Dynamic Positioning Systems for the Offshore Wind Industry

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Abstract

The offshore wind power capacity has increased steadily for the past decade and new wind farms are increasing in size. In 2017, the London Array in the UK was the world’s largest at 630 MW. The Hornsea Wind Farm under construction will be largest when completed at 1200 MW. Projects at the planning stage include the Dogger Bank at 4800 MW and Greater Changhua in Taiwan at 2400 MW. The decreasing cost and low carbon footprint are key drivers for an expanding business.

This paper considers the background, design and use of dynamic positioning systems for the offshore wind service industry. Service operation vessels may operate in a windfarm for weeks at a time, servicing a number of wind turbines each day. The paper will consider how accurate and continuous dynamic positioning are essential for efficient operation.

The paper will study the operational requirements particular for service operation vessels. It will take a closer look at the functionality required for mission planning and examine how automated operations between wind turbines improve productivity and speed up mobilization and demobilization at each wind turbine. A case study demonstrates how the positioning system design integrates with heave compensated walk-to-work gangways to increase efficiency and safety of the gangway landing. Furthermore, the paper will show how accurate positioning and vessel control for a range of different working speeds increase service capability within the wind farm.
Introduction

The offshore wind market value increase for DP systems with the rise of offshore wind generation. New regulations increase the demand for emission-free power production. Offshore wind power technology has matured and lowered the installation costs. The decreasing cost and low carbon footprint are key drivers for an expanding business. Offshore wind may also produce electricity for existing oil and gas operating platforms.

New and larger wind farms are going to be located further offshore than before. This influence the operations & maintenance logistical concept, and the design of service operation vessels (SOVs). The need for cost efficient operations dictate that the vessels must depend less on shore and operate as an independent service base equipped with all the supplies needed. The vessels will be responsible for both planned and unplanned maintenance tasks and may operate in a windfarm for weeks at a time, servicing a number of wind turbines each day.

Vessel design and systems must account for wind farm variations in size, platform heights, tidal range, environmental conditions, distance to shore etc. Vessel must also take into consideration different wind turbine constructions. The operator deploy service crews to different turbines so they can start their work according to schedule. For normal maintenance, there will be a high number of service missions and procedure repetitions every day.

The changing environmental conditions encountered each day and between each turbine visit, the difference in direction between the environmental forces, and the close operation with the turbine structures, make the DP capability of the vessels an important performance parameter.

Vessels with dynamic positioning technology may play a part at all stages of a wind farm’s lifecycle, but the remainder of this paper considers service operations vessels and how accurate and continuous dynamic positioning are essential for efficient operation. We will show how the DP system increase performance and lower cost for wind turbine maintenance operations with

- Transit operation between wind turbines with high-speed automatic control
- High precision DP operation with gangway integration
- Effective mobilization and demobilization at each wind turbine
- Waiting mode with minimum energy consumption

Offshore wind market

The offshore wind power capacity has increased steadily for the past decade from a global capacity of about four MW in 2011 to almost 19 MW in 2017. Most installations are located in the waters off the coast of eleven European countries, particularly in the North Sea. The industry spreads now to North America, East Asia, India and elsewhere. New wind farms are increasing in size. In 2017, the London Array in the UK was the largest in the world at 630 MW. The Hornsea Wind Farm under construction will be larger when completed at 1200 MW. Projects at the planning stage include the Dogger Bank at 4800 MW and Greater Changhua in Taiwan at 2400 MW. Analysts estimate that offshore wind will have a global capacity of 120 GW in 2030.

New technology and designs, decreasing cost and low carbon footprint are key drivers for an expanding business. Some projects have a healthy economy without subsidies but there are large differences between the offshore wind farms and sea bottom conditions. DNV GL Energy Transition Outlook report of 2018 estimates that, in 2050, offshore wind will account for about six percent of the global electricity production.
Floating offshore wind power generation is in the early development phase with only one field in operation: Equinor’s Hywind Scotland began production in October 2017. However, some analysts estimate that floating offshore wind could have a 10 GW capacity worldwide in 2030 (Global Wind Energy Council, 2018).

**DP System Considerations**

To address the SOV requirements the DP system must address four main groups of considerations: operations, vessel speed ranges, and sensors.

