Offshore coordination project

Stakeholder feedback 29 June – 3 July

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nationalgridESO

Contents

Introduction

The offshore coordination project has been set up to assess the most beneficial approach for consumers and coastal communities to meet the levels of offshore wind that will be required to meet the Government's commitment to net zero carbon emissions in the United Kingdom by 2050. As a first step, we will set out the costs and benefits of different integrated offshore conceptual network designs by October and determine the next steps to unblock barriers to achieving the recommended approaches.

At the end of June 2020, we facilitated a webinar with all interested stakeholders to talk through our findings at our first milestones in the project.

Our project has four workstreams which are outlined below and this feedback document dives into the milestones we have reached in **workstream one and two** as highlighted below:

1) Technology readiness and cost for offshore integration	**2) Offshore conceptual network design, impact on the onshore network and cost benefit analysis**
3) A review of the offshore connections process to encourage more coordination	4) Gap analysis and review of existing work to inform a potential phase 2 scope of work

Following the webinar on 30 June 2020, we also hosted stakeholder workshops to get feedback on the work completed to date and invited stakeholders to provide feedback in writing should they prefer to do so. Stakeholders included representatives from onshore and offshore transmission owners, interconnectors, offshore developers and technology providers.

This document provides the following:

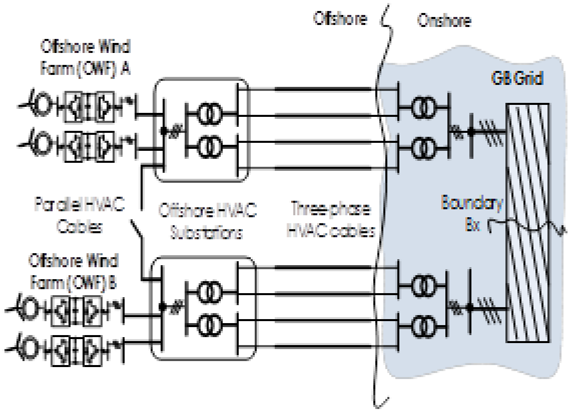
- **Themes** that have emerged from the feedback provided along with what we are doing with that feedback
- **A summary** of the responses we received to the eight questions we sought feedback on and what we are doing with that feedback
- All **question & answers** from the webinar
- **Next steps** - what will we be working on next and when will we be seeking your feedback again

Five clear themes emerged from the feedback received. Many thanks to everyone who has provided feedback on our work to date. We explore these in more detail on the next page.

The main amendments to our thinking following stakeholder feedback are the addition of some non-technical Key Performance Indicators (KPIs) to assess our network designs and the addition of a new design option on integrated high voltage alternating current (HVAC).

1.HVAC integration	**2.SQSS limitations**	**3.Non-technical KPIs**	**4.Technology ambition**	**5.Minimal onshore impact design option**

Table 1: Feedback themes

Theme	Feedback received	What we are doing with the feedback
1.HVAC integration	Stakeholders across a range of sectors including offshore wind developers and OFTOs felt the work is geared towards a high voltage direct current (HVDC) solution and that more work could be done to: • Consider the reliability of HVAC and that this currently works as it has been tried and tested • Consider interim solutions on the journey to the future solution that could use an HVAC solution	There are widely understood design parameters for the onshore transmission system and for the offshore wind developments. To date, offshore windfarms have been constructed with a project specific alternating current (AC) connection with one or more radial circuits. Given the significant step change in offshore wind generation developments that is required by 2050, there is a particular need to consider a range of design options to connect these new developments to the existing transmission system. The newer offshore development zones are more distant from the shore line. Within Great Britain, use of HVAC technology for offshore wind farm connections is approaching its maximum distance at around 200km from shore. Beyond this distance, considerations of infrastructure cost, loss of load cost, and the stability of the solution along the cable, reach an unviable level. These radial connections also normally involve one or more parallel HVAC route between an onshore connection point and an offshore collector platform and may require a further platform along the route for the siting of voltage regulation plant. Conceptual design **Topology T1A (Integrated HVAC),** shown in the figure below, will be used to assess the maximum scale of offshore wind farms (in terms of size and distance from shore) that can be connected using today's HVAC technology.  Our assessment will consider for HVAC technology options: • flexibility to gather power from multiple wind farms, distribute power across parallel routes, and connect together multiple windfarm projects; • limits in terms of the size of power that can be transported and the circuit length;

