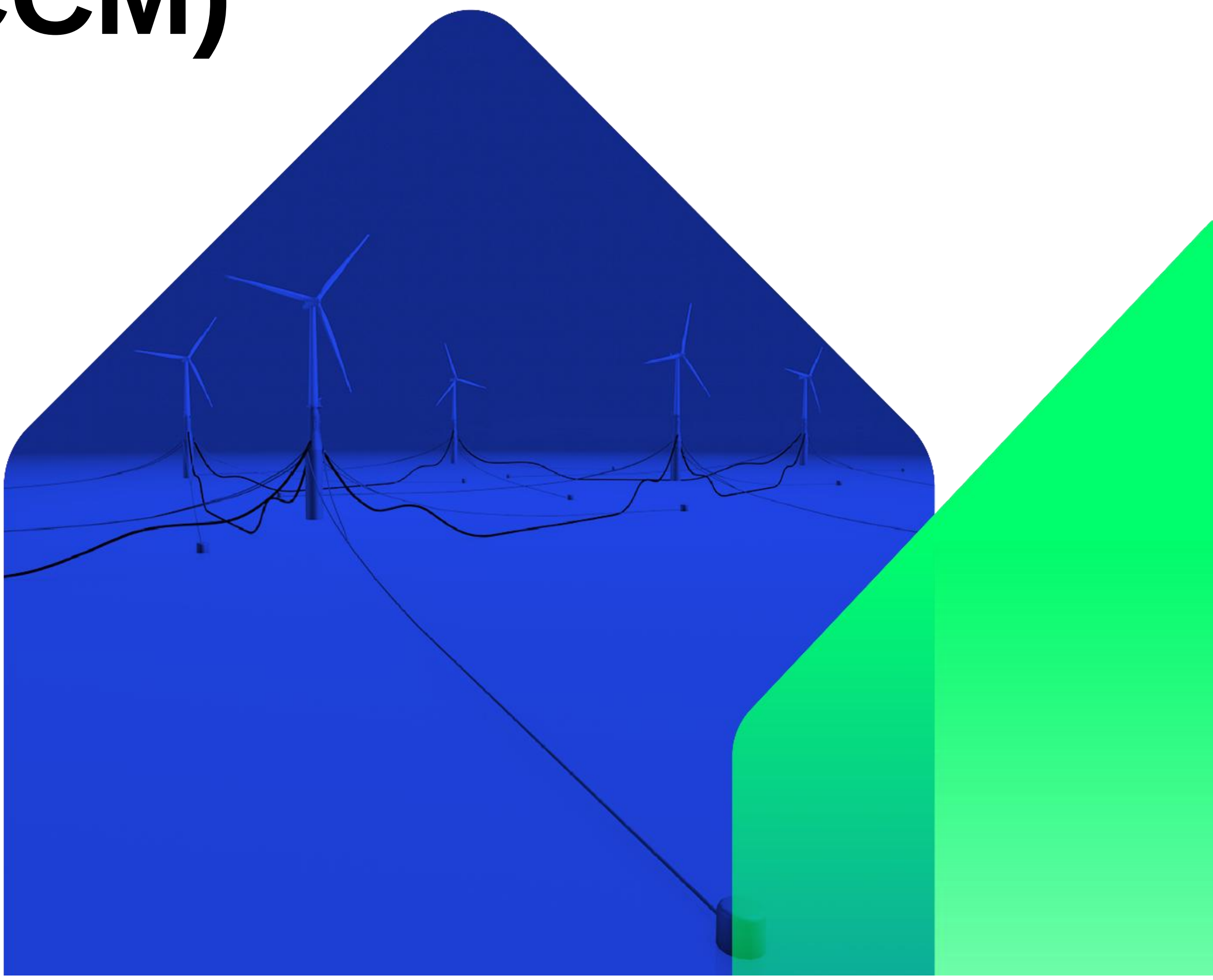
FLOATING WIND JOINT INDUSTRY PROGRAMME

Dynamic Cable Condition Monitoring (DCCM)

January 2025



Contents

Authors:

Karolina Zieba
Associate, Carbon Trust
karolina.Zieba@carbontrust.com

Luisa Amorim
Manager, Carbon Trust
luisa.amorim@carbontrust.com

George Walker
Associate Director, Arup
George-A.Walker@arup.com

Emily Walport
Senior Engineer, Arup
Emily.Walport@arup.com

Dr Philip Thies
Professor of Renewable Energy, University of Exeter
P.R.Thies@exeter.ac.uk
karolina.zieba@carbontrust.com

