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# IOWTC2025-164626

## SUBSEA SMART HUBS FOR FLOATING WIND

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### ABSTRACT

*Subsea Smart Hubs (SSH) Joint Industry Project has been initiated with the aim of addressing new Inter-Array Cable (IAC) system architectures for floating wind farms. Subsea hubs allow Fishbone and Star architectures, that diverge from the traditional daisy-chain configuration with the potential to lower overall costs over the life of field, enhance availability and higher capacity factors resulting in a lower Levelized Cost of Energy (LCoE).*

*In order to precisely estimate potential cost savings, the study is based on different scenarios that will be detailed. A number of scenarios are chosen encompassing several possible farms layouts as foreseen by developers for the near future (66kV or 132kV IAC system, 500MW or 1GW wind farm, medium or deep water). A comparison of 3 different IAC architectures is performed: Daisy-chain (without subsea hub), Fishbone and Star configurations. This enables to identify floating wind farm configurations most susceptible to take advantage of subsea hub technology.*

*Regarding initial CAPEX, for each scenario, the design optimization and assumptions used to determine the required cables and associated ancillaries and accessories; and used to define Transport & Installation strategy are presented. Specific attention is given to the effect on offshore installation vessel and equipment and on offshore operations duration, as installation costs are a large part of the CAPEX. Then Operation & Maintenance strategies are discussed.*

*CAPEX is to be ultimately compared versus the potential reduction in OPEX through O&M strategies enabled by a subsea hub connection system, such as quick disconnection for two-to-port for Wind turbine maintenance. The results of this study will ultimately enable to issue a comprehensive design basis for Subsea Hub and CAPEX envelope. From there it will be possible to define a typical qualification program for such a subsea hub, as this technology is not yet covered by any industry standard. This will be part of a second phase of the project.*

Keywords: floating wind, Inter Array Cable, dynamic power cable, array architecture, subsea hub, wet mate connector.

### NOMENCLATURE

AHC	Active Heave Compensation
CAPEX	CAPital EXpenditure
FOW	Floating Offshore Wind
FWT	Floating Wind Turbine
IAC	Inter-Array Cable
LCoE	Levelized Cost of Energy
LW	Lazy Wave
MBR	Minimum Bending Radius
mT	metric Ton
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
O&M	Operation and Maintenance
OPEX	OPERational EXpenditure
OSS	Offshore Sub-Station
SSH	Subsea Smart Hub
T&I	Transport and Installation
TDP	Touch Down Point
TRL	Technology Readiness Level
WD	Water Depth
WT	Wind Turbine
XLPE	Cross Linked PolyEthylene

## 1. INTRODUCTION

### 1.1 Floating Wind European context

The European Union's Strategy on Offshore Renewable Energy (ORE) sets ambitious goals to expand Europe's offshore wind capacity to 60 GW by 2030 and 300 GW by 2050. Floating wind energy plays a crucial role in achieving these targets, providing higher capacity factors and a potentially lower Levelized Cost of Energy (LCoE) as technology matures. To realize the full potential of floating offshore wind and support

Europe's Green Deal for climate neutrality by 2050, the industry must overcome performance and maturity challenges through accelerated innovation, standardization, and industrialization. While the current offshore wind market relies heavily on a bottom-fixed foundation mindset, the floating wind sector demands new solutions, particularly in grid connection and electrical infrastructure, to drive down costs and improve energy supply security.

## 1.2 Subsea Smart Hubs JIP

Subsea Smart Hubs (SSH) Joint Industry Project has been initiated by a consortium of 3 companies, SuperGrid Institute, Aventa & SCM, and is sponsored by several offshore wind farms developers and major providers. The project started mid-2024 and is structured around four work packages that will guide the specification, validation and deployment methodologies of the combined subsea hub and inter-array cable system. Collaboration among wind farm developers and technology suppliers is central to this project, as developers will provide insights into cable system requirements and prioritize functionalities aligned with the overall project goals. By addressing technical and commercial risks, this project aims to advance the scalability of subsea-hub based architectures, benefiting the entire supply chain—from cable suppliers and connection technology providers to floating wind farm operators.

This project addresses the critical need for a subsea-hub-based inter-array cable system architecture for floating wind farms, a novel approach that diverges from the traditional “daisy-chain” configuration. Although subsea hub systems are yet to be deployed in offshore wind, their potential to lower operational costs, enhance availability, and offer robust risk mitigation strategies could result in substantial reductions in LCoE. The project's main objective is to establish a reliable design basis for subsea-hub based 66 kV and 132 kV inter-array cable (IAC) systems, focusing on innovative fishbone and star architectures. Additionally, the project seeks to define comprehensive specifications for subsea hubs, targeting specific functions, reliability metrics, and price benchmarks to make these solutions viable and scalable for various industry stakeholders.

Among the main deliverables are a comparison of IAC architectures both from a technology maturity point of view and a CAPEX and OPEX cost based on O&M strategies.

## 1.3 Paper presentation

The paper sections developed below follow the chronological progress of the project. It will first set the state-of-the-art and the need for optimized installation and O&M philosophies for FOW farm by referring to a number of publications and reviews of connection/disconnection systems for power cables along with maintenance strategies.

Then the basis of design for the study will be detailed: first the wind farm layouts and the power cable cross-sections that have been specifically designed. The dynamic cables

configurations obtained will be detailed with the associated design assumptions.

From these basis, optimized array cables layouts have been determined with the OpTEAssoft software from SuperGrid Institute. The software will be briefly presented with a focus on the new functionalities that have been implemented in order to cope not only with traditional daisy-chain configuration, but also with so-called Fishbone and Star configurations which are enabled by the use of subsea hubs which are central to this project. Optimization parameters and assumptions are presented.

Finally, Installation and Maintenance methodologies are presented along with cost analysis methodologies, based on vessel selection for typical metocean conditions analyzed for two typical offshore zones.

## 2. FWT Connection Technologies

### 2.1 IAC connection systems

In recent years, many public funded projects and JIPs have analyzed the technologies required to develop commercial scale FOW in order to achieve the target LCoE. These projects have considered many installation methodologies and operation and maintenance philosophies which include feasibility of two-to-port, one can cite ORE Catapult reports ref.[1,2] and World Forum on Offshore Wind report and white paper ref.[3,4].

One of the most critical items in terms of cost, in particular installation cost, and reliability is the connection of the dynamic cable, both to the floating platform and to the subsea static part of the electrical power system. Several connection systems have been installed or are being developed to enable quick connect-disconnect of dynamic cable at the floating platform level. Two types of systems are proposed for topside connection: pre-terminated cables systems and integrated connection systems. All aim at enabling rapid disconnection with subsea wet storage. Review of these systems is included in ORE Catapult ref.[5] and Carbon Trust Floating Wind JIP recent report [6].

