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# DYNAMIC CABLE CONNECTION AND TOPOLOGY COMPARISON

Public Summary Report



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Date: 27/11/2024

Status: Public

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DOCUMENT HISTORY

| Revision | Date  | Prepared by       | Checked by             | Approved by   | Revision History               |
|----------|-------|-------------------|------------------------|---------------|--------------------------------|
| Rev 1    | 25/10 | Emily Sarveswaran | Charlotte Strang-Moran | Jack Paterson | First draft for Partner review |

## EXECUTIVE SUMMARY

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The Floating Offshore Wind (FOW) industry is exploring innovative cable topology and connection designs that diverge from traditional fixed-bottom offshore wind systems. The variety in cable array configurations, connector types, and subsea hub designs introduces new risks and opportunities. The FOW Centre of Excellence (CoE) project "Cable Topology Comparison" undertakes a high-level techno-economic study to evaluate the costs, risks, and opportunities associated with different cable topologies and connection methods.

The project included failure mode, effects, criticality analysis (FMECA), and reliability, availability, and maintainability (RAM) methods to compare cable ancillary technologies and topologies. The study used assumptions identified through industry engagement and focused on 900 MW commercial-scale reference arrays for 66 kV and 132 kV cable designs at a water depth of 100 m. The estimated supply costs of traditional and emerging technologies over the next 5 to 10 years were also considered. Costing included project lifecycle phases: installation and operation (including maintenance and tow-to-port (T2P) costs).

This public summary report does not include the calculated values for capital expenditure (CAPEX), operational expenditure (OPEX), and levelised cost of energy (LCoE). Instead, the study presents the results as percentage differences from the baseline scenario: a 66 kV radial topology with a conventional connection with a pre-termination design. The study selected the 66 kV radial as the baseline due to its simplicity, proven reliability, and comparatively low CAPEX and OPEX. The pre-terminated connection for a conventional subsystem offered the lowest LCoE compared to newer connection technologies during the initial phases of the study. Initially, the study assumed high failure rates for novel designs. However, the study anticipated that engineering improvements and technology qualifications would decrease these anticipated rates. Therefore, the study included reliability sensitivity cases that demonstrated the value of these new connector technologies and the topologies they enable.

The analysis identified several key findings regarding the LCoE across different topologies and technologies, as listed below.

- **Radial topology:** The study identified radial designs as the most straightforward topology with low CAPEX. The study also considered a radial return by including a 100% capacity redundancy cable from the first turbine, farthest from the offshore substation (OSS) to the OSS. The additional cable led to an increase in CAPEX; subsequently, the LCoE rose by 2.5%. A benefit of a radial return design over the radial is increased availability. Exploring relocation of the substation could shorten the return cable's length, reducing CAPEX.
- **Ring topology:** Two variations of the ring design were investigated—with 20% and 67% redundancy. These topologies employ a redundancy line between two strings. The topology design increased availability compared to the radial design, reducing lost production during operation. However, their approximated LCoE increased by 1.7% and 1.2%, respectively, compared to the baseline scenario. This increase was due to the rise in calculated CAPEX.
- **Disconnectable I-tube and quick connector designs:** The study concluded that deploying these novel connectors could lead to an improvement in the LCoE compared to the baseline scenario when considering the introduced reliability sensitivities. The reliability sensitivities were assumed to improve novel connector reliability substantially (between 50 and 95% from the initial failure rates identified during the reliability assessment). The sensitivity cases allowed the study to compare the value of each novel connection instead of focusing on the uncertainties related to

risks that the study did not directly address. The improvements in LCoE identified in the study are due to the components' quicker mating and de-mating capabilities.

- **Star topology:** These designs feature subsea hubs, connecting turbines directly to the hub instead of daisy-chaining them together. This study identified that the star topology benefits from higher availability than the baseline scenario. The design also deploys smaller dynamic cable cross-sectional areas. Considering reliability sensitivities, the study suggested that the star designs would lower the LCoE by 1% to 4% compared to the baseline scenario.
- **Fishbone topology:** The fishbone and fishbone radial designs require many hubs daisy chained together. The study initially identified the fishbone topology as having a high LCoE due to the number of needed subsea hubs and the expected chance of failure. As reliability sensitivity cases were introduced (providing up to 95% reliability improvement), the fishbone topologies were identified as some of the lowest in LCoE.
- **Uncertainties of novel connectors:** This study has concluded that novel connector designs can provide added value to FOW. However, there are some existing uncertainties. For example, some uncertainties exist around the ease of connection and disconnection procedures. The assumptions used within the study may vary in actual practice. There are also gaps in knowledge regarding likely failures and risks, optimised monitoring techniques and replacement strategies of connectors. These uncertainties emphasise the need for further investment and technology qualification.

This study highlights the critical balance between emerging technology adoption and risk management, underscoring the potential for cost savings and increased reliability for FOW systems. It also highlights uncertainties regarding component integrity, operational expectations, such as the frequency of T2P and repair processes, and the need and feasibility of equipment standardisation.

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## NOMENCLATURE

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|       |                                            |
|-------|--------------------------------------------|
| AEP   | Annual Energy Production                   |
| CAPEX | Capital Expenditure                        |
| CoE   | Centre of Excellence                       |
| CSA   | Cross Section Area                         |
| DC SP | Dynamic Cable Strategic Programme          |
| DECEX | Decommissioning Expenditure                |
| DEVEX | Development Expenditure                    |
| FMECA | Failure Modes and Effects Analysis         |
| FOW   | Floating Offshore Wind                     |
| FOWT  | Floating Offshore Wind Turbine             |
| JIP   | Joint Industry Project                     |
| MTTF  | Mean Time to Failure                       |
| MTTR  | Mean Time to Repair                        |
| O&M   | Operation & Maintenance                    |
| OPEX  | Operational Expenditure                    |
| ORE   | Offshore Renewable Energy                  |
| LCoE  | Levelised Cost of Energy                   |
| QCS   | Quick-Connection System                    |
| RAM   | Reliability, Availability, Maintainability |
| RBD   | Reliability Block Diagrams                 |
| SP    | Strategic Program                          |
| T2P   | Tow-to-Port                                |
| TRL   | Technology Readiness Level                 |
| W2W   | Walk-to-Work                               |

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# 1 INTRODUCTION

## 1.1 Floating Offshore Wind Centre of Excellence

Established in 2020, the Floating Offshore Wind Centre of Excellence (FOW CoE) is a joint industry project (JIP), and as of writing this report, the industry, academic, and stakeholder partners are displayed in Figure 1. The collaborative programme was created with the vision:

*‘To establish an internationally recognised centre of excellence in FOW that will work towards reducing the Levelised Cost of Energy (LCoE) from floating wind to a commercially manageable rate, cut back development time for FOW farms, and develop opportunities for the local supply chain, driving innovation in manufacturing, installation and Operations and Maintenance (O&M) methodologies in floating wind.’*



Figure 1: FOW CoE Industry Partners as of 2024.

The FOW CoE has established strategic programmes (SPs) centred around high-priority areas, such as environmental interactions, mooring and anchoring, operations and maintenance, and dynamic cables. The Dynamic Cable Strategic Programme (DC SP) was launched to coordinate and deliver a range of activities to address challenges associated with dynamic cables. The ‘Cable Topology Comparison’ project was delivered under the DC SP.

## 1.2 Project Overview

As the development of FOW accelerates, new array topologies are being considered, including various combinations of connector types and subsea hub designs. This FOW CoE project is a high-level techno-economic study of the costs, risks, and opportunities for different cable topologies and cable connection methods. In Section 2 the report discusses the initial phase of the project. The study outlined a set of cable array topologies to compare enabling connection technologies.

An assessment of risk and reliability was conducted, investigating failure modes, potential connection losses, and re-connection times. The study also explored how array topology and connector configuration influence tow-to-port (T2P) activities in terms of activity costs, downtime, and feasibility. A cost-benefit analysis on various topology scenarios focused on capital expenditure (CAPEX), operational expenditure (OPEX), annual energy production (AEP), losses, and overall levelised cost of energy (LCoE) for each topology and connector scenario.

### 1.2.1 Objectives

The project objectives were as follows:

- Define technically viable array topologies with and without subsea connectors.
- Assess the risk and reliability of each topology design and connector variation.
- Compare subsea hub topologies to conventional topologies regarding cost, risk and uncertainties.
- Identify opportunities and industry gaps for large-scale supply of connectors.

### 1.2.2 Considerations

This project considered:

- Emerging technology, exploring the technology readiness level (TRL) for connector technology and identifying both near-term (5-year) and longer-term (10-year) trends.
- 100 m water depth.
- Commercial size reference array topologies of 900 MW.
- Both 66 kV and 132 kV cable system designs.
- Failure modes, reliability estimates, consequences of failures, and potential mitigations.
- Costing of project lifecycle phases for topologies includes purchase, installation, planned maintenance, unplanned failure, electrical losses, and T2P assumed costs.

## 2 TOPOLOGY VARIATIONS

The initial part of this project focused on comparing different cable array topologies and cable connection technology for FOW.

### 2.1 Array Layout Ground Rules

Dimensions and substation location of the assumed array footprint impact the required cable lengths and, therefore, the total array cost. Ground rules allowed a clear comparison between different arrays:

- Substation and export cable designs and costings were not part of the study scope.
- The fixed substations can be positioned at the East or South of the array, whichever works best for the individual configuration.
- The array must broadly fit within 20 km East/West and 11 km North/South.
- The site consists of 60 x 15 MW turbines.
- It has been identified that two substations (500 MVA transformers) would be necessary.

### 2.2 Cable Parameters

The topology designs were based on the 60-turbine site (900 MW total) for 66 kV and 132 kV arrays. The cable CSA was selected for each topology to satisfy the power requirements according to ampacity and capacity (assuming max power assumptions). This assumed ampacity and power capacity are displayed in Table 1.

