Grid-access Technologies for GB Offshore Wind Industry

January 2020

Offshore Wind Industry Council

Executive Summary

The UK Government has set an ambitious target to reduce all greenhouse gas emissions to net zero by 2050. This would require large-scale integration of up to 75GW offshore wind capacity into the GB electricity system, up from 8GW in 2018, according to the Committee on Climate Change.

The coordinated development of future offshore electricity transmission infrastructure is essential to achieve the levels of deployment required.

With government's commitment to a strategic target (of 40GW of offshore wind by 2030), the Offshore Wind Industry Council (OWIC) wanted to investigate how the future offshore electricity transmission system should develop to realise the full potential of GB's offshore wind resource.

In response to this, the OWIC formed a Future Offshore Transmission group comprising a Technical Solutions work stream led by The National HVDC Centre in collaboration with three offshore windfarm developers (EDPR, Scottish Power Renewables and Vattenfall) and the Offshore Renewable Energy (ORE) Catapult. The technical solution work stream led a review into Grid-access Technologies for the GB Offshore Wind Industry.

This report, by the Technical Solutions work stream identifies the following issues to be analysed:

1. **Integrated electricity transmission planning** – coordinated planning can facilitate economic and efficient development of future offshore and onshore transmission networks, based on High Voltage -Alternating Current (HVAC) or Direct Current (HVDC) technologies;

2. **Key enabling infrastructures** – shared transmission assets such as coastal HVAC grid hubs; offshore HVDC hubs; and demonstration and innovation hubs, would be required to realise the full potential of GB's offshore wind resource; and

3. **Design authority and system operator** – there is a need to plan appropriate enabling infrastructures and funding of the future offshore transmission systems.

Further details behind these recommendations are outlined later in this report.

1. Introduction

The two main technologies for transmission of electricity from remote offshore generation sources to terrestrial grids are HVAC and HVDC systems. This section presents key drivers for the development of GB's offshore transmission networks.

1.1. Drivers for the Development of Offshore Electrical Transmission Systems in GB

Decarbonisation of the GB electricity system would require a fundamental shift from conventional thermal generation source to low carbon energy technologies including offshore wind.

a. Offshore Wind Sector Deal Targets

In March 2019, the UK Government in collaboration with industry announced an offshore Wind Sector Deal with a strategic target aimed at increasing the installed offshore wind capacity from 8GW in 2018 to 40GW by 2030. Also, the Committee on Climate Change published a Net Zero report with a 2050 target of 75GW of offshore wind, which would require up to 7500 wind turbines and could fit within 1-2% of the UK seabed, comparable to the area of sites already leased for wind projects by the Crown Estate.[1]

b. Electricity Interconnection Targets

Electricity markets in GB and the rest of Europe are physically linked by subsea cables, known as interconnectors. The European Commission has set an interconnection target for countries to provide up to 15% of total installed electricity generation capacity from cross-border interconnectors by 2030,[2] this would represent 19GW to 25GW based on National Grid's Future Energy Scenarios 2019.[3] At present, GB has about 5GW of installed electricity interconnection capacity based on HVDC transmission links with five different electricity grids. Further interconnection can contribute to energy security, affordability and decarbonisation objectives. There are around 26GW of additional interconnection capacity proposed between GB and the grids of other countries,[4] with the UK Government only currently supporting the market delivery of at least 9GW of additional interconnection capacity.[5]

c. Onshore Network Reinforcements with Offshore HVDC links

GB has two existing offshore reinforcement circuits based on onshore HVDC converter stations connected via coastal transmission circuits implemented using subsea HVDC cables. The National Grid 2019 Network Options Assessment document identifies at least two Anglo-Scottish reinforcements (Eastern HVDC links and/or onshore circuits) each with an installed capacity of about 2GW, planned beyond 2025 and intended to accommodate the high North-to-South power flow mainly from renewable sources.

