Buoyant Production Technologies Floating Offshore Substation (FOSS)

Buoyant Production Technologies FOSS

As floating offshore wind (FLOW) progresses over the coming years and wind farms move into deeper waters, floating offshore substations will be crucial in ensuring the efficient transfer of power back to shore. They have therefore been identified as a critical building block of commercial scale FLOW developments; however, to date they have not received the same level of attention as the floating turbines themselves.

Floating offshore substations present a number of design challenges driven by the sensitive substation payload, harsh offshore environment and the requirement to drive down the levelised cost of energy (LCOE) of renewables projects. Buoyant Production Technologies (BPT) have developed a patented FOSS solution that has the potential to be a key technology as FLOW progresses towards commercial-scale projects.

Background

There is a clear need to rapidly decarbonise our society in order to limit global warming and the damaging impacts of climate change. The necessity to transition the global energy mix away from fossil fuels was highlighted by the UN's International Panel on Climate Change 2022 (IPCC, 2022).

Energy security and affordability must also be considered, increasing the challenges facing the energy sector. The decarbonisation of the power generation system from one which predominantly uses fossil fuels to a renewable energy based system is one key aspect of the energy transition that in some regions is already moving at pace.

In the UK wind energy contributed 24.7% to the total electricity generation in 2022, the highest percentage of any clean power source (renewableUK, 2023). Offshore wind contributed 56% of all wind energy generation in 2022 and is forecast to grow 12% year on year between 2022 and 2032 making it one of the fastest growing energy sectors (GWEC, 2023).

Offshore wind presents a number of advantages over onshore wind, from higher average wind speeds to increased site flexibility.

Floating Offshore Wind Opportunity

FLOW is considered for deeper water sites, where deploying a fixed foundation becomes uneconomic relative to a floating solution. FLOW is the natural progression of offshore wind as developers move into deeper water to seek even higher average wind speeds and further site flexibility.

80% of the world's offshore wind resource potential lies in waters deeper than 60m and so may be suitable for a FLOW development (GWEC, 2023).

In the latest DNV forecast floating offshore wind is predicted to contribute 264GW globally in 2050 accounting for 15% of all offshore wind (DNV, 2023).

This scenario would require roughly 18,000 individual 15MW floating wind turbines.

The UK Sector

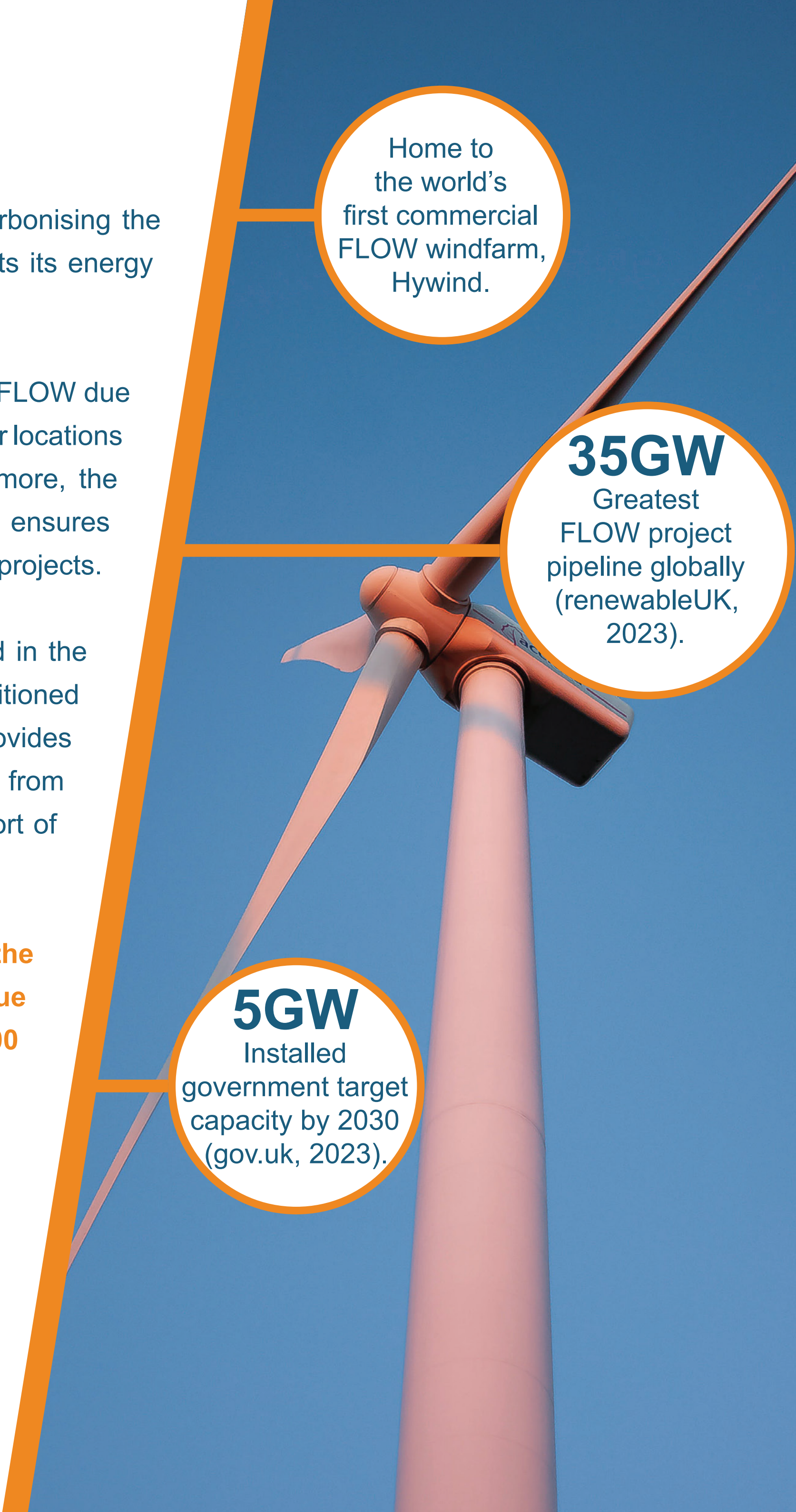
FLOW will play a crucial role in decarbonising the UK energy mix, ensuring the UK meets its energy security and net zero targets.

