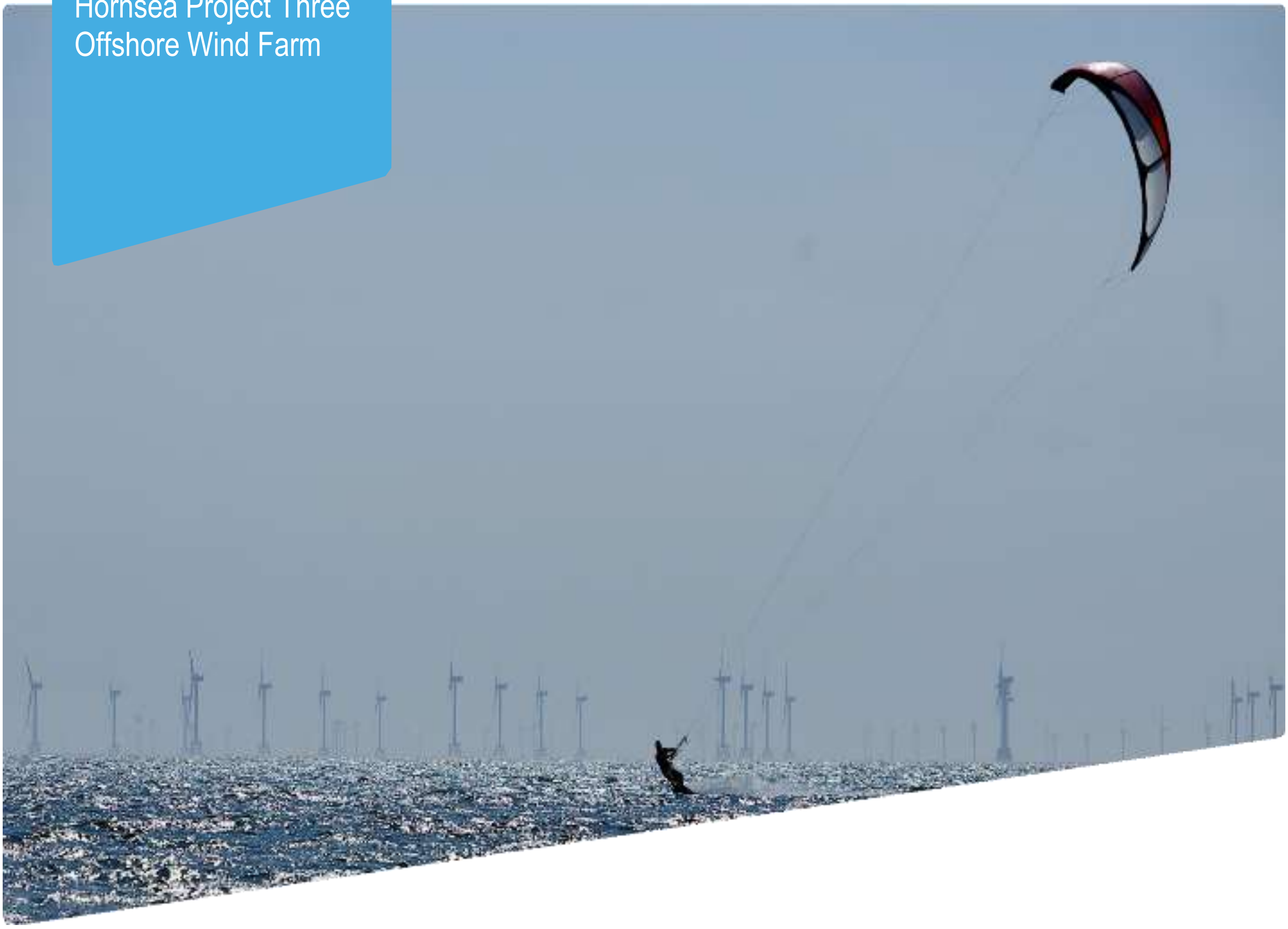
Hornsea Project Three
Offshore Wind Farm



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Appendix 22 to Deadline I submission - Transmission System (HVAC/HVDC) Briefing Note

Date: 7th November 2018

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1. PART 1: Introduction

Background

1.1 Ørsted Hornsea Project Three (UK) Ltd., on behalf of Ørsted Power (UK) Ltd., is promoting the development of the Hornsea Project Three Offshore Wind Farm (hereafter referred to as Hornsea Three). Hornsea Three is a project that will consist of an offshore generating station(s) with a capacity of greater than 100 MW and therefore is a Nationally Significant Infrastructure Project (NSIP), as defined by Section 15(3) of the Planning Act 2008, as amended. As such, there is a requirement to submit an application for a Development Consent Order (DCO) to the Planning Inspectorate (PINS) to be decided by the Secretary of State for Business, Energy and Industrial Strategy.

1.2 Within the DCO application, Hornsea Three has applied for consent to use either High Voltage Alternating Current (HVAC) or High Voltage Direct Current (HVDC) transmission, or a combination of both technologies in separate electrical systems. This is to allow for suitable flexibility to ensure a low cost of energy to the UK consumer and to facilitate successful completion of Hornsea Three in a competitive market.

1.3 This position statement has been prepared in response to Relevant Representations submitted by interested parties as part of the examination process and to provide responses to the ExAs first Written Questions regarding the inclusion of both HVAC and HVDC technologies within the project envelope.

Purpose of this Statement

1.4 This statement is split into three parts.

- **Part 1** sets out a summary of the key relevant representations made on transmission technology and sets out the ExA's first written questions regarding the inclusion of both HVAC and HVDC technologies within the project envelope.
- **Part 2** sets out a summary of the general differences between HVAC and HVDC technology, the use of HVAC and HVDC technology in the offshore wind industry and the reasons why both HVAC and HVDC technology has been included within the Application.
- **Part 3** reviews the maximum design parameters, specific to Hornsea Three, for HVAC and HVDC transmission technology and a comparison of the likely environmental effects arising from the use of HVAC and/or HVDC technology, as they relate to Hornsea Three[1].

2. Transmission Technology Relevant Representations

2.1 A number of Relevant Representations have been made which refer to the inclusion of HVAC and HVDC technologies within the project envelope. They include:-

[1] The Environmental Statement which accompanied the DCO application in May 2018 assessed the effects of the maximum design scenario for each impact assessment, which reflects the Rochdale Envelope approach (Planning Inspectorate's (PINS) Advice Note Nine: Rochdale Envelope (PINS, 2012)). With this approach, the maximum design scenario assessed is therefore the scenario which would give rise to the greatest potential impact and therefore, it can therefore be concluded that the impact (and therefore the effect) will be no greater for any other design scenario than that assessed for the maximum design scenario. Within the Environmental Statement, both HVDC and HVAC have been identified as the maximum design scenario, dependent upon the receptor and impact type in question.

- Sarah Griggs-Smith [RR-001], resides very close to the proposed substation at Mangreen and has made representations relating to views, noise, disruption, road and access and devaluation of property.
- J D Jennings [RR-013], need for HVAC Booster station.
- N2RS [RR-026], made representations regarding Norfolk Vanguard's use of HVDC.
- Norfolk Wildlife Trust [RR-045] that habitat disturbance will be less if DC option is used.
- Mr William Horabin on behalf of Friends of North Norfolk [RR-058], concerns that Hornsea Three has not fully considered or open to the full and proper consideration of HVDC Transmission technology.
- Cllr. Georgina Perry-Warnes [RR-069] Promotion of HVDC transmission system and associated need for an onshore HVAC Booster Station if HVAC is used.
- Edgefield Parish Council [RR-050] visibility of the HVAC Booster Station.
- National Farmers Union and Land Interest Group (various) prompting the use of HVDC technology to reduce land take.
- North Norfolk District Council [RR-133] prompting the use of HVDC technology to reduce land take.

3. Transmission Technology ExA first Written Questions

3.1 The Examining Authority has raised a number of questions around the inclusion of HVAC and HVDC technologies within the project envelope. Table 1 sets out where the Applicant's response to the question is contained in this Position Statement.

Table 1: Examining Authority's First Written Questions referencing transmission technology

Q No.	Relevant Examining Authority's First Written Question		Matter Addressed in Paper
1.1.7	Applicant	The application seeks to use either high voltage alternating current (HVAC) or high voltage direct current (HVDC) transmission, or a combination of the two. The ES states that flexibility is required to ensure a low cost of energy to the UK consumer and to facilitate successful completion of the project in a competitive market [APP-058] (paragraph 3.5.1.5). Relevant representations have pointed out that other projects have committed to HVDC transmission [RR-026, RR-096 amongst others]. A) Please provide an updated justification for retaining this element of design flexibility, given what is now known about the intentions of comparable projects. B) Please provide an assessment of the relative advantages and disadvantages of HVAC and HVDC, including environmental impacts (offshore and onshore), project delivery and implications for compulsory acquisition. C) Please explain how and why HVAC and HVDC might be combined. D) At what point would the choice of transmission technology be made?	A) Part 2 sets out the justification for retaining HVAC in the building envelope and setting out the applicant's comparison of HVAC and HVDC transmission technologies. These factors need to be considered on project by project basis and as such the Applicant is not in a position to comment on the reasons why Norfolk Vanguard has had commercial confidence in HVDC transmission to limit its application. B) Part 3 sets out an assessment of the relative advantages and disadvantages of HVAC and HVDC, including environmental impacts. C) Part 3 details the scenarios where a Combination of HVAC and HVDC may be used. D) The point at which the choice of transmission technology be made, and how this would be made known to members of the public and landowner is set out on Part 2 Overview of the Applicant's Position and Part 3 Point of Choice of Transmission Technology.