The large number of concepts for Floating platform cable connection that are being engineered and at various stage of development show the importance of having a reliable quick connect-disconnect system additionally with possibility of ensuring power production from other FWT when one requires to be towed-to-port.

### 2.2 Subsea Electrical Connectors

Subsea connections encompass wet mate connectors and hub systems, with a particular interest in systems for voltage ratings above 33kV. When considering IAC architecture with subsea hub or subsea disconnectable systems wet-mate subsea connector is a key component.

A number of companies, mostly with existing 30kV to 45kV connectors, are in the process of qualification of 66kV connectors which are to become the norm in the near future. One can mention the following, all being under qualification testing, at TRL 4 to 5:

- MECON connectors (3-pins connector), from Baker Hughes [7]

- Benestad 66 kV AC wet mate connector and penetrator, under qualification within the Ocean Grid project, financed by the Research Council of Norway, [8].
- SpecTRONnx66 from Siemens Energy, [9]
- SEA-VI-66-1250 dry-mate and wet-mate subsea connectors (66kV and 1250A) from SCM Le Mans currently under qualification testing [10]. See **Figure 1** below.



**FIGURE 1:** SCM SEA-VI-66kV-1250A dry mate and wet mate subsea connectors [10].

### 2.3 Hub systems for multiple FWT

Regarding existing electrical power collector hubs for multiple energy devices,

- floating hubs are used for test and pre-commercial scale such as Zephyros at METCenter in Norway, Fukushima Floating Substation in Japan, and the last one being commissioned on the Eolmed pre-commercial farm in the French Mediterranean, with 66kV IAC.

- subsea-hubs exist for limited voltages (mostly below 20kV) and all with dry-mate connectors. One should cite the SMER-REV test center offshore west Atlantic coast in France, in operation since 2018 with the connection of the first FWT in France, ref.[11].

As of today, existing MRE electrical hubs, include mainly demonstrators, test sites and pre-commercial farms, are below 33kV and the ones with 66kV are without wet mate connectors.

From this review, one can see that there is a strong interest from the industry for connection/disconnection systems in particular for IAC architectures based on subsea hubs. These would rely on wet-mate connector technology under qualification. However, for subsea hubs, target CAPEX and functionalities are required, along with qualification process as no specific standard exists. These targets can be assessed by studying the T&I and O&M costs and reliability for various offshore wind farm configurations.

For such assessment, of particular interest regarding the SSH JIP, IEA Wind Task49 design basis report [12] gives data

for development of reference floating wind farm designs. General cost assumptions for key components are given; as well as installation activities assumptions for duration, required equipment and metocean condition limitations.

## 3. MATERIALS AND METHODS

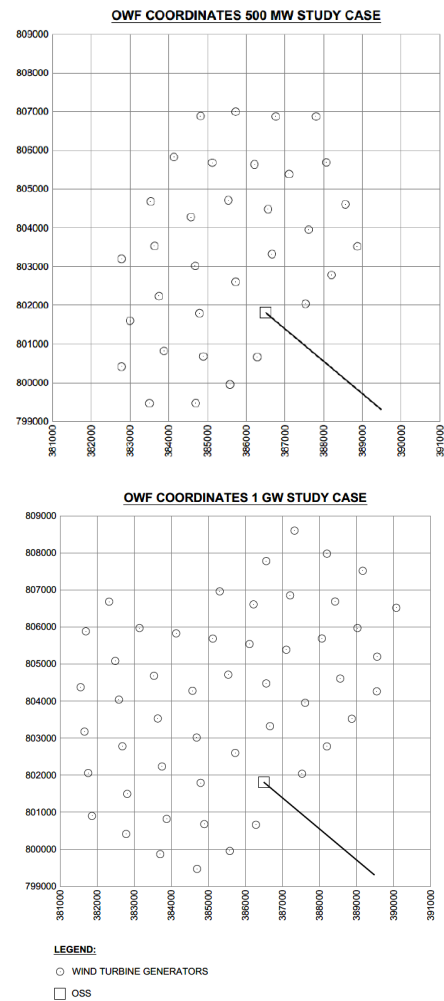
### 3.1 Wind Farms Layouts studied

In agreement with wind farm developers supporting this project, with a view on soon to be developed and near-future floating wind farms, several case studies are chosen for this project. This enables us to determine for which type of wind farm, IAC architecture based on subsea hub present a competitive advantage.

The cases studies cover 500MW farm with 15MW turbines and 66kV IAC at both 150m and 700m water depth (WD). And 1GW farm with 20 MW turbines and 132kV IAC at 150m WD.

For each of these 3 Wind Turbines layouts, 3 IAC architectures are compared: ‘daisy-chain’, ‘fishbone’ and ‘star’.

Therefore, a total of 9 cases are considered within the present study.



**FIGURE 2:** 500MW wind farm with 33-off 15MW WT 1GW wind farm with 50-off 20MW WT layouts.

### 3.2 IAC architectures: daisy-chain, fishbone and star configurations

Figure 3 below, taken from ref.[13], shows schematics of the 3 studied configurations.

The particularity and advantage of the configurations with subsea hubs, is that a single dynamic power cable cross-section is required.

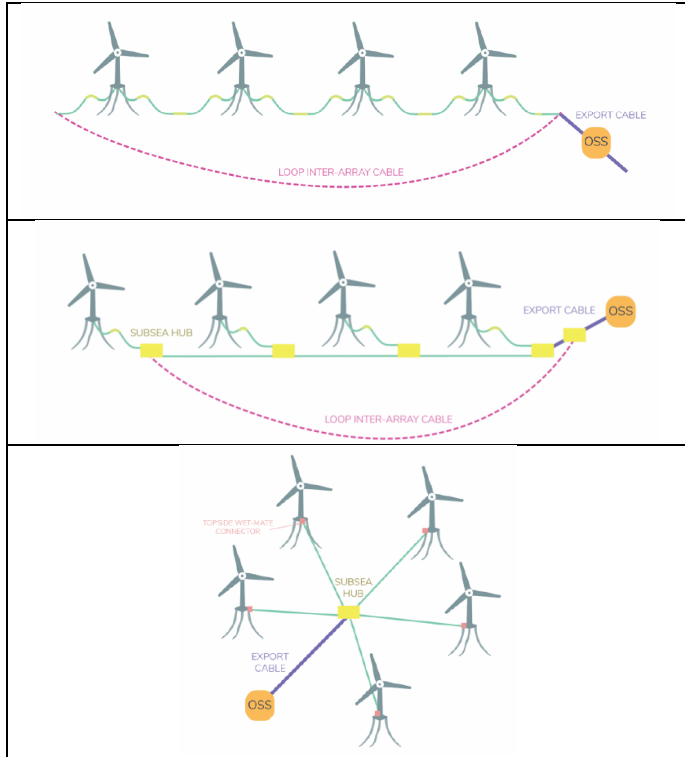


FIGURE 3: Schematic of Daisy Chain, Fishbone and Star array configurations [13].

