FLOATING WIND JOINT INDUSTRY PROGRAMME

Stick building wind turbine generators on-site

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Cover image courtesy of Saipem, taken at Hywind Scotland.

Introduction

The fixed-bottom offshore wind market has experienced steady growth over the last two decades, but the floating offshore wind (FOW) market is anticipated to develop much faster, to match the global demand for renewable energy. To date, FOW projects have been deployed as small demonstration scale and pre-commercial scale projects, where the wind turbine generator (WTG) assembly process has taken place at the quayside. The WTG is integrated into the floating substructure, before being towed to the offshore site, and subsequently anchored to the seabed and connected to the subsea cables.

As the FOW industry grows and larger floating turbines are installed in deeper waters, attention must be placed on finding practical solutions for their installation. Quayside assembly may not be suitable or cost-effective for larger commercial floating wind projects due to factors such as weather restrictions for tow-outs, quayside capacity and length, harbour water depth restrictions and onshore crane capacity at port.

This Stick Building Wind Turbine Generators On-Site (SBOS) project, delivered by Heerema Engineering Solutions (HES) for the Floating Wind Joint Industry Programme (Floating Wind JIP) built upon previous projects to further identify and assess innovative methods and technologies that permit WTG assembly at floating offshore wind farm sites.

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. Assess and evaluate different innovations and enabling technologies that permit WTG assembly at floating offshore wind farm sites;
2. Outline and define the operational procedures for stick-building on site;
3. Determine the limitations for on-site assembly and identify potential major showstoppers;
4. Encourage versatility in installation methods for floating WTGs and enable significant cost reductions.

Figure 1: Kincardine Wind Farm, courtesy of Arturo Anderson.

Methodology

A review of technologies to assist with stick building on-site was undertaken and technologies assessed against their ability to address floating-to-floating (F2F) challenges and their respective technology readiness level (TRL). These technologies need to enable F2F installation to occur whilst addressing the challenges of relative motions between the floating substructure and vessel, large lifting height and capacity, and the impact of lifting off-centre of gravity (COG) components. The available technologies were categorised as:

- Installation assets;
- Soft landing systems;
- Quick connection systems;
- Complete installation solutions.

Installation scenarios were developed for a shortlist of technologies to identity the critical parameters for SBOS. Four floating substructure types were modelled to assess the WTG installation process considering onshore preparation, transport and offshore installation. The following geographical locations and lifting asset scenarios were used:

- Narbonne, France, reflecting a 'benign' weather environment with a monohull lifting asset, shuttling to port;
- The Straight of Taiwan, reflecting a 'moderate' weather environment with a semi-submersible crane vessel (SSCV) installation with one critical lift and shuttling to port;
- Morro Bay, USA, reflecting a 'harsh' weather environment with a wind farm installation vessel and feeding with a heavy transport vessel (HTV).

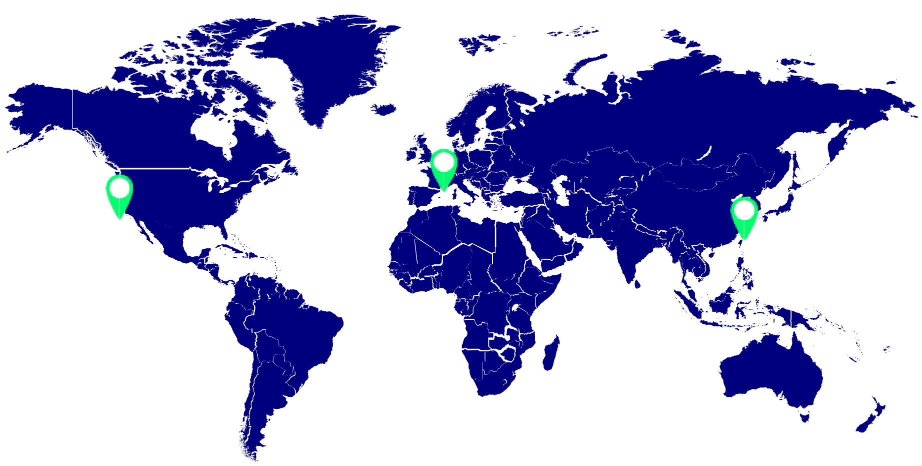


Figure 2: Selected geographic locations for reference environmental conditions.

