OFFSHORE WIND

CABLE ROUTEING CONSIDERATIONS AND CONSTRAINTS FOR DEVELOPERS

ABSTRACT

The development of windfarms means that it is necessary to understand some of the key considerations and constraints associated with the installation and maintenance operations of offshore windfarm (OWF) export and inter-array cables. Whilst this paper was inspired by offshore wind developments off the east coast of the US, the principles outlined herein are applicable to the industry as a whole. The aims of this paper are to provide the prospective developer with an awareness of these considerations and constraints when engineering the cable routes for a newly proposed offshore windfarm installation. The main focus is on the routeing of the cables, to facilitate safe access to the site for construction and maintenance operations over the windfarm's operational lifespan.

Recognizing industry best practice, this paper references recommendations cited in The Crown Estate (TCE) published Red Penguin Associates Ltd 2012 document, *Submarine Cables and Offshore Energy Installations – Proximity Study Report*.

General recommendations on the separation between export cables are discussed, including the use of shallow drafted vessels for shore end operations and the potential for anchor placement zones which may be required if anchors are used for position keeping.

Further considerations around crossings and crossing design with existing cable assets are also explored. Here, the option of implementing mutualised crossings is reviewed to minimise potential conflict with existing seabed users, making reference to ESCA's (European Subsea Cables Association) 2016 guideline, *Guideline No.6 – The Proximity of Offshore Renewables Energy Installations & Submarine Cable Infrastructure in UK Waters*.

Setback calculations of export cables in proximity to existing seabed infrastructure, focussing in particular on wind turbine generators, are then illustrated. The significance of using DP 1 and DP 2 class construction vessels and how this may impact installation and maintenance operations is also assessed.

Finally, a short discussion explores the future of offshore wind, focussing on floating windfarm installations and the potential adoption of HVDC cables.

As members of ICPC and ESCA, OceanIQ as part of Global Marine Group has contributed to industry guidance documents on this subject and has been involved in the engineering of numerous offshore wind cables, both export and inter-array.

1.0 CONSIDERATIONS AND CONSTRAINTS

The considerations and constraints for offshore windfarm cables are in many ways the same as for other linear seabed infrastructure. This includes most of the topics covered by cable route Desk Top Studies shown in table 1.

TOPIC	DETAIL
1. Geohazards	Geological faults, slope instability, mobile bedforms, pockmarks, seabed types
2. Anthropogenic Factors	Other marine stakeholders and their activities such as fishing, maritime traffic and risks from anchors, military activities, aggregate extraction, recreational activities, other cables and pipelines, and existing offshore renewable energy developments
3. Environmental Factors	Marine protected areas and their associated restrictions
4. Archaeological Factors	Archaeologically significant marine protected sites
5. Unexploded Ordnance	Avoidance and/or removal of munitions found near cable routes

Table 1: Common cable route considerations and constraints

How we adapt to the resulting influences generated by these common topics has been covered over many years of published guidance and papers and we don't intend to cover those in this paper.

This paper provides an overview of some of the key considerations and constraints during the cable route engineering phase of a newly proposed offshore windfarm installation not covered in table 1. This includes:

- General separation recommendations between export cables
- Crossings of the export and inter-array cables with existing submarine cables and the crossing design at each point, including the potential for mutualised crossings
- The proximity of the proposed cables to existing infrastructure in order to facilitate safe, future maintenance and recovery operations
- Possible future trends in offshore wind and how separation recommendations may need to evolve

1.1 Cable Separation Recommendations

The minimum separation distance adopted between export cables is driven mainly by the ability to repair the cable post-installation. It is normal to adopt cable routes which will allow for a repair at all points along the route which does not then compromise the condition of neighbouring cables. In practical terms this means the ability to lay out the repaired section of cable onto the seabed without it crossing adjacent cables and to allow for re-burial or protection by other means should it be a requirement.

When a marine repair operation for an export cable takes place in most cases it will necessitate two joints. After the second of these joints has been made, a repair bight (sometimes described as an omega) would normally be laid on the seabed. This will be deployed by the installation vessel to one side of the original cable route. The maximum horizontal offset of this bight is a function of the water depth at the location of the repair site and the physical characteristics of the cable repair vessel. Prevailing weather conditions at the time of the laydown operation and the local seabed characteristics must also be considered as this can influence how the cable repair vessel will set up for the repair. The dimensions and further detail of the rationale presented here can be found in recommendations cited in The Crown Estate (TCE) 2012 published Red Penguin Associates Ltd document, *'Submarine Cables and Offshore Energy Installations – Proximity Study Report'*.

