferred corridors through the analysis of environmental constraints to the project.

3 TECHNOLOGIES

3.1 GENERAL

There are currently four basic high voltage transmission technologies that could be applied to the Grid West project and are considered in this report.

The transmission technologies covered in this section are:

- High Voltage Alternating Current Overhead Line (HVAC OHL) utilising either conventional or alternative tower designs.
- High Voltage Alternating Current Underground Cable (HVAC UGC) utilising underground cables along the full length or major part of the length of the line.
- High Voltage Direct Current Overhead Line (HVDC OHL).
- High Voltage Direct Current Underground Cable (HVDC UGC) utilising underground cables along the full length or major part of the length of the line.

Further details of each of these technologies are outlined below, and more information is provided in Annex D.

It should be noted that no single “right solution” exists for all applications (Normark, B., *et al*, 2011) (Parsons Brinckerhoff Report, 2012). Hence each different technology must be judged on its own merits and be considered against the requirements of the specific project where it will be applied. This is the purpose of this report.

In addition to the transmission technologies there are three basic high voltage substation technologies that will need to be considered for the Grid West project. These are either Air Insulated Switchgear (AIS) and Gas Insulated Switchgear (GIS) hybrid equipment or fully enclosed GIS equipment which is predominantly installed indoors. As noted in the Introduction, this report does not address the selection of the substation technology, although further information is available in Annex D.

3.2 HIGH VOLTAGE ALTERNATING CURRENT OVERHEAD LINES (HVAC OHL)

HVAC OHL is the conventional technical solution for high voltage power transmission. This technology utilises steel lattice towers with one or more conductors per phase, supported on insulator strings which allows a sufficient air gap to insulate the live conductors.

It is well established, flexible, and presents low impact to the land it crosses, although its visual impact is considered to be significant by comparison to other technologies. It offers the most economical and technically viable solution for the Grid West project.

There have been many developments in recent years to make the conventional HVAC OHL a more visually attractive option (Normark, B., *et al*, 2011). These alternative solutions are discussed in more detail within Annex D. They have achieved varying levels of success and are considered to increase the cost and the risk to the project due to the unproven nature of the technologies. Nonetheless with sympathetic treatment, these alternative designs could provide a suitable compromise between technical, environmental and visual requirements for the Grid West project.

OHL lines utilise the characteristics of air as an insulation medium and as such the size of towers and insulation is determined by the transmitted voltage. Therefore the greater the voltage, the greater the required clearance distances and associated tower heights.

Conventional tower design combines steel lattice sections to transfer loadings caused by the weight of the conductor, wind pressure, short circuit forces and ice weight acting upon the tower and the conductors, to ground.

3.3 HIGH VOLTAGE ALTERNATING CURRENT UNDERGROUND CABLE (HVAC UGC)

One of the technology options considered in this report is undergrounding the proposed Grid West transmission line, using cables laid either directly or indirectly underground. There are two key variations, total undergrounding, where a cable is laid from end to end, and partial undergrounding where sections of the line are laid underground to avoid or overcome constraints that preclude overhead lines, while the remainder of the line is run overhead.

Total undergrounding of a line the length required for Grid West imposes significant technical constraints, which are discussed further below. The authors are not aware of any land-based transmission project of this length having been completed using underground cables for an AC system (Normark, B., *et al*, 2011). However it is accepted that partial undergrounding must be considered where there are unavoidable local constraints to be overcome or mitigated as part of any solution to a new transmission line, where OHL technology has been adopted. This will be designed in accordance with EirGrid 400kV requirements or applicable international standards.

HVAC underground systems include the following key components:

- High voltage transmission cable.
- Sealing ends – where the underground cables are terminated so they can be connected to a transmission line or substation plant.
- Cable system accessories, including cable joints, cooling, etc.
- Trenching, ducting or tunnelling.
- Ventilation/cooling systems, typically when installed in ducts or tunnels.
- Compensation equipment (where necessary);

- Maintenance roads; and
- Cable protection and earthing.

HVAC UGCs are installed either directly buried or within ducts/concrete trenches or tunnels. Cable tunnels are very costly to build. They are typically only used in densely developed urban areas where neither overhead lines nor direct buried underground cables can be used. The cost of constructing a tunnel for the full length of the Grid West line would be prohibitive and therefore the use of a cable tunnel would not be appropriate for a line the length and location of Grid West.

The laying of underground cables is highly dependent on soil type. There are two major influences:

- Excavation: Trenching for underground cables requires the excavation of significant quantities of soil; up to $2m^3/m$ (depending on local ground conditions). Areas of hard rock, very high water table, and extensive infrastructure can make this both complex and expensive. Extensive areas of deep peat, as found in County Mayo also have a significant impact on the excavation of trenches for underground cables.
- Backfill: The suitability of the soil as a backfill material and its thermal resistivity are important considerations. Frequently the soil is not suitable as a backfill material and must be either replaced or combined with imported improved material. Typically up to 50% of the excavated material needs to be removed and additional material imported.

The imported backfill may have repercussions with regard to local drainage patterns and soil stability, particularly if a cable were laid across country rather than in public roads. This is of particular relevance in peat bog where there can be adverse effects on the ecosystem and the stability of the ground.

The construction of linear infrastructure, such as an underground cable system, in areas of deep peat has the potential to impact on the hydrological regime of the bog, potentially causing the peat to dry out and compact and eventually destroy the habitat. (Mayo Wind Energy Strategy). In particular the Mayo County Development Plan requires that '*the potential impacts arising from inappropriate development in areas of bog, **deep peat soils** or other unsuitable soils or subsoils, must also be considered in the context of the overall sustainable development of the County*'. (Mayo Co Development Plan).

The installation of underground cables requires the use of heavy equipment, not only for the excavation but also for the transport and 'pulling' of the cable. A drum of 400kV cable may weigh between 30 and 40 tonnes, which has to be transported on a low–bed trailer or a specialist vehicle. In certain cases it may not be possible to access wetlands and peat lands with this heavy equipment.

The installation of underground cables is discussed in more detail in Annex D.

There are three basic high voltage cable technologies:

- Oil-filled cables;
- Crossed Linked Polyethylene insulated cables (XLPE); and

- Gas-insulated Lines (GIL).

Current cable technologies have been discussed in Annex D to provide a holistic overview of the technology. While technically all three cable types could be applied to Grid West, in practice because of the route length only XLPE would normally be considered. Given the limited length of existing projects and lack of international experience, GIL can be excluded as a viable and acceptable project option. Oil-filled cables have now generally been replaced by XLPE cables at 400kV.

3.4 HIGH VOLTAGE DIRECT CURRENT (HVDC)

Historically HVDC has been used to allow transmission of electrical power over large distances where HVAC is not technically or economically feasible. The breakeven point has generally been considered as being at distances of over 1,000km, although many factors can cause this to vary. However recent advances in HVDC technology, in particular the development of voltage sourced convertor (VSC) technology have challenged this.

The primary reasons for using HVDC is that it offers:

- Economical transmission of bulk electrical energy over extremely long distances via overhead lines or underground cable with reduced losses. This is because inductive and capacitive effects associated with AC transmission are greatly reduced in DC transmission and thus do not limit the transmission capacity or the maximum length of a DC line.

- With advances in technology, underground HVDC transmission has become a viable alternative to HVAC underground transmission for distances over approximately 50km. (Normark *et al*, 2011). If a total underground cable solution is found to be necessary, HVDC UGC could be a better solution since an HVAC underground solution over the full length would be technically difficult to achieve for the Grid West project, which is approximately 100km – 130km.

- A viable alternative to overhead transmission in areas where tower installations are not practical such as high density urban areas or areas of high environmental sensitivity.

- The possibility to connect asynchronous grids or grids with different frequencies.

- A transmission solution to overcome transient stability issues which can occur in equivalent length AC transmission.

The main technological components of an HVDC system are:

- A converter station at each end which provides the means to convert from HVAC to HVDC and vice versa. There are two main technologies for these stations, Line Commutated or Current Source Converters (LCC or CSC) and Voltage Source Converters (VSC). For the purpose of this report only VSC will be discussed in detail, being the most suitable for a transmission line of the length required for Grid West. This is in line with the Parsons Brinckerhoff report of 2012.

One or more pairs of HVDC conductors (underground or overhead line) to allow the power to be transmitted to its destination. The most significant advantage offered by HVDC is the ability to provide a fully underground solution. HVDC OHL does offer a reduced visual impact as a result of only requiring the two poles[5], compared with the three phases of an HVAC OHL. This reduces the wirescape and allows lighter towers to be used, thus resulting in a reduction in visual impact.

- VSC HVDC technology was developed during the 1990s, and the first commercial transmission link was commissioned in 1997. VSC converter technologies are based on power transistors, (IGBTs - Insulated Gate Bipolar Transistors), as the converting components. IGBTs, being more controllable devices than thyristors (used in LCC technology), make VSC HVDC a more flexible technology than LCC HVDC. In theory, this allows the VSC converters to be more easily integrated into an AC grid, with the ultimate goal, as the technology matures, for them to be able to fully replicate the operational characteristics of equivalent AC components. However this goal has not yet been achieved in any commissioned system. This characteristic also allows them to response better to variable outputs of renewable generation sources such as wind farms.

VSCs function as independent voltage sources that can supply or absorb active and/or reactive power, therefore requiring no independent power source and can operate down to an AC short circuit ratio (SCR) of 0, making it suitable for connection to XLPE cable installations. This ability to supply and absorb active and/or reactive power also makes VSC technology suitable for applications where integration into the grid system is important, such as the Grid West project.

As well as offering system benefits, physically VSC technology occupies 40 – 60% less space than an equivalent CSC station.

The technology continues to develop with converter stations becoming more efficient, reliable and compact. VSC technology now offers converter efficiencies of around 99% (Normark *et al*, 2011).

3.5 HIGH VOLTAGE DIRECT CURRENT OVERHEAD LINES (HVDC OHL)

An HVDC OHL requires only a monopole, single conductor and earth return, however due to reliability and safety requirements, the Grid West system would utilise two conductors, a positive and a negative conductor. This allows HVDC OHL to utilise lighter towers than an equivalent AC line, thus reducing the profile and therefore visual impact of the towers. The reduced number of conductors also offer less visual impact, although as conduits for large quantities of power, their visual impact is still significant.

---

[5] HVDC uses a two conductor system of electricity transmission, commonly designated as the positive and negative poles. HVAC normally utilises a three conductor system of electricity transmission, termed as phases, e.g. red phase, yellow phase and blue phase.

3.6 HIGH VOLTAGE DIRECT CURRENT UNDERGROUND CABLING (HVDC UGC)

Cable technologies and installations methods are similar to those used for HVAC UGC discussed above. Therefore the following notes will discuss specific technological details associated with HVDC UGC technologies where they deviate from HVAC UGC.

As HVDC only requires two paths (positive and negative) for each circuit there are a number of system configurations which can be applied, these include:

- Monopole, earthed return: Used for transmission over very long distances and in particular for undersea cable transmission, a return path via an earthed electrode can be used thus only a single cable needs to be laid. This can only be applied when there is no risk, such as buried metals of injecting large current into the earth. An alternative monopole solution utilises a LVDC cable for the negative pole or return path, this cable being arranged so that its potential is at or close to earth potential. (Siemens Energy, 2011, Pg 6).

- Bipolar long distance transmission: Can combine a number of combinations of two poles providing a return path via dedicated transmission cable or may include a common low voltage return path if available. The bipolar arrangement is used when the required transmission capacity exceeds a single pole configuration. Bipolar systems with electrodes or LVDC return path also have the flexibility to operate as monopole earth return under failure of a single pole at 50% capacity. (Siemens Energy, 2011, Pg 6).

4 GRID WEST CONSIDERATIONS

4.1 TECHNICAL CONSIDERATIONS

The Grid West Transmission scheme is proposed to meet development needs of the EirGrid system. Its primary purpose will be to allow the connection of approximately 647MW of Gate 3 wind generation proposed in the County Mayo area around Bellacorick. However in future, the Grid West project could form part of the electrical network necessary to connect further amounts of renewable generation and meet the long-term electricity needs of consumers in the region.

Grid25 clearly sets out the benefits of developing the grid in the west, of which Grid West is a key development. These include:

- The region becomes a net exporter of power to the rest of Ireland.
- Facilitate the growth of renewable generation connections, such as wind, wave, tidal, pumped storage.
- Increased power supply will accommodate and help attract future industry and development into the region.

EirGrid has a statutory role regarding the provision and/or facilitation of grid connections for the wind farms seeking grid connections and recognises the importance of these to Ireland's ability to meet 2020 Renewable energy targets set by the EU.

The Grid West scheme requires the construction of a new transmission circuit from the Bellacorick area to connect to the existing EirGrid 220kV network at either Flagford or Cashla, a distance in either case of 100-130km, depending on the final route[6]. The final connection point will be determined following a comprehensive technical, environmental and consultation exercise, which commenced in January 2012. This will ultimately lead to an application for planning consent for the scheme.

EirGrid has a statutory obligation to provide a 'safe, secure, reliable, economical and efficient transmission system'. Clearly in the development of any extension to the system, it is a fundamental requirement that these obligations are considered. Technical considerations form the foundations for achieving these objectives.

Initial studies by EirGrid (GWITS) have determined that the least cost scheme providing the optimum long-term system development and investment option is the construction of a single circuit 400kV AC OHL. However part of the terms of reference for the application for planning consent, is to review this technology and determine whether an alternative solution would be preferred. This report sets out the review of the technology to be used for the scheme.

---

[6] The straight-line distance is approximately 100km, however a distance of 130km has been allowed in EirGrid technical studies which based on experience allows a provision for the effects of line routing around constraints and accommodation of stakeholder considerations

4.1.1 System Requirements

In considering the technical requirements of the Grid West Transmission scheme, the following factors need to be considered:

- The immediate power transfer capability to allow connection of planned renewable wind generation and the future long-term development of the renewable resources in the County Mayo.
- The capacity and ability of the Irish grid to connect large amounts of renewable energy and still maintain secure and reliable electricity supplies to the island.
- The route for the new transmission circuit.

Capacity:

The initial requirement is to facilitate approximately 647MW of wind generation, of which approximately 170MW can be connected to the existing 110kV network with reinforcements at Bellacorick [GWTS]. Thus Grid West would need to transfer at least 477MW which would have required a number of 110kV circuits, indicating the need for transmission at either 220kV or 400kV.

In future significant quantities of additional renewable generation could be connected in the region. To maximise the benefits to Ireland, including meeting EU obligations, it is important that as much of this generation as possible is connected to the grid. This would require further reinforcement of the system across the network. If a second 400kV transmission line were constructed from Bellacorick, this would allow the connection of approximately 1500MW of renewable generation (determined by the thermal rating of a single 400kV circuit of 1424MW plus 170MW exported on the 110kV network). This second line would be arranged such that it would connect to the other station (Flagford or Cashla) forming a part of the meshed network. If the generation in the region were to exceed this figure, the Irish Grid is unlikely to operationally be able to accept this amount of renewable generation and the excess would have to be exported, possibly using an HVDC direct link to outside the Irish grid.

This level of connection in County Mayo requires that that the system be developed at 400kV, if the number of high voltage transmission lines is to be minimized. These conditions are illustrated in the diagrams below.

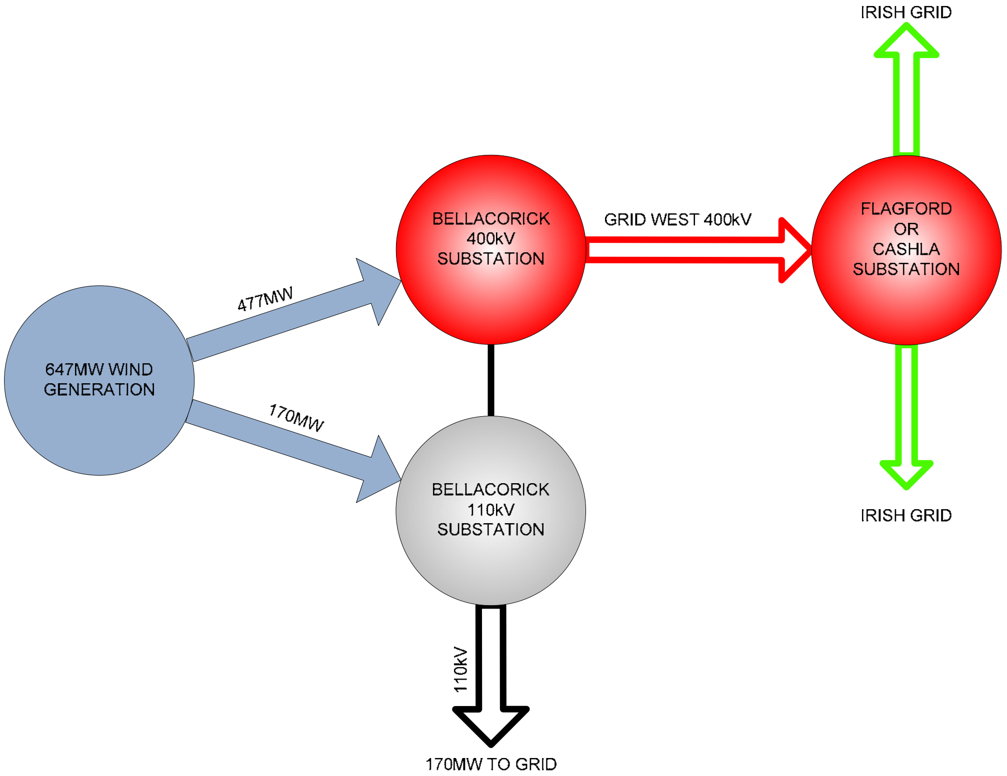


Figure 1: **Schematic Diagram of Grid West Transmission Scheme**

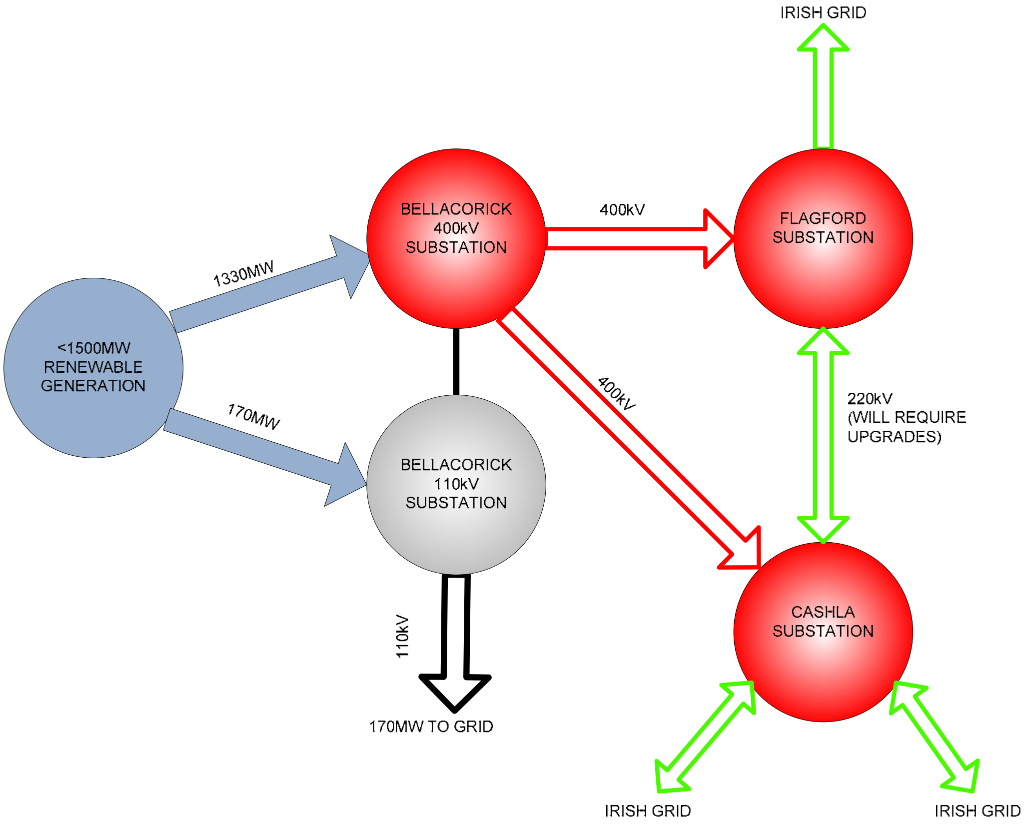


Figure 2: **Schematic Diagram of Future Development of Grid West Transmission Scheme**

A 400kV AC OHL built to EirGrid standards has an inherent transfer capacity of approximately 1424MW. This is provided at marginal additional cost compared to a line rated at the required 477MW, as the base construction costs such as access tracks, mobilisation of personal and equipment to site, preparation and pouring of footings and stringing cost are similar for both capacities. It would not be practical to operate a single 400kV line at 1424MW as in the event of a fault it would be difficult to keep the system stable, resulting in potential loss of electricity supply to large parts of Ireland. However if a second 400kV line were to be built in the future, with associated developments to the Irish grid, this problem is eliminated as the power being carried in the one line could immediately be transferred to the other line. Thus by rating the Grid West Transmission Circuit at 1424MW, as provided by a standard 400kV AC OHL, future expansion of the system by the construction of one additional 400kV OHL will allow the connection of up to 1424MW of generation to be connected to the Bellacorick 400kV substation.

Thus for the purpose of this report, the base case for comparison purposes is taken as a transmission line having a transfer capacity of 1424MW. The report does not consider system requirements should more than 1424 MW of generation seek to connect to Bellacorick 400 kV station.

Route Length

One of the primary considerations in the selection of the appropriate transmission technology once the voltage and capacity have been determined is the length of the transmission circuit. The distance from Bellacorick to either Flagford or Cashla is approximately 100km, straight line or up to 130km[7] after avoiding identified constraints. [GWTS]. This distance will be determined during the detailed route investigation process within Stage 2 of the Grid West development process.