Table 1: Cable ampacity and power capacity and CSA ratings from ABB [1].

| CSA (mm <sup>2</sup> ) | Ampacity (A) | Power Capacity at 66kV | Power Capacity at 132kV |
|------------------------|--------------|------------------------|-------------------------|
| 150                    | 375          | 39 MW (2 x 15 MW)      | 77 MW (5 x 15 MW)       |
| 240                    | 480          | 49 MW (3 x 15 MW)      | 98 MW (6 x 15 MW)       |
| 300                    | 530          | 55 MW (3 x 15 MW)      | 109 MW (7 x 15 MW)      |
| 400                    | 590          | 61 MW (4 x 15 MW)      | 121 MW (8 x 15 MW)      |
| 630                    | 715          | 74 MW (4 x 15 MW)      | 147 MW (9 x 15 MW)      |
| 800                    | 775          | 80 MW (5 x 15 MW)      | 160 MW (10 x 15 MW)     |
| 1200                   | 875          | 90 MW (6 x 15 MW)      | 180 MW (12 x 15 MW)     |

### 2.3 Selected Topologies

The study considered the inter-array cables connecting turbines to turbines, turbines to subsea hubs, and feeder cables connecting a turbine or hub to the OSS. This includes dynamic cable, static cable, and cable ancillaries.

Nine array topologies were considered for this project: radial, radial return, ring with 20% redundancy, ring with 67% redundancy, fishbone, fishbone radial, star, branching with a turbine, and branching with a subsea hub. In total, there were 38 topology and connector scenarios (T1-T38), with the complete list of all scenarios in Appendix 1.

2.3.1 Radial Topology

This topology is the most traditional, has low CAPEX, and is widely established. It operates by having the turbines daisy-chained together and transmitting power along the string. Although this topology is low-cost, it offers little in terms of redundancy. If there is a cable failure, the entire string might be compromised. A full-string shutdown would result in significant time and intervention costs to reinstate power production. Figure 2(a) illustrates the schematic of the 66 kV design and Figure 2(b) illustrates the schematic of the 132 kV design.

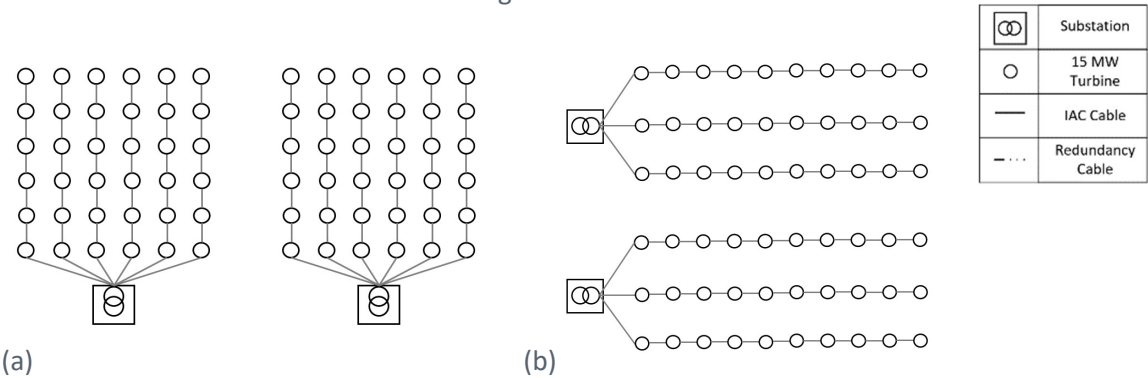


Figure 2: Schematics for the radial design (a) 66 kV and (b) 132 kV.

2.3.2 Radial Return Topology

A radial return topology is a potential solution to overcome the lack of redundancy in the radial array and improve availability. Within this study, a design offering 100% redundancy was considered. This topology includes a return cable connecting the first turbine in the string, farthest from the offshore substation (OSS) to the OSS. This return cable was composed of dynamic cable at the turbine and static cable buried in the seabed due to the length of the cable. It should be noted that in a realistic scenario, the return line could be shorter than what has been explored in this study, as the substation has been kept to the outside of the array following the initial ground rules (as denoted in Section 2.1). Additionally, the return cable's CSA depends on the percentage of planned redundancy; reducing the return cable's CSA can reduce supply costs. Figure 3(a) illustrates the 66 kV design and Figure 3(b) the 132 kV design.

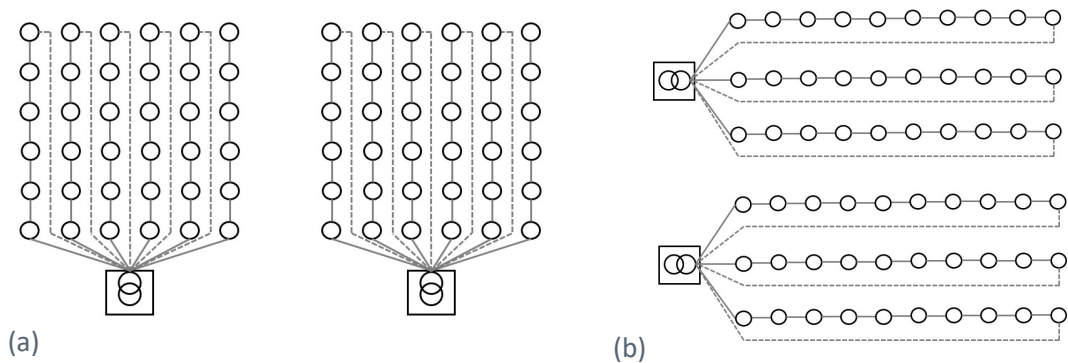


Figure 3: Schematics for the radial return design (a) 66 kV and (b) 132 kV.

### 2.3.3 Ring 20% and 67% Redundancy Topologies

The ring topology includes a redundancy cable that connects two strings, forming a closed ring. The CSA of the redundancy cables can be varied to accommodate different levels of redundancy. This study considered 20% redundancy (66 kV and 132 kV arrays) and 67% redundancy (132 kV array). Due to the shorter redundancy cables, these topologies require less supply cost than the radial return. Figure 4(a) illustrates the 20% redundancy 66 kV design, Figure 4(b) illustrates the 20% redundancy 132 kV design and Figure 4(c) illustrates the 67% redundancy 132 kV design.

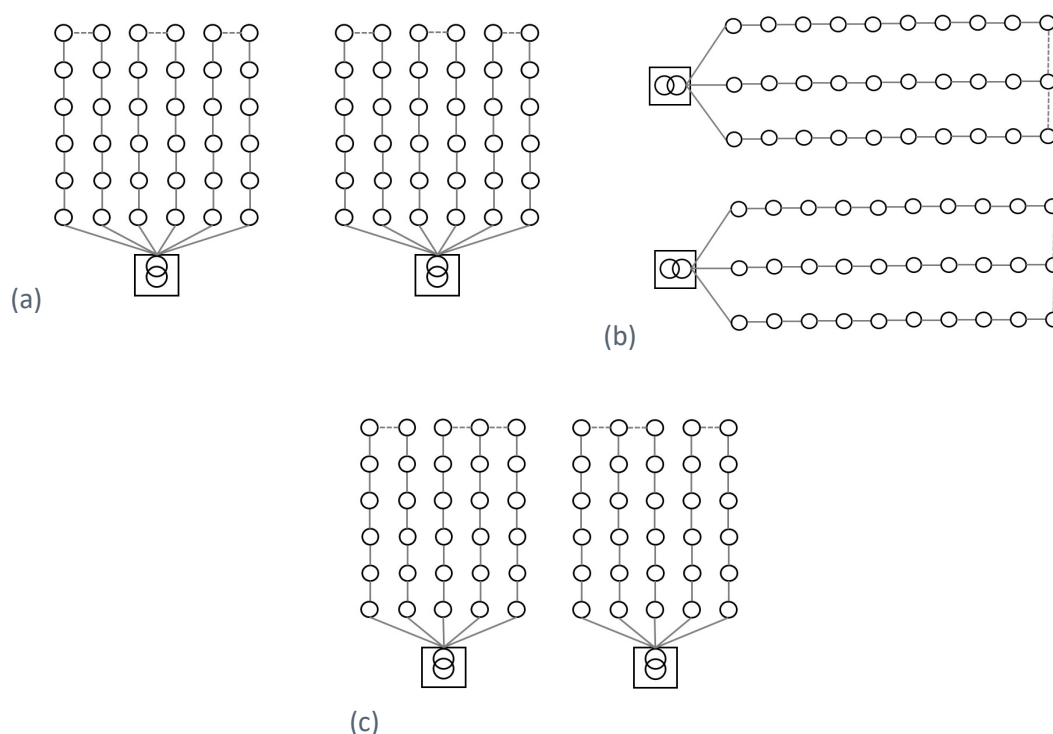


Figure 4: Schematics for the ring design with (a) 20% redundancy, 66 kV, (b) 20% redundancy, 132 kV and (c) 67% redundancy, 132 kV.

### 2.3.4 Fishbone Topology

The fishbone topology removes the need for a large CSA of dynamic cable. It uses three-way subsea hub connections between the turbine and static cables between hubs. The connections on the hub could be of wet-mate or dry-mate design. For comparative purposes in this study, it was assumed that all subsea hub-connected topologies were deployed with a conventional (future case) connection at the substructure. However, further LCoE reductions may be achieved through utilising novel substructure connector designs for topologies using subsea hubs. A disadvantage of the fishbone design is that if a hub fails, the remaining section of the string would be compromised due to its daisy-chain configuration. Figure 5(a) illustrates the 66 kV design and Figure 5(b) the 132 kV design.

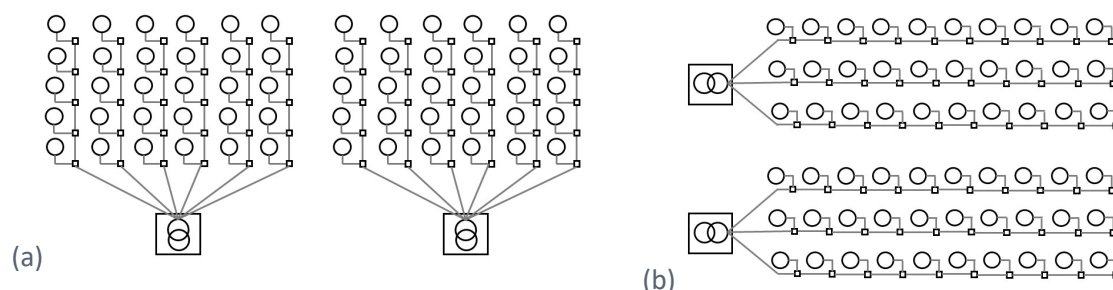


Figure 5: Schematics for the fishbone design (a) 66 kV and (b) 132 kV.