		• additional equipment required for improved voltage regulation, to facilitate transmission over distances up to 200km, to ensure harmonics do not exceed required limits and for operational control purposes, and • opportunities to extend or integrate design solutions including in combination with other technology options. We will address the feedback received in full as part of the more detailed assessment phase.
2.SQSS limitations	Stakeholders noted that the security standards onshore would currently limit the amount of generation that could be brought onshore at any one point along the coast line.	At this stage of the project, we will ensure that our design options meet the requirements defined in the existing regulatory framework, including the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS). As part of our further work on technology availability, we will identify whether there is further scope for benefits from the design options with different regulatory arrangements.
3.Non-technical Key Performance Indicators	Stakeholders highlighted that the set of key performance indicators (KPIs) presented were well thought out and compiled but that these could not be considered in isolation. They suggested that there should be some non-engineering KPIs that should be considered alongside the technical ones to ensure that the full picture regarding the deliverability of the design options was considered.	Following feedback in this area we have included some broader, non-technical KPIs. These include deliverability of technology solutions (availability of required equipment from manufacturers at required scales) and environmental effects (based on the location of landing points). We will consider all KPIs (Technical and non-Technical) as we further develop our work during the detailed design and CBA stages. We welcome the feedback of stakeholders on both the weighting of our KPIs and the form of our non-technical KPIs which will be further presented in our webinars and reports implementing the conceptual designs within the GB system.
4.Technology ambition	We were encouraged to explore the need to consider the future and not limit innovation in technology through our design options. There is a drive to be ambitious in the technology options considered.	The timespan for the required offshore wind farm developments is large (30 years) and there are likely to be many technological developments across that time. We will be considering how these developments may be harnessed to overcome existing barriers in the next stage of our technology availability workstream. In the next stage of the project we are applying the conceptual designs to the GB system. We are confining ourselves to technologies being actively developed now - those technologies which across vendors are either available today or would be made available in a defined timeframe. This is because at this time only these options may be meaningfully costed and compared across the power system analysis and cost-benefit analysis (CBA) stages that follow, to a clear deployment timeframe. The opportunities to improve upon this starting point are highlighted in our upcoming report on overcoming technology barriers work, which provides a potential framework for focussed innovation to realise further efficiency over time.

		We consider that this approach will allow deliverability to be balanced with future proofing as part of our assessment of options.
5.Minimal onshore impact design option	One of the drivers for this piece of work is the impact on local communities. Stakeholders expressed that the onshore impact should be explored further in a specific design option that would limit the impact on the onshore coastline.	Impact on local communities is one of the KPIs we have defined for the comparative assessment of possible design options that will be carried out at the next stage of this project. As a part of workstream two, within the cost-benefit-analysis we will further consider impact on the local communities as we plan to engage with a range of councils around the country.

Feedback form

Table 2: Questions on the feedback form

Question Unit costs	Summary of Feedback received	What we are doing with the feedback
1: Are you comfortable all relevant assumptions and sources of data are being captured. If not, what others would you recommend/ can you provide?	• HVDC projects considered for costing purposes should also include the most recent GB related schemes as these reflect a range of installation conditions (e.g. weather and environmental) • Have learning rates been considered as it's not clear what assumptions have been used? • Could you gather further feedback and information confidentially to aid this piece of work including on HVAC cost assumptions? • Ensure that this work only covers the technological costs and that it doesn't dive into construction.	We have and continue to monitor new GB related HVDC scheme developments. In particular, the contract value from recent GB HVDC experience has been reflected in our cost model now puts a higher weighting on the UK projects. Updated HVDC cost estimate information will form part of the project report. The actual cost reduction potential (sometimes referred to as "the learning curve effect") is not within scope for this project stage. The 30% reduction by 2050 estimate is based on outputs from an EU research and development detailed study which examined the various cost drivers on the individual component categories, as discussed in our webinar. A comparative cost-benefit-analysis of design options will be carried out at the next stage of this project. For this comparative assessment, construction costs will be treated equally across topologies. Our project report will provide an explanation of the: • assumptions and data sources used for HVAC and HVDC costs, and • cost breakdown (excluding construction) for each main component type. .