### 3.3 Power Cables Cross-sections and Properties

For each of the case studies cross sections have been designed for 3-phases power cables, both static and dynamic, all with standard copper conductors and XLPE wet insulation.

For each cable the main characteristics have been determined:

- mechanical characteristics: diameter (OD), weight in air and in water, allowable bending radius (MBR). These are used to set dynamic cables configurations (see next section), and packing, transportation and installation equipment.

- electrical characteristics: nominal current, ampacity in I-tube, ampacity on seabed buried section, resistance & capacitance. These are used by the optimization software (see section below) to determine the optimal IAC system and compute electrical losses.

Figure 4 shows a typical 3-phases dynamic IAC cable (integrating optical fibres); and Table 1 gives mechanical and electrical characteristics of such cable.

	OD (mm)	Weight in air (kg/m)	Weight in water (kg/m)	MBR (mm)
3 x 185 mm <sup>2</sup>	151	46.1	27.6	2275
	Ampacity in I-tube (A) (*)	Resistance 20°C (Ohm/m)	Capacitance 20°C (F/m)	Inductance 20°C (mH/km)
	423	99.10 <sup>-6</sup>	181.10 <sup>-12</sup>	0.404

(\*) ampacity for Daisy Chain, slightly higher Ampacity for single WT.

TABLE 1: Computed Mechanical and Electrical properties of dynamic IAC 66kV.



FIGURE 4: View of dynamic IAC 66kV cable for the Provence Grand Large pre-commercial wind farm.

### 3.4 Dynamic cables configurations

Cable configurations have been designed to connect safely the floating platform to the subsea hub. A platform offset equal to 20% of water depth has been considered in all directions, without any other environmental conditions.

A typical tethered lazy-wave (LW) configuration has been chosen as it drastically reduces the motion at the touch down point (TDP), while maintaining it at the expected location. Figure 5 below illustrates the typical configuration of a lazy-wave with a tether system and introduces the designations of some key parameters.

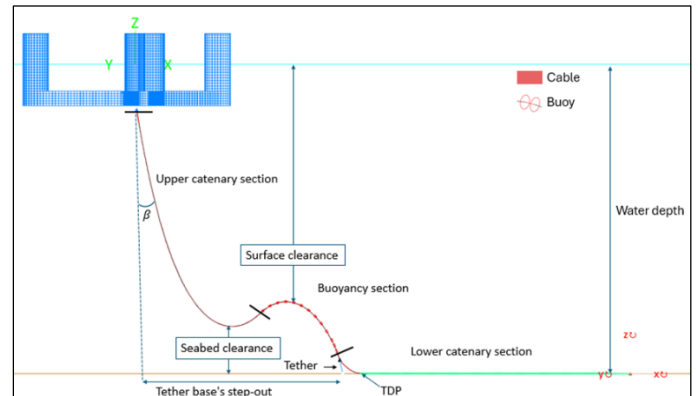


FIGURE 5: General view of tethered lazy-wave configuration for dynamic cables

Tether system is made of a tether clamp, a tether and anchoring that could be a pile or gravity base depending on the loads and on the soil properties. It is to be noted that to ensure a higher upthrust near the tether clamp, a reduced spacing between adjacent buoyancy modules near the tether has been considered compared to the rest of the buoyancy section.

In total, 6 cable configurations have been designed with variations on the water depth (150m & 700m) and cables cross sections (66kV or 132kV, with either 3x185mm<sup>2</sup>, 3x400mm<sup>2</sup>, or 3x800mm<sup>2</sup> power phases).

To allow for a better comparison between the configurations, the same general shape of the configuration has been targeted whatever the cable cross section, the configuration shape depends only on the WD. To achieve this, the size and number of the buoyancy modules have been adapted to each configuration.

**Table 2** below provides the main parameters of the cable configurations, as well as the required buoyancy modules characteristics.

These parameters are to compute an estimate of costs associated with each dynamic cable depending on its cross-section. These costs are then used as input data by OpTEAssoft for optimization of IAC routing and lengths and will also be used for the final CAPEX and OPEX evaluations.

Code	Parameter				Unit	
a	Cable length from I-tube exit to TDP				m	
b	TDP Step out				m	
c	Tether length				m	
d	Tether base step out				m	
e	Cable length from I-tube to tether clamp				m	
f	Seabed clearance (at SAG)				m	
g	Surface clearance (at HOG)				m	
h	Total number of buoys				-	
i	Net up thrust of a single buoy				kg	
j	Total net up thrust				mT	
k	Buoyancy section total length				m	
Code	150m 185mm <sup>2</sup> 66kV	150m 800mm <sup>2</sup> 66kV	150m 400mm <sup>2</sup> 132kV	150m 3x800mm <sup>2</sup> 132kV	700m 185mm <sup>2</sup> 66kV	700m 800mm <sup>2</sup> 66kV
a	230				865	
b	130				270	
c	7				7	
d	130				270	
e	215				850	
f	18				30	
g	120				635	
h	14	14	13	16	18	20
i	270	508	508	508	508	718
j	3.8	7.1	6.6	8.1	9.1	14.4
k	49.1	51.5	47.5	55.5	58.0	95.0

**TABLE 2:** Computed dynamic IAC general arrangement lengths and properties (tethered lazy wave as per Figure 4 above).

## 4. IAC LAYOUT OPTIMIZATION

### 4.1 OpTEAssoft Wind pre-existing functionalities

OpTEAssoft Wind is a software developed by SuperGrid Institute enabling to optimize the electrical connection (especially the inter-array cable routing) of an offshore wind farm [14]. The wind turbines (WT) and offshore substation(s) (OSS) locations are needed as input, as well as a cable database including cost and electrical models for several cable sections. The software optimizes the choice of the cable sections to use, as well as the cable routing, in order to minimize the CAPEX of the IAC. The CAPEX of a cable is computed thanks to cables lengths and the database cost model (including supply of cable, ancillaries and accessories, and installation costs).