Dr Ajit Pillai
Senior Lecturer/Royal Academy of Engineering Research Fellow, University of Exeter
A.Pillai@exeter.ac.uk

Roman Svoma
Director, Powersure Technology Ltd
Roman.Svoma@powersuretechnology.com

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 that has contributed their time and expertise during the preparation and completion of this report. Special thanks go to: MeyGen PLC, Cambridge Marine Ltd, Codan Forsikring A/S, Viper Innovations Ltd, Sonardyne, FibrisTerre, Synaptec Ltd, FEBUS Optics, FBGS, Indeximate Ltd, Ocean Information Services Ltd, NKT A/S, Proserv, Luna Innovations.

CARBON TRUST | OFFSHORE WIND

DYNAMIC CABLE CONDITION MONITORING (DCCM)

Introduction

The Dynamic Cable Condition Monitoring (DCCM) project was delivered by Ove Arup & Partners in collaboration with the University of Exeter on behalf of the Floating Wind Joint Industry Programme (Floating Wind JIP).

The vulnerability of subsea cables to electrical and mechanical risks due to marine exposure is a critical concern. Even in bottom-fixed offshore wind installations, as indicated by insurance data, cables pose the most common failure risk. Implementing condition-based monitoring can be instrumental in detecting premature failures early and informing design decisions to enhance reliability. However, the lack of consensus on reliable and cost-effective monitoring methods for dynamic cables remains a challenge.

To address this, DCCM aims to identify the most effective condition-based monitoring techniques for dynamic cables in a floating offshore wind context.

ARUP | University of Exeter

PowerSure Technology Limited

Project objectives

1. Evaluate the risks associated with dynamic cables and understand the different mitigation techniques.
2. Assess the different dynamic cable motions and lifetime monitoring technologies and their applicability in context to predicting premature failures.
3. Determine priority actions to support the development and accelerated deployment of condition monitoring strategies for dynamic cables.
4. Establish recommendations on an operation and maintenance (O&M) strategy for dynamic cable condition monitoring systems.

Methodology

Literature review and problem definition

Scenarios to capture possible dynamic cable configurations for floating wind applications were defined. These scenarios were then used as the basis of a comprehensive literature review that addressed:

1. Current subsea cable designs in bottom fixed Offshore Wind Foundations (OWF);
2. Potential improvements based on dynamic cables deployed in the oil and gas (O&G) and floating offshore wind industries; and
3. Suitable cable monitoring techniques across all offshore sectors (O&G, fixed and floating offshore wind, and tidal energy).

The review included analysis of cable motions and failure mechanisms, including those caused by the use of static cables in dynamic applications, to identify components of focus for improved cable O&M.

The scope of this project encompassed cables, terminations and ancillary equipment such as latches and buoyancy systems.

Stakeholder engagement

Relevant stakeholders were engaged as required throughout the duration of this project. These included floating offshore wind developers, insurance companies, certification bodies, investors, cable designers and monitoring technology developers.

The engagement with these stakeholders was made by conducting a wide Request for Information (RFI), followed by workshops and one-to-one interviews facilitated by subject matter experts.

Technology assessment

A thorough technical assessment and comparison of cable condition monitoring technologies was undertaken. The evaluation considered various factors including feasibility, risk, safety, cost, scalability, robustness, digital implementation, and asset value potential for each system or product. The data was sourced from technology suppliers, as well as insights from previous experimental testing and monitoring studies performed by the University of Exeter.

Gap analysis and technology road mapping

The results of the technology assessment enabled the identification of gaps in the relevant technologies, and the technical and commercial barriers to addressing these gaps.

Technology roadmaps were developed for the main technologies of interest. The roadmaps focused on the technologies with the highest potential impact, and provided implementation plans for the uptake of those technologies.

O&M Recommendations

Recommendations on an O&M strategy were also provided. These recommendations address the costs incurred during operation, expected maintenance measures, and an indication of where the technology would be located in the cable system.

