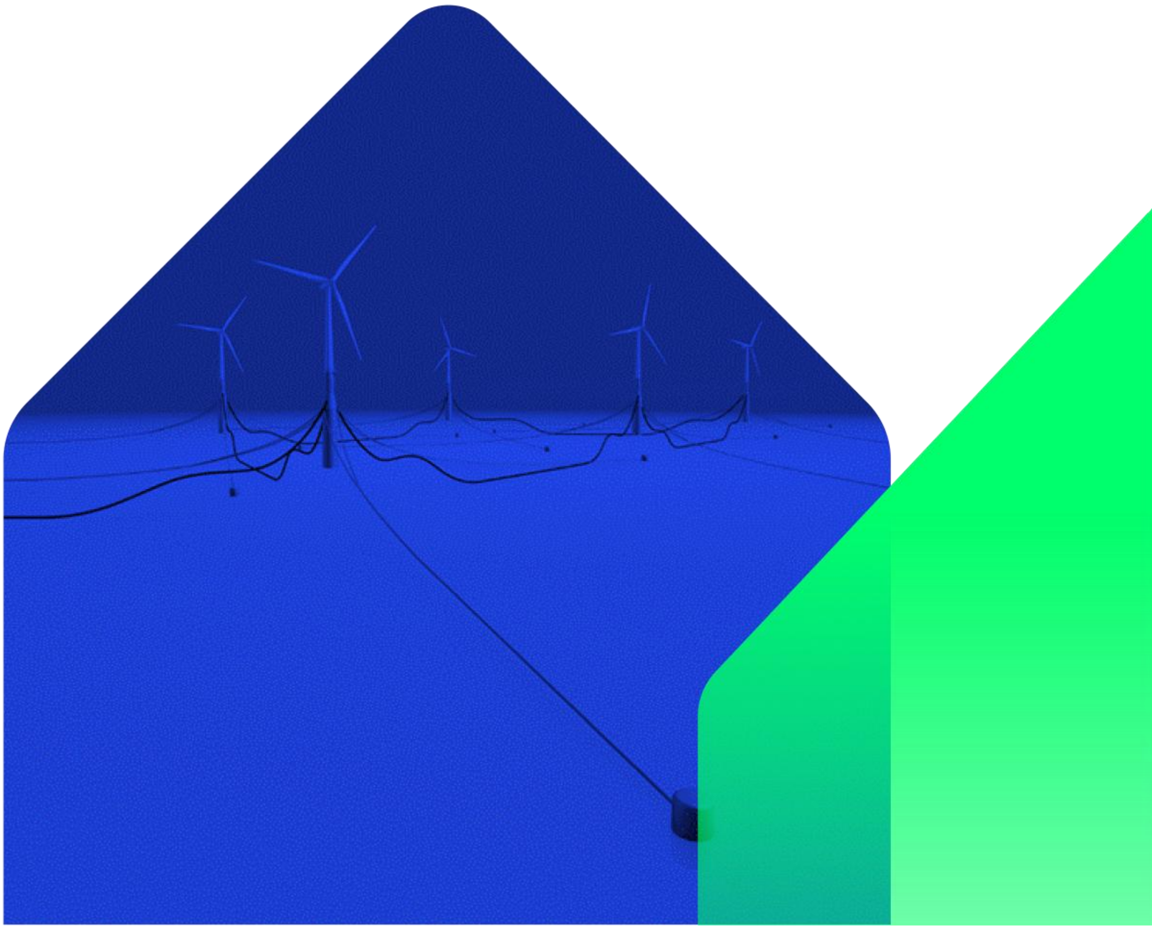
FLOATING WIND JOINT INDUSTRY PROGRAMME

132 kV Dynamic Cable Development (132 DCD)

April 2026



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2H in collaboration with the Carbon Trust wrote this report based on an impartial analysis of primary and secondary sources, including expert interviews.

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Introduction

Floating offshore wind (FOW) technology is advancing rapidly, with significant industry focus to date on the development of floating substructures. However, the successful delivery of commercial-scale FOW projects in a cost-effective, safe, and reliable manner depends on the readiness and integration of a much broader set of enabling technologies.