### 4.2 New functionalities for Fishbone and Star configurations

OpTEAssoft Wind was initially developed for bottom-fixed WT. New developments have been made to deal with the 3 IAC architectures considered in this study (Daisy chain, Fishbone, and Star configurations), including both static and dynamic cables. Dynamic cables induce extra length of cable and also quite a number of ancillaries (buoyancy modules, tether, clamps etc...). Transport & Installation costs of dynamic cables are thus higher than static cable ones.

### 4.3 IAC Length computation for accurate assessment

To correctly assess the IAC CAPEX, the length of each cable must be accurately estimated, which requires some methodology adaptation to deal with floating architecture (for bottom-fixed, the length of a cable is considered to be the distance between both wind turbines plus an extra length equal to twice the water depth).

For floating turbines, the layout of the dynamic cable between the floating platform and the seabed has a LW configuration shape (W shape, as shown on **Figure 5** above).

Let's call "lazy wave extra-length" the LW length minus its horizontal length (its projected length on the seabed). For the two WD considered in this study, 150m and 700m, as per **Table 2** computed data (codes d and e), this extra length is 215 – 130 = 85m for a water depth of 150 m, and 850 – 270 = 580m for a water depth of 700 m.

While for bottom-fixed architectures cables are connecting WT to offshore OSS, in floating architectures there can be intermediate points: the subsea smart hubs (SSH).

The extra-length (to be added to the distance between terminals) to be considered depends on the configuration, as detailed in **Table 3** below.

3 kinds of IAC architectures are considered in this study, Daisy chain (no SSH), Fishbone (1 SSH per WT), and Star (1 SSH for up to 6 WT at 66kV and 9 WT at 132kV). For SSH-OSS cables in Fishbone, distance correction must be applied. Indeed, each SSH is not located exactly below its WT: it is shifted by the LW horizontal length. Thus, the distance between the OSS and an SSH connected to it must be reduced by the LW horizontal length.

WT type	Cable extremities	Cable type	Extra-length
Bottom-fixed WT	WT-WT	Static	2 * Water depth
	WT-OSS	Static	2 * Water depth
Floating WT	WT-WT	Dynamic	2 * LW extra-length
	WT-SSH	Dynamic	LW extra-length
	WT-OSS	Dynamic	2 * LW extra-length
	SSH-SSH	Static	0
	SSH-OSS fixed	Static	Water depth
SSH-OSS floating	Dynamic	LW extra-length	

**TABLE 3:** Cable Length Model for IAC optimization

#### 4.4 Optimization Routine Algorithm

The routing algorithm initially implemented in OpTEASoft Wind, for bottom-fixed WT, was considering cable layout as straight lines between WT and was ensuring no crossing between cables and obstacles. This algorithm minimizes the CAPEX of the inter-array cables.

For Daisy chain configuration, the routing algorithm used is unchanged. Only the cable length computation is modified, as explained above to account for lazy-wave configuration of dynamic cables.

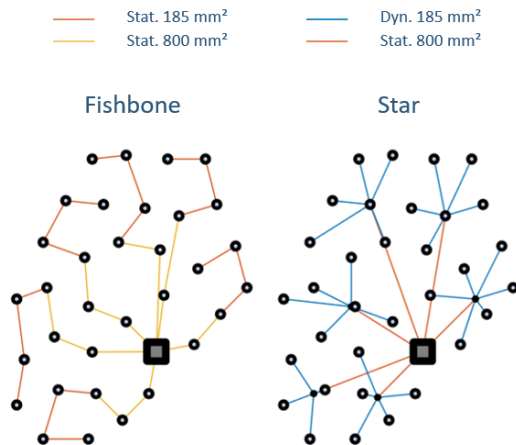
For Fishbone configuration, the same routing algorithm is also used, considering static cables as straight lines between WT. The SSH and dynamic cables are added only then.

For Star configuration, a new routing algorithm has been implemented. First, the WT are clustered to minimize the distances between WT and cluster centers. Then, the location of each SSH is optimized.

#### 4.5 IAC lengths results

The results of the optimization routine described above are presented here for the 500MW – 150m WD cases with 33-off 15MW WT and 66kV IAC (layout pictured on Figure 2 above).

Daisy-chain uses only dynamic IAC: 3x185mm<sup>2</sup> and 3x800mm<sup>2</sup> cables. Fishbone uses Dynamic 3x185mm<sup>2</sup> and Static 3x185mm<sup>2</sup> and 3x800mm<sup>2</sup> cables. Star configuration uses Dynamic 3x185mm<sup>2</sup> and Static 3x800mm<sup>2</sup> cables.



**FIGURE 6:** Fishbone (similar for Daisy Chain) and Star IAC layouts for 150m WD, 500MW & 66kV cables cases.

On **Figure 6**, Daisy Chain and Fishbone configurations cable routes appear similar from top view output; however Daisy Chain only uses dynamic cables with connection systems at both ends whereas fishbone uses only short dynamic cables all identical.

Cable lengths computed for each of these 3 configurations are given in **Table 4** below.

As expected, when accounting for subsea hubs costs, Daisy Chain appears to have the lowest CAPEX (less cable lengths even if all dynamic and no subsea hub). Fishbone present the shortest dynamic cables lengths, however when accounting for subsea hubs, as fishbone requires one small 3-way hub for each WT, total CAPEX is expected to be higher than for Star configuration which presents 6 subsea hubs (5 or 6 ways).

The optimum choice will depend on the O&M costs. The installation and maintenance methodologies are described in next section, from which the OPEX will be derived.

Config.	66kV cable lengths (km)				Total
	Dyn. 185mm <sup>2</sup>	Dyn. 800mm <sup>2</sup>	Stat. 185mm <sup>2</sup>	Stat. 800mm <sup>2</sup>	
Daisy Chain	23.8	23.2	/	/	47
Fishbone	7.1	/	20.8	20.3	48.2
Star	37.1	/	/	17.7	54.8

**TABLE 4:** 66kV cables lengths for Fishbone/Daisy-chain and Star IAC layout for 150m WD, 500MW cases.

## 5. INSTALLATION AND MAINTENANCE

For each of the case studies provided in paragraph 3.1, it has been determined:

- the *Installation & Maintenance philosophy* in order to estimate the time required for each operation and identify the critical loads acting on the submarine cables.
- the *Metoccean data*, which was used to calculate the stand-by time for each installation vessel considered.
- and the *Installation vessel required* based on a methodology developed to filter the most convenient asset for each study case.

The loads acting on the cable will be required in a Detailed design phase to dimension the cables.

The time required for the operations and the kind of vessel and equipment required will be the basis for the determination of the T&I CAPEX and also the O&M OPEX.