Q No.	Relevant Examining Authority's First Written Question		Matter Addressed in Paper
1.1.8	Applicant	Paragraph 3.5.1.5 of the ES [APP-058] states that Hornsea Project Three may use HVAC or HVDC transmission or a combination of both technologies. Please explain how a combination of HVAC and HVDC transmission systems could be achieved without exceeding the maximum parameters used as the basis for the assessments in the ES.	Part 3 details the scenarios where a Combination of HVAC and HVDC may be used.
1.1.9	Applicant	Figure 3.32 in the ES [APP-058] shows an indicative layout for the onshore cable corridor. … What would the corridor width be if HVDC transmission were used? Please provide an indicative layout for HVDC in similar format to Figure 3.32.	… C) The corridor width if HVDC transmission were used is documented in Maximum Design Parameters for HVAC and HVDC technology for the onshore export cable installation" under Part 3. D) An indicative layout for HVDC transmission cables would consistent with Figure 3.36 of Project Description ES Chapter under a design scenario where a HVDC "plus one HVAC circuit" is used which may be required to supply power from the onshore HVDC converter/HVAC substation to the offshore wind farm in some HVDC system designs.
1.8.3	Applicant	Figure 3.37 of the ES [APP-058] provides an illustrative layout/design of the proposed onshore HVDC convertor/HVAC substation. Paragraph 5.8.13 of the Overarching National Policy Statement for Energy (EN-1) states that account should be taken of the desirability of new development making a positive contribution to character and local distinctiveness of the historic environment and that the consideration of design should include scale, height, massing, alignment, materials and use. … What would be the differences in layout and design, along with any difference in effects, between a HVDC convertor and a HVAC substation? What scope is there to refine the parameters of the HVDC convertor/HVAC substation in order to minimise as far as possible any adverse effects upon heritage assets?	Part 3 confirms that the land take required for either the HVDC converter or HVAC substation are the same.
1.9.7	Applicant	The ES [APP-078] assesses the impact upon agricultural land and operations in terms of the maximum design scenario. In comparison with the maximum design scenario, please set out the effects on agricultural land and operations that would result from: the use of high voltage direct current (HVDC) rather than high voltage alternating current (HVAC); …	The effects on agricultural land and operations by way of land take are presented in Part 3.
1.9.8	Applicant	Paragraph 3.7.3.13 of the ES [APP-058] states that the concrete link boxes would be likely to be completely buried. Representations from the Land Interest Group [for example RR-147 and RR-148] have referred to the potential effects of link boxes upon agricultural operations. Would the need for link boxes be affected by the choice of HVAC or HVDC technology? …	The need for link boxes are presented in Part 3.
1.10.6	Applicant	The ES [APP-078] assesses the implications for farm holdings from the construction and operation/maintenance of the development. … How could measures such as... the choice of HVAC/HVDC technology mitigate any economic impacts upon agriculture? …	The effects on agricultural land and operations by way of land take are presented in Part 3.

Q No.	Relevant Examining Authority's First Written Question		Matter Addressed in Paper
1.11.15	Applicant	The ES [APP-079] assesses the potential impacts on traffic and transport on the basis of the maximum design scenario which includes the use of HVAC technology. What would be the main differences for traffic generation during construction between the use of HVAC and HVDC technology?	The effects on traffic generation during construction are presented in Part 3.
1.14.5	Applicant	Paragraphs 5.3.1.4 and 6.2.1.3 of the Statement of Reasons [APP-032] refer to the need (or otherwise) for an onshore booster station at Little Barningham (sheet 9 of the onshore land plans [APP-011]) and paragraph 6.2.1.5 of the Statement of Reasons refers to the maximum permanent land take. … Depending on whether or not the onshore booster station is required, how and when would landowners know the extent of compulsory acquisition of their land and/or interests? … To the extent that there is land that would not be required if there were no onshore booster station, how can the compulsory acquisition of such land be justified given the availability of alternative transmission technology?	Part 3 details when the Applicant anticipates making a decision on whether to use a HVAC or HVDC transmission system and that choice will be made public. Part 2 sets out, the reasons why the Applicant is seeking consent for both HVAC and HVDC transmission systems.
1.14.6	Applicant	Paragraph 5.3.1.5 of the Statement of Reasons [APP-032] refers to the outstanding choice between a HVDC converter station and a HVAC substation close to the existing Norwich Main substation at Mangreen. Paragraph 6.2.2.5 of the Statement of Reasons implies that the area required for the HVDC converter station is less than that required for the HVAC substation. (A) If the HVDC option is selected, what would the extent of compulsory acquisition be? (B) Depending on whether or not the HVDC is selected, how and when would landowners know the extent of compulsory acquisition of their land and/or interests? (C) Would the uncertainty imposed upon the landowners in question be justified and proportionate? To the extent that there is land that would not be required if the HVDC option is selected, how can the compulsory acquisition of such land be justified given the availability of alternative transmission technology?	Part 3 confirms that the land take required for either the HVDC converter or HVAC substation are the same and how the projects will communicate with landowners.
1.14.17	Applicant	Paragraph 1.1.2.2 of the Statement of Reasons [APP-032] states that 'Hornsea Three may use HVAC or HVDC transmission, or could use a combination of both technologies in separate electrical systems'. (A) Please explain how the choice of HVAC, HVDC, or a combination of both technologies in separate electrical systems, would affect how much land would actually be required for the project. …	Part 3 confirms that the land take required for either the HVDC converter or HVAC substation are the same and how the projects will communicate with landowners. Wider CA matters are considered in the response to Q1.14.17.

4. PART 2: Overview of HVAC and HVDC technology

HVAC

4.1 The acronym HVAC stands for high voltage alternating current. HVAC technology is the principle means of power transmission in all modern power systems, including the UK's national transmission grid. The vast majority of all electrical power is generated, transported and consumed as alternating current, where the voltage and current values oscillate over time at a specific frequency (50Hz in the UK, or 50 cycles per second). Transforming alternating current to higher voltages is relatively simple technology with low losses and enables power transmission over longer distances with reduced losses and fewer power lines than low voltage transmission.

4.2 Connection of offshore wind farms via HVAC transmission has been commonplace since the development of the first large scale offshore windfarms. Wind Turbine Generators (WTGs) generate in AC, typically at relatively low voltages. This is stepped up to medium voltage (MVAC) within the turbine itself before being transmitted through array cables to an offshore high voltage substation where it is transformed once again to a still higher voltage for export to shore. The high voltage transmission, from the array to the onshore substation, where the voltage will generally be stepped up once more to the voltage of the onshore HVAC grid. The following image illustrates a typical HVAC offshore transmission system.

4.3 As noted in Volume 1, chapter 3: Project Description of the Environmental Statement [APP-058], long distance, large capacity HVAC transmission systems require reactive compensation equipment to balance the reactive power generated by the capacitance of the export cable in order to allow the power delivered to the National Grid to be useable. The electrical equipment required to provide the reactive compensation, in the form of an HVAC booster station, can be located onshore, on an offshore platform, or within a subsea structure. Alternatively, a combination of these options could be used. Without reactive compensation at some mid-point along the export cable, the reactive power would reduce the cable's capacity to transmit active power to the point that HVAC transmission became unfeasible. The optimal location and rating for this reactive compensation will be determined during detail design (and post consent) once the offshore wind farm and cable design parameters are known.

HVDC

4.4 The acronym HVDC stands for high voltage direct current. HVDC technology is an alternative to HVAC for point-point power transmission and may be appropriate in some circumstances for bulk power transfer over long distances or between different grids (for example, HVDC is typically used for electricity interconnectors between different countries). Because most electricity, including that in an offshore wind farm, is generated as alternating current it is necessary to 'convert' the alternating current to direct current (with constant voltage and current values) and 'invert' the direct current back to alternating current for onward transmission through to connection into the national grid. An illustration of a typical HVDC offshore transmission system follows. Whereas HVAC transmission has been widely utilised in the offshore wind industry, the use of HVDC in the offshore wind industry has been limited to a handful of projects in the German North Sea sector.