Effective operations during wind turbine service operation reduce time and cost. Gangway integration ensures a rapid mobilization during arrival procedure. Knowledge of the best position for gangway...
connection to wind turbine is essential to save time. Previously, operators would spend time searching for the best vessel position and even a precise DP system alone cannot compensate for the lack of known position setpoints.

The vessel-motion control system can reduce the number of manual procedures by automating parts of the operation. Vessel control for all speed enables one-touch actions to command motion, position and heading. It is important that further operational information and overview accompany the automation process to keep operator in the loop and let them focus on their task.

A control system for zero, low and higher speed enable complete control of the vessel from wind turbine approach to docking. The control system must suit a wide range of vessel sizes and different thruster setups to suit different wind farms. The DP system should support astern motion to allow an efficient operational movement pattern between wind turbines and avoid turns.

Areas suitable for offshore wind farms have of course favorable wind conditions, which affect the vessel’s station-keeping ability. Shallow waters makes it easy to install wind turbines. On the other hand, deeper waters outside the wind farm area induce a strong current and the tidal conditions may limit the operational window additionally.

Operators describe scenarios where gangway and vessel operators coordinate their actions with limited visibility of the gangway tip and manual coordination with radio communication. Typically, an operator will control the SOV to approach a wind turbine and dock while another operator controls the gangway in the following order:

1. Move to approach zone
2. Move gangway to approximately 45 degree angle
3. Move vessel to landing point
4. Turn gangway to about 90 degrees
5. Adjust telescope length and connect to structure

This approach can result in trial and errors to find a suitable vessel position to connect the gangway. Additionally, the gangway may not have full operational margins compared to the optimal position where there is maximum available movement for gangway length and angle.

Position reference systems for SOVs face some particular challenges.
- There is limited suitable space for targets for relative position reference systems.
- Operators have observed and reported frequent GPS outage near turbines. The source is not yet determined.
- New proximity sensors designed for monopoles. Adjust camera/proximity sensors to fit other wind turbines foundations.
- Limited space leads to high density of personnel with reflective clothing onboard
- Expensive to deploy and maintain reflectors for entire wind farm

Some of the items discussed in this paper, such as the gangway integration, are also valid for other applications such as crew boats.
The All-Speed Challenge
The discussion above shows that the SOV operation will benefit from full control of vessel position, speed and heading from transit speed to station-keeping position. This is challenging for a single control system because the mathematical models and algorithms must cover the entire speed range.
As a general simplification, we can separate traditional automatic control systems into two domains: An autopilot controls the vessel heading and speed at transit speed. A dynamic positioning system controls the vessel position, heading and speed at zero or low speed.

The classical autopilot model, the Nomoto model (Nomoto et al (1957)), describes the relationship between rudder angle and vessel heading for a given speed. This differs significantly from the DP-model (e.g., Fossen (2011)) where zero-speed considerations simplify the model to give an effective and robust control algorithm. Both models produce incorrect results when applied outside their intended operating conditions.

The thruster models and usage change significantly with speed. The DP model may assume negligible water speed and equal thrust in all directions. Tunnel thrusters does not produce thrust at higher speeds. Speed change the thruster characteristics, azipull thrusters obtain a rudder effect in higher speeds and thrust allocation must consider operational limits on azimuth angles to avoid additional wear and tear.

Wind Turbine Support for Service Operation Vessels
The Wind Turbine Support is a system function in the Icon Dynamic Positioning System that aids the operator in approaching and connecting to wind turbines using a gangway. The main function features are

- Automatic transit to turbine area
- Adjustable approach to turbine
• Known vessel position before connecting gangway calculated with the turbine docking point and the gangway.
• Automatic departure

The Wind Turbine Support is based on a wind farm file that contains information about all turbines. Operators at DP systems with Wind Turbine Support may import new wind farm files for redeployment at new locations independent of service engineers.

The function supports different wind turbines types and wind farms. Technical drawings with exact measurements of the wind turbine’s shape and gates or gangway connection points are necessary to correctly indicate the wind turbine and position the vessel.