The key vessel dimensions to take into consideration when judging how far the bight will be offset from the original cable line are illustrated in Figure 1 below.

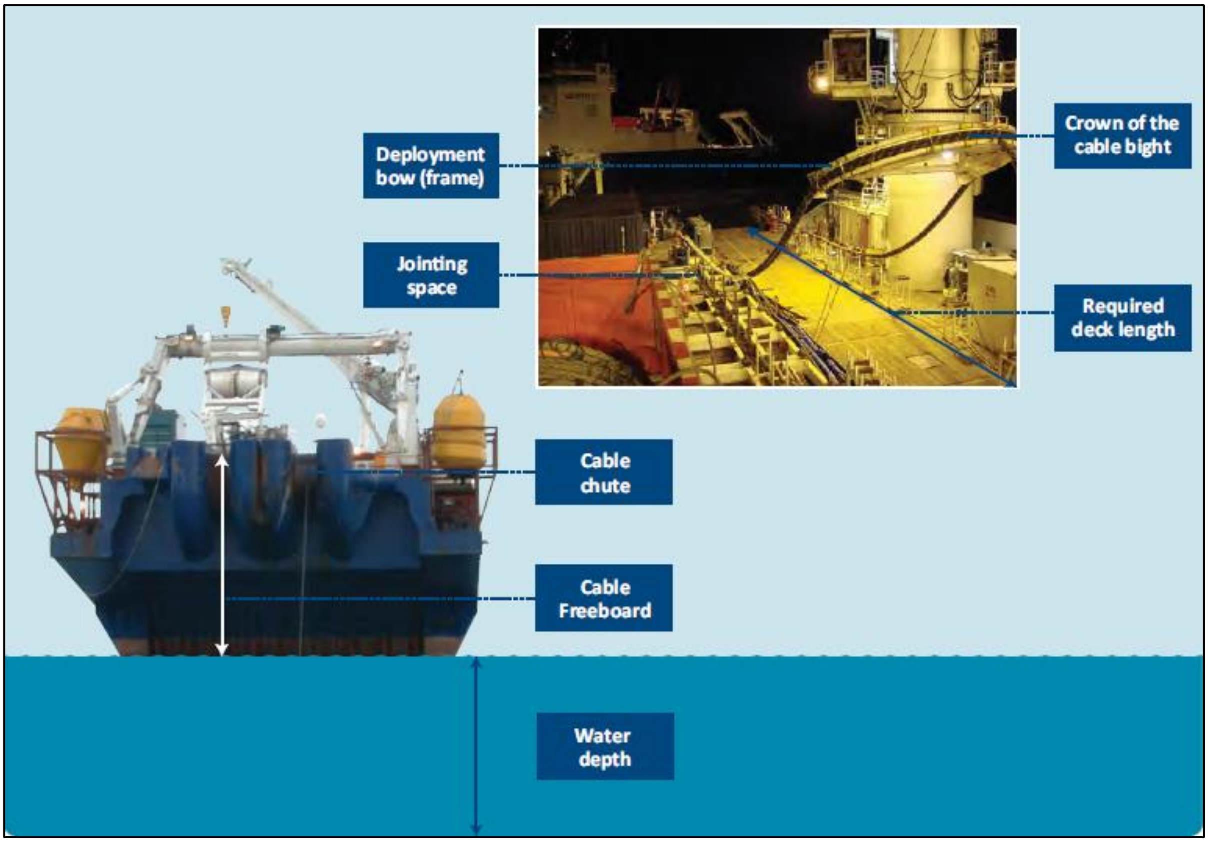


Figure 1: Dimensions and terms relating to cable repair bights (Red Penguin Associates Ltd, 2012)

There are four dimensions which make up the repair bight length. These are the depth of water, the freeboard distance from the water surface to the cable chute, the deck length from the cable chute to the jointing space, and the crown of the cable bight. Additional space adjacent to the repair bight is also advised to allow for future access to the repaired section of cable. A base case assessment of the seabed space required to lay down a repair bight in accordance with the *'Submarine Cables and Offshore Energy Installations – Proximity Study Report'* (TCE, 2012) is shown in Table 2. A water depth of 50m was assumed as this is approximately the current limit in which fixed WTG foundations can be installed.

OWF export cables by necessity need to make landfall. The section of the cable taken ashore from the closest approach of the main lay vessel is called the shore end. In the event the floated section of a shore end pull in is beyond the practical distances a cable line can be managed, the shore end can be sometimes laid by a shallower drafted vessel. Alternatively, a shallower drafted vessel may install all the export cable, especially if most of the route is shallow water.