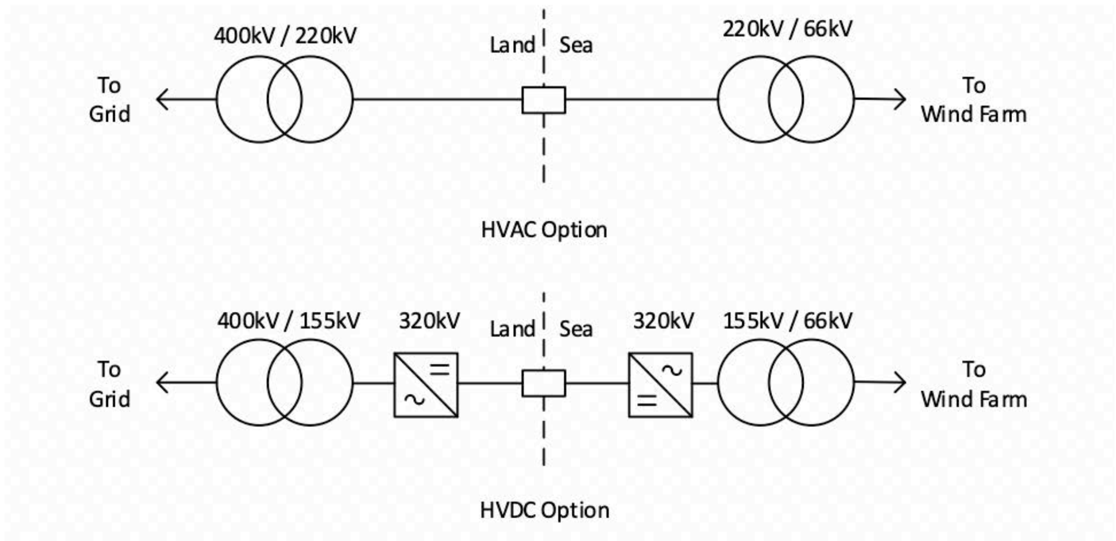
Integrated planning of both offshore and onshore electrical transmission infrastructure has several benefits including: less infrastructure overall, reduced consenting challenges, ability to choose the connection point on the onshore GB system, thereby minimising onshore transmission reinforcement, cost, programme risk and consent, and increasing availability of resource, giving greater resilience of offshore system to network access. Offshore transmission development is intrinsically more costly than an equivalent onshore capacity, but if consents required cannot be obtained, or the solution would require massive onshore cabling, then the costs comparison tends to drive more integrated development of the offshore and onshore networks.

Therefore, integrated offshore solutions would be required to achieve an economic, efficient and coordinated development of GB offshore wind industry to meet the strategic targets of 40GW by 2030 (and up to 75GW by 2050). An example of the East Coast integrated offshore network design is shown in Section 3.2b below.

1.2. Benefits of Integrated Planning of Transmission Systems

Offshore grid construction for offshore windfarms has to date been point-to-point with the largest developments in the North Sea located in the UK and Germany. This approach has proved valid, both with the developer-built approach in UK and the transmission system owner/operator (TSO)-built approach in Germany. However, with the increase of offshore windfarms, the pressure on the onshore network and the likely uplift in interconnectors, potential improvements should be considered with regards to asset utilisation and costs that may be realised with a planned and integrated transmission development approach. Separation of offshore and onshore transmission developments from offshore wind generation build would potentially allow a whole-system approach to planning the transmission infrastructure to unlock the full potential of the offshore wind resource.

Figure 1: Schematic diagram of offshore transmission system based on HVAC and HVDC technology options



This approach will be needed as the offshore grid concept will likely 'evolve' from the radial offshore connections rather than be designed from the beginning as one large master-plan so solutions like these should be able to provide the first stages in creating or integrating with this 'grid' when the time is right.

For the future wind development areas potential onshore connection points and options of grid topology that may provide different levels of benefit to the developers, customers and other stakeholders need to be identified.

> If the potential onshore connection points are identified across different scenarios such as hubs, offshore links or offshore rings, the benefits of integrated planning could manifest themselves through reduction of cable corridors, reduction of onshore connection points, better environmental planning approach, quicker permitting process, a commitment to make transmission infrastructure available in advance of the windfarm connection, a reduction in infrastructure costs and thus delivering a net consumer benefit.

All these improving coordination of onshore reinforcements and moving towards hybrid projects and ultimately the evolution of offshore grids.

1.3. Use of HVAC and HVDC in the Offshore Wind Industry

a. Overview of HVAC and HVDC Technology

When transmitting electrical power over long distances the higher the voltage the more efficient the process in terms of transmission losses. 400 kV is the highest onshore transmission voltage in the UK so it is expected that the future connection of large offshore windfarms will be done at this voltage. Modern wind turbines generate electricity at voltages up to 66 kV AC and this needs to be stepped up to a higher voltage to transmit if from the offshore substation to the onshore substation. This process can be done using High Voltage Alternating Current (HVAC) or Direct Current (HVDC) technology. A high-level schematic diagram of the both systems is shown in Figure 1 above.