4.2 ENVIRONMENTAL CONSIDERATIONS

In the preparation of this report appropriate environmental experts have contributed to the environmental analysis. Their advice was largely qualitative, given the high level of assessment which is carried out at this stage, and is based on the professional opinion of these experts, given the information available at this time. Annex B sets out the opinion provided by these experts.

The environmental impacts of any new electrical transmission scheme must always be minimised to the extent reasonably practical during its design and development. The environmental impacts of the scheme are a function of both the technical requirements and the route selected. This report considers the environmental impact of each technology in general terms; the detailed environmental impacts are then assessed for the scheme as part of the route selection process as the Stage 2 work is developed.

It is considered to be fundamentally important to include general environmental criteria in the selection of the preferred technology. To not do so, would mean that a key consideration in selection process is

---

[7] The straight-line distance is approximately 100km, however a distance of 130km has been allowed in EirGrid technical studies which based on experience allows a provision for the effects of line routing around constraints and accommodation of stakeholder considerations

not taken into account. However the environmental impacts of the Grid West scheme have not yet been studied in detail. Therefore at this stage only general readily apparent environmental considerations can be taken into account. These cover the following aspects:

- Ecology
- Cultural heritage
- Landscape
- Geology
- Water

Further details are set out in section 6.6 and Annex B.

Some of the key environmental considerations in the Grid West study area have been identified.

The study area includes a number of sites designated both as Special Protected Areas for birds (SPA's) and Special Area of Conservation (SACs). Key sites requiring consideration include the Owenduff / Nephin Complex, Lough Conn, Lough Carra, Lough Corrib, and moving eastwards, Lough Ree on the Flagford route. Key sites, designated as SPAs, include Lough Gara SPA, the River Suck Callows SPA and Lough Arrow SPA. There are also a large number of other SAC sites, most notably the Bellacorick Bog Complex SAC, River Moy SAC, perhaps less significantly the Ox Mountains Bogs SAC. The Bellacorick Bog Complex to the north-west of Bellacorick forms part of the proposed UNESCO World heritage Site of the Ceide Fields; the extent of this site is not yet fully defined so its impact cannot yet be assessed.

In addition to the important historical towns of the region, such as Tuam, Athenry and Roscommon which are archaeologically and architecturally important, there are also important demesnes, such as the Mahon Estate at Strokestown, which contains the Famine Museum. Furthermore, several significant abbeys and friaries are located in the study area, as are megalithic cemetery complexes at Carrowmore and Carrowkeel, and a Royal Site at Rathcroghan. The preliminary study area also contains culturally sensitive loughs, which also have high amenity value such as Lough Key.

The main landscape considerations within the study area are detailed in the respective County Development Plans and County Landscape Character Assessments. The Assessments describe the character of the landscape in terms of topography, prevalent vegetation and landscape patterns and identify areas that might be more sensitive than others to the introduction of a power line. Each Local Authority has identified views and routes considered scenic.

In general, within the study area, the uplands are considered more sensitive than the lowlands. Lakes and coastlines are considered sensitive, as well as areas where the landscape is very flat and open.

The eastern shores of Lough Corrib are characterised by deep peat deposits, with a particularly high water table, known to be underlain by karstic limestone at Carrowbrowne Landfill, with the peat running out to shallow depths at the line of the N17 Galway-Tuam road. The land from Claremorris, to Ballindine, and towards Tuam have been found to be karstic limestone, with areas of deep peat on the outskirts of Claremorris.

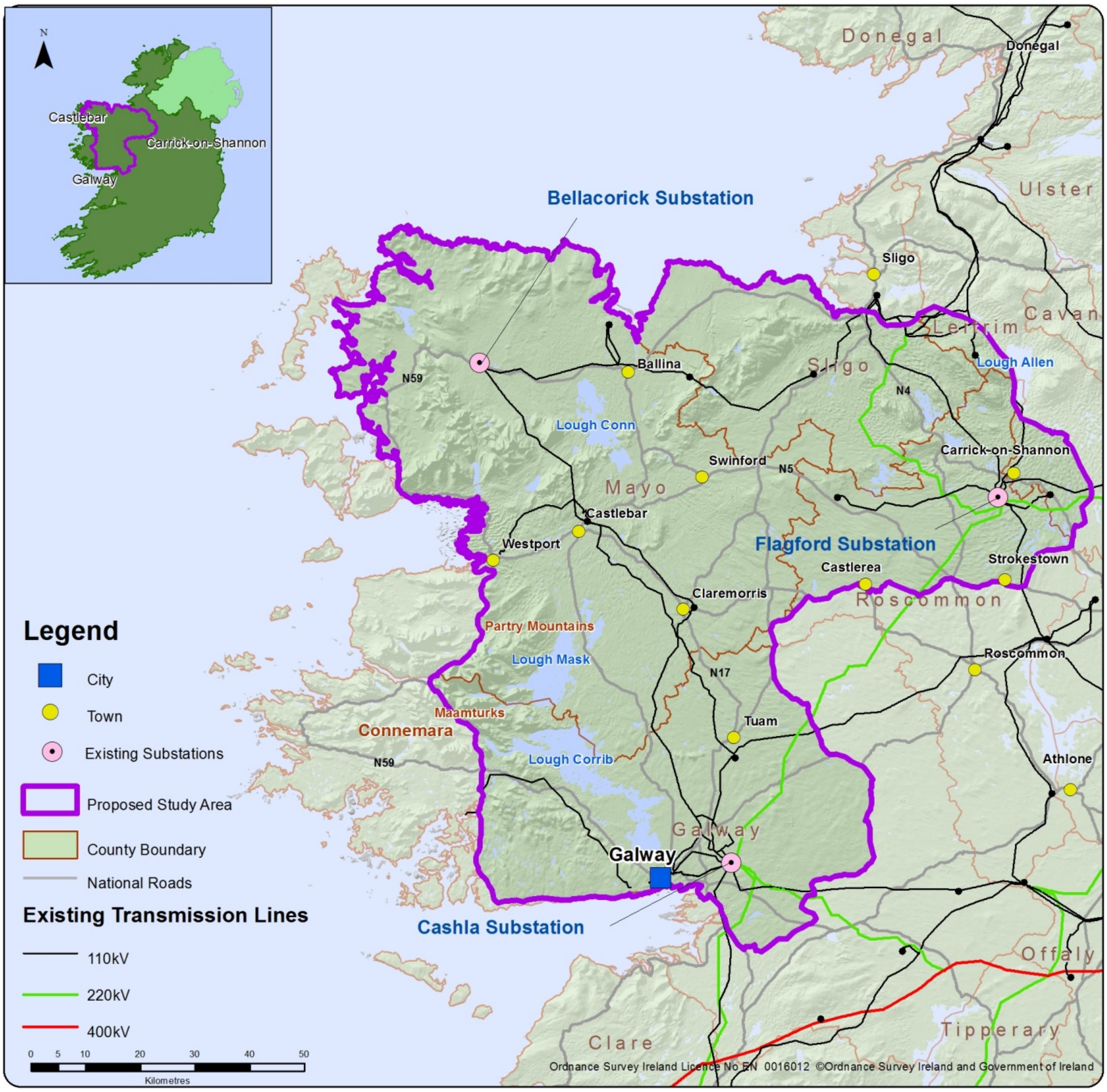
There are significant geographical influences in the broad route toward Cashla. These include the western lakes of Mask and Corrib the valley taken by the R312 between Nephin and Birreencorragh, Beltra Lough and Croaghmoyle, the Derrinumera Landfill (Mayo County Council), the Bilberry/Lannagh lakes and the dense glacial drumlin topography in Glenisland. It will be necessary to consider the proposed N5 upgrade, which Mayo County Council has taken through to Route Selection.

Areas south of Castlebar would encounter the Ballintubber archaeological complex around the Tóchar Phadraig, the dry, karstic limestone geology and on moving across the county boundary into the Clare River catchment, which was subject to severe flooding in November 2009. There are deep peat deposits each side of the Curragh Line.

In considering corridors from Bellacorick towards Flagford, it will be necessary to take into account Lough Conn and the airport at Knock, the Loughs Arrow-Key-Gara complex and national monuments in this area.

The map on the following page (Map 4-1) shows the study area for the Grid West project, this may assist in understanding of the issues set out above.

Map 4-1: Grid West Study Area



5 SELECTION CRITERIA

5.1 GENERAL

This section presents an assessment of the different criteria considered in determining the emerging preferred technology for the Grid West project.

These criteria are then utilised in the methodology set out in section 2 of this report.

The criteria selected need to consider all issues that affect the selection of the technology. There are a large number that can be considered covering the range of technical, environmental, cost, risk and other factors. It is considered important that the criteria provide a reasonable balance between technical and non-technical criteria. Following discussions within the TOBIN/URS team and with EirGrid, the following criteria were agreed:

- Operability;
- Maintainability;
- Constructability;
- Losses;
- Future expansion and flexibility (Future-proofing);
- Environmental impact;
- Investment costs; and
- Risk to project implementation, including consenting risk.

Many other factors were discussed, including importantly health and safety. As all options will be designed to meet relevant health and safety requirements and standards all the potential technologies are acceptable.

5.2 TECHNICAL CONSTRAINTS

5.2.1 Operability - Operational Requirements

Operationally, the Grid West transmission line will be connecting to and becoming an integral part of the Irish electricity grid. As such, and in common with any new connection to the grid, it has to be able to interface with and then operate in an integral manner with the grid. This is fundamental to meeting the obligations for a secure, reliable and efficient system.

The different technologies exhibit different electrical characteristics that affect their integration into the grid. Generally the different characteristics can be technically accommodated but special measures, which increase the cost, reduce the reliability and increase the complexity of the system, are required. Therefore the preferred technology should offer the best compromise between these different operational characteristics.

5.2.2 Maintainability - Maintenance Requirements

EirGrid has a statutory role in the provision of a reliable electrical transmission system for Ireland. Maintenance is always required, either as planned, preventative maintenance to minimise the risk of unplanned outages or as emergency maintenance to re-establish supplies as quickly as possible. Increased maintenance requirements could result in an increased amount of commissioning and testing associated with plant that has returned to service or replaced following maintenance.

The maintenance requirements in terms of both frequency and duration must be minimised and are an important criterion in the selection of the technology.

5.2.3 Constructability - Construction Requirements

The constructability of a transmission circuit is determined by the technology adopted and the characteristics of the route.

There are obvious differences in the construction requirements for overhead lines and underground cables. Underground cables require a continuous linear excavation of a trench or trenches in which to lay the cables, with joint chambers every 500m to 800m, whereas OHL require the construction of towers at discrete locations along the route, typically every 350m – 450m for a 400kV line.

Geography and geology will also impose constraints on the construction. Typical considerations that need to be applied include hilly areas, hard rock close to the surface, areas of peat lands, extensive forest, urban areas and areas of intense agriculture.

While the selection of the route will be the subject of a separate detailed study, it is important to consider the general route characteristics for any project when making the initial determination of the technology.

5.2.4 Losses

It is important that the Grid West transmission line is as efficient as possible in its contribution to Ireland meeting its EU obligations of 40% reduction of CO2 by 2020. All transmission systems incur losses but the amount of the loss for a given capacity is dependent on the technology.

It is important that the losses be minimised to assist in the achievement of an economical transmission system.

5.2.5 Future Expansion and Flexibility

A key criterion in the selection of the technology for any new transmission circuit is the flexibility that can be provided to meet future expansion requirements. Grid infrastructure is expected to have a design life of 50 years, based on the rate of return set by CER, with some of the current infrastructure having been in place for 50 – 60 years. System requirements over this time frame cannot be predicted and it is therefore important that the system be readily expandable to accommodate additional capacity and also flexible to adapt to changing requirements.

The Grid West Transmission Circuit will connect the Bellacorick node to the Irish electrical grid at one point (either Cashla or Flagford). It is reasonable to expect that in the future additional generation and load in the County Mayo region will need to be connected to the grid, at which time a second connection will be required. It is preferable that this second connection allows the Grid West project to become a fully meshed part of the Irish grid, since this provides the greatest operational flexibility.

When designing and developing any new piece of transmission infrastructure it is desirable to ensure that it can facilitate the connection of future or existing generation / load at any point along its length to minimise the build required for those future projects.

5.3 COST

EirGrid has an obligation to transmit electrical power as economically as possible. Thus the cost of implementing any technology is an important criterion in the assessment of the technology to be selected for the Grid West project.

A transmission line is now considered to have a life of up to 50 years and the costs need be assessed over its lifetime. The lowest construction cost may not result in the lowest life time costs, if the operating and maintenance costs are high.

The driver for the Grid West project is primarily to facilitate the connection of Independent Power Producers (the wind farms). In terms of the EirGrid tariffs, the developers will be responsible for meeting the ‘least cost chargeable’ (LCC) of the new line required to allow this. EirGrid have initially estimated the LCC costs as €100 million, being the minimum additional infrastructure that would be necessary to export the 650MW for an intact network.

However EirGrid has taken the decision to use this project to reinforce the grid and defer higher costs in future by strategic development of the grid. This is in line with the Grid25 strategy. The Grid West project will have an impact on the overall cost of electricity in Ireland, therefore it is important that due regard is given to the total cost of the scheme

The total life-time cost of any transmission circuit consists of:

- Construction costs – the capital costs required to plan, design, build and commission the new line.
- Operational costs – includes the cost of losses, staff and systems necessary to operate the circuit
- Maintenance costs – costs of all planned and unplanned maintenance and repair, including any refurbishments.
- Production cost savings – Netting of costs associated with the reduction of power production costs through better operation of the network.

The reported cost of transmission schemes internationally shows wide variations in price (see Annex C) and to compare prices of specific schemes is difficult unless detailed cost models covering the elements set out above are prepared. At this very early stage of the project the design of the Grid West line has not been developed, specifically a line route has not been established, meaning that many of the major cost parameters, such as foundation or trenching conditions, access requirements cannot be determined

As set out above the purpose of this report is to identify the preferred technology for the Grid West project, which will then allow the scheme design to be developed. In terms of costs, it is recognised that there are wide variations in the cost estimates associated with any specific technology. However it has been assumed that the Grid West project is a reasonably typical 400kV project, being neither very long or very short; it does not have a very high transfer capacity and its purpose will be to support standard electricity grid operations. It is therefore considered reasonable to assume at this stage that the relative costs of implementing the project in the different technologies would be similar to the average relative costs reported internationally, particularly in Europe.

5.4 ENVIRONMENTAL IMPACT

The assessment of the environmental impact of a new transmission scheme and mitigation of any environmental concerns is a crucial and major element of the consenting process. The scheme is developed in detail as part of the preparation of the planning application and it is not the intention or the purpose of this report to develop a comprehensive assessment of the environmental impact of the Grid West project.

However it is necessary to generally assess the relative environmental merits of the different technologies if they were to be used for Grid West. It would not be appropriate to ignore the environmental impact entirely when selecting the technology.

The general environmental impact of both HVAC and HVDC OHL is similar[8], as is the environmental impact of both underground cable technologies[9]. For this report the environmental advantages and disadvantages of overhead vs underground have been assessed in general terms for the Grid West study area. This analysis is set out in Annex B and a single environmental impact criterion is brought forward into the technology evaluation.

5.5 RISK

In implementing any new power line project, there are risks to that development. These risks generally occur in the three major phases of the project:

---

[8] HVDC OHL only requires two poles compared with 3 phases required for HVAC OHL. This results in potentially lighter towers, with less visual impact. However the reduction in visual impact would be limited as the HVDC OHL still presents a significant feature in the landscape.

[9] HVAC underground cables do require a wider trench than HVDC cables, and therefore could have a greater environmental impact. However this would be limited as the major impacts of a significant linear trench would still be present.

- Consenting
- Construction
- Operation and maintenance

All developers of large infrastructure projects face risks related to delays during the consenting process. Public opposition to new transmission projects has been a cause of delay and in some cases it has been shown that the type of technology for such projects has been the driver for the opposition.

This report, therefore, considers the risk the technology selection imposes on the consenting of the project.

The construction, operation and maintenance risks dealt with in this report relate to the technical risks to these activities imposed by the technology selected and are covered under those criteria. However there are other risks that potentially affect the successful implementation of the project. These include issues such as:

- Experience of the application of the technology in applications similar to Grid West.
- Maturity of the technology and the risk new and emerging technology imposes
- Selection of an inappropriate technology may create risks to the subsequent development of the electricity infrastructure in the region and in Ireland generally, with potential long-term consequences.

6 ASSESSMENT OF TECHNOLOGIES

In this section, each of the technologies is assessed against each of the criteria set out in the previous section. Where information on the likely requirements of the Grid West project is understood; these have been taken into account. Where there is not yet sufficient information to allow specific analysis, then the assessment has been done using general or typical information.

It should be noted that in the assessment below, it has been assumed that HVAC lines, either overhead or underground, would be constructed to current EirGrid standard specifications. These specifications are not available for the HVDC systems. It has therefore been assumed that the HVDC systems will be VSC monopole systems, requiring two conductors (the positive and the negative), allowing fully controlled active and reactive power flow in real time.

6.1 OPERABILITY

6.1.1 Summary of Advantages and Disadvantages

Table 6-1: Operability: Summary of advantages & disadvantages of HVAC Overhead Lines

HVAC Overhead Lines	
Advantages	Disadvantages
Advantages: - No difficulties with frequency control, as part of synchronised AC system - As the standard technology integration into the grid is straight forward, with proven systems for: ▪ Voltage control ▪ Switching and isolation ▪ Protection and control ▪ Network stability - Above advantages result in a system with high reliability and availability - Modern protection systems can be included into the design allowing rapid fault clearance and fault location - Short repair times enable a higher level of confidence that n-1 system conditions can be maintained -The use of auto-reclose schemes allows rapid restoration of supplies following transient faults caused by lightning or contact with vegetation -Relatively easy to uprate or modify -Do not Impact on security of supply for technical reasons such as resonance, etc.	Disadvantages: - OHL has a higher probability of lightning strikes or contact with vegetation than underground circuits - However the reliability and availability is not significantly reduced since auto re-close protection functions can be used to reduce power restoration times to a few seconds for typical transient faults and in this way reducing the impact of related forced outages - There are no real disadvantages to the operability of HVAC OHL

Table 6-2: Operability: Summary of advantages & disadvantages of HVAC Underground Cables

HVAC Underground Cables	
Advantages	Disadvantages
- No difficulties with frequency control as part of synchronised AC system - As HVAC technology standard systems can be used for connection to the grid, including: ▪ Switching and isolation ▪ Protection and control ▪ Network stability	- Capacitance of the cable requires reactive compensation for voltage control (typically every 15km) - It is not appropriate to apply auto-reclose protection to underground cables - Due to extended delays in the repair of the underground cable the n-1[10] security can be temporarily jeopardised if there is a 2nd fault within the network during this period - Long-term overload is more critical in underground cables. This occurs where the current limit is below the threshold of the cable protection however over long periods the heating effect reduces the life of the cable and increases the risk of faults - Risk of damage by digging and other construction activities, most common cause of faults on cable systems - Resonance – cable circuits with the associated compensation pose significant risks of resonance and transient instability and over -voltages can propagate well beyond the cable circuit - Cable circuits are difficult to restore under black start conditions

Table 6-3: Operability: Summary of advantages & disadvantages of HVDC Overhead Lines

HVDC Overhead Lines	
Advantages	Disadvantages
- Inherent dynamic reactive power support - Electronic controls facilitate voltage and frequency control - Enhanced controls can benefit system operation - Can operate on an unsymmetrical network (e.g. during AC network faults) and can be used to compensate for unsymmetrical loads	- Reduced short-circuit capacity - HVDC circuit breakers not yet commercially available - Complex hardware and software in convertor stations - Higher probability of lightning strike and flashover as for AC OHL - Auto reclose is not available at present for HVDC due to circuit breakers not being commercially available - Additional operator training to operate the more complex system - Possible interference between the power electronics of the HVDC converter station and types of wind generators. - Emerging technology without a proven track record, particularly for operation in a meshed grid. - HVDC circuits do not integrate inherently with AC networks (with current technology) - A control failure can result in major network disruption

---

[10] n-1 refers to the design condition for abnormal operation whereby the design allows for one outage or failure while maintaining full service/capacity. An n-2 design conditions allows full operation with two elements out of service.

Table 6-4: Operability: Summary of advantages & disadvantages of HVDC Underground Cables

HVDC Underground Cables	
Advantages	Disadvantages
- VSC provides inherent reactive power support - Electronic controls facilitate voltage and frequency control - Enhanced controls can benefit system operation - Can operate on an unsymmetrical network (e.g. during AC network faults) and provide unbalance control to compensate unsymmetrical loads	- Reduced short-circuit capacity - HVDC circuit breakers not yet commercially available - Complex hardware and software in convertor stations - Additional operator training to operate the more complex system - Possible interference between the power electronics of the HVDC converter station and types of wind generators. - Emerging technology without a proven track record, particularly for operation in a meshed grid. - HVDC circuits do not integrate inherently with AC networks (with current technology) - A control failure can result in major network disruption

6.1.2 Review of Operability

In comparing the HVAC OHL and HVAC underground cable technologies, the major disadvantage of the underground cable solution is the high capacitance of the cable. The Expert Commission Report on the Meath-Tyrone Project (Normark, B., *et al*, 2011) recommended against using a total underground HVAC cable solution for that project. For the same reasons a total HVAC underground cable solution would present significant operational difficulties for Grid West and is the least preferred of the technology options for operability.

However the Expert Commission (Normark, B., *et al*, 2011) noted that HVDC technology has advanced significantly in recent years. The commercial availability of voltage source converter (VSC) systems, which offer operational characteristics allowing relatively simple integration into an HVAC system, makes HVDC a feasible alternative for a project such as Grid West. This is still emerging technology, with a limited number of projects commissioned world-wide. There are however a significant number either under construction or contracted, including the EirGrid East West Interconnector between Ireland and Great Britain. Of this limited number of projects, most are either major interconnectors (such as the East West Interconnector) or provide connection to an off-shore wind farm. There is currently no operational experience of an HVDC link utilised in the mode proposed for Grid West i.e. as an integral part of the meshed grid network. However it is possible that the technology may have evolved to allow this by the time Grid West is commissioned, although it would still be one of the world's first such systems and as such is unlikely to be suitable for this project, given its impact and scale on the Irish network.