Figure 1: Main components of HVAC transmission system with an offshore wind farm

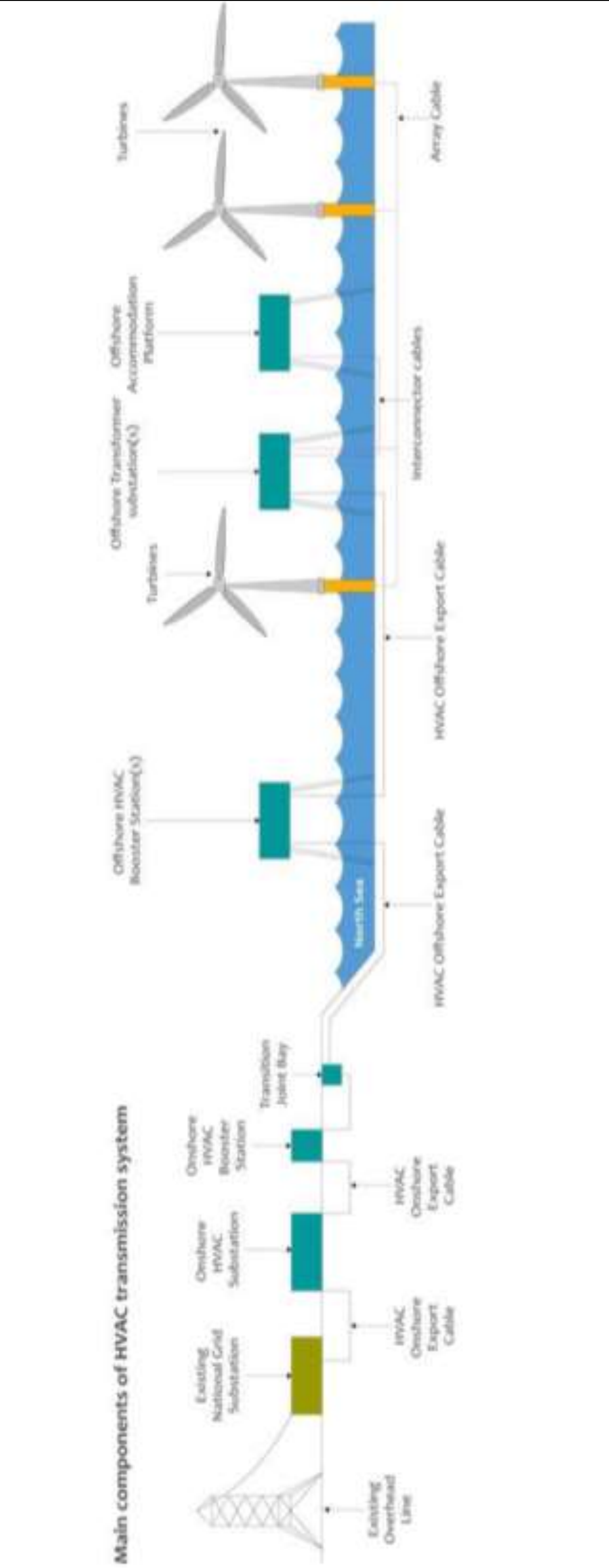
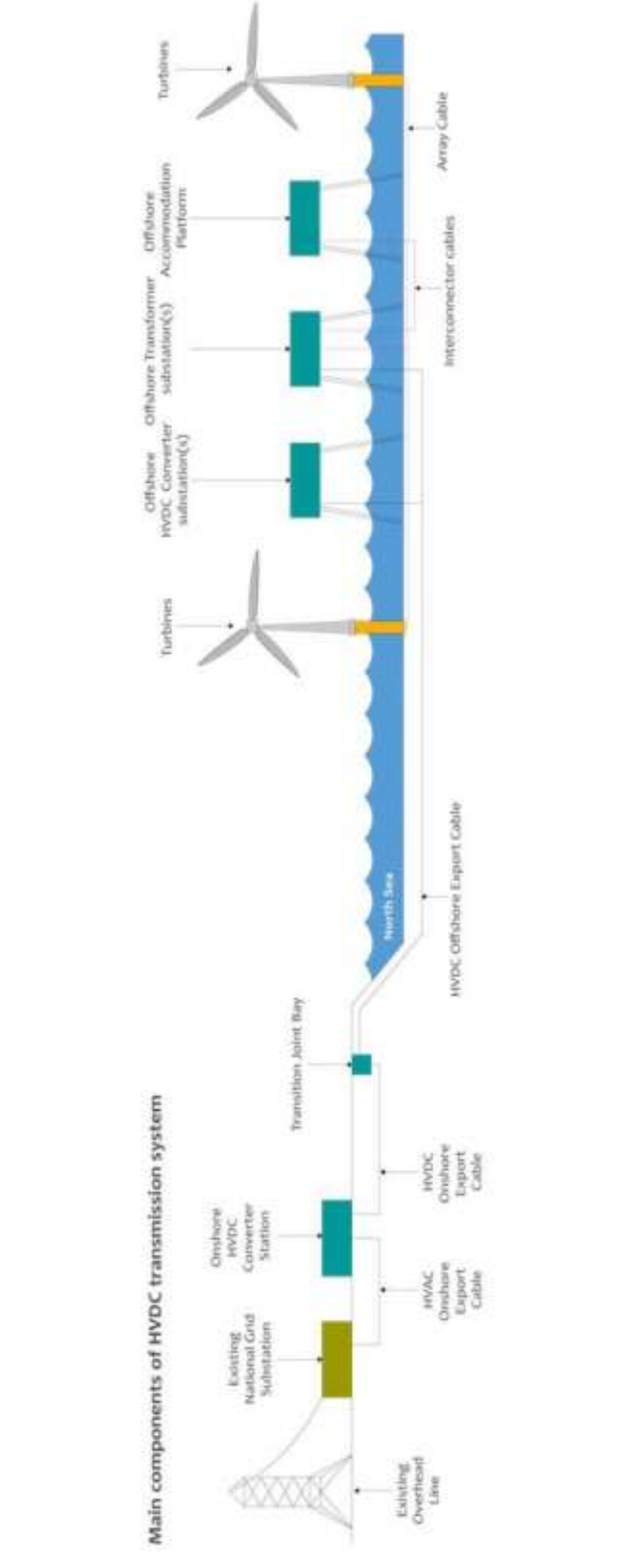


Figure 2: Main components of a HVDC transmission system with an offshore wind farm



5. Overview of the Applicant's Position

5.1 The UK government's stated policy objective[2] is to support the development of a domestic offshore wind industry which delivers renewable energy at a reducing cost to the UK consumer through competitive market mechanisms. The Applicant strongly supports this policy and recognises the value that vigorous competition between offshore developers and within the offshore supply chain brings to the wider industry and to the UK consumer.

5.2 Within the Hornsea offshore wind zone alone, continual development of the supply and offshore construction industry, incentivised by the competitive allocation of price support contracts, has delivered reductions in the cost of energy from £140/MWh for Hornsea Project 1 to £57.50/MWh for Hornsea Project 2 between 2015 and 2017 respectively. These reductions have been facilitated in part by continued optimisation of offshore transmission technologies generally, and HVAC transmission technology specifically.

5.3 Notwithstanding the above, the Applicant does not maintain a technology bias to either HVAC or HVDC transmission systems. Hornsea Three is currently engaged in a detailed technology assessment exercise and is in discussions with key supply chain players to determine the most suitable transmission system for the project which will not conclude prior to the end of the consent examination phase. In order to continue to deliver reductions in the price of offshore wind energy Hornsea Three requires flexibility in the choice of transmission technology. This flexibility encourages competition within the supply chain across a greater number of potential suppliers, and ensures that an economic and efficient transmission system can be delivered within project timescales that reduces the cost to the UK consumer. This in turn can be reflected in any CFD auction bid strategy that the applicant may take forward and volume and pricing levels that are proposed/delivered.

5.4 Remaining conscious of the challenges faced in the German offshore wind industry (documented further below) in respect of the first offshore wind farm HVDC grid connection projects, the Applicant remains confident that the HVDC market will continue to develop and that HVDC will represent a viable technology choice for certain offshore wind farms in the UK in the future. However, it should be recognised that the introduction of any technology to a new market (let alone a maturing technology) is inherently risky and as a responsible developer the Applicant must remain cognisant of these risks to ensure the Hornsea Three is deliverable.

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[2] The Clean Growth Strategy: Leading the way to a low carbon future (HM Government, Oct 2017, updated April 2018)

5.5 The Applicant is aware of offshore wind projects (such as Norfolk Vanguard and Dogger Bank Creyke Beck projects) that have publicly stated a commitment to solely using HVDC technology (and have limited themselves as such in their respective DCO applications). Those projects are in development along similar timescales as the Hornsea Three and may compete in the same auctions process. The Applicant is concerned that the current supply chain does not possess suitable capacity to deliver multiple HVDC transmission systems to numerous developers concurrently, but acknowledges that this may change over time.

5.6 In light of the above, the Applicant is of the view that committing to solely HVDC now in the consented envelope of Hornsea Three could restrict or even prevent the development of Hornsea Three in the future. Thus, in the Applicant's opinion a decision on which transmission system to adopt for Hornsea Three (HVDC or HVAC) should not be made until after extensive engagement with potential systems suppliers has taken place, which is likely to be further informed by future CfD auction allocation announcements (i.e. post consent). The selection of transmission technology is then only expected to be made public when Hornsea Three completes a Final Investment Decision, which is likely to be after a successful CfD auction allocation or after the exploration of alternative funding mechanisms. This public decision point will, however, occur sometime prior to any commencement of works and after the project has entered into major supply contracts for the transmission system.

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

HVAC and HVDC Transmission in the UK Offshore Wind Market

At present, all UK offshore wind farms operating or in construction utilise an HVAC transmission technology.

Table 2 details the status of all offshore wind farms over 400MW[3] and their use of transmission technology.

[3] 400MW threshold identified for ease of presenting the data. All offshore wind farms below 400MW are HVAC.

