Understanding dynamic assets in dynamic environments:

How floating wind monitoring can make sense

White paper

Published 19th September 2023

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Introduction

The offshore wind industry is fast shifting from maintaining assets reactively to focusing on predictive maintenance. The aim is to optimise operation and maintenance (O&M) and reduce any unplanned costs, such as those incurred from failure remediation.

Asset condition monitoring is now becoming an essential part of a predictive O&M methodology. It is however a complex topic and the cost/benefit of implementing any system or strategy requires thorough prior investigation