The additional complexity of the HVDC system and additional control functions available increase the complexity in the operation of an already complex system, and require that the operators receive additional training to not only ensure the safe and reliable operation of the system but also take advantage of the additional benefits that can be realised from an HVDC system. There are also additional challenges for the system planners in both modelling and implementing the HVDC system into the network plans and operational procedures. As these are still not fully established and standardised in HVDC systems, this creates some risk to the operation of the network.

A further operational risk associated with HVDC systems is that a control failure can have significant impact on the integrity of the network, potentially resulting in network failure. The complexity of the control systems in an HVDC system tends to exacerbate this risk.

The key potential disadvantage of HVAC OHL technology is an increased incidence of faults resulting from the increased susceptibility to lightning strikes and contact with vegetation. These faults are typically only transient and therefore although more numerous in total than for an underground system there is less forced outage time of the line. In this respect EirGrid report that there has not been a single sustained fault on a 400kV OHL in Ireland in over 25 years of operation.

It is possible that in the future the disadvantages set out above for both HVDC OHL and UGC can be managed. However this will come at an increased operational complexity. Thus either HVDC technology could be utilised for the Grid West project although the complexity makes this technology less preferred than the HVAC OHL solution.

6.2 MAINTAINABILITY

6.2.1 Summary of Advantages and Disadvantages

Table 6-5: Maintainability: Summary of advantages & disadvantages of HVAC Overhead Lines

HVAC Overhead Lines	
Advantages	Disadvantages
Advantages: - Well proven maintenance techniques with trained and experienced staff available - Rapid location of faults, allowing rapid repair - Live-working techniques can allow routine maintenance without line outage (Not currently used in Ireland) - Visual inspection can be carried out from the ground or air - Self-healing protection	Disadvantages: - Repairs have to be undertaken at height - Routine cutting of vegetation along line route required - Cleaning of insulation in high pollution environments is required - On-going condition assessments, LIDAR surveys and tower maintenance (painting)

Table 6-6: Maintainability: Summary of advantages & disadvantages of HVAC Underground Cables

HVAC Underground Cables	
Advantages	Disadvantages
- Work is done at ground level (no working at height safety issues) - Limited routine maintenance requirements - Limited access makes line less susceptible to vandalism and other anti-social acts	- Location of faults on the cables is difficult and time consuming - Extended repair times (GIGRE 379 indicates average of 25 days) - Exposing and repairing the cable fault requires special equipment and the specialised repair techniques. - Repair work has to be undertaken below ground level, with the associated risks of this working - Permanent access is required for heavy vehicles and digging equipment - Continuous monitoring of earthing is required throughout the life of the cable - Cable jointing and repairs require specialist techniques and skills - Cable route must remain free of shrubs or deep rooted vegetation to ensure there is no possibility of root damage - Due to extended delays in the repair of the underground cable the n-1 security can be temporarily jeopardised if there is a 2nd subsequent fault elsewhere within the network during this period - Owing to the requirement to excavate continuous lengths of route, may cause disruption to ground activities, e.g. farming (rural) or road traffic (urban)

Table 6-7: Maintainability: Summary of advantages & disadvantages of HVAC HVDC Overhead Lines

HVDC Overhead Lines	
Advantages	Disadvantages
- Well proven maintenance techniques for the overhead line with trained and experienced staff available - Rapid location of faults, allowing rapid repair - Visual inspection can be carried out from the ground or air	- Repairs have to be undertaken at height - Routine cutting of vegetation along line route required - HVDC convertors are complex, required specialist skilled maintenance staff, increased repair times - Cleaning of insulation in high pollution environments is required - On-going condition assessments, LIDAR surveys and tower maintenance (painting) - HVDC convertors are complex, require specialist skilled maintenance staff and frequently extended repair times

Table 6-8: Maintainability: Summary of advantages & disadvantages of HVDC Underground Cables

HVDC Underground Cables	
Advantages	Disadvantages
- Work is done at ground level (no working at height safety issues) - Limited routine maintenance requirements for underground cables - Limited access makes line less susceptible to vandalism and other anti-social acts	- Location of faults on the cables is difficult and time consuming - HVDC convertors are complex, require specialist skilled maintenance staff and frequently extended repair times - Exposing and repairing the cable fault requires special equipment and the specialised repair techniques - Repair work on the UGC has to be undertaken below ground level, with the associated risks of this working. - Permanent access is required for heavy vehicles and digging equipment - Continuous monitoring of earthing is required throughout the life of the cable - Cable jointing and repairs require specialist techniques and skills - Easement must remain free of vegetation to ensure there is no possibility of root damage - Due to extended delays in the repair of the underground cable the n-1 security can be temporarily jeopardised if there is a 2nd subsequent fault elsewhere within the network during this period - Owing to the requirement to excavate continuous lengths of route, may cause disruption to ground activities, e.g. farming (rural) or road traffic (urban) - HVDC convertors are complex, require specialist skilled maintenance staff and frequently extended repair times

6.2.2 Review of Maintainability

The maintenance techniques for HVAC OHL have been developed over many years. They are now well-proven with trained and experienced staff available to undertake this work.

The complexity and the increased component count of the converter station increases the probability of failures and the time to repair, thus reducing both the reliability and availability of the transmission line. Outages due to an HVDC converter fault are longer when compared with HVAC and have a higher probability of requiring specialist staff to be available to undertake the repair. The rapid expansion of HVDC applications has led to a shortage of skilled engineers able to work on this technology.

OHL has a higher probability of forced outages due to lightning strikes or contact with vegetation; however outage time are considerably less than underground cable options as protection systems enable accurate fault locations and access to the lines are comparatively simple. Most faults are transient and are cleared within seconds. Frequently faults can also be visually located, reducing outage times. For HVAC OHL auto-reclose function allows transient faults to be cleared very rapidly and supplies restored in seconds.

The location of faults in underground cables can be difficult and time consuming, resulting in extended outages. It typically requires the application of a number of different fault location systems and ultimately relies on maintenance staff to pinpoint the fault location. A number of different fault location systems have been developed, which can accurately locate most faults to within 1% of the distance of the route. Other systems allow accurate location of the fault (for example thumper systems) but these require the maintenance staff to walk the route of the line in the area identified by the fault location equipment.

Once the fault has been located the cable then has to be exposed and a specialised repair effected. This is an extended process resulting in long repair and outage times. CIGRE Report 379 (2009) found that the average repair times for cable circuits rated at 220kV and higher is 25 days for extruded (XLPE) cables and 38 days for oil-filled cables. This would be made more difficult in wet lands, which cannot support vehicular traffic under normal circumstances unless a permanent access track is provided along the route of the underground cable. As the circuit is out of service on forced maintenance, potentially for these extended periods, there is an increased risk to the network because of an n-1 contingency.

Routine maintenance is required for both underground and overhead lines. Typically this includes regular cutting of vegetation but also includes insulator cleaning and tower painting for overhead lines.

Thermal imaging techniques are used for preventative maintenance. This is normally done from helicopters for EHV lines, and cannot be done for underground cables.

In summary it can be seen that the maintenance, particularly emergency maintenance, of either underground cable system is significantly more difficult than for the overhead line system. Maintenance of HVDC convertor stations is also more difficult due to their complexity and the shortage of skills in this new technology. As a result HVAC OHL technology emerges as the preferred technology for maintainability, with HVDC underground being the least preferred.

6.3 CONSTRUCTABILITY

6.3.1 Summary of Advantages and Disadvantages

Table 6-9: Constructability: Summary of advantages & disadvantages of HVAC Overhead Lines

HVAC Overhead Lines	
Advantages	Disadvantages
- OHL technology is flexible to variable and unstable terrain - Piled foundation and variable leg extension allow construction in almost any terrain - Limited access to towers sites is required (compared with u/g circuit where continuous access along route is required) - Towers are transported in relatively small light sections, requiring smaller vehicles, facilitating access in difficult ground conditions - Construction techniques available for construction in inaccessible locations, e.g. by helicopter	- Access and temporary works required for construction of towers in fields, forest and peatlands - Transmission lines need to be designed so as to maintain clearances above ground obstacles

Table 6-10: Constructability: Summary of advantages & disadvantages of HVAC Underground Cables

HVAC Underground Cables	
Advantages	Disadvantages
- Routing is possible in road and other infrastructure easements (where possible or permissible) - Cable routes can be designed with more bends, allowing greater flexibility in avoiding highly sensitive areas of limited size	- Compromise between number of cable joint chambers and the length of cable on a drum, which in turn affects size and weight of drum - Requirement for accessible joint chambers at regular intervals (500-800m) - Need to import thermally stabilised backfill - Need to cart away significant quantities of excavated material to allow placing of imported thermally stabilised back fill - Difficulties in reinstating walls, fences and vegetation. - Need for extensive road closures and traffic management during construction if cables are laid in public roads - Access and temporary works required for construction in fields, forest and peatlands, including access for heavy cable trucks - Additional land take required for construction of reactive compensation compounds at frequent intervals along the cable route - Complex earthing systems need to be developed and installed to prevent unsafe voltages occurring within the cable sheath - Specialist cable installers and jointers are required - Peat bogs can become destabilised thus creating construction difficulties. - Steep gradients are to be avoided to reduce compression and expansion strain at joint locations - Topsoil needs to be removed along the full length of the route - Cable joints and core must remain free of moisture hence specialised construction techniques are required - Owing to the requirement to excavate continuous lengths of route, may cause disruption to ground activities, e.g. farming (rural) or road traffic (urban)

Table 6-11: Constructability: Summary of advantages & disadvantages of HVDC Overhead Lines

HVDC Overhead Lines	
Advantages	Disadvantages
- OHL technology is flexible to variable and unstable terrain - Limited access to towers sites required (compared with UGC where continuous access along route is required) - Towers are transported in relatively small light sections, requiring smaller vehicles, facilitating access in difficult ground conditions - Construction techniques available for construction in inaccessible locations, e.g. by helicopter - Towers are lighter and lower than equivalent HVAC towers	- Additional land take for the converter stations - Construction and installation of HVDC converters requires skilled specialists - Access and temporary works required for construction of towers in fields, forest and peatlands - Transmission lines need to be designed so as to maintain clearances above ground obstacles

Table 6-12: Constructability: Summary of advantages & disadvantages of HVDC Underground Cables

HVDC Underground Cables	
Advantages	Disadvantages
- Routing is possible in road and other infrastructure easements - Trench is smaller for HVDC cables compared to equivalent HVAC cable circuit - Cable capacitance is not applicable to HVDC hence cable compensation is not required	- Compromise between number of cable joint chambers and the length of cable on a drum, which in turn affects size and weight of drum - Need to import thermally stabilised backfill - Need to cart away significant quantities of excavated material to allow placing of imported thermally stabilised back fill - Difficulties in reinstating walls, fences and vegetation. - Need for extensive road closures and traffic management during construction if cables are laid in public roads. - Additional land take for the converter stations - Access and temporary works required for construction in fields, forest and peatlands, including access for heavy cable trucks. Construction and instalment of HVDC converts requires skilled specialists - Specialist cable installers and jointers are required - Steep gradients are to be avoided to reduce compression and expansion strain at joint locations - Topsoil needs to be removed along the full length of the route - Cable joints and core must remain free of moisture hence specialised construction techniques are required - Peat Bogs can become destabilised thus creating construction difficulties - Owing to the requirement to excavate continuous lengths of route, may cause disruption to ground activities, e.g. farming (rural) or road traffic (urban)

6.3.2 Review of Constructability

Review of the advantages and disadvantages set out above clearly shows that OHL are simpler to construct than underground cable circuits.

The fact that towers are located at discrete intervals (Typically 350m – 400m between towers for a 400kV OHL), occupy a relatively small area, with only limited infringement required on the land between towers during the stringing operation, typically facilitates construction. OHLs can also be constructed over terrain where it is impossible to install underground cables.

The smaller physical size of the HVDC towers and cables allows smaller, lighter towers and smaller, narrower trenches to be constructed. However there is limited advantage to this from a constructability perspective.

Considering the large expanses of peat (refer to section 5.2) and varied terrain within the Grid West study area, the possibility of providing a total underground solution imposes a significant constraint to the Grid West project. The terrain profile of the proposed route also covers hills/mountainous areas with the associated difficulties and expense in excavating and installing cable in these areas (Normark *et al*, B., 2011).

6.4 LOSSES

6.4.1 Summary of Advantages and Disadvantages

Table 6-13: Losses –Summary of Advantages and Disadvantages

	Relative Losses (normalised to HVAC OHL)
400kV HVAC Overhead Line	1.0
400kV HVAC Underground Cable	1.0 (Note 1)
320kV HVDC Overhead Line with VSC stations	1.0[11]
320kV HVDC Underground cable with VSC stations	1.0[12]

Note 1: See bullet point 1 in section 6.4.2 below

6.4.2 Review of Losses

For this report the level of losses has been not been independently calculated. The references have been used.

1. The EirGrid internal report for the proposed North-South Interconnector showed a break even for a transfer of power for 2 x 1600mm XLPE UGC at around 600MVA. Given the maximum generation export for the Grid West circuit of 474MW and a typical maximum load factor for onshore wind generation of approximately 30% (Irish wind energy Association[13]), then it is expected that the typical loading would be less than 200MVA. At this level the losses are reported to be markedly higher for UGC cable compared to overhead line (See point 3 below). However for the purposes of this report, as no specific calculations have yet been done for the Grid West project, it has been assumed that the losses on both HVAC OHL and HVAC UGC are approximately the same, as this allows bench-marking against DC technologies.
2. The ECOFYS Report (page 180) notes that the losses on OHL are highly dependent upon line loading. This is much less the case for UGC. In the case of realistic loading (kA = 0.12 to 0.2) the transmission losses for both options are in the same range. Therefore for the purposes of this report it has been assumed that the losses in HVDC systems are similar to the losses in HVAC systems.
3. Parson Brinckerhoff (2009) show that a lightly loaded underground cable would exhibit higher losses than a similarly loaded and rated OHL. For lines loaded at the nominal loading of the Grid West line (477MW), which is approximately 33% of the nominal rating of the OHL, and in the absence of any detailed calculations for this project, it is considered reasonable for the purposes of this report to assume that for the Grid West project the losses in an HVAC OHL

---

[11] Golder Associates 2008 (ECOFYS Report) page 180
[12] Golder Associates 2008 (ECOFYS Report) page 180
[13] http://www.iwea.com/index.cfm/page/windenergymyths1

would not be greater than in a similarly rated UGC line. For the purposes of this report they have been assumed to be similar.

6.5 FUTURE EXPANSION AND FLEXIBILITY

6.5.1 Summary of Advantages and Disadvantages

Table 6-14: Future Expansion & Flexibility: Summary of advantages & disadvantages of HVAC Overhead Lines

HVAC Overhead Lines	
Advantages	Disadvantages
Advantages: - Inherent 1424MW capacity exceeds Grid West requirement for 477MW, allows significant capacity for future development - Additional substation(s) can be introduced along the line of route relatively easily - New conductor technologies can be applied to existing towers to allow greater power flow - Conductor temperature monitoring combined with weather monitoring can be applied to further up-rate the line and utilise convection cooling by wind during times of maximum generation	Disadvantages: - There are no obvious disadvantages to HVAC OHL in terms of future expansion or flexibility

Table 6-15: Future Expansion & Flexibility: Summary of advantages & disadvantages of HVAC Underground Cables

HVAC Underground Cables	
Advantages	Disadvantages
- Additional substations can be introduced along the line of route	- Limited transfer capacity, requires a second line to be constructed to meet future expansion - Need to rebalance reactive compensation for new stations added into the circuit - Uprating difficult and expensive - Changes to the configuration can result in further resonance issues impacting on both the cable system and the wider network

Table 6-16: Future Expansion & Flexibility: Summary of advantages & disadvantages of HVDC Overhead Lines

HVDC Overhead Lines	
Advantages	Disadvantages
- Bi-directional control of power flow adds flexibility to future operation	- Difficult to introduce additional substations along line of route - Capacity of the converter stations is fixed - Uprating difficult and expensive

Table 6-17: Future Expansion & Flexibility: Summary of advantages & disadvantages of HVDC Underground Cables

HVDC Underground Cables	
Advantages	Disadvantages
- Bi-directional power flow adds flexibility to future operation	- Difficult to introduce additional substations along line of route - Capacity of the converter stations is fixed - Uprating difficult and expensive

6.5.2 Review of Future Expansion and Flexibility

In reviewing the future expansion and flexibility, or future proofing, of the different technologies there are two key elements that need to be considered.

1. Capacity: A single circuit 400kV HVAC OHL constructed to current EirGrid standards has an inherent transfer capacity of 1424MW. While this capacity cannot be realised on a single radial circuit as proposed for Grid West, due to system limitations at present[14], in future changes to the system or the construction of one additional similar line would allow this full capacity to be realised, (subject to deep reinforcement requirements). This provides significant capacity for future extensions, including the connection of further renewable generation in the region.

---

[14] Current operational limits restrict the maximum loss of connection following the loss of a single circuit to 500MW. This is determined by the capacity of the Irish network and its ability to withstand the system disturbance caused by a sudden loss of load generation.

The HVAC underground cable used as the basis for the analysis in this report has a capacity of 1500MW.[15]

Similarly for HVDC the capacity of the transmission line is largely determined by the rating of the converter stations at either side. The cost of these, and currently the available ratings (see Annex D), limits the overall transfer capacity of the line thereby limiting the capacity for future expansion. Future generation could only be connected to an HVDC system by installing additional converter stations and cables.

2. Future Expansion of the Grid: It is to be expected that over the next 50-60 years the grid will need to expand and adapt to accommodate increasing and changing demand for electrical power. Few could have predicted the electrical requirements of today when the grid was first being developed in middle of the last century. In the future, it is expected that the need to connect small local generation at domestic level, new uses such as charging of electric vehicles, etc. will place significant demands on the electrical infrastructure. The HVAC grid has proved to be resilient to these changes. In future, if HVAC was adopted, either overhead or underground, it would be relatively straight forward to connect the Bellacorick substation with a second line, allowing Grid West to become part of the meshed network. It would also be straight forward to add additional substations along the line of the route to accommodate any significant new generation or loads.

   HVDC does not currently offer this flexibility. VSC technology does theoretically allow the construction of multi-drop or multi-terminal transmission systems, but none have been commissioned at the time of preparing this report. There is also additional cost of these converters.

   The other difficulty currently with HVDC is that international standards for inter-operability have not yet been defined. There are concerted efforts in progress to define these standards but these have not been published to date.

Thus it can be seen that HVAC technology offers better potential for future expansion, particularly the OHL system with its inherent capacity, has been proven to be a flexible technology able to adapt to the changing load profiles. While HVDC may achieve this or at least similar flexibility in the future, this technology is still emerging and cannot be considered as mature at this time.

---

[15] The 400kV circuit used requires 2 x 1600mm^2 XLPE cables per phase. Capacity of an underground cable is very dependent on ground conditions, in particular the thermal conductivity of the soil. As no soil investigations have been done and the design has not been developed, it is not possible to establish a definitive capacity

6.6 ENVIRONMENTAL IMPACT

A general assessment of the environmental impact of each of the transmission technologies has been set out in Annex B. This has been prepared by considering each technology against the standard environmental criteria of:

- Ecology
- Cultural heritage
- Landscape
- Geology
- Water

In this section a summary of the advantages and disadvantages is presented so as to allow a discussion of the overall environmental impact of each technology. At this early stage where more general characteristics are being considered the environmental impact of the two overhead line technologies (HVAC and HVDC) are similar as are the characteristics of the two underground cable technologies.

As indicated earlier, it is considered essential that the environmental impact is taken into consideration when selecting the technology. However the detailed environmental impact cannot be determined until the full environmental impact assessment has been undertaken. Thus this initial general assessment is used to select the preferred technology, but this will be kept under constant review as the project is developed.

6.6.1 Summary of Advantages and Disadvantages

Table 6-18: Environmental Impact: Summary of advantages & disadvantages of HVAC and HVDC Overhead Lines

HVAC and HVDC Overhead Lines	
Advantages	Disadvantages
Advantages: - Ecology: Significantly less impact to habitats, greater flexibility in routing allows significant habitats to be avoided - Ecology: Except during construction, habitat can be retained during operation - Cultural heritage: Smaller footprint and greater flexibility in routing allows heritage sites to be avoided - Landscape: Landscape patterns continue relatively unbroken under the transmission line - For HVDC OHL, the requirement for only two poles (positive and negative) reduces the number of conductors and results in lighter towers, which does reduce the visual impact - Geology: Flexibility in routing and design and small footprint allows avoidance of areas of geological constraints - Water: Flexibility in routing and design and small footprint allows avoidance of areas where adverse impact on water resources would occur	Disadvantages: - Ecology: Collision impacts to birds - Ecology: Maintenance requirements during operation (pollarding and vegetation) - Cultural heritage: High visibility of towers can impact on heritage sites - Landscape: High visibility of towers and conductors

Table 6-19: Environmental Impact: Summary of advantages & disadvantages of HVAC and HVDC Underground Cables

HVAC and HVDC Underground Cables	
Advantages	Disadvantages
- Ecology: less risk of collision to flighting birds of conservation concern - Cultural heritage: Unlikely to impact on setting of cultural heritage sites - Landscape: Less visible built infrastructure - Water: Can be used to traverse wide rivers or lakes, where an OHL would not be able to cross	- Ecology: Habitat in a large corridor permanently modified - Ecology: Impact in sensitive areas of peatland habitats, as present in the study area - Cultural heritage: Potential impact on known and unknown archaeological and architectural sites - Landscape: Landscape patterns disrupted due to removal of trees and hedgerows and changes to landscape colour/texture resulting from temperature/drainage changes - Geology: Disturbance of soils and sub-soils - Geology: Difficult to avoid areas of peat and hard rock - Geology: Risk of encountering karstified rock - Water: Disturbance to river banks and lake (lough) shore, and disturbance to river and lake (lough) beds - Water: Potential disruption to drainage patterns, resulting in erosion or unstable ground

6.6.2 Review of Environmental Impact

The underground cable option has more potential for adverse ecological impacts than the overhead line option, primarily due to permanent modification of habitats over a much greater area and requirement for permanent access infrastructure. This is particularly significant for peat land habitats which probably cannot be avoided in the Grid West project.