BIGHT DISPLACEMENT	DISTANCE (m)
Water depth =	50
Freeboard =	5
Repair bight crown =	5
Deck length =	45
Repair bight offset =	105
With 50m future access space =	**155**

Table 2: Repair bight length calculations

Shallow drafted barges can have dynamic positioning systems, but there are many which use multi-point anchor systems for position keeping during cable installation or repair operations.

When such a solution is used consideration needs to be given to where the anchors can be placed, especially when multiple export cable routes are being designed. Depending on the number of cables, anchor positioned installation vessels can require a central anchor placement zone solution. This can help mitigate the risks posed by having anchors and their lines deployed over other adjacent export cables during cable installation and any future maintenance operations. In a situation where 4 export cable routes are being designed an anchor placement zone can be created by moving the two innermost cables closer to the outer two, thus creating two cable "pairs" with reduced separation between each. A repair bight may still be laid on one side of each cable pair. This solution is illustrated in Figure 2. The cable pairs could still retain a separation distance which allows for a repair bight on both sides, but this will require a wider overall cable corridor and therefore larger marine survey coverage.

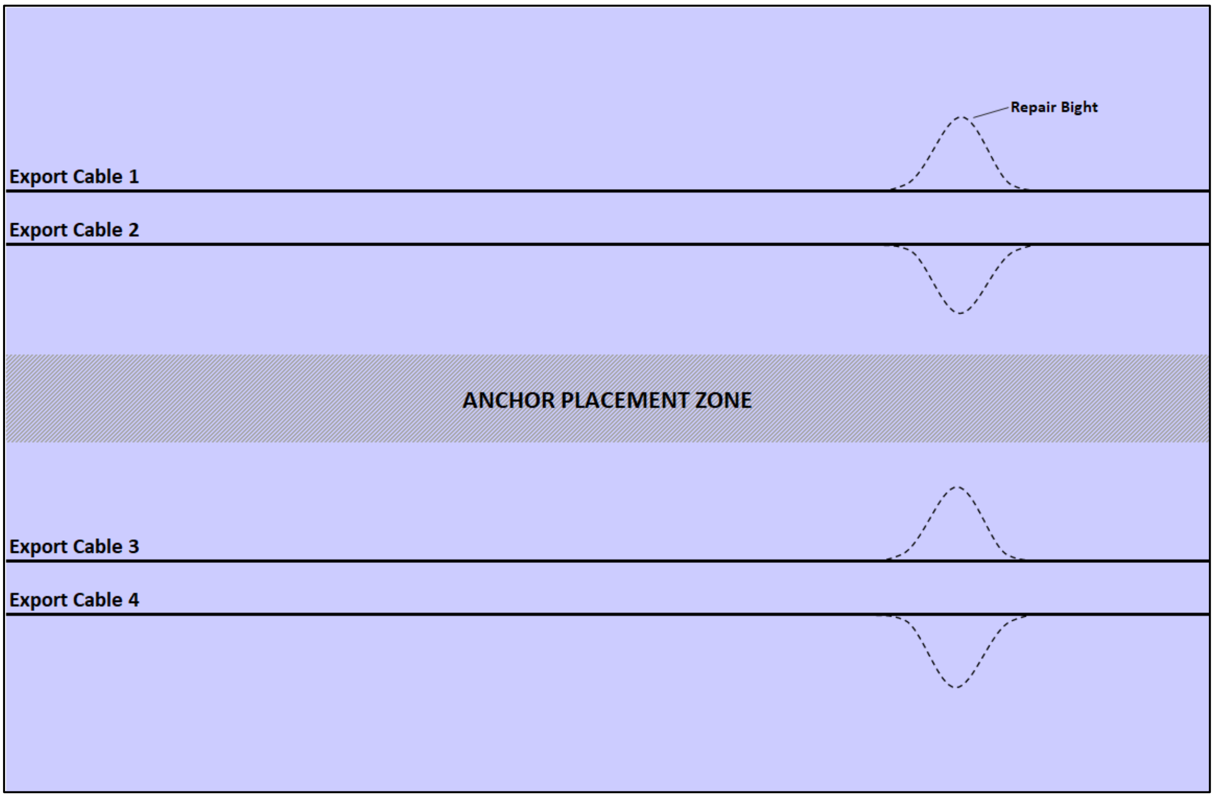


Figure 2: Anchor solution for two export cable pairs

The adoption of an anchor vessel solution is one of several factors which may inform the width of the marine survey corridor. Other considerations include the number of export cables as well as the maximum water depths at the windfarm site, as this will drive the offset from the installed cable line of the repair bight omega as previously discussed. Additionally, differing amounts of space across the corridor may also be required due to the variance in HVDC and HVAC cable configurations. Planning ahead of time taking account of all possible scenarios will assist in determining the initial survey corridor width.

