Abstract title: Development of a Semi-submersible barge for the Installation of a TLP floating substructure. TLPWIND case study.

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1. Introduction (144)

The booming Floating Wind market has seen both Semi-submersible and SPAR technologies being demonstrated full scale but no Tension Leg Platforms have been installed yet, while a lot of preliminary reports highlighted its huge cost reduction potential thanks to its light weight and extraordinary behaviour. One of the biggest challenges to introduce TLP technology in Offshore Wind are the Transport & Installation stages, since most of TLPs are not self-stable as semisubmersible or SPAR platforms and consequently requires the need of additional means to perform these operations. This paper wants to explain how this problem has been overcome through the development of an Semi-Submersible "Transport & Installation" Barge for the TLPWIND technology that has been designed both through the use of numerical models and an extensive basin testing campaign at University of Strathclyde's facilities for the TLPWIND UK R&D project supported by INNOVATE UK.

2. Approach (451)

The development of offshore floating wind turbines is one of the most significant engineering challenges in Wind energy at present. A lot of synergies have been established with former Oil&Gas floating technologies (Spar, Semi-submersible and TLP) in order to determine the optimum concept designs that better matches with the conditions of the forecasted development areas worldwide. Oil&Gas floating technologies are designed like "one of kind projects" that can be easily installed in reduced period of times and weather windows, while Offshore Wind floating technologies needs to develop innovative systems that can operate at more severe sea-states to increase the installation windows (workable days per year), since this has a significant effect in the overall LCOE. In this sense, the possibility of assembling the wind turbine onshore has been determined as a major asset for floating technologies through the development of a project lifecycle much more "onshore based" with advantages like:

- Minimising overall **Project Risks** (less Offshore operations during construction and O&M → less weather dependence & hazards)
- Much lower dependence on **OWTG loads** than current bottom fixed structures (improved upscaling for future 8/10 MW Wind Turbines → **Lighter Structures**: Increasing need for development the **Floating Market** to help **Offshore Wind** at driving down the **LCOE**.

- **Equal** structures per project →**Real Manufacturing Standardisation Potential** to develop in coming years → attracting new Supply Chain players → Market Competitiveness → driving down **LCOE**.
- Maximising **Local Content** by maximising **Onshore Content** (OWTG assembly & commissioning→ New project contracts structure)