The risks to wintering birds are less likely with underground cable as the collision issue is avoided from underground cables post construction. Overall there are options for reduction of the impact for both technology types, though for designated sites in particular for the Grid West project it is clear that the impacts will be greater from underground cable with the possible exception of bird collisions.

An underground cable and associated work has a higher potential to impact upon the cultural heritage resource than construction of overhead line tower bases primarily due to the increased excavation work required. This may result in additional archaeological mitigation and unanticipated rerouting. The small footprint and greater flexibility of overhead line towers offers reduced impact on as yet undiscovered archaeological and architectural features.

The high visibility of overhead lines can have a direct impact on the setting of cultural heritage sites if routing does not allow mitigation of these effects. However overhead lines offer a degree of flexibility in avoiding not only direct impacts upon known sites but also impacts upon setting through sensitive placing and route selection.

The underground cable option has less landscape and visual impact than the overhead line option, primarily due to the visual effects of towers at close range. However, the underground cable option is not without landscape and visual effects, albeit at a lesser magnitude.

It is worth noting that the landscape continues relatively unbroken under an overhead line, while it becomes severed to a degree by the planting restrictions resulting from underground cabling. Intensive farmland with large fields or parts of the landscape with stone walls in place of hedgerow would be least affected by the underground option as the required breaks in hedgerow and woodland pattern would be least apparent. A change in colour of ground vegetation is usually apparent (particularly when viewed from above), Route markers are required at points along the route and large infrastructure is required at cable ends.

The potential impacts on geology as a result of an underground cable far outweigh the potential impacts on the geology of the site as a result of overhead line construction. An underground cable will require a much larger area to be cleared than the bases for a tower. Soils, subsoils and possibly bedrock will need to be removed in order for the construction of the underground cable to proceed. In addition, this study area has been mapped as an area with a high potential for karstified rock and therefore bedrock should be avoided where possible in order to mitigate against the potential for subsidence.

The potential impacts on the water environment as a result of an underground cable option are greater than the potential impacts of an overhead line option. There are a significant number of rivers and lakes, as well as coastal areas, within the study area and it will be very difficult for an underground cable route to avoid these features. An underground cable will require a much larger area to be cleared than an overhead line and will require crossings of many water features where significant disturbance will be required during the construction phase of the project. Avoidance of water features can be incorporated into the design of an overhead line, thereby mitigating negative impacts of crossing large areas of water.

Therefore in summary both technologies have environmental impacts but these impacts are different for the different technologies and mitigation measures are available.
Underground cables are found to have a greater environmental impact on geology and water.

Both technologies have an environmental impact on ecology and cultural heritage with arguably the underground cable having the greater impact.

Overhead line has a greater negative environmental impact in terms of landscape though there are options for reduction of the impact of tower infrastructure through careful siting and tower design.

The Consultant’s environmental specialists have advised that their initial reviews indicate that, on balance, the underground solution does not offer any less environmental impact than the overhead line solution. For the specific environmental factors of importance in the Grid West study area, the underground solution could present a higher impact. For this reason, and recognising that case-by-case variation is to be expected, as envisaged by the EcoFys Report, the evaluation of the environmental impact of the overhead and underground solutions for both HVAC and HVDC has been rated as equal for the Grid West project.

A site specific environmental impacts statement incorporating site surveys is required to ensure a full understanding of the environmental issues associated with this study area.

6.7 COST

6.7.1 Summary of Relative Costs

The basis for estimating the relative costs of the different technologies set out in Table 6-20 below is set out in Annex C.

Table 6-20: Summary of Relative Costs

	HVAC OHL	HVAC UGC	HVDC OHL	HVDC UGC
Relative Cost (Average value in Table C.1)	1.0	4.6	4.2	5.4

6.7.2 Review of Costs

The relative costs determined in this report show that HVAC OHL technology offers the lowest of all the technologies by a considerable factor, with the other technologies typically being at least 4 times more expensive.

The next lowest cost is offered by the HVDC OHL solution. Although a HVDC line is lower cost than the equivalent HVAC line, the higher cost of the converter stations still makes a HVDC scheme a much more expensive option. The current break even length of line for an HVDC link is in the range of 500 to 800km (Siemens Energy, 2011). For a line the length of Grid West, the cost of the HVDC OHL solution will be significantly more expensive.

HVAC UGC is likely to be similar in cost to an HVDC OHL solution, if it were to be found to be technically feasible. As is to be expected HVDC underground cable solution is the most expensive.

A review of the literature shows a wide variation in the cost of transmission systems. The Parsons Brinckerhoff report (Summary of Main Findings, page viii) found that for all the technologies (except HVDC OHL, which the report did not investigate) the price per kilometre can vary by a factor of at least 2.

The actual prices are highly dependent on the specific route, the detailed design to allow the transmission line to be constructed as well as factors such as the terrain, the number of major crossings of natural features and other infrastructure, the availability of outages, etc. As this report was prepared at an early stage of this project, there was insufficient information available to allow a reasonable cost estimate to be prepared for the Grid West project. However as discussed in Annex C, it is considered that establishing the relative cost between the different technologies does allow cost to be used as one of the evaluation factors in determining the preferred technology for Grid West.

While a wide range of costs has been reported, the analysis in Annex C found that there is a degree of correlation between the comparative costs of the different technologies. Thus while the data presented should not be used for costing purposes, it does allow qualitative comparison between the costs of the different technologies.

6.8 RISK

6.8.1 Summary of Risk and Mitigation

Table 6-21: Risk and mitigation - Summary of advantages & disadvantages of HVAC Overhead Lines

HVAC Overhead Lines	
Risk	Mitigation
- Stakeholder and landowners objections, primarily due to visual and local impacts	- Use lower visual impact towers and conductors. This is part of the Grid25 strategy, '*As part of all new developments, an investigation into appropriate structure design taking into account all current and emerging designs, will take place so as to minimise the impact on the existing environment*' Examples of this emerging new practice are shown in Annex D - Appropriate route selection, so as to minimise impact on landowners and stakeholders - Continued stakeholder engagement during the planning process

Table 6-22: Risk and mitigation - Summary of advantages & disadvantages of HVAC Underground Cables

HVAC Underground Cables	
Risk	Mitigation
- No previous project of this length under similar conditions has been found in the world - Achieving stable system operation under all operating conditions - Geological conditions in the Grid West study area including extensive areas of peat, shallow bedrock and karstified rock. - A cable of this length cannot be tested before entry into service	- Use alternative technology - Extensive design development and modelling - Geological conditions can only be mitigated by careful route selection to minimise the difficult geological areas and then design for the difficult conditions - Appropriate route selection, so as to minimise impact on landowners and stakeholders - Continued stakeholder engagement during the planning process

Table 6-23: Risk and mitigation - Summary of advantages & disadvantages of HVDC Overhead Lines

HVDC Overhead Lines	
Risks	Mitigation
- HVDC is a relatively complex technology, requiring specialist operation and maintenance - Limited global experience of 500MW VSC HVDC projects Stakeholder and landowners objections, primarily due to negative visual impact - Long lead times in securing HVDC equipment especially converters	- Best mitigation is to use an alternative technology - Although of lesser impact, any high voltage overhead line system does have a visual impact. Mitigation would be as for the HVAC OHL - Early decision to utilise HVDC - Appropriate route selection, so as to minimise impact on landowners and stakeholders - Continued stakeholder engagement during the planning process

Table 6-24: Risk and mitigation - Summary of advantages & disadvantages of HVDC Underground Cables

HVDC Underground Cables	
Risks	Mitigation
- HVDC is a relatively complex technology, requiring specialist operation and maintenance - Limited global experience of 500MW VSC HVDC projects - Geological conditions in the Grid West study area including extensive areas of peat, shallow bedrock and karstified rock - Long lead times to securing HVDC equipment especially converter	- Best mitigation is to use an alternative technology - Geological conditions can only be mitigated by careful route selection to minimise the difficult geological areas and then design for the difficult conditions - Early decision to utilise HVDC - Appropriate route selection, so as to minimise impact on landowners and stakeholders - Continued stakeholder engagement during the planning process

6.8.2 Review of Risks

In reviewing the risks to the consenting and implementation of the Grid West project, recent past experience suggests that the technology selected can have an impact on the consenting process. There are two main ways that the project can mitigate this risk:

- Through the adoption of the most appropriate technology.
- Through the extensive and detailed consultation with all stakeholders required for the Grid West project, setting out in detail the justification of the selection of the preferred technology. This report plays an important role in this justification process.

The selection of HVDC technology, either as underground or overhead, also presents some significant risks to EirGrid. These arise primarily because the VSC technology that would be needed for the circuit to operate as an integral part of the Irish grid is still an emerging and developing technology. The relatively small size of the Irish grid is not conducive to the application of new and relatively unproven technology. EirGrid is gaining experience of HVDC through the East-West Interconnector, which was commissioned in September 2012. This link currently has the highest transfer capacity in the world of a VSC link. For East-West there were no practical alternative technologies. This is not the case for Grid West, making the risk posed by VSC HVDC, less acceptable by comparison.

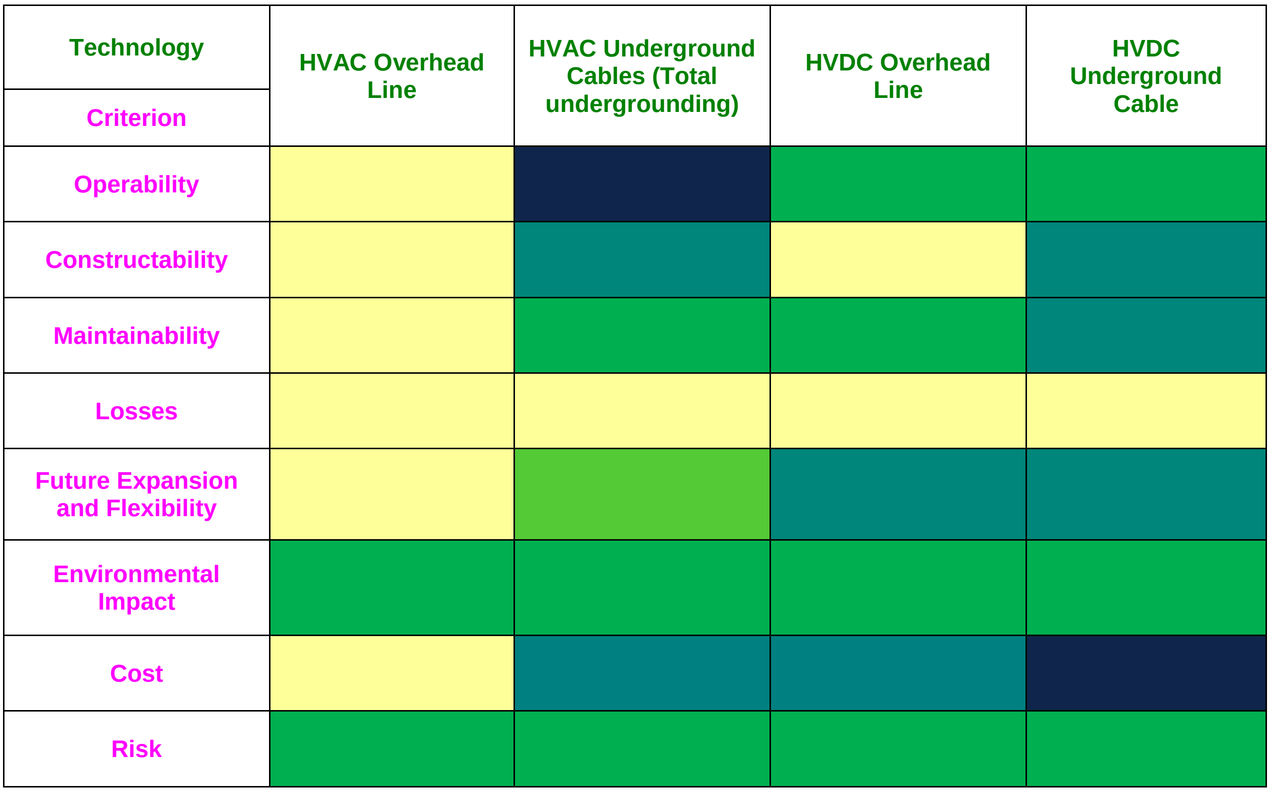
The Grid West project is one project in the greater Grid25 development. All the different projects forming Grid25 need to connect into the grid and operate as an integrated system. It is important that this is not put at risk by the selection of an inappropriate technology for one project.

Thus all technologies present significant risk to EirGrid and the Grid West project, in different ways and for different reasons. Practical mitigation, but not elimination, of some of these risks is possible and this does influence the overall assessment of the risks associated with each technology in the following section.

7 ANALYSIS OF GRID WEST TECHNOLOGY OPTIONS

In the analysis table below each technology is rated against each criterion, on a five point graded scale. The rating of each has been qualitatively assessed on the basis of the impact, difficulty, acceptability, etc. of the technology against each specific criterion. No weighting has been applied to the different criteria at this stage; all criteria are considered to have equal relevance or importance and thus the technology exhibiting the least impact, difficulty, etc. or the best acceptability, lowest value etc. when considered across all eight criteria will be the emerging preferred technology.

Table 7-1: Analysis of Grid West Technology Options



Technology Criterion	HVAC Overhead Line	HVAC Underground Cables (Total undergrounding)	HVDC Overhead Line	HVDC Underground Cable
Operability	🟨	⬛	🟢	🟢
Constructability	🟨	🟦	🟨	🟦
Maintainability	🟨	🟢	🟢	🟦
Losses	🟨	🟨	🟨	🟨
Future Expansion and Flexibility	🟨	🟩	🟦	🟦
Environmental Impact	🟢	🟢	🟢	🟢
Cost	🟨	🟦	🟦	⬛
Risk	🟢	🟢	🟢	🟢

Table 7-2: Key to Technology Options

Key	
Light Yellow	Preferred, very limited impact, no difficulty, fully acceptable
Green	Limited impact, limited difficulty, acceptable
Dark Green	Some impact some difficulty, limited acceptability
Aqua	High impact, difficult, poor acceptability
Dark Blue	Least preferred, major impact, high difficulty, unacceptable

Notes:

The following notes are provided in explanation of selected constraints in the above matrix, where it is considered that the ranking is not self-explanatory:

- HVAC Underground Cables; Operability – Light Yellow: The reactive power requirements of an underground cable installation for a project of this size are such that this is an impractical solution.

- HVAC Underground Cables & HVDC Underground Cables; Constructability – Dark green: This could be a white (worst) rating if the route requires traversing large distances in peat bog or rugged terrain. This would make constructability more difficult (and expensive).

- HVDC Overhead Line/HVDC Underground Cable; Maintainability – Dark green/aqua: The HVDC systems will be more difficult to maintain because of the complexity of the converter stations and limited access to qualified personnel. In turn the underground system is more difficult to maintain than the OHL because of the increased difficulty in locating, accessing and repairing a fault.

- All technologies; Risk – Dark green: On considering the implementation risk to the project, all the technologies impose a risk. Although these risks are different, it is considered that overall the level of risk is similar for each of the technologies.

Review of the above matrix shows the following:

- HVAC OHL technology offers the highest rated solution by some margin, being rated as having the least impact for 5 of the 8 selection criteria.

- The second ranked technology is HVDC OHL, which is rated as low impact against two criteria and limited or some impact against 4 others.

- Both the underground cable technologies have been evaluated as similar in terms of ranking, but rate significantly lower than either of the OHL technologies.

Based on this analysis it can be concluded that the use of an HVAC OHL can be considered as the emerging preferred technology for the Grid West project.

8 CONCLUSION

This report has presented an analysis of the different technical solutions that could be adopted for Grid West. Using techniques analogous to those used for the evaluation of environmental impacts, a range of different criteria were assessed and their impact analysed. The analysis is based on qualitative assessment and assigns the same relative weighting to each of the criteria. This technique has allowed a reasonable assessment of the different technologies across a range of potential impacts, and the technology with the least impact identified.

The analysis matrix in section 7 above shows that HVAC OHL offers the most acceptable technical solution when assessed against the selection criteria adopted, and is thus the emerging preferred technology to be adopted for Grid West at this stage of the project. This result validates the conclusion reached by EirGrid in its GWTSR.

However the visual impact of the conventional OHL constructed on steel lattice towers is frequently considered to be unacceptable by the general public. It may be possible to mitigate to some extent this visual impact by implementing a design using lower visual impact towers and conductors. However doing this would add to the risk of the project as there is no international standard for this type of tower and the design would therefore be considered as unproven.

The research and analysis carried out for this report does also demonstrate that a total underground HVAC cable solution is not appropriate for the Grid West project. It also shows that HVDC technology is not preferred, mainly because of greater operational difficulties, increased maintenance requirements, higher cost, limitations in future expansion and the inflexibility to adapt to changing network requirements, possible in the future.

It must be recognised that this analysis has been made at an early stage in the project development as is necessary at this stage. However, as with any development project, subsequent activities may require this analysis to be re-assessed, if new information or factors arise.

BIBLIOGRAPHY

Anderson, B.R., HVDC Transmission – Opportunities and Challenges. The 8th IEE International Conference on AC and DC Power Transmission, 2006.Retrieved from: http://freespace.virgin.net/bjarne.andersen/IEE%20ACDC%20Conf%202006%20Keynote.pdf. Accessed on 20th July 2012

Askon Consulting Group, The Askon Report on Undergrounding, Summary and Recommendations, October 2008, North East Pylon Pressure. Retrieved from: http://www.nepp.ie/wordpress/wp-content/uploads/2010/01/AskonReportSummary.pdf Accessed on 23rd July 2012

Burges, K., Bomer, J., Nade, C., Papaefthymiou, G., Brakelmann, H., Maher, M., Mills, C., Hunt, J. (2008). Study on the comparative merits of overhead electricity transmission lines versus underground cables. Department of Communications, Energy and Natural resources Ireland. Retrieved from: *http://www.dcenr.gov.ie/NR/rdonlyres/4F49D5FA-0386-409A-8E72-6F28FD89EC7C/0/FinalReport_StudyonOHLversusUGC_June2008.pdf* . Accessed on 5th March 2012

Cigre Working Group B1.10 (2009), Update of Service Experience of HV Underground and Submarine Cable Systems, Report 379 (Cigre technical report ISBN: 978-2-85873-066-7). Made available by EirGrid

Cigre Working Group B2.08 (2010) Innovative Solutions for Overhead Line Supports (Cigre technical report ISBN: 978-2-85873-103-9). Retrieved February 20, 2012 from CIGRE website **www.Cigre.org**

ECOFYS/Golder Associates, Study on the comparative merits of overhead electricity transmission lines versus underground cables. (2008), commonly known as the ECOFYS Report. Retrieved from:

http://www.dcenr.gov.ie/NR/rdonlyres/4F49D5FA-0386-409A-8E72-6F28FD89EC7C/0/FinalReport_StudyonOHLversusUGC_June2008.pdf

EirGrid, EirGrid Position on NEPP ASKON Study, 2009, EirGrid, Retrieved from:

http://www.eirgridprojects.com/media/EirGrids%20Position%20on%20the%20ASKON%20study.pdf

Accessed on 23rd July 2012

ENSTOE and Europacable. December 2010. Feasibility and technical aspects of partial undergrounding of extra high voltage power transmission lines –Cable joint report. Retrieved on 8th March 2012 from: **http://ec.europa.eu/energy/infrastructure/tent_e/doc/off_shore_wind/2010_annual_report_annex7_en.pdf**

Faria da Silva, F., Bak, C. L., Wiechowski, W.T., (2008). Study of High Voltage AC Underground Cable Systems. Received 20 February, 2012 from IEEE Website www.ieee.org

EirGrid, Grid West Initial Technical Studies, February 2011,*EirGrid Internal Publication*

Government of Ireland White Paper. 2007. Delivering a Sustainable Energy Future for Ireland. Retrieved from: ***www.dcenr.gov.ie/Energy/Energy+Planning+Division/Energy+White+Paper.htm***

Grid25: A Strategy for the Development of Ireland's Electricity Grid for a Sustainable and Competitive Future, (2009). EirGrid Publication

International Commission on Non-Ionizing Radiation Protection ICNIRP, ICNIRP guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz – 100 kHz) published in: Health Physics 99(6):818-836 [online] (2010) Available at: http://www.icnirp.de/documents/LFgdl.pdf [accessed 8th March 2012]

IEEE Standards Coordinating Committee 28. (2002). IEEE standard for safety levels with respect to human exposure to electromagnetic fields, 0-3 kHz (IEEE Std C95.6-2002). *IEEE, New York, NY.*

Inglehearn, T. 2011. National Grid 400kV Underground Cable Construction. A Power Point Presentation, National Grid internal presentation

Cigre: Jacobson B, Karlsson P, Asplund G, Lennart Harnefors L, Jonsson T (ABB Sweden), 2010. VSC-HVDC Transmission with Cascaded Two-Level Converters. Retrieved February 20, 2012 from Cigre ABB website ***www.ABB.com***

Mohana Rao M Dr.,2010, Introduction to Gas insulated Switchgear and Substations. BHEL Corporate R&D, Retrieved on February 20, 2012 from the University College of Engineering - Osmania University website ***www.uceou.edu***

Mayo County Council, 2009, Mayo County Development Plan 2008–2014

Incorporating Variation No. 1. Mayo County Council. Retrieved March 2012 from http://www.mayococo.ie/en/

Mayo County Council, 2009, Mayo Wind Energy Strategy. Mayo County Council. Retrieved March 2012 from http://www.mayococo.ie/en/

National Grid, 2008, Underground High Voltage Electricity Transmission The Technical Issues. Received February 20, 2012 from ***www.landsnet.is/uploads/1068.pdf***

Normark, B., Hoelsaeter, O-H., Belmans, R (2011). Meath-Tyrone Report: Review by the International Expert Commission, August – November 2011. Retrieved from: ***http://www.dcenr.gov.ie/Press+Releases/2012/Minister+Rabbitte+publishes+International+Expert+Commission+Report+on+North+South+Interconnector.htm***. Accessed on 5th March 2012.