### 2.3.5 Fishbone Radial Topology

This can be considered a hybrid topology between the radial and the fishbone layouts. The topology requires fewer subsea hubs than the fishbone, so it is assumed to be cheaper in CAPEX. Similarly to the fishbone design, the remainder of the string will be compromised if a hub fails. However, an advantage would be that there are fewer hubs. A 66 kV fishbone radial layout was excluded as there would only be 2 or 3 hubs per string, increasing the cable costs and complexity of routing to the substation, and therefore assumed not cost-effective for such a small number of turbines per string. Figure 6 illustrates the 132 kV design.

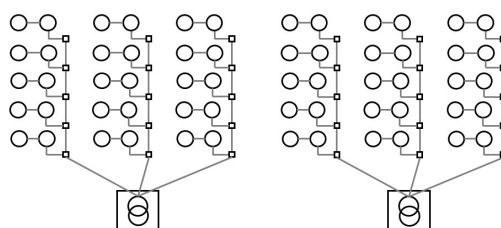


Figure 6: Schematic for the fishbone radial design 132 kV.

### 2.3.6 Star Topology

The star topology uses dynamic cables to connect multiple turbines to a central subsea hub, and the subsea connections could be wet-mate or dry-mate. Distant star-formed strings were found to have exceptionally long static cable lengths (due to the placement of the substation in the study), leading to higher losses. The 66 kV design is limited to only five turbines per hub due to the maximum CSA for the static feeder cable to the OSS. For the 132 kV design, six turbines were connected. Figure 7(a) illustrates the 66 kV design and Figure 7(b) illustrates the 132 kV design.

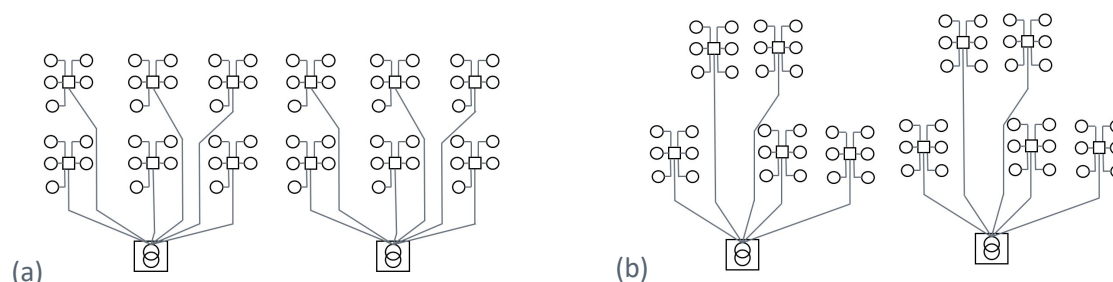


Figure 7: Array schematics for the star design (a) 66kV and (b) 132 kV.

### 2.3.7 Branching (Turbine and Hub) Design

The branching design deviates from the radial design, with each string split into two at the turbine nearest the substation. This split feature reduces the total cable length on the feeder cable to the OSS while offering some redundancy. The study excluded the 66 kV cable configuration due to the increased routing complexity for five turbines per split string. The schematic for the described branching layout is illustrated in Figure 8(a).

Alternatively, branching can be integrated with a subsea hub instead of branching from the nearest turbine, as seen in Figure 8(b). The subsea hub layout was deployed using a static feeder cable and two dynamic cables connecting turbines.

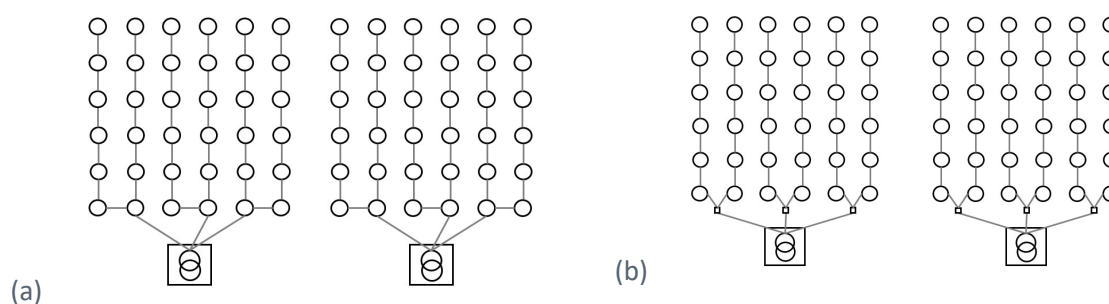


Figure 8: Schematic for the (a) branching at turbine 132 kV and (b) branching with hub design 132 kV.

## 2.4 Substructure Connections

All topologies considered included a cable connection to the Floating Offshore Wind Turbine (FOWT) substructure. The cable connections at the FOWT were divided into four categories based on their electrical and mechanical connection.

- Dry connection using topside splice at the termination (conventional);
- Dry connection using topside pre-terminated cable (future case);
- Disconnectable I-tube design;
- Quick-connection wet-mate design.

### 2.4.1 Conventional Dry Connection (incl. Future Case) Substructure Connection (Sub-System)

The conventional dry connection was considered well established, having been successfully deployed on 66 kV FOW demonstrator projects, such as WindFloat Atlantic [2] and Fukushima [3]. -

Traditionally, the mechanical connection between the bend stiffener and the substructure is made via a bend stiffener latching mechanism. The physical latching can be triggered without ROV intervention; however, an ROV can confirm that the latching was successful. The cable is pulled up the FOWT to above the waterline and manually terminated at the hang-off flange by a technician. The electrical termination is made by breaking out and connecting the power core to the matching cable routes from the turbine's switchgear. This electrical connection is made via manual splices (conventional design) but has also been considered in the study to be connected via pre-terminations (future case).

The conventional connection requires a 20 m overpull and additional duration to make the dry connections. The traditional connection will require walk-to-work (W2W) crossings, leading to a relatively high cost, weather windows, schedule risk and personnel risk. It can be assumed that the other connection concepts will reduce the number of W2W crossings during installation and T2P, reducing the person-hours and related risks. The schematic for this connector type is displayed in Figure 9(a) with notation for the subcomponents within the connection system identifying the variation between the conventional design and future case design and Figure 9(d) displays a real-life example of a pre-termination (for future case design) – Prysmian Group’s termination for 66 kV cable [4].

#### **2.4.2 Disconnectable I-tube Substructure Connection (Sub-System)**

The entire cable connection can be made to be detachable from the FOWT structure to allow for easier disconnection of the cable from the substructure during any major component replacement. A watertight structure is required to protect the cable system from water ingress during wet storage. The increased size and complexity of the detachable housing increase the capital cost of such a system, but this must be balanced against the cost of vessel time on standby. At the same time, manual splicing (or a pre-termination design) is performed for the conventional design in the FOWT. The connection and disconnection procedures are relatively quick and can be fully reversed, reducing the time and vessels required for mating and de-mating the cable from the FOWT. There were some technological uncertainties at the time of study due to limited deployment, such as the complexity of the re-connection operation. The labelled schematic for this connector type is displayed in Figure 9(b), and an example (Principle Powers disconnectable spliced connection [5]) is displayed in Figure 9(e).

#### **2.4.3 Substructure Quick-Connection (Sub-System)**

A fully wet-mateable FOWT substructure quick-connection system could, in theory, allow rapid connection and disconnection with limited manual intervention required. Connection and disconnection can be achieved by pulling the device in or out with a winch wire. Whilst having the potential to save vessel hire costs and installation time, any fully wet-mateable substructure connection system is likely to be relatively large to accommodate high voltage systems, expensive and require extensive qualification to prove reliable long-term performance. In the study, the connection and disconnection procedures were considered relatively quick and fully reversible, reducing the time and necessary vessels to mate or de-mate the cable from the FOWT. The schematic for this connector type is displayed in Figure 9(c), along with an example in Figure 9(f) - the Apollo PALM Quick-Connection System (QCS) [6]. Several variations of the quick connection design are available on the market at a low technology readiness level.

