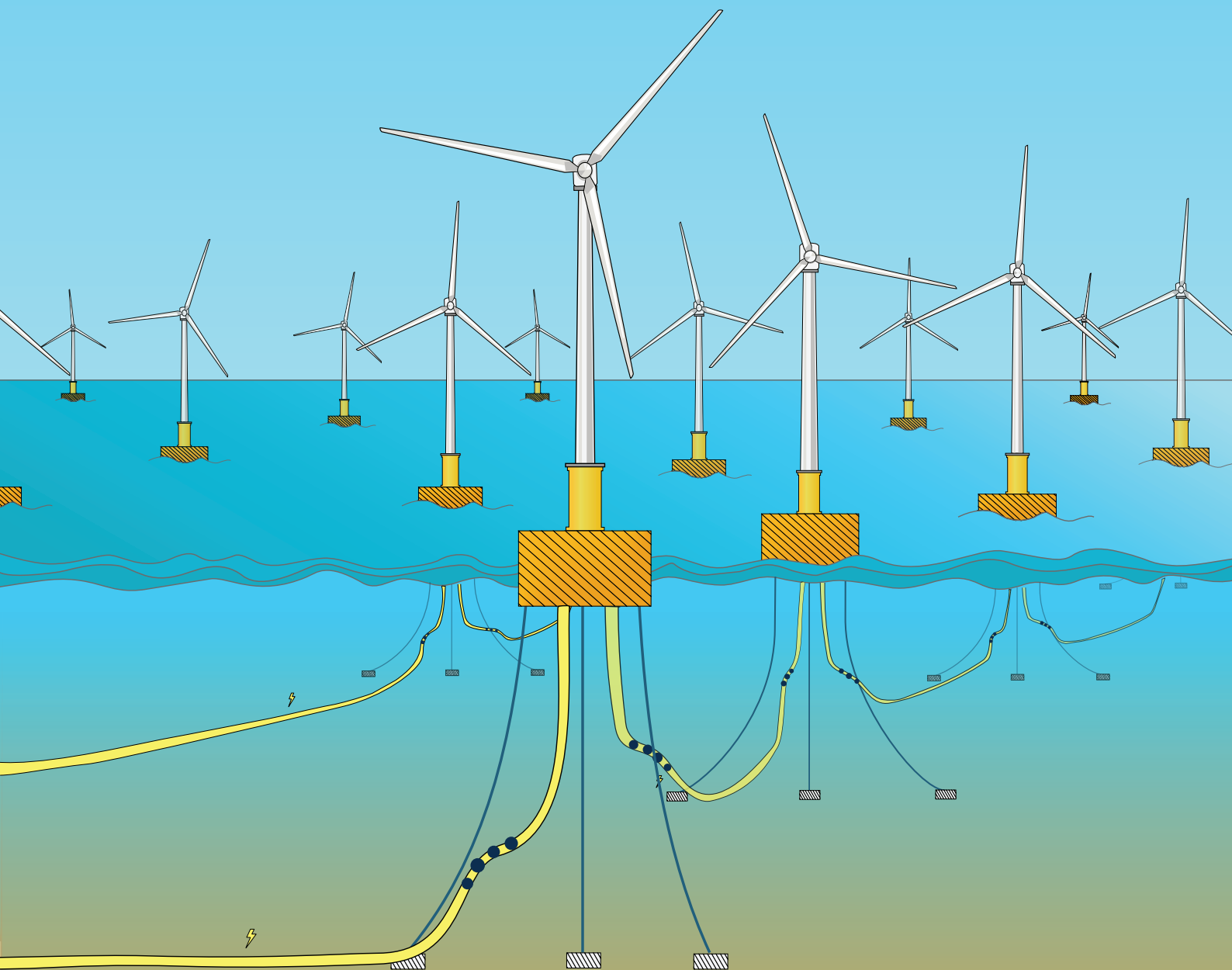


Modular Lifting Solution

Floating Wind Technology Acceleration Competition

Executive summary



June 2021

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FLW JIP, formed in 2016, is a collaborative research and development initiative between the Carbon Trust, and fifteen leading international offshore wind developers: EDF Renewables, EnBW, Equinor, Kyuden Mirai Energy, Ocean Winds, Ørsted, Parkwind, RWE, ScottishPower Renewables, Shell, SSE Renewables, TEPCO, TotalEnergies, Vattenfall, and Wpd.