The UK is in a unique position to exploit FLOW due to the relative ease of access to deep water locations with high average wind speeds. Furthermore, the established offshore expertise in the UK ensures that the UK is well placed to deliver FLOW projects.

The early adoption of floating offshore wind in the UK and the current project pipeline has positioned the UK as a potential global leader. This provides significant opportunities to share learnings from UK projects to the global market through export of services in the future.

With key strategic investment FLOW has the potential to deliver £43.6bn in UK gross value added (GVA) by 2050, creating more than 29,000 jobs in the process (renewableUK, 2023).

A report by the UK Floating Offshore Wind Task Force recommended that £4 billion should be invested into key UK port locations to support the growth of FLOW (renewableUK, 2023).



UK FLOW Commercialisation Challenges

FLOW faces several challenges as it moves towards commercial-scale projects, focussed around two key issues:

- **Commercial viability:** Keeping capital and operational costs under control is critical to achieve an acceptable LCOE from the floating wind projects of the future.
- **Technology readiness:** While the floating wind generators have been subject to offshore testing, several technologies crucial for future FLOW projects are still unproven such as floating offshore substations and high voltage cables.

Reducing the LCOE of floating offshore wind

As commercial scale FLOW projects proceed, the supply chain will be pressured to increase capacity, spanning key turbine components, installation vessels, and port facilities. Unless supply chain capacity increases, project schedules will be constrained, and/ or costs will increase due to tension between supply and demand, threatening the LCOE of developments and the economic viability of projects.

Development of key technologies

The design of floating offshore wind turbines has been a hot topic for many years, with numerous different design concepts and multiple prototypes tested in the ocean environment. However, the floating turbine itself is only a single part of the overall offshore wind farm infrastructure, for which the overall functional requirement is to convert offshore wind power into available electrical power on land.

Supporting infrastructure such as the connection between offshore energy sources and the grid will need to be upgraded to enable the increased power produced to reach end users efficiently.

As FLOW progresses over the coming years, and wind farms move into deeper waters further from shore, floating offshore substations (FOSS) will be required to ensure the efficient transfer of power back to shore.

Whilst the FOSS technology will be a key building block of commercial scale FLOW developments, substations have not received the same level of attention as the floating turbines themselves. Within an article titled “Floating Substations: the next challenge on the path to commercial scale floating windfarms” DNV state; “now that the first commercial floating windfarms are about to enter the development phase the industry needs to pay attention to this critical element…”. As such, the FOSS itself presents a potential technology risk for future FLOW developments (DNV, 2021).