2: We will not include LCC HVDC or overhead lines, does it make sense to you? If not, please include your reasoning	Most stakeholders agreed that this was the best approach. Stakeholders asked whether some work could be done to look at HVDC overhead lines (OHL). This would be where the connection substation locations are away from the shore landing point.	As part of our detailed design work, we will carry out power system analysis of region-specific connection solutions within GB that are based on the conceptual designs identified. Results from this analysis will be used to assess each region-specific solution option identified. Whilst technical limits restrict maximum HVAC circuit length (to around 200km from shore), this type of length restriction does not apply to HVDC circuits. Within that context, HVDC solution options could offer more flexibility in terms of the location of the connection to the onshore transmission system. HVDC circuits can be cabled offshore to a: • connection point with the existing onshore transmission system (which may be at a coastline or more inland location), or • location near to the coastline and transmitted via OHL to a connection point with the existing onshore transmission system at a more inland location. Our comparative assessment of options will take account of the KPIs that have been identified Including those associated with environmental considerations. We note in particular that introduction of an overhead line component would introduce additional technical risks (e.g. the management of the impact on the subsea cable of lightning strikes on the overhead line). Additional technical risks would be expected to drive additional infrastructure requirements as part of our conceptual design models and influence views in respect of technology maturity.
3: We will not differentiate between XLPE and MInd HVDC cable, do you agree? If not, please include your reasoning	Some stakeholders agreed that this was a sensible assumption but a few raised concerns around the fact that: • Installation and repair costs are likely to be different. • There are different levels of service experience for each cable type. • The two cable types have different environment risk impacts.	Our actual cost information has been checked by Imperial College [1]as a further reviewer and were found to broadly align with other data sources. The minor differences identified are not considered to be an issue for the CBA comparison of viable network topologies required for this project.
4: We will not include any HVDC cost with rating lower than 900MW, do you agree? If not, please include your reasoning	The majority of stakeholders agreed with this. A couple of points were raised around whether a lower powered link maybe of use and whether a CBA should be used when comparing the use of HVDC and HVAC for wind farms 50km from the shore. The extension of existing equipment was also raised as an opportunity for less waste in the process.	We have used 900MW as: • Most recent offshore wind projects that have DC connections are 900 MW or above • We note that 900MW @+/-320kV has become a quasi-standard rating for offshore HVDC wind connections in the German market

[1] Imperial College are reviewing our work as we work through our key milestones on the project

		• We have not seen extensive application of lower power ratings for HVDC and there is very limited data available • We have also received feedback from cable original equipment manufacturers (OEMs) that the cost difference between 700MW and 900MW HVDC cables is small As the analysis work for this project progresses and if the need arises, we will consider extending the limit down to 700MW.
Conceptual network designs		
1: Are there considerations within our high-level objectives and assumptions that should be refined via a wider framework review? If so which areas should go forward into possible phase two work?	Stakeholders raised: • The SQSS limitations and the fact that the maximum Infeed loss would need to be reviewed to be able to accommodate the levels of offshore wind being connected • The environmental impact of infrastructure onshore needs to be considered further - distant brownfield sites could be used as an example • The Issue of two offshore developers sharing a bipole connection - how would capacity shared in the event of a fault • Ensure that what we are proposing is future proof	At this stage of the project, we will ensure that our design options meet the requirements defined in the existing regulatory framework, including the NETS SQSS. As part of our further work, we will identify barriers within the existing regulatory arrangements and how these have limited the scope of the design options that have been assessed. Environmental impacts of infrastructure, future proofing of solutions and project sharing opportunities will continue to be considered in the detailed design and CBA phases of this work.
2: Are there any conceptual designs not considered at this stage that you would propose- if so what and why?	• A parallel HVAC topology; including the implications of offshore interconnection with existing windfarms • How would a transmission link also be an interconnector and how would the capacity be sized and when necessary shared? • How does this piece of work relate to National Grid Electricity Transmission's RIIO-T2 plan? • AC technology should be considered further • A design option with minimal onshore and environmental impact (smaller footprint and fewer cables)	We have identified seven conceptual designs that have different technology and configuration options. Of these conceptual designs three use HVAC technologies that are available today, and four examine the opportunity of using HVDC technology options that are used in Europe and Asia today. The following is a list of the wide range of conceptual design options that we propose to apply as part of the next stage of our assessment: • HVAC (Integrated HVAC & HVAC at lower frequency) • HVAC combined with HVDC (Integrated HVAC with parallel HVDC) • HVDC (Symmetrical monopole, Bipole HVDC with return cable, multi-ended HVDC & meshed HVDC) Following feedback received from a variety of stakeholders, we also propose to apply a radial HVAC design option (Project Specific HVAC) as part of the next stage of our assessment. We will address the feedback received in full as part of the more detailed assessment phase.