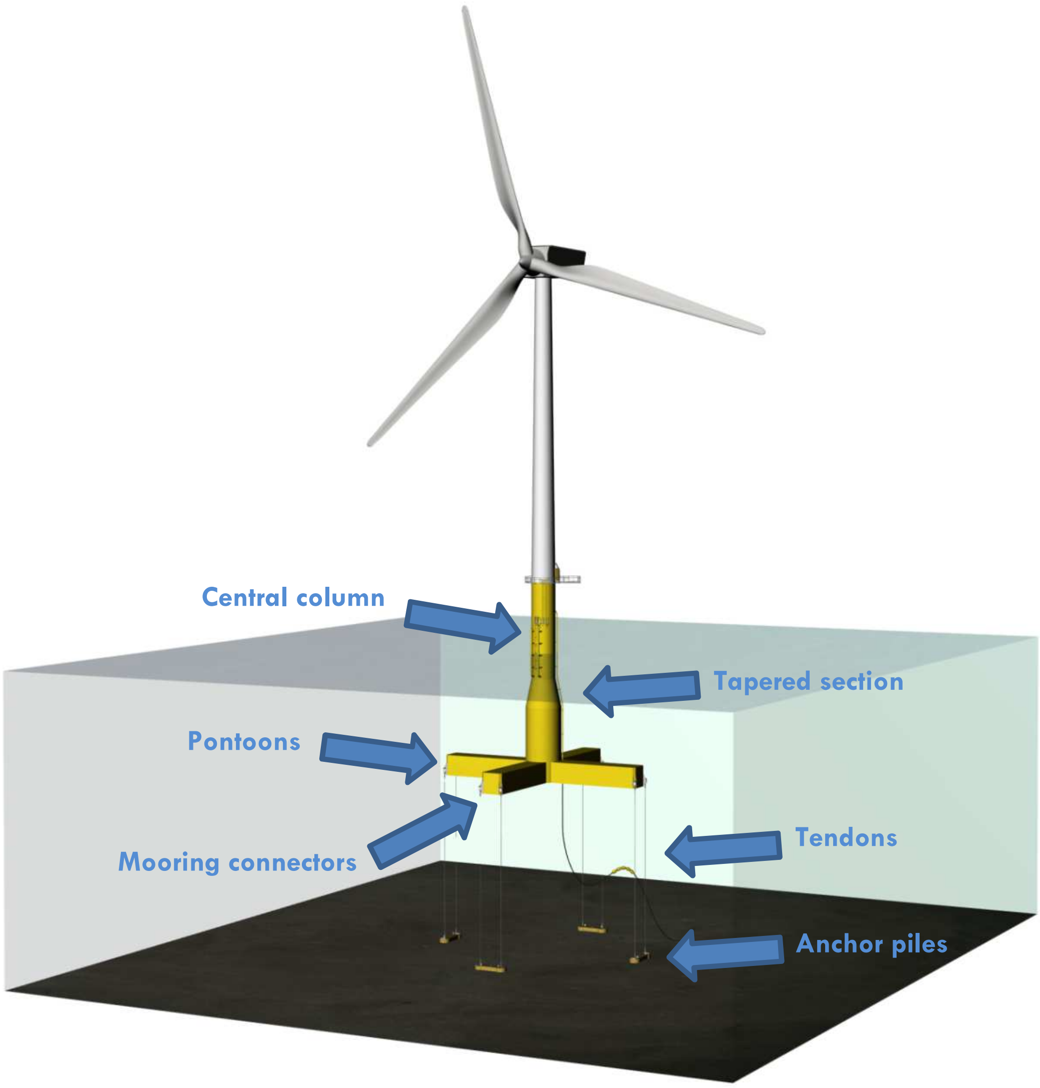

Figure 2-1 TLPWIND technology main components and sections

SPAR designs cannot meet the requirement of assembling the Wind turbine onshore due to its deep draught, while TLPs have an outstanding dynamic behaviour in comparison to other floating technologies with a much lighter weight than Semi-Submersible´s, as well as much simpler construction processes and rated costs.

TLPWIND is an innovative TLP concept designed specifically to withstand very aggressive conditions in mid/deep waters, with a simplified geometry and light weight (900 – 1000 tons TLPWIND 5MW) which drives to much simpler construction processes and costs, but requires an ad-hoc system to confer stability during T&I to avoid the use of the expensive Heavy Lift vessels.

Figure 2-2 TLPWIND technology developed “ad-hoc” T&I solutions. U-shaped barge (left), re-usable floaters (right) and U-shaped semisubmersible barge (down) awarded with PCT/2013/070697

Since 2012, Iberdrola Ingeniería & Construcción has designed and tested at a reduced scale three “ad hoc” solutions for addressing this problem. An U-shaped barge, which can effectively perform the transport operations, a set of re-usable floaters which grant enough stability for performing both transportation and installation operations, but also an U-shaped Semisubmersible barge (SSB; awarded PCT/2013/070697) that merged the advantages of the two systems formerly developed (High towing speed due to a significant low water resistance for transport operations & Outstanding seakeeping capabilities at variable draughts) but also decrease the overall installation risks by integrating the columns in the barge designed.

