Design Standard for Floating Wind Turbine Structures

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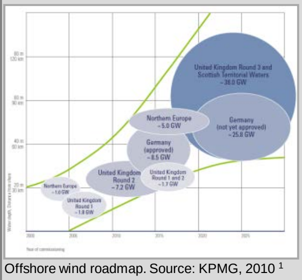
Status of Floating Wind Turbine Technologies

Introduction

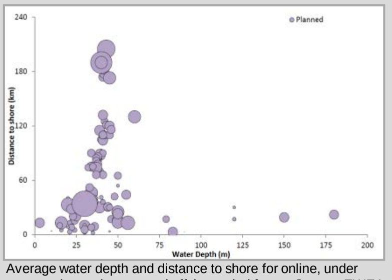
Offshore wind power is expected to play an increasingly important role in the future energy supply and floating wind turbine solutions have received considerably more attention during the last few years.

A large number of concepts are being developed, full-scale prototypes have already been installed and several are under operation in testing phases. Floating wind turbine structures have several advantages compared to their bottom-fixed peers. Much of the world's shallower waters have already been developed and/or are subject to other interests than energy production. Other areas, closer to shore, are just not suitable for bottom fixed installations due to environmental or public reasons.
The abundant wind resources available in deep waters, advancing technologies, the potential for a global market and decreasing cost levels are all parameters that have helped to create the recent momentum for the floating wind turbine industry, attracting investments and allowing for the development of demonstration projects.

The evolvement and future prospect for offshore wind, going into deeper waters and to further distances from shore have been addressed in several assessments during the last years, as shown in the below figures:



Offshore wind roadmap. Source: KPMG, 2010 [1]



Average water depth and distance to shore for online, under construction and consented offshore wind farms. Source: EWEA, 2012 [2]

Floating wind turbine concepts

Within the floating wind turbine industry, three key design philosophies are preferred by the developers, all of them well known from the oil & gas industry, the spar buoy, the semi-submersible and the tension leg platform (TLP). The semi-submersibles with their low draft have a high site flexibility. The spar buoys are simple structures with an inherently high stability, while the tension leg platforms are low weight structures which impacts the investment costs. The most suitable design will have to be found by analyzing the actual site with associated manufacturing facilities and transport route, the metocean conditions and the actual concept's design and characteristics, to find the optimal concept with the least trade-offs.

Hywind
Source: Statoil

The **spar buoy** is typically a steel or concrete cylinder with low water plane area, ballasted with water and/or solid ballast which results in a weight-buoyancy stabilized structure with a large draft. The philosophy uses simple (few active components), well-proven technology with inherently stable design and few weaknesses.
Based on the large draft, the spar may however require towing to the deep-water site in a horizontal position. In such cases the structure needs to be up-ended, stabilized and the turbine is then installed using a crane barge. A spar is generally moored using catenary or taut spread mooring systems.

Statoil's Hywind is a 2,3 MW prototype that was deployed outside the west coast of Norway in 2009. It is the first floating wind turbine structure installed and is still in operation.

WindFloat
Source: PrinciplePower

A **semi-submersible** is a free-surface stabilized structure with relatively small draft. It is a very flexible structure thanks to its relatively low draft and high flexibility related to soil conditions. It is a heavy weighted structure with a considerable amount of steel and a relatively high manufacturing complexity due to the many welded connections. A semi-submersible structure is kept in position by the mooring lines, which typically are taut or catenary.
In 2011 the first large scale semi-sub prototype, Principle Power's WindFloat structure, was installed outside Portugal. The 2,0 MW turbine on a semi-submersible platform is the first offshore wind turbine to be installed without the use of any heavy lift vessels or piling equipment at sea. All final assembly, installation and pre-commissioning of the turbine and substructure took place on land in a controlled environment and the complete system was then wet-towed using simple tug vessels.

PelaStar
Source: Glosten Associates

The **Tension Leg Platforms (TLP)** are tension restrained structures with relatively shallow draft. The tension leg philosophy enables low structural weight of the substructure, and thus lower material costs. TLPs have high buoyancy and are held back by tendon arms connected to the anchors. This adds additional requirements with regard to soil conditions at site.

No TLP has yet been deployed as a large scale prototype, but the PelaStar concept being developed by Glosten Associates is probably the concept furthest in development. The PelaStar concept is currently being considered for a demonstration site in 60-100 m water depth outside the UK.

A Global Market

The development of deep water offshore floating systems has so far mainly been led by Northern European countries, but today a considerable amount of R&D, concept developments and testing of floating systems are performed also in the US, Japan and elsewhere within the EU, creating the potential and environment for a global market. Recent developments are described below:

- In late December 2012, The European Commission decided to provide project funding for a 27MW floating offshore wind farm, utilizing the WindFloat semi-submersible structures and the next generation multi-megawatt offshore wind turbines.

- In the UK, ETI plans to invest £25m in a 5 to 7 MW demonstrator project in 60 to100 m water depth. Considerable parts of UK Round 3 zones are in deep waters, suitable for floating wind turbine installations.

- The Japanese government are currently involved in several large national development projects with floating wind turbine platforms , e.g. the Fukushima Floating Pilot Wind Farm and the Kabashima demonstration turbine, a 1:2 spar solution with a 100 kW turbine installed in 2012. A full scale 2 MW turbine installed on a spar is planned to be deployed in 2013 as a part of the Kabashima project. In addition, in mid January 2013 Japan released a plan to build the world's largest offshore wind farm with 143 turbines mounted on floating platforms outside the coast of Fukushima.

- In late December 2012, the US Department of Energy (DOE) decided to partly fund the development of seven offshore wind projects, including three floating solutions. This is in line with the US ambition to create a momentum in their domestic wind energy industry, utilizing their vast deep-water wind resources.