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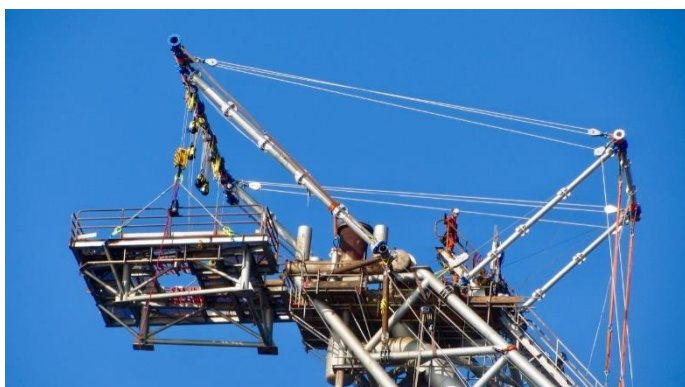
SUMMARY

INTRODUCTION

In October 2019 The Floating Wind Joint Industry Project (JIP) defined four key challenge areas for future floating wind development. One of these areas was defined as:

"Safe and cost-effective exchange of large turbine components offshore when floating foundation structures are moving due to wave motion"

In the context of a technology acceleration competition initiative initiated by the JIP, and funded by the Scottish Government, Conbit has been awarded a fund for an R&D project to study the exchange of major components in an offshore environment by use of the typical lifting technology Conbit has developed in the offshore Oil & Gas industry.



Picture 1 Replacement of top platform on offshore flare stack by use of modular lifting technology

This technology comprises the methodology to lift and install components by use of temporary modular lifting devices, installed on existing structures, close to the final location of the component.

OBJECTIVES

The challenge as identified by the JIP refers to the challenging marine operation when lifting from a floating vessel to a floating foundation structure (floater). This operation is especially challenging since it should be performed at nacelle height with an accuracy which ensures a safe and damage free operation.

There are currently no crane vessels available providing such operations that are likely to be compatible with the next generation turbine sizes. The modular lifting approach provides an equipment set which will be temporarily connected to the nacelle. This approach eliminates the relative motions between the crane and turbine, providing the conditions for a safe operation.

Although it is a proven technology, it has never been executed on a scale as required for floating wind. The relative motions have been eliminated, but various other challenges were left to solve. This resulted in the following research question:

"Is it feasible for the modular lifting technology typically used by Conbit, to be used to replace major components of future floating wind turbines?"

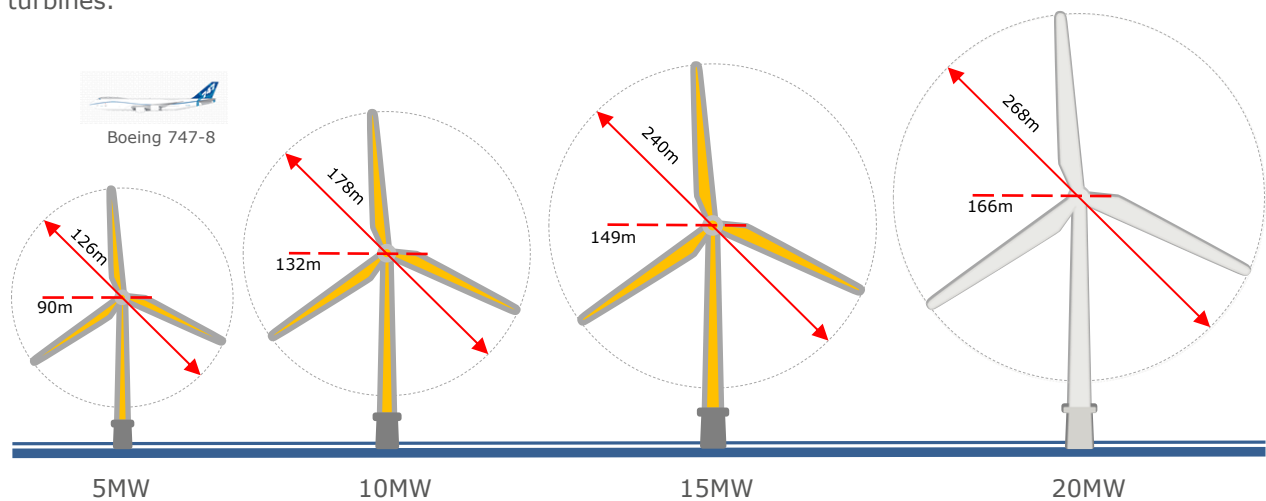
STUDY RESULTS

The following phases were carried out as part of the R&D project:

PHASE		ACTIVITIES
1.	Design bases	Defining the conditions for the replacement
2.	Floater motions	Studies of the expected motions during maintenance conditions
3.	Methodologies	The definition and evaluation of different methods in the overall procedure
4.	Technical design	Technical specification of the most valuable methods of the methodology phase
5.	Commercial evaluation	Scheduling and cost estimation of technical specification

DESIGN BASIS

The major turbine components, subject to replacement have been quantified by type and rating of future turbines.



