Floating platforms: technical challenges

Recently, Statoil AS, Norway’s largest energy company, revealed plans to build a demonstration site testing floating offshore wind turbines off the coast of Scotland. It’s a move that rubber-stamps the industry’s gradual shift towards floating platforms, but is the technology up to the task? PES takes a look at the various engineering challenges.

Statoil is also considering Norway and the US state of Maine to test the commercial potential of its “Hywind” project, and it aims to build three to five Hywind machines at the site, when selected. A 2.3-megawatt prototype 10 kilometres offshore at Karmoy in Norway has been working “beyond expectations” at waters 200 metres deep, using a Siemens AG turbine and floating technology provided by French company, Technip SA.

The vision for large-scale offshore floating wind turbines was introduced by Professor William E. Heronemus at the University of Massachusetts in 1972, but it was not until the mid 1990s, after the commercial wind industry was well established, that the topic was taken up again by the mainstream research community. Current fixed-bottom technology has seen limited deployment to water depths of 20m, but as the technology has advanced into deeper water, floating wind turbine platforms may be the most economical means for deploying offshore wind turbines at some sites.

Technically, the long-term survivability of floating structures has already been successfully demonstrated by the marine and offshore oil industries over many decades. However, the economics that allowed the deployment of thousands of offshore oilrigs have yet to be demonstrated for floating wind turbine platforms.

For deepwater wind turbines, a floating structure may replace driven monopoles or conventional concrete gravity bases that are commonly used as foundations for shallow water turbines. A floating structure must provide enough buoyancy to support the weight of the turbine and to restrain pitch, roll and heave motions within acceptable limits. The turbine design philosophy for floating may be impacted if platform dynamics require a more dynamically compliant machine but the platform costs are likely to dominate the cost trade-offs. Therefore,
Water depth will play a key role in the economics of floating systems and will primarily decide the economic break point at which a particular floating configuration becomes more economical than its fixed counterpart. Floating systems may have unique advantages over bottom fixed structures depending on the topology, wave, sea ice, and seabed conditions. The cost/benefit of various engineering solutions is very different for shallow and deepwater applications.

Many of the same issues that govern oil and gas platforms will also be present in the design of wind platforms, but the importance of each variable will be weighted differently. There are a vast number of possible offshore wind turbine platform configuration permutations when one considers the variety of available moorings, tanks, and ballast options in the offshore industry. Unfortunately, a designer might find that most of the resulting topologies would have some undesirable aspects that would drive the system cost out of range for most wind applications. The optimum platform does not exist, of course, but there are many features that such a platform would embody that most designers could agree on.

Typically, the overall architecture of a floating platform will be determined by a first-order static stability analysis, although there are many other critical factors that will determine the size and character of the final design. However, once the platform topology has been established, a crude economic feasibility analysis becomes possible. Therefore to focus the discussion, a classification system was developed that divides all platforms into three general categories based on the physical principle or strategy that is used to achieve static stability:

1) **Ballast:** Platforms that achieve stability by using ballast weights hung below a central buoyancy tank which creates a righting moment and high inertial resistance to pitch and roll and usually enough draft to offset heave motion. Spar-buoys apply this strategy to achieve stability.

2) **Mooring Lines:** Platforms that achieve stability through the use for mooring line tension. The tension leg platform (TLP), relies on mooring line tension for righting stability.

3) **Buoyancy:** Platforms that achieve stability through the use distributed buoyancy, taking advantage of weighted water plane area for righting moment.

Each of these approaches for achieving stability can be thought of as an idealised vessel with limited properties; some of these characteristics may be desirable and some may be undesirable for use on a floating wind turbine. For example, in the extreme case the idealised spar buoy will have a tank with zero water plane area suspending sufficient ballast below the waterline to offset the tower top moments. The mooring lines would only function to provide station-keeping. Similarly, the idealised TLP would be a weightless tank with zero water plane area, held only by the tension of the vertical tendons. Finally, the idealised barge would be weightless and moored only to prevent drifting.

In practice, all floating concepts are actually hybrid designs that gain static stability from all three methods, although generally relying on one primary source for stability. Physical hybrid floating platform designs will almost exclusively lie inside the triangle, between the primary points. Designers will seek the “optimum” platform from a unique balance of stability options that will achieve the best functionality and lowest cost.

