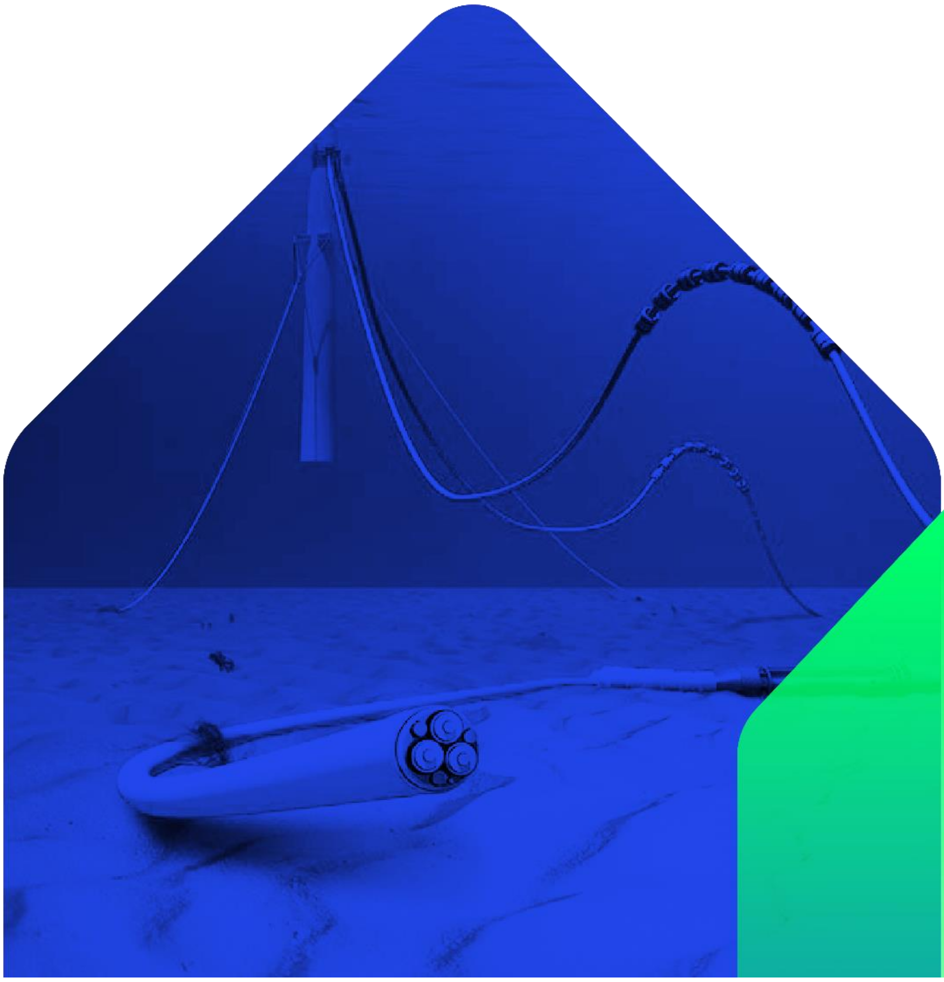
FLOATING WIND JOINT INDUSTRY PROGRAMME

Dynamic cable failure rates

December 2023



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

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Introduction

This Dynamic Cable Failure Rates (DCFR) project was delivered by Offshore Wind Consultants in collaboration with the University of Exeter for the Floating Wind Joint Industry Programme (JIP).

With floating wind technology only approaching its early commercialisation phase, dynamic cable systems for floating wind are still under development. Since the dynamic nature of floating offshore wind structures presents unique challenges, and with large scale floating wind installations planned in the coming years (e.g., 4.5 GW in the Celtic Sea), the development of robust dynamic cable systems and solutions is essential.

Knowledge about both static and dynamic power cable technology, and their associated lifetimes, is a key limiting factor in the move towards the realisation of successful installation and operation of floating offshore farms. However, due to the immaturity of the technology and its short history in the industry, there is currently a limited understanding of the fatigue lifetime and expected failures of dynamic cable systems.

Improving the understanding of subsea cable failure rates and mechanisms is integral to the development of the offshore floating wind industry. To achieve this, the collection, classification and analysis of failure rate data is critical to determine and mitigate the highest risk failures. Furthermore, standardisation of rules and regulations for the design and testing of dynamic power cables could be seen as essential to mitigate risk and provide a good foundation for confidence in dynamic cable operation and longevity once installed in a floating offshore wind farm.