Key findings

1 Dynamic cables present a potential operational risk for floating offshore wind assets.

- Even in bottom-fixed offshore wind applications, insurance data indicates that cables present the most common failure risk.
- A review of common failure modes for existing inter-array and export cables infrastructure identified that the main cable failure modes are mechanical, which often precede other failure modes, such as insulation degradation or thermal failure.
- The cable components most exposed to mechanical failure were identified as the outer cable sheaths and the integrated optical fibre.
- Given the increased cyclic load conditions and higher mechanical stresses for dynamic cable sections, mechanically induced failure is a key risk factor for dynamic submarine cables in floating wind.

2 There is clear demand for condition monitoring across many stakeholder groups.

5. All stakeholders interviewed throughout the course of this project demonstrated a clear demand for cable condition monitoring solutions, further evidencing the prevalence of operational risks that High Voltage (HV) cables introduce to operations.

- Beyond risk reduction, other use cases identified include verification of modelling and data-driven design improvements/optimisation; life extension and/or through asset life health checks to determine residual life and net present value of an asset.
- The benefit and demand for cable condition monitoring is expected to grow significantly with the deployment of floating offshore wind solutions, and with increased cable power rating for fixed installations.
- Stakeholders believe that the deployment of DCCM could bring financial benefits to operators in terms of insurance. Providing a risk mitigation strategy that reduces the Estimated Maximum Loss as part of annual reviews is one such mechanism (assuming the technologies can be proven to reliably mitigate a risk).
- As a risk mitigation solution (rather than revenue generating), there isn't a clear financial driver or business case yet for operators, and the cost/benefit analysis associated with risk reduction requires further analysis and quantification.

3 Few HV cable condition monitoring technologies have been demonstrated in the field.

- To date, risk mitigation approaches for cable assets typically rely on the use of periodic Remote Operated Vehicles (ROV) or other subsea surveying methods.
- Awareness of different technologies and experience in the adoption of condition monitoring has been variable, with asset developers/operators often influenced by their individual experience to date with cable failures.
- Two technologies, Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS), have been widely applied, with variable success and impact. One operator interviewed described successfully utilising DTS as part of the forensic analysis of a recurring cable failure

with subsequent use of the insight within an insurance case, alongside investigative data and modelling. In another instance, a DTS system was taken out of service as it could not demonstrate any value.
- Beyond these two technologies, there is limited confidence in the maturity of other technologies to accurately and reliably assess cable risk, particularly those related to mechanical failure modes.

4 **A range of condition monitoring technologies are in development and could support risk mitigation, alongside other value propositions.**

- Measuring temperature (DTS) and acoustic (DAS) signals are the two most developed technologies. These technologies show the highest prevalence of reported Technology Readiness Levels (TRLs) greater than 6 from the technology developers engaged.
- Some other technologies have achieved commercial adoption in other sectors, such as the rail network. This provides potential for significant knowledge transfer to offshore wind applications, but substantial demonstration and field verification and experience would be required to demonstrate their suitability for cable monitoring for floating offshore wind.
- Based on the review, no single monitoring technology could cover all potential failure mechanisms.
- A combination of different technologies could provide an enhanced condition monitoring system and may enable different information aspects of a failure mode to be 'learned' and signatures for early warning and degradation scenarios to be developed.

5 **No technology is yet fully mature, but several present significant potential for future delivery of long-term condition monitoring.**

Based on analysis of the breadth of technology solutions, from mature to nascent, three technologies were identified as representing the most potential for commercial availability in the short/medium term, with the opportunity to be synergistic when deployed together, namely:

1. Distributed Strain Sensing (DSS, Brillouin + Fibre Bragg Grating)
2. Motion Sensing (IMU)
3. Spread-spectrum Time Domain Reflectometry (SSTDR)

These were identified through use of a Balanced Scorecard (BSC) Approach, combining the findings from engagement with potential users to determine the relative importance of different evaluation criteria, and data from technology developers to understand the maturity and technical capability of each technology. Two examples of the BSC results are shown in Figure 1, for the Develop and Insurer stakeholder groups, with strain 1 and Strain 2 representing two different suppliers of DSS technology.