As mentioned earlier the turbine design is impacted by the choice of platform. Therefore, it must be included in the table of challenge trade-offs. The TLP is likely to provide the most stable platform and thus have the least impact on the turbine dynamics. A ballast-dominated design such as a buoy is likely to be heavier and therefore more expensive to build. The barge is likely to be subject to higher wave loading, which will increase the systems response (motions) to waves. Therefore, a turbine design that is tolerant of larger tower motions is needed. Turbines can be designed to tolerate larger motions but likely at a high cost.

**Platform design challenge ratings**

**Design tools and methods**

The complexity of the task to develop accurate modelling tools will increase with the degree of flexibility and coupling of the turbine and platform. Usually this results in greater responses and motions to wave and wind loading. Predicting wave loads and dynamics for a stable platform such as the TLP will require new analytical tools but is likely to be less difficult than for platforms that are more subject to wave loading. Platforms, such as the barge, that have a large part of their structure near the free surface will have larger pitch, roll, and heave forces. A barge is likely to violate simple

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American DOE cost-of-energy models indicate that if platform costs can be held near 25 per cent of the total system capital cost, then a cost goal of Euro 0.05/kWh would be attainable. However, the economic viability is almost an afterthought when aligned with the technical challenges that must be overcome to reach this economic goal and to provide a framework from which the first-order economics can be assessed.

Floating platforms for wind turbines must be optimised to achieve the lowest life cycle cost of the entire system. Unlike onshore installations, the cost of offshore wind is not dominated by turbine costs, but by multiple balance-of-station (BOS) and operating expense (OPEX) factors. Clearly, to be effective in meeting cost goals all cost aspects must be addressed. When floating wind turbines are introduced, a large focus must be placed on limiting foundation costs, but at the same time intelligent system-engineering decisions must be made to assure that platform costs do not drive up the cost of other critical cost elements.
Morison’s Equations assumption, which will be more complex to model and validate. Spar concepts will have smaller tower top motions relative to the barge but may still be subject to nonlinear wave forces requiring more advanced tools.

Additional offshore loads arise from impact of floating debris and ice and from marine growth build-up on the substructure. The analysis of offshore wind turbines must also account for the dynamic coupling between the translational (surge, sway, and heave) and rotational (roll, pitch, and yaw) platform motions and turbine motions, as well as the dynamic characterisation of mooring lines for compliant floating systems.

Buoyancy tank cost/complexity

All platform types require a system to provide buoyancy. A barge is likely to be the lowest cost per unit of displacement because the simple shape will employ equally simple fabrication techniques that are well established. However, since the barge depends primarily on water plane area, it would likely be a heavy structure. The spar-buoy is likely to be a simple rolled steel fabrication but more displacement is needed to counter the added weight of the ballast, resulting in an overall high material cost for the system. The TLP tank is likely to have the lowest displacement requirements and the lowest cost, but more complexity is required in the tank structure to support the loads from the mooring lines.

Mooring line system cost/complexity

The cost of the mooring lines is highly dependent on water depth. A barge and spar-buoy are likely to have catenary mooring lines that are attached to drag embedded anchors. In such a system the cost of the lines and chain will be driven by long lengths needed to minimise vertical loading on the anchors. A TLP will have short lines since they extend vertically, but they must carry a much higher load to assure constant tension between the anchors and buoyancy tank.

Anchor cost/complexity

Drag embedded horizontally loaded anchors associated with a barge or buoy would have lower material cost and complexity than high capacity vertical load anchors. Catenary moorings are loaded horizontally and are not subjected to the full loads experienced by the platform. TLPs require vertical or taut leg mooring systems employing high capacity anchors that must offset the buoyancy forces acting on the tank plus a reserve to prevent the lines from going slack under severe conditions. This is the primary design challenge for concepts relying on mooring lines for stability.

Float out cost/complexity and weather window tolerance

Any platform that is stable during float-out with a fully-assembled turbine will avoid the high cost of special purpose ships to carry and place the turbines on site. A self-stable platform can be towed by low-cost tugboats or buoy tenders. This characteristic may reduce life cycle costs when major turbine retrofits, long-term maintenance or decommissioning is needed.