Many of the technologies proposed for FOW deployment, including 132 kV dynamic array cables, are not entirely new but rather represent adaptations of solutions previously applied in fixed-bottom offshore wind and the oil and gas sector. While the underlying engineering principles remain largely unchanged, the specifications, operating environments, scale, and deployment volumes associated with floating wind present new challenges that must be addressed.

In 2022, the High Voltage Array Systems (Hi-VAS) project[1] identified 132 kV as the optimal next-step array voltage above the current industry standard of 66 kV, enabling more efficient power collection from increasingly large wind turbine generators in bottom-fixed offshore wind. This conclusion was reached through extensive stakeholder engagement, engineering design studies, risk assessments, and cost-benefit analysis. While no fundamental barriers to the adoption of 132 kV array systems were identified, gaps were highlighted in the availability and maturity of qualification standards for 132 kV array cables.

The 132 kV Dynamic Cable Development (132 DCD) project was delivered by 2H Offshore Engineering (2H) and Vekta under the Floating Wind Joint Industry Programme (Floating Wind JIP).

The project reviewed existing industry publications and engaged with a broad range of stakeholders to develop a detailed roadmap for the qualification and subsequent maturation of dynamic, lead-free 132 kV cable systems for floating offshore wind applications.

[1] Carbon Trust (2022) High Voltage Array Systems (Hi-VAS). Link

Project objectives

The main objectives of the project were:

1. Understand and review the existing data within the offshore wind and analogous industries relevant to 132 kV dynamic cable development and qualification.
2. Engage with the relevant stakeholders across offshore wind and analogous industries to understand current status of their 132 kV dynamic cable development programs, challenges and gaps.
3. Develop a roadmap towards the 132 kV dynamic cable qualification[2], identifying applicability and gaps of the current qualification tests, and providing recommendations to cover those gaps.

Methodology

The project adopted a structured, evidence-led approach that combined technical review, industry engagement, and analytical consolidation to support the qualification and maturation of 132 kV dynamic cable systems for floating offshore wind applications.

Literature review and stakeholder engagement

Literature review and stakeholder engagement were undertaken to establish a clear understanding of the current state of the art in 132 kV dynamic cable systems for floating offshore wind. The review covered industry guidance, standards, research outputs, and qualification frameworks relevant to dynamic cables operating within the voltage range 132 kV ≤ Um ≤ 245 kV, drawing on experience from floating wind, fixed-bottom offshore wind, and adjacent sectors such as oil and gas.

Insights from the literature review informed engagement with a broad cross-section of the dynamic cable supply chain, including wind farm developers, cable manufacturers, component suppliers, installation contractors, certification bodies, and research organisations. The engagement captured perspectives on existing and emerging 132 kV dynamic cable designs, current development and qualification approaches, and perceived technical, commercial, and regulatory barriers to deployment.

Together, these activities provided a consolidated view of current capability and technology readiness, and highlighted areas where existing qualification approaches may not fully address the operating conditions and risk profile associated with floating offshore wind.

Assessment of qualification pathways and technical maturity

Information gathered through the review and engagement activities was synthesised to assess the maturity of 132 kV dynamic cable technologies and the applicability of existing qualification methodologies. This assessment examined how established practices for lower-voltage dynamic cables and higher-voltage static systems translate to floating wind applications, and where adaptations or new approaches may be required.

Particular attention was given to the identification of gaps in standards, guidance, testing requirements, and verification processes relevant to dynamic operation at 132 kV. Differences in qualification needs between dry and wet cable designs were examined to understand implications for development pathways, testing scope, risk exposure, and timelines. Dry-design dynamic cables incorporate an impermeable water barrier to

[2] Roadmap document developed within this project is confidential to the Floating Wind JIP partners.

keep seawater out of the insulation, while wet-design dynamic cables allow controlled seawater ingress to the insulation system, which is qualified to operate under wet conditions.

Roadmap development for 132 kV dynamic cable qualification

A roadmap was developed to help Floating Wind JIP partners to set out the key steps required to progress from current capability to full qualification, including design validation, testing and demonstration requirements, and certification considerations.

The roadmap distinguishes between critical and non-critical activities, highlights indicative sequencing and dependencies, and identifies risks that could impact development timelines or confidence in performance. Differences between dry and wet cable qualification pathways are explicitly reflected, alongside priority areas for further collaboration to accelerate technology maturation.