Floating Offshore Substations

Offshore substations are crucial for ensuring the efficient transmission of power from offshore windfarms back to shore by stepping the output voltage of wind turbines up to a higher transmission voltage.

Fixed bottom wind farms already rely on offshore substations on fixed jacket structure platforms. Siemens Energy have developed an Offshore Transformer Module (OTM) which has been widely used across North Sea wind farm developments. The OTM transforms the output voltage of wind turbines from 66 kV to the transmission to shore voltage of 220kV (Siemens Energy, 2020).

As offshore wind progressses into deeper water fixed bottom substations will not be feasible and a floating solution will be required.

The FOSS design is constrained by the following key criteria:

- Cost efficiency is a key criteria, for all components of a wind farm, including the floating substation.
- Floating units are subject to wave loading and hence motions in 6 degrees of freedom, unlike fixed platforms. Substation equipment is highly sensitive to motions, so any floating solution needs to deliver an acceptable motions performance.

Whilst it might be attractive to support the substation payload on the same floater type as the wind turbine generator (so as to access economies of scale), the requirement differs from that of the wind turbine generator sufficiently to justify a bespoke design:

- The substation **payload** differs from the wind turbine generator, and would require significant hull design changes to account for this.
- The substation equipment **motion sensitivity** differs significantly from that of a wind turbine nacelle.
- The substation **interfaces** with multiple dynamic cables, whereas a WTG interfaces with one, or two. This interface has a significant impact on the hull design.
- The substation is a critical component of a wind farm, where failure results in total loss of the power export route. As such, the **survivability requirements** of a floating substation are likely to be more onerous than that of a single WTG, which will equate to more stringent hull and mooring design requirements.

- The wind turbine generator hull should be optimised for rapid fabrication at scale, due to the numbers being produced. The substation design can be **less standardised**, with less focus on fabrication speed, as there are many fewer substations than floating wind turbines.

When considering hull designs suitable for a FOSS, it is worth considering the strengths and weaknesses of traditional offshore substructure types.

Traditional floating substructures

Semi-submersible platform

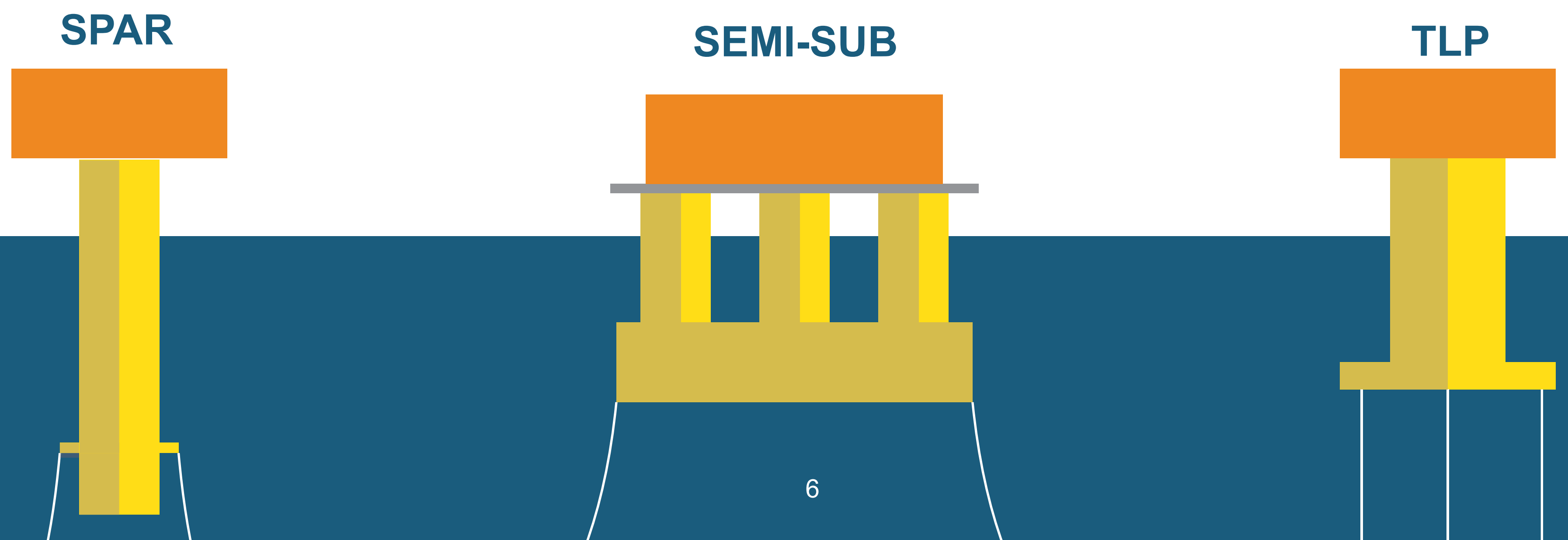
Semi-submersibles have a small waterplane area and are therefore less affected by wave loading leading to a good motions performance in the offshore environment. However, the semi-submersible design, with multiple column legs can be expensive and complex to construct, with costly maintenance campaigns through life to inspect and repair bracing and columns.