6.1 Table 2 notes that whilst applications for DCOs have comprised a mix of both transmission technologies, only projects that make use of AC have moved through the development cycle from consented into construction and operation.

Table 2: Status of transmission technology consented, under construction and operational for UK OWF over 400MW

Project (Over 400MW)	Max Capacity (MW)	Status	Technology Type (Originally consented where different / options)
Seagreen Phase One (Alpha & Bravo Projects)	1500	Consented	HVAC / HVDC
Dogger Bank Crekye Beck A	1200	Consented	HVDC
Dogger Bank Crekye Beck B	1200	Consented	HVDC
Dogger Bank Teesside A	1200	Consented	HVDC
Sofia Offshore Wind Farm (Formerly Dogger Bank Teesside B)	1200	Consented	HVDC
East Anglia Three	1200	Consented	HVDC / Low Frequency AC (LFAC)
Moray East	950	CfD Award / FiD	HVAC
Hornsea Project Two	1386	Under Construction	HVAC (HVAC/HVDC)
Hornsea Project One	1218	Under Construction	HVAC (HVAC/HVDC)
Triton Knoll	860	Under Construction	HVAC
Beatrice	588	Under Construction	HVAC
East Anglia ONE	714	Under Construction	HVAC (HVDC)* See notes below
Walney Extension	659	Operational	HVAC
London Array	630	Operational	HVAC
Gwynt Y Mor	576	Operational	HVAC
Race Bank	573	Operational	HVAC
Greater Gabbard	504	Operational	HVAC
Dudgeon	402	Operational	HVAC
Rampion	400	Operational	HVAC

6.2 It is noted that the transmission technology applied at East Anglia ONE offshore wind farm was amended from the initially sought HVDC technology to a deliverable HVAC technology. East Anglia One Offshore Wind farm, submitted to the Planning Inspectorate on 8th November 2012, was subsequently granted consent by the Secretary of State on 16 June 2014 for the construction and operation of a 240 turbine / 1200MW scheme located a minimum of 43km off the Suffolk coast. This serves as good example of why both transmission technologies should be included in the DCO.

6.3 In May 2015, an amendment application was made to construct East Anglia ONE either as a 750MW wind farm with a HVAC transmission system, or a 1200MW HVDC transmission system (as permitted in the original application). That change to provide for an HVAC transmission system also requested a need to increase the height of electrical equipment at the onshore substation from 10m to 15m (although it is noted that the maximum building height of the onshore substation would decrease from 25m to 21m). The Application was made on the grounds that East Anglia ONE had participated in the first Allocation Round of the CfD auction round and was awarded a contract for 714MW capacity project, with the applicant considering that a project of that size would need to connect to the National Grid transmission system through HVAC technology rather than HVDC apparatus.

6.4 The East Anglia ONE change request was considered non-material under paragraph 2(1) of the Schedule 6 of the Planning Act 2008, with the amendment application and associated representations made, focussing on the different environmental impacts associated with the change (in the context of those assessed as part of the original application).

6.5 Whilst the scope of material presented in the East Anglia ONE amendment application focussed on assessing the differences to the project's approved building envelope – the need to include AC technology retrospectively into a secured application reaffirms that the selection of transmission technology deployed is dependent on a range of commercial and design factors, not least the makeup of the final project to be built, which may not be known at the point of application submission. East Anglia THREE then sought consent for both HVDC and Low Frequency AC (LFAC) transmission technology.

6.6 It is acknowledged that some projects to be recently consented, including Dogger Bank Creyke Beck A&B and Dogger Bank Teesside A&B, have had the confidence in HVDC transmission to limit their applications. The Applicant cannot comment on these commercial decisions, but notes that none of these projects have successfully transitioned through to the construction or operation stages at this time.

6.7 The Applicant is not in a position to comment on the reasons why Norfolk Vanguard has had confidence in HVDC transmission to limit its application.

Ørsted's Experience of HVAC Transmission

6.8 As the world's largest offshore wind developer, Ørsted has significant experience developing, consenting, designing, constructing and operating HVAC offshore transmission systems. In the UK alone Ørsted currently operates (or has a financial interest in) 10 offshore wind farms connected to the National Grid via HVAC transmission. Furthermore, the Hornsea Project One and Hornsea Project Two projects (nearing completion of construction and under construction respectively) will represent the first and second longest HVAC subsea transmission systems worldwide demonstrating the efficiency of HVAC transmission over longer distances than previously assumed viable. In both projects, both HVAC and HVDC transmission technologies were consented, assessed, and ultimately HVAC transmission was found to represent the optimal design which would deliver the lowest energy price to the consumer in the UK Government's CfD auctions.

6.9 Ørsted operates offshore wind farms in Denmark which also export power though HVAC transmission cables. The export system for these projects is delivered by the national Transmission System Operator TSO (Energinet.dk) who has so far opted for HVAC transmission as the most suitable transmission technology for projects within Danish waters.

6.10 The Dutch national transmission operator, Tennet, is also delivering HVAC export systems for offshore wind projects which Ørsted is developing in the Netherlands.

6.11 In addition, Ørsted is developing HVAC transmission systems suitable for emerging offshore wind markets globally.

6.12 Aside from developing HVAC transmission systems, Ørsted is involved in numerous UK and international industry panels, working groups and technical bodies working to develop more optimal offshore wind HVAC transmission systems; including:

- The Carbon Trust (UK)
  - Offshore Transformer Modules
  - Optimisation of 50Hz offshore networks
- CIGRE (International)
  - Working Group B1.40 – Offshore Generation Cable Connections
  - Working Group B1.47 - Implementation of long AC HV and EHV cable systems

Ørsted's Experience of HVDC Transmission

6.13 Whilst Ørsted (and all other offshore wind developers worldwide) has not yet delivered a HVDC transmission system for their offshore wind projects, they have keenly observed developments in this emerging market. As noted in previous paragraphs, HVDC has been extensively considered for several of their UK projects before being discounted for technical and economic reasons. Furthermore, Ørsted operates four offshore wind farms in Germany where the local TSO (Tennet) has opted to connect them through HVDC technology. These windfarms currently export power through HVDC transmission systems to the German Grid (further detail on this is set out below).

6.14 Ørsted is actively engaged in industry bodies seeking to mature HVDC offshore transmission systems and commercialise them in new markets. These include:

- The Carbon Trust (UK)
  - Integrated HVDC offshore substations
- NETS SQSS Review Group (UK) - Offshore Infeed Loss Working Group (GSR013)
- Grid Code Review Panel (UK) - GC0101: EU Connection Codes GB Implementation – Mod 2
- PROMOTioN (EU) – Progress on Meshed HVDC Offshore Transmission Networks
- CIGRE (International)
  - Working Group B1.55 - HVDC connection of offshore wind power plants
  - Working Group B1.55 - Guide for the Development of Models for HVDC Converters in a HVDC Grid

The German Offshore Transmission Market

As noted above, Ørsted operates four offshore wind farms in Germany where the local TSO (Tennet) has opted to connect them through HVDC technology. To date, the German North Sea region is the only jurisdiction in which HVDC offshore transmission systems have been developed to connect offshore renewable generation to the onshore grid. Tennet (the local TSO for the North Sea Region) has opted to deliver a majority of HVDC connections to offshore wind farms under their connection remit, whilst three projects are connected via HVAC (Alpha Ventus, Nordergründe and Riffgat projects).

6.15 Table 3 details list of offshore HVDC projects developed in Germany[4].

6.16 Elsewhere in Germany, the Baltic region TSO (50Hz Transmission) has so far delivered two HVAC connections for offshore wind farms within their jurisdiction with several more HVAC offshore transmission connections in construction or in planning[5].

[4] https://www.tennet.eu/index.php?id=2130&L=0
[5] https://www.50hertz.com/en/Grid-Extension/Offshore-projects/Projects

Table 3: Offshore HVDC projects developed in Germany

Project	Capacity (MW)	Commissioning Year	HVDC Manufacturer
In operation			
BorWin1	400	2010	ABB
BorWin2	800	2015	Siemens
DolWin1	800	2015	ABB
DolWin2	916	2016	ABB
HelWin1	576	2015	Siemens
HelWin2	690	2015	Siemens
SylWin1	864	2015	Siemens
In construction			
BorWin3	900	2019	Siemens
DolWin3	900	2018	GE (Formerly Alstom)
DolWin6	900	2023	Siemens

6.17 Whilst Tennet has pioneered the development of HVDC connections for offshore wind farms and is still the only organisation worldwide to have placed orders for offshore HVDC grid connections, the Applicant understands that this has not been without challenges, as may be expected from any nascent technology industry.

6.18 The complexity of HVDC projects, their design interfaces and control systems, coupled with the need to marinise the technology and their capital-intensive nature have led to significant challenges to German offshore wind market participants, HVDC suppliers and to Tennet.

6.19 It has been reported that both main HVDC suppliers have written down significant losses against their first projects with Siemens, the HVDC manufacturer, reported to have booked approximately €800M losses covering cost overruns for their share of the platforms now in operation[6]. Whilst such experiences can be expected when driving forward new technologies, this learning curve must be taken into account when evaluating transmission solutions for Hornsea Three.