Comparative assessment of 132 kV and 66 kV dynamic cable solutions

A comparative case study assessed the cost-benefit implications of adopting 132 kV dynamic cables relative to the current 66 kV baseline for floating offshore wind applications. The assessment considered differences in system architecture, qualification effort, and anticipated development risk, alongside potential benefits associated with higher array voltage, such as improved power collection efficiency and reduced cable count. The findings show how technical and qualification considerations translate into broader commercial and system-level trade-offs.

Key findings

1 Most of the qualification requirements for 132 kV cables are likely to remain the same as 66 kV.

- Many mechanical, electrical, and project-specific qualification tests defined for 66 kV dynamic cables already cover the performance requirements relevant at 132 kV, so the underlying test methods and procedures remain largely applicable.
- Existing design codes such as IEC 60840, CIGRE TB 490, and CIGRE TB 623 already incorporate voltage ranges up to or beyond 132 kV, meaning large portions of the qualification framework are applicable and do not require revision.
- While many tests are retained, it is important to understand how the increased voltage level of 132 kV may influence test specifications and performance criteria.
- Although the majority of tests remain unchanged, some areas will require updates for 132 kV, particularly wet-ageing tests under CIGRE TB 722, full-scale fatigue testing (including insulation fatigue), and revised criteria for dielectric stress and water barrier performance.

2 A qualification framework is available, but standards are still incomplete for 132 kV.

- There is an ongoing working group from CIGRE, WG B1.92, to address gaps in qualification of lead-free submarine cables at 72.5kV<Um<170 kV, and a new technical brochure is expected to be released before 2027 by CIGRE WG B1.92 to address gaps in qualification of dynamic submarine cables above 66 kV.
- The tests defined in CIGRE TB 722[3] are the main ones identified as likely to change for 132 kV.
- The changes on CIGRE TB 722 are likely to have higher impact on wet designs, however, the definition of "dry" for 132 kV cables may become more stringent, potentially requiring cable manufacturers to reassess and adapt their dry designs to demonstrate compliance with the revised testing criteria.
- Changes are also expected to CIGRE TB 862[4] regarding mechanical fatigue of 132 kV cables.
- It remains uncertain which of the proposed tests by CIGRE for qualification of 132 kV cables will ultimately be adopted into IEC design standards. Nevertheless, wind farm developers, cable manufacturers, and certifying bodies may opt to incorporate CIGRE-recommended tests into their technical specification, particularly while IEC standards for 132 kV dynamic cables are still pending.

3 Risks remain in the roadmap to 132 kV and should be mitigated to avoid wind farm construction delays where 132 kV is proposed.

- Key risks identified in the roadmap towards the 132 kV dynamic cable qualification include:

[3] CIGRE (2018) Recommendations for additional testing for submarine cables from 6 KV (UM=7.2 KV) up to 60 KV (UM = 72.5 KV). Link

[4] CIGRE (2022) Recommendations for mechanical testing of submarine cables for dynamic applications. Link

- Delays in standard publication for dynamic testing above 66 kV;
    - Limited availability of facilities for specialist fatigue and HV testing;
    - Uncertain commitment within the floating wind market slowing down supply-chain investment;
    - Potential re-testing if standards evolve mid-qualification.
- Early supply chain alignment, phased testing, and late execution of high-risk tests are essential risk-mitigation strategies to achieve successful installation of 132k V in future floating wind farms.

4 Wet cables have a longer timeframe to qualify compared with dry cables. Dry designs are expected to be used initially in 132 kV floating wind farms.

- Wet cable designs require extensive accelerated water-ageing tests to validate long-term dielectric performance, which significantly increases the duration and complexity of qualification compared to dry designs. The scope and severity of water-ageing requirements are expected to be more demanding for 132 kV cables than for 66 kV, reflecting the higher electrical stresses and updated CIGRE testing criteria.
- Additional testing is needed to characterise how insulation materials behave when continuously exposed to seawater and dynamic loads, including water-treeing (the formation of small, branching crack-like defects within insulation materials) susceptibility.
- Wet designs must also demonstrate system-level reliability under combined electrical, thermal, mechanical, and moisture-ingress conditions, leading to more stringent test sequences and longer overall qualification timelines.
- Dry designs are likely to reach commercial readiness faster and may play a larger early-market role, even if wet designs offer long-term cost benefits.