### 5.1 Installation & Maintenance Philosophy

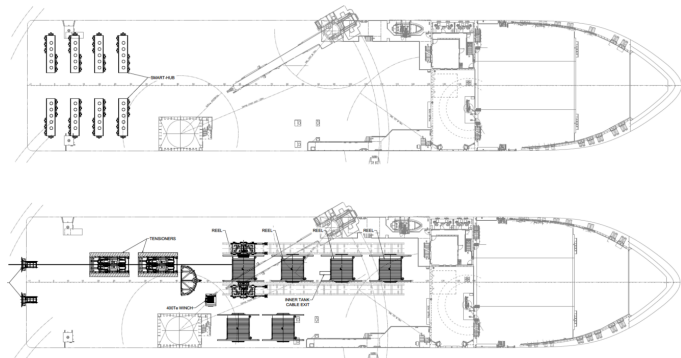
An evaluation of installation methods was conducted to optimize IAC and SH installation processes, aligning with established industry practices where practicable.

The following common installation logistic considerations were applied across the different study cases:

- Cables are assumed to be pre-terminated at the manufacturing facility.

- Subsea Hub (SH) plug structures are assembled onboard, on cable ends already pre-terminated with wet-mate connectors.
- Inter-array cables (IACs) are assumed to be spooled on reels, transported via a transport vessel to the local mobilization port. Cable lengths, as determined using OpTEAssoft, have been verified for compatibility with the selected reel capacity.
- At the local mobilization port, near the installation site, empty IAC reels are offloaded from the Cable Laying Vessel (CLV) and replaced with fully loaded reels.
- The same vessel is assumed to perform both IAC and SH installation operations, where applicable.

The following **figure 7** shows, at the top, an example of the V3 vessel (ref. **Table 5**) deck layout configured for SH installation, and at the bottom, the deck layout configured for IAC installation.

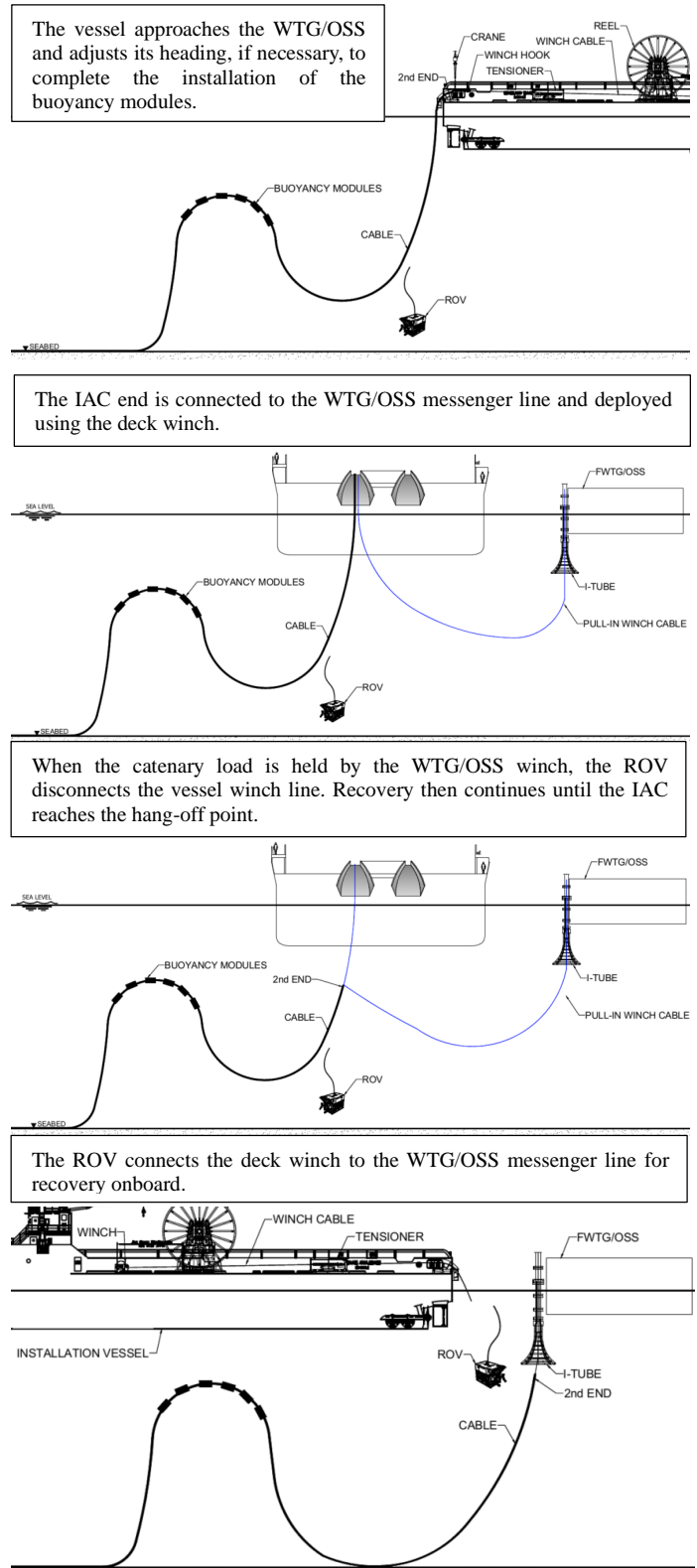


**FIGURE 7:** Deck layout of V3 for SH installation (Top) and IAC installation (bottom).

The deck was configured with two inline tensioners to provide sufficient thrust for cable laying across all installation scenarios. Two deployment chutes are included to support various operations, such as second-end pull-ins into jacket structures with quadrant support. The cable reels are stored in-line and secured to the deck; they are only unfastened when required and are then operated using a reel hub drive system that moves along deck-mounted rails. Additionally, two spare reels are stored on deck and can be lifted into the primary reel position as needed, allowing them to be served by the same reel hub drive.