Tension leg platform (TLP)

TLP's also provide a very good motions performance with the mooring system effectively eliminating heave and pitch/ roll motions. However, the mooring tendon cost escalates considerably with water depth, limiting their economic viability.

Spar platform

Spar platforms are deep draught facilities, often with a draught in excess of 100m. They deliver a very good motions performance in the offshore environment. However, unless they can be integrated with their payload at a very deep water quayside, the offshore payload installation can be very expensive. As such, the spar platforms are unlikely to be economically viable for the majority of FLOW projects.



BPT Floating Substation

BPT have been developing their patented FOSS since 2020. The design aims to overcome the limitations of conventional floater designs whilst delivering the necessary motions performance required by the substation equipment.

The BPT floater design has been sized to support a Siemens Energy OTM topsides and to operate in a harsh environment offshore of the UK.

The BPT FOSS is a stiffened steel, deep draught, cylindrical structure with slender waterline and wider base. The hull form can be broken down into two main sections: the buoyant central column and the lower buoy soft tanks/water ballast tanks.

The main benefits of the BPT FOSS are:

1. **Quayside payload installation and commissioning.**
   At launch the lower buoy soft tanks are buoyant, providing the BPT FOSS with a shallow launch draught of around 5-6m. The substation payload can be installed and commissioned at the quayside before the unit is towed to deeper water and ballasted down to the deep operational draught. This reduces offshore hook-up and commissioning (HUC) costs.

2. **Excellent motions performance.**
   The deep draught and hull geometry ensure the design has minimal motions as required by the substation equipment. The motions performance is comparable to a spar unit.

3. **Simple structure.**
   The BPT FOSS structural arrangement is simple with two key sections, the upper column and the lower buoy. This ensures a simple modular fabrication process which reduces the cost of fabrication.

4. **Insensitive to water depth.**
   The BPT FOSS is moored with a catenary or semi-taut mooring system. The BPT FOSS mooring system cost is significantly less sensitive to water depth than a TLP.

A FOSS Solution for the UK Market

The BPT FOSS design is suitable for fabrication in the UK and for deployment on UK offshore wind projects.

Local content opportunity and low cost

Simple modular fabrication

This has been achieved through the simple cylindrical geometry, readily subdivided into blocks for construction. The hull is constructed separately from the substation topsides, which is mated to the hull at the quayside. By splitting the hull and topsides construction, the design provides the ability to maximise regional local content by fabricating the steel hull close to the wind development, while the more complex substation is fabricated elsewhere.

Shallow launch draft

In the UK, where fabricator quaysides are rarely located in deepwater, the ability to launch the hull in shallow water is a significant advantage, increasing the number of fabricators able to construct and launch the BPT FOSS throughout the UK. The BPT FOSS can be launched, and topsides installed in water depths of 5-6m.

Simplified offshore installation

The BPT FOSS provides the opportunity to fully install and commission the topsides at the quayside. This is a key advantage when compared to a spar unit which requires an expensive offshore campaign for topsides installation and integration.

Floating Wind Demonstration Project

In 2021 BPT was awarded a grant from the government Department for Energy Security & Net Zero (DESNZ) to demonstrate that BPT's patented hull design, configured to support a substation payload, is suitable for fabrication in the UK and for deployment on UK offshore wind projects.

These objectives were achieved through a set of model test campaigns supported by the Wolfson Unit at the University of Southampton and a detailed UK fabricator compatibility study.

