FLOATING WIND JOINT INDUSTRY PROGRAMME

Wet Storage and Quick Connectors of Dynamic Cables

March 2025

Contents

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Acknowledgments

The Carbon Trust wrote this report based on an impartial analysis of primary and secondary sources, including expert interviews.

The Carbon Trust would like to thank everyone who has contributed their time and expertise during the preparation and completion of this report. Special thanks go to: Aker Solutions, Axess Group, Baker Hughes, Balltec Engineered Solutions, Balmoral Comtec, Benestad, CRP Subsea, DTI Deepsea Technologies, Hellenic Cables, Oceaneering, Apollo, Orient Cable, Principle Power, Quoceant, Siemens Gamesa, Siemens, Flexible Engineered Solutions, Polytech, SCM, Ditrel, Encomara.

Introduction

As the commercial pipeline for floating offshore wind (FLW) farms grows, there is an increasing need for technologies to improve installation and operation and maintenance (O&M) procedures. One possible route for carrying out major O&M operations is to undergo tow-to-port (TTP) of the floater (platform) and turbine. TTP maintenance requires the connection and disconnection of dynamic cables (as well as mooring lines) from the FLW turbine, an activity that needs to be executed with minimal risks, while maintaining the electrical connection in the array string.

The installation and hook-up of floating wind turbines (FWTs) is a timely operation involving multiple equipment owners, multiple physical interfaces, and various installation disciplines. The dynamic power cable is a critical component in the wind turbine setup, as well as the connection system of the dynamic power cable. Failure of these constituent parts of the connection system will jeopardise the wind turbine operation as well as the ability to generate and export energy.

Quick connector technologies can streamline installation by reducing both time and complexity during initial operations. By enabling wet storage, they also provide flexibility during installation as the cables can be installed before the wind turbine, leading to greater efficiency and cost savings in the long term. These technologies can also help reduce operating costs over the life cycle of the FLW turbine by reducing downtime of power generation, should a major repair be required.

The Wet Storage and Quick Connectors for Dynamic Cables (SCC) project delivered by 2H Offshore Engineering built on previous project results to understand the technology options available to enable quick (dis)connection, along with their risks and limiting factors. The project aimed to understand and evaluate the differences between dynamic cable connection technologies and determine factors contributing to these systems' commercial feasibility.

Project objectives

1. Understand and evaluate different connection technologies for dynamic cables, focusing on the connection procedure, speed of connection, and duration of connection operations compared to traditional methods;
2. Understand different wet storage options when disconnecting the dynamic cable for TTP operations;
3. Compare relevant connection technologies to determine the most feasible and safe options for the connection and disconnection of dynamic cables in commercial floating offshore wind farms.

Methodology

Problem Definition

A technology qualification basis (TQB) was initially developed to define the optimal parameters for the assessment of quick connector technologies and configurations. The TQB, designed to support the evaluation of current and emerging market technologies, was used to identify the functional requirements and constituent components required for effective wet storage and quick connection.

Table 1: The Technology Qualification Basis outlines the optimal parameters for the assessment of connector technologies and configurations.

Parameter/criteria	Qualification requirement
Required constituent technology	*All constituent technologies are identified.*
Environment	*Any environmental limitations for the specific technologies are identified.*
Marine growth	Marine growth should ideally not be considered a concern for the connection and disconnection process. Identify if cleaning is expected and if the bend stiffener latching mechanism is likely to be remotely disconnected.
Service life	The desired service life of the connection system is 35 years.
Wet storage duration	The wet storage will be required for a maximum of 2 years.
Continued power during wet storage	The connection technology or configuration should provide continued power during wet storage, assessed against the daisy chain and the star and fishbone cable configurations, (Figure 1).
Floater type	There should be no restriction on the floater type for the connection technology or configuration.
Water depth	The maximum water depth is expected to be 1,500 m. This is applicable if the connection is laid on the seabed for extended periods during O&M operations.
Voltage rating	The target voltage rating is 66 kV and 132 kV.
Installation efficiency	The connection technology or configuration must improve the efficiency of the installation and hook-up connection duration, with a baseline estimated to be 56 hours (site dependent).
Disconnection and reconnection	Capable of up to 50 mates and de-mates for subsea wet mate and dry mate connectors (as per IEC/IEEE 61886-1). Capable of 5 connections and disconnections for the entire cable assembly.

Market Review and Stakeholder Engagement

A comprehensive market review was conducted to evaluate the availability of quick connector technologies in the market today. This review involved consulting 18 key industry suppliers, including system-level connector technology providers and companies closely associated with connection technology, such as cable manufacturers, platform designers, turbine OEMs and installation contractors.

The objective was to understand the capabilities of existing technologies, identify gaps in offerings and gather insights into the latest developments. Through this process, valuable information was gained that informed the selection of potential configurations and technologies, guiding the overall evaluation and decision-making for the project.