[6] https://www.windpoweroffshore.com/article/1331191/siemens-looks-recover-offshore-wind-hvdc-losses

6.20 Beyond cost overruns, the Applicant understands that programme delays have been experienced by offshore wind farms seeking connection to the German grid (including those connecting Ørsted's German portfolio[7]) with delays ranging from several months[8] to several years[9] for the worst affected projects (although it is recognised that these delays are not exclusively due to the selection of grid connection technology). As well as impacting developer and investor confidence, the rules in Germany require that the TSO compensates affected parties for any delays to grid connection. This has led to the introduction of an 'Offshore Liability Levy' on German electricity consumers' bills to cover TSO costs relating to grid connection delays[10].

6.21 Whilst it is expected that, as confidence in and knowledge of the application of HVDC technology offshore grows, the future delivery of HVDC grid connections will face fewer cost overruns and delays, the German experience is illustrative of the risks faced by early movers in new transmission technologies. Is therefore reasonable and proportionate for the Applicant to seek consent for both technologies in respect of Hornsea Three.

7. A Comparison of HVAC and HVDC transmission technologies

7.1 The following section sets out the main differences between HVAC and HVDC transmission as viewed by Ørsted's technical teams applicable at this point in time and has been provided to illustrate the main considerations when selecting either HVAC or HVDC transmission technology.

System Capacity

7.2 The capacity of offshore HVAC cables is currently more limited than HVDC cables where the higher operating voltage and lack of reactive power means that more power can be transmitted on a single export circuit. The largest offshore HVDC grid connection delivered to date transmits up to 916MW per circuit. HVAC cables may operate up to approximately 400-500MW per circuit depending upon voltage, cable design, export route length and installation conditions. When applied to the project envelope for Hornsea Three this leads to a design solution where an HVAC system would require more cables to transmit the same amount of power compared to HVDC systems (position reflected in Part 3 below).

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7 http://www.ewea.org/blog/2013/04/is-german-offshore-wind-under-threat/
8 https://www.windpoweroffshore.com/article/1189654/sylwin-1-converter-platform-delayed-6-months
9 https://www.offshore-stiftung.de/sites/offshorelink.de/files/documents/Offshore_Stiftung_2012-06-14MB_UKGlobalOffshorePresentation_fin.pdf
10 https://www.netztransparenz.de/EnWG/Offshore-Netzumlage/Offshore-Netzumlagen-Uebersicht/Offshore-Haftungsumlage-2018 (Source in German)

7.3 Whilst cable numbers (and cable cost) for HVAC are generally higher, with this comes an increase in the level of modularity of HVAC transmission systems. Offshore HVDC grid connections may be economically viable only for a very large wind farm size (such as Hornsea 3) at or near the effective limits of a given system topology due to the high fixed costs of the converter stations and offshore platforms, meaning that efficient utilisation of the transmission system requires a multi-dimensional optimisation of wind farm size, transmission distance, transmission voltage and converter station and cable capacity. HVAC transmission systems, on the other hand, are inherently modular, more scalable to project capacity and can be more readily optimised to a given project's characteristics.

Transmission Distance

7.4 Typically, HVDC transmission is used for bulk power transmission over very long distances. The high capital cost and complexity of HVDC converter stations makes it an inefficient choice for short distance transmission or for smaller power volumes unless there are overriding system needs which drive it's selection (e.g. between two unsynchronised power grids, or the need to be able to control power flows precisely between grids).

7.5 Over long distances, offshore HVAC transmission systems generate large amounts of reactive power which reduces the cables effective capacity and requires reactive compensation to be installed at either end (as provided for in the Hornsea Three envelope), and over still longer distances establishes a need for an HVAC booster station (either onshore, offshore or both (as provided for in the Hornsea Three envelope)) to enable the cables to transmit useful, active power from the offshore wind farm through to the onshore grid.

7.6 HVDC does not generate reactive power and transmission distance is theoretically unlimited without need for additional compensation (thus not requiring either an offshore or onshore booster station on route).

Technology Maturity

7.7 HVAC has been successfully used for onshore and offshore power transmission for over 100 years. The capabilities and limitations of the technology are well known and understood, and the design of its constituent components has improved over the years to offer ever greater performance, flexibility and reliability.

7.8 Offshore, HVAC technology has been used to connect offshore wind farms since the early 2000s.

7.9 Whilst the Applicant appreciates that HVDC technology has been used since the 1950s[11] and since then has been used widely for power transmission between grids and subsea interconnectors, the design of HVDC systems used for such projects (current source, or HVDC 'classic') is not suitable for use in offshore wind applications. A more recent innovation (voltage source HVDC) is necessary to connect to remote, offshore grids and this has been in use in onshore and interconnector applications since 1999, with the first offshore wind farm connection being commissioned in 2010 (Borwin Alpha). The Applicant understands that Borwin Alpha experienced several years of issue resolution following its initial commissioning[12].

7.10 The Applicant notes that significant diversity has evolved in HVDC system design and that of the supporting balance of plant and offshore platform design. There are less developed national and international standards and guidance governing the HVDC sector; with the main repository of expertise being the HVDC manufacturers themselves.

7.11 The maturity levels of HVDC transmission systems are therefore considered to still be evolving, and lessons are still being learnt from recent projects which will inform future generations of offshore wind farm HVDC connections.

System Complexity & Reliability

7.12 The maturity and relative simplicity of HVAC transmission means that its limitations and failure modes are well understood, and consequently high levels of availability can be achieved for integrated systems. The modularity of HVAC transmission systems means that, for larger projects at least, there are multiple export routes to the onshore grid connection point and therefore the overall system is more resilient to single points of failure which could leave the entire wind farm disconnected for the failure of a single constituent part. Offshore HVAC transmission systems can easily achieve levels of reliability in excess of 98%.

7.13 The requirement to convert power from HVAC to HVDC and vice versa necessitates larger onshore and offshore converter stations containing power electronic switching devices than the substation required for a HVAC transmission system (see Part 3 for building height requirements detailing the differences between HVAC (15m) and HVDC (25m)). These systems are inherently complex, are in addition to traditional HVAC components such as transformers and switchgear, and require advanced control systems to ensure their correct operation.

[11] https://new.abb.com/systems/hvdc/references/the-gotland-hvdc-link
[12] https://www.windpowermonthly.com/article/1349269/politics-block-german-offshore-wind-link

7.14 Reliability statistics for HVDC transmission systems (particularly offshore) are limited given the lack of full lifecycle experience with the technology to date. Some statistics (for example those collated by the international body, CIGRE[13]) are available for a relatively limited dataset of Voltage Source HVDC projects and even fewer offshore (which are still not of the most modern system designs). These statistics are influenced by the 'teething problems' of early projects and therefore exhibit poor levels of reliability compared to equivalent HVAC transmission systems. Whilst it is expected that reliability of HVDC offshore transmission systems will continue to improve over time as more experience in their design and operation is gained, the inherent additional complexity of the HVAC/HVDC conversion (offshore) and then HVDC/HVAC conversion (onshore) process and greater exposure to 'single points of failure' mean that reliability levels are likely to remain below HVAC systems for the foreseeable future.

Supply Chain

7.15 Given the maturity of the HVAC transmission supply market there are numerous suppliers for each system and subset of components, giving a diverse supply chain with vigorous competition which helps to drive market efficiencies. The ubiquity of HVAC transmission in the modern power industry means that scale effects have and continue to drive value and innovation which benefits developers, transmission companies and ultimately consumers.

7.16 Conversely, there are limited suppliers with the technical capability and experience of delivering offshore HVDC transmission systems. In the past this has been limited to two suppliers; ABB and Siemens; and these remain the only manufacturers with fully operational offshore HVDC systems.

7.17 The offshore converter station platforms for HVDC are typically much larger than those for HVAC offshore substations as they need to contain the power electronic devices necessary for power conversion. This limits the number of offshore fabricators with facilities capable of manufacturing such large platforms, and it has been reported that HVDC suppliers have been looking further afield than the traditional European yards to supply such offshore structures[14]. Larger HVAC platforms (as well as large oil & gas installations) may also face similar constraints and compete for the same manufacturing capacity as HVDC projects. It is noted that the maximum offshore platform provided for Hornsea Three have been developed with these larger HVDC offshore structures in mind.

7.18 Consequently, the capacity for these manufacturers to supply multiple projects across diverse markets simultaneously is limited, and the ability to secure a HVDC system in a timely manner could be adversely impacted by wider market forces and a constrained supply/demand balance. In contrast the number of suppliers of HVAC components and systems and the developed market outside of the offshore wind and transmission industries mean that HVAC is less exposed to short term supply constraints.

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[13] A survey of the reliability of HVDC systems throughout the world during 2011 – 2012 (CIGRE Study Committee B4, 2014)
[14] https://www.petrofac.com/en-gb/regions/europe/projects/borwin3-offshore-wind-project/

Manufacturing Lead Times

7.19 The lead time (time from placing an order, to system commissioning and operation) of HVDC transmission systems is longer than for equivalent HVAC transmission systems.

7.20 The inherent modularity of HVAC systems, global supply capacity and maturity of manufacturing methods and techniques allows for relatively swift transition from design to delivered system. Detailed system design can be conducted by numerous parties (including the developer themselves) and outside of a supply contract thereby removing it from a project's critical path and enable parallel design and procurement of separate system components. Typically HVAC export cables represent the longest lead items for HVAC systems, alongside fabrication of offshore substations.