O'Sullivan, D, (2012). A Review into Recent Investigations into the Possible Health Effects of Exposure to Electromagnetic Fields (EMF) from Power Lines. *Dubligrahan: Office of the Chief Scientific Officer for the Irish Government*

Parsons Brinckerhoff (February 2009). Cavan-Tyrone and Meath-Cavan 400kV Transmission Circuits, Comparison of High Voltage Transmission Options: Alternating Current Overhead and Underground and Direct Current Underground. Retrieved from:

http://www.nie.co.uk/documents/NS/TCInt_2ndES_Addendum/Appendix-3-1-PB-Power-Report.aspx?bcsi_scan_AB11CAA0E2721250=0&bcsi_scan_filename=Appendix-3-1-PB-Power-Report.aspx

Parsons Brinckerhoff (January 2012). Electricity Transmission Costing Study - An Independent Report Endorsed by the Institution of Engineering and Technology. Published by Parsons Brinckerhoff in association with Cable Consulting International Ltd. Received 20 February 2012, from IET website **www.iet.org**

Peterson, A., Hoffmaan, S., 2003, Transmission Line Conductors Design Comes of Age. Transmission and Distribution World. Retrieved February 20, 2012 from ***www.tdworld.com/mag/power_transmission_line_conductor***

RIBA (2011). Pylon Design Competition. Accessed on 5th March 2012 from the RIBA website: ***www.ribapylondesign.com/***

RSE (Ricerca sui Sistema Energetico) SpA, REALISEGRID D3.3.2: Review of costs of transmission infrastructures, including cross border connections. June 2011. Retrieved 18 December 2012 from

http://realisegrid.rse-web.it/Publications-and-results.asp

Siemens Energy. 2011, High Voltage Direct Current Transmission Proven Technology for Power Exchange. Retrieved February 20, 2012 from Siemens Website ***www.Siemens.com***

TransGrid Solutions Inc, 2009, Investigating the Impact of HVDC Schemes in the Irish Transmission Network, TransGrid Solutions Inc., Winnipeg, Canada

GLOSSARY

AAC – All Aluminium Conductor
AAAC – All Aluminium Alloy Conductor
AC – Alternating Current
ACSR – Aluminium Conductor, Steel Reinforced
ACSS – Aluminium Conductor, Steel Supported
AIS – Air Insulated Switchgear
CSC – Current Source Convertors
DC – Direct Current
EHV – Extra High Voltage
EMF – Electromagnetic Field
GIL – Gas Insulated Lines
GIS – Gas Insulated Switchgear
GWITS – Grid West Initial Technical Studies,(included as Appendix 3.1 of this report)
HV – High Voltage
HVAC – High Voltage Alternating Current
HVDC – High Voltage Direct Current
IET – Institution of Engineering and Technology
IGBT – Insulated Gate Bipolar Transistor
LCC – Line Commutated Convertor
LCC – Least Cost Chargeable
OHL – Overhead Line
SAC – Special Area of Conservation
SF_6 – Sulphur hexafluoride
SPA – Special Protected Area
TSO – Transmission System Operator
UGC – Underground cable
UNESCO – United Nations Educational, Scientific and Cultural Organisation
VSC – Voltage Source Convertors
XLPE – Crossed Linked Polyethylene

ANNEX A

Reference Documents

Following consultation with EirGrid, the following documents were reviewed or consulted in the preparation of this report.

While not all are necessarily referenced, the information available was important in forming the knowledge of the authors.

Documentation Sourced from EirGrid's Existing Documentation

EirGrid: North South 400kV Interconnection Development: Preliminary Re-evaluation Report, May 2011

Operating Security Standards April 2010

Assessment of the technical issue related to significant amounts of EHV Underground Cable in the All-island Electricity Transmission System – Tokyo Electric Power Company November 2009 (TEPCO Report)

Grid25: A Strategy for the development of Ireland's Electricity Grid for a Sustainable and Competitive Future ***www.EirGrid.com*** (particularly Appendix A: Technical Options for Grid Development)

Transmission Forecast Statement 2011 -2017.
http://www.eirgrid.com/aboutus/publications/transmissionforecaststatement2011-2017/

Transmission Development Plan 2010 (Draft for Public Consultation)
http://www.eirgrid.com/media/TDP%202010%20Final%20Draft%20for%20Public%20Consultation%20v3.pdf

Transmission Planning Criteria

All Island Generation Capacity Statement 2012 -2021

All Island Transmission Map

UCTE Letter to APG dated 2008-01-14

EirGrid Grid Code

The Electricity Regulation Act 1999 and subsequent amendments

European Communities (Internal Market in Electricity) Regulations 2000-2011Note of the DG Energy & Transportation on directive 2003/54/EC and 2003/55/EC on The Internal Market in Electricity and Natural Gas

EU Directive 2001/77/EC - Promotion of electricity produced from renewable energy sources in the internal electricity market

EirGrid: Information on Electrical and Magnetic Fields October 2007

Electric Field Simulations, PB, November 2011

EMF & You – General Information about Electric & Magnetic Fields in Ireland.

Laois-Kilkenny Reinforcement Project, Technical Comparison of AIS v GIS Substation Options

Meath-Tyrone Interconnection Development Project, Tower Outline Evaluation and Selection Report, 30/11/09

Turleenan-Kingscourt 400kV Project, Visual Assessment of New Tower Outline, 23/08/07

TransGrid report: *http://www.eirgridprojects.com/media/TransGrid%20Report.pdf*

Documentation Sourced from Alternative External Locations

Meath-Tyrone Report Review by the International Expert Commission August-November 2011

Study on the Comparative merits of overhead electricity transmission lines versus underground cables – Golder Associates 2008, commonly known as the ECOFYS Report.

An Independent Report Endorsed by the Institution of Engineering and Technology – Parsons Brinckerhoff 31 January 2012

Feasibility and technical aspects of partial undergrounding of extra high voltage power transmission lines – ENSTO and Europa Cable joint report 20 January 2012

Study of High Voltage AC Underground Cable Systems - F. Faria da Silva, Claus L. Bak, Wojciech T. Wiechowski 4th November 2008

World Health Organisation – various publications on the effects of EMF (Note: only recently issued fact sheet is for radiation from mobile phones. The current fact sheet at power system frequencies pre-dates the EirGrid publication)

IEEE Standards Coordinating Committee 28. IEEE standard for safety levels with respect to human exposure to electromagnetic fields, 0-3 kHz. New York, NY, IEEE - The Institute of Electrical and Electronics Engineers, 2002 (IEEE Std C95.6-2002).

National Grid 400kV Underground Cable Construction: Presentation by Tim Inglehearn

RIBA: Pylon Design Competition

Innovative Solutions for Overhead Line Supports, CIGRE, Ref 416 and 416A, Working Group B2-08, January 25 2010.

Office of the Chief Scientific Officer for the Irish Government, *A Review into Recent Investigations into the Possible Health Effects of Exposure to Electromagnetic Fields (EMF) from Power Lines.*

Government White Paper – Delivering a Sustainable Energy Future for Ireland *http://www.dcenr.gov.ie/Energy/Energy+Planning+Division/Energy+White+Paper.htm*

Planning and Regulatory Documents

The National Development Plan (NDP) 2007-2013

The National Spatial Strategy (NSS) for Ireland 2002-2020

Strategic Infrastructure Act 2006

ANNEX B

Review of the Environmental Impact Advantages and Disadvantages of Overhead Lines VS Underground Cables

B1 Introduction

This Annex sets out a review of underground cables compared to overhead lines from the following environmental specialist perspectives:

- Ecology;
- Cultural Heritage;
- Landscape;
- Geology; and
- Water

It outlines the advantages and disadvantages of both underground cables and overhead lines and provides an opinion based on the specialists expertise and experience on which technology is considered more or less preferred.

B2 Ecology

B2.1 Underground Cable Option

Advantages

- Eliminates risk of collision to flighting birds of conservation concern;
- Possibly less risk to sensitive breeding waders in specific locations because of the lack of towers which would provide predator perches. (However note increased disturbance associated with an underground cable);
- EMF impacts (while relatively unstudied and its impact is likely to be minimal) likely to be less for wildlife.

Disadvantages

A much more significant impact will arise to sensitive peat habitats from underground cable in comparison to overhead line. This is particularly relevant in the North West of the study area if peatland habitats (particularly in Natura 2000 sites) cannot be avoided. This will arise as follows:

- A large corridor of habitat is permanently modified for locating the cable, retaining an access road; and storage of soil removed. Mitigation and design could reduce this impact but significant adverse permanent impact will still arise. This impact is particularly relevant to sensitive receptors (bog habitat in particular) in Natura 2000 sites. The footprint impact of towers in comparison is much less than underground cable and access in sensitive habitats can be via non-permanent access roads hence retaining in particular bog habitat;
- Permanent fragmentation of habitats and loss of commuting corridors for more widespread fauna is much more significant from an underground cable option due to permanent habitat impact and the (possible) requirement for a permanent access road when constructing through green field sites;

- During construction there would be a significant added risk to water quality particularly in peat habitats and sensitive aquatic receptors e.g. freshwater pearl mussel from underground cable. This is particularly relevant in high rainfall and relatively sloping ground (unstable) areas (North West of study area);
- During the construction phase potential adverse impacts to habitats used by wintering birds and other fauna may be much more significant and permanent if these specific areas cannot be avoided;
- Though trimming of vegetation is required under towers; retention of vegetation is nevertheless implemented with no permanent modification to habitat; and
- The overall impact footprint (space under development) of underground cable is more significant than overhead line.

B2.2 Overhead Line Option

Advantages

- Significantly less impact to habitats as a relatively much smaller impact footprint (compared to cable) and no requirement for permanent access roads;
- Less risks to water quality and aquatic / riparian habitats as overhead line can avoid these while this is not possible with underground cable (though impacts can be minimised);
- Overall overhead lines can be designed and located much more easily so as to have a minimal impact on significant habitats;
- Operational management requires less disturbance risks (vehicular access road required).

Disadvantages

- Collision impacts to birds;
- Hedgerow removal / damage required at tower locations;
- Ongoing trimming/ following initial pollarding of woody vegetation (woodlands and hedgerows) required during operational phase under the transmission line;
- Potential operational phase maintenance impacts (vegetation and faunal disturbance) required during operational phase for access/ maintenance particularly in semi natural areas (e.g. bogs);
- Towers may provide perch points for predators of wading birds (towers may be located to reduce this risk).

Review of Potential Ecological Impacts

The underground cable option has more potential for adverse impacts from underground cable than the overhead line option, primarily due to permanent modification of habitats over a much greater area and requirement for permanent access infrastructure. This is particularly significant for peat land habitats which probably could not be avoided in the Grid West project. Potential risks to water quality/ riparian habitats and associated aquatic species are also more significant for underground cable compared to overhead line.

The risks to wintering birds are likely less with underground cable as the collision issue is avoided though risks of disturbance to wintering and breeding sites are greater from underground cable particularly during construction.

There are options for reduction of the impact of in both options though for designated sites in particular it is clear that the impacts will be greater from underground cable except for bird collisions.

B3 Cultural Heritage

B3.1 Underground Cable Option

Advantages

- Underground Cables and associated works are unlikely to impact upon the setting of cultural heritage sites.

Disadvantages

- Underground Cables and associated works are more likely to impact physically upon known and previously unrecorded archaeological and architectural sites as a greater amount of topsoil stripping and excavation works would be required. The presence of other constraints may make it more difficult to avoid such sites when they are encountered.

B3.2 Overhead Line Option

Advantages

- Overhead Lines have a smaller physical footprint and avoidance of all direct impacts upon known archaeological and architectural sites is usually achievable;
- Overhead Lines offer a degree of flexibility in avoiding not only direct impacts upon known sites but also impacts upon setting through sensitive placing and route selection.

Disadvantages

- The high visibility of towers could impact upon the setting of cultural heritage sites.

Review of potential cultural heritage impacts

Underground Cables and associated work has a higher potential to impact upon the cultural heritage resource than construction of Overhead Lines tower bases primarily due to the increased excavation work required (sub surface remains may exist with no visible trace above ground and unrecorded sites may be present in areas that have not been surveyed by the DAHG or that may be covered by existing vegetation). This may result in additional archaeological mitigation and unanticipated rerouting.

There is, nonetheless, potential for direct impacts on as yet undiscovered archaeological and architectural features in the case of both Underground Cables and Overhead Lines. However, Overhead Lines offer a degree of flexibility in avoiding not only direct impacts upon known sites but also impacts upon setting through sensitive placing and route selection.

B4 Landscape

B4.1 Underground Cable Option

Advantages

- Much less visible built infrastructure, however, above-ground infrastructure would be visible at the cable sealing ends and at locations along the route.

Disadvantages

- Landscape patterns disrupted with removal of trees and hedgerows along cable route and/or changes to landscape colour or texture resulting from soil temperature/drainage changes.

B4.2 Overhead Line Option

Advantages

- Landscape pattern continues relatively unbroken under transmission line, although some tree and hedgerow removal required.

Disadvantages

- High visibility of towers and transmission lines at close range.

Review of Potential Landscape Impacts

The underground cable option has less landscape and visual impact than the overground line option, primarily due to the visual effects of transmission towers at close range. However, the underground cable option is not without landscape and visual effects, albeit at a lesser magnitude.

There are options for reduction of the impact of tower infrastructure through careful siting and tower design. The standard lattice tower, is a common feature within the Irish landscape, and has proven to be cost efficient and reliable. Other countries are considering the use of alternative tower designs which can offer a reduced visual impact.

It is worth noting that the landscape continues to a lesser extent unbroken under an overhead line owing to the reduced requirements for planting restrictions by comparison to underground cables. Intensive farmland with large fields or parts of the landscape with stone walls in place of hedgerow would be least affected by the underground option as the required breaks in hedgerow and woodland pattern would be least apparent. A change in colour of ground vegetation is usually apparent (particularly when viewed from above) Route markers are required at points along the route and large infrastructure is required at cable ends.

B5 Geology

B5.1 Underground Cable Option

This review of underground cables and overhead lines takes into account that the current study area is recognised as a relatively environmentally sensitive area, with features such as karstified rock, regionally important aquifers, coastal areas, peatlands, rock outcrops and a dense network of lakes, turloughs and rivers.

Advantages

- As extensive site works will be required (in comparison to overground line works), areas of karstified rock will be identified as ground works progress and mitigation can be incorporated into the design. This will also be possible for the tower locations for the overground line but the site specific geology of the surrounding area will be unknown.

Disadvantages

- Karstified rock should be avoided where possible as specific engineering works will be required at the construction stage to ensure that there is no risk of subsidence in the area of the transmission line. Overall, if there is a large area of karstified rock it may be difficult to find a cable route as the general area surrounding and underlying the line may be prone to subsidence.
- Disturbance of soils;
- Disturbance of subsoils;
- Disturbance of bedrock;
- Increased risk of encountering karstified rock which may include caves, swallow holes, large fissures etc.;
- Increased disturbance of soil will lead to increased risk of erosion, particularly in coastal areas; and
- Will be difficult to avoid areas of peat and to avoid areas of rock outcrop.

B5.2 Overhead Line Option

Advantages

- The proposed transmission line can be designed to avoid areas of known geological constraints (where possible). Geotechnical input and engineering design can help minimise the impact on geologically sensitive areas where avoidance is not possible; and
- The footprint for impact will be insignificant in comparison to the footprint that will be impacted for underground cable, particularly during the construction phase of the development.

Disadvantages

- With respect to Geology, it is difficult to list a disadvantage for an overhead line when compared to underground cable.

Review of Potential Geological Impacts

In summary, the potential impacts on the geology of the Grid West study area as a result of an underground cable option far outweigh the potential impacts on the geology of the site as a result of an overhead line option. Soils, subsoils and possibly bedrock will need to be removed in order for the construction of the transmission line to proceed. In addition, this study area has been mapped as an area with a high potential for karstified rock and therefore bedrock should be avoided where possible in order to mitigate against the potential for subsidence. An underground cable will require a much larger area to be cleared than an overhead line and therefore, based on potential geological impacts, an overhead line is preferable.

B6 Water

This review of underground cables and overhead lines takes into account that the fact that the current study area is recognised as a relatively environmentally sensitive area, with features such as regionally important aquifers, coastal areas, a dense network of lakes, turloughs and rivers, karstified rock (including swallow holes, springs and caves), peatlands and rock outcrops.

B6.1 Underground Cable Option

Advantages

- Geotechnical - underground cable can traverse wide rivers or lake that an overhead line would need to avoid.

Disadvantages

- Disturbance of river banks, river beds;
- Disturbance of lake shores, lake beds;
- Disturbance of coastal areas, dunes etc.;
- Increased risk of coastal erosion;
- Increased volume of suspended solids impacting on downstream water channels, particularly during the construction phase; and
- Maintenance issues will have the potential to cause contamination of estuarine or freshwaters (depending on final location of transmission line –maybe both).

B6.2 Overhead Line Option

Advantages (similar to geology)

- The proposed transmission line can be designed to avoid water features and water-related constraints (such as karst features) and allow for buffer zones around water features, such as rivers. Geotechnical input and engineering design can help minimise the impact on particularly sensitive areas where avoidance is not possible e.g. towers close to river banks or lake shores.
- The footprint for impact will be insignificant in comparison to the footprint that will be impacted for underground cable, particularly during the construction phase of the development.

Disadvantages

- With respect to Water, there are no significant disadvantages for overhead when compared to the impact of underground cable.

Review of Potential Water Impacts

In summary, the potential impacts on the water environment of the Grid West study area as a result of an underground cable option far outweigh the potential impacts on the water environment of the study area as a result of an overhead line option. There are a significant number of rivers and lakes, as well as coastal areas, within the study area and it will be very difficult for an underground cable route to avoid these features. An underground cable will require a much larger area to be cleared than an overground line and will require crossings of many water features where significant disturbance will be required during the construction phase of the project. Therefore, an overhead line is preferable to an underground cable as the potential impacts on the water environment will be less significant and avoidance of water features can be incorporated into the design.

B7 Conclusion

In conclusion both technologies have environmental impacts but these impacts are different for the different technologies and mitigation measures are available.

Underground cables are found to have a greater environmental impact on geology and water.

Both technologies have an environmental impact on ecology and cultural heritage with arguably the underground cable having the greater impact.

Overhead line has a greater negative environmental impact in terms of landscape though there are options for reduction of the impact of tower infrastructure through careful siting and tower design.

The risks to wintering birds are eliminated with underground cable as the collision issue is avoided post construction. Overall there are options for reduction of the impact for both technology types though for designated sites in particular for the Grid West project it is clear that the impact will be greater from underground cable with the exception of bird collisions.

A site specific environmental impacts statement incorporating site surveys is required to ensure a full understanding of the environmental issues associated with this study area.

ANNEX C

Basis for Cost Comparisons

Almost all reports that have been published in recent years that compare the different transmission technologies note the wide variation in costs and the influence specific requirements and conditions affect the overall cost of implementing different schemes. At the early stage of the project when this report was prepared the level of development did not allow the influence of these different factors to be identified, making reasonably accurate estimating difficult. For the purpose of this Technical Foundation Report it was not necessary to have detailed costing information – rather sufficient information to allow the relative costs of the different technologies to be evaluated using the five points evaluation scale adopted in section 7.

Thus the basis for the costing used in this report is to identify the relative costs between the different technologies, based on published documentation, publically available. A comparative ratio will be used to show the differences in cost between the different technologies. HVAC overhead transmission is used as the base case, being assigned the value of 1.0. The relative cost of each of the other technologies is then expressed as a ratio of this base cost.

The following reports have been used to obtain comparative figures:

- Meath-Tyrone Report: Review by the International Expert Commission, August – November 2011
- ECOFYS, Golder Associates, Study on Comparative Merits of Overhead Electricity Transmission versus Underground Cables, May 2008
- Parsons Brinckerhoff: Electricity Transmission Costing Study - An Independent Report, January 2012
- Realise Grid – D3.3.2: Price, Cost and Financial Aspects of Network Expansion in the European Context, 2010
- ENSTO-E and Europa: Feasibility and technical aspects of partial undergrounding of extra high voltage power transmission lines, December 2010
- Parsons Brinckerhoff: Cavan-Tyrone and Meath-Cavan 400 kV Transmission Circuits, Comparison of High Voltage Transmission Options, final report Feb 09
- National Grid: Comparison between National Grid's findings and Parsons Brinckerhoff Report on Electricity Transmission Costing Study, February 2012

The comparative figures obtained by consideration of these reports are presented in Table C.1 below. The following points should be noted with respect to the figures reported in this table.