Within the defined survey corridor, bedforms or other obstructions may be present which require microrouteing of the cable routes. Table 3 below shows five ways in which the routes may be altered to avoid or reduce interactions with such obstructions.

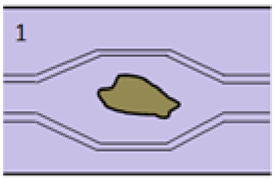
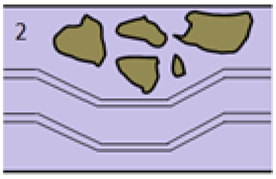
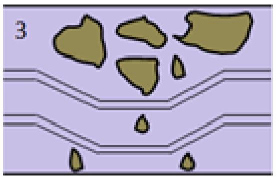
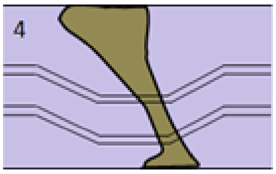
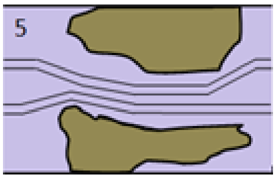
SCENARIO	DETAIL
	Two route pairs diverge around the obstruction in the centre of the corridor where there is sufficient space. The obstruction may prevent anchors being placed in the anchor placement zone but over a short distance or with a DP vessel this may not impinge on installation.
	Two route pairs diverge around the obstruction areas to the north of the corridor where there is sufficient space to accommodate all the cables. The obstruction may prevent anchors being placed to the north of the cables but over a short distance – or using DP vessel capabilities – this may not impinge on installation.
	Two route pairs avoid a main obstruction area in the north of the corridor and smaller areas in the central and southern part of the corridor. Sufficient space remains to accommodate the cables. A wider scattering of obstructions may complicate or prevent anchor deployment over this section. A larger field of obstructions may result in a DP vessel being the only solution.
	The obstruction extends across the entire survey corridor but narrows on the southern side. Two route pairs avoid the wider northern obstruction area and cross at its narrowest point in the corridor. There is no resulting impingement on installation.
	A continuous but relatively narrow gap exists between two large obstruction areas. Two route pairs avoid these but lose the majority of the anchor placement zone. This may complicate or prevent anchors being used over this section. A larger field of obstructions may result in a DP vessel being the only solution.
Legend Cable Corridor Obstruction Cable Route	

Table 3: Options for hypothetical microrouteing of export cables

1.2 Proximity Guidelines

This section provides proximity guidelines and setback calculations in relation to subsea infrastructure such as wind turbine generators (WTGs). As set out in The Crown Estate published Red Penguin Associates Ltd 2012 document, *Submarine Cables and Offshore Energy Installations – Proximity Study Report*, one of the main goals of the proximity guidelines is to provide risk assessed access for cable repairs. This should take into account the technical performance of the vessel and its dynamic positioning (DP) class, as well as other site-specific conditions which are discussed later in this section. Figure 3 shows the contingency required for a marine joint, along with further space necessary in order to facilitate safe future recovery/repair operations at or near the repair bight area.