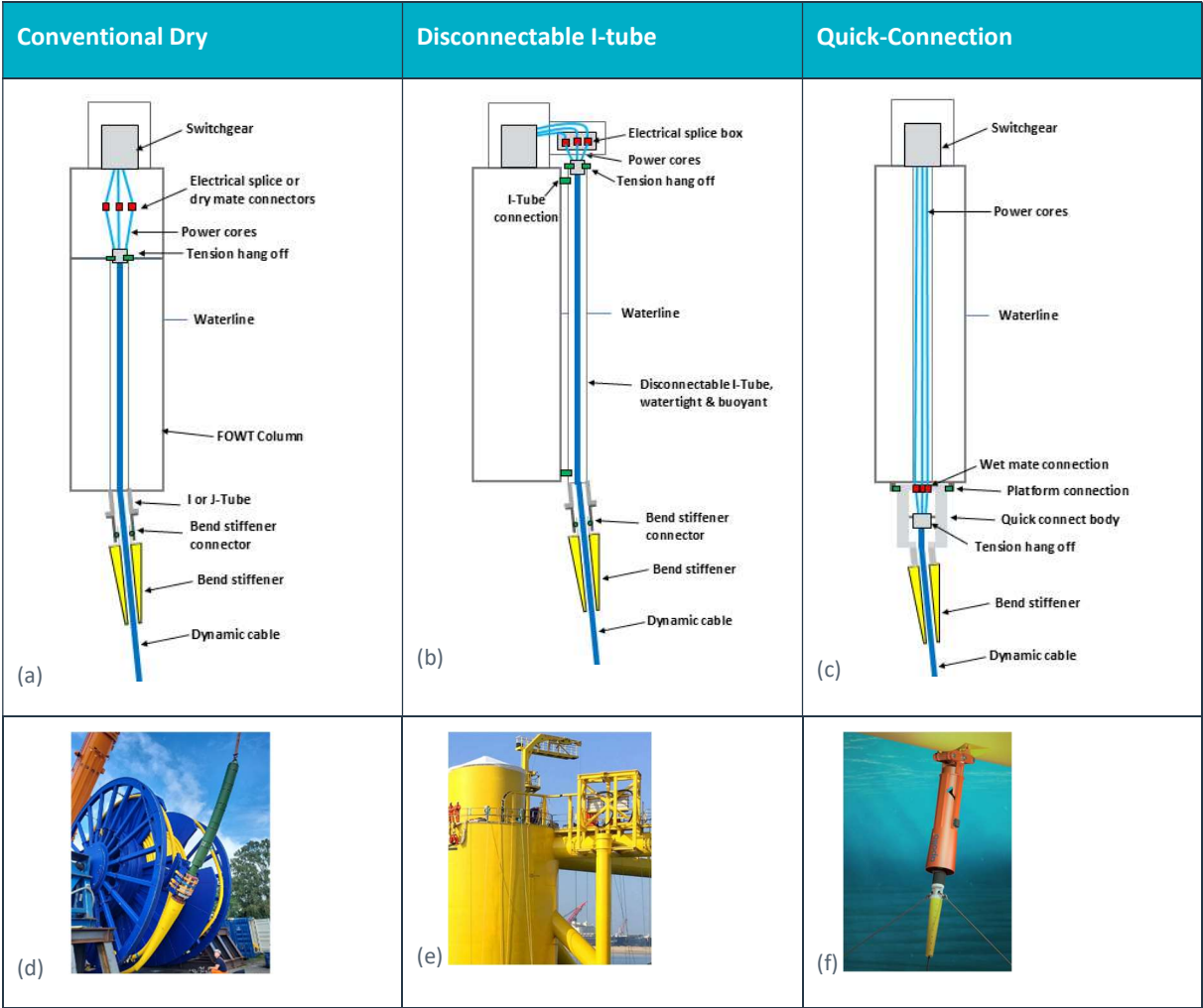


Figure 9: (a) Schematic of the conventional dry connection (b) Schematic of the disconnectable I-tube connection (c) Schematic of the quick-connection system (d) Prysmian pre-termination cable (e) Principle power disconnectable dry spliced connection (f) Apollo PALM Quick-Connection System.

2.5 Subsea Hub Connection

Subsea hub designs were categorised based on their connections: wet-mate subsea hub connections and dry-mate subsea hub connections, as described in Section 2.5.1 and 2.5.2, respectively.

‘Smart’ hub designs such as those advocated by ABB and Aker [7] incorporate switchgear and protection equipment, enabling advanced monitoring and control capabilities, while ‘standard’ hub designs do not. It should be noted that the focus of this study had been on ‘standard’ subsea hubs. Although a high level of consideration was given to the ‘smart’ subsea hubs in the project activity, it was not included in the cost analysis.

2.5.1 Wet-mate Subsea Hub Connection (Sub-System)

Figure 10(a) displays a labelled schematic for the wet-mate subsea hub and Figure 10(b) shows an illustration of a subsea hub by Aker Solutions [7]. The wet-mate subsea hubs considered in this study consist of relatively short, roughly 3 m long, single-phase cables connecting to a single-pin wet-mate connector. The cable has been terminated with a subsea termination unit, where the power cores are broken out individually into male parts for the wet-mate connection. An alternative method would be to use a three-phase stab connection head, simplifying the installation and commissioning process.

This study has considered 3-way up to 7-way hub designs for fishbone and star topologies.

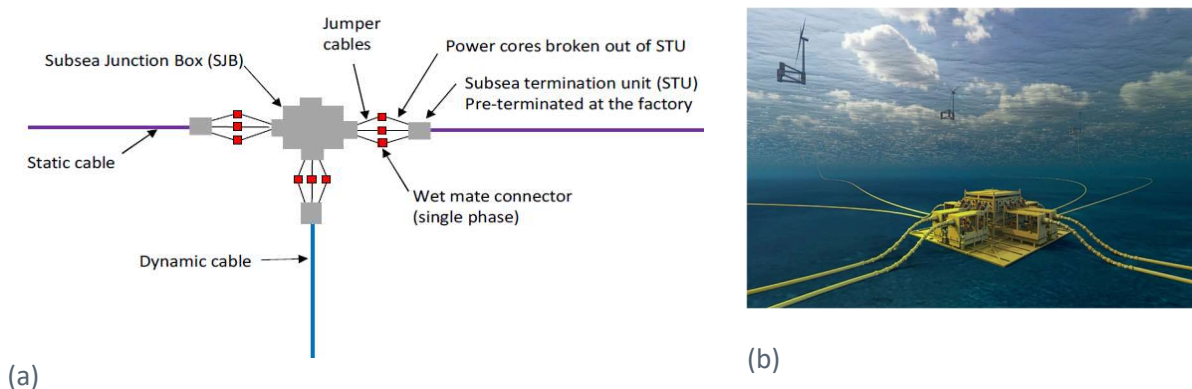


Figure 10: (a) Wet-mate subsea hub schematic (b) Aker solutions subsea hub with wet-mate connections.

### 2.5.2 Dry-mate Subsea Hub Connection (Sub-System)

The cable tails for a dry-mate subsea hub connection were considered much longer, roughly twice the water depth, to ensure that the cable could be pulled up above the water line for connection and disconnection. The schematic considered in the study can be seen in Figure 11(a). The GreenLink dry hub, as developed by MacArtney, is shown in Figure 11(b) as an example [8]. The in-air connection is made either with a 3-pin dry-mate connector or a spliced cable joint. As the number of connections increases, the dry-mated hub will become more expensive and complex.

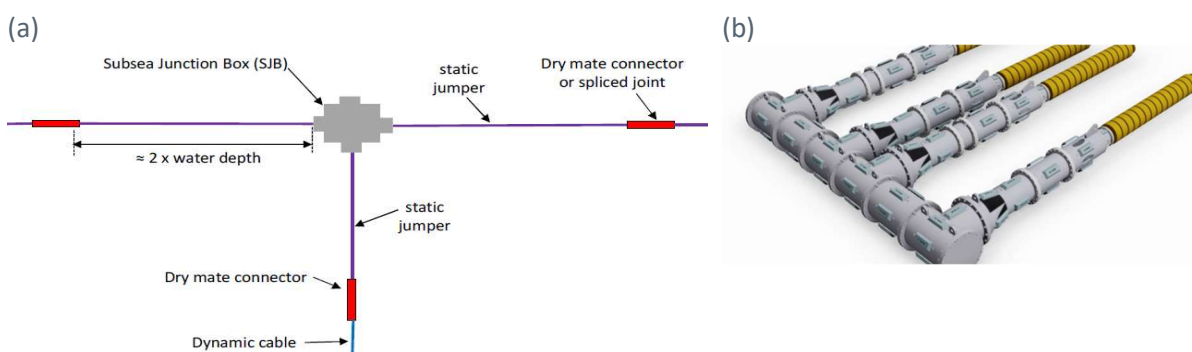


Figure 11: (a) Dry-mate subsea hub schematic (b) MacArtney GreenLink hub with dry-mate connections.

### 3 RISK AND RELIABILITY

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DNV performed the 'Cable Topology Comparison: Risk and Reliability Assessment' as part of this project. Their study utilised Failure Modes, Effects and Criticality Analysis (FMECA) and Reliability, Availability and Maintainability (RAM) methods to assess different cable topologies for FOW.

Information in the report conducted by DNV is classified as restricted; therefore, specific details or data cannot be shared publicly. The risk and reliability assessment included the following steps:

- DNV reviewed various risk assessment methods and selected FMECA and RAM studies as the most effective for this study.
- Stakeholder engagement was carried out and involved gathering insights from connector and cable manufacturers and floating wind developers to assess the technology status, risks, and failure rates.
- FMECA sessions were conducted with experts to analyse failure modes of different connector types. Due to the novelty of the technology, the mean time to failure (MTTF) and mean time to repair (MTTR) were estimated based on expert judgment.

This assessment led to calculating substantially high failure rates for novel connector designs. Data about failure and failure rates are not readily available for novel connectors, and expected failure modes and mitigation methods are carefully guarded. The limited availability of data contributes to the high calculated failure rates for connection systems because there is not enough data to accurately anticipate a failure mode and how it would be mitigated or engineered out of the design. Subsequently, various sensitivity cases were determined and approved through engagement with the FOW CoE partners and supply chain. These sensitivity cases ranged from 0%, 50%, 90% and 95% improvements in reliability. The RAM study was carried out as follows:

- Different topology designs (radial, radial return, star, and fishbone) were analysed using Reliability Block Diagrams (RBD) and assigned failure models. Branching and ring topology designs were not addressed due to limitations in the scope.
- Monte Carlo simulations were performed for each topology scenario, assuming a single string of a fictive FOW farm with five wind turbines of 15 MW each. The simulations, which ran over a 25-year assumed lifetime, calculated failure probability, mean availability, total downtime, and number of outages.

The high-level RAM concluded that the radial return design was the topology type that performed the best in terms of failure probability, mean capacity, mean availability, total downtime, and number of outages. This was as expected due to its 100% redundancy. The star design was the poorest performing topology, having a high failure probability due to large subsea hubs and a high total downtime due to 'standard' hub procedures for fault finding and the need to isolate all connecting turbines. It should be noted, however, that there are techniques and technologies available to improve the availability of the star design or any topology deploying a subsea hub. These include:

- Deploying 'smart' subsea hub designs for subsea HV switching capabilities.
- Utilising insulation caps. These caps help protect against sealing and insulation failures that occur through thermal cycling, incorrect design, installation errors and fouling.

- Engineering out some of the significant expected failure modes identified in the assessment. The star topology's true value is demonstrated by improving the hub design's reliability. This has been shown in the cost comparison (Section 4).