- Many of the reports contain a wide range of different costings, covering a wide range of example or reference projects, commonly with a wide range of transmission lengths and capacities. Where available in the report, averages or summaries have been brought forward into this report, where possible by including figures reported in the Executive Summary or Abstract.
- The Grid West line if constructed as HVAC OHL would be rated at a nominal 1500MW and would be approximately 130km long. While it is not essential that the costs used to establish the relative costs are for transmission lines of the same capacity and length, it is preferable

that lines of similar capacity and length be used. Thus in reports where costs for a range of different capacities/lengths were given, the costs most closely matching the capacity/length of the Grid West line were used. For example, in the DENA Report four configurations were considered, 1000MW/100km; 1000MW/400km; 4000MW/100km and 4000MW/400km. In this case the figures for the 1000MW/100km configuration were used, as being the most representative of the Grid West line. It is important to note that with the method used to identify the relative costs between the different technologies in this report it is not critical that the reference documentation closely reflects the requirements of the Grid West line. This is because the relative costs obtained are used to establish the ranking of the different technologies, this ranking then being used as one of the criteria in the multi-criteria evaluation matrix. The method has been specifically selected because it is appropriate for circumstances where it is not possible to establish accurate information

- Where available whole life costs were used to calculate the ratios, however if these were not available, then the ratios of the costs reported were adopted. It is emphasised that the purpose of this report is only to establish a qualitative comparison of the costs of the different technologies and therefore it was considered that all the ratios used are valid for the purpose of this analysis.
- A review of the data presented in Table C.1 indicates that while a wide range of costs are reported, there is a degree of consistency between the comparative costs between the different technologies. Thus, while the data presented should not be used for costing purposes, it does allow qualitative comparison between the costs of the different technologies.
- It was found that some reports used the same reference documents and thus care needed to be taken to ensure that the figures being used were not being repeated as the same sources had been used.
- When considering the impact of these relative costs, this should be considered in the context of the initial estimate of the cost of constructing the Grid West line using HVAC OHL. This estimate is that the cost will be approximately €240million.

Table C.1: Cost Comparison Between Different Technologies

Report	**Reference within Report**	**HVAC OHL**	**HVAC UGC**		**HVDC OHL**		**HVDC UGC**	
		Ref Value	**min**	**max**	**min**	**max**	**min**	**max**
		1						
The Meath Tyrone Report, Review by International Expert Commission, November 2011	Reference section 9, Cost Estimation Alternatives for Meath-Tyrone	1					3	3
DENA, Grid Study II, Integration of Renewable Energy Sources in the German Power Supply System from 2015-2020, with an Outlook to 2025	Table 10.15, page 186, source ABB/Siemens	1	3	5	1.7	3.5	2	4
ECOFYS, Golder Associates, Study on Comparative Merits of Overhead Electricity Transmission versus Underground Cables	section 9 - Case Studies, Lifetime Costs	1	2.9	2.9				
Parsons Brinckerhoff, Electricity Transmission Costing Study, 31st January 2012,	From Executive Summary	1	4.25	5.7			5.6	7.5
D3.3.2 Realise Grid, project no: 219123 - Review of costs of transmission infrastructures, including cross border connections, submitted date June 2011	Averages (Tables 4.1, 4.2 and 5.1)	1	2.5	4.3	5.2	6.4	7	8.9
ENTSOE-Europacable: Feasibility and technical aspects of partial undergrounding of extra high voltage power transmission lines, December 2010	section 3.5.1	1	5	10				
Parsons Brinckerhoff, Cavan -Tyrone and Meath-Cavan 400 kV transmission circuits, comparison of high voltage transmission options: Final report Feb 09	Table in Executive Summary - life cycle cost	1	5.4	5.4			6.3	6.3
National Grid, Electricity Transmission Cost Study: How does the independent report(endorsed by IET done by PB) compare to National Grid's view? Feb 2012	75km lifetime costs	1	4.3	4.3				
		HVAC OHL	HVAC UGC		HVDC OHL		HVDC UGC	
AVERAGE		**1.0**	**4.6**		**4.2**		**5.4**	

ANNEX D

Review of Technologies

D1 Introduction

The following section will describe current high voltage transmission technologies. As they stand currently it should be noted that no single “right solution” exists for all applications (Normark, B., *et al*, 2011) (Parsons Brinckerhoff Report, 2012). Hence each technology must be judged on its own merits and be considered as it will be applied.

Technologies covered in this section include:

- High Voltage Alternating Current Overhead Line (HVAC OHL) utilising either conventional or alternative line designs

- High Voltage Alternating Current (HVAC) Underground Cable 500MVA capacity utilising under grounding cables along the full length or partial length of the route

- High Voltage Direct Current (HVDC) with 796MVA capacity utilising either transmission lines or underground cable

- High Voltage Substation Technologies utilising either Air insulated Switchgear (AIS) and Gas insulated switch gear (GIS) hybrid layouts or fully enclosed GIS

D2 High Voltage Alternating Current Overhead Lines (OHL)

HVAC OHL is the conventional technical solution for high voltage power transmission. This technology utilises lattice steel towers with one or more conductors per phase, supported on insulator strings to insulate the live conductors from the earthed tower.

It is well established, flexible, and presents low impact to the land it crosses, although its visual impact is considered to be significant. It offers the most economical and technical viable solution for the Grid West project.

There have been many developments in recent years to make the conventional HVAC OHL a more visually attractive option (Normark, B., *et al*, 2011). These alternative solutions discussed in more detail within section D2.4 below, have achieved varying levels of success and are considered to increase the cost and the risk to the project due to the unproven nature of the technologies. Nonetheless with careful assessment and introduction, sympathetic treatment these alternative designs may provide a suitable compromise between technical, environmental and visual requirements for the Grid West project.

D2.1 Current EirGrid Practice

OHL lines utilise the characteristics of air as an insulation medium and as such the size of towers and insulation is determined by the transmitted voltage. Therefore the greater the voltage, the greater the required clearance distances and associated tower heights.

Conventional tower design combines steel lattice sections to transfer loadings caused by the weight of the conductor, wind pressure, short circuit forces and ice weight acting upon the tower and the conductors, to ground.

The current EirGrid tower designs are in compliance with respected international standards such as ASCE standard 10-97 and hence operation and performance of the tower has been well proven. Maintenance techniques are well established and utility personnel are familiar with the towers, conductors and associated equipment. This familiarity increases level of inherent safety and risk awareness.

EirGrid's conventional standard conductor for 400kV is ACSR (Aluminium Conductor, Steel Reinforced), with a cross sectional area corresponding to twin ACSR Curlew. The standard conductor is also ACSR Curlew; however earthwires will be rated to the line profile and line characteristic, therefore sizes are subject to change.

One of the major advantages of using OHL is the ability to restring. In the future EirGrid has plans to take advantage of new conductor technologies offering higher capacities than ACSR while maintaining the equivalent overall weight and thus having limited impact on the towers.

There is also the option to install a double circuit tower type, while only stringing one circuit at this time. When power transfer demand increases then the second circuit can be equipped. If this option is adopted then it will need to be considered within the current planning application as it affects the design, size and type of the towers proposed. However historically the size of the Irish grid has limited use of double circuit 400kV transmission towers, as although there are two circuits, it is possible that a single fault could result in the loss of both circuits simultaneously, which at the rating of 400kV circuits could result in system instability.

D2.2 Electrical Characteristics

Power Capacity

A single circuit 3 phase 400kV AC line strung with ACSR twin Curlew has a capacity of approximately 1424MVA[16]. In addition to the conductor used, the capacity of an overhead line is determined by the insulator configuration, operating temperature, sag and load flow. Where greater capacity is required multiple conductors can be used in bundles. As conductor weights and cross section increase so does the conductor sag and tower loadings. Hence towers either become taller or require further reinforcement (larger structural steelwork) or more numerous. Once the cost of this reinforcement outweighs the economic benefits of a single circuit construction; a double circuit arrangement may become more economical.

---

[16] Based on EirGrid/ESB assumptions for wind speed, solar radiation and ambient temperature.

Alternatively advances in technologies such as real time conductor monitoring, new conductor materials and construction techniques (see section D2.6) have allowed greater utilisation of capacity in real time, but do not increase deterministic rating for network planning purposes.

Systems Integration

HVAC OHL is the predominant technology applied to HVAC systems; the technology operates using HVAC hence system integration is the easiest of all the technologies. Control and protections systems and philosophies related to OHL are well established and transient fault restoration times can be reduced to seconds (using delayed auto reclose), rather than hours to weeks expected for cable faults.

D2.3 Installation of Overhead Lines

There are a number of installation techniques for HVAC OHL due to the long established and well developed nature of the technology. Almost all technical challenges applicable to developing a solution for Grid West have been addressed somewhere in the world using this technology.

The following is a brief outline of the installation of a 400kV overhead line.

Detailed site selection is undertaken evaluating environmental, geotechnical and social impacts, a wayleave is negotiated with land owners and design completed. A 400kV single circuit OHL corridor is typically 30m in width with towers spaced 350-400m apart. EirGrid maximum ruling span length of 385m[17] will be maintained for the Grid West project. (EirGrid Standard Specifications, 2011, section 9.5)

Access is arranged depending on the location and environmental sensitivity; however this will normally consist of an access track suitable for a crane and heavy vehicles, although in environmental sensitive areas the construction works can be completed using lighter vehicles. EirGrid current practice requires a minimum clearance distance of 9m between the lowest point of the conductor and the ground over normal ground for a 400kV transmission line. This determines the height of the towers and reflects the construction difficulties encountered when erecting steel lattices towers. In extremely difficult or environmentally sensitive terrains helicopters can be used to transport and install the towers. Examples of this were provided by Powerlink Queensland for the wet-tropics heritage forest in Northern Queensland (www.powerlink.com.au).

Foundation civil works will be undertaken. Depending on the type of tower these will be of various sizes and include earthing - refer to the IET Transmission Report Appendix E for additional details (Parsons Brinckerhoff, 2012, Appendix E). For difficult soil types such as peat which is found around the Bellacorick area, pile foundations that extend down to the bedrock/stable soil are recommended. These provide support for the tower and have limited impact to the environment at the surface.

---

[17] Ruling span is the standard distance between two towers, used as the basis for design. Both longer and shorter spans are then used as necessary in the design so as to position towers at practical locations.

Towers are assembled using standard rigging techniques, cranes or if necessary can be assembled in sections off site then the sections lifted in by helicopter and fitted together. Typical double circuit conventional steel lattice tower heights for 400KV range from 40 to 60m (Parsons Brinckerhoff, 2012) depending on the type of tower, line profile and the type and distance of the land it spans. Other influencing factors include the type of conductors used and the power transmitted through them. Tower types can be separated into three main groups:

- Suspension towers are used when the line continues straight ahead and the conductor needs to maintain clearances. These towers are of a lighter build and can have a taller profile due to the reduced forces acting upon them. They generally have the insulator strings in a vertical profile with the conductor suspended from the insulators, hence the term “suspension tower”. This is the most common type of tower.

- Angle/tension towers are used when there are changes in direction and the forces are not sufficient enough to warrant a terminal tower. They are not as heavy as terminal towers but are still capable of taking the forces associated with line deviations. Dependant on the route, tension towers may need to be included in straight line routes, to ensure adequate support for the line in the event of a conductor break, which imposes higher forces on all the towers. Using just suspension towers over a straight line route may lead to a cascade effect if one of the conductor strings fails.

- Terminal towers are used where there are connections to a substation, a sealing end compound, or where the conductor ends and the line direction changes sharply. These are more heavily built and have larger foundations. A terminal tower is capable of taking the full load of the conductors even if the other side is not strung, take the twisting forces present where lines deviate or support the line under catastrophic failure of a suspension tower.

- Transposition towers are used to rearrange the sequence of the phases, For example the sequence may be changed from R,S,T to S,T,R at a transposition tower.

Towers from one terminal tower to the next are constructed. This will include a number of suspension towers and angle towers. Once the towers have been erected the conductors can then be strung. The conductors are winched into place, with the tension having been accurately calculated so as to achieve the required sag between the towers.

It is becoming increasingly common to incorporate a fibre optic cable within the earthing conductor. This enables the route to be used for dedicated communication and control of the transmission operator’s facilities.

D2.4 Alternative Tower Design

Alternative tower designs offer effective solutions to reduce the visual impact at a moderate increase in cost. A large number of alternative tower designs have been developed and are in service though out the world. A publication by the Cigre Working Group B2.08, Innovative Solutions for Overhead Line Supports (Cigre Working Group B2.08, 2010) details the development of alternative designs. A number of alternative designs are illustrated below. In addition The Royal Institution of British Architects (RIBA) ran a competition in 2011 for alternative tower designs for use in the UK. Alternative tower designs are a developing trend and offer a potentially viable alternative solution type that could be considered for the Grid West project.

From the Cigre report (Cigre Working Group B2.08, 2010) it can be noted that the most successful solutions have been:

- Designs which the public can relate to. This includes symbolic or iconic forms such as shapes with historic or cultural significance or conventional symbols

- Designs that are easily adapted to the environment in which they are to be located this includes reducing profiles and colouring towers

- Towers which have been designed to provide both a technical and aesthetic solution

- Designs that present the tower in a different way such as by applying artistic decoration to the towers, which can provide a visually attractive alternative with limited impact to the transmission line.

- Use of lower profile conductors and insulators, decreasing the visual impact from a distance.

As with the development of any new technology there are a number of inherent risks associated with utilising alternative tower design. These include delays to the delivery of the project while tower designs are being developed, tested and approved, heightened risk of cost over-runs caused by instances where there are problems or failures due to manufacturing new or unique items, installation problems due to lack of experience and possible design, health and safety or regulatory issues. Increased maintenance and repair constraints where parts are not readily available “off the shelf” and have to be manufactured, thus increasing outage periods. All of these are common issues when dealing with a new technology.

Details of the full design development required by EirGrid to allow this option to proceed is outside of the scope of this report however the following images showing current designs from around the world give an indication of the alternative design types that could be adopted. The list is by no means complete, however it is envisaged that it will provide an overview of the current range of alternative designs and how they have been applied. Detailed engineering analysis would be required before any of the following could be confirmed as acceptable in the Irish network.

Monopole Towers

Monopole towers are constructed from rolled steel or reinforced concrete designed to provide sufficient strength to support the 400kV conductors and insulating top section. These designs provide reduced visual noise with the single pole and due to the smaller foot prints have limited impact to the environments where they are installed.

From a structural point it is important to note that monopoles exert a high level of elastic deformation when compared to steel lattice towers. Therefore a detailed analysis is required for all designs. The forces experienced by the pole are further exaggerated by its inherent physical load imbalance caused by the majority of loads being exerted near the pole top and dissipated at the base. This can add significantly to the overall diameter and expense of the pole as high levels of reinforcement are required to compensate these forces. The inherent design of a monopole tower also presents a single point of failure at the base of the tower, which if occurring would result in extended outage of the line.

Figure 3: Left 400kV Top Insulated Support Sweden (in service)

Right 110kV in service Yellow Beak Southwest Finland (in service)

Source: Cigre Working Group B2.08, 2010)

Figure 4: 400kV Suspension and Angle Mono Pole with Lattice Top – Denmark

(Source: Cigre Working Group B2.08, 2010**)**

Figure 5: Concept Design Winning RIBA Pylon Design, Bystrups T-Pylon

(Source: www.ribapylondesign.com)

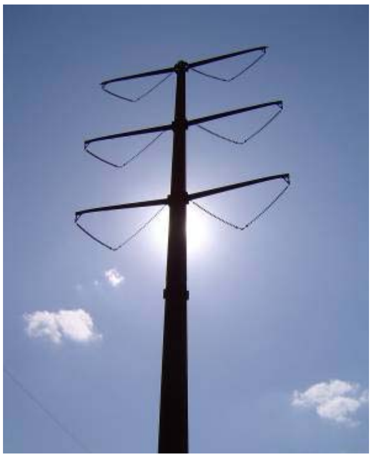


Figure 6: 220kV Double Circuit Monopole, USA

Compact Tower Designs

Compact lattice tower design offers reduced visual impact while maintaining the benefits of steel lattice structural design. The principles for the development of compact towers has been to apply modern construction, material forming and clearance distances to allow for a lower profile tower with a smaller foot print

Proposed EirGrid Alternative Tower Designs

EirGrid has developed the following compact tower concept designs which offer a reduced environmental impact (Burges, K., *et al*, 2008), Pg 60).

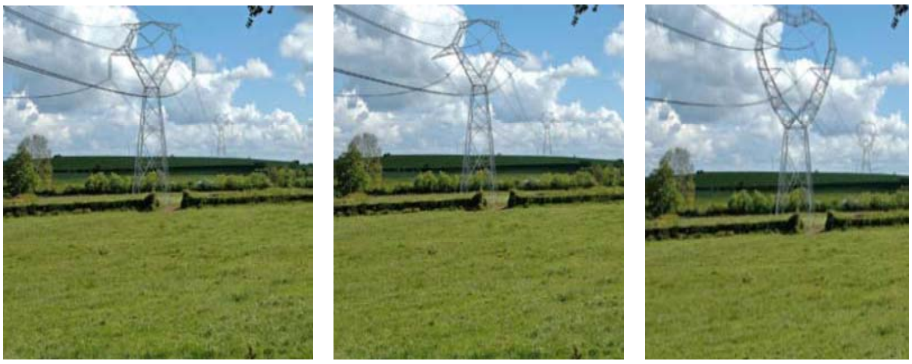


Figure 7: 400kV EirGrid Candidate Compact Tower Designs Ireland

(Source: Burges, K., *et al*, 2008, Pg 60)

Other Alternative Tower Designs

Since the 1960s a large number of other alternative designs have been developed for specific lines projects. A number of these are shown in the images below:

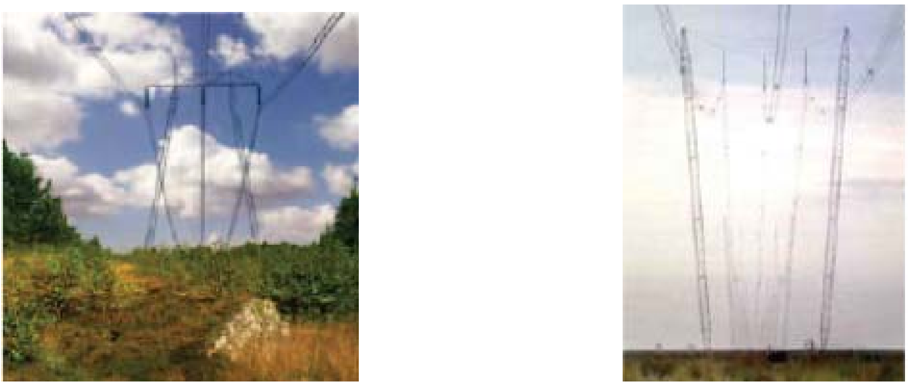


Figure 8: 750kV Guyed Portal Sweden. 500kV Invisible Cross Ropes Argentina

(Source: Cigre Working Group B2.08, 2010)

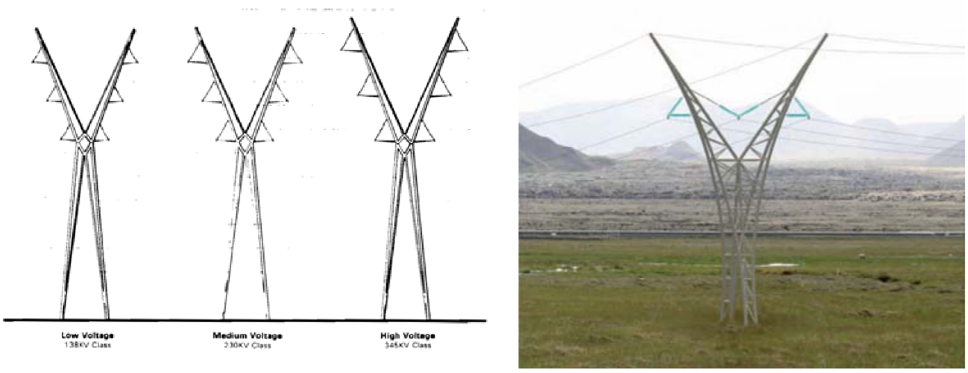


Figure 9: Left all voltage prototype Design Right Iceland

Artistic Design

An alternative to redesigning the structure of the tower is to incorporate the steel lattice structure into an art installation. For this approach the designer uses the structure as an exhibition to be admired. This technique has been used successfully in France as illustrated in Figure 9. However this approach is only considered appropriate for urban environments; it would not be appropriate for the typically rural areas associated with the Grid West project.

Figure 10: Art Installation on Overhead Line Supports

(Source: Cigre Working Group B2.08, 2010)

D2.5 Tower Colouring

Tower colouring can have a substantial impact on the overall visual impact of the structure. This can be as simple as painting the steel a colour which matches the background or it can involve using alternative construction materials. Both techniques provide camouflage for the tower allowing it to merge into the background. The visual reduction provided by tower painting is entirely reliant on the line routing and the tower backdrop. Ideally this should be continuous across the full profile of the tower with a textured appearance as provided by bush or forest covered hills.

Painting towers can add to maintenance costs as re-painting can only be carried out by specially qualified persons who can work while the line still in service. However ESB do not currently carry out live maintenance of transmission lines and towers.

D2.6 Alternative Conductor Technologies

Conductor technologies are continually advancing. The operation, weight and characteristic of the conductor are one of the single most influential aspects of OHL design and therefore advances in conductor technology can have a major impact.

As described in section D2.1 conductors are selected according to their current/power transfer capacity. This is limited by the resistance of the conductor and determined by the cross sectional area of the conductor, its material and operating temperature. This in turn determines the conductor weight, the tower spacing, tower sizes, types and foundations. The design of conductor should also consider ambient temperatures, wind effect and possible icing conditions.

Modern advances in conductor technology attempt to increase the current capacity of the conductor without compromising weight or efficiencies. These include:

Gap Conductors

Gap technologies contain a small gap between the central strengthening wire and the outer conductive material of the conductor. This gap is then filled with grease. This allows the two separate layers to be tensioned independently and hence limiting the conductors' knee point[18]. Gap manufacturing techniques can be combined with special materials that maintain their strength and conductive properties at much higher temperatures, such as an aluminium-zirconium alloy, to produce a conductor which can operate at higher temperatures with less sag and thus more capacity than an equivalent weight ACSR type (Peterson and Hoffmaan, 2003). Figure 11: Gap conductor vs. ACSR shows the comparable sag between the ACSR and Gap conductor technologies.

---

[18] The Knee Point of a conductor reflects the temperature where the thermal expansion of the outer conductor (aluminium) becomes so great that the total force is transferred to the core (steel). From this point on the conductors expansion coefficient will be equivalent to that of the core (steel). With a lower Knee Point more advantage can be taken of the high temperature alloys.