3: What is your view on topology KPIs? Do you view any of these factors as more important than others? If so which?	• Connection to the onshore network and implications need to be considered
	• Should just designs that meet SQSS requirement be progressed?
	• **Broader KPIs** than those compiled should be considered, some suggestions were:
	  • Safety
	  • Economic impact (jobs, UK supply chain)
	  • Future Proof/Flexibility to Extend/Compatibility with other offshore grids
	  • Deliverability (including consent and community acceptance)
	  • Onshore community impact
		As highlighted above, following feedback in this area we will represent broader, non-technical KPIs. These include deliverability of technology solutions (availability of required equipment from manufacturers at required scales) and environmental effects (based on the location of landing points).
		
		We will consider all KPIs (Technical and non-Technical) as we further develop our work during the detailed design and CBA stages. This work may include further refinement of the list of KPIs that have been identified.
		
		Feedback comments will be taken into account as we continue to move through the milestones in the project.

5: How far beyond available project experience should proposed conceptual designs for up to 2030 go; are you aware of any further project or vendor activity that would stretch that envelope?	• It was voiced that the project should look at three horizons - what can be done now and then expanded on in the near future and then further expanded as new technology emerges that is not available today • VSC and cable commercial viability were raised - market places different across China and Europe	The approach that we have followed in our technology availability, barriers and overcoming barriers workstreams is to consider: • what is available; • what will come soon, and • what is yet uncertain but is expected to offer benefits and solve existing issues. Commercial viabilities are not the main determinants for the conceptual designs. For the unit cost collection mainly EU and GB projects were used. For the technology readiness level (TRL) assessment and technology availability global market state is considered.

We also received further feedback on our other workstreams and helpful information that we will use as we move through the milestones and workstreams on the project at the appropriate points.

Questions and answers from 30 June 2020 webinar

We received some questions as part of the webinar on 30 June 2020, the answers to these can be found below:

1.Could you elaborate more on why the HVDC offers "flexible landing via onshore end location selection"? What are the differences there against HVAC connections?

There are a number of considerations in this area. Within GB, HVAC technology is approaching its maximum distance in supporting offshore connection at around 200km. Beyond this distance considerations of infrastructure cost the losses of load cost, and the stability of the solution along the cable reach an unviable level. These radial connections also normally involve one or more parallel HVAC route to an onshore connection point from an offshore collector platform, involving a further platform along the route for the siting of voltage regulation plant. As we discuss across slides 24 and 25 of the slide pack, new offshore development areas across the areas to 2050 are typically more distant from the shore line.

Within these offshore development areas all of the offshore AC collector substation platforms installed would need to be capable of harvesting the entire area of the offshore development zone. These would be spread out within that offshore development zone, as close to the zone's edges facing the coast line as possible, and no further than 200km from the coastline. The green areas shown in the webinar slide 25 describe the available flexibility. Each triangle describes the approximate 200km triangular sweep of geographic area between the offshore AC collector substation and the onshore system. It may be noted from this drawing that not all of the sweeps cross the onshore transmission system, in which case the transmission system may be then needed to be extended to these areas, and others in very limited areas of the existing onshore system may be connected into- which may drive a concentration of connections at these points. This means that the closest geographical areas to offshore zones onshore would be more likely to see most of the HVAC connection activity as these are the circumstances to which the technology is most suited.