Weather window tolerance is the ability of an offshore turbine to be floated out and installed in a broad range of weather conditions. Weather conditions frequently cause delays in installation processes costing standby fees and idle installation crews. A platform that can be installed in higher sea states, higher wind conditions with less special-purpose vessels will reduce the cost of installation. A system that can be towed-out, fully assembled, in more demanding sea states will reduce installation costs as well as long-term maintenance costs if the platform has to be towed back into port for overhaul.

Unlike oil and gas platforms, wind turbines will be deployed in quantities of 100 or more which will permit the development of tolling and mass production technique to lower cost. Of all the strategies this will impact the long-term costs most by taking advantage of assembly line toolling where material and components are brought from the factory instead of the final site for assembly. Higher quality and safer work conditions can be sustained with less impact from poor weather and sea conditions. This is a major advantage of the barge. Certainly special purpose floatation could be designed to stabilise a TLP or other platform during float-out but not without adding cost and complexity to deployment.

Onsite installation simplicity

The cost of onsite construction is driven by the charter fees of special purpose craft and cost of crew which is all multiplied by the complexity of the assembly process and weather tolerance of the assembly process. A heavy lift of a nacelle to mate with a moving platform could prove difficult and expensive. For this reason at sea assembly must be minimised. The best situation is likely to be a self-contained anchor deployment system on a stable barge. It might be economical to assemble a spar-buoy system with turbine in place and tow it out de-ballasted with the turbine leaning over and resting on the tug. This would minimise draft in port and allow tank ballast to be added at sea for final vertical orientation. This strategy would eliminate some of the large vessel equipment. Similarly, a hydrodynamically stable TLP could be designed to float-out with an unballasted gravity anchor, which can be deployed on site without special equipment.

Decommissioning and maintainability

Platforms that are stable with a low draft can be towed into port for long-term maintenance or decommissioning. The ease at which this can be accomplished will lower maintenance cost during critical overhaul cycles. Systems that are more difficult to un-tether and float back to shore, such as the TLP or a spar-buoy, may be more costly for large maintenance operations. Another aspect is the relative burden of maintenance required for the platform itself. Simple systems may require less maintenance. Finally, accessibility has been demonstrated to be a key factor in sustaining high availability. Platforms that facilitate access during poor weather will lower the overall system cost by increasing energy capture and lowering O&M.

Corrosion and ice Resistance

Platforms that have much of their structure near the free surface will be subject to higher corrosion and ice flow loading. This is a disadvantage for substructures, such as the barge, that depend on water plane area to achieve stability. This problem can be addressed by using non-corrosive materials such as concrete, corrosion-resistant coatings, and cathodic protection, however, addressing this issue will add cost to the system.

Water depth independence

The ability to install a single platform design over a broad range of depths increases the number of sites suitable for that design. Each platform type has a minimum depth that it can operate in. Platforms that depend on water plane area can operate in shallow or deep water sites. TLPs and spars require depths of at least 50-m for a 5-MW turbine. A shallow draft self-stable platform can also be towed out of a shallow port to either deep or shallow water sites. A barge meets these characteristics while TLPs and spar-buoys are likely to require greater channel depths during float-out and deployment. In deeper waters the costs are driven more
by anchor line lengths which impact barges and buoys more than TLPs.

**Sensitivity to bottom soil conditions**

Geotechnical surveys are expensive and time consuming. If an anchor system requires certain minimum soil conditions or design modifications to suit the soil conditions, then site-specific engineering is needed for each site. Any anchor system that meets a broad range of soil conditions will require less geotechnical work and less site-specific anchor design. Drag imbedded vertical load anchors are likely to suit a broader range of soil conditions than suction piles because they loaded more lightly and their failure consequences are less catastrophic than for a vertical load anchor on a TLP.

**Minimum footprint**

Environmental impact is likely to affect cost. Large spread mooring systems impact more bottom area, reducing the space between turbines and increasing the obstacles that may impact other uses of the sea. This issue may be critical for project permitted in environmentally sensitive regions.

**Wave Sensitivity**

Extreme waves are the design drivers for most offshore structures. Some platforms might be more tolerant of higher sea states. A platform that is tolerant of high sea states during extreme weather conditions can be placed at a broader range of sites. Generally, submerged platforms can more easily avoid extreme waves relative to platforms at the surface.