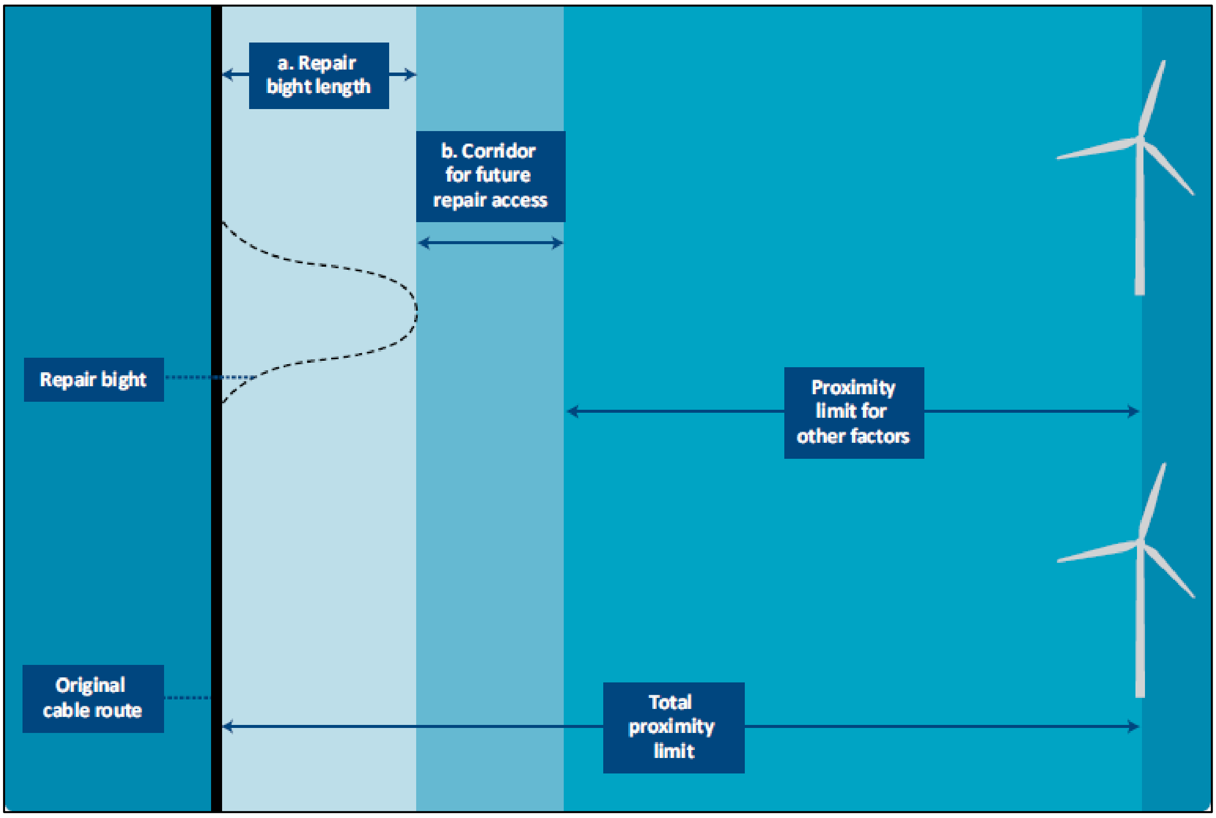


Figure 3: Cable repair bight access requirements (Red Penguin Associates Ltd, 2012)

The length of the repair bight, distance a, has been discussed previously in Section 0. The additional corridor for future repair access, distance b, is determined by the water depth at the site of the repair bight and is detailed in Table 4.

WATER DEPTH (m)	ADDITIONAL CORRIDOR WIDTH (m)
Minimum	50
10-100	100
100-200	200

Table 4: Minimum dimensions for future access to repair bight (Red Penguin Associates Ltd, 2012)

The proximity limit for other factors as seen above is determined by the vessel capability conducting the repair operation. In the case of a power cable repair in the vicinity of a windfarm structure, it is likely that the vessel will have a minimum DP 2 Class positioning system. As well as the DP Class of the vessel carrying out the cable repair, there are two scenarios which can affect the proximity limit to the windfarm structure. These are determined by whether the vessel conducting the cable repair is in lee of, or on the weather side of, the windfarm structure. Base case proximity limits covering all scenarios are presented in Table 5. Further details on IMO DP Classification are available from Kongsberg Maritime at: https://www.kongsberg.com/maritime/support/themes/imo-dp-classification/.

SCENARIO	MANUAL CONTROL PROXIMITY LIMIT (m)	DP 1 CLASS VESSEL PROXIMITY LIMIT (m)	DP 2 CLASS VESSEL PROXIMITY LIMIT (m)
Conducting repair operations in the lee of a windfarm structure	**200** (Control of propulsion failure resulting in a drift off scenario)	**100** (Control or propulsion failure resulting in a drift off scenario)	**50** (Control or propulsion failure resulting in a drift off scenario)
Conducting repair operations on the weather side of a windfarm structure	**500** (Control or propulsion failure resulting in a drift on and subsequent manual control correction)	**500** (Control or propulsion failure resulting in a drift on and subsequent manual control correction)	**100** (Propulsion failure in DP 2 mode would require propulsion redundancy to correct drift on)

Table 5: Base case proximity limits for cable repair vessels (Red Penguin Associates Ltd, 2012)

The minimum approach distance between the repair vessel and the WTG structure in order to deploy a repair bight is a factor of five dimensions. These are the depth of water, the length of the vessel, the cable freeboard distance from the water surface to the cable chute, the deck length from the cable chute to the jointing space, and lastly the distance of minimum approach.