## 4 COST COMPARISON

A cost model was developed to explore the LCoE across all 38 topology scenarios. Table 2 lists the parameters defined for the wind farm criteria.

Table 2: Wind farm parameters selected for the study

| Parameter                          | Conditions                                    | Notes                                                                                                                                                                                                                                                            |
|------------------------------------|-----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wind farm size                     | 900 MW                                        | The 66 kV farm will total 900 MW (60 turbines), creating an even number of turbines per string.                                                                                                                                                                  |
| Farm voltage                       | 66 kV and 132 kV                              | CSA calculations and topology design for both voltages.                                                                                                                                                                                                          |
| Turbine rating                     | 15 MW                                         | Electrical considerations use turbine capacity rating.                                                                                                                                                                                                           |
| Floater type                       | Steel semi-submersible                        | Expected to be dominant in UK projects.                                                                                                                                                                                                                          |
| Water depth                        | 100 m                                         | Mid-range of UK bathymetry.                                                                                                                                                                                                                                      |
| Seabed                             | Sand or soft clay soil                        | There is little impact on cable design comparisons at the level of this study. The study does not include seafloor cable protection systems, which will have negligible variations across designs.                                                               |
| Substation Type                    | Bottom fixed, 2.4 km from the nearest turbine | It is likely for shallow sites and short-term until HV dynamic export cables are available. Using bottom fixed makes for a fairer like-for-like comparison between different topology options. Limited sensitivities on substation positioning will be assessed. |
| Distance between floating turbines | 2.2 km                                        | To be consistent with the previous PR5 study [9]; IEA 15 MW turbine rotor OD of 240 m.                                                                                                                                                                           |

This study focused on CAPEX and OPEX and their contributions to the LCoE. Development expenditure (DEVEX) and decommissioning expenditure (DECEX) were not included in this study; however, they were estimated through ORE Catapult's internal cost model and remained the same to compare the impact of CAPEX and OPEX on the LCoE.

### 4.1 Capital Expenditure

The study found that CAPEX significantly impacted the LCoE and varied with cable topology and selected technology. The critical elements investigated were dynamic inter-array cable supply, installation equipment, and labour.

#### 4.1.1 Supply Costs

The supply cost had been defined as the price of sourcing equipment and components, where the supply costs of cables, connectors and ancillaries were collated. Firstly, the study collated the required number of components and the expected cost of each item. This was gathered through ORE Catapult's own analysis insights and stakeholder engagement. The study found that:

- Wet-mate hubs were found to be more expensive than dry-mate hubs due to their complex connector and mating technology. For example, a 3-way dry-mate hub was expected to be 20% less costly when compared to a 3-way wet-mate hub.
- Arrays that include dry-mate hubs will require additional cable length (equal to twice the water depth per connection) to ensure that in the event of a repair, there is enough length to pull up above the water to connect and disconnect.

- Quick connections at the substructure were estimated to have a high supply cost due to the technology's low TRL and the connector's anticipated complexity.
- The conventional spliced FOWT connection was estimated to be the least expensive due to its lower complexity of subcomponents and its already well-established configuration in offshore wind.
- The conventional future case was expected to have only a slightly higher supply cost than the conventional splice. It was found to be much lower than the supply cost for the quick connection at the substructure.
- The disconnectable I-tube was estimated to be a similar cost to the conventional future case connection.

The supply costs for each topology scenario were collated and have been provided in Figure 12. The baseline scenario, T1, is highlighted below, and the complete list of topology scenarios (T) is provided in Appendix 1 .



Figure 12: Total supply costs across a range of topologies (T1-T7) Radial (blue); (T8-T14) Radial Return (grey); (T15-T20) Ring 20% (yellow); (T21-T23) Ring 67% (green); (T24-T27) Fishbone (dark blue); (T28-T29) Fishbone Return (navy); (T30-T33) Star (light blue); (T34-T36) Branch (no hub) (purple); (T37-T38) Branch (hub) (blue)

For the supply cost of various cable designs, it was concluded that:

- Cable with a higher CSA had a higher cost due to the volume of material required, mainly due to the price of the power core material.
- Dynamic cables were considered to have a higher supply cost due to their more complex structure and manufacturing process. From engagement with industry, it was concluded that a 66 kV dynamic 630 mm<sup>2</sup> cable is estimated within the study to cost roughly 46% more than its static counterpart.
- 132 kV cables were considered to have a higher supply cost than 66 kV. The study concluded that static 1200 mm<sup>2</sup> cable rated at 132 kV was estimated to be 34% more expensive than the same design rated at 66 kV.

The total supply costs were accumulated across each topology scenario (T). The following outcomes were identified (please refer to Appendix 1 for all T scenarios):

- Fishbone designs (T24-T27) were expected to have high supply costs due to the high number of subsea hubs, with higher supply costs for wet-mate connections.
- Topologies with a return cable were found to have a high supply cost due to each string's long dynamic-static return cable.
- The 132 kV branching design, which uses the future-case pre-terminated connections and disconnectable I-tube (T34 and T35), was expected to have a low supply cost due to the smaller CSA cable required than radial.
- Topologies that included dry-mate hubs, such as the fishbone (T24-T27) were seen to have a high overall supply cost. This was due to the hub's initial cost and quantity required.

#### 4.1.2 Installation Costs

Installing subsea hubs, cable laying, and cable hookup were all explored as part of the total calculated CAPEX. The installation duration was a key factor in the total CAPEX, where a more extended installation procedure meant expensive cable-laying vessels would be deployed longer.

Vessel capacity was considered for each topology and connector scenario. The number of connectors and cables that could fit onto the vessel reel or carousel influenced the number of port calls required. The study also considered pre-terminated cable. Since the cable is cut to length and pre-terminations are fixed on the cable ends, less cable can be stored onboard the vessel, resulting in more port trips. A previous FOW CoE project, 'Dynamic Cable and Mooring Installation Methods.' [10], assumed that cable with a CSA greater than 400 mm<sup>2</sup> would be transpoiled onto a carousel, while cable with a CSA less than 400 mm<sup>2</sup> would be transpoiled onto reels. It was assumed that the cable-laying vessel considered in the study had sufficient capacity for accessories, including buoyancy modules. This assumption was based on the required number of buoyancy modules for a 100 m water depth. If the water depth were to increase, the number of buoyancy modules would also increase, leading to the vessel requiring more port trips. The vessel considered for the study was the Skandi Acergy vessel [11]. The study found a requirement for more cable-laying vessels with sufficient capacity.

Figure 13 displays the total installation costs determined during the cost analysis. The costs were broken down into the cable laying activity, cable hookup at FOWT, and subsea hub installation (if required). The baseline scenario, T1, is highlighted below, and the complete list of topology scenarios (T) is provided in Appendix 1 .

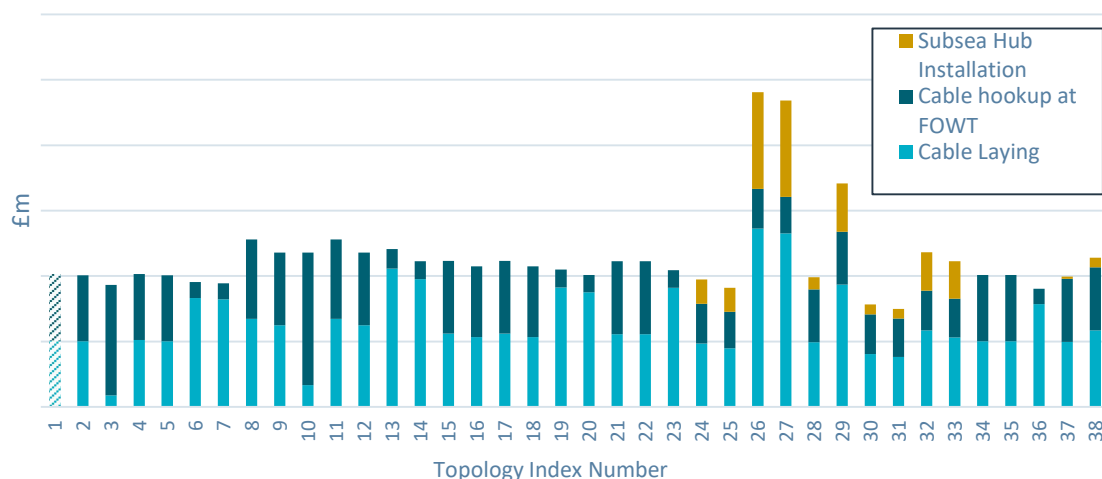


Figure 13: Total calculated cable system (including accessories) installation costs, categorising subsea hub installation, cable hookup at FOWT and cable laying activities. (T1-T7) Radial; (T8-T14) Radial Return; (T15-T20) Ring 20%; (T21-T23) Ring 67; (T24-T27) Fishbone; (T28-T29) Fishbone Return; (T30-T33) Star; (T34-T36) Branch (no hub); (T37-T38) Branch (hub).

The following outcomes were identified (please refer to Appendix 1 for T index):

- The dry-mate fishbone designs (T26 and T27) had high installation costs due to their long installation durations.
- Installation costs were low for those with shorter installation durations, such as the 132 kV radial design and the 132 kV branching turbine design.
- Topology designs that include the quick connection (T6-T7, T13-T14, T19-T20, T23 and T36) had a small proportion of installation cost attributed to the cable hookup at the FOWT. This is because the hookup process was assumed to be relatively short for a quick connection, reducing the installation time for the cable hookup stage.
- Designs that include a splice connection (T3 and T10) had a significant proportion of their installation costs attributed to the cable hookup, which was assumed to be a lengthy operation.

### 4.1.3 CAPEX findings

The total CAPEX of each topology scenario is shown in Figure 14. The baseline scenario, T1, is highlighted below, and the complete list of topology scenarios (T) is provided in Appendix 1 .



Figure 14: Total cable-related CAPEX for the various topology and connection types (T1-T7) Radial (blue); (T8-T14) Radial Return (grey); (T15-T20) Ring 20% (yellow); (T21-T23) Ring 67% (green); (T24-T27) Fishbone (dark blue); (T28-T29) Fishbone Return (navy); (T30-T33) Star (light blue); (T34-T36) Branch (no hub) (purple); (T37-T38) Branch (hub) (blue).