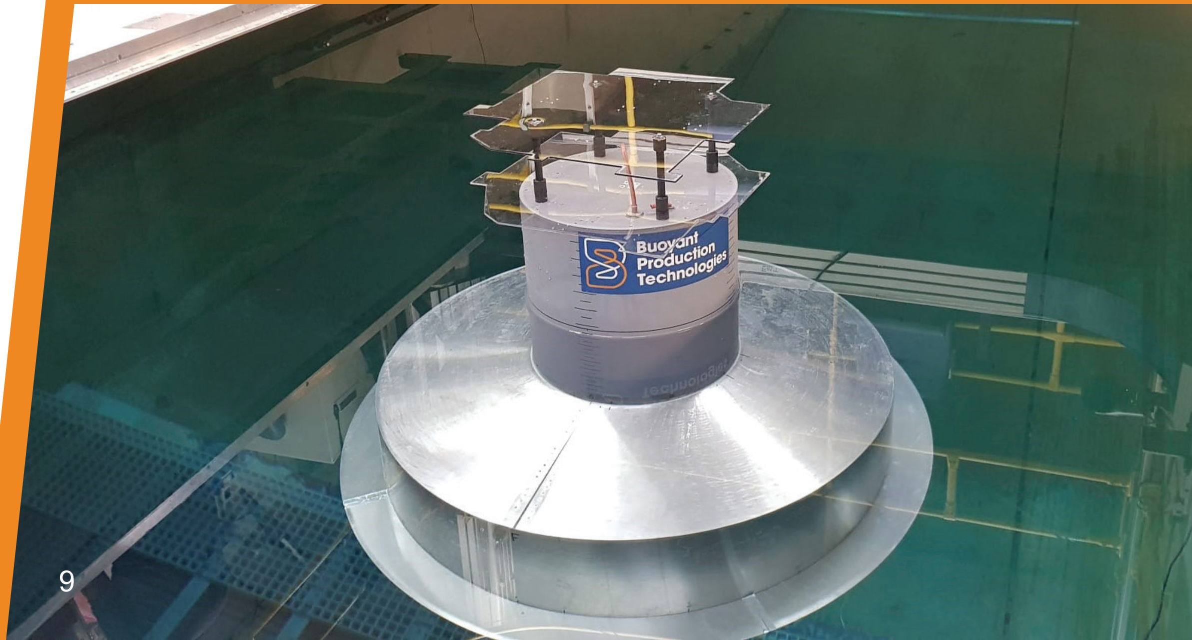
Model Test campaign

1:55th scale model tests have been conducted at the University of Southampton, Wolfson Unit. Model testing was conducted to assess the motions performance of the BPT FOSS in harsh North Sea conditions and to assess the marine operations.

The motions performance was assessed though a combination of decay tests and irregular sea state tests.

Decay tests consist of setting up the buoy in a free-floating equilibrium condition (i.e. free of any mooring system or restraining devices). The buoy is then displaced in one singe degree of freedom. After being displaced the buoy is left to move freely until it comes back to its equilibrium position and the motions of the unit recorded.

The irregular sea tests consist of subjecting the model test buoy to an irregular wave train which can be characterised by its significant height (H_s), its peak period (T_p) and its peakedness factor γ.



The correlation between the BPT's numerical model and the model tests observations provide confidence in the unit's performance in extreme offshore environments.