5 Market conditions in the floating wind sector are a critical driver for the development of 132 kV technology.

- For floating wind to successfully adopt 132 kV, both dynamic cables and compatible high-voltage interface solutions must be developed.
- Interfaces can become hidden critical path items for 132 kV commercialisation. Floating platforms, the turbines, connectors, and switchgear must all scale to 132 kV. Projects that do not coordinate cable design with OEMs early may discover spatial, mechanical, or electrical compatibility issues late in FEED or detailed design phases.
- While 132 kV cable interfaces are technically feasible, their development is contingent on strong market signals, including project pipeline certainty, policy stability, and coordinated supply-chain investment.

6 Analysis tools are mature, but need validation for dynamic 132 kV cables.

- Existing analysis tools are technically mature, and the same modelling approaches used for lower-voltage dynamic cables remain applicable to 132 kV designs, however, their accuracy must be demonstrated for the larger, stiffer, and higher-stress 132 kV cross-sections.

- Physical testing is essential to validate analytical models, ensuring simulations correctly capture electrical, thermal, and mechanical behaviour under 132 kV operating conditions, including fatigue performance.
- Model-test correlation is needed to build industry confidence, supporting verification of design limits, reducing uncertainties, and enabling more efficient and cheaper qualification of 132 kV dynamic cable systems.

Industry needs/innovations

1 Further research is needed into the combined effects of temperature variation, mechanical fatigue, electrical stress, and water tree development in 132 kV cables.

- The combined impact of cyclic loading, thermal gradients, and moisture ingress on tree initiation and their subsequent growth is not yet fully understood.
- Integrated testing approaches are still limited; further research is needed to simulate real operational conditions where thermal, mechanical, electrical, and moisture-related stresses occur simultaneously rather than in isolation.

2 Development of new materials for insulation and semi-conducting screen is ongoing and necessary for increasing reliability of 132 kV cables and reducing cost.

- The choice of cable materials has a direct impact on the cable qualification process.
- Advancing insulation materials is essential to improve dielectric strength, reduce ageing mechanisms such as water-treeing, and enable reliable performance at higher voltage levels for wet cable designs.
- The metallic sheath and screen represent a significant challenge in the design and qualification of dry cables.

3 Agreeing post-installation cable standards and equipment for 132 kV cables will be critical.

- Several post-installation testing methods are already established for dynamic offshore cables and are directly applicable to 132 kV systems. However, the industry lacks consensus on which specific test methodologies to adopt.
- For floating offshore wind to succeed at scale, it is crucial that stakeholders align on standardised testing protocols, particularly as higher voltage levels demand more rigorous verification of correct installation.

4 Detailed cost benefit analysis of different wind farm layout types and substation scenarios can incentivise novel wind farm architectures that maximise the value of 132 kV systems.

- A detailed cost-benefit analysis across multiple field layouts and substation configurations can push the industry to innovate beyond traditional radial arrays (e.g., hybrid radial-star, modular hubs, dynamic offshore substation concepts). This would help ensure investment is driven by performance optimisation and not simply by scaling up 66 kV designs.

- Comparing 132 kV performance across various layouts can provide the robust quantitative evidence needed for developers, OEMs, and certifiers to align on future standards. This clarity could potentially reduce uncertainty for cable manufacturers, developers, and suppliers of other cable interfaces, encouraging them to invest earlier in innovative 132 kV technologies, materials, and test facilities.

5 Accelerated development of 132 kV interfaces and ancillary systems is required.

- The development of cable interfaces and ancillary technologies for 132 kV dynamic depends heavily on market confidence and investment, as suppliers typically invest in development only once commercial demand becomes clear.
- Some key systems requiring further development include floating platforms, WTG interface arrangements, wet-mate electrical connectors, and subsea collector hubs, all of which must be adapted or redesigned to accommodate the larger, stiffer, higher-voltage 132 kV cables.
- Interfaces can become hidden critical path items. Projects that do not coordinate cable design with OEMs early may discover spatial, mechanical, or electrical compatibility issues late in FEED or detailed design.

ABOUT THE FLOATING WIND JIP

The Floating Wind Joint Industry Project (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 132 kV Dynamic Cable Development (132 DCD) 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 3 summary reports can be found here: Phase I, Phase II.

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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