This aims of the project were to provide insight into the basis of feasibility for the application of dynamic cables in floating wind, as well as to advise on the potential changes required in dynamic cable design, qualification, and testing.

This summary report outlines the project's key findings based on the objectives and highlights future requirements or needs for the industry.

Project objectives

1. Obtain a better understanding of dynamic cable failure rates and standards, to inform the data collection requirements for future floating wind development and dynamic cable modelling and testing.
2. Provide insight into dynamic cable design considerations for preventing failure events.
3. Provide recommendations for the standardisation of testing and fatigue modelling methods for dynamic cables.
4. Provide recommendations on a standard process for working with dynamic cables, leading to reductions in overall costs.

Methodology

The project methodology sought to provide a better understanding of dynamic cable failure rates, modes, and root causes, as well as to evaluate existing cable testing and qualification standards through extensive literature and data review, and stakeholder engagement. In addition, a methodology was proposed to approach both the load modelling and fatigue assessment that could be used to understand the impact of a wide range of dynamic cable design decisions on its fatigue life.

The cable failure literature and data review covered both static and dynamic systems in offshore renewables and oil and gas contexts, and was conducted in the following stages:

i. mapping the relevant components and sub-assemblies of dynamic cable systems,
ii. reviewing failure data sources,
iii. analysing failure data,
iv. contextualizing failures with a view to lifetime phases and system configurations for floating wind.

Surveys and interviews with key industry stakeholders (including cable and ancillary manufacturers and research institutes) were undertaken to obtain industry views on the main risks involved in working with dynamic cable systems and to understand the main challenges that are anticipated in the future.

The review of standards related to submarine dynamic power cables was mainly focused on mechanical, electrical, and fatigue testing, and covered 62 publications from multiple regulatory bodies, including DNV, ISO, API, IEC, CIGRE, ABS, and BV. The standards were categorised based on three criteria:

- Type of cable (static/dynamic)
- Field of application (oil and gas/offshore renewable energy)
- Type of component (cable/ancillaries)

The identified standards were further screened regarding their direct applicability to subsea cables; the resulting shortlist of standards was used to assess and summarise best practices, and recommendations were made for future development and applications of standards for dynamic subsea cables.

Cable load modelling and fatigue assessment was carried out using OrcaFlex software and was focused on a single reference model – a semi-submersible floater, water depth of 150m and harsh environmental conditions. The dynamic cable parameters were varied in order to ascertain the impact on the resulting loads and cable fatigue. It is important to note that although different offshore sites and floater/cable configurations will have different absolute fatigue life's, the relative qualitative assessment performed identifies relations and trends which can be applied more widely.

Key findings

Due to few installations and a short history of dynamic cable failures, there is currently only very limited data focused on dynamic cables specifically. The review and analysis of the available failure rate data of static offshore wind subsea cables yielded an average failure rate envelope between 0.0019 failures/km/year and 0.0213 failures/km/year[1], with installation and manufacturing as the most common failure modes.

While the historically observed causes of cable failure will continue to be crucial to address, due to the cyclical nature of wave, wind and current loads in floating offshore wind structures, fatigue is expected to play a much more important role in dynamic cables systems.

1 **There are no comprehensive standards for the testing and qualification of dynamic cables, with too much reliance on standards intended for the oil and gas industry.**

- Dynamic subsea cable systems are still under development with no large-scale commercial farms yet installed. The testing and qualification of dynamic cables and associated infrastructure is therefore also at a developmental stage.
- Of the 62 standards and guidelines reviewed, 16 were directly applicable to subsea power cables (11 indirectly applicable). Only 6 publications were directly applicable to dynamic subsea power cables, but all of them refer to previous standards.
- The main concerns relate to the over-reliance on oil and gas publications, implying that standards are not specific to offshore wind applications. For example, certain oil and gas standards imply high safety factors and installations in very deep waters, which are less applicable to most floating renewable energy installations.
- No existing cable standard gives detailed guidance on selection, design, and use of ancillary equipment such as bend stiffeners and buoyancy modules, especially for high voltage dynamic cables.