In the telecoms cable industry, cable repair agreements are typically contracted to use DP1 Class vessels. This paper uses this as an example scenario together with the assumption that repair operations are being conducted on the weather side of the windfarm structure. The resulting worked example is presented in Table 6. In this case, the minimum approach distance is 500m from the closest extremity of the vessel and a hypothetical water depth of 50m has been used. Note that these calculations are based on the most conservative values of any potential scenario. For example, the deck length of the repair vessel may be slightly less than 40m, in which case the minimum separation from the windfarm structure would be reduced by equal amount. Similarly, water depths of around 50m is currently the limit in which fixed WTGs can be installed. The overall result is a requirement for a 755m separation distance.

ASSESSMENT CRITERIA	DISTANCE (m)
Minimum approach distance =	500
Length of vessel (assuming bow-on) =	150
Water depth =	50
Freeboard =	15
Deck length =	40
Minimum separation from structure =	755

Table 6: Proximity limit calculation for repair operations on the weather side of a WTG

1.3 Crossings and Crossing Design

Large offshore windfarm developments have the potential for a high concentration of crossings by multiple export and/or inter-array cables over existing cables on the seabed. As a result, the space available for cable repair vessels to operate is restricted and may hinder recovery/replacement and repair operations at the crossing area.

So that future maintenance and recovery operations are as safe and practical as possible, ESCA's 2016 document, *Guideline No.6 – The Proximity of Offshore Renewables Energy Installations & Submarine Cable Infrastructure in UK Waters* recommends that crossings less than 500m apart are considered a single entity thus "sterilising" that area of seabed over the existing crossed cable. A way of reducing the overall number of crossing locations is to concentrate the crossings over existing cables at specific points along the cable routes. This results in sets of mutual crossing points. It extends the distance between these mutual crossings and should the crossed cable require a repair in the future, it can enable it to be cut either side of the mutual crossing and laid back over the top across a much shorter distance. A diagrammatic example of how inter array cable crossings might look with and without mutualisation are show in Figure 4 and Figure 5.

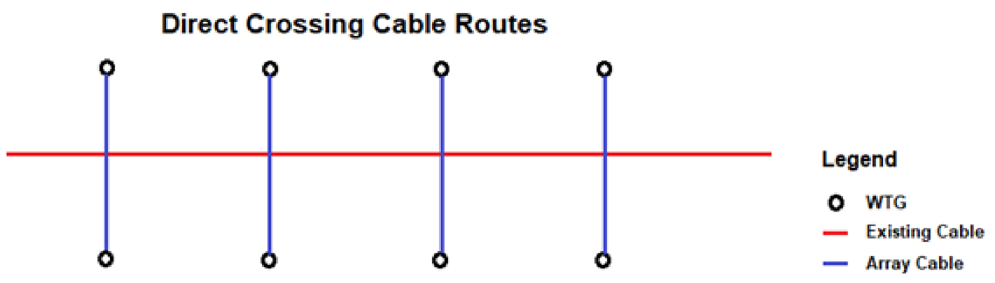


Figure 4: Direct OWF Array crossings over a 3rd party cable

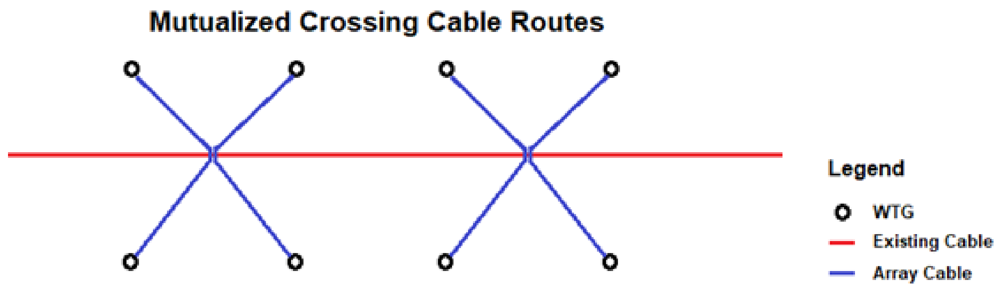


Figure 5: Mutualised OWF Array crossings over a 3rd party cable

When considering the crossing design for each crossing, there are a number of options and scenarios which could occur. These are summarised below.