Technology Assessment

Three possible connection configurations were identified:

1. Disconnectable FLW turbine connections that float on the surface of the water during wet storage;
2. Disconnectable FLW turbine connections that are submerged and buoyant during wet storage;
3. Modified traditional configuration:
   - Disconnected and laid on the seabed or supported with a temporary floating structure;
   - Disconnected subsea and not at the FLW turbine.

Each configuration requires specific system-level connection technologies, along with constituent level technologies to ensure the wet storage capability. Constituent level technologies including mechanical hang-off, wet mate connectors, dry mate connectors and bend stiffener connectors were investigated, along with several other connector technologies. Analysis of the mooring systems and buoyancy required for wet storage was not included as part of this project.

A shortlist of connector technologies and configurations was selected, and a thorough life assessment conducted against the current methods for dynamic cable termination. The life assessment considered the alignment with the TQB and also the technical and operational feasibility, technology readiness level (TRL), manufacturing capabilities, operational considerations (such as safety and risks) and indicative costs of these technologies. The assessment also included the definition of wet storage options for the technologies identified, and provided guidance on the maximum length of time and environmental conditions under which wet storage is possible as part of the design criteria.

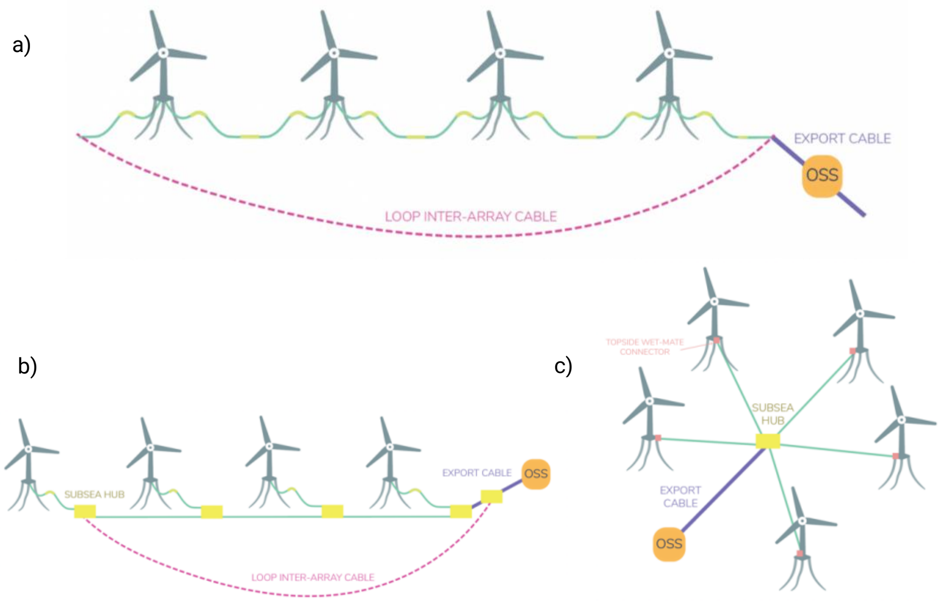

Figure 1: Simplified illustrations of a) daisy chain array; b) fishbone configuration; and c) star configuration. OSS = offshore substation. Sources: WFO, information from Siemens Subsea.[1]

[1] Floating Offshore Wind Dynamic Cables: Overview of Design and Risks, World Forum Offshore Wind (WFO), 2024

Key findings

1 **No existing connection technology addresses all the requirements for quick connection and wet storage of FLW turbines.**

- Currently, no singular technology addresses the requirements for quick connection and wet storage required for floating wind as established in the TQB. Each of the technologies and configurations assessed required integration with technology supplied by other parties, as outlined in Table 2. The connection of the dynamic power cable to a FLW turbine is a complicated system, with multiple physical interfaces (that are the shared responsibility of different hardware suppliers) that must complement one another.
- Additional constituent technologies can be combined with modified traditional connection configurations to enhance functionality. These combinations can improve efficiency and also be considered a tool to assist wet storage.
- System-level connection technologies are being developed for the purpose of integrating essential constituent technologies that offer greater functionality for quick connection and wet storage capability. Some of these new technologies are looking beyond the dynamic power cable and are also targeting a comprehensive wet storage solution, including the mooring lines of the floater. The interaction with the mooring lines was not assessed as part of this project.