**Impact of stability class on turbine design ratings**

It is common for the offshore turbine designers to focus on the support structure, but the extra motion allowed by floating platforms will significantly affect the turbine designs as well. More active dynamics will be experienced by all the floating concepts resulting in greater tower top motions and coupling between the support structure and rotor. The following are four of the major issues that one might consider in the initial trade off.

**Turbine weight**

The weight of the nacelle/rotor assembly (NRA) will directly affect the size and cost of the buoyancy tank required to support the total weight of the system. Thus, any reductions in tower-top weight will result in further reductions in total system weight. This is strong incentive to reduce the weight aloft. This can be done in many ways, and including some methods were rejected for land-based systems because of acoustic emissions or aesthetics. For all designs, higher rotor tip speeds will result in NRA weight reductions. This is realised by several physical advantages. Higher rotational speeds allow smaller blade platform and lower blade weight for the same energy output. Higher speeds mean lower input torque and lower gear ratios, and hence smaller shafts and gearboxes. Current trends in offshore drive train designs are towards direct drive generators which can be made smaller for higher rotational speeds. Direct-drive generators are expected to be more reliable than modular gear driven, systems but present wound rotor generators are heavier.

Permanent magnet generator designs promise to offer further weight reductions and improved efficiency for future designs. The heaviest component above the water is by far the tower. Lower thrust loads and alternative lightweight materials may also help lower tower weight. The weight reductions may also be realised in the platform itself where, for example, lightweight aggregates can provide concrete options 40 per cent below standard mixtures.

**Tower top motion**

The degree of platform motion will have a proportional impact on the NRA design requirements and hence system cost. The turbine design will have to be more robust to accommodate high heel angles, increased nacelle displacements, heave motion, and angular accelerations resulting from pitch and roll motions. A barge design might experience larger rotational motions from wave loading, which will induce dynamic loads in the rotor, tower, and blades. Flexible rotor designs might accommodate these dynamics more easily than current ridged rotor designs. Downwind rotors might accommodate large deflections more readily than upwind rotors, which have smaller tower clearances. While platforms that allow higher nacelle motion may benefit more from these turbine innovations, generally all floating turbine systems could realise a greater potential cost reduction from flexible designs when compared to fixed bottom systems.

**Controls complexity**

Controls are playing an increasingly important role in the overall stability of wind turbine systems. Controls are already used in onshore turbines to damp undesirable structural resonances and reduce dynamic response to turbulence in the wind. In floating platforms it is conceivable that controls would be used to limit the response of the entire turbine/platform system to stochastic wave loading. For example, pitch motions (fore/aft direction) can easily be limited by an intelligent collective pitch control strategy. Similar techniques have already been used to dampen tower motions on onshore turbines. A greater challenge will be in damping roll motions, which are translations of the rotor in the plane of rotation (side-to-side), but researchers are also working on control methods to limit these responses. Some platform choices might introduce dynamics that are more difficult to control than others. Thus, it is important to consider the benefits and challenges posed by this issue.

**Maximum healing angle**

Healing angle – the displacement angle of the tower during extreme loading – can disturb lubrication distribution in gearboxes, alter bearing loading, and create abnormal component forces and dynamic loads. Some onshore wind turbines have been designed to operate at extremely high shaft tilt angles for passive load alleviation, but some offshore platforms might require heal angle specifications that are both dynamically acting and much higher than any land-based application to date. The questions are can these systems be designed to economically include these additional requirements, and what additional dynamics are introduced? Spar buoys, for example, might experience high static heal angles that require special mechanical design considerations when making configuration choices.

**Conclusions**

Floating platforms for wind turbines have been proposed for many years but only recently has the technology matured enough to seriously consider overcoming the technical challenges required to design successful machines. The offshore oil and gas industry has proven that the technical challenges can be overcome but the economics of implementing this industry’s solution would possibly prohibit any deployment of machines in a competitive wind energy market.

The challenge is a primarily economic one. These economic challenges present technical challenges. Floating systems offer the opportunity to perform most of the assembly process onshore in production facilities that can maximise the advantage of series production. Through high production floating systems that are lower cost than fixed bottom systems, which must be constructed at sea, may be possible. These systems could be deployed in a wide range of site conditions including high wind sites located further offshore in deep water, ultimately leading to the lowest cost offshore turbines. It remains to be seen how successful the Statoil AS demonstration is. ■