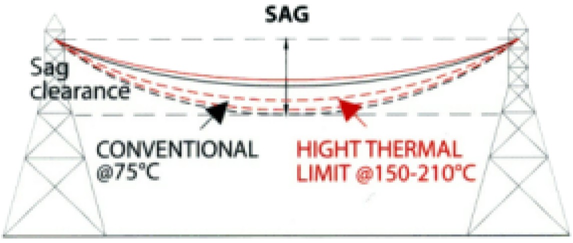
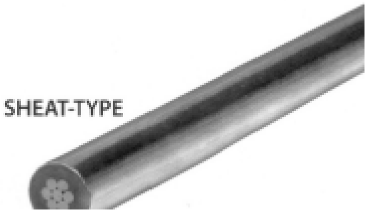


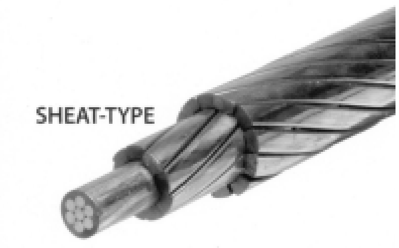
Figure 11: **Gap conductor vs. ACSR**

(Source: www.wiretec.eu)

EirGrid have assessed the additional installation cost of using Gap conductor as being 10% higher than using conventional ACSR (GWTS, 2011).

Sheat-type Conductors





These extremely compact conductors are characterized by the complete lack of hollow space due to a high strength steel core covered by extrusion of a penetrating annealed aluminium sheet. This allows:

- The same current carrying capacity with lower diameters
- The reduction of the wind pressure on the conductor
- Low losses due to the high conductivity of annealed aluminium
- Characteristics like ACSS with the thermal expansion coefficient linked to that of the steel core limiting the sag increase with the temperature
- Continuous operating temperatures up to 200°C with no long term creep

Sheat-type conductors are especially suitable to replace small AAC, AAAC and ACSR conductors in short span lengths.

These offer the same current carrying capacity as ACSR type cables with a smaller diameter. This reduces wind resistance and can lead to a reduction in tower reinforcement. However this conductor is relatively soft and easily damaged during erection.

(Source: Wiretec Europe website: wiretec.eu)

Elliptical Conductors

Non-circular conductors are twisted along their entire length to providing a continuously varying profile to the wind. The increased surface area provides better thermal conductivity and thus higher capacity especially during times of high wind. This may also reduce the visual impact of the line from a distance. However these are a relatively new technology and the long-term operational performance is unproven.

Conductor Colouring

Conductors can have a spray film of paint coating applied to their surface so that they better merge with the surrounds. This is particularly effective where a line is located within a forested backdrop as shown below:

Figure 12: Application of coloured conductors left before, right after application

(Source: www.wiretec.eu)

There are a number of other conductor technologies under development, incorporating special alloys and composite materials to increase capacity and reduce sag. However these are not yet proven in service.

D3 High Voltage Alternating Current (HVAC) Underground Cable

D3.1 Total vs Partial Undergrounding

One of the technology options considered in this report is undergrounding the proposed Grid West transmission line, using cables laid either directly or indirectly underground. There are two key variations, total undergrounding, where a cable is laid from end to end, and partial undergrounding where sections of the line are laid underground to avoid or overcome constraints that preclude overhead line, while the remainder of the line is run overhead.

Total undergrounding of a line over 110km long imposes significant technical constraints, which are discussed further below. The authors are not aware of any land-based transmission project of this length having been completed using underground cables for an ac system (Normark, B., *et al*, 2011). However it is accepted that partial undergrounding may have to be considered to overcome local constraints as part of any solution to a new transmission line, where overhead line technology has been adopted. If found to be necessary, the partial underground section would have to be designed in accordance with EirGrid 400kV requirements and to meet the operational requirements of the system.

D3.2 HVAC Underground Systems

HVAC underground systems include the following key components:

- Transmission cable
- Sealing ends – where the cables are connected to transmission line or substation plant
- Cable system accessories, including cable joints, cooling etc.
- Trenching, ducting or tunnelling
- Compensation equipment (where necessary)
- Maintenance roads
- Cable protection and earthing

D3.3 HVAC Cable Installation

HVAC cables are installed underground, either directly buried, ducts/concrete trenches or tunnels. As for road tunnels, cable tunnels are very costly to build. They are used in densely developed urban areas where neither overhead lines nor direct buried underground cables can be used. The use of cable tunnels would not be appropriate for a line the length of Grid West although could be considered if a partial undergrounding solution was adopted.

The laying of underground cables is highly dependent on soil type. There are two major influences:

- Excavation: Trenching for underground cables requires the excavation of significant quantities of soil; up to 2m^3/m (depending on local ground conditions). Areas of hard rock, very high water table, and extensive infrastructure can make this both complex and expensive. Extensive areas of deep peat, as found in County Mayo also have a significant impact on the excavation of trenches for underground cables.

- Backfill: The suitability of the soil as a backfill material and its thermal resistivity are important considerations. Frequently the soil is not suitable as a backfill material and must be either replaced or combined with imported improved material. Typically up to 50% of the excavated material needs to be removed and additional material imported.

The imported backfill may have repercussions with regard to local drainage patterns and soil stability, particularly if a cable were laid across country rather than in public roads. This is of particular relevance in peat bog where there can be adverse effects on the ecosystem and the stability of the ground.

The installation of underground cables requires the use of heavy equipment, not only for the excavation but also for the transport and ‘pulling’ of the cable. A drum of 400kV cable may weigh 30 – 40 tonnes, which has to be transported on a low–bed trailer or a specialist vehicle. In certain cases it may not be possible to access wetlands and peat lands with this heavy equipment. Considering the large expanses of peat (refer to section 3.2) and varied terrain within the Grid West study area, the possibility of providing a total underground solution imposes major risk to the Grid West project, [particularly in view of the requirements of the Mayo Co Development Plan. The terrain profile of the proposed route also covers hills/mountainous areas with the associated difficulties and expense in excavating and installing cable in these areas (Normark *et al*, B., 2011).

The installation of underground cables is discussed in more detail in section D3.9 below.

D3.4 Cable Technologies

There are 3 basic high voltage cable technologies:

- Oil-filled cables
- Crossed Linked Polyethylene insulated cables (XLPE)
- Gas-insulated cables (GIL)

Current cable technologies have been discussed below to provide a holistic overview of the technology. While technically all three cable types could be applied to Grid West, in practice because of the route length only XLPE would normally be considered.

D3.5 Crossed Linked Polyethylene (XLPE) Cables

XLPE cables utilise a layer of XLPE insulation to allow the transmission of HV through either a copper or aluminium core. Additional layers are added for screening, protection against water ingress and to increase the cables mechanical strength. Figure 13: XLPE Cable Construction, shows a typical 400kV XLPE cable structure.

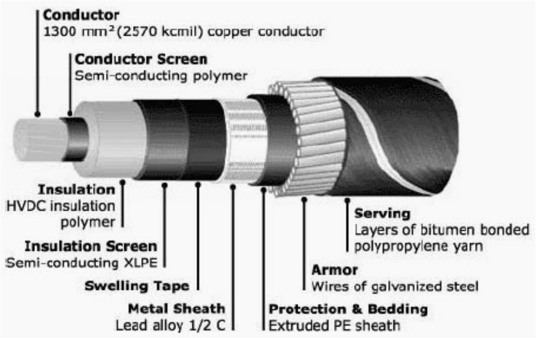


Figure 13: XLPE Cable Construction

(Source**:** www.electrical-engineering-portal.com)

XLPE technology is used for both HVAC and HVDC cables.

HVAC XLPE cables exhibit a high capacitance which has a major effect on the integration of the cable into the electrical system. Cable runs of greater than a few tens of kilometres require reactive compensation as described below (Normark, B., *et al*, 2011). The high capacitance from cables also creates a major risk of resonant overvoltage which can cause major damage to equipment and are difficult to control.

Electrical Performance

The electrical performance of an XLPE is determined by a number of factors, including:

- The operating temperature of the cable. XLPE insulation has a maximum rated operating temperature of typically 90ºC. Up to this temperature, the manufacturers guarantee the performance and life of the cable. Above this limit the properties of the XLPE insulation deteriorates rapidly, shortening the life of the cable, making it prone to flashovers and faults. The operating temperature is in turn affected by a number of factors:

    - The current being carried in cable. This current has the effect of heating the conductor because of the resistance and it is necessary that this heat is conducted away through the cable structure to the surrounding medium.

    - The thermal properties of the surrounding medium. The greater the capacity of the surrounding medium, soil, air, oil, etc. to conduct the heat generated in the cable away, the greater the current, and hence power, that can be carried by the cable. Thus a cable laid in soil with a good thermal conductivity will be able to transfer a larger amount of power than a cable laid in soil with a poor thermal conductivity. Similarly, it is common practice to use forced ventilation in cable tunnels to extract heated air from the tunnel, thus allowing the cables to operate at higher currents.

- Cable construction and design. Cable manufacturers use various techniques to improve the voltage rating, the current rating and the life of XLPE cables. For example an outer armour layer is normally applied to minimise the risk of physical damage to the cable during installation. XLPE cables are also prone to water ingress, which causes electrical breakdown of the insulation and failure of the cable. To mitigate this risk an expansion layer is added to absorb any moisture that penetrates the cables exterior.

Power Capacity

XLPE cables are generally sized between 500mm^2 to 2500 mm^2 and are available up to 3000mm^2 for high power applications (Parsons Brinckerhoff, 2012).

At 400kV this typically allows a transfer capacity of a single cable of between 454MW and 1015MW based on a direct buried copper cable at an ambient temperature of 30ºC. (www.nexans.co.uk)

Losses

All standard conductors of electricity have some resistance. This resistance causes the heating effect described above, with this heat causing losses such that the power received at one end of the cable is less than that sent at the other end. These losses, in addition to causing technical difficulties, also continuously cost money over the life of the cable.

In addition to the current (or power) delivered to the load at the end of the cable, the losses in an XLPE cable are increased by the capacitive characteristic of the cable. The capacitance causes charging currents to flow along the length of the conductor. This is summated with the real power current reducing the real power component available at the load, increasing the losses and potentially causing unwanted changes to system voltages. As the capacitive component is a function of the structure of the cable, which is determined by the operating voltage, and the length, increasing either further escalates the problem. Unlike HVAC overhead and HVDC cable, capacitance of HVAC underground cables plays a major role in limiting the technical and economic feasibility of the length of an XLPE HVAC underground transmission line.

Capacitive Effects and Reactive Compensation

As describe above, the capacitance of the cable reduces the percentage of real or usable power arriving at the load because of the capacitive charging currents. The cable has to be rated for the total current and thus the ability of the cable to transfer real power is reduced.

When installing underground cable over extended distances, capacitive charging will increase to a point where the real power losses are too great to be acceptable. In this situation reactive power compensation is provided by supplying inductive power which acts in the opposite way to capacitive power and consequently cancels it out. Reactive power compensation is applied in the form of shunt reactors located within either a sealing end or a substation compound.

The maximum distance between reactors is determined by power flows, cable types and cable installations. However it is likely that intermediate compensation stations would be required along the length of the Grid West line if a fully underground solution were to be adopted. The effect can be most noticeable at times of low load when the capacitive reactance is greater than the load related voltage drop.

A typical reactor compound will include:

- Sealing ends
- Bank of reactors
- 400kV circuit breaker (minimum of one)
- Isolators
- Control building
- Secure compound including auxiliary services

It should be considered that a reactive compensation facility would cover an area of up to 2,500 m^2 and be required approximately every 15 km. These will add significantly to the visual impact of the route.

D3.6 Oil Filled Cables

Before the advent of XLPE technology, the majority of high voltages cables were oil-filled cables.

Oil filled cables utilise either oil saturated paper or pressurised oil to prevent the build-up of voids within the paper insulation caused by changing load (power) profiles.

They offer a similar performance to XLPE cables but at the cost of additional complexity and environmental risk posed by the insulating oil. They are now seldom used as oil leaks can be difficult to locate, expensive to repair and the specialist skills needed to work with these cables are no longer being developed. They are not considered further in this report.

D3.7 Gas Pressurised Cable

These operate in much the same principal as the oil filled cables; however use nitrogen gas to prevent void formation during times of varying load. These have been unreliable and have not been considered further for this study

D3.8 Gas Insulated Line (GIL)

This system comprises of aluminium conductors that are supported by insulators contained within sealed aluminium tubes. The tubes are pressurised with an insulating gas usually a mixture of nitrogen and SF^6 (National Grid, 2008, Pg 06).

GIL offers an alternative where OHL cannot be used due to space restrictions (Normark *et al*, 2011). As GIL systems have an increased distance between each phase and earth, problems associated with line capacitances that are experienced with ac XLPE technologies are greatly reduced.

Environmental risks associated with the release of the insulating material specifically SF_6 which is a potent greenhouse gas remains a concern and monitoring which is usually applied to switchgear is not feasible over the longer distances posed by GIL installations.

Typical GIL installations are between 100m to 10km with manufacturers specifying lengths of up to 100km as being possible and not requiring reactive compensation. GIL can be installed above ground, in tunnels or be direct buried where cables are enclosed in polyethylene giving an expected life of 40 years. Although the technology has been commercially available since the 1970s, there are only a limited number of projects in operation, with the longest installation being 12.75km, noted on the Siemens Energy Website – Gas Insulated Transmission Line (http://www.energy.siemens.com/hq/pool/hq/power-transmission/gas-insulated-transmission-lines/GIL_e.pdf).

This technology offers a higher priced alternative to AC partial undergrounding using XLPE cable and a price-competitive alternative to total underground HVDC. However the technology has not been proven in distances comparable to Grid West's transmission line, hence any utilisation of this technology would present an unacceptable risk.

Electrical Performance

Due to the improved insulation provided by the gas insulation and greater distance between the conductor and earth, the negative capacitive effects experienced by XLPE are greatly reduced so that the electrical performance is thus determined by the heating effect of the real current being carried in the conductor and is not adversely affected by cable induced components.

Power Capacity

GIL technology is capable of transmitting up to 3700MVA at 400kV. However, as this requires additional forced cooling, a more typical load would be in the range up to 2500MVA. By increasing conductor core, cross sectional area increases capacity, this is only limited by the thermal dispersion of the cable and its installation.

Losses

Losses are lower compared with either overhead line or XLPE due to the increased cooling provided by the heat transfer of the aluminium casing and the greatly reduced capacitive properties of GIL.

Electromagnetic Effects

One major advantage of GIL technology is that it offers a solution that inherently causes low magnetic and electric fields.

D3.9 Installation of Underground Cables

There are a number of methods of installation for high voltage underground cables. While the principles are similar, the detailed requirements are varied and relate to a multitude of factors including terrain and soil characteristics, technical limitations such as cable pulling distances, pulling torque limits, sheath voltage limits and winching equipment. Manufacturing and site limitation such as weight and height of cable drum, gradients, access tracks etc. To determine the most suitable installation practice a full site survey and design would need to be completed (Parsons Brinckerhoff, 2012).

The following lists some common approaches to cable installation:

Direct Buried Cables

Direct burial is the most common means of installing high voltage cable in rural areas. They do not require the level of civil engineering required by cut and cover or deep bore tunnelling type installations (National Grid, 2008).

Direct buried cables are the conventional means of installing high voltage cable in urban and rural areas (National Grid, 2008) and most suitable for the Grid West project as it provides the least intrusive, most cost effective (where restrictions of land use are not an issue) underground solution. However the extensive areas of peat in Mayo would make direct burying of cable more difficult.

Direct buried cables are subject to national regulations however a typical installation requires a trench of 1.2 -1.5 metres in width to a depth of approximately 1.2 metres to be excavated with the sides supported by timber or sheet pilling. A sand bed is placed in the bottom of the trench and the cables are then located on top of it. Selected backfill with good thermal conductivity is then placed around the cabling and if required a concrete protective cover is included above the cable (National Grid, 2008). Cement stabilised sand is commonly used as the backfill.

For a single circuit 400kV line the cable trench easement is approximately 18.5m which includes 1.2 to 1.8 metres for the trench, 9m for the haul road sized to appropriately to accommodate trucks delivering cable to be able to pass each other, 3 metres between the fence and the trench to allow cable pulling equipment and 5 metres for top soil storage (National Grid, 2008). Cable pits and complex earthing systems are required as described below.

Due to the nationally critical nature of the infrastructure, the risks to health and safety and the cost of repairs, it is recommended that only selected agricultural activities be undertaken within route corridors. Trees and vegetation must be excluded over the route, and regular inspections carried out to ensure the route remains clear. A permanent access road along the full length of the route is required for continued routine inspection and maintenance and emergency works,

After construction the land can be used for selected agricultural purposes but must remain free of trees to prevent root damage to the cable and prevent inductive flashovers.

When faults occur on 400kV underground cables, outage times are, on average, 25 times longer and more expensive than for an equivalent OHL primarily due to the difficulties in locating and access the fault (National Grid, 2008). CIGRE Report 379 reports that the average time to repair an EHV cable is 25 – 38 days, with up to 10% of repairs taking longer than 3 months.

Direct buried cable offers the additional advantage of being able to be installed with a minimum bending radius of 5 metres. This allows for considerable flexibility when selecting a cable route (National Grid, 2008).

Under Boring

Under Boring utilises directional drilling to be able to install relatively short sections of underground cable with a lesser effect on the land or ground surface. Although the equipment is expensive, it provides a feasible option where conventional excavation or access is not possible such as under rivers, roads and highways and railways. It should be considered that riverbeds can vary over a period of time; therefore long term maintenance requirements should be addressed.

Cut and Cover Tunnels

Cut and cover tunnels are located in deep troughs and constructed using preformed concrete sections. These require the excavation of large areas of land and have considerable environmental and cost implications. For the Grid West project the use of cut and cover tunnels is not likely to provide any advantage over direct buried construction and therefore is not recommended.

Deep bored Tunnels

Deep bore tunnels are generally used in urban locations where direct buried installations would cause unacceptable disruption (National Grid, 2008). The other application would be through very mountainous areas, where the terrain does not permit the construction of overhead lines or allow direct burying of cables. No location within the Grid West study area is foreseen as requiring deep bored tunnelling; hence this technique is not considered further in this report.

Jointing

These are the connections between cable sections. They are typically every 500-800m depending on the cable drum length. For direct buried cable the joints connecting the two cables are located in jointing pits. These can be 30-40m in length and 5m in width, requiring concrete lining and trench capping (National Grid, 2008).

The jointing terminations are the weakest points of the cable system and require special care when terminating and continued maintenance. Therefore limiting the number of joints is preferable.

Earthing

Earthing is a critical part of the design of underground cables as it limits the voltage which can be induced though the sheath and shielding metals. As this voltage must remain within safe limits, without proper design becomes a limiting factor for the allowable length of each cable section. By providing sufficient earthing, there is a path available to discharge these voltages. To allow the even dissipation of voltage along the length of the cable, the shielding between cable sections is bonded in link boxes which are positioned above ground over cable joints for testing purposes.

D3.10 Installation of Underground AC Cable - Cable Sealing Ends

Sealing ends are required where a cable sections terminate to overhead lines or connect to reactive compensation. These will consist of substation terminations or underground to overhead connections. The land required for a sealing end compound is approximately 30m x 80m for a 400kV circuit (National Grid, 2008).

A sealing end compound requires

- Sufficient room for insulators to allow the clearance distances between the overhead line conductor connections and the ground.
- Sealing ends which connect the cable to the overhead line.
- Surge arrestors to prevent any large currents caused by lightning strikes or faults to be dissipated without damaging the cable.
- Site auxiliary services including security fencing, lighting etc.
- In addition earth switches and reactive power compensation may need to be located in the same compound depending on maintenance and operational requirements.
- Sealing end compounds connecting to overhead lines will also have a terminal tower located near or within the compound. This will add sufficient visual impact to the overall design (National Grid, 2008).

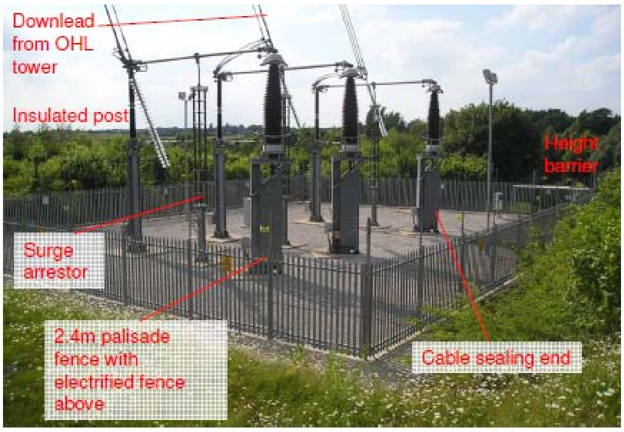


Figure 14: **Typical Sealing End Structure**

(Source: National Grid, 2008)

D3.11 Underground Cable Environmental Impacts

The following discusses the environmental issues associated with the underground cable installations. These are all applicable for both HVDC and HVAC underground installations.

Underground cabling installation, excluding associated stations for reactive support when compared to overhead lines, offers a reduction in visual impact. However other significant environmental issues associated with underground construction methods and land use remain. These include:

Land Use Restrictions

Any land that is to be used for easement must be cleared and remain free of any deep rooted vegetation for its lifetime to prevent roots from penetrating the cable and causing faults. A maintenance road is to remain after construction, being suitable for heavy earthmoving equipment so that maintenance and fault repairs can be undertaken

Maintenance

Cables are designed to have an asset life of around 60 years. During their life routine inspections and testing are carried out to insure joints, insulation and earthing all operates properly. To allow this and emergency works, the entire length of the cable must be accessible at all times hence a permanent road is required.

Civil Works

Excavation of cable trenches and roads requires the removal of large quantities of top soil, which affect any flora or fauna or archaeological sites located within the easement.

Construction Access

To allow construction a haul road will be constructed. This is to be of sufficient load bearing strength to allow access by the heavy plant, which in turn restricts the length of cables and ultimately is a limiting factor in determining the number of joints and thus the reliability of the cable system.