Offshore there are equally limitations in the distance that can exist between the offshore AC collection substation platform and the wind farms themselves. Normally offshore connections are made via a lower voltage collection network between wind farms and the offshore AC collection substation platform at which point they connect to the transmission system offshore. the lower voltage collection network will operate at voltages of t 66 kV or lower, meaning there is limited flexibility to extract the potential for wind power within that development zone given its distance from an available AC collection substation platform is limited by losses and other practical factors associated with that lower voltage network.

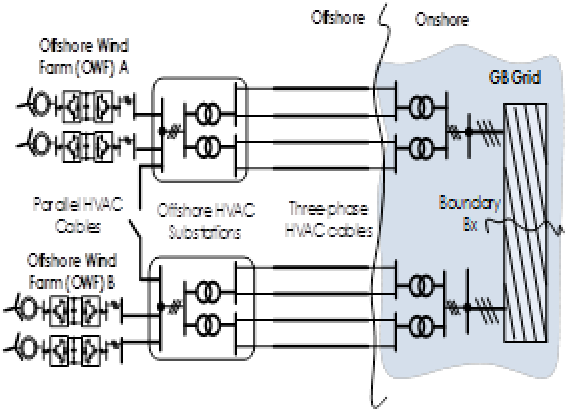
Low Frequency HVAC operates in similar arrangements at a lower frequency – for example 16.5Hz. Whilst this can help with voltage regulation, and other factors contributing to power quality and stability at the same distances, once these distances exceed 400km the same considerations relating to 50hz HVAC management begin to manifest. As such it helps the limitations in flexibility but does not remove them.

In comparison, HVDC solutions do not have limitations on distance of DC route, which is one of the many reasons this technology has been used for HVDC interconnection between within different countries in GB and internationally to augment onshore transmission system capacity. As such the submarine cables to shore may be landed at a greater range of locations and indeed consolidated at these locations. This is because HVDC options benefit from higher capacity individual submarine cables and as such can land greater capacities of offshore wind onto the onshore system with less cable infrastructure Also, the physical spacing associated with the width of cable easement (the legal term for permission to use land) is less when considering comparative scales of AC and HVDC cabling. As such the impacts of consolidated infrastructure at a given location would be lesser in extent via a HVDC approach. We note in comparing HVAC with integrated solutions, the overall number of cables saved can be some 45-55% across the period up to 2050. HVDC solutions do however require an onshore convertor substation at or near the connection point with the onshore system. However, the location of that connection point can be flexibly selected to a location of lower amenity impact. Integrated solutions which minimise the number of offshore cables equally have an effect of reducing the size and numbers of convertors supporting them onshore.

The above discussion describes the physical constraints in comparing technology however there are also underlying technical differences which influence the ease of integration as well which we will expand upon further as the project progresses.

2.Are you not considering conventional interconnected AC offshore? Some less developed sea areas, nearer to shore could be economic as conventional AC.

In response to stakeholder feedback we have created conceptual design **Topology T1A (Integrated HVAC),** shown in the figure below, will be used to assess the maximum scale of offshore wind farms (in terms of size and distance from shore) that can be connected using today's HVAC technology.



Our assessment will consider for HVAC technology options:

- flexibility to gather power from multiple wind farms, distribute power across parallel routes, and connect together multiple windfarm projects;
- limits in terms of the size of power that can be transported and the circuit length;
- additional equipment required for improved voltage regulation, to facilitate transmission over distances up to 200km, to ensure harmonics do not exceed required limits and for operational control purposes, and
- opportunities to extend or integrate design solutions including in combination with other technology options.

Q3. Have any of the Topologies picked up on 'boot straps'?

Topology T6 is specifically applicable to an offshore extension of an onshore transmission system HVDC reinforcement offshore, often referred to as a bootstrap. However, topologies T4-T7 may be utilised within the context of bootstrap integration. In the next stage of the project we will take into account the presence of existing bootstraps and the planned bootstraps as noted within the 2020 ESO Network Options Assessment[2] and transmission works register[3]. We consider both their potential for integration and the various considerations to integration that would need to be addressed in a GB context.

Q4. Please explain why a bipole has higher capacity than a symmetrical monopole.