Hydrodynamic modelling was undertaken to determine the workability and analyse the free-hanging installation stage before set-down. Workability is defined as the amount of time an operation can be performed within predefined weather conditions. Wind loads were not considered as part of this modelling scenario, therefore advanced hydro-aerodynamic simulations in the time domain will be required to capture the dynamic behaviour affected by varying wind and wave loads.

Key findings

1 **The current fleet of installation vessels is not designed for large floating WTG installations. Certain new vessel concepts are better equipped for dealing with relative motions between floating structures.**

- For assembly and installation of a 15 MW floating offshore wind turbine (FOWT), a large lift height is required, meaning that few vessels can undertake the installation and those that can are required to utilise their maximum lift height. Consequently, this results in lifts with very short rigging lengths and tight clearances between the payload and the crane.
- To avoid collisions between delicate WTG items and any other objects, minimal allowable clearances between the items should be investigated. In general, smaller clearances result in a lower operability and as such a lower workability.
- Limited space is available on the crane for the connection of tugger systems working in the horizontal direction. With relative motions between the floating bodies offshore, this makes the SBOS operations in general, weather sensitive.
- A tower, nacelle and blade installation were modelled between a monohull vessel and a Tension Leg Platform (TLP) in the benign condition. The tower installation was found to have the highest workability and the blade installation was found to have the lowest workability. The required lift height of the components compared to the crane size leaves short rigging lengths, which results in short pendulum periods. Active compensation tuggers are available on the market, which can actively control the applied damping force on the blades in order to maintain position.
- Certain novel vessel concepts are better equipped to solve the challenge of relative motions, though many of these concepts have low technology readiness levels.

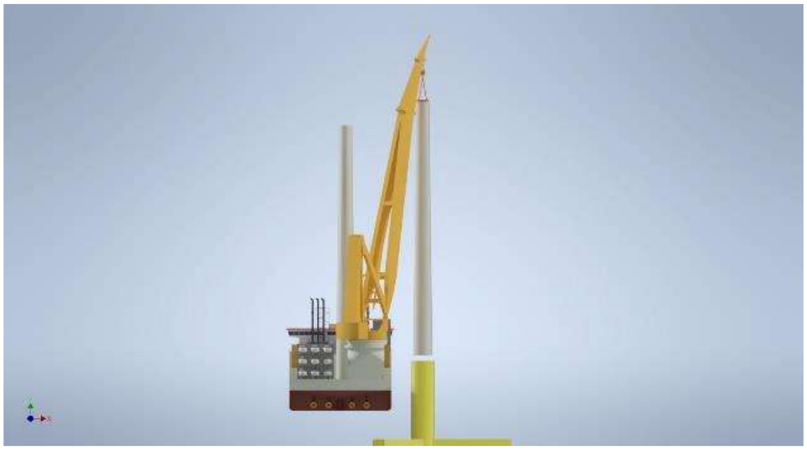


Figure 3: Monohull vessel tower installation (aft view), delivered for the SBOS project by HES.

2 **Mechanical motion compensation grippers allow for a significant relative motion reduction, and avoid unfavourable pendulum behaviour of payloads suspended in slings.**

- A fully assembled WTG installation was modelled in two scenarios: on a TLP with a semi-submersible vessel in moderate conditions and on a spar platform using a wind-installation vessel in harsh conditions.
- The lowering of the WTG onto the foundation is a weather-sensitive process. In moderate conditions, the workability was found to be extremely poor (47%) during the winter, but

manageable during the summer months. The limiting factor in this scenario is the restricted crane boom clearance due to WTG motions. In the harsh conditions, due to natural periods mainly outside the wave domain, the limiting factor was found to be the force of the gripper holding the spar and the vessel motion.

- Mechanical motion compensation grippers are currently entering the market, which allow for significant relative motion reduction, and avoid unfavourable pendulum behaviour of payloads suspended in slings. The limitations of these systems are that they are fairly complex and have a high energy consumption. They also need to overcome a lot of internal friction forces, which limits their ability to quickly respond to motions.

3 Novel connection systems can improve the workability of the mating operation by reducing the time required to be connected to the floater.