7.21 This flexibility is not as developed for HVDC, whereby detailed system design must be (at present) conducted by the HVDC system supplier and the inherent complexity of the system leads to longer design lead times. The detailed design of the HVDC system must be complete prior to finalising the offshore converter station platform design. The scale of these large HVDC converter platforms and the long fabrication lead time for such structures puts the HVDC system design element on the critical path for project execution and leads to a significantly longer end to end procurement, design and supply lead time than for HVAC systems.

8. The UK Offshore Transmission Policy

8.1 Offshore wind farm export systems (operating at or over 132kV) are classed as offshore transmission networks under UK legislation. This means that only licensed offshore transmission operators (OFTOs) are permitted to own and operate offshore transmission systems.

8.2 UK policy[15] provides for a framework of 'generator build' whereby offshore wind farm developers are entitled to construct their own export system provided it is transferred to a licensed OFTO through a competitive sales process administered by the Regulator (Ofgem). To date, all offshore wind farm transmission connections have been delivered via the generator build mechanism and this is also Ørsted's long standing policy. In opting for this approach, the developer is obligated to ensure that the transmission asset is delivered with due regard to the economy and efficiency of the design and project execution, to ensure that the UK consumer is not exposed to excessive costs.

8.3 As part of this sales process Ofgem will conduct an ex-post assessment of costs for the construction of the offshore transmission system and whether they have been reasonably incurred. Where Ofgem deems that a developer has overspent, costs will be disallowed and will not be recouped as part of the sales process. As such, the developer has both an obligation and strong incentive to ensure that the most economic and efficient transmission system is constructed.

[15] The Electricity (Competitive Tenders for Offshore Transmission Licences) Regulations 2013

8.4 When designing the offshore transmission system for their project, a developer must also consider the OFTO's ability to operate and maintain the asset over the lifetime of the project, and ensure that they can meet their obligations as a licensed operator of offshore transmission, including meeting system reliability targets, which are governed by the wider UK regulatory framework. These third party and regulatory considerations will therefore influence the final transmission system design.

9. Technology Selection

9.1 The choice between HVAC and HVDC transmission technology is influenced by all of the previously outlined factors and each must be considered in the context of the specific characteristics of the individual project. It is not possible to define the most appropriate transmission technology deterministically, based upon 'rules of thumb' and therefore an involved techno-economic optimisation exercise is necessary.

9.2 Key factors which will influence the decision are:

- distance from the grid connection point;
- project generation capacity (MW size);
- cost of system (both transmission and substation installation);
- relative environmental impacts and consent implications;
- predicted system reliability and availability;
- technical characteristics of the HVAC and HVDC transmission system and their ability to comply with local regulations and codes;
- the policy environment supporting offshore wind farm development;
- local (UK) content supply chain objectives;
- project execution schedule; and
- supply chain capacity.

9.3 Due to the complexity and proprietary nature of HVDC systems it is not currently possible for a developer to assess all of the stated factors using internal expertise, or that of consultants, and extensive engagement with the HVDC supply chain is necessary before the transmission system design can be fixed. As noted above, Ørsted is active in this engagement with the HVDC supply chain. However, in order to do so the developer must have foresight as to the scope and timing of the construction of the offshore generation project, which is necessarily influenced by the wider policy environment and competitive allocation of CfDs to the most cost effective offshore wind farm developers.

9.4 Notwithstanding the wider influences outlined above, in purely economic terms, the relative cost of HVDC and HVAC technology comes down to a trade-off between the large, expensive converter stations required at either end of the link for the HVDC system and the reduced number and cost of export cable circuits for the HVDC system compared to the HVAC system. Consequently, larger projects, further from shore may favour HVDC based on purely economic grounds, although recent experience has indicated that the cost breakeven point of HVDC has been moving further and further from shore.

9.5 In certain cases, there may be a clearer decision between HVAC and HVDC technologies based upon the specific characteristics of the project and the commercial strategy of the developer in question. Furthermore, whilst it is, of course, possible to define the transmission technology for a project without having all or most of the necessary information available, to do so increases the risk that the project will not deliver the optimum connection design and may be unable to deliver to within their stated timeline, in accordance with their wider project development strategy and comply with their project consents, wider regulatory frameworks and commercial obligations.

10. PART 3: Maximum design parameters for HVAC and HVDC technology (Specific to Hornsea Three)

Combination of HVAC and HVDC

10.1 Ørsted is seeking the power to construct Hornsea Three either in one or two phases. As the phasing strategy is developed for Hornsea Three, the different phases within the wider Hornsea Three may have different characteristics and therefore lend themselves to having different transmission design solutions. The optimised design for Hornsea Three could therefore be the use of different transmission technologies for each phase.

Point of Choice of Transmission Technology

10.2 There are a number of key project decision points remaining in the project lifecycle of Hornsea Three before the choice of transmission technology will be known or made public. The choice of transmission decision will be informed by how Ørsted will enter Hornsea Three into the CfD allocation rounds and the bid make up of project(s) it wishes to take forward. At the point in time the results of the CfD auction and announced and if a tender(s) are successful this will allow Ørsted team to develop detailed design and be in a position to confirm the transmission technology being taken forward for any successful project.

10.3 It is noted that if unsuccessful in any CfD allocation round Ørsted would at this point explore the reasons and then may look to adjust its tender strategy, bid make up in advance of next CfD allocation rounds or consider other financing options. Under these circumstances the selection of transmission technology may be altered.

10.4 Notwithstanding this, the scope of the Outline Code of Construction Practice (CoCP) [APP-179] has been updated to ensure that, prior to commencement of onshore works, the project notifies parties as to the transmission technology to be taken forward for that phase. The updated text to the Outline CoCP provides for:-

- The Applicant has added the following wording to the Outline CoCP [Revision 1, submitted for Deadline 1] at Appendix A, A.1.1.3, with additional commitment that *"As further detail becomes available during the detailed design, landowners will be regularly updated on key project design parameters. This will include for example, details of the transmission system to be used for Hornsea Three"*;
- Appendix A 'Communication Plan Framework' two bullet points are proposed to be added to A.1.1.3 stating:-

  "Newsletters will be published and distributed to advise of the proposed phasing of the authorised project, the use of HVAC or HVDC transmission system to be used for that phase, land take and period of construction works and the details of the body responsible for carrying out those works. The first newsletter is to be issued at least four months in advance of commencement of works."

  "The Newsletters (or appropriate alternate form such as a letter) will be issued to landowners to advise of the proposed phasing of the authorised project, the use of HVAC or HVDC transmission system to be used for that phase, land take and period of construction works and the details of the body responsible for carrying out those works."

Design Parameters

10.5 This section provides a comparison of the design parameters for each project element, for both HVAC and HVDC technologies. The project elements considered follow the headings used in Volume 1, chapter 3: Project Description of the Environmental Statement [APP-058]. The objective of this section is to clearly identify where the maximum design parameter for each project element was driven by the HVAC parameters, the HVDC parameters, or both technologies (where the parameter value was the same).

Offshore

10.6 The Environmental Statement (volume 1, chapter 3 Project Description) [APP-058] documents the project envelope. Offshore infrastructure required is detailed in Section 3.6 and Table 3.37 details the infrastructure required for HVAC and HVDC systems. Although this information is not reproduced here key references are set out below.

10.7 Table 3.9 details foundation options for turbines and offshore structures and confirms *"Offshore HVDC converter substation(s) are mutually exclusive with HVAC booster station(s) in a single transmission system. Therefore, these two figures should not be combined in the total number. The maximum number of structures within the Hornsea Three array area is therefore 319 (i.e. 300 turbines, three accommodation platforms, 12 offshore transformer substations and four offshore HVDC converter substations)".*

10.8 Table 3.38 details the number of cables required per circuit, which is supported by paragraph 3.6.8.5 which details the makeup of an HVAC and HVDC electrical system. Table 3.44 establishes the maximum design parameters for offshore export cables and Table 3.45 establishes the maximum design parameters for Hornsea Three offshore cable corridor. Unlike onshore parameters detailed below where different parameters can be provided for export cable corridor widths, the width of the offshore cable corridor is set at 1.5km irrespective of transmission technology.

10.9 Rather than an assessment of "land take" the ES worst case assessments of the offshore export cable circuits follows impact parameters, typically derived on a per cable circuit basis. As the maximum number of HVAC cable circuits is six, and the maximum number of HVDC cables is four, each worst case assessment can be scaled by a factor of 2/3rds based on the reduced maximum number of HVDC cable circuits.

Landfall and Onshore

10.10 The following landfall and onshore works are set out by way of a comparison of the maximum design parameters between HVAC and HVDC transmission technologies. Where there is a difference in parameters, the value not reported in the Environmental Statement [APP-058] is highlighted in red.

Landfall

10.11 Table 4, provides a comparison of the maximum design parameters for the landfall should HDD be used for HVAC and HVDC technologies respectively. Table 3.52 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for HDD at landfall.