The soil excavated for an underground cable system, where two cables per phase (approximately equal to twice a single circuit as required by Grid West) are installed, is some 14 times greater than for an equivalent overhead line route (National Grid, 2008). Removal and disposal of soil can lead to cross contamination, soil stability problems and drainage issues.

Hydrological Impact

The natural water hydrological system is very complex especially in areas of peat land similar to those found within the Grid West study area. The implementation of sections of underground cable can cause alterations to the natural drainage by acting as barriers or channels leading to drying or pooling, potentially destroying the habitat.

Audible Noise

Underground cables do not produce noise along the route however noise is produced at cable sealing ends and jointing sections. Jointing chambers may require a silence generator to limit the noise to below 45dB at night or 50dB during the day at the boundary of the nearest residence. (Parsons Brinckerhoff, 2012).

Electromagnetic Compatibility

EMFs will be produced. However they will be reduced by the surrounding ground. It is considered that the route is predominately over rural and low population areas, therefore the effects of EMFs can be considered negligible compared to an equivalent OHL.

D4 High Voltage Direct Current (HVDC)

Historically HVDC on land has been used to allow transmission of electrical power over large distances where HVAC is not technically or economically feasible. The breakeven point has generally been considered as being at distances of over 1,000km, although many factors can cause this to vary. However recent advances in HVDC technology, in particular the development of voltage sourced convertor (VSC) technology have challenged this.

The primary reasons for using HVDC are that it offers:

- Economical transmission of electrical energy over long distances via overhead lines or cable with reduced losses. This is because inductive and capacitive effects associated with alternating current transmission do not limit the transmission capacity or the maximum length of a DC line.

- Normark *et al* (2011) note that with advances in technology, underground HVDC transmission becomes a viable alternative to HVAC underground transmission for distances over approximately 50km. This is relevant to the Grid West Transmission Circuit, which is approximately 110km, where an HVAC underground solution over the full length would be technically difficult to achieve.

- A viable alternative to overhead transmission in areas where tower installations are not practical or public opposition is very high, such as high density urban areas or areas of outstanding natural beauty.

- The possibility to connect asynchronous grids or grids with different frequencies.

- A transmission solution to overcome transient stability issues which can occur in a long length equivalent ac transmission.

The major disadvantages are:

- Although a HVDC line is lower cost than the equivalent HVAC line, the high cost of the converter stations still makes HVDC a more expensive option for shorter lines.

- The current break even length of line for an HVDC link is in the range of 500 to 800km (Siemens Energy, 2011)

- HVDC exhibits the highest proportion of losses of any of the technologies. However the losses in the converter stations remain relatively constant, thus the total system losses are proportionally reduced over extended distances, making HVDC more efficient when applied to long distance transmission (Parsons Brinckerhoff, 2012)

- The complexity and increased component count of the converter station increases the probability of failures and also increases the time to repair, thus reducing both the reliability and availability of the transmission line.

- The converter stations require significant land area to facilitate the equipment and there is significant noise pollution from the converter plant.

- Future generation and network development could only be connected to an HVDC system by installing additional converter stations.

D4.1 HVDC System Components

The main technological components of an HVDC system are:

- A converter station at each end which provide the means to convert from HVAC to HVDC and vice versa. There are two main technologies for these stations, Line Commutated or Current Source Converters (LCC or CSC) and Voltage Source Converters (VSC), for the purpose of this report only VSC will be discussed in detail, being the most suitable for a connection of 100km length and 500MVA capacity (Parsons Brinckerhoff, 2012)

- One or more pairs of HVDC conductors (underground or overhead line) to allow the power to be transmitted to its destination. As the most significant advantage offered by HVDC is the ability to provide a fully underground solution and overhead HVDC lines do not offer any significant environmental or visual impact advantages over conventional transmission lines, HVDC overhead lines are not commonly implemented in applications similar to that of the Grid West project.

D4.2 Converter Technology - Current Source Converters

Line Commutated or Current Source Converter (LCC/CSC) technology utilises thyristors with high voltage and current capacity to enable the conversion of HVDC to HVAC.

LCC HVDC has very high power transmission capacity and is the preferred technology for feeding power over distances of 1000km or more. Projects where this technology has been applied include large remote located hydropower plants, subsea interconnections and other international interconnections. Although this technology is relatively well established, due to the length and utilisation of the Grid West proposed line it would not offer the most beneficial HVDC solution. If HVDC is to be adopted, the most appropriate technology would be VSC HVDC as detailed below.

LCC technologies also required an external AC voltage source for the thyristor valves to commutate. These have an inherent reactive power demand and produces harmonic currents at the converter stations which requires mechanically switched capacitor banks and harmonic filters for mitigation. In addition current state of the art technologies can also include air insulated water cooled valves, adding additional complexity (Siemens Energy, 2011).

D4.3 Converter Technology - Voltage Source Converters

VSC HVDC technology was developed during the 1990s, and the first commercial transmission link was commissioned in 1997. VSC converter technologies are based on power transistors, (IGBTs -Insulated Gate Bipolar Transistors), as the converting components. IGBTs, being more controllable devices than thyristors, make VSC HVDC a more flexible technology than LCC HVDC. This allows the VSC converters to be more easily integrated into an alternating current grid, with the ultimate goal for them to be able to fully replicate the operational characteristics of equivalent AC components. This characteristic also allows them to respond better to variable outputs of renewable generation sources such as wind farms. (TransGrid, 2009, page 68)

VSCs function as independent voltage sources that can supply or absorb active and/or reactive power, therefore requiring no independent power source and can operate down to an AC short circuit ratio (SCR) of 0, making it suitable for connection to XLPE cable installations. This ability to supply and absorb active and/or reactive power also makes VSC technology suitable for applications where integration into the grid system is important, such as the Grid West project.

VSC technology occupies 40 – 60% less space than an equivalent CSC station.

The technology continues to develop with converter stations becoming more efficient, reliable and compact. VSC technology now offers converter efficiencies of around 99% (Normark *et al*, 2011).

Current projects identified for 2010 to 2011 included 7340MW of connected capacity with the maximum single circuit capacity of 1000MW (Normark *et al*, 2011). Many of these projects are being pursued for offshore wind development, however the technological advances are still applicable for land based projects. For this reason it expected that a full capacity 1500MW underground HVDC circuit will be available by the time this project is to be implemented (Parsons Brinckerhoff, 2012,).

For a detailed description on the operation of VSC please refer to VSC-HVDC Transmission with Cascaded Two-Level Converters, CIGRE 2010 (Jacobson *et al*, 2010).

D4.4 Transmission Mediums - HVDC Overhead Lines

A HVDC overhead line requires only two conductors, a positive and a negative conductor. This allows HVDC overhead lines to utilise lighter towers, thus reducing the profile and the visual impact of the towers. The conductors also offer less visual impact, although as conduits for large quantities of power, there is still a significant visual impact. Thus there is limited advantage in utilising the more expensive HVDC technology compared to the HVAC OHL technology. [Normark *et al*, 2011]

D4.5 Transmission Mediums - High Voltage DC Underground Cabling

The principles of the cable technologies and installation methods are similar to those used for HVDC/HVAC underground cables discussed in Section D3. However the design details do vary according to the differing requirements of the two systems Therefore the following notes will discuss specific technological details associated with HVDC underground cable technologies as they deviate from section D3.

Cable Technologies

If a VSC HVDC technology system was to be used the most applicable cable solution for a project of this length would incorporate XLPE cable. An XPLE cable utilises either copper or aluminium conductor insulated within XLPE. The insulation is then waterproofed and strengthened with additional layers. The end product is a high voltage cable capable of operating at 320kV. The limitation of the cable is determined by its thermal conductivity. Modern XLPE cables are rated to 90ºC, if the temperature of the XLPE continues above this temperature the insulating characteristic of the XLPE begin to diminish and faults can occur. For this reason detailed studies into the cable installation incorporating the thermal characterises of the soil, installation methods, cable induction, cable capacity and additional cooling must be undertaken to determine the feasibility of any XLPE solution.

Installation Methods

As the cable installation methods and issues for HVDC cables, are similar to those for HVAC cables, refer to section ‘D3.9 Installation of Underground Cables’.

In Ireland, the emerging practice is to install HVDC (and other high voltage) cables in public roads. This has the advantage that impact on landowners properties is minimised and environmental impact is reduced. However there is a significant construction impact requiring extensive traffic disruption as a result of complete and partial road closures. This method of installation typically requires special installation methods to cross rivers and streams as the bridge typically cannot be used to carry the cables. Most commonly horizontal directional drilling will be required for river/stream crossings.

A typical cross section of a high voltage cable construction trench is shown in Figure 15 below.

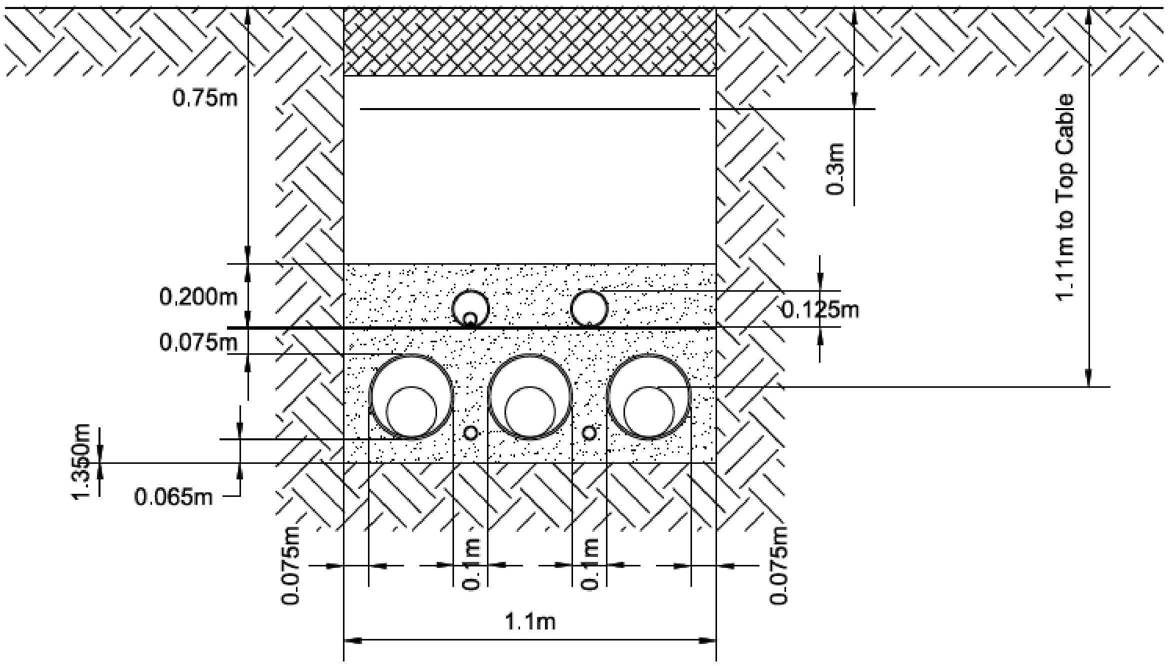


Figure 15: Typical cross section of a high voltage cable construction trench

D4.6 HVDC System Characteristics

As HVDC only requires two paths (positive and negative) for each circuit there are a number of system configurations which can be applied, these include:

- Back to Back Converters indicates that the rectifier and inverter are located at the same station. These are mainly used for transfer between AC grids of different frequencies (Siemens Energy, 2011, Pg 6).

- Monopole, earthed return. Used for transmission over very long distances and in particular for undersea cable transmission, a return path via an earthed electrode can be used thus only a single cable needs to be laid. This can only be applied when there is no risk, such as buried metals of injecting large current into the earth. An alternative monopole solution utilises a LVDC cable for the negative pole or return path, this cable being arranged so that its potential is at or close to earth potential. (Siemens Energy, 2011, Pg 6).

- Bipolar long distance transmission: Can combine a number of combinations of two poles providing a return path via dedicated transmission cable or may include a common low voltage return path if available. The bipolar arrangement is used when the required transmission capacity exceeds a single pole configuration. Bipolar systems with electrodes or LVDC return path also have the flexibility to operate as monopole earth return under failure of a single pole at 50% capacity. (Siemens Energy, 2011, Pg 6).

At the time of preparation of this Technical Foundation Report (August 2012) the largest commissioned VSC converter station has a capacity of 500MW. Thus a VSC link to match the capacity of a 400kV OHL built to current EirGrid standards would be significantly larger than is currently in commercial operation. An underground system of this capacity would also require multiple cables for each pole to meet the required capacity.

Losses

HVDC exhibits the highest proportion of losses of any of the technologies. However these losses principally occur at the converter stations and at the end of the connection. Thus for long HVDC connections the system would have higher proportional efficiencies and thus lower cost per km. (Parsons Brinckerhoff, 2012, pg 119)

For a given cable conductor area, the line losses with HVDC cables can be about half those of AC cables (minus converters). This is due to AC cables requiring more conductors (three phases), carrying the reactive component of current, hysteresis effect, skin-effect, and induced currents in the cable sheath and armour. As the length of the cable installation increases, the real power associated with HVAC cable decreases rapidly due to the capacitance of the cable, while HVDC losses remain relatively constant.

The major losses for HVDC are in the converter station. These have continued to decline and are now around the 1% per converter station (2% per pair) for VSC technologies (Normark *et al*, 2011). Converter losses combined with line losses represent a significant cost over the life time of the system.

Power Capacity

The power capacity of VSC HVDC has continued to increase. Technological advances in converter power electronics and cable manufacturing techniques has allowed transmission voltages to increase and cables to operate at higher temperatures. However the largest capacity VSC system currently in service is 500MW with links up to 1000MW currently being built (Parsons Brinckerhoff, 2012). Systems capacities are expected to continue to increase as the technologies advances.

Operation and maintenance of HVDC schemes

One of the benefits of any type of HVDC scheme is that its active power transfer can be controlled irrespective of the ac voltage phase angle or angle at its terminals.

Grid codes typically stipulate that a generator has to be able to operate with a controllable power factor and that the reactive power capability has to be available throughout most of its operating range. Typically, ac voltage controllability is also required. The ability of a VSC Transmission scheme to control the reactive power at its two terminals independently of each other and independently of the active power transmission is a valuable technical benefit in this respect. (Anderson, 2006)

A HVDC system is relatively complex with potentially powerful operational controls. Operation is facilitated by the control system which executes the necessary detailed sequences and control commands to achieve high level objectives given by the operator, e.g. power order and reactive power exchange with the ac network. Typically the control systems allow operation in either manual or automatic modes, as selected by the operator.

However given the complexity and range of functions available, it is important that operators are trained in the operation of the HVDC system with particular attention to the benefits and constraints of any system within the transmission network.

Specially trained personnel are required for maintenance and fault finding of HVDC scheme equipment. These activities occur infrequently, but time has to be allocated to enable the personnel to keep their skills up to date, and this cost needs to be taken into account by the Owner. This situation is not that different from the maintenance and fault finding of the complex SCADA systems in ac substations. In fact, equipment manufacturers or specialist companies often provide this service. By providing long term service contracts as an extension to the HVDC scheme contract, the costs become known, and the network operator can take these costs into account in their comparisons. The maintenance and fault finding requirements could be reduced by further development of the monitoring system. Self-diagnosis of problems is increasingly built into the HVDC convertors, reducing the need for specialist maintenance staff. However, specialists are likely to still be required to provide the comprehensive maintenance service necessary for a utility service provider. (Anderson 2006)

Integration of HVDC scheme in AC network

Integration of a HVDC terminal into an ac system requires specialist engineering. For example the TransGrid Report indicates that this is a complex system, which introduces significant risk. Development in HVDC control has resulted in improved performance during and after faults in the ac network, and the performance can be optimised to suit particular network requirements. Nonetheless, the performance is different from that of an ac connection, and present challenges to network planners and operators to understand the benefits and mitigate the constraints, so that the HVDC scheme does become properly integrated into the network. (Anderson, 2006)

Harmonics

All power electronic converters produce harmonics as a by-product of the conversion process. In order to prevent these harmonics spreading into the ac network, where they could cause problems, ac harmonic filters are used at the ac terminals of the HVDC scheme. As the number of converters connected to an ac network increases, the harmonic pollution in the network increases, as filtering is not perfect. Therefore, the harmonic pollution that a new scheme is permitted to contribute is reduced, making ac harmonic filtering increasingly difficult, and therefore expensive. Since LCC HVDC produces harmonics at relatively low frequencies (primarily 550Hz and above), the problem is worse for this type of HVDC than it is for VSC Transmission (usually >1kHz). Another issue is that the ac harmonic filters and any shunt capacitor banks used for reactive power compensation can cause magnification of the distortion caused by other remote harmonic sources. (Anderson 2006)

These harmonics can also cause sub-synchronous resonances in certain types of wind turbine generators, which can cause interference with both wind generator controls and HVDC link.

Stability of Network with multi-infeed of HVDC

If HVDC were used for many more applications in a network, then the issue of interaction between multiple HVDC schemes would become increasingly important. Commutation failures, which are typically caused by large voltage dips or sudden ac voltage phase angle changes, could be caused by disturbances on another HVDC scheme, and interaction between schemes could potentially cause instability, unless appropriate steps were taken. It should be noted that VSC Transmission does not suffer from commutation failures, and is therefore not likely to suffer from instability, even if several HVDC terminate in close proximity to each other. (Anderson, 2006). However currently no multi-infeed HVDC scheme has been commissioned, although a small number of schemes have now been contracted globally.

D4.7 Environmental Impacts

The greatest advantage applying HVDC is the ability to provide a fully underground solution as this would remove the requirement of overhead lines and towers. It is expected that this would significantly reduce the amount of public opposition to the project and allow for a greater chance of award of the planning approval. However other more detrimental environmental impacts must be considered. These have been outlined in Annex B. It should be noted, however, that access route and cable trenching would be required along the whole route length.

HVDC underground cable is the only technology which can practically be used for a 110km fully undergrounded solution. However the complexity providing a solution of this nature is reflected in its cost. Visual impact is reduced although there are other more environmentally destructive practices normally required to allow implementation of long distance underground solutions. National Grid of the UK has found that “in both rural and urban environments land disruption is greater when laying underground cable than when erecting overhead lines” (National Grid, 2011).

D5 Substation Technologies

While not discussed elsewhere in this report, the selection of the technology for the new substations is also an important consideration. Substation technologies as discussed below consider the following substation configurations.

- Air Insulated Substation with gas Insulated or vacuum circuit breakers (AIS). AIS substation utilises air which is a relatively poor insulator to insulate the substation equipment. This requires insulation coordination with minimum phase to earth clearance distances of 4.1m which is achieved using steel lattice structure supports, and post insulation, to mount HV equipment which maintain required clearance distances.
- Gas Insulated Substation and Switchgear (GIS). GIS utilises SF_6 gas to insulate all exposed high voltage components or conductors, reducing the electrical clearance distances for 400kV to 100's of mm with limiting criteria becoming EMF and thermal dissipation. This leads to a reduced foot print for a substation as can be seen in the two equivalent substation layouts shown in Figure 15: It is normal for full GIS substations to be built in a building; the building can be treated architecturally to reduce its visual impact.

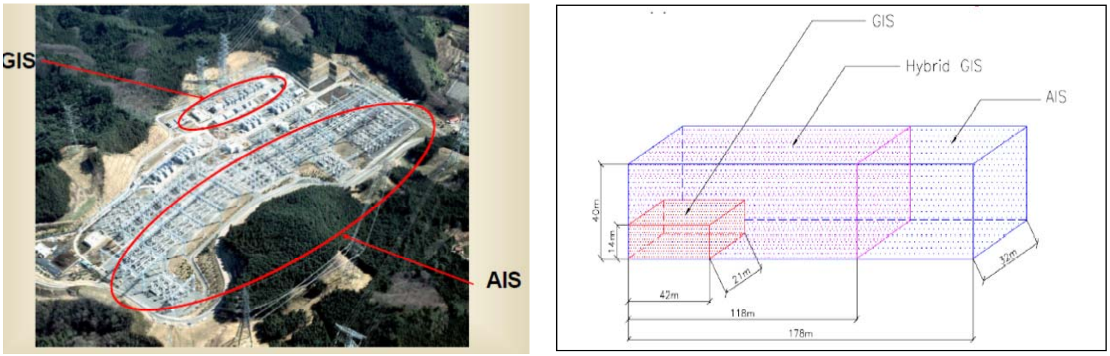


Figure 16: **GIS vs. AIS Equivalent Substation Layouts**

Source: (Mohana Rao, 2010, Pg 17)

D5.1 Air Insulation Switch Gear (AIS) Vs Gas Insulated Switch Gear (GIS)

Both AIS and GIS are well proven technologies and have been implemented successfully around the world and in Ireland. Both technologies offer advantages depending on the application and the selected substation site.

In areas where sufficient space and planning consent can be obtained, AIS offers the

- Most cost effective solution
- Reduced complexity and hence increased reliability.
- Reduced probability of failure caused by insulation failure resulting from gas leakage or contamination
- Maintenance is simplified as busbars are accessible without requiring degassing
- With sufficient room, AIS can be easily extended with additional bays
- Increased risk of faults due to lightning strikes, pollution contamination, moisture and dust, etc.
- Reduced potential for SF_6 gas release (SF6 being a greenhouse gas)

Alternatively GIS offers a reduced foot print where AIS is not practical or planning permission cannot be obtained. GIS offers the following advantages over AIS.

- A reduced substation footprint size due to substantially reduced insulation distances allowing compact installation
- Can be located within building to reduce visual impact
- Reduced probability of failure as equipment located in a clean and conditioned indoor environment
- Health and safety increased as equipment contained within the building
- With all high voltage components fully enclosed in an insulated environment, can operate in highly polluted areas, unsuitable for air-insulated systems.
- In areas where land prices are very high, GIS can offer a more cost effective solution

GIS substations can present some difficulties when trying to extend the facility if the equipment has become obsolete or is no longer manufactured.

The Grid West Project

Lead Consultant's Stage 1 Report

March 2013 **Revised September 2014**