2 **Fatigue is expected to be one of most the predominant failure modes for dynamic cables that the industry will have to address moving forward, primarily by ensuring adequate cable design.**

- A combination of high tension and large curvature over many wave cycles is the primary cause for cable fatigue damage.
- Dynamic cable fatigue damage is in large part driven by curvature as the cable transitions from the water column into the I-tube. Due to the proximity with the sea surface and the floater, the cable will see the most hydrodynamic load applied to it and higher bending in this location. It is also relatively close to the hang-off, where the weight-derived tension is the highest. However, all dynamic sections need to be carefully analysed as other locations can also be of concern.

[1] Using the failure rate data from Warnock et al. (2019) and additional sourced data regarding asset age and cable length.

- For the modelled cable design and environmental conditions, much greater fatigue damage was observed when the direction of environmental loads was closely aligned with the cable orientation. Based on these results, cable azimuth should be designed away from the prevalent wave directions.
- Greater cable diameter was found to induce higher hydrodynamic load ranges, and consequently higher stress ranges inside the cable, leading to reduced fatigue lifetime.
- Under the specific cable design and load conditions applied in the model, marine growth was found to increase fatigue life, primarily by decreasing curvature at the critical section where the cable exits the I-tube and bend stiffener.

3 **Comprehensive model inputs are required and should be validated for dynamic cable fatigue modelling to be accurate and applicable to real world scenarios.**

- Detailed site conditions, floater specific modelling (considering the floater's shape and weight distribution, its dynamic response to environmental loads), and mooring system specifications are essential in modelling and can help reduce failure risk.
- It is important to define an accurate and relevant cable segmentation, as well as to have consistent cable global parameters.
- Cable ancillaries (buoyancy modules, bending stiffeners, I-tube) must be modelled, including sensitivities regarding the containment between the dynamic cable and its ancillaries. Ancillary specifications should be provided by manufacturers as they become available.
- Consistent and related S-N curves and stress factor data must be provided and be consistent with the actual dynamic cable studied.
- Future studies would be advised to always run both with-current (and using the maximum floater offsets) and without-current cases to ensure all possible catenary shapes are captured, since it appears to have an effect. In addition, local analysis accounting for stick-slip behaviour in the cable is recommended.

4 **Dynamic cable accessories need to be appropriately designed and implemented to provide the necessary support to the full cable system and to prevent accessory-related failures.**

- The dynamic cable system includes not only the cables themselves, but also a range of accessories and components used to connect, stabilise and protect the cables, as highlighted in **Figure 1** below.
- Bend stiffeners were the accessories indicated as the most likely to impact the probability of the dynamic cable itself to fail in terms of how well it is designed, manufactured, or installed.
    - Dynamic bend stiffeners can be an excellent solution to cope with heavy axial loads and curvatures to avoid overbending and fatigue failure. However, these components are currently limited to a certain cable size.

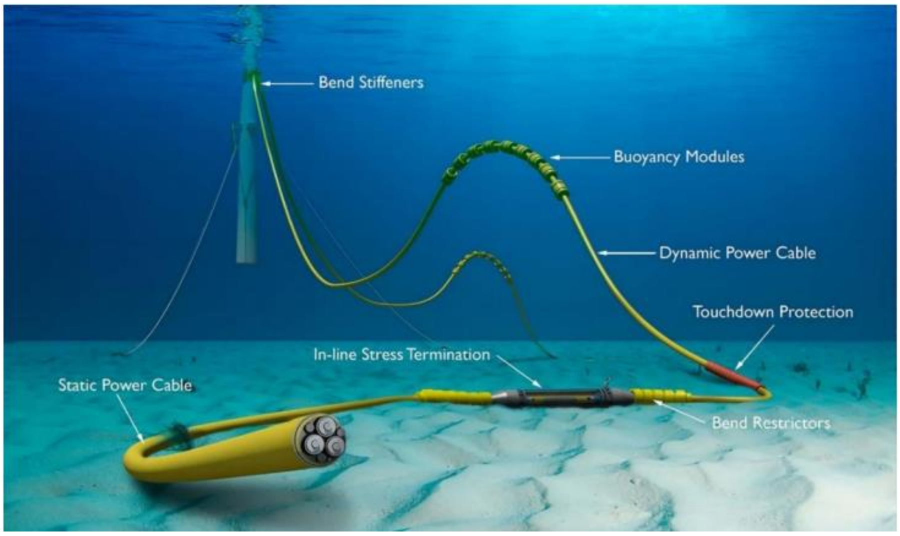


Figure 1. Primary components of dynamic subsea cable systems. (Joshua Bauer, NREL)

- Buoyancy modules also require further development in design, with emphasis on clamps used to secure the distributed buoyancy modules to the cable. Fewer, larger buoyancy modules can reduce the installation's time, costs, and HSE hazards, but considerations on the system's dynamic performance are necessary.