Positioning system design integrates with heave compensated walk-to-work gangways to increase efficiency and safety of the gangway landing. A pushing-type gangway push toward the structure. The control system compensate for the pushing force to reduce any deviation caused by the gangway’s connection to a structure. Experience has shown that the gangway feed-forward force is a critical component in the control law for minor vessels. The vessel rotation point must be set to the gangway rotation point.

The service missions to and between wind turbines is a repeatable task, likely to benefit from automated operation. Standardized controlled vessel movements replace continuous position updates and provides a smoother and faster approach and departure. This increase the operational efficiency, reduce number of button pushes and ease the operator workload. The DP system must include all-speed functionality to capture the full potential for automated operations.

The all-speed requirements require some changes to the SOV dynamic positioning control system modules, particularly the state estimator, reference model, position and heading control loop and the thrust allocation scheme.

The high-speed waypoint tracking function relies on automatic heading adjustments to stay on the track. For small cross-track errors, the vessel heading will adapt to wind, waves, and current to ensure that the course-over-ground aligns with the track direction. The thrust allocation method must consider the thruster efficiencies for different speeds and use the appropriate set of thrusters for low and high speed. The Icon DP system controls the vessel in both low and high-speed mode without operator interactions. The vessel operator is then free to concentrate on the operation at hand instead of manually control thrusters or switch between systems.

The DP system graphical user interface (GUI) is equally important as it feeds the operator information about all necessary onboard systems and serves as a planning tool for current and future operations. It provides a wind farm overview in a compact presentation and adds the operational context to the DP system by displaying accurate and absolute positions of vessel and wind turbines in wind farm.

The GUI offers the operator an overview to plan and execute movement towards a wind turbine with docking points. The main parts are
• Monitoring bar: Shows vessel and system performance.
• Main view or 3D scene: Shows the vessel in its environment with wind turbines, setpoints, performance, target locations and thruster feedback presented graphically.
• Bottom bar: Shows information on the current command state, DP class monitoring and system alerts.
• Configurable curtains on the side: Access to different system functions and operations.
The GUI is highly customizable and can accommodate a wide array of specialized applications. The main scene in Figure 3 shows the application for SOV operations with vessel and wind turbines at their true position. When zoomed out, the GUI displays a wind farm overview with all turbines. Upon zoom-in, system display wind turbine actual shapes and indications for docking points. The wind turbines will also indicate safety- and approach zones.

The gangway sensors is an opportunity to provide additional position information: The gangway has sensors that provide full knowledge of the tip position relative to the vessel. When connected to a fixed, known position, e.g., the wind turbine landing point, it is straightforward to calculate the vessel position.

![Figure 3 Icon DP GUI adapted for Wind Turbine Support](image)
Wind Turbine Support stages
The Wind turbine support mode consists of five stages:

![Figure 4 Stages in Wind turbine support mode](image)

After the operator selects a wind turbine destination and docking point, the GUI shows a shadow where the vessel will position itself to connect the gangway. This position is the ideal connection point where the gangway is in the middle of available stroke with tolerances for both gangway length and angles.

![Figure 5 Vessel approach wind turbine](image)

The operator may control the vessel manually towards the approach zone. Alternatively, the system can generate a waypoint track from the current vessel position to the approach zone. Operator can edit intermediate waypoints before confirming and activate tracking. GUI visualizes all turbines and their safety zone so operator can safely plan the track between wind turbines. Operator may also take advantage of weather forecasts; tidal conditions etc. to plan daily operations. The setup allows schedule deviations for urgent service assignments and changed priorities.
The vessel can start the automatic approach to the docking point when inside the approach zone. During the automatic approach, the heading of the vessel aligns to 90 degrees relative to the docking point, and the vessel moves to a position where the gangway is ready to connect. This position corresponds with the vessel shadow indicated at the docking point in the GUI main scene. Operator may specify minor position and heading offset setpoint changes without interrupting the operation. Based on operator feedback there are three different methods to approach wind turbine. The vessel’s heading align first in all cases. Then, during position alignment, the vessel either aligns across before towards (see figure), towards before across or both simultaneously.

![Figure 6 Approach directions](image)

After aligning heading and position to the docking point, the vessel keeps position until the operator is ready to depart. The system should now have an optimal heading and position for connecting the gangway. The system keeps the vessel stationary automatically without the need for operator actions.