b. Status of Transmission Technologies in UK Offshore Wind Sector

Existing offshore wind farms in GB have to date only used HVAC technology for point-to-point connections to the terrestrial grid for operational projects. The HVAC offshore transmission networks operate at voltages of up to 220kV AC and a maximum power transfer capacity in the range of 400MW-500MW per transmission circuit.[6] HVDC technology is an alternative for the implementation of offshore transmission circuits and will be deployed by the 1200–1400MW Dogger Bank projects that secured Contracts for Difference in 2019.[7]

c. German Offshore Wind Transmission Experience

In Germany about nine different HVDC-connected offshore transmission systems based on voltage source converter (VSC) technology with rated power of up to 900MW per transmission circuit and DC voltage of ±320kV have been installed to transfer bulk power from multiple offshore wind farms to shore. The HVDC transmission system typically consists of an offshore converter platform, HVDC cable and onshore converter station, built by the onshore transmission system owner/operator. Onshore VSC-HVDC stations with rated power of 1400MW and DC voltage of ±525kV are currently under construction in Germany and the UK (for interconnection projects), however there is yet to be an equivalent 1400MW offshore converter platform for offshore wind farms.

2. Grid-access Technologies

2.1. Onshore electrical transmission (400kV HVAC)

The interface of any new offshore transmission infrastructure to the existing National Electricity Transmission System (NETS) will be at an onshore substation. This will consist of a transformer that will step down the grid voltage to a level more manageable for the onshore and offshore cables. This transmission voltage level is currently up to 220 kV for AC system and 320 kV for DC system.

a. Outdoor and Indoor Substations

For HVAC technology, the onshore and offshore AC substations will also contain other equipment needed to ensure that the windfarm can safely and securely connect to the NETS. This includes: switchgear, harmonic filters, dynamic reactive power compensation plant and reactors. For HVDC systems this will also include the DC to AC converter station. The requirement for this extra equipment means that substations utilise more land than is necessary, which subsequently has an impact on planning and the cost of land acquisition. Space saving can be made by using gas-insulated switchgear instead of air-insulated switchgear. Gas insulated switchgear based on sulphur hexafluoride (SF_6) gas as an insulating medium are mature and well understood by industry with innovations in leakage mitigation.[8] This can provide the same switching capability as air-insulted switchgear at a much-reduced size. Alternative gas-insulated switchgear technologies based on clean air and other new gas mixtures are being brought to market by equipment manufacturers for high voltage applications up to 400kV AC and beyond.

b. Hosting Capacity and Maximum Infeed Limit

There is also a limit in the size and rated capacity for the onshore substations of 1800MW. This limit is based on the maximum loss of generation that the NETS can withstand and remain stable in terms of frequency and voltage control performance, as specified in the Security and Quality of Supply Standards (SQSS). Therefore, parallel transmission circuits and substations may be required as a part of the offshore interconnected area for onshore connection points where the offshore wind generation infeed limits may exceed the permissible limits of 1800MW.

c. Cables / Overhead Lines

Onshore substations for large offshore wind farms would be built typically close to power lines or transmission substations operating at up to 400kV AC voltage. This means that the HVAC or HVDC power cables connecting the wind farm need to travel from the inland substations to the coast. This can sometimes be tens of kilometres. This can be done using buried cables or overhead lines. In terms of planning permission, it is easier to install underground cables over long distances as there is little visual impact. Installing underground cables is itself a challenging construction project. It requires a 2m deep trench as wide as a road to be dug along the cable route.

Cables for the onshore route will come in sections up to around 1km so concrete jointing bays need to be built along the route. When the route passes under roads and rivers these may require tunnels to be drilled. Permission and wayleaves also need to be sought from all the landowners along the route. When the cable finally reaches the sea, it will need to be joined to the subsea cable at a transition joint bay. Transitioning from land to sea will require a different cable designed for subsea installation. These subsea cables are laid under the sea bed using special cable storage and handling vessels.