Industry needs and innovations

1 Investment in cable testing facilities is needed to enable full-scale, combined testing of dynamic cables.

- Current testing approaches that make use of S-N curves of material coupons are likely to lead to conservative estimates of the fatigue life of complete dynamic cables. Alternative methods should be investigated, such as full-scale cable fatigue tests for representative cables, allowing to determine the fatigue life of the full assembly.
- Combined fatigue testing to concurrently assess dynamic cable performance under mechanical, electrical, and thermal stress would make testing more representative. Further development of non-destructive testing techniques to enable monitoring and assessment of fatigue failure during testing (rather than through dissection at the end) would improve failure detection and cable qualification.
- Testing for cable ancillaries should be more specified, including tests on their own (e.g., simulating extreme metocean conditions) as well as combined tests with the cable itself to get a more realistic assessment of failure modes and component capacities.

2 The industry would greatly benefit from specific dynamic cable standards and load classes.

- Increased effort is needed to develop bespoke standards for the offshore renewable energy industry and reduce reliance on oil and gas standards, where possible.

- The design and loading of dynamic cables are highly dependent on environmental conditions, installation method, cable configuration and floater type. As a result, current cable designs and test programs are project specific. However, large scale commercial installation will require a more standardised design and test program, including representative design load classes.

3 **Continued stakeholder cooperation and knowledge exchange will be crucial for further development of dynamic cable systems.**

- The development of new testing programmes and cable standards will require the collaboration of multiple stakeholders, including cable manufacturers, the ancillary supply chain, certification agencies, installation contractors, insurers, test facilities, researchers, and asset owners.
- An industry-wide platform for sharing the experience and knowledge between different segments of the industry could be very beneficial. A stronger interface between the suppliers and manufacturers of different components could facilitate the cable design process.
- The collection, classification and analysis of failure rate data is critical to determine and mitigate the highest risk failures. Higher data quality and more data availability will be instrumental for quantifying and reducing the risk of cable failure for floating wind installations.

References

Warnock, J., McMillan, D., Pilgrim, J. and Shenton, S., 2019. Failure rates of offshore wind transmission systems. *Energies*, *12*(14), p.2682.

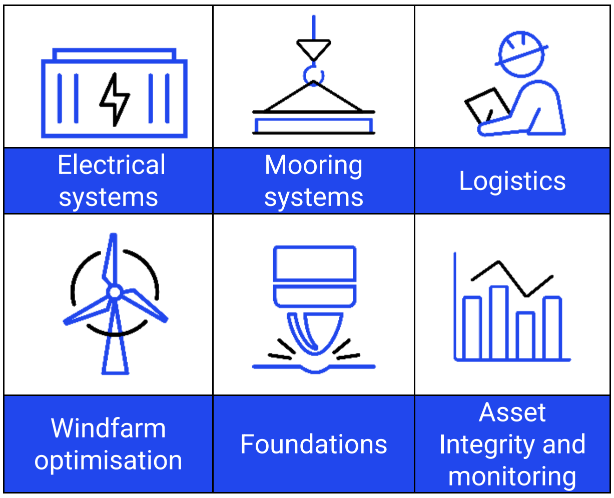
ABOUT THE FLOATING WIND JIP

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
- Industrialisation
- De-risking technology challenges
- Identifying innovative solutions
- Cost reduction

This Dynamic Cable Failure Rates and standards (DCFR) study was delivered under Stage 2 Phase V of the floating wind JIP. Contrasting to previous phases, the Floating Wind JIP partners decided to publish individual project reports for Phase V due to an increased number of projects with different durations. The summary reports for previous Stage 2 phases can be found here: Phase I, Phase II, Phase III & Phase IV



Research areas

The Floating Wind JIP selected six research areas where further understanding and advancement is required to reach full commercialisation of floating offshore wind projects.

These research areas are explored through different Carbon Trust research mechanisms such as common R&D projects, discretionary projects and industry competitions

ABOUT THE CARBON TRUST

Who we are

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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