- Due to the dynamic nature of floating to-floating installation, weather windows can be a bottleneck for the operation. For this reason, quick connection of the WTG components onto the floater is essential for effective installation. Examples of novel connection systems which allow for a quick connection are:
    a. Slip Joints;
    b. Wedge Connections;
    c. Flange Clamp Tools.
- These systems are operated remotely, removing the need for personnel at the instance of mating; thereby reducing the risk of injury during an operation. These example systems are applied in various pilot projects, however, there is yet to be a demonstration in large commercial projects.
- By reducing the duration of the critical stage of connection between the crane vessel and the floater, smaller weather windows can be utilized to increase the overall installation speed.

Industry needs and innovations

1 Further analysis of motion compensation systems is required to define their limitations in terms of motion and velocity.

- The level of motion compensation these systems can provide is governed by the velocity and stroke that the system can achieve. Further investigation is required to obtain a more thorough understanding of the limits of the systems.
- Other effects which determine the efficiency of the compensation system are the interaction between the compensation system and the dynamic positioning system, the effect of friction and sensor delays, and the control strategy.
- Further research and in-field tests are required to increase understanding of these aspects of motion control during the FOWT installation scenarios. Validation of results with data from commercial projects in the future is also recommended.

2

Investigate opportunities to optimise floating offshore wind turbine installation strategies by decoupling blade and nacelle installations from the tower installation.

- Several solutions were identified which install WTG components with a separate lift system on the foundation, removing the need for an expensive installation vessel and reducing relative motions. These solutions would also allow installation optimization by decoupling the installation of the wind-prone components (blades/nacelle) from the heavier components (towers) which could be installed with the current fleet of installation vessels.
- The potential of such an installation strategy is expected to be large, however, the TRL of these systems is currently low, and more detailed studies and investments are required.

Figure 4: Assembly of tower section, assembly of nacelle on tower section, blade installation, delivered for the SBOS project by HES.

3

Apply structural adjustments to WTG components to aid floating installation from a floating vessel.

The road to industry acceptance includes changes to the current WTG design to aid floating to floating installation. These changes will need to be developed with and supported by turbine OEMs to ensure full industry acceptance. The following modifications are recommended:

- Modifying WTG towers to enable the upending of tower sections, which would result in more efficient deck layouts and reduced installation durations.
- Incorporating strong points in the tower design to withstand external loading during installation. For example, increasing the tower's structural capacity in the radial direction would allow for the application of guiding frames during blade installation, reducing weather sensitivity.
- In the case of direct-drive turbines, the centre of gravity (COG) of the nacelle and WTG assembly is shifted towards the hub. This complicates the installation operation, as the crane hook ends up in an awkward position relative to the COG. It also makes the WTG structure inherently unstable, requiring large and expensive frames to hold the WTG during assembly on deck. Therefore, it is recommended to investigate possibilities for bringing the COG of the WTG assembly closer to the centre of the tower structure.
- It would be beneficial to develop industry-accepted installation guidelines for floating-to-floating WTG installation, which can be implemented and reviewed by contractors, developers and marine warranty surveyors. The objective is to guarantee the secure and safe installation of WTGs with consistent and reliable outcomes.

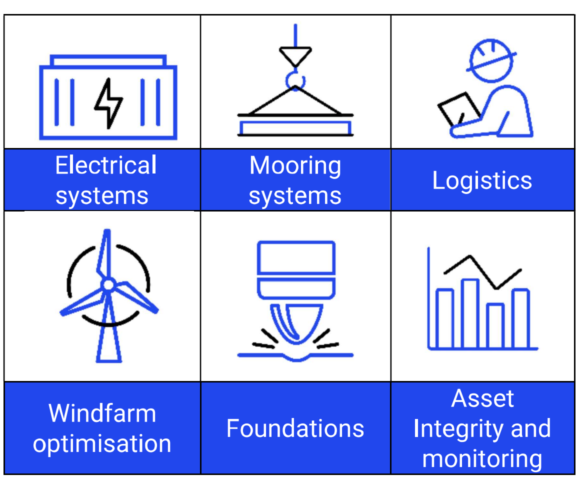
ABOUT THE FLOATING WIND JIP

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 stick building wind turbine generators on-site (SBOS) 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 and 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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