2.2. Offshore electrical transmission

The subsea export cable will terminate at the offshore substation which will contain a transformer to step down the voltage to that used by the wind turbine generators (which is currently up to 66kV AC). There will also be switchgear to distribute the 66kV AC to multiple strings of wind turbines. If HVDC is used there will also be a DC to AC converter station.

a. 220kV HVAC Cables and Offshore Substations

There are trade-offs to the voltage levels and transmission distances that subsea HVAC cables can be used for, without the requirement for additional voltage compensation devices installed at either ends of the cable terminals or at the midpoint. Increasing the transmission voltage from 132kV AC to 220kV AC has allowed distances of circa 100km to be met using compensating reactors at the onshore and offshore substations. Longer distances can be achieved using additional compensation along the cable route. Using HVDC technology allows for much longer cable routes as the capacitive losses in the cable are no longer an issue. The use of HVDC technology requires additional converter stations at the offshore and onshore substations. Due to the cost of the converter stations HVDC connections are usually a single connection. Windfarms using AC systems can transmit over multiple circuits connecting to several offshore substations. This allows for a degree of redundancy as these offshore substations can be connected via offshore AC interlinks.

b. ±320kV VSC-HVDC Offshore Converter Stations and Cables

HVDC systems based on voltage source converter (VSC) technology are suitable for point-to-point connection of remote generation sources such as offshore wind farms. VSC HVDC technology has independent control of real and reactive power with inherent black start capability, hence it can establish an AC voltage with a fixed frequency, amplitude and phase angle to export power generated from an offshore wind farm. The key components of HVDC-connected wind farms are the offshore converter platform, HVDC cable and onshore converter station. Existing schemes for HVDC-connected wind farms operating at a DC voltage of ±320kV DC and rated power of up to 900MW are operational in Germany.

2.3. Interconnectors and Embedded Offshore HVDC links

All GB interconnectors and embedded HVDC links so far employ exclusively onshore converter stations. HVDC technology has seen a very rapid growth in recent years which has come together with the increase of converters and cables power capacity. Currently the largest HVDC mass-impregnated non-draining type paper-insulated cable has a rated DC voltage of ±600kV and over 2000MW active power rating, and has been utilised for conventional line-commutated converter-based HVDC technology.

Also, a ±400kV VSC-HVDC system with cross-linked polyethylene plastic-insulated cable interconnector and rated power of 1000MW recently started commercial operation.
In addition, there are currently interconnectors in different stages of construction at ±525kV VSC-HVDC systems employing paper insulated cables with power ratings in the range of 1400MW.[9 | 10]

The potential for use of extruded plastic cables with HVDC VSC systems also resulted in the fast development of higher-level voltage HVDC extruded cables, with up to ±525kV DC extruded cable systems being qualified by the major cable manufacturers in the last years. Similarly, the evolution of HVDC VSC systems has seen the latest generation of power electronic devices (known as insulated gate bipolar transistors) to increase current capacity enabling HVDC VSC systems beyond 2000MW.