![Figure 7 Vessel positioned and gangway connected to wind turbine](image)

When ready to depart and after disconnecting the gangway, the Depart stage automatically moves the vessel to a safe position away from the wind turbine. During departure, it is possible to prepare the next operation by selecting a new wind turbine.
Operational Experience
There are currently four vessels equipped with the RRM Icon DP with offshore wind support function in operation. RRM installed the system on Eddat Passat February 2018 before operator tested the system during the initial wind farm operations in March. It operates at the Race Bank Offshore Wind Farm, off the UK coast. Edda Passat is a Rolls Royce UT540WP design with hybrid propulsion (diesel-electric propulsion plant and battery: Rolls Royce SAVe Cube), and a 23-meter-long Uptime heave compensated walk-to-work gangway.

A single vessel motion control system eases operator workload and reduce risk of errors in manual procedures. The operator only needs a single control station and does not have to be concerned with proper deactivation and activation procedures for several control systems. A single system enables automation between different speed regimes further.

The operation started with a waypoint track towards the first wind turbine. The system position waypoint between vessel position and turbine approach zone and generates the track automatically. The operator edits the track before confirming transit phase towards turbine.
Crew tested several approaches towards wind turbine to familiarize themselves with the system and support function.

The approach stage eliminates guesswork and trial/error procedures for positioning before gangway connects to turbine. The GUI outlines the wind farm area for operational planning and focus on the current turbine operation in detail. With an understanding of current and next operational stage, the operator will know how vessel will perform and may coordinate other activities accordingly.

The following pictures show the approach after aligning vessel heading and already positioned in a suitable position to move towards wind turbine.

![Image sequence showing approach](image)

*Figure 9 Waypoint track towards selected wind turbine*

The image sequence shows the turbine from the vessel during the approach stage. Figures below show the position deviation during approach and a snapshot of the graphical user interface. The system controls both towards and across distances simultaneously.
Figure 11 Position deviation and vessel orientation during approach

The following group of figures shows an alternative approach with a longer astern and a short sway movement. When the operator selects to move across before towards, the system positions the vessel alongside turbine before progressing towards the ideal position for connecting the gangway.

Figure 12 Wind turbine from vessel during another approach
The positioning deviation plots outline the wind turbine approach method. Upon activating approach stage, the system reduce the across deviation to zero before regulating the towards deviation.

With a positioned vessel and connected gangway, personnel can move between vessel and turbine. The following pictures illustrate this position.

The crew connects the gangway after arrival and the vessel is then ready for station keeping.
The GUI displays a green gangway when connected and the wind turbine support window shows the related measurements. The Posrefs view shows how the system use the turbine position and gangway measurements to calculate the vessel position. The result is an additional position information to assist the operator.
The plot shows the constant force compensation set by the operator and the measured pushing force. The heading and position errors are well within the required margins.

![Gangway measurements and positioning errors](image)

**Figure 17** Gangway measurements and positioning errors

**Conclusion**

The offshore wind is a growing market and generates power in a way that meet environmental regulations with a decreasing cost. There will probably be more wind farms in diverse areas that call for a wide range of OSVs. The maritime industry will likely see more interest in this market and stakeholders should position themselves to solve the distinctive challenges for this set of vessels.

This paper discussed some challenges for the service operation vessels addressable in the DP system. By embedding the operational procedures in the system, the operator is able to

- plan ahead and control current operation in the graphical user interface and
- use standardized and pre-defined commands to control operations.

The Wind Turbine Support mode is a scalable solution that fits a large range of vessel sizes. Our overall philosophy is to improve the operator workload. We will continue to do so by using crew feedback and experiences and our own observations during development phase.

Rolls-Royce Marine is also involved in the NEXUS project that “will develop and demonstrate novel, beyond state of the art, specialized vessel and logistics for safe and sustainable servicing of offshore wind farms”. NEXUS is an EU H2020 research project to develop concepts for: simulation, model testing, consideration of the most suitable construction and production principles for small series or one off vessels of this type and validate on demonstrator. Partners in the NEXUS project are Rolls-Royce Marine AS, University of Strathclyde, Astilleros Gondan SA, Parkwind, DNV GL AS, and Global Marine Systems Limited.
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