- One cable laid over the other with no additional protection. Neither cable buried.
- One cable buried and the other laid on the surface, with additional protection applied.
- One cable buried and the other buried to a lesser depth, with additional protection applied.
- One cable buried deeply and the other buried over the top to a sufficient depth.
- One cable laid over the other, with additional protection applied only to the top cable.
- One cable laid over the other, with additional protection applied to both.

Additional protection measures can be in the form of concrete mattresses, rock bags, loose rock placement, Polyurethane half shells or metal articulated piping.

Concrete mattresses and rock bags come in different weights and sizes. Concrete mattresses can be articulated in both directions or just one and have features such as fronding to help retain sediments, or tapered outer edges to help prevent fishing gear snagging in heavily fished areas. Rock bags are advantageous in that they do not require deployment frames or the need to be orientated underwater they conform well with uneven seabeds and can be recovered at a later date.

Loose rock placement can be achieved using a flexible fall pipe to deliver rock to the seabed in a controlled manner. The rock cannot be removed as easily after deployment but is more efficient for larger areas than numerous rock bags. Rock berms with tapered gradients can be made so that they are over trawlable, but this can extend the volume and area of rock required.

Polyurethane protection systems typically use polyurethane half shells and metal banding to add a layer of abrasion and impact resistance to protect cables which are in contact with rock or concrete mattresses. The poly system is applied to the cable before deployment from the cable ship.

Articulated piping can be added to the cable to provide additional ballast and a higher level of cable protection from ductile or cast-iron half shells. The application can be limited by water depths and so it often used in depths where divers can operate.

2.0 THE FUTURE FOR OFFSHORE WIND AND CABLES

Offshore windfarms are now commonplace in Europe and are becoming more so in other areas of the world. Foundation designs to date have typically used fixed foundations, with predominantly monopiles and small jacket legged designs. The desire to utilise offshore wind energy in places where these foundation designs are not suitable, often further offshore, is leading towards intense interest in floating platforms for wind turbine generators. To illustrate this Equinor published the following reasons floating wind is attractive to the offshore energy industry:

- Winds are stronger and more consistent further out to sea
- Close to 80% of the world's offshore wind resource potential is in waters deeper than 60 metres
- 2.4 billion people live within 100km of the shoreline - floating offshore wind can deliver major-scale power directly to global markets
- Floating wind can potentially power 12 million homes in Europe by 2030
- Removing water depth constraints allows us to select the best sites in the world
- Floating wind has a higher capacity factor thanks to better wind further offshore
- Equinor's goal is that floating wind be competitive with other forms of energy by the year 2030

(source: www.equinor.com/energy/floating-wind)

Floating platforms require some means of anchoring them to the seabed in order to maintain their position offshore. Several types of mooring designs have been proposed. Given how early it is in the commercial development of floating offshore windfarms, no single mooring design predominates. To date the two types of design which have started to breakthrough are semi-submersible floating platforms with anchor mooring patterns and spar-buoy designs, also with anchor mooring patterns. These all therefore require anchor patterns with associated anchor wires which extend from the turbine generator to the seabed. Such mooring patterns will mean the subsea footprint of floating wind will far exceed existing fixed foundation developments. Tension leg designs which have much smaller seabed footprints have been proposed but so far have not proved popular. Some examples showing how these designs differ are provided in Figure 6.