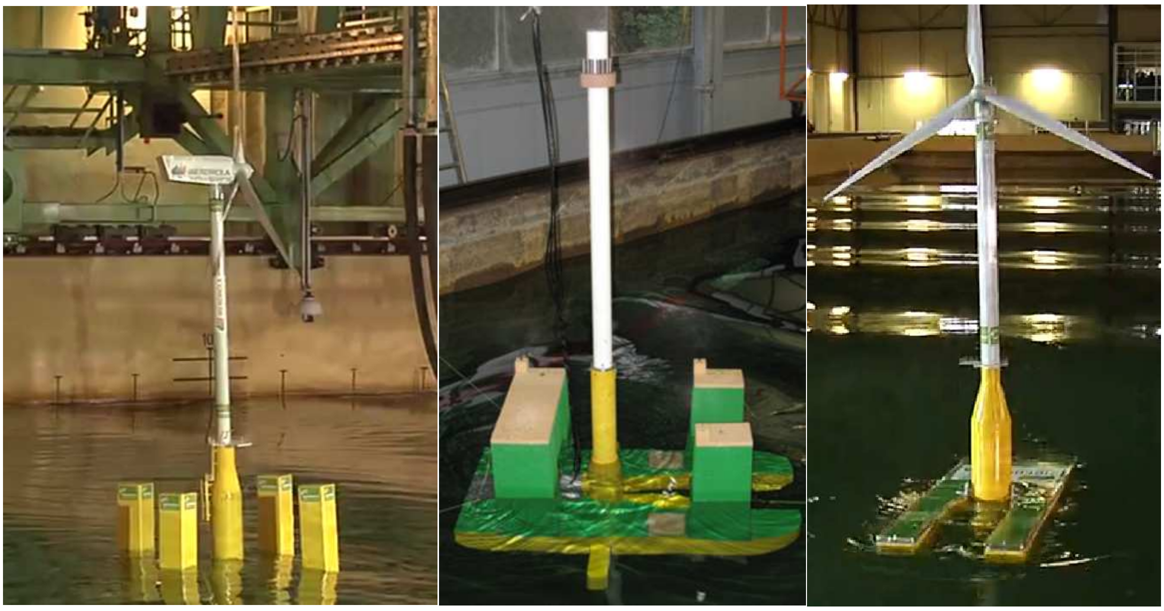

Figure 2-3 “ad-hoc” floaters (left) and U-shaped barge (right) tested at CEHIPAR in 2012; U-shaped Semi-Submersible barge (centre) tested at University of Strathclyde Kelvin Hydrodynamics Laboratory in 2016

3. Main body (668)

A large part of the work done for TLPWIND UK project was focused on the development and detailed study of the Transport & Installation operations and the necessary means to perform these operations with the TLPWIND floating platform. This included in a first step the design of the “ad-hoc” SSB, taking into account the stability, towing resistance, dynamics and seakeeping characteristics of the vessel to comply with the requirements imposed by the wind turbine, the navigational limits and installation tolerances. The design of the SSB was validated through an extensive basin test campaign with more than **190 recorded** tests which included:

- **Characterisation tests:** Free decay tests which allowed to obtain a full characterisation of the hydrodynamic properties of the SSB and to verify the correct manufacture of the scaled model which proved to have a great level of accuracy.

- **Transport operation tests:** Towing drag tests were performed using an accurate semi-captive system and a realistic wired towing in still water, regular and irregular waves conditions and for a large number of different sea states which allowed to identify the operational limits for the towing operations.

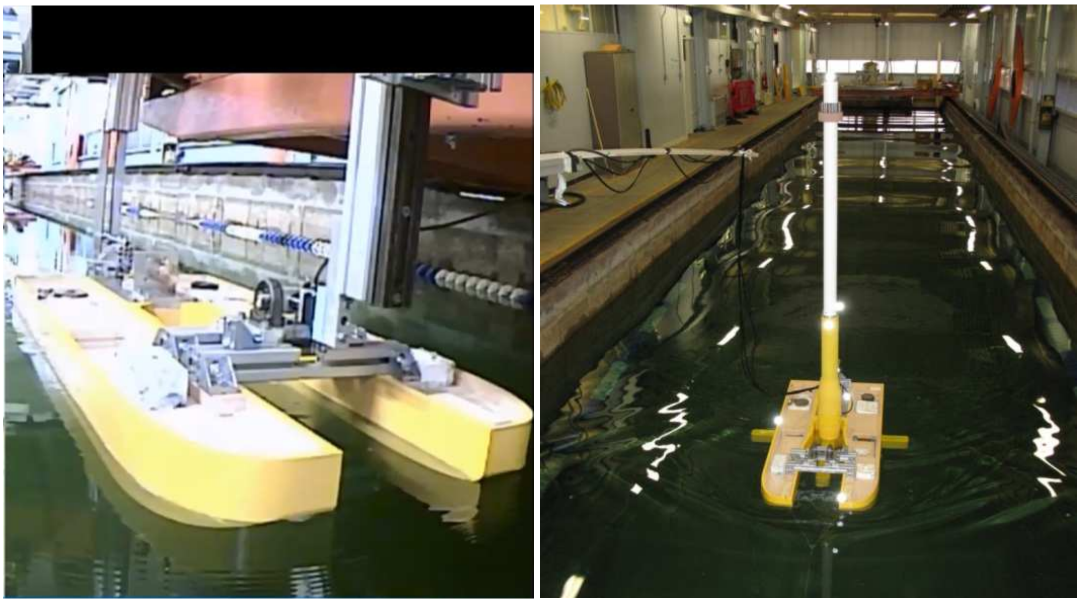

Figure 3-1 U-shaped SSB semi-captive towing methodology (left) and wired towing (right) extracted from videos recorded at Strathclyde´s University basin facility

- **Installation operation tests:** Seakeeping tests of the Semisubmersible barge at the most representative draughts were performed in both regular and irregular waves for several wave headings.