2.4. Integrated Multi-Infeed HVDC Systems

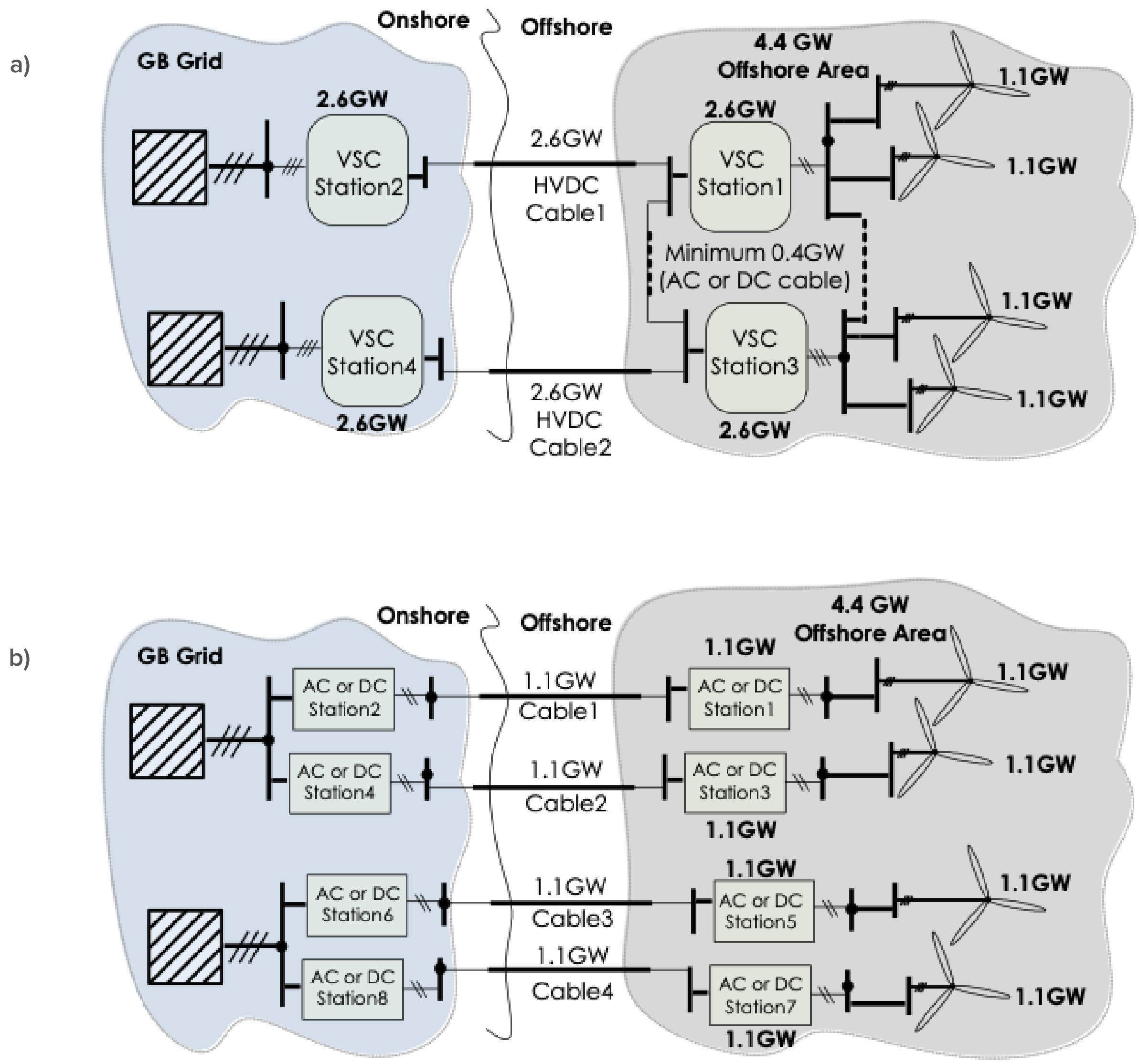
Multi-infeed VSC-HVDC systems can facilitate the integration of offshore wind generation, electricity interconnection and onshore network reinforcement. It is easier to form multi-terminal HVDC systems using VSC technology compared to the classic line-commutated converter HVDC technology. Figure 2(a) illustrates an integrated multi-infeed VSC-HVDC system, which connects a hypothetical 4.4 GW offshore area with four offshore wind farms to an onshore network. In the diagram below (see Figure 2(b)), it is illustrated that about twice the amount of infrastructure would be required for a non-integrated solution, with more limited options for high availability of the offshore transmission infrastructure and a potentially larger impact on the onshore system would result from radial point-to-point systems, where the full capacity of each project would need to be connected to a single point on the onshore system. These impacts and their associated cost benefit will be the subject of further analysis.

Anticipatory spend would be required at the two offshore VSC HVDC stations, two HVDC export cables and two onshore converter stations to enable integrated development of the electricity transmission circuits for connection of the four offshore wind farms (shown in Figure 2(a)) into the onshore network. The anticipatory spend is to oversize key electricity transmission assets that would facilitate multi-terminal extension of the HVDC system to future offshore windfarms, interconnections or planned onshore grid reinforcements. Provided the ultimate direction of network development would result in the full transmission capacity being utilised, this anticipatory investment is expected to result in net consumer benefit.
Also, a standard DC voltage (of ±320kV or ±525kV) can be utilised for design and implementation of the offshore multi-infeed HVDC schemes (see Figure 2(a)), depending on the required power transfer capacity. HVDC integration with multi-terminal option has already been considered by an onshore transmission owner in GB, and implemented into a commissioned project. At present, an existing HVDC scheme in GB has been designed with the option of using a three-terminal system with a maximum power transfer capacity of 1200MW based on the ±320kV VSC-HVDC technology. It is expected that VSC-HVDC schemes with rated DC voltage of ±525kV will achieve power transfer capabilities beyond 1800MW. Standardisation of HVDC design can help to achieve modular solutions and reduce costs associated with project delivery for offshore applications.

Should further resilience of the availability of the integrated HVDC schemes be required, DC circuit breakers are an emerging technology which is actively being developed by industry to facilitate fast and reliable isolation of faulted circuits in meshed DC grids.

> Above and beyond the consumer benefits, the integrated multi-infeed HVDC design can enable solutions involving less offshore and onshore transmission assets (e.g. less cable routes, reduced landing points, reduced locations for substations and options to avoid onshore system reinforcement); therefore it is more scalable to achieving the strategic targets of 40GW offshore wind by 2030.