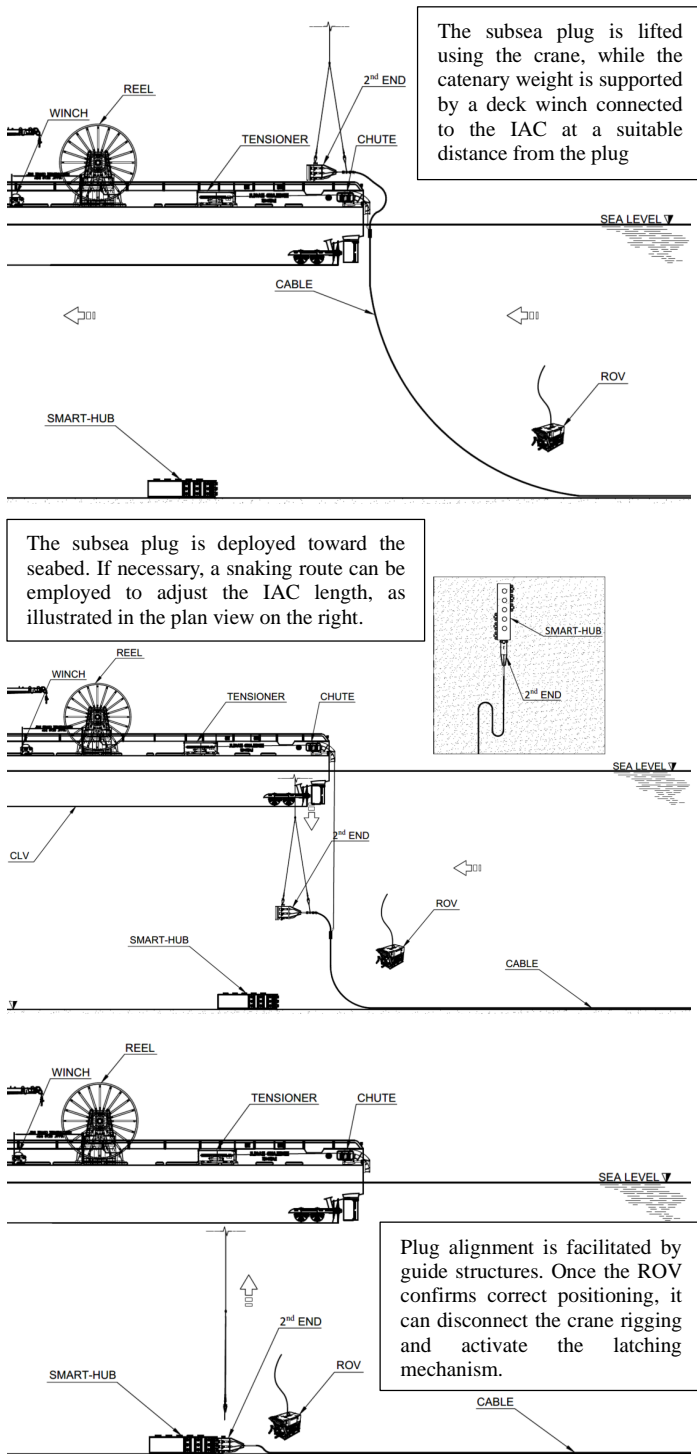
All potential installation scenarios have been investigated to enable accurate calculation of the loads applied to the cables during installation, as well as to determine the time required for each specific operation across the 9 different study cases.

**Figure 8** illustrates, for example, the step-by-step installation sequence of the dynamic IAC second end into a floating object (WTG/semi-sub OSS), which is considered an established and consolidated procedure.



**FIGURE 8:** Step-by-step Dynamic IAC second-end installation at the floating WTG/Semi-sub OSS

**Figure 9** below presents a conceptual step-by-step illustration of an ROV plugging the subsea plug, equipped with wet-mate connectors, into a subsea hub.



**FIGURE 9:** Step-by-step plugging of a second end subsea plug into a SSH

For corrective maintenance, three scenarios have been considered to cover all nine study cases:

1. IAC disconnection and wet storage, along with WTG mooring removal for towing the WTG to port.
2. SH recovery for maintenance or replacement.
3. IAC recovery for jointing or replacement.

The time required for these operations has been calculated and will be combined with the Mean Time Between Failures (MTBF) to estimate the operational expenditure (OPEX).

### 5.2 Metrocean Data

Wave and wind data were extracted from CMEMS – COPERNICUS, ref.[15, 16 and 17], for two locations: off the coast of Marseille in the Mediterranean Sea and offshore of Lorient in the Atlantic coast of France, at water depths of 150m, 300m, 500m and 700m.

Based on exceedance values and considering the non-operational nature of the project, the differences between depth levels were found to be minimal. As a result, only the 500m depth location was selected for further analysis, and its conditions were considered representative for water depths ranging from 150m to 700m.

The stand-by time was applied to each individual IAC or SH installation operation, taking into consideration conservatively the Lorient location and the month of December. Additionally, the P80 was considered.

### 5.3 Installation and Maintenance Vessels

The vessels considered in this study are presented below **Table 5**. Base assumption for the Vessel choice is that the vessel shall perform the SSH and IAC installation.

Vessel Name	Typical general dimensions [Loa x B x D]	Description
V1	80m x 25m x 6m	Small DP2 work vessel with open deck space to be fitted with the required equipment.
V2	110m x 27m x 8m	Medium size DP2 Offshore Supply vessel with large crane capacity
V3	140m x 30m x 12m	Large size DP2/DP3 Offshore Supply vessel with large crane capacity and built-in turntable
V4	170m x 34m x 15m	Large DP2/DP3 CLV with tensioners and Capstan. Turntable storage.

**TABLE 5:** Installation vessels comparison

Each of the above-mentioned vessels is assumed to have different specifications in terms of available deck space, crane and cable-laying machinery capacity, as well as maximum weather limits during operations, in alignment with offshore market availability in Europe.

The installation and maintenance philosophy served as the basis for identifying the critical loads, which were then used to specify the cable lay machinery required for vessels V1, V2, and V3 to ensure they are equipped with the appropriate equipment.

Following in **Table 6** are listed some key specifications for each vessel.

Vessel Name	Dynamic positioning	Free Deck space	CLE capacity	Crane capacity	Weather limits	
					Limiting Hs	Wind Speed
V1	DP2	40m x 20m	Tensioner Max 50Te	Crawler Crane Max 100Te	1.5m	9m/s
V2	DP2	70m x 23m	Tensioner Max 50Te	Marine Crane 250Te	2.5m	13m/s
V3	DP2-DP3	80m x 26m	Tensioner Max 50Te	Marine Crane 400Te	3.0m	15m/s
V4	DP2-DP3	28m x 30m	Tensioner Max 75Te Capstan Max 100Te	Marine crane 100Te	3.5m	15m/s

**TABLE 6:** Installation vessels key specifications

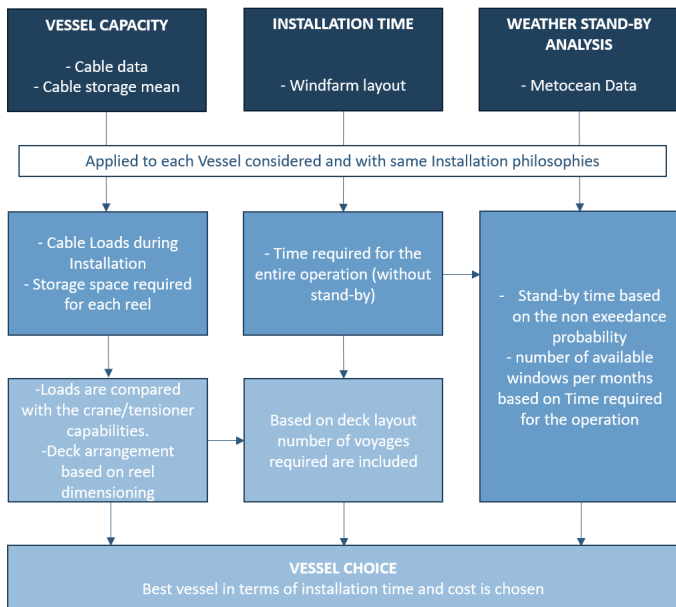
The storage calculation formed the basis for determining the number of SSH and IAC units that could be carried onboard, as well as the number of voyages required to the loading port, which was identified as the nearest local mobilization port.