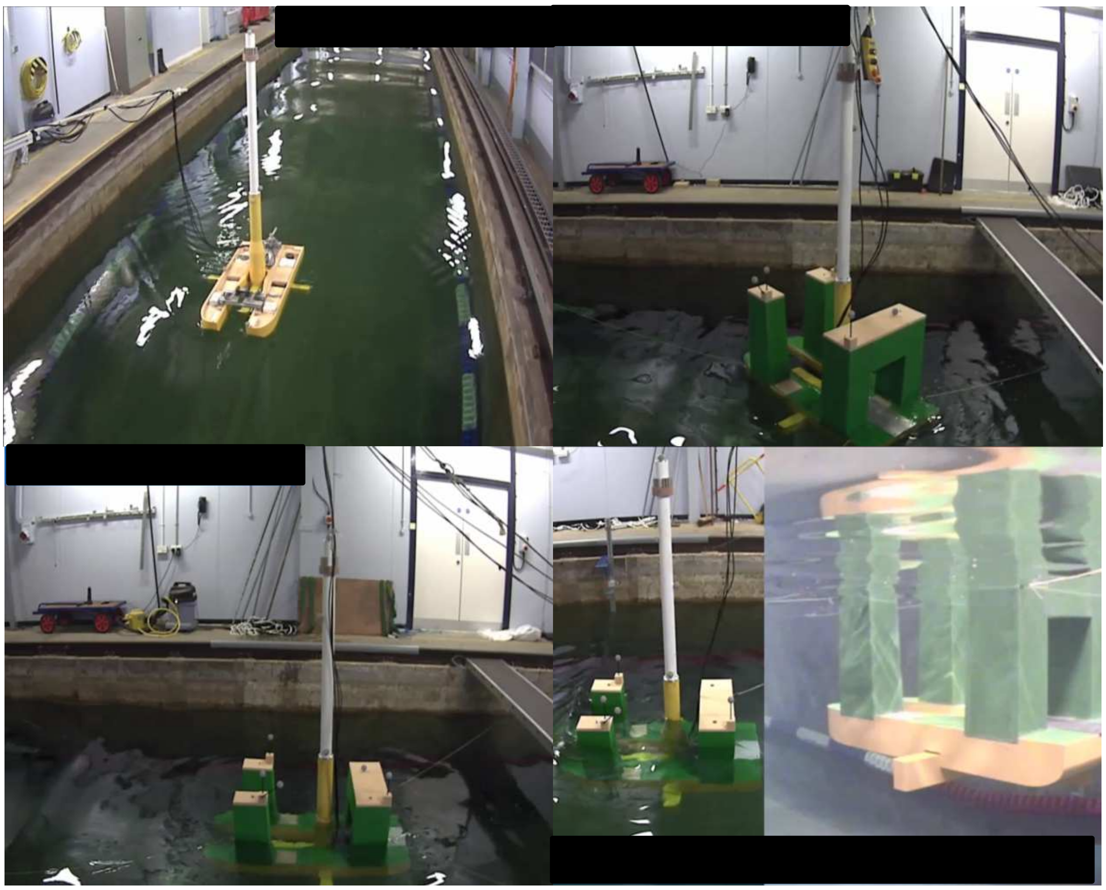

Figure 3-2 Wired towing test (upper left), intermediate draught installation test (upper right), deeper intermediate draught installation test (upper right) and connection draught installation test (lower bottom) extracted from recorded videos.

For the designed SSB and TLPWIND platform, an identification and analysis of the steps to follow in order to perform the installation of a platform was also carried out, firstly focusing in a single platform scale to later consider a full wind farm scale (100x5MW TLPWIND units). Fifteen main operations were identified for a single unit which can be summarised in five main stages starting from the required port operations, followed by a transport phase, installation of the TLPWIND platform and final recovery of the SSB and tow back to port. For this study a detailed estimation of the duration of each of these steps in ideal conditions (no weather delay) was additionally performed.