The key findings are listed below (please refer to Appendix 1 for T index):

- Topologies that offer redundancy, such as radial return (T8-T14), were likely to have a high CAPEX due to the total cable length. 132 kV designs had a particularly high CAPEX due to the cable requirements.
- Fishbone designs, particularly those with dry-mate hubs (T26 and T27), had high CAPEX due to the high number of hubs and the lengthy installation process.
- It was assumed that there are high costs associated with developing novel connector technologies, such as quick connections at the substructure. This may change as the technology becomes more established.

## 4.2 Operational Expenditure

The OPEX included routine O&M, cable repairs, and unexpected interventions, such as major component exchanges that require T2P operations. OPEX contributes significantly to LCoE; its magnitude can vary considerably depending on the topology and connector type deployed.

### 4.2.1 Cable System Maintenance

This study assumed that scheduled maintenance was conducted periodically on a routine basis and that it was the same across every topology for all topside equipment. Subsea equipment was expected to be maintenance-free. Scheduled maintenance was divided into two categories.

- **Subsea maintenance:** This applies to infrastructure below the water's surface. A supplier engagement concluded that electrical subsea equipment is focused on being maintenance-free.
- **Topside maintenance:** This applies to infrastructure above the water, which was anticipated to make up most of the maintenance work.

### 4.2.2 Cable System Repair

Each topology varied in cable parameters (CSA, ampacity and lengths), connectors, hubs and accessories, leading to varied repair costs. The complete techno-economic comparison considered the durations for pre-repair, connection, disconnection, replacement and post-repair. Each connection type (substructure connection and hub design) had a predicted repair time defined within this study that was initially confirmed by the industry. This was explored within the comparison, leading to various degrees of impact on the cost and duration of repair activities. A description of the repair procedures for each connector type is given in Table 3.

Table 3: Details of the assumed repair procedures for various connector types.

| Connector                   | Procedure Details                                                                                                                                                                                                                                                                                                                                                                                               |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Conventional Dry Connection | A support vessel, an ROV, and a Walk-to-Work (W2P) vessel are required to disconnect the cable and replace the bend stiffener connector. This study assumes the cable does not need to be replaced, as there should be adequate slack.                                                                                                                                                                          |
| Disconnectable I-tube       | A support vessel, an ROV, and a W2W vessel are required to disconnect the cable and replace the bend stiffener, which subsequently requires replacement. The cable is disconnected from the I-tube connector, and the bend stiffener and connector are replaced. It is assumed that the cable does not need to be replaced, as there should be adequate slack.                                                  |
| Quick-Connection            | A support vessel, an ROV, and lifting equipment will be required to replace a damaged wet-mate connector.                                                                                                                                                                                                                                                                                                       |
| Wet-mate Hub                | A support vessel, an ROV, and lifting equipment will be required if a hub is damaged. The cable does not need to be replaced, as there should be adequate slack. It has been assumed that the 'smart' hub design requires fewer days in pre-repair; however, 'smart' and 'standard' will have the same duration of repair time.                                                                                 |
| Dry-mate Hub                | A support vessel, an ROV, and lifting equipment will be required if a hub is damaged. The hub will be lifted with the jumper cable still attached. It is assumed that the cable does not need to be replaced, as there should be adequate slack. It has been assumed that the 'smart' hub design requires fewer days in pre-repair; however, 'smart' and 'standard' will have the same duration of repair time. |

DNV's reliability assessment identified high failure rates due to the risk uncertainty for the new novel designs used in this study. Using the insights gained from DNV's assessment, a range of sensitivity cases were selected. The sensitivity cases range from an improvement in reliability, increasing from 0% to

50%, 90%, and 95%. This sensitivity study exemplified the potential impact of novel solutions through varying degrees of assumed reliability.

#### 4.2.3 Tow-to-Port

T2P refers to disconnecting and transporting a turbine to its required port for a significant repair or replacement, such as a major component exchange. It presents a challenge to the success of FOW as it poses a substantially expensive and time-consuming challenge. It was assumed in a previous FOW CoE project, Tow to Port Offstation Management [12], a T2P would be expected to occur at a frequency of 0.03/turbine/year.

Continuity is reinstating a disconnected string segment in an array after removing one of the turbines during T2P activities. Without continuity, the rest of the affected string (at the removed turbine) will not be connected, thus leading to lost production. With continuity in place, the disconnected cable ends will be re-attached. A visualisation of this process is demonstrated in Figure 15. Due to the varied connector designs, continuity was assumed to be feasible only for certain connector types. These included the conventional connection (splice), conventional with pre-terminated cable (future case), and disconnectable I-tube.

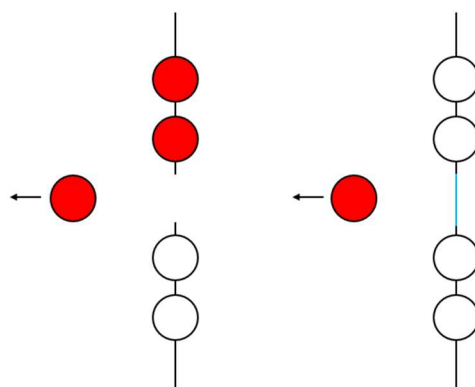


Figure 15: T2P of the damaged turbine before and after continuity.

#### 4.2.4 OPEX findings

OPEX is significantly impacted by reliability and T2P activities. The overall OPEX determined in the study is shown in Figure 16 for the sensitivity cases of 0% and 95% improvements in reliability discussed in Section 3. The baseline scenario, T1, is highlighted below.

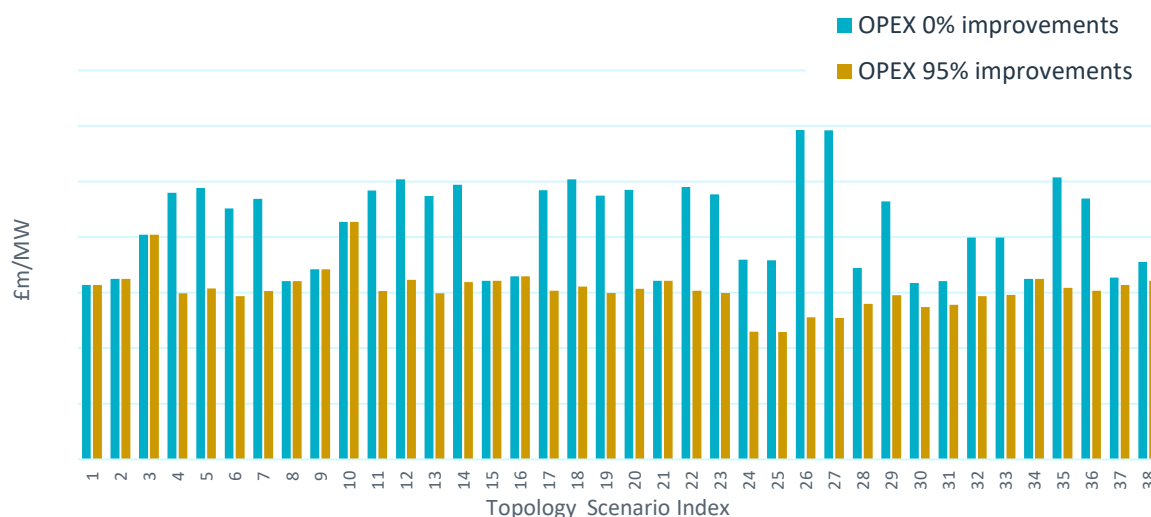


Figure 16: The estimated OPEX per year for a range of topologies with 0% and 95% engineering improvements. (T1-T7) Radial; (T8-T14) Radial Return; (T15-T20) Ring 20%; (T21-T23) Ring 67; (T24-T27) Fishbone; (T28-T29) Fishbone Return; (T30-T33) Star; (T34-T36) Branch (no hub); (T37-T38) Branch (hub).

The key findings are listed below (please refer to Appendix 1 for T index):

- T2P can substantially impact the OPEX. It was observed that connectors that required a longer duration to connect and disconnect led to higher vessel costs.
- The fishbone design with a dry-mate hub, 66 kV (T26) and 132 kV (T27), had significantly higher OPEX when no reliability improvements were applied. Low reliability and the subsequent lengthy repair durations led to higher OPEX estimates. It was observed that OPEX was reduced significantly when reliability improvements were introduced.
- Furthermore, the fishbone designs that used wet-mate hubs (T24 and T25) had lower OPEX than dry-mate, as dry-mate hubs were anticipated to have higher failure rates than wet-mate hubs.

The study suggested exploring sensing technology to monitor the health and integrity of the cable and components to mitigate the expenditure on expensive repairs and replacements. Sensing technology can detect early signs of damage to a cable before it reaches the point of failure. The value of cable monitoring systems (CMS) is yet to be fully understood. More work is needed to determine the most effective monitoring technologies and how data should be acquired and managed.

### 4.3 Energy Production

The study addressed each scenario's energy production, focusing on its performance, such as core losses and annual energy production (AEP).

There are four primary power losses for subsea cables: dielectric, screen, armour, and core. This study explored the power core losses, while other losses were not considered. Power core losses were identified as the primary influence of electrical loss in the cable system. Mechanical considerations were not included in this project's scope; however, there is a potential to investigate the effects of dynamic loads and mechanical stresses on the cable systems' performance in future projects.

Figure 17 compares the power core losses in the various topologies. A considerable variation was observed across the designs; however, losses did not exceed 1% of generation. Topologies that utilise 132 kV cable are subject to lower power core losses. The baseline scenario, T1, is highlighted below.

