

FLOATING WIND JOINT INDUSTRY PROGRAMME

Fixed-to-Floating WTG Integration

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FIXED-TO-FLOATING WTG INTEGRATION (WTG-I)

Introduction

Typically, the installation of Wind Turbine Generators (WTGs) on fixed-bottom foundations is executed by a jack-up vessel, supported by the seabed, which eliminates any excessive vessel motions. The integration of WTGs on floating platforms is more challenging than for fixed-bottom turbines given the dynamic nature of a floating platform. In floating offshore wind, WTGs can be integrated either offshore or onshore. As quayside WTG integration is likely to be one of the earliest solutions, this study aims to assess the operability of quayside integration of WTGs on floating platforms, considering a fixed quayside crane with moored and buoyant platforms.

There is still some uncertainty in relation to the acceptable tolerances for WTG integration on moored platforms. The acceptable conditions within the port for integrating turbines onto platforms, such as wind speed, wave conditions and tidal range, relative motions associated with the moored floating substructure, and the technical requirements for mating operations, require further industry research. The Fixed -to-floating WTG Integration (WTG -I) project, delivered by Heerema Engineering Solutions (HES) through the Floating Wind Joint Industry Programme (Floating Wind JIP), explored the operational functionality of quayside WTG integration through the development and modelling integration scenarios informed by input from key industry stakeholders.

Project objectives

1. Define a tolerance range and limiting factors for safe fixed-to-floating integration of WTGs.
2. Engage with stakeholders, Original Equipment Manufacturers (OEMs) and 3rd party specialists, to understand the risks and mitigation measures for WTG integration operations at quayside, as well as to obtain feedback on the proposed tolerances.
3. Develop a guidance document for fixed-to-floating WTG integration at quayside¹, outlining the conditions and parameters where it is feasible to carry out WTG integration procedures.

¹ Guideline document developed within this project is confidential to the Floating Wind JIP partners.

Methodology

Turbine and platform definition:

To model fixed-to-floating WTG integration, three platform types and two WTG ratings were assessed:

- 15 megawatt (MW) and 22 MW centred semi-submersible;
- 15 MW and 22 MW eccentric semi-submersible;
- 15 MW and 22 MW tension-leg platform (TLP).

By combining these platform types and turbines, six different floating offshore wind turbine designs were defined.

Lifting scenario definition:

The first step in reviewing WTG integration process was the assessment of the relative motions of five specific lifting scenarios. Through this assessment, the operational tolerances and acceptable limits for WTG integration at the quayside were defined. The five lifting scenarios were based on different elements of the WTG:

- WTG tower top section;
- WTG tower bottom section;
- WTG tower, pre-assembled at the quayside, and installed onto the platform with a single lift;
- Nacelle;
- Blade(s).

Dynamic behaviour assessment:

For each lifting scenario, the dynamic behaviour was assessed by performing time domain simulations within OrcaFlex. To develop these simulations, the main system parameters (inertia, hydrostatic and hydrodynamic) were modelled. The responses were determined for each of the following three external excitations:

- Wind;
- Wave;
- Ship traffic waves; primary and secondary component.

Stakeholder input

A restrictive horizontal motion limit at the installation interface was also proposed for the abovementioned lifting scenarios. In practice, applying the proposed limit by the OEM meant that the platform could not roll more than 0.1 degrees at any installation phase, including final blade installation. Therefore, HES proposed to use a limit of 1.5 meters (m) and 1.0 m in relative horizontal and vertical motions, respectively, more common in the offshore wind installation industry, as a starting point, to challenge the use of typical offshore installation aids. The criteria were assessed against a 3-hour Single-amplitude Most Probable Maximum (SMPM) response.

The tolerances, acceptable limits and integration procedure were discussed in several workshops with industry stakeholders to understand the risks and mitigation factors for the proposed tolerances. Additionally, operational challenges of the integration process, installation tools and durations of quayside WTG integration were discussed.

The relative motion between the lifted turbine component and its connection point was assessed. Following input and feedback gathered during various workshops with industry stakeholders, the scenario modelling was revised, and three sensitivity studies were executed:

- Utilizing pontoon draught, where the floater sits higher in the water. This is compared to the operational column draught, where the floater is ballasted to sit deeper in the water;
- Contribution of increased stiffness of mooring lines;
- Study of reduced limiting motion criteria, together with a different statistical approach and duration.

The results were consolidated into an internal guideline that outlines feasible procedures for fixed-to-floating WTG integration. It provides recommendations for future research related to quayside WTG integration, with emphasis on how to make quayside WTG integration commercially feasible. The guideline is not publicly available, but its key findings are summarised in this report.

Key findings

1

The installation of the final blade is considered the most critical phase for fixed-to-floating WTG integration.