- Whilst bipole technology has been frequently used onshore, current offshore experience has been in monopole technology deployment. The challenges for a monopole design in capacity terms in comparison to a bipole are: Under the SQSS, the offshore AC island is subject to radial normal infeed loss considerations, which in practice limit an offshore AC development scale to no greater than 1320 MW unless there is more than one connection to shore. Therefore, a dedicated monopole solution may only deliver a 1320 MW maximum capacity to shore under the SQSS, in comparison to a bipole which can be

[2] https://www.nationalgrideso.com/research-publications/network-options-assessment-noa
[3] https://www.nationalgrideso.com/connections/registers-reports-and-guidance

engineered with a fast monopole restoration scheme control and protection approach to deliver a maximum of 2640 MW under the same SQSS consideration. It does so with the added benefit of a reduced number of cables compared to a double monopole arrangement, thereby reducing the required cable corridor width that may otherwise also be a limit or at least restriction to maximum transmittable power.

- For a monopole arrangement, the overall insulation requirements of the power cables and converter valves are higher and as such even if the above point was not fundamental it would continue to show further limitations in comparison.
- The offshore platform top weight for a bipole design can be rationalised given:
  - Each pole can represent a separate platform
  - Improved voltage control reduces plant specification- e.g. DC smoothing reactors
  - Reduced insulation needs reduce space consumed by assets.
  - We note in balance to these points there are other requirements such as commutation switches and convertor transformer design areas which offset these considerations to a degree.
- We note that the onshore consequence of these above considerations can similarly mean that the onshore bipole convertor footprint can also be less than that of the equivalent two monopole convertor arrangement.

Q5. Why not consider the German model of a HVDC radial connection with several windfarms connected to the HVDC 'collector'

This German model is considered in Topology T4, which is set out on slide 18. This allows the connection of multiple wind farms to symmetrical monopole HVDC links connected offshore via HVAC interlinks to improve redundancy. The capacity of the German solution is lower than we will require in GB though. We are assuming large offshore wind clusters which could be split into smaller blocks and connected via AC. We also note that in the German design, whilst AC interconnection is present across monopole HVDC offshore terminal, it is intended principally to support efficient outage operation. Within the context of the GB system, we have identified broader areas of benefit from this interconnection when integrating the offshore solution and in the scaling of this topology across large step changes in offshore development. We will discuss this further as we explore implementation in GB in detail in the next stage of our work. We note that whilst this option exists, in comparison bipole options provide for greater flexibility and capability offshore.

Q6. Will T5 allow connections greater than 1800MW?

Yes. A 2640 MW T5 design capacity is available which continues to meet existing SQSS requirements and offers reduced number of HVDC cables in comparison to two 1320 MW symmetrical monopoles. Such a solution requires a fast monopole restoration solution which facilitates monopole restoration within protection timeframes.

Q7. What about reduction in onshore impacts?

A reduction in onshore impacts is an important driver for all of the options. We appreciate this did not come out clearly in the KPIs and we will be making it clearer along with adding some less technically-focused KPIs for assessing the network options.

Q8. Are other technologies such as MVDC superconductors being considered? It offers the ability of lower voltage levels (100 - 200kV) with higher currents (>40kA)

Alongside the development of conceptual network designs we have extensively investigated the technology options available to realise future offshore installation. Whilst research has been undertaken on superconducting Medium Voltage Direct Current (MVDC) together with some initial trial onshore deployment in both Europe and Asia, our findings have been that this technology has yet to be demonstrated at a scale of capacity and distance within a submarine environment. In principle, if this concept is realisable across the timeframe, its deployment would follow the principles of those HVDC based solutions discussed in T4-T7. The technology itself does not introduce a new conceptual design, rather if available in the future a different approach to delivering the current designs and would need to demonstrate practical benefits in its deployment over those more established technologies.

Q9. When will the CBA workstream be undertaken?

The CBA workstream is underway now. We will be sharing a draft of the CBA for consultation in early September with the final version planned for completion by late October.

Q10. Who will develop the offshore HVDC integrated infrastructure? Will this be the developer responsibility? How will this be coordinated with multiple developers responsible?

This is outside the scope of Phase 1 of the project in which we are just considering the technical aspects and costs and benefits. We are currently scoping a potential second phase and will agree with others such as BEIS and Ofgem whether consideration of this factor is for us or another organisation.