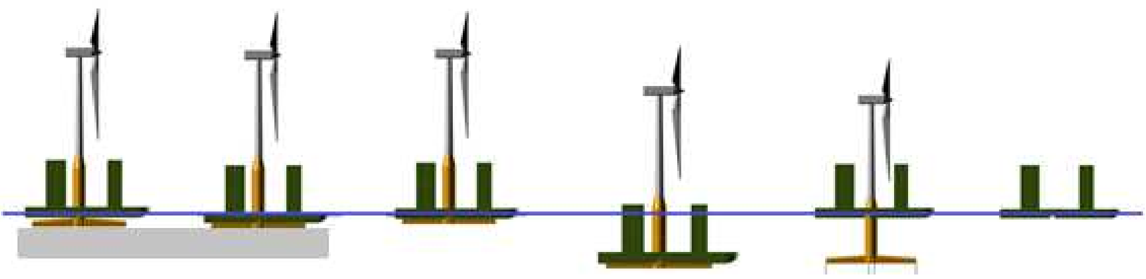

Figure 3-3 From left to right. SSB Ballasting, SSB-TLP connection, SSB-TLP transport, SSB – TLP ballasting, TLP tendon connection and SSB de-ballasting and SSB return transport operation

The results obtained from the scaled model tests were also used to calculate the operational limits for each of the fifteen T&I operations previously defined. The results from this study showed that towing operations for the SSB+TLP can be performed up to a significant wave height (Hs) of 2.5 meters, while most of the remaining operations can be carried out in Hs = 2 meters except for the most critical tendon connections operations that would require a less severe sea state of Hs = 1.5 meter, although as this operation has a very short duration the averaged Hs for the whole T&I operation is close to 2.4 meters.

In a next step, weather affection was considered by completing a study of the weather conditions for three UK waters representative locations. The operational limits for each step along with the associated duration were contrasted against the sea state probability of exceedance for the selected sites, resulting in the estimation of the necessary weather windows and expected weather downtime.

Finally, the insights obtained from the previous studies were implemented for a complete offshore wind farm project scale model for 100 units, taking into account that these operations would need to be repeated hundred times with the subsequent learning curve when applicable. This thorough study allowed estimating the total duration for the installation process of a 500 MW floating offshore wind farm based on 5MW TLPWIND platforms in different scenarios varying the staging port to site distance, weather conditions and the use of one or two SSB for the T&I strategy. The whole study derived some outstanding results:

If a **single SSB** is considered and a continuous installation process starting in April is assumed for the installation of the whole offshore wind farm, the total estimated duration obtained for the installation of 100 platforms was:

100 units T&I duration (days)		Annual mean wave height		
		1.0 m	1.5 m	2.0 m
Port to site distance	100 km	225 days	241 days	264 days
	250 km	365 days	397 days	425 days
	400 km	492 days	524 days	577 days

Also, if two SSBs are considered for an equal continuous installation process starting in April for the installation of the whole offshore wind farm, the total estimated duration obtained is reduced by more than half since some severe weather months could be avoided.

100 units T&I duration (days)		Annual mean wave height		
		1.0 m	1.5 m	2.0 m
Port to site distance	100 km	110 days	121 days	130 days
	250 km	175 days	185 days	197 days
	400 km	245 days	262 days	290 days

4. Conclusion (167)

A technically and economically feasible solution for the T&I of TLP substructures carrying a Wind turbine pre-assembled onshore has been achieved for the Construction, O&M and Decommissioning stages:

- **Towing**: Exceptional navigation capability at HS=2,5m with very low pitching angles, nacelle accelerations and towing drag (< 100 tons) at 5 knots or even higher (Towing back at 8 knots)

- **Installation**: Impressive results in seakeeping and dynamic behaviour of the TLP+SSB, especially for the lowest draught which represents the most critical installation operation (videos available).

- High number of workable days per year, since offshore operations are minimized. Installing a 100x5 MW windfarm in less than 8 months is possible in sites with mild weather conditions (Irish Sea) and relatively close to a staging port (100 km) with just one SSB.

- Low-cost marine spread for the T&I operations: AHT with BP>100 (20-35 k€/day) assisted by standard tugs (8-15 k€/day) and a WROV (8-12 k€/day) to carry out tendon connections, instead of expensive specialised vessels (150-500 k€/day).

5. Learning objectives (67 words)

- Design of an “ad-hoc” SSB tailored to TLPWIND technology, simple to manufacture and cost optimized

- Correlating Numerical models with Basin Tests for Prototype optimization

- Modelling and tank testing of a T&I system

- A marine operations plan for T&I Floating wind turbines

- A new O&M scheme including “tow back” operations for Major Corrective actions, as well as berthing and maintenance of the SSB