Table 4: Maximum Design Parameters for HVAC and HVDC technology for the landfall HDD

Parameters	HVAC	HVDC
HDD cable ducts	8*	**6**
Diameter of ducts (m)	1*	1*
Length of ducts (km)	2.5*	2.5*
HDD burial depth maximum (m)	40*	40*
HDD burial depth minimum (m)	5*	5*
HDD exit pits number	8*	**6**
HDD exit pit area – short a HDD (m2)	450*	450*
HDD exit pit area – long a HDD (m2)	900*	900*
HDD exit pit excavated material volume – short a HDD (m3)	1,000*	1,000*

Parameters	HVAC	HVDC
HDD exit pit excavated material volume – long a HDD (m3)	2,500*	2,500*
HDD exit pits depth (m)	3*	3*

*Entries marked with a * indicate that the values represent Maximum Design Parameters identified in the Environmental Statement [APP-058] and the relevant maximum design tables of each technical chapter of the Environmental Statement. In some instances, the values are relevant to one technology only, in others, both technologies are comparable.

[a] A short HDD length equates to an exit pit located approximately 200 m from MHWS and a long HDD length equates to an exit pit located approximately 800 m from MHWS.

10.12 Table 5, provides a comparison of the maximum design parameters for the landfall should open cut be used for HVAC and HVDC technologies respectively.

Table 5: Maximum Design Parameters for HVAC and HVDC technology for the landfall (open cut)

Parameters	HVAC	HVDC
Landfall construction compound (m2)	42,000*	42,000*
Distance between circuits (m)	20*	20*
Burial Depth (m)	1 to 3*	1 to 3*
Intertidal Burial progress rates (m/day)	100*	100*
Corridor Width (per cable, m)	15*	15*
Cobble size for backfilling (mm)	250*	250*

*Entries marked with a * indicate that the values represent Maximum Design Parameters identified in the Environmental Statement [APP-058] and the relevant maximum design tables of each technical chapter of the Environmental Statement. In some instances, the values are relevant to one technology only, in others, both technologies are comparable.

10.13 Table 4 and Table 5 indicate that in respect to the landfall (HDD or open cut), HVDC and HVAC are comparable on all parameters with the exception of the number of HDD cable ducts and HDD exit pits where HVAC is the maximum design scenario.

Onshore Export Cables

10.14 Table 6, provides a comparison of the maximum design parameters for the onshore export cables for HVAC and HVDC technologies respectively. Table 3.55 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for the onshore export cables.

Table 6: Maximum Design Parameters for HVAC and HVDC technology for the onshore export cables

Parameters	HVAC	HVDC
No. of Cable circuits	6*	4 (plus one HVAC circuit)[a]
No. of cables	18*	11
Approximate Hornsea Three onshore cable corridor length (km)[b]	53*	53*
Voltage (kV)	600*	600*
Diameter of cable (mm)	220*	220*
Diameter of duct (mm)	330*	330*

*Entries marked with a * indicate that the values represent Maximum Design Parameters identified in the Environmental Statement [APP-058] and the relevant maximum design tables of each technical chapter of the Environmental Statement. In some instances, the values are relevant to one technology only, in others, both technologies are comparable.

[a] Assuming a maximum of four HVDC circuits plus one HVAC circuit (with three cables) which may be required to supply power from the onshore HVDC converter/HVAC substation to the offshore wind farm in some HVDC system designs.

[b] For the purposes of EIA, the length of the onshore cable route length has been rounded to 55km.

10.15 Table 7provides a comparison of the maximum design parameters for the onshore export cables installation for HVAC and HVDC technologies respectively. Table 3.56 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for the onshore export cable installation.

Table 7: Maximum Design Parameters for HVAC and HVDC technology for the onshore export cable installation

Parameters	HVAC	HVDC
Trench width: at base (m)	1.5*	1.5*
Trench width: at surface (m)	1.5*	1.5*
Corridor width: permanent (m)	60*	**40****
Corridor width: temporary and permanent (m)	80*	**68**** An indicative layout for HVDC transmission cables would consistent with Figure 3.36 of Project Description ES Chapter under a design scenario where a HVDC "plus one HVAC circuit" is used which may be required to supply power from the onshore HVDC converter/HVAC substation to the offshore wind farm in some HVDC system designs.
Corridor area – permanent (m2)[1]	3,200,000*	**2,132,000**

Parameters	HVAC	HVDC
Corridor area – temporary and permanent (m2)[1]	4,300,000*	3,700,000
Burial depth: target (m)	1.2*	1.2*
Burial depth: maximum (m)	2*	2*
Trench: depth of stabilised backfill (m)[a]	1.5*	1.5*
Total Installation duration (months)	30*	30*

* Entries marked with a * indicate that the values represent Maximum Design Parameters identified in the Environmental Statement [APP-058] and the relevant maximum design tables of each technical chapter of the Environmental Statement. In some instances, the values are relevant to one technology only, in others, both technologies are comparable.

** The Temporary and permanent corridor widths are provided not withstanding localised constraints, such as more complex HHD crossing points, where a wider corridor may be required.

[a] The average depth of stabilised backfill will be 0.6 m, with the depth going to 1.5 m in limited locations.

[1] For the purpose of calculating the permanent corridor area, the approximate onshore cable corridor length of 53.3 has been used and then rounded to the nearest ten thousand.

[2] For the purpose of calculating the permanent corridor area, the approximate onshore cable corridor length of 53.3 has been used and then rounded up to the nearest hundred thousand.

10.16 Table 6 and Table 7 indicate that in respect to the onshore cables and associated installation, HVDC and HVAC are comparable on all parameters with the exception of the number of cables which in turn influences the number of cable circuits and the permanent and temporary corridor width, which also then influences the total corridor area (permanent and temporary) where HVAC is the maximum design scenario.

Transition Bays, Joint Bays and Link Boxes

10.17 Table 8, provides a comparison of the maximum design parameters for the transition joint bays (TJB) and landfall works for HVAC and HVDC technologies respectively. Table 3.51 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for the transition joint bays (TJB) and landfall works.

Table 8: Maximum Design Parameters for HVAC and HVDC technology for the transition joint bays

Parameters	HVAC	HVDC
Number of TJBs	6*	4
TJB Depth (m)	6*	6*
Landfall construction compound (m^2)	42,000*	42,000*
Duration of trenching works (per cable) if open cut (weeks)	2*	2*

Parameters	HVAC	HVDC
Duration of works for each HDD (months)	4*	4*
Duration of works (start – finish) (months)	32*	32*
* Entries marked with a * indicate that the values represent Maximum Design Parameters identified in the Environmental Statement [APP-058] and the relevant maximum design tables of each technical chapter of the Environmental Statement. In some instances, the values are relevant to one technology only, in others, both technologies are comparable.		

10.18 Table 9, provides a comparison of the maximum design parameters for the joint bays for HVAC and HVDC technologies respectively. Table 3.57 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for the joint bays.

Table 9: Maximum Design Parameters for HVAC and HVDC technology for the joint bays

Parameters	HVAC	HVDC
Number of JBs	440*	**292**
Max Distance between JBs (on one circuit) (m)	2500*	2500*
Min distance between JBs (on one circuit) (m)[a]	750*	750*
JB width (m)	9*	9*
JB length (m)	25*	25*
JB area (m2)	225*	225*
JB depth (m)	2.5*	2.5*
JBs – Total Area (m^2)	99000*	99000*
Spoil volume per JB (m^3)	563*	563*
JBs total spoil volume	247500*	**164,396**
* Entries marked with a * indicate that the values represent Maximum Design Parameters identified in the Environmental Statement [APP-058] and the relevant maximum design tables of each technical chapter of the Environmental Statement. In some instances, the values are relevant to one technology only, in others, both technologies are comparable. [a] Excluding JBs on either side of trenchless crossings where closer spacing may be required.		

10.19 Table 10, provides a comparison of the maximum design parameters for the link boxes for HVAC and HVDC technologies respectively. Table 3.58 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for the link boxes.

Table 10: Maximum Design Parameters for HVAC and HVDC technology for the link boxes

Parameters	HVAC	HVDC
Number of LBs	440*	**52**
Max distance between LBs (on one circuit) (m)	2500*	2500*
Min distance between LBs (on one circuit) (m) [a]	750*	750*
LB dimensions (length & width) (m)	3*	3*
LB area (m^2)	9*	9*
LB depth (m)	2*	2*
LBs – Total area (m^2)	3,960*	3,960*
Spoil Volume per LB (m^2)	18*	18*
LBs – Total Spoil volume (m^2)	7,920*	**936**
* Entries marked with a * indicate that the values represent Maximum Design Parameters identified in the Environmental Statement [APP-058] and the relevant maximum design tables of each technical chapter of the Environmental Statement. In some instances, the values are relevant to one technology only, in others, both technologies are comparable. [a] Excluding LBs on either side of trenchless crossings where closer spacing may be required.		

10.20 Table 8 – Table 10 indicate that in respect to the transition bays, joint bays and link boxes, HVDC and HVAC are comparable on all parameters with the exception of the total number and spoil number of TJBs, Joint Bays and link boxes, where HVAC is the maximum design scenario.

Field Drainage

10.21 Table 11, provides a comparison of the maximum design parameters for the onshore cable route field drainage for HVAC and HVDC technologies respectively. Table 3.59 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for the onshore cable route field drainage.