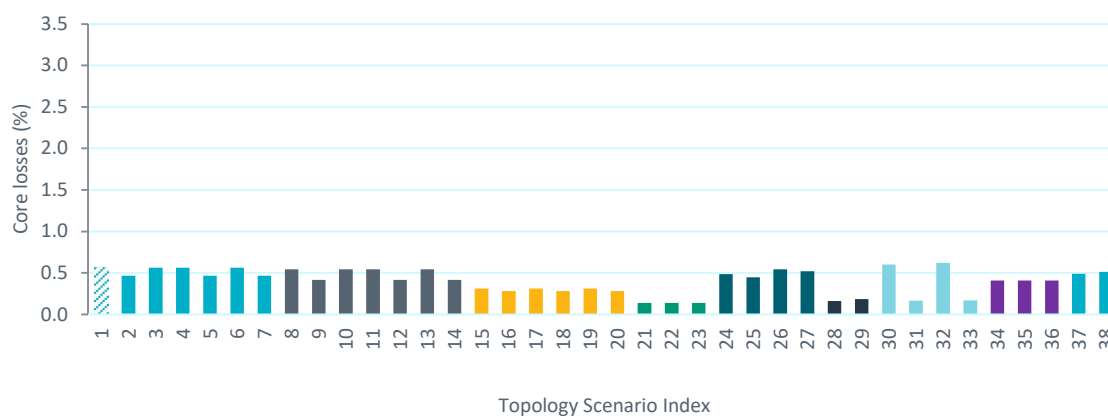


Figure 17: Power core losses (%) across a range of topologies (T1-T7) Radial (blue); (T8-T14) Radial Return (grey); (T15-T20) Ring 20% (yellow); (T21-T23) Ring 67% (green); (T24-T27) Fishbone (dark blue); (T28-T29) Fishbone Return (navy); (T30-T33) Star (light blue); (T34-T36) Branch (no hub) (purple); (T37-T38) Branch (hub) (blue).

Figure 18 displays the AEP estimated across various topology scenarios. The baseline scenario, T1, is highlighted below.

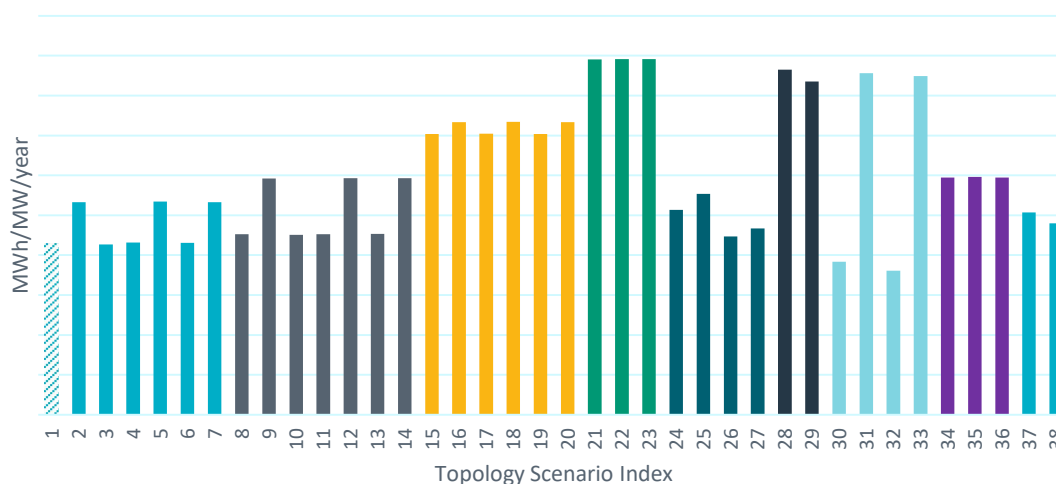


Figure 18: Annual Energy Production across a range of topologies (T1-T7) Radial (blue); (T8-T14) Radial Return (grey); (T15-T20) Ring 20% (yellow); (T21-T23) Ring 67% (green); (T24-T27) Fishbone (dark blue); (T28-T29) Fishbone Return (navy); (T30-T33) Star (light blue); (T34-T36) Branch (no hub) (purple); (T37-T38) Branch (hub) (blue).

The main findings are listed below (please refer to Appendix 1 for T index):

- Radial designs (T1-T7) had a mid-range AEP compared to other topologies—due to the expected operational downtime for the traditional daisy chain design. It was observed that adding a return

line (T8-T14) improved the AEP by improving availability. The study considered the potential risks associated with the lengthy redundancy cable leading to a heightened chance of repairs and potential short-term operational downtime for connecting turbines.

- Branching topologies (T34-T38) were found to have reduced single points of failure, resulting in a higher AEP.
- Ring designs with 20% redundancy (T15-T20) had a relatively high AEP due to redundancy cable, which resulted in lower generation loss than the radial topology.
- The same was inferred for ring topologies with 67% redundancy (T21-T23). However, the expected generation loss was lower, resulting in a higher AEP than 20% redundancy.
- Across the scenarios, 132 kV variations had a higher AEP than 66 kV variations. This was most apparent in the star designs (T30-T33).

## 4.4 Levelised Cost of Energy

The LCoE refers to the total cost of generating electricity through the project's operational lifespan, considering all aspects of the project previously discussed and used as a comparison metric. The impact of the various reliability improvements is displayed in Figure 19, and is discussed below. The baseline scenario, T1, is highlighted below.

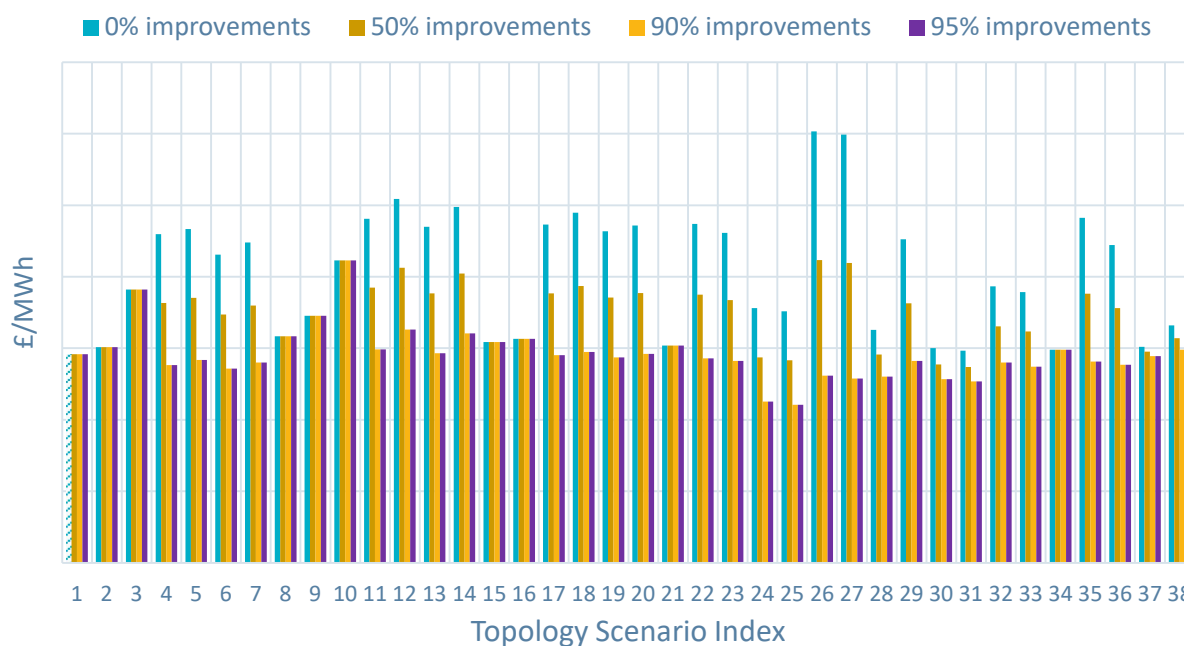


Figure 19: Levelised cost of energy (£/MWh) estimations across 38 scenarios for 0-95% improvement in reliability for the various connection types. (T1-T7) Radial; (T8-T14) Radial Return; (T15-T20) Ring 20%; (T21-T23) Ring 67; (T24-T27) Fishbone; (T28-T29) Fishbone Return; (T30-T33) Star; (T34-T36) Branch (no hub); (T37-T38) Branch (hub).

Specific CAPEX, OPEX and LCoE values were excluded from this public summary report as they were estimated for comparative purposes and should not be taken as exact values. Instead, they are displayed as a percentage difference from the baseline scenario: 66 kV radial design with conventional (future case) with pre-terminations, as highlighted in Figure 19.

- **Baseline Scenario-T1—Conventional (future case), 66 kV radial design:** The LCoE was expected to be consistently low for all reliability sensitivities. The design's simplicity kept the CAPEX low, and the conventional connection was found to be well-established.
- **T4—Disconnectable I-tube, 66 kV radial design:** The 95% reliability improvement sensitivity led to an LCoE at least 1.5% lower than the baseline scenario.
- **T6—Quick Connect, 66 kV radial design:** The 95% reliability improvement sensitivity led to a 2% lower LCoE compared to the baseline scenario, demonstrating the benefits of quick mating and de-mating.
- **T11 – Disconnectable I-tube, 66 kV radial return design:** The 95% improvement sensitivity led to the LCoE of T11 decreasing from 19% higher than the baseline scenario (with 0% improvements) to 0.6% higher.