Table 2: Matrix of FLW turbine connector technologies and configurations and the limiting constituent technology parts.
** = site specific*

Constituent technologies		Disconnectable FWT connection - floats during wet storage	Disconnectable FWT connection - submerged and buoyant during wet storage	Modified traditional connection (disconnect at turbine)	Modified traditional connection (disconnect subsea)
FLW turbine connection assembly hardware	Electrical connector		Wet and dry mate connectors	Dry mate connectors	Wet and dry mate connectors
FLW turbine connection assembly hardware	Mechanical hang off		Submersible or system-integrated hang off	Submersible mechanical hang off	
FLW turbine connection assembly hardware	Bend stiffener connector *				
FLW turbine connection assembly hardware	Bend stiffener *				
FLW turbine connection assembly hardware	I-tube/ interface	Disconnectable I-tube	Connection system		
Other required hardware			Subsea anchors and mooring lines	Hardware solution to connect two cables	

Continued power transmission	Possible with daisy chain configuration	Connection technology dependent	Reconnect cable at surface and lay on seabed	Possible with fishbone or star cable layouts

(grey)	The constituent technology part is not expected to be a barrier as it is either not applicable, relies on existing hardware or accessible hardware.
(green)	Constituent technology is available but may present a potential limitation.
(blue)	The constituent technology part required is a new or differentiating technology.

Figure 2: Colour code key for the constituent technology parts described in Table 2.

2 **Temporary wet storage of dynamic power cables on the seabed adds significant risk for cable and constituent technology damage.**

- Laying the cable on the seabed during wet storage risks damage to the cable due to interaction with the seabed. Mitigation techniques include detailed seabed survey plants, temporary cable routings to suit local topography and detailed analysis of the expected cable movement due to currents, with the development of relevant mitigation plans. Despite mitigation measures, laying the cable on the seabed will always encounter risk of cable damage and long term integrity of the cable may be impacted following a period of wet storage on the seabed.
- In some configurations, the connection assembly - including the mechanical hang-off connected to the power cable - may be submerged for a period of time for wet storage. Additional risks include corrosion of the connectors, marine growth on the mechanical components and compatibility of connection parts with seawater.
- Another configuration option is to wet store the connection system in the water column, using buoyancy modules to support the power cable or additional constituent technologies in the water column if there is no buoyancy built into the connection system. This solution requires the installation of a dedicated mooring system for station keeping and a market buoy to aid recovery and reconnection. There is, however, a high risk of compromising cable integrity in the wet storage configuration when suspended in the water column.
- The design of the subsea power cable must consider the anticipated wet storage scenario along with the in-place configuration connected to the FLW turbine. The design analysis for the power cable should include extreme and fatigue loads. Power cable design feasibility is expected to be challenging in shallow waters and harsh environments such as the northern North Sea.

3 **Technology providers are uncertain about the ownership of the cable connection for future floating offshore wind projects.**

- A common concern raised during the market review and engagement phases of this project is the uncertainty over who will ultimately be responsible for the power cable connection to a FLW turbine. Providing clarity over the ownership and responsibility could ensure future compatibility between constituent parts.

- As with the oil and gas industry, it is unlikely that a single hardware supplier will assume ultimate design or installation responsibility for the entire connection assembly due to the liability exposure from 'others' hardware.

4 **There are connection technologies and configurations that can offer wet storage and increase connection efficiency compared to conventional connection methods.**

- Out of the connection technologies and configurations assessed as part of this project, some solutions can offer wet storage whilst increasing connection efficiency. The connection and hook-up process could be increased by sixfold, taking between 4 and 6 hours, against the baseline of 56 hours. This significantly improves the current method of cutting and removing connection hardware and laying the power cable on the seabed.
- Based on the market review and responses from suppliers, the system level connection technologies that include wet mate connector technology are estimated to have a significantly higher CAPEX (2 to 6 times) than a traditional connection configuration, which uses dry separable (non-submersible) electrical connectors.
- O&M strategies will be a driving factor in the technology selection and configuration, and improvements in operational efficiency offer a potential reduction in OPEX compared to traditional connection configurations.
- A full cost analysis should be conducted for each technology and configuration identified, considering the wind farm size, layout and developer operational strategies, such as the requirement for TTP maintenance.

5 **The reliance on integration with constituent technologies may be the limiting factor for readiness of 66 kV and 132 kV connection systems.**

- For the category of connector technologies which are disconnectable and can be submerged and buoyant during wet storage, the limiting factor for 66 kV is the qualification of wet mate connector technology. Through industry engagement, it is understood that several wet mate connectors are in the advanced stages of TRL and are on track for qualification in 2025. This would enable connector technologies in this category to be qualified between 2027 to 2030.
- When considering 132 kV compliant systems, the limiting factor for the connection technology is the 132 kV wet mate connector. Availability of connectors in a 132 kV system requires a 5 to 9 year development period when market conditions are considered favourable for technology suppliers to begin major investment.
- A modified traditional connection configuration using dry separable (non-submersible) electrical connectors is type qualified for 66 kV and only requires qualification of some of the constituent hardware to meet 132 kV.
- Dry separable connectors rated to 132 kV are used in land applications and would not require specific qualification for its use offshore. Enabling wet storage capability would require redesigning constituent components for larger electrical connectors, and a qualification programme for 132 kV would be required.