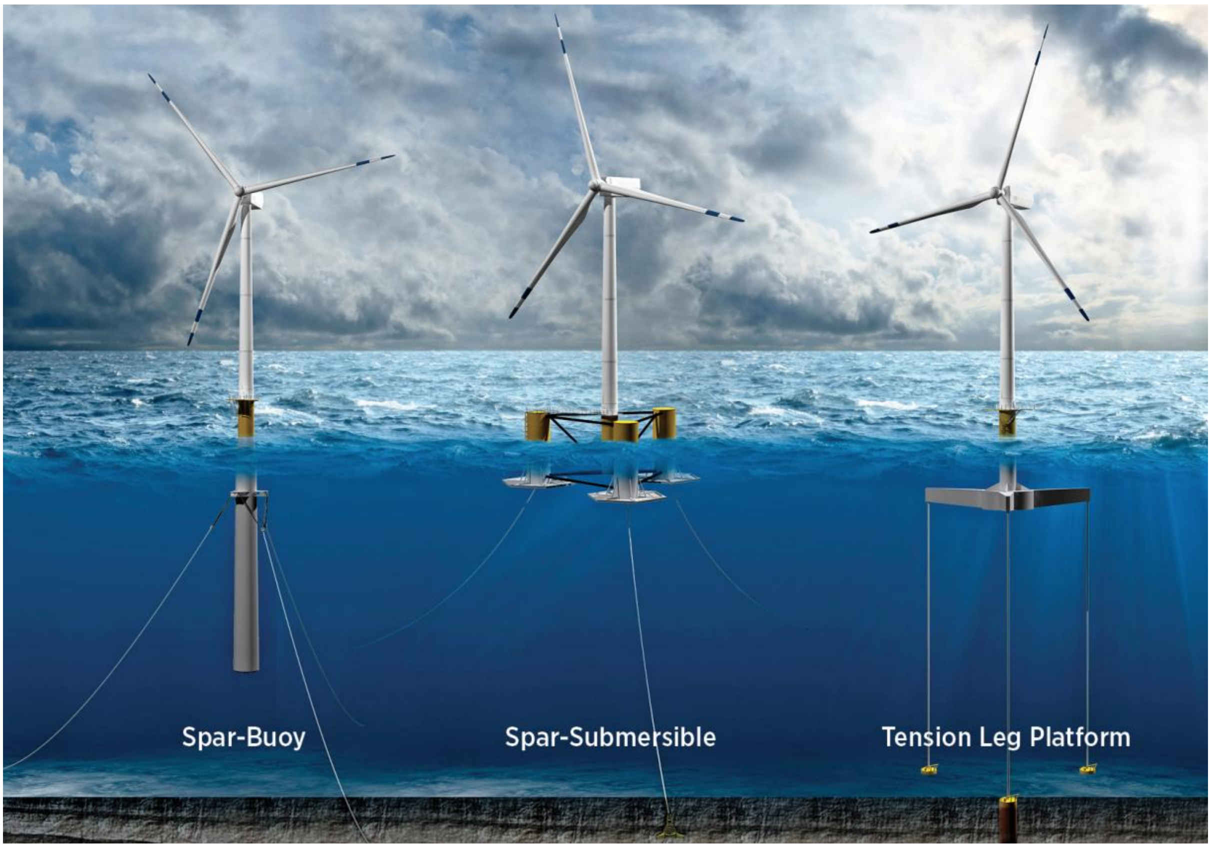


Figure 6: Offshore wind floating foundation concepts

Illustration by Joshua Bauer, National Renewable Energy Laboratory (US Department of Energy)

The other big difference with floating wind farms are the export and inter array cables themselves. Unlike fixed foundations which use static cables buried into the seabed between fixed foundations, floating designs require dynamic cables and this leads to some form of cable catenary in the water column. These are either free hanging or using buoyancy modules to form movement absorbing lazy wave designs to decouple the floater from the cable seabed touch down point. The catenaries of the power cables through the water column therefore also contribute to the expansion of the subsea footprint of floating wind developments compared to fixed foundation designs.

So few commercial scale floating windfarms have been built to date that the effect and issues around cable proximity and route design constraints are to some extent theoretical and will no doubt vary as new floating developments become a reality.

OceanIQ has been involved in cable route engineering for early floating wind developments and the following route engineering issues are likely to be ones which the submarine cable industry needs to consider in the future:

- Separation distances between existing cables and floating platforms will require larger distances than fixed foundations if repair cable ships are to retain the ability to maintain cables within floating wind developments.
- Export cables are likely to require a transition joint between a static part of the cable laid to shore and a dynamic part which connects to the floating platform. These may be factory joints, but could also require a marine joint.
- With the non-fixed nature of a floating windfarm, over the design life of a development will generator positions change as upgrades to turbines become available and therefore the array layout and associated inter array cable routes change over time?
- Existing industry guidelines will need to be modified or new ones created to address floating designs.

Another emerging trend in offshore wind is the use of HVDC cables for export and offshore transmission networks. As the array voltage moves from 33kV towards 66kV the amount of energy to transmit to shore is increasing and it is becoming common to see HVDC technology being proposed for export cables for OWFs and for domestic interconnector and transmission networks along coastlines.

With HVDC technology there are always two poles and in most cases that equates to two cables. There are single cable HVDC solutions with two poles side by side or concentrically arranged, but for the most part separate cables have been used. For the same amount of energy transmission capacity, this tends to mean the overall cable count increases when using HVAC instead of HVDC.

This increase in the cable count for a particular project means HVDC technology may result in larger overall seabed footprints for projects. The issues with cable separation to allow for future maintenance and potential anchor placement corridors then become even more important to consider. With the marine environment becoming an ever more congested space, offshore windfarm cables and route engineers face tougher tasks in the future to plan and design routes that are fee from disruptive constraints.