Figure 2: Offshore transmission design. (a) Integrated Multi-infeed HVDC. (b) Point-to-point HVAC or HVDC option.



3. Enabling Infrastructures

The enabling infrastructures for integration of large offshore wind farms into the AC network are likely to include coastal grid hubs, HVDC hubs and demonstration & innovation hubs.

3.1. Coastal Grid Hubs

At present, developers of offshore wind projects have little option but to plan and build transmission infrastructure that links their individual project to a suitable location – usually a substation – on the existing onshore transmission system. In many cases this involves not just the installation of an offshore platform and subsea export cables, but also considerable amounts of onshore cabling works. Consequently, in some regions local communities and landowners have faced unnecessary disruption resulting from multiple onshore cabling projects traversing the same area.

The development of 'coastal grid hubs' at strategic locations would facilitate the development of offshore wind projects, while avoiding the need for extensive onshore cabling works. Developers would still have to construct radial subsea links from each project to a nearby hub. Hubs would be planned and designed to accommodate multiple generator connections.

a. Onshore Infrastructure and Land Requirements

Each 'coastal grid hub' could comprise:

- A designated area of land near the coast, for construction of (i) a transmission substation with space for future busbar extensions, (ii) incoming overhead line or underground cable connections into this substation, plus (iii) several offshore transmission substations (or HVDC converter stations). The layout and allocation of land within this area would be planned to facilitate HVAC connections (via busbar or cable) between each offshore transmission substation;
- A designated location or area at the coastline, for construction of multiple cable landfalls and transition joint bays; and
- A designated corridor of land linking the substation area and the landfall area, for installation of multiple onshore export cables.

The total land requirement for a hub will be substantial, but presumably less than the status quo for the corresponding amount of capacity. More in-depth scoping and design studies would be required to determine exact requirements and critical dimensions (e.g. width of cable corridor); however, an indicative figure of 100 hectares (i.e. 1km2) for the substation area alone is an initial estimate.

The transmission substation itself should be planned with the following requirements in mind:

- The total generation infeed at the substation is likely to exceed 1800MW and could be well in excess of this figure. In order to comply with SQSS requirements, the substation should be planned to accommodate three or more onshore transmission circuits. Sectionalisation of the 400kV busbar will also be required as and when connected generation exceeds 1800MW; and
- Existing offshore wind farm projects such as Gwynt y Môr and Dudgeon (which both have capacities close to 500MW) have opted for dual connections at the 400kV interface between the offshore transmission asset and the onshore transmission system. This interface arrangement is a sensible 'worst case' planning scenario for future projects with capacities of up to 1800MW. So, if a hub is designed to accommodate five projects in total, there should be enough space for up to ten 400kV 'offshore transmission bays'.