Following in **Table 7** are listed the Number of SH or IAC Units Loaded per Installation Campaign

Vessel Name	Number of SH or IAC Units Loaded per Installation Campaign		
	SH	IAC on Reels	IAC in Turntable
V1	2	2	N/A
V2	8	4	N/A
V3	8	6	9
V4	3	N/A	26

**TABLE 7:** Number of SH or IAC units loaded per installation campaign

For each combination of vessels and wind farm layouts presented in paragraph 3.1 the filtering methodology presented in **Figure 10** was followed.



**FIGURE 10:** Flow chart for vessel choice

Based on the load calculations and storage assessment, it is possible to summarize as follows the vessel filtering:

- **DP system** - all vessels are DP2 with sufficient capacity to hold position during installation and maintenance. DP3 vessels have much redundant systems and whenever it is possible they should be preferred from the DP2 systems especially during installation operations. V3 and V4 should be preferred for installation operations, DP3
- **Cable Lay Machinery** - on each vessel it is possible to install the tensioner and winch with sufficient capacity to lay and overboard the cable.
- **Crane** - not all vessel has a crane capable to overboard the cable especially in deeper water in particular:
  - Vessels V1 and V4 have crane capacity limitations of 100 mT, which are considered a constraint for maintenance activities involving the lifting of WTG anchors, as well as for installation operations in case studies at 700 m water depth.
  - Vessels V2 and V3 are capable of performing all required installation and maintenance activities.
- **Total Time Required for the Operations** - the following general rules apply:
  - The mobilization time has a large impact on the results: vessels that require less equipment to be installed should be preferred (V2-V3-V4).
  - Better environmental limits provide less standby time. For Vessels V2-V3-V4, the Stand-by time can be considered acceptable.
  - The presence of a Helideck is crucial for safety on installations far from shore, and each specific case should be evaluated carefully.
  - The farther offshore the installation is, the more relevant is the influence of the number of trips to shore with increased costs for fuel and additional time required for transit.

#### 5.4 Operational durations and Vessel choice

Total duration of operations has been determined for all 9 cases. **Table 8** below shows the results for the 500MW-66kV - 150mWD cases.

	Systems - 500MW - Water Depth 150m					
	Daisy Chain		Fishbone		Star	
	Stand-by Time for Installation [days]	Total time required [days]	Stand-by Time for Installation [days]	Total time required [days]	Stand-by Time for Installation [days]	Total time required [days]
V1	88.7	193.6	74.9	263.2	48.1	159.0
V2	66.8	157.1	10.1	172.7	10.1	105.0
V3	3.0	90.6	1.4	154.6	0.9	96.5
V4	1.6	82.7	1.1	151.1	0.8	94.0

**TABLE 8:** Operational durations for different types of vessels for 150m WD – 66kV – 500MW cases.

After careful evaluation, V3 has been identified as the most suitable vessel for SSH and IAC installation due to the following key advantages:

- High crane capacity, enabling efficient handling of heavy components.
- Expansive deck space, providing ample room for equipment and operational flexibility.
- Inner carousel, which can improve the storage capability and flexibility.

For SSH and IAC maintenance, V3 remains the preferred choice due to its superior crane capacity. However:

- V2, equipped with an AHC (Active Heave Compensation) crane, can also be utilized for anchor lifting. Additionally, maintenance activities primarily require large deck space rather than an inner carousel for cable storage, further supporting the use of V2 when necessary.
- V1, could also be utilized if anchor removal is not necessary.

V4 can be a suitable vessel which is offering a complete cable lay machinery without necessity of mobilization and cable lay operations could be engineered to reduce the use of the crane, however it is still to be studied whether pre-terminated IAC can be loaded in the carousel.

## 6. COST COMPARISON DISCUSSION

For all of the 9 wind farm configurations studied, as detailed in Section 3.1, the methodology described in Section 4 and 5 allow to determine:

- IAC cables optimized lengths

It is to be noted that optimization routine with OpTEAssoft uses estimated installation costs that can then be refined once a first assessment is done, depending on cables lengths and their packing, then an iterative loop can be done to further optimize.

- IAC and ancillaries/accessories CAPEX

- Transport and Installation CAPEX depending on metocean conditions.

Methodology also allows computation of Maintenance costs for operations such as Two-to-Port of FWT and SSH retrieval for maintenance.

For the cost analysis, typical rates for vessels and other equipment are proposed within IEA Wind Task Force 49, ref.[12], and the value provided can be used for items where no vendor information is publicly available. Based on the experience from the present JIP partners and sponsors, typical costs for power cables and ancillaries / accessories, subsea hub and associated structures have been defined.

This enables us to compute Procurement, Transport and Installation CAPEX.

For the case presented above in Section 4.5 and Table 4, the daisy chain configuration has the smallest CAPEX, and the most expensive is the fishbone configuration; with the star configuration being in between. Indeed as can be seen on Table 4, total length of IAC is smallest with daisy-chain configuration; and for fishbone and star configuration one has to add the cost of the subsea hubs. Fishbone will be the most expensive due to the cost of the quantity of subsea hub integrating wet-mate connectors and the associated installation costs. Indeed the saving brought by standardizing to one single dynamic cable and ancillaries by the IAC configuration with subsea hubs are largely below the cost of these subsea hubs whatever their functionalities (circuit breaker or other). This is the case for all the scenario studied here.

The addition of subsea hubs increase the CAPEX, and their procurement and installation cost is to be compared to the savings expected during the lifetime of the field with higher wind turbine uptime and production with reduced show down for maintenance.

Then it is of paramount important to correctly assess OPEX costs. Indeed, it is expected that OPEX costs and production losses can be reduced noticeably for architectures with subsea hubs. Reliability of dynamic cables may also be improved by standardization with a single design for an entire field.