Development of design standard for Floating Wind Turbine Structures

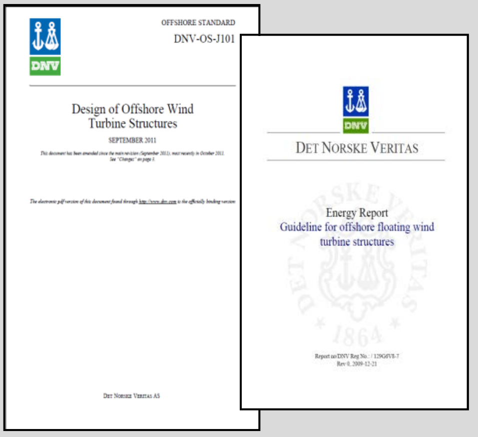
Background

Floating wind turbines is a field currently undergoing major development. Several companies and research institutes worldwide are engaged in research programs, pilot projects and even planning of commercial floating wind farms. Developing standards for design of floating wind turbine structures is crucial and necessary for the industry to continue to grow. A technical standard embodies the collective experience of an industry and contains normative requirements that shall be satisfied in design. Development of a standard for floating wind turbine structures will lead to:

- Expert consensus on reliable approaches to achieve a tolerable level of safety
- Industry consensus on practicable approaches to achieve tolerable level of safety
- Experience from the industry reflected in the contents of an industry-wide standard regarding safe design, construction and in-service inspection
- A tool to be used related to innovative designs and solutions within given acceptance criteria
- A full-fledged reference code supplementing existing offshore wind turbine structure codes that do not cover floating units

As a first step towards developing a standard for design of floating wind turbine structures, a *DNV Guideline for Offshore Floating Wind Turbine Structures* was established in 2009 as a supplement to *DNV-OS-J101 Design of offshore wind turbine structures*. The development of this guideline was based on identification of current floating wind turbine concepts in conjunction with experience from other floater applications. The guideline, which is less formal than an official standard document, addresses floater-specific issues such as stability and station keeping.

The standard DNV-OS-J101 "Design of Offshore Wind Turbine Structures" provides principles, technical requirements and guidance for design, construction, in-service inspection and decommissioning of offshore wind turbine structures. However, DNV-OS-J101 does not cover floater-specific design issues. This is also the case for other existing standards for offshore wind structures e.g. *IEC61400-3 Wind turbines - Part 3: Design requirements for offshore wind turbines* and *GL (IV Part 2) Guideline for the certification of offshore wind turbines*.



Joint Industry Project

As a second step, initiated in September 2011, DNV is currently conducting a joint industry project (JIP) for development of a full-fledged DNV standard for design of floating wind turbine structures. Ten of the world's leading players in the wind industry (Europe, USA and Asia) are currently participating in this JIP. The standard will be a supplement to DNV-OS-J101. The JIP is looking into floater specific design issues: suitable safety level, calibration of safety factors, global performance stability, station keeping, site conditions in relation to low frequent floater motions, necessary simulation periods, higher order responses and design of floater-specific structural components.
The following technical issues will be covered in the standard:

- Safety philosophy and design principles
- Site conditions, loads and response
- Materials and corrosion protection
- Structural design
- Design of anchor foundations
- Stability
- Station keeping
- Control and protection system
- Mechanical system and electrical system
- Transport and installation
- In-service inspection, maintenance and monitoring
- Cable design
- Guidance for coupled analysis

The project secures quality assurance through a technical reference group where all participants have a representative. The standard will also go through an internal DNV and external industry hearing process. The standard is expected to be released during Q2 2013.

Assessment of acceptable safety level

An important task in the JIP is to determine which safety level that is necessary or acceptable in design of floating wind turbines structures. The target safety level of the existing standards is taken as equal to the safety level for wind turbines on land as given in *IEC61400-1 Wind turbines - Part 1: Design requirements*, i.e. normal safety class.
As the consequence of failure is primarily a loss of economic value, this is evaluated through a cost-benefit analysis. The analysis is to be used as part of the basis for selecting target safety level. This target safety level originally developed for small, individual turbines on land has been extrapolated to be used also for:

1. Larger MW size turbines on land
2. Offshore turbines
3. Support structures for offshore turbines
4. Many large turbines in large offshore wind farms

It is foreseen that the future floating wind farms will consist of a large number of turbines. Different target safety levels may be reasonable for offshore turbines in a large farm. The selected target safety level is likely to depend on the number of turbines in the wind farm.

Structural design

Another important issue is structural design. Reliability-based calibration of partial safety factor requirements for design of structural components is assessed for e.g. tendons and mooring lines. Existing design standards from other industries will be capitalized on, e.g. *DNV-OS-C101 Design of Offshore Steel Structures, General (LRFD Method)* and *DNV-OS-C105 Structural Design of TLPs (LRFD Method)* for tendons and *DNV-OS-E301 Position Mooring* for mooring lines. The JIP has access to full scale data from Hywind (Statoil) and analysis data from Pelastar (Glosten Associates) and WindFloat (Principle Power). These data will be used as part of the basis for calibrating the safety factors.

Acknowledgements and references

JIP participants:
Statoil (Hywind), Navantia, Gamesa, Alstom Wind, Iberdrola, Sasebo Heavy Industries, Nippon Steel, STX Offshore & Shipbuilding, Principle Power (WindFloat), Glosten Associates (Pelastar),

[1] EWEA ; Task Force 'Deep Offshore & New Foundation Concepts' 2012; [2] KPMG, 2010; Offshore Wind in Europe, 2010 Market Report