Table 11: Maximum Design Parameters for HVAC and HVDC technology for the onshore cable route field drainage

Parameters	HVAC	HVDC
Number of drainage trenches	12	**10**
Pipe diameter (mm)	250*	250*
Trench Width (mm)	500*	500*
Trench depth (mm)	1,200*	1,200*
Stabilised backfill depth (mm)	1,000*	1,000*

Parameters	HVAC	HVDC
* Entries marked with a * indicate that the values represent Maximum Design Parameters identified in the Environmental Statement [APP-058] and the relevant maximum design tables of each technical chapter of the Environmental Statement. In some instances, the values are relevant to one technology only, in others, both technologies are comparable		

10.22 Table 11 indicates that in respect to the field drainage, HVDC and HVAC are comparable on all parameters with the exception of the total number of drainage ditches, which is directly related to the maximum number of cables as set out in Table 6, where HVAC is the maximum design scenario.

Access and Haul Roads

10.23 Table 12, provides a comparison of the maximum design parameters for the access and haul road for HVAC and HVDC technologies respectively. Table 3.60 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for the access and haul road.

Table 12: Maximum Design Parameters for HVAC and HVDC technology for the onshore cable access and haul road

Parameters	HVAC	HVDC
Temporary Haul Road	2*	2*
Roadway Width (m)	6*	6*
Roadway width – passing placed (m)	7*	7*
Roadway construction	Crushed aggregate on geo-textile, soil stabilisation or temporary trackway.*	Crushed aggregate on geo-textile, soil stabilisation or temporary trackway.*
Aggregate depth (m)	1*	1*
Temporary culvert/bridge crossing length (m)	10*	10*
Temporary culvert/bridge crossing width (m)	6*	6*
* Entries marked with a * indicate that the values represent Maximum Design Parameters identified in the Environmental Statement [APP-058] and the relevant maximum design tables of each technical chapter of the Environmental Statement. In some instances, the values are relevant to one technology only, in others, both technologies are comparable		

10.24 Table 12 indicates that in respect to the onshore cable access and the haul road, HVDC and HVAC are comparable on all parameters, thus both technologies represent the maximum design scenario.

Temporary construction compounds

10.25 Table 13, provides a comparison of the maximum design parameters for the temporary construction compounds for HVAC and HVDC technologies respectively.

10.26 Clarification on the number of compounds (main and secondary) as well the duration of the construction compound use is provided, shown in *italics*.

10.27 Table 3.61 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for the temporary construction compounds.

Table 13: Maximum Design Parameters for HVAC and HVDC technology for the temporary construction compounds

Parameters	HVAC	HVDC
Onshore route main compound size (m^2)	40,000*	40,000*
Number of secondary construction compound	*5**	*5**
Number of major HDDs per construction phase	15*	15
Number of total HDDs per construction phase	120*	120
Major HDD compounds (length and width) (m)	70[a]*	70[a]
HDD compound construction duration per compound (month)	1*	1
JB compounds dimensions (length and width) (m)	40 [a]*	40 [a]
JB compounds construction duration per compound (month)	1*	1
Construction compounds dimensions (length and width) (m)	90 [a]*	90 [a]
Construction Compounds: area (m^2)	33,000 [a]*	33,000 [a]
Construction compound use duration per compound (months)	30 [a]*	30 [a]

[a] These values should be considered realistic required dimensions for the proposed works for the purposes of this application for Development Consent, the actual dimensions will be dependent on the location and surrounding environment and may be larger than these values to optimise the use of each specific location.

10.28 Table 13 indicates that in respect to the onshore cable access and haul road, HVDC and HVAC are comparable on all parameters.

HVDC converter/HVAC substation

10.29 Table 14 provides a comparison of the maximum design parameters for the HVDC converter/HVAC substation for HVAC and HVDC technologies. Table 3.63 of the Environmental Statement [APP-058] sets out the overall maximum design parameters for the HVDC converter/HVAC substation.

Table 14: Maximum Design Parameters for HVAC and HVDC technology for the HVDC converter/HVAC substation

Parameters	HVAC	HVDC
Permanent area of site for all infrastructure (m^2)	149,302	149,302
Temporary works area (m^2)	91,000	91,000
Maximum main building height	**15**	25
Height of fire walls (m)	**15**	25
Main building – lightning protection height (m)	**20**	30
Viewing platform height [for construction] (m)	**15**	30
Duration of construction (months)	36	36
Maximum number of main buildings	2	3
Maximum length of main building (m) (if single building/if multiple buildings)	220	220/150
Maximum width of main building (m)	75	75

Grid Connection export cable

10.30 The grid connection export cable, linking the substation to Norwich Main National Grid substation is detailed in Figure 3.36: Grid connection export cable corridor indicative layout of the Environmental Statement [APP-058]. This section of cabling will be similar in design to the onshore export cabling, but must be HVAC at 400 kV, and will have a maximum of four circuits, with a total of 12 export cables, installed within a 60 m cable corridor. These parameters do not change if HVAC or HVDC transmission technology is used connecting the array to the substation.

11. Onshore - Likely environmental effects arising from the use of HVAC and/or HVDC

11.1 In terms of the effects resulting from the use of HVDC and/or HVAC, both transmission systems have a range of relative benefits and drawbacks (as set out in the Environmental Statement, which accompanied the DCO application [APP-055 to APP-171]. Set out below is a high-level summary of the different effects that an HVDC or HVAC system will have for the following project elements below.

Landfall

11.2 The construction of the HVDC transmission option at landfall would not change the assessment conclusions for any of the onshore topics as reported in the Environmental Statement. The number of HDD cable ducts, HDD exit pits and number of cables/cable circuits are the only parameters that are different for the HVDC option, which would not lead to a change in the magnitude of impact. The proposed construction techniques (i.e. HDD or open cut trenching) are the main drivers of the magnitude of impacts and these techniques could be used for either of the transmission options.

11.3 The same mitigation and management measures (as set out in the Outline CoCP (APP-179)) would be implemented for both transmission options such that the conclusions as reported within the Environmental Statement would be unchanged.

Onshore export cable installation

11.4 As the HVDC option would require fewer cable trenches, the temporary and permanent onshore cable corridor would be narrower compared to the HVAC option as assessed in the Environmental Statement and therefore, the overall area of land along the onshore cable corridor would be less. The type of construction activities required for the HVDC option would be the same as for the HVAC option, however there would be fewer transition joint bays, junction boxes, link boxes and drainage trenches along the cable trenches. These different parameters would lead to the following changes in onshore chapters:

- Geology and Ground Conditions (APP-073): there would be a reduction in the area of mineral safeguarded area lost and a reduction in the area of potential disturbance to secondary aquifers, principal aquifers and Source Protection Zones, however the conclusions of the assessment would remain unchanged at negligible to minor adverse.
- Hydrology and Flood Risk (APP-074): there would be a reduction in the area of potential disturbance to drainage infrastructure and field drainage, however the conclusions of the assessment would remain unchanged at minor adverse.
- Ecology and Nature Conservation (APP-075): the majority of the onshore cable corridor is located within arable habitats, however there would be a reduction in the area of habitat loss and disturbance of Norfolk LBAP priority habitats such as arable field margins. Nevertheless, the conclusions of the assessment would remain unchanged a minor adverse.
- Landscape and Visual Impacts (APP-076): the HVDC option along the onshore cable corridor would lead to a smaller area of disturbance of vegetation, however the conclusions of the assessment for landscape and visual receptors would be negligible to moderate adverse.
- Historic Environment (APP-077): there would be a reduction in the width of the onshore cable corridor that would require topsoil and subsoil stripping, which potentially may avoid or reduce damage to buried archaeological remains or reduce the temporary impact on the setting of heritage assets, however the conclusions of the assessment would remain unchanged at negligible to minor adverse.
- Land Use and Recreation (APP-078): there would be a reduction in the area of land taken out of agricultural production and potentially the number of PRoW affected, however the conclusions of the assessment would remain unchanged at minor to moderate adverse.
- Traffic and Transport (APP-079): the change in parameters for the HVDC option may reduce the number of construction traffic movements given the reduced number of cable trenches, jointing bays etc, the conclusions of the assessment of the environmental impacts of traffic would remain unchanged at negligible minor adverse.
- Noise and Vibration (APP-080) and Air Quality (App-081): the reduced number of construction traffic movements may reduce the noise immisions and air emissions from construction traffic, however the conclusions of the assessment would remain unchanged at negligible.
- Socio-economics (APP-082): the conclusions of the assessment would remain unchanged.

Onshore HVAC booster station

11.5 The HVDC transmission option would not require the construction of the onshore HVAC booster station and therefore, the potential impacts associated with the construction and operation and maintenance of this infrastructure would not have to be considered within the assessments of the onshore topics.

Onshore HVDC converter/HVAC substation

11.6 The HVAC transmission option would reduce the height of the main building at the onshore HVDC converter/HVAC substation from 25 m (as assessed in the Environmental Statement) to 15 m. The reduced height of the HVAC substation would result in a slight reduction in the scale and extent of effects on landscape receptors beyond the site due to some reduction in visibility and there would greater potential for localised screening. There would also be a reduction in the potential of some views from settlements, key routes and designated heritage assets, however this would not however be sufficient to change the conclusions of the assessment for Landscape and Visual Impacts (APP-076) and Historic Environment (APP-077).