b. Offshore Corridors for Subsea Export Cables

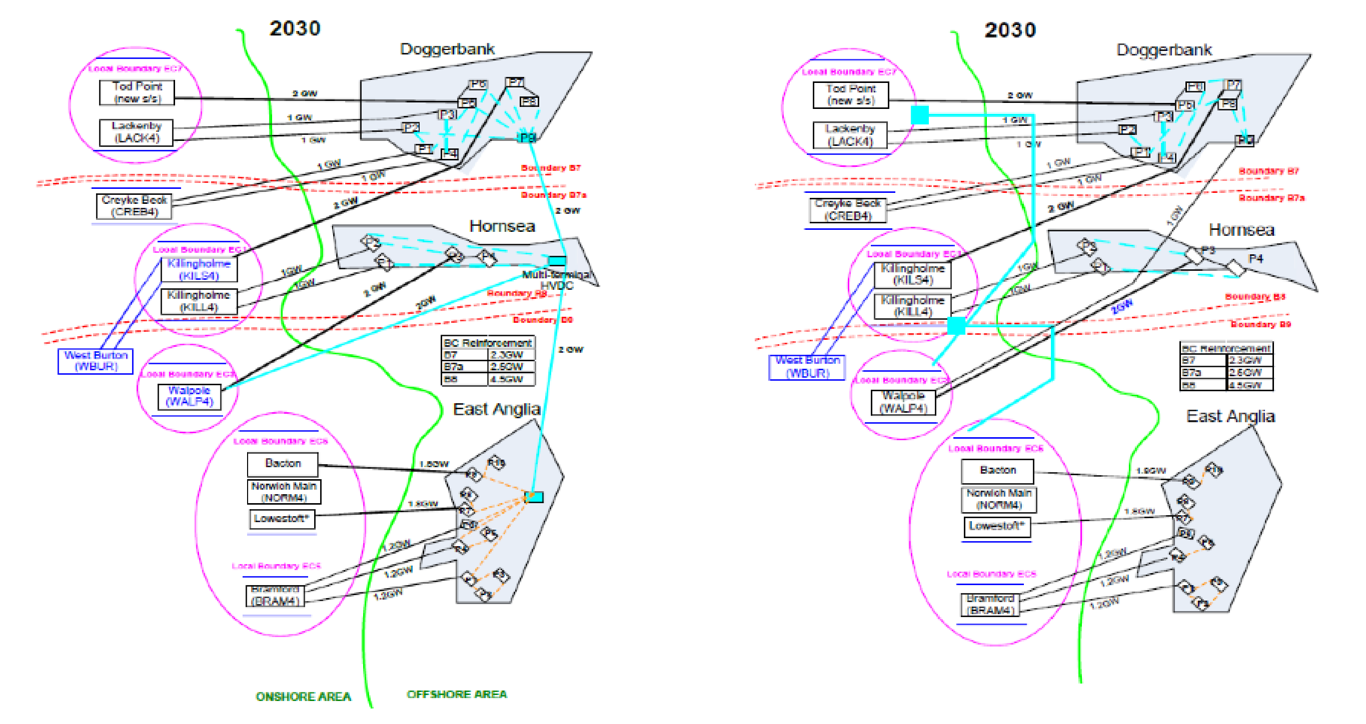
The process of selecting locations for coastal grid hubs must also take account of offshore environmental and engineering factors that would affect the routing and installation of subsea export cables coming in at the designated landfall area. Given the need for this 'strategic assessment' of the offshore environment at the approaches to the landfall, there could be some benefit (to both developers and stakeholders) in designating a 'preferred' offshore corridor (or corridors) for subsea cables in the near-shore zone. This designation would be undertaken in consultation with stakeholders, and all relevant 'baseline' data made public.

3.2. HVDC Link Hubs

a. Offshore Hubs and Interconnectors

There are several operational HVDC interconnectors linking the GB grid to grids in other countries. More HVDC interconnectors are currently in construction, and in planning. These interconnectors generally have bi-directional transfer capacities of between 500MW and 2000MW. There is clearly potential for this infrastructure to be adapted to provide export capacity into the onshore grid for offshore wind projects. The control techniques required for multi-terminal operation of HVDC systems are close to becoming 'market-ready'. Although

Figure 3: 2030 East Coast Network. (a) Integrated offshore design. (b) Coastal Interconnection design (Source: National Grid)



it will not be possible to convert all existing interconnectors to multi-terminal operation, it is likely that many of the newer ones could be converted as part of a control system upgrade. Each of these HVDC schemes could then accommodate the integration of an offshore HVDC converter platform (possibly more than one in some cases), which would act as an offshore hub for one or more offshore wind projects. This hub platform would be located close to the route of the existing subsea cable; some new cable would have to be installed to connect the platform to the existing cables. This strategy would allow for the connection of significant new offshore generation capacity without any substantive onshore works, any new cable landfalls, and with minimal requirements for new subsea cable.

b. Onshore Hubs and Bootstraps

In 2015, National Grid Electricity Transmission completed an Integrated Offshore Transmission Planning Project which examined two offshore design options for the GB 2030 east coast network [11]. These are: (i) offshore integrated design; and (ii) coastal interconnection design. Figure 3(a) illustrates the offshore integrated design with a proposed multi-terminal HVDC system for 2030. Figure 3(b) illustrates the coastal interconnection design for 2030 with two onshore HVDC reinforcements connected via subsea cables. These concepts were based on available technology at the time and can be further refined based on increased capacity of HVDC links now available.

c. Island Hubs with DC Links to Multiple Grids/Markets

The 'North Sea Wind Power Hub' concept [12] has been widely publicised and discussed in the offshore wind sector. This envisages the development of a 'hub and spoke' energy infrastructure to facilitate exploitation of the North Sea's wind energy potential.
A key component of this concept is the 'artificial island hub' [13]. The Dutch TSO, TenneT has been active in developing this idea, and it was considered as one of the options for the proposed HVDC export infrastructure for the 4GW 'Ijmuiden Ver' offshore wind zone. Island hubs have the potential to open up huge areas of sea for offshore wind development, although siting is constrained by water depth – a key driver of cost per hectare. The key elements of an island hub include:

- Electrical transmission infrastructure;
- Port and maintenance base; and
- Airstrip.