- **T14 – Quick Connect, 132 kV radial return design:** The 95% improvement sensitivity led to the LCoE of T14 decreasing from 21% higher than the baseline scenario (with 0% improvements) to 3% higher.
- **T24—Conventional (future case), 66 kV fishbone design:** The 95% improvement sensitivity led to the LCoE of T24 decreasing from 6.5% higher than the baseline scenario (with 0% improvements) to 7% lower.
- **T25 – Wet-mate hub, 132 kV fishbone design:** The 95% improvement sensitivity led to the LCoE of T25 decreasing from 6% higher than the baseline scenario (with 0% improvements) to 7.1% lower.
- **T26—Conventional (future case), 66 kV fishbone design:** The LCoE was observed to be among the highest for 0% reliability improvements, over 31% higher than the baseline scenario. By improving the expected reliability by 95%, the LCoE decreased to 3% lower than the baseline.
- **T27—Dry-mate hub, 132 kV fishbone design:** The 95% improvement sensitivity led to the LCoE of T27 decreasing from 31% higher than the baseline scenario (with 0% improvements) to 3.5% lower.
- **T30—Conventional (future case), 66 kV star design:** This design had a low LCoE of approximately less than 1% higher than the baseline with 0% reliability improvements. This was due to a lower dependency on dynamic cable and more emphasis on traditional static cable. By improving the reliability by 95%, the LCoE decreased to 3.5% lower than the baseline.
- **T31—Wet-mate hub, 132 kV star design:** This design had a low LCoE of 0.5% higher than the baseline scenario for 0% reliability improvements. By improving reliability by 95%, the LCoE decreased 4% lower than the baseline.
- **T34 – Conventional (future case), 132 kV branching (turbine) design:** The LCoE was found to be one of the lowest at 0% reliability improvements as it was only 0.5% higher than the baseline. This remained the same across each sensitivity.
- **T35—Disconnectable I-tube, 132 kV branching (turbine) design:** Without any improvements to reliability, the LCoE was high, over 18% above the baseline scenario. Improving this connector type's reliability and quick mating and de-mating benefits led to an improved LCoE, which decreased to 1.1% lower than the baseline.
- **T36—Quick Connect, 132 kV branching (turbine) design:** Without any improvements to reliability, the LCoE was high, over 15% above the baseline scenario. Improving this connector type's reliability and quick mating and de-mating benefits led to an improved LCoE, which decreased to 1.5% lower than the baseline.
- **T37 - Conventional (future case), 132 kV branching (hub) design:** The LCoE was observed as one of the lowest at 0% reliability improvements, approximately 1% higher than the baseline. By improving the reliability by 95%, the LCoE decreased to 0.3% lower than the baseline.

The reliability improvement sensitivities of 0% and 95% have been explored in this study to demonstrate the value of connector technologies across various topology designs. However, the expected failure rates of these novel technologies are still unknown. It has been observed that the star designs have a relatively low LCoE across each reliability improvement sensitivity case. This demonstrates the value of the star topology in comparison to the other topologies. The configuration required less dynamic cable length and fewer subsea hubs than other hub-reliant topologies, such as the fishbone layout. The novel connector designs were not considered for hub-reliant topologies (such as star and fishbone). However, the value of novel connectors for hub-reliant topologies could further reduce LCoE if reliability improvements are considered.

## 5 CONCLUSIONS

The study identified various best scenarios depending on the reliability improvement sensitivity used. The most cost-effective topologies, according to the techno-economic comparison across sensitivities of 0% reliability improvement and 95% reliability improvement, have been displayed in Table 4 and Table 5 respectively. The topologies have been ranked from 1-10, 1 being the most cost-effective.

Table 4: Most cost-effective topology and connector scenarios identified in DC06 with a sensitivity of 0% reliability improvements for novel connector failure rates.

| Index Number | Topology Design | V (kV) | Substructure Connector     | Numerical Ranking |
|--------------|-----------------|--------|----------------------------|-------------------|
| 1            | Radial          | 66     | Conventional (future case) | 1                 |
| 31           | Star            | 132    | 7-way wet mate             | 2                 |
| 34           | Branching       | 132    | Conventional (future case) | 3                 |
| 30           | Star            | 66     | 6-way wet mate             | 4                 |
| 2            | Radial          | 132    | Conventional (future case) | 5                 |
| 37           | Branching       | 132    | 3-way wet mate             | 6                 |
| 21           | Ring (67%)      | 132    | Conventional (future case) | 7                 |
| 15           | Ring (20%)      | 66     | Conventional (future case) | 8                 |
| 16           | Ring (20%)      | 132    | Conventional (future case) | 9                 |
| 8            | Radial Return   | 66     | Conventional (future case) | 10                |

Table 5: Most cost-effective topology and connector scenarios identified in DC06 with a sensitivity of 95% reliability improvements for novel connector failure rates.

| Index Number | Topology Design | V (kV) | Substructure Connector  | Numerical Ranking |
|--------------|-----------------|--------|-------------------------|-------------------|
| 25           | Fishbone        | 132    | 3-way wet mate          | 1                 |
| 24           | Fishbone        | 66     | 3-way wet mate          | 2                 |
| 31           | Star            | 132    | 7-way wet mate          | 3                 |
| 30           | Star            | 66     | 6-way wet mate          | 4                 |
| 27           | Fishbone        | 132    | 3-way dry mate          | 5                 |
| 28           | Fishbone Radial | 132    | 3-way wet mate          | 6                 |
| 26           | Fishbone        | 66     | 3-way dry mate          | 7                 |
| 6            | Radial          | 66     | Quick connect, wet mate | 8                 |
| 33           | Star            | 132    | 7-way dry mate          | 9                 |
| 4            | Radial          | 66     | Disconnectable I-tube   | 10                |

It should be noted that the technology reviewed within this report is, in some cases, classified as novel technology, and the assumptions gathered are to the best of ORE Catapult's knowledge. Therefore, the results should not be taken as exact costs or durations but as assumptions for comparative purposes to identify potential technology development priorities. Each topology and technology scenario had assumed supply, installation, operation, and maintenance requirements, concluding that some designs would be more desirable than others regarding LCoE. Observing the industry's uncertainties when considering topologies and connectors for large-scale deployment is important. Some of the uncertainties have been listed below:

- Developing and qualifying more novel connector designs. Investment in these designs is crucial to helping reduce the LCoE. Although novel connectors were not applied to all topology designs in this study, they will likely lower the LCoE across all topologies after reliability improvement.
- Optimisation in operational strategies. This refers to reducing the requirement for T2P. Explore alternatives such as in-situ or implementing continuity to reduce the loss due to downtime during a T2P operation.
- ‘Smart’ hubs, both dry and wet mate designs, are not in deployment at the time of completing this study, and concepts aren’t available to feed into the study. Therefore, limited information can be shared on how exactly these hubs will be designed. ‘Smart’ hubs are expected to have advanced utilisation of condition monitoring and will be deployed with subsea switchgears. This will allow operators to identify potential issues before they become major problems and isolate them accordingly. This will ultimately reduce the time and cost associated with pre-emptive repair.
- This study is only a high-level comparison of topology designs, and there is potential to include more novel technologies and more topology variations in future studies.

For novel technologies, failures and risks are difficult to determine; therefore, these technologies need further investment towards technology qualification. This study identifies that novel designs have the potential to lower LCoE. This was demonstrated through the decreased LCoE expected for fishbone designs (due to 95% improvements in reliability). This is due to the reduced risk of failure associated with the high volume of subsea hubs. The star designs have a reasonable LCoE across all sensitivities; this can be attributed to their reduced requirement for dynamic cable and fewer subsea hubs than the fishbone designs.

It is clear to the industry that FOW differs from fixed wind and oil and gas projects. This study highlights the importance of considering these novel connector technologies and topology layouts effectively to optimise future large-scale floating wind sites.

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## APPENDIX 1

| Scenario Index | Topology Design | V (kV) | Substructure Connector     | Subsea Hub     |
|----------------|-----------------|--------|----------------------------|----------------|
| 1              | Radial          | 66     | Conventional (future case) | -              |
| 2              | Radial          | 132    | Conventional (future case) | -              |
| 3              | Radial          | 66     | Conventional (splice)      | -              |
| 4              | Radial          | 66     | Disconnectable I-tube      | -              |
| 5              | Radial          | 132    | Disconnectable I-tube      | -              |
| 6              | Radial          | 66     | Quick connect, wet-mate    | -              |
| 7              | Radial          | 132    | Quick connect, wet-mate    | -              |
| 8              | Radial Return   | 66     | Conventional (future case) | -              |
| 9              | Radial Return   | 132    | Conventional (future case) | -              |
| 10             | Radial Return   | 66     | Conventional (splice)      | -              |
| 11             | Radial Return   | 66     | Disconnectable I-tube      | -              |
| 12             | Radial Return   | 132    | Disconnectable I-tube      | -              |
| 13             | Radial Return   | 66     | Quick connect, wet-mate    | -              |
| 14             | Radial Return   | 132    | Quick connect, wet-mate    | -              |
| 15             | Ring (20%)      | 66     | Conventional (future case) | -              |
| 16             | Ring (20%)      | 132    | Conventional (future case) | -              |
| 17             | Ring (20%)      | 66     | Disconnectable I-tube      | -              |
| 18             | Ring (20%)      | 132    | Disconnectable I-tube      | -              |
| 19             | Ring (20%)      | 66     | Quick connect, wet-mate    | -              |
| 20             | Ring (20%)      | 132    | Quick connect, wet-mate    | -              |
| 21             | Ring (67%)      | 132    | Conventional (future case) | -              |
| 22             | Ring (67%)      | 132    | Disconnectable I-tube      | -              |
| 23             | Ring (67%)      | 132    | Quick connect, wet-mate    | -              |
| 24             | Fishbone        | 66     | Conventional (future case) | 3-way wet-mate |
| 25             | Fishbone        | 132    | Conventional (future case) | 3-way wet-mate |
| 26             | Fishbone        | 66     | Conventional (future case) | 3-way dry-mate |
| 27             | Fishbone        | 132    | Conventional (future case) | 3-way dry-mate |
| 28             | Fishbone Radial | 132    | Conventional (future case) | 3-way wet-mate |
| 29             | Fishbone Radial | 132    | Conventional (future case) | 3-way dry-mate |
| 30             | Star            | 66     | Conventional (future case) | 6-way wet-mate |
| 31             | Star            | 132    | Conventional (future case) | 7-way wet-mate |
| 32             | Star            | 66     | Conventional (future case) | 6-way dry-mate |
| 33             | Star            | 132    | Conventional (future case) | 7-way dry-mate |
| 34             | Branching       | 132    | Conventional (future case) | -              |
| 35             | Branching       | 132    | Disconnectable I-tube      | -              |
| 36             | Branching       | 132    | Quick connect, wet-mate    | -              |
| 37             | Branching       | 132    | Conventional (future case) | 3-way wet-mate |
| 38             | Branching       | 132    | Conventional (future case) | 3-way dry-mate |

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