- This is primarily due to substantial wind-induced horizontal displacements of the platform, rather than motions of the blade being lifted.
- Wind may induce large horizontal displacements, especially during nacelle and blade installation. This is largely influenced by the platform's movements, particularly in their natural roll and pitch modes.
- When wind excitations occur, blade installation is the governing installation stage (the stage with the lowest operability) for all platform types. The relative displacements are governed by the floater and not the lifted objects. The platform motions are largely amplified during blade installation, compared to other installation stages, due to the increased wind-exposed area, as well as the rotational hydrostatic stiffness reduction as a result of a higher vertical centre of weight.
- For the initial assembly stages (full tower, tower bottom), relative displacements are governed by the lifted object pendulum motions. For the intermediate stages (tower top, nacelle), both the platform and pendulum motions become equally more important.
- Waves result in an inertia-dominated dynamic behaviour of the floating offshore wind platforms. The natural periods of a floating platform during assembly are outside of typical wave sea states for port conditions. Wave conditions appear less limiting than wind. As the WTG assembly procedure progresses, from tower to nacelle to blade(s), it is noted that the platform motion (roll and pitch) decreases for the examined wave range. This is attributed to the increased inertia in the floating structure as more WTG components are being installed, leading to higher natural periods and an increased inertia-dominated system.

2

Primary ship traffic waves may result in significant dynamic motions during the WTG assembly.

- Floating WTGs moored in harbours are subjected to hydrodynamic forces due to ships passing nearby. The wave patterns induced by these passing vessels can be analysed into primary and secondary waves.
- Primary waves are mainly governed by the geometry of the passing vessel and the waterway, as well as the vessel speed. Secondary waves originate from the vessel's hull discontinuities at the bow and the stern and have short periods.
- Primary ship traffic waves may result in significant dynamic motions during the WTG assembly. Secondary ship traffic waves, however, result in motion dynamics of low magnitude compared to those from primary waves. These waves are, in general, short and the dynamic behaviour is dominated by the inertia of the floating wind platforms.

- As primary ship traffic waves may result in high motions and loads, port selection should take into account vessel sizes, speed, waterway width and specific regulations. It is recommended to regulate port traffic during critical lift stages.

3

No significant differences in operability are observed between the various platform types and power ratings.

- For the platforms analysed in this study, no significant differences in operability were observed between platform type and power ratings. It should be noted that the TLP modelled for this study was designed with stabilising tanks required for the assembly process, as the TLPs were inherently unstable in the absence of tendons. Accordingly, its behaviour was similar to the centred semi-sub configuration. It is expected that a different design of these tanks and the resulting impact towards the TLPs overall dynamic behaviour may result in different observations.
- Across all installation stages, the 22 MW platforms show improved dynamic behaviour in wind environments compared to the 15 MW case. This is primarily due to the platform's reduced roll and pitch motions. The only exception was for the eccentric semi-submersible platform during blade installation, where the combination of its configuration and load asymmetry lead to less favourable dynamic behaviour when scaled to higher power ratings.
- The main differences between platform types and power ratings are operational, for example ballasting procedures, crane reach requirements for the land crane and mooring procedures.
- Eccentric platforms require less land crane outreach than centred designs. However, their asymmetrical layout complicates ballasting operations, making it more challenging to keep the WTG within tilt tolerances before and after each lift.

4

Mooring line stiffness and floater draught optimisation can improve the operability during blade installation.

- For wind excitations, an increased mooring stiffness translates into improved behaviour during the blade installation stage, highlighting the need for higher rotational stiffness and lower natural periods. However, mooring stiffness does not affect the tower installation stage, since the platform's motions are negligible compared to those of the lifted object.
- For wave excitations, the selected mooring configuration and corresponding additional stiffness have a negligible impact on the operability.
- When the platform sits high in the water, at pontoon draught, it can maintain a higher level of stability in windy conditions. This makes blade installation easier compared to the deeper columns-draught scenario, where the platform behaves similarly to its operational offshore condition.
- This improvement highlights the need for higher rotational stiffness and lower natural periods, which are the consequence of the increased waterplane area.

- Pontoon draught configurations, under wave excitations, show relatively small reduction in operability (at blade installation stage), which may, however, be eclipsed by the increase in wind operability.

5

Adopting a different statistical approach, such as the Probability of Exceedance, is more appropriate than a 3-hour SMPM for assessing operational limits.

- Revising the initial displacement limits, 1.5 m and 1.0 m in relative horizontal and vertical motions, respectively, in comparison to indicative restrictive motions limits, and assessing against 3-hour SMPM responses, result in significant operational downtime due to wind-induced platform motions. This could deem specific stages of the WTG integration non-feasible and create a bottleneck for commercial-scale floating wind farms.
- The 3-hour SMPM is a conservative statistical approach to be applied to limits of “indicative” nature and on operations of shorter duration than those assessed in this study. It leads to low operability as it assesses the probability of exceeding the specified limit once in three hours, whereas the operation, in reality, could still continue even if this indicative displacement limit is exceeded on occasions.
- An approach that examines the allowable probability of exceedance (PoE), i.e. how often in a given amount of time this criterion is being exceeded, is deemed more appropriate and thus the crew responsible to carry out the operation (and the marine warranty surveyor) should decide what level of probability of exceedance is acceptable for the mating processes to go forward.