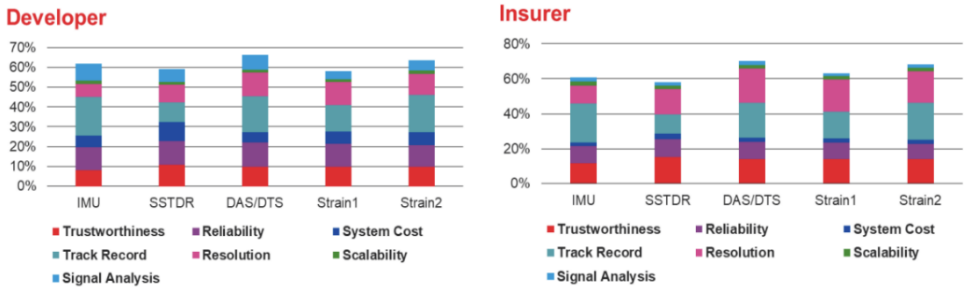


Figure 1. Balanced scorecard results for the Developers and Insurer user groups.

The more established DAS and DTS technologies are also expected to be used in floating offshore wind projects. The evaluation of these technologies was not prioritised within this study, however, since they have already achieved a higher level of maturity and widespread adoption. In addition, DTS and DAS technologies are also used to support the monitoring of electrical components, which falls outside the scope of this project, primarily focused on failures in dynamic cables due to motion.

Industry needs/innovations

1 **Addressing technology barriers in the early stages of development will be crucial to de-risk dynamic cable condition monitoring technologies and ensure a clear route to adoption.**

Perceived knowledge gaps and technical and commercial barriers to the deployment of dynamic cable condition monitoring generally, i.e. not specific to any single technology solution, were identified, including:

- General lack of awareness of and confidence in possible condition monitoring technologies. Lack of confidence in the business case for condition monitoring and applications and systems.
- Lack of knowledge sharing, collaboration and common language and metrics across the industry leading to prolonged delivery of prototypical solutions, a general lack of consistency with design and solutions, and a repetition of mistakes.
- Lack of clear translation of technical data and analysis to meaningful insights and recommendations.
- Lack of certainty on data storage approaches suitable for vast quantities of data recorded through long-term condition monitoring, and feasibility of developing software to interrogate the monitoring data and provide the analysis.
- Lack of availability of operational windfarms with the capacity to deploy both a new technology and an established survey method for demonstration and validation.

Many of these industry-wide barriers, among others, need to be addressed upfront, otherwise there is a risk that solutions are developed without clear routes to adoption and/or with limited usefulness in deployment.

2 **Collaboration across the supply chain is essential to increase the TRL of key condition monitoring technologies.**

- With no single technology yet mature and proven, and each having varying strengths and weaknesses, it is necessary to continue supporting the development of multiple solutions.
- It is anticipated certain technologies closer to maturity, such as DSS, may be demonstrated in shorter timescales, which could make more nascent technologies redundant.
- Given the necessity for testing, from laboratory scale through to trial deployment in the field, there is a significant risk that the development of all technologies will be delayed if suitable facilities and demonstrator projects are not established quickly enough.
- To enhance system development, it is worth exploring the potential for combined prototype testing of multiple technologies, for example IMU combined with SSTDR.
- There is further potential for combined solutions and integration in the cable manufacturing process, requiring collaboration between monitoring equipment suppliers and cable manufacturers. For example, the combined measurements of acoustic, strain and temperature through multiple fibres could provide a valuable condition monitoring network using established technologies (if fibres are suitably integrated during cable production).
- An 'agile' approach is envisaged to manage the on-going innovation. This comprises incremental delivery of activities with each designed to validate assumptions regarding technology feasibility, business case viability and / or user desirability, whilst delivering standalone, incremental value along the way.

3 **The utilisation of dynamic cable condition monitoring systems can lead to increased O&M costs and needs to be carefully considered in a wind farm's operational strategy.**

- Operational costs associated with continuous monitoring of offshore wind infrastructure are routinely underestimated. A bottom-up assessment of O&M activities and prices for similar systems in fixed offshore wind applications estimates operational cost ranging between £1,500/yr/MW - £9,000/yr/MW (2023 prices), which represents a significant portion of total expected O&M budgets.
- A focus on operational strategy is required to improve financial viability, in particular potential optimisations of monitoring extent (both in terms of number of assets/length of cable and data collection duration).

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 Dynamic Cable Condition Monitoring (DCCM) project addresses the ambitions of the e.g. 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.

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.

carbontrust.com

+44 (0) 20 7170 7000

The Carbon Trust is a company limited by guarantee and registered in England and Wales under Company number 04190230 with its Registered Office at: Level 5, Arbor, 255 Blackfriars Road, London SE1 9AX, UK.

Published in the UK: 2025