For geared wind turbines, the gear box is the heaviest item. For direct drive types, the generator is by far the heaviest part, followed by much lighter items. In terms of complexity, the blades are most complicated to handle. Based on this analysis the base cases for the design phase have been defined as:

- Replacing an object of 150t from the nacelle on a 10MW floating turbine
- Replacing a blade of 44t from the nacelle on a 10MW floating turbine

FLOATER MOTIONS

The estimated motions of the floaters during maintenance conditions are one of the main parameters impacting the design. Typically these motions are studied by use of a simulation method developed by the US National Renewable Energy Laboratory (NREL). Due to the absence of standardized model data for the

10 and 15MW turbines, new models have been developed in cooperation with Innosea Marine Energy Engineering. The motion analysis resulted in the following findings:

FINDING	RESULT
For 'standard' Tension Leg Floater types (TLP), the estimated horizontal accelerations at hub height exceed the acceptable limits for human work.	Based on this finding, TLPs are defined as not feasible for the modular lifting technology. Note: Due to new developments in the TLP floater types, this conclusion might be revised in future.
The frequencies of the motions result in resonance risks over full height of the tower when lifting from the nacelle	Any lift from the nacelle must be guided to avoid resonance.

METHODOLOGIES

The overall method is divided in three design areas:

DESIGN AREA	EVALUATED METHODS
Lifting device connected to the nacelle	Luffing gantry on top of nacelle Luffing gantry along the nacelle Lifting to the nacelle side or back
Guiding principle	Guide/tag lines to the floater Guide/tag lines to a boat / barge Rail / trolley structure along the tower
Load transfer to a boat or barge	Guide/tag lines to a boat / barge Crane vessel to lay-down area Mooring or clamping to the floater

For each area, various methodologies have been studied and evaluated. Some variants have been rejected due to intrinsic safety issues, others have been selected or rejected for efficiency reasons.

TECHNICAL DESIGN



Picture 2 Nacelle modular lift device

The final conceptual design comprises a luffing gantry, supported by a base frame, connected to the base of the nacelle. The gantry is suitable to lift any item up to a weight of 150t from the top of the nacelle and lower it below the base frame. It also enables the removal and installation of a blade by use of an additional blade handling tool.

All items lifted or lowered are connected to a trolley. This trolley runs over the tower by wheel sets which are automatically adjusted by the changing diameter of the tower. Two guide lines at both sides of the trolley will ensure a minimal wheel pressure.

Depending on the floater type, two approaches are considered at the tower base:

1. For semi-subs and barge floaters, the component is located on a (temporary) lay-down area from where the crane on an offshore construction vessel (OCV) can lift or position it.
2. For spar-type floaters, an offshore construction vessel is provided with a semi-flexible clamp, which reduces the relative motions between the vessel and floater. This enables lifting of the turbine's component directly by use of the OCV crane.

The pre-required structural interfaces to the turbine are limited to:

- 6x hang-off points from the base of the nacelle
- 2x4 'stubs' welded on the tower

COMMERCIAL EVALUATION

Based on a hypothetical case study, the turn-key costs for a typical component replacement has been compared with the 'tow to port' method for a semi-sub floater type including the required marine spread and quay side crane.

For this specific case, the estimated costs for the modular lifting solution where 10-15% lower than the compared 'tow to port' option. It should be noted that the case study included many assumptions which might vary by specific cases. Specifically the availability of a near-by suitable quay-side and the floater type can have huge impact on the 'tow-to-port' option. Also the assumed return on investment for the modular equipment affects this comparison.

The overall findings are:

- The amount of maintenance cases is an important parameter for the costs of the of the modular lift method.
- The availability of a suitable quayside in the close vicinity of the wind farm is an important factor for the costs, related to a 'tow-to-port' scenario

CONCLUSION

For most typical floating wind turbines, currently under development in the industry, the modular lifting technology is technically feasible.

Structural interfaces to the turbine structure are required and should be developed in cooperation with industry parties.

Close cooperation between stakeholders is required, to create sufficient assurance necessary for vital investments for the development of the modular lifting equipment