6

Integration of fixed-to-floating WTGs requires the use of a large ring cranes.

- The crane requirements for the critical lifts (22 MW, TLP) are a minimum lifting height of 210 m with a hook load capacity of around 1000 metric tonnes (mT) and a lifting height of 200 m with a hook load capacity of around 1800 mT.
- Crane requirements, including hook load, outreach, and lifting height, for 15 MW and 22 MW WTG integration pose a challenge, as the number of suitable land cranes currently available on the market is limited. The industry will require enough availability of land cranes, especially when multiple commercial-scale projects and major component replacement campaigns, which also require the use of this equipment, are performed simultaneously in a key market.

Industry needs/innovations

1

A shift from wind speed driven installation limits to motion driven installation limits should be considered in collaboration with WTG OEMs.

- The wind speed limit approach is inherited from the onshore industry and later extrapolated to the offshore bottom fixed sector, with the maximum wind speeds for component installation being based on practical experience. However, for floating wind, the platform behaviour will be different for each project. Therefore, it is recommended that.
- It is recommended to define the reasoning of the restrictive motion limits on a technical basis and investigate together with OEMs how much this limit can be increased, based on a redesign of the internal bumper and guide systems already present in WTGs. It is key to understand what modifications on the turbine could be possible and how to build different installation limits based on the use of installation guides (i.e. maximum feasible impact loads).
- The indicative relative motion limit at the blade-hub interface should be assessed against a PoE, considering the frequency and magnitude of potential exceedance. This is subject to a decision taken by the WTG designer together with the operational crew and a marine warranty surveyor. For the same parameter, an associated allowable SMPM value should also be assessed, to ensure that even when the “safe-boundary” limit is exceeded, the response value reached does not exceed the specified SMPM limit.

2

All WTG integration stages should be assessed and considered in the design phase to improve overall operability.

- With the sequential integration of each WTG component, the platform’s dynamic behaviour will change, primarily due to its change in mass and inertia but also due to the increasing wind-exposed area, and as such, each installation stage could call for different design considerations.
- Future studies on WTG integration would benefit from breaking down their scope into more specific topics to identify the governing parameters in detail, and also to quantify their impact on the final outcome.
- Sensitivity studies performed as part of this project on critical aspects of the system’s configuration, such as mooring stiffness and platform draught, showed that certain design parameters, such as those influencing rotational stiffness and damping, should also be evaluated at early stages.
- Dedicated studies on individual system components should be performed during design stages, including distinguishing between lifted object and platform motions, varying platform parameters, and accounting for passing ships.

3

Novel installation tools, methodologies, and alternative pre-assembly methods for WTG integration could increase workability during WTG integration.

- The potential for novel lifting aids that can assist the lift and reduce the motions could be explored. Operational tools such as guides, bumpers, and catchers should be investigated in combination with the relative motions between the load and the platform. Additionally, it is key to understand what modifications on the turbine could be possible and how to build different installation limits based on the use of installation guides.
- Passive tugger lines were accounted for only during the blade installation stage. However, the use of an active damping configuration during all WTG component lifts could significantly improve the motion behaviour of the lifted objects. Installation tools that reduce motion during WTG integration, such as heave compensators, motion-controlled tagline systems, soft landing systems and damping devices, should therefore be included in the method statement. By doing this, operability could be limited by the motion of the platform only, and operability could be improved.
- A single rotor-nacelle assembly (RNA) lift, instead of individual lifts of the nacelle and each blade, is a way to reduce the number of critical lifts and is expected to show a more favourable behaviour. The RNA motions could be limited with tugger lines, and the large weight of the lifted object could result in lower motions, while the platform would have more favourable motions in higher wind conditions. It is recommended to assess this lifting configuration via detailed lift analysis and on a case-by-case basis.
- Other methodologies for mitigating platform motions that could be explored include: the pre-assembly of the WTG rotor to reduce the number of weather-sensitive lifts, grounding or storing the platform on the quayside and storing the platform on a semi-submersible dock.

4

For future modelling work, it is recommended to examine the transient engagement phase and to account for the combined action of all relevant excitations in later stages operability assessments.

- All of the numerical studies performed investigated the effect of each environmental condition individually, per excitation. In later stages of the design process, assessing the combined action of these environmental components and developing a relevant methodology for this assessment is recommended.
- The scope of this study was limited to the hovering phases and the free-hanging phase just before integration of components. It is recommended to also study the transient engagement phase of each component, where the lifted object first comes into contact with its interface, taking into account load transfers, impact loads and hydrostatic effects.

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 Renouvelables, 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 **Fixed-to-Floating WTG Integration** project addresses the ambitions of the Logistics research area:



1	Understand the required port developments for commercial scale floating wind farms assembly.
2	Understand how water depth and environment affects the entire installation process.

The Stage 3 summary reports can be found here: [Phase I](#).

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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