O&M is a major cost and at the same time a major area for cost reduction in offshore wind. To correctly assess these costs, one needs to account not only for offshore rates but also reliability, energy yield and production depending on availability, this is shown on work flow diagram of Figure 11, from [18].

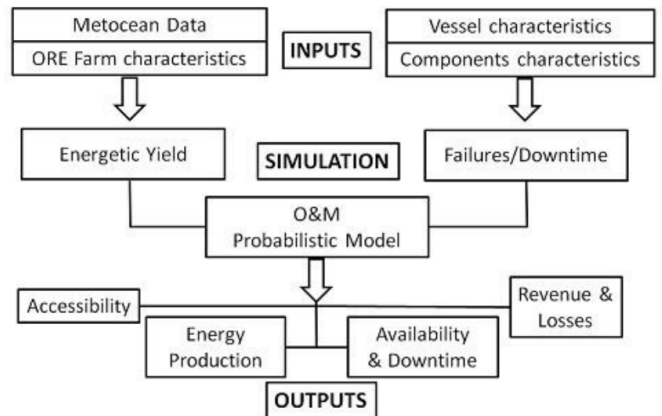


FIGURE 11: Workflow diagram for O&M model [18].

In order to compute OPEX, one needs to estimate the number of interventions for maintenance over the life of field (be it for connectors, subsea hubs retrievals or for FWT stop for maintenance or two-to-port for major events). For this, within this JIP, a reliability analysis is being performed on the IAC system. Reliability results will depend on the cables, subsea hubs and connection equipment used for the 9 studies cases. Reliability study will help derive MTBF for each configuration.

The maintenance costs will be estimated based on the fault frequency. The time necessary for fault detection and repair (MTTR) is required to estimate the loss of production at each failure event. Fault detection within cable network will be estimated for each configuration. Hansen et al, ref.[19], have proposed method for fault detection for fishbone IAC architecture.

IEA Wind Task Force 49 is also to issue as part of its ongoing Task3 an array-level failures risks and mitigation report that may also be used to help set the intervention rate.

Then from the duration of these interventions and the loss of production, a LCoE can be derived. Results will be presented in a future paper.

## 7. CONCLUSION

The subsea smart hub JIP has set a methodology, basis of case studies, to compare CAPEX costs – procurement transport and installation – and OPEX costs of array-system for floating wind farms.

Reliability of the system components will be used to compute LCoE. This will ultimately enable to set specifications / design basis and utilization domain / cost objectives for such subsea hubs.

## ACKNOWLEDGEMENTS

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## REFERENCES

- [1] Apollo & Global Energy Group. P45 Project - Two to Port Offstation Management, ORE Catapult - Floating Offshore Wind Centre of Excellence, public report PN000615-RPT-002, July 2024.
- [2] Apollo & DOF. DC07 Project - Gigawatt Scale Cable and Mooring Installation, ORE Catapult public summary report PN000583-RPT-003, April 2024.
- [3] Bayati, Ilmas and Efthimiou, Louise. 'Challenges and Opportunities of Major Maintenance for Floating Offshore Wind, World Forum Offshore Wind, 2021. White Paper.
- [4] Bayati, Ilmas and Efthimiou, Louise. Onsite Major Component Replacement Technologies for Floating Offshore Wind, World Forum Offshore Wind, 2023.
- [5] Bradley McKay, Optimised cable connection options for floating offshore wind, Cornwall FLOW Accelerator Project / Celtic

Sea floating offshore wind (FOW) initiative, 2022. ORE Catapult report PN000463 CFAR-OC-028-30092022.

[6] Mary Harvey, Luisa Amorim, Luiza Ferreira and John Tapley. Wet Storage and Quick Connectors of Dynamic Cables (SCC). Carbon Trust - Floating Wind JIP - Phase 3 Stage 1 Technical Studies. March 2025.

[7] Laursen, Wendy. Subsea Redesign Underway for Floating Offshore Wind. Offshore Engineer (OE Digital). 23 12 2024. <https://www.oedigital.com/news/520572-subsea-redesign-underway-for-floating-offshore-wind>

[8] Ocean Grid, The Research Council of Norway. New Grid Solutions. [Online] <https://oceangridproject.no/>.

[9] Lucy Bain, Julien Manach, Vincent Boulliat, Machael Mitchell, SIEMENS Energy & Seaway 7, ENERGY HUB, Poster from Seanergy2024 conference and exhibition (Nantes, France, June 2024).

[10] Système et Connectiques du Mans. Technologies / High Voltage. [Online] <https://www.scmlmans.com/product-category/technologies/high-voltage/>.

[11] Izan Le Crom, Centrale Nantes, Sharing knowledge for Ocean Energy. SEM-REV, 7th International Conference on Ocean Energy (ICOE), Cherbourg, France, 12 June 2018.

[12] IEA Wind TCP Task49 - The IEA Wind Task 49 Reference Floating Wind Array Design Basis, NREL report TP-5000-89709, June 2024.

[13] Marcollo, Hayden and Efthimiou, Louise. Floating Offshore Wind Dynamic Cables : Overview of Design and Risks, World Forum Offshore Wind, 2024. White Paper.

[14] OpTEAsoft Wind on the SuperGrid website : <https://www.supergrid-institute.com/offer/opteasoft-wind/>  
OpTEAsoft Wind on YouTube : <https://www.youtube.com/watch?v=ACpQozN3jNI>

[15] IBI\_MULTIYEAR\_WAV\_005\_006. European Union's Copernicus Land Monitoring Service information <https://doi.org/10.48670/moi-00030>

[16] MEDSEA\_MULTIYEAR\_WAV\_006\_012. European Union's Copernicus Land Monitoring Service information. [https://doi.org/10.25423/cmcc/medsea\\_multiyear\\_wav\\_006\\_012](https://doi.org/10.25423/cmcc/medsea_multiyear_wav_006_012)

[17] WIND\_GLO\_PHY\_L4\_MY\_012\_006. European Union's Copernicus Land Monitoring Service information. <https://doi.org/10.48670/moi-00185>

[18] G. Rinaldi, P.R. Thies & L. Johanning, "Improvements in the O&M modelling of floating offshore wind farms", 4th International Conference on Renewable Energies Offshore, RENEW 2020, Lisbon October 2020.

[19] Kristian Hansen, Amjad Mouhaidali, Guangya Yang, Martin Henriksen, Isabelle Najarre. Fault detection and location in floating windfarms with fishbone inter-array architecture. 17th International Conference on Developments in Power System Protection (DPSP 2024), Mar 2024, Manchester, France, pp.33-37, 10.1049/icp.2024.0868. HAL Id: hal-04769896.