- The bend stiffener and bend stiffener connector are not technically designed for a given voltage rating. Therefore, validating existing qualified hardware with respect to size and external loading limits applicable for a 132 kV would likely not require new hardware or qualification.
- Similarly, a concern raised during the market review and engagement is the uncertainty of future cable layout configurations for commercial floating wind farms to use either a daisy chain layout versus a star or fishbone layout. This challenge was one of the hindering factors for developing a continued power solution with a daisy chain cable layout for certain technologies.

Industry needs/innovations

1 **The development of a framework for qualification of cable connection systems to FLW turbines would provide more guidance to suppliers for each of the constituent parts of the overall system.**

- The constituent technologies that make up a dynamic power cable connection system are provided by multiple hardware suppliers, covering multiple disciplines. Each technology has a dedicated design code that is followed in full, or in principle if the scope of the code lags behind the development of the technology.
- There is not a single design code or industry guidance document for the qualification of the entire connection system of a dynamic power cable. The lack of cohesion in the set of standards followed by each company results in a lack of standardisation of the connection system. A lack of standardisation in the qualification programme can encourage innovative technologies to be developed but can increase risk around the final qualification standard for the technology.

2 **Development of a design code for qualification of electrical connectors of voltage higher than 36 kV.**

- The main code for designing and qualifying wet mate electrical connectors is IEC/IEEE 61886- 1, which applies to voltages up to 36 kV. Technology providers currently developing 66 kV wet mate connector technologies each follow their own framework for qualification, the details and results of which are not known.
- The development of design standards for 66 kV and 132 kV wet mate electrical connectors should be considered a priority task by the industry.
- The availability of qualified wet mate connector technology is driving the schedule for qualification of 66 kV system level connection technology and should also be prioritised.

3 **Conduct further assessment and validation of wet storage dynamic cable configuration(s).**

- Nearly all system-level technologies for dynamic power cable connection systems state they can provide a submersible wet storage configuration during TTP maintenance of the FLW turbine. However, further analysis is required to assess the dynamic power cable's response and ensure that the wet storage configuration does not affect cable integrity.

- Further assessments should be conducted to understand extreme load and fatigue performance, considering a number of lazy wave 66 kV power cable configurations, different mooring systems and different environmental conditions.
- To achieve the submerged wet storage configuration solution, a mooring system will need to maintain station-keeping of the power cable termination within the water column. The number of mooring lines required, water depth limitations, and whether these systems are permanent fixtures or temporary installations is currently unknown and should be the subject of further analysis.

ABOUT THE FLOATING WIND JIP

The Floating Wind Joint Industry Programme (Floating Wind JIP) is a collaborative research and development (R&D) initiative between the Carbon Trust and 17 leading international offshore wind developers: bp, EDF Renouvables, EnBW, Equinor, Kyuden Mirai Energy, Ørsted, Ocean Winds, Parkwind, RWE Renewables, ScottishPower Renewables, Shell, Skyborn Renewables, SSE Renewables, TEPCO, Tohoku Electric Power Company, Total Energies and Vattenfall.

The primary objective of the Floating Wind JIP is to overcome technical challenges and advance opportunities for commercial scale floating wind. Since its formation in 2016, the programme scope has evolved from feasibility studies to specific challenges focusing on:

- Large scale deployment
- De-risking technology challenges
- Identifying innovative solutions
- Cost reduction

Stage 3 of the Floating Wind JIP commenced in 2022, and projects are expected to run until early 2027. With several commercial scale floating offshore wind farm projects in design phase and having the ambition to be commissioned by 2030, the industry needs to address several challenges. The 17 Floating Wind JIP partners agreed on six research areas where further understanding and advancement is required to reach full commercialisation of floating offshore wind projects.

Electrical systems	Mooring systems	Logistics	Windfarm optimisation	Foundations	Asset Integrity and monitoring

This SCC project addresses the ambitions of the Electrical Systems research area:

Electrical systems

1	Understand full electrical system design for commercial scale floating wind farms.
2	Define dynamic array and export cable architecture for commercial scale floating wind.
3	Advance understanding of dynamic cable failures to accelerate towards more reliable and insurable systems.

The Stage 2 summary reports can be found here: Phase I, Phase II, Phase III, Phase IV and Phase V.

ABOUT THE CARBON TRUST

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Our mission is to accelerate the move to a decarbonised future. We are your expert guide to turn your climate ambition into impact.

We have been climate pioneers for more than 20 years, partnering with leading businesses, governments and financial institutions to drive positive climate action. To date, our 400 experts globally have helped set 200+ science-based targets and guided 3,000+ organisations and cities across five continents on their route to Net Zero.

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Published in the UK: 2025