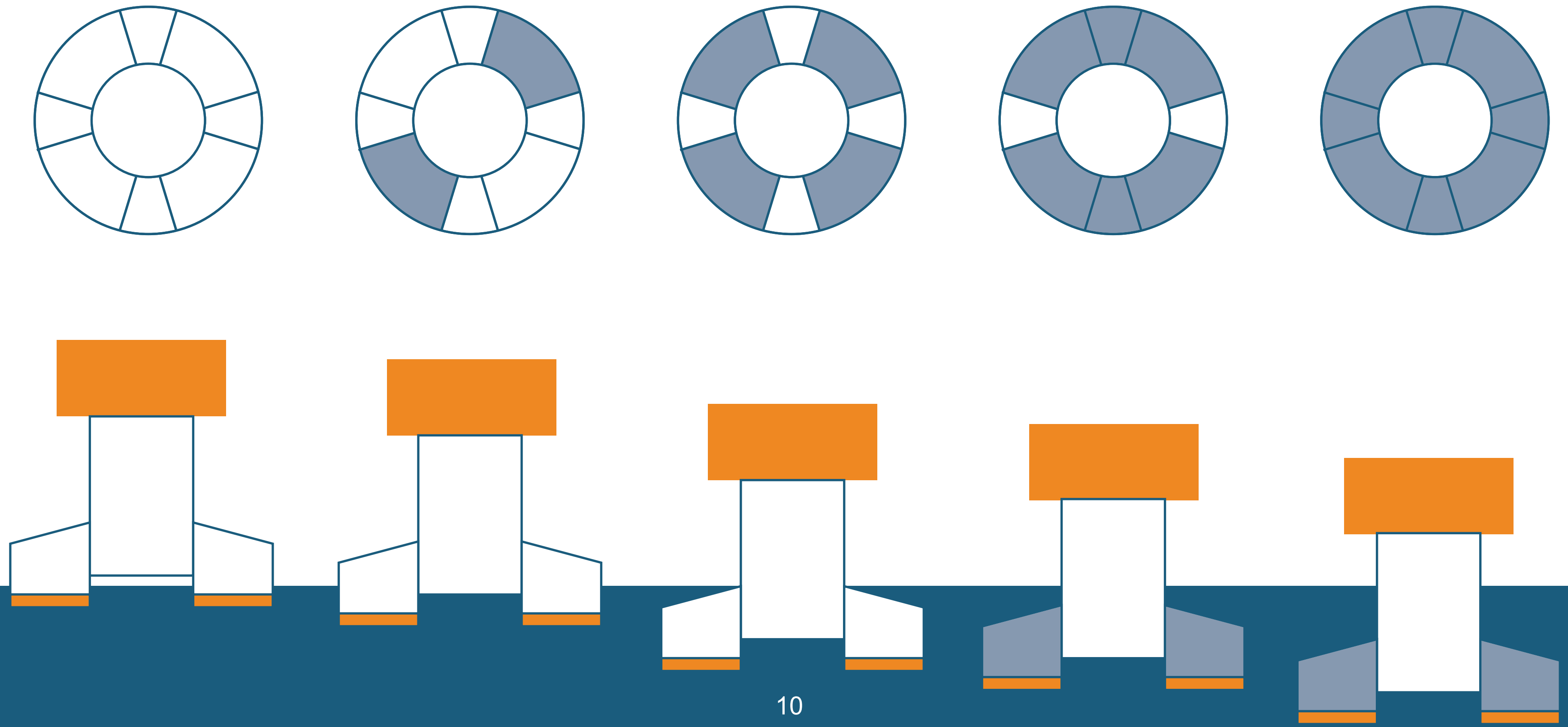
Results show the BPT FOSS has excellent motions performance with maximum pitch excursions of 0.7 degrees and lateral accelerations of 0.29m/s² in normal day conditions and maximum pitch excursions of 6.75 degrees and lateral accelerations of 1.45m/s² in the 1-year storm conditions (11.6m H_s and 15.6s T_p).

Shallow water launch & ballasting

One key feature of the BPT FOSS is its ability to be launched at a shallow draught with the topsides fully installed, prior to the BPT FOSS being transported to deep water for the ballasting operation.

The ballasting operation involves the sequential filling of ballast tanks, taking the BPT FOSS from its shallow launch draught to the deep operational draught. This avoids the need for an expensive offshore campaign for topsides installation and integration.