The electrical infrastructure would be likely to comprise the following elements:

- HVAC substation with 'incoming' switchgear bays for cables from nearby wind projects, and 'outgoing' bays for HVDC links to onshore grids;
- HVDC converter station, or stations – for links to onshore grids; and
- Incoming HVAC cables and outgoing HVDC cables.

In principle, an island hub could be designed to be extendable, so that new land could be added as required, to accommodate additional incoming and/or outgoing connections. HVDC links from the island could be developed and financed on a merchant basis; power take-off arrangements for wind farm developers would need to be considered to provide predictable project revenues.

3.3. Demonstration and Innovation Hubs

a. System Operability and Compliance Testing

The System Operability Framework (SOF)[14] takes a holistic view of the changing energy landscape to assess the future operation of Britain's electricity networks. The SOF combines insight from the Future Energy Scenarios with a programme of technical assessments to identify medium-term and long-term requirements for operability. These requirements will surely demand code compliance testing, as well as full-scale demonstration projects where new solutions can be brought forward by the offshore power transmission industry. As examples of this it is worth noting demonstration projects with relevant grid integration innovation such as Hywind-Batwind, the European Offshore Wind Deployment Centre (EOWDC), or the Caithness-Moray HVDC link, which has been designed as a multi-terminal HVDC scheme, including a proposed terminal extension to Shetland.

b. Multi-Vendor System Testing Hubs

Multi-vendor compatibility is required for testing the interoperability of electricity network equipment supplied by different manufacturers while preserving the associated intellectual property arrangements. Multi-vendor testing of offshore wind farm components and the associated offshore transmission technologies would ensure reliable operation and avoid adverse interactions with existing control and protection systems on the AC network.
The National HVDC Centre is an Ofgem-funded network innovation competition project, which uses real-time simulation facilities with HVDC replica control and protection systems for supporting the deployment and integration of HVDC schemes into the GB electricity network. The HVDC Centre is led by Scottish Hydro Electric Transmission in collaboration with two Transmission Owners (Scottish Power and National Grid) and the Electricity System Operator.

c. Ongoing Innovation Projects on Offshore Wind Integration

The Offshore Wind Innovation Hub[15] is the UK's primary coordinator for innovation, focusing on offshore wind cost reduction and maximising UK economic impact. The Hub is Funded by the Department for Business, Energy and Industrial Strategy (BEIS) and delivered jointly by the Offshore Renewable Energy (ORE) Catapult and the Knowledge Transfer Network (KTN). Its roadmaps have been built in collaboration with industry and academia and identify priorities and key challenges for offshore wind, as well as relevant innovation projects in each area. The Carbon Trust's Offshore Wind Accelerator (OWA) programme[16] is aimed at reducing the cost of offshore wind, overcoming market barriers, developing industry best practice and triggering the development of new industry standards. The OWA model brings together Carbon Trust's expertise in delivering innovation and convening industry consortiums with the industrial partners' technical knowledge and resources. It is part funded by the Scottish Government with the remaining funding coming from nine offshore wind developers accounting for more than three quarters of the offshore wind power installed in European waters.

4. Summary and Recommendations

Integrated planning of future offshore electricity transmission networks can facilitate efficient, economic and coordinated development of the GB's offshore wind industry to achieve the strategic targets of 40GW offshore wind by 2030 and up to 75GW by 2050, as recommended by the Committee on Climate Change.

This report, by the OWIC's Offshore Transmission Group Technical Solutions work stream, has reviewed both national and international experience across the offshore wind industry, and identifies issues to be analysed to facilitate the grid-connection of GB offshore wind farms using both on HVAC or HVDC technologies.

Whereas the technology challenges for long radial HVAC links are significant and require extensive further investigation, there are credible HVDC technology solutions available today and further development would concentrate on improving the design, maximising value and reducing costs of these alternatives.

It is anticipated that there would need to be an assessment of the value of anticipatory spends on long-term investments in enabling infrastructures and future electricity transmission shared assets including coastal (HVAC) grid hubs; HVDC link hubs and demonstration and innovation hubs. This is because individual incremental developments are unlikely in total to represent an efficient overall solution in comparison to a modular integrated approach based on standardised design.

Furthermore, there needs to be clear and holistic long-term planning of future offshore and associated onshore electricity infrastructure, while key stakeholders continue to stimulate growth in the offshore wind industry through market governance.

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Notes

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