Q11. Has there been any operational experience of HVDC circuit breakers which will be required to make an offshore HVDC gird feasible?

Within Asia DC circuit breakers (DCCBs) up to 500 kV are under commissioning for integrated onshore application, and 200 kV and 160 kV prototypes are in operation. Within the PROMOTioN project[4] further testing and control and protection validation within a European context was conducted. In 2020, EU manufacturers demonstrated DCCB solutions rated up to 350kV DC. Across Europe a range of demonstration projects utilising DCCB are currently under discussion. Whilst there is no current operational experience, such experience will soon become available. Across the time period through to 2050 realising DCCB approaches is entirely feasible.

DCCB delivery is not essential to two of the four forms of integration set out in the conceptual designs. In addition, across regions of GB the need to realise integrated solution may arise at different stages across the 2050 horizon, as technology readiness in this area continues to evolve rapidly.

Q12. What do you believe the relationship of this with current development projects in flight?

It is not the remit of this work to delay or impact projects at advanced stages of development. We note in slide 15 that for projects occurring after 2024 the scope may exist for integrated approaches to be captured in their designs ensuring flexibility to further such extension if it is appropriate. Once a cost-benefit analysis has been completed on the different designs, a view on how to progress the recommended solution(s) will be taken within the scope of BEIS's recently launch Offshore Transmission Network Review[5].

Q13. I've no doubt there will be technological solutions suitable to the nature of developing offshore wind. The key questions are typically economic and regulatory as the current framework would be restrictive to achieving offshore grids. Are these expected to be the main focus of this workstream?

Phase 1 of our project is focused on the technical aspects and costs and benefits of different approaches. We are currently scoping a potential second phase, which will consider whether there is a role for us in removing some of the barriers to achieving a more integrated offshore grid, if that is the recommendation of the CBA. As highlighted above, BEIS, Ofgem and others are also taking work forward in this area which will consider some of these aspects too.

[4] https://www.promotion-offshore.net/
[5] https://www.gov.uk/government/publications/offshore-transmission-network-review

Q14. Outage rates on HVDC links seems to be quite high - is this an issue?

Outages and availability are included in our KPIs that are used to consider the conceptual designs, as they are then applied to the GB system.

Outage rates must be seen within the context of the implemented design capabilities to manage outages (for example Insulated Gate Bipolar Transistor (IGBT) redundancy levels within a convertor may be specified to define an intended reliability). They should also be seen within the context of a varied project specific deployment, the technologies used and varied reporting.

As discussed in our presentation, many of the conceptual designs under discussion include the ability to continue to transmit power via alternative routes if there is an outage, which may act to mitigate the consequence of any individual component outage. These considerations are also a factor within the KPIs we identify.

Q15. The OPEX cost of HVDC systems far exceed HVAC has this been taken into account?

The considerations of opex outages and availability are included in our KPIs used for consideration across the conceptual designs, as they are then applied onto the GB system. From that perspective, a fair comparison with AC for specific applications and within the capabilities of technologies will be made.

Q16. What about an integrated HVAC solution using offshore reactors? Appears very HVDC offshore grid centric which may be the right answer but other options should be considered in further details to ensure this is the case.

HVAC options are included in 4 of the 8 designs discussed - T1, T2, T3 and the new T1A design. There are however some limitations. Their integration capability is limited by distance, capacity and power management capability. It is worth noting that offshore reactors are only part of the challenge involved in long HVAC solutions; they address steady state voltage regulation only. In the National HVDC Centre's webinar on small signal stability, other related factors limiting offshore AC scale are set out[6]. These factors remain in low frequency HVAC solutions also. As discussed in the earlier response, HVAC options are very much an available conceptual design and may be appropriate in specific limited contexts for the scale of overall development going forward, and this will be considered further in our detailed design scope. But equally we would like to manage expectations that this solution is not technically capable by itself of meeting the scale of development required. We do not yet see a persuasive case for a "one-size fits all" solution for all future GB offshore capacity, from any single technology, or any one conceptual design option and continue to investigate a range.

Q17. Validation slide - the top right plot (converter & platform). That's for both onshore and offshore?

Yes, the cost data covers both onshore and offshore converter stations plus the platform, and in almost all the German projects we have investigated, those items were grouped under one package**.**

Q18. In the charts is it time on the horizontal axis?

The horizontal axis is the individual offshore wind HVDC projects sorted by contracting year.

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[6] https://www.hvdccentre.com/2020/02/hvdc-centre-and-strathclyde-university-host-webcast-on-stability-assessment-of-converter-interactions/.0

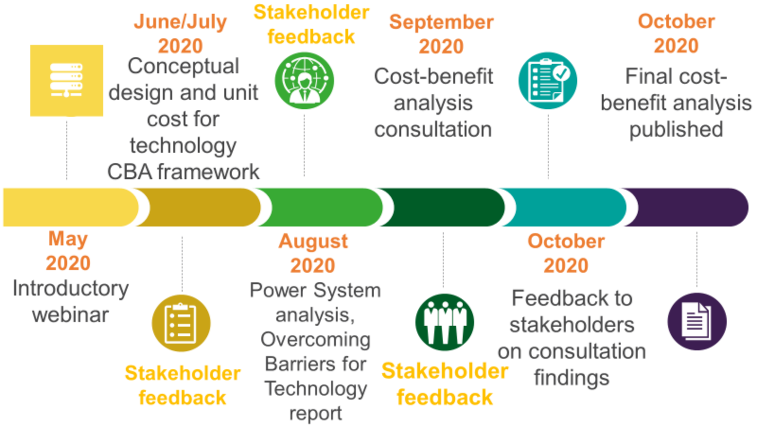
Next steps and acronym table

Ahead of the next engagement we have planned for w/c 3 August 2020 we will be:

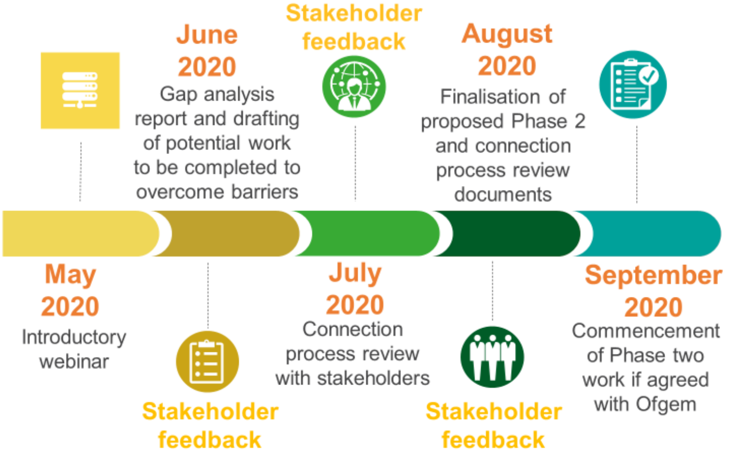
- developing the conceptual designs into a Great Britain view
- finalising the technology availability report including assessing the barriers and how they can be overcome
- gathering information on the connection process and barriers to a more coordinated approach

We are also currently getting ready for the next engagement sessions we have planned for week commencing 3 August 2020. Further Information around the plans can be found on our website at the following link, the timelines below provide an overview of our key milestones. If you have any questions, comments or feedback on the project or our engagement please get in touch with us by emailing us at christine.brown1@nationalgrideso.com.

Technical and cost-benefit-analysis workstreams



Connection and potential phase two workstreams



Acronym table

Acronym	Meaning
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
DC	Direct Current
IGBT	Insulated Gate Bipolar Transistor
OFTO	Offshore Transmission Owner
TRL	Technology Readiness Level
KPI	Key Performance Indictor
CBA	Cost-Benefit-Analysis
NETS SQSS	National Electricity Transmission System Security and Quality of Supply Standard
MInd cable	Mass-Impregnated non-draining (direct current submarine cable)
XLPE cable	Extruded cross-linked polyethylene (direct current submarine cable)
BEIS	Department for Business, Energy & Industrial Strategy
DCCBs	Direct Current Circuit Breakers
MVDC	Medium Voltage Direct Current
LCC	Line-Commutated Converters
OHL	Overhead line

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