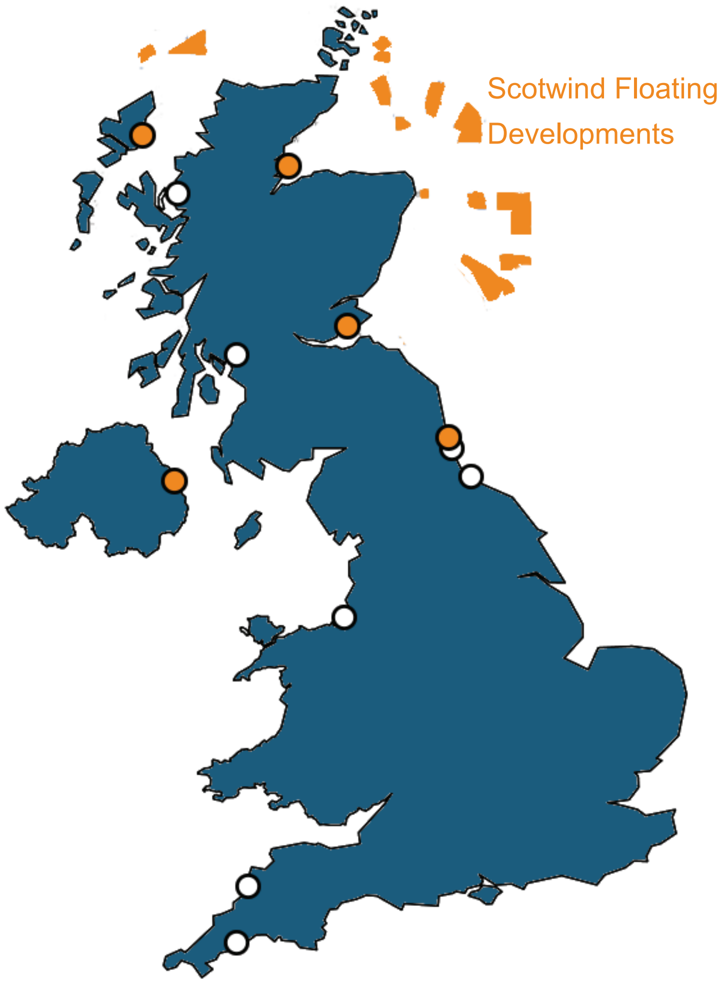
The technical feasibility of the ballasting operation was assessed during the model test campaign. The figure below shows the sequential filling of tanks during the ballasting operation.



UK Fabricator compatibility study

A UK fabricator screening was performed to assess which UK fabricators have the facilities and experience required fabricate and launch the BPT FOSS. The screening considered the following key details:

1. Experience fabricating steel structures of this size.
2. Size of fabrication workshops.
3. Fabrication equipment.
4. Quayside or dry dock dimensions.
5. Suitable channel to open water for tow to deep water ballast site.



The fabricator screening study & fabricator engagement process identified several fabricators that currently have all the facilities required to fabricate and launch the complete BPT FOSS, these are highlighted as orange dots on the map. Predominantly located in the north of UK, with access to North Sea developments, these sites all have experience of fabricating large steel offshore structures, access to the necessary workforce, and the quayside berthing/clear channel required by the BPT FOSS.

However, an area of concern identified from the study was that there is a relatively low level of fabrication automation available in UK fabrication facilities. As a simple, cylindrical structure, the BPT FOSS design lends itself to automated plate rolling and welding which would increase the fabrication productivity, reducing costs and therefore reducing the LCOE.

There are also several UK fabricators with facilities capable of fabricating some blocks of the BPT FOSS, such that a fabrication consortium approach could be employed, offering opportunities for regional local content to be achieved for developments further away from the more traditional shipbuilding hubs, these are depicted as white dots on the map.

UK fabrication of the BPT FOSS is feasible as several yards have the experience, know-how, and facilities required for this size of structure.

The UK fabrication capability is stronger in the north of the country. Southern fabricators are likely to be able to offer some block fabrication capabilities, but unlikely to be able to take on the whole contract.

UK fabricator facilities do not yet maximise the use of automated fabrication facilities. As such, fabricating the BPT FOSS in the UK is likely to carry an economic penalty.

Conclusions

Floating offshore wind provides enormous opportunities to access the untapped potential of deepwater offshore wind energy around the globe.

Whilst currently at a pre-commercial stage, the growth of floating offshore wind is forecast to take-off over the coming decades and is a key step towards delivering the reduced emissions required to keep global warming under the 1.5 degree Celsius limit as set out in the Paris Agreement in 2015 (Paris Agreement, 2015).

The UK currently has several existing small-scale demonstration projects underway and the largest pipeline of FLOW projects globally. As such, the UK is leading the development of the FLOW technology with an exciting opportunity to both decarbonise the UK economy, and also develop technologies and services that can be exported globally as developments take off elsewhere.

A key building block for future commercial-scale projects in deeper water will be the floating offshore substation (FOSS). Whilst floating wind generators have been subject to considerable R&D focus over the past decades, the FOSS concept is less developed, with fewer competing designs at this time.

BPT has developed a FOSS substructure design configured to support an AC substation payload, capable of operating in harsh environmental conditions. With support from DESNZ, BPT has demonstrated that the floating substation can operate in harsh, North Sea environmental conditions, and can be fabricated within the UK, offering opportunities for local content in future offshore wind projects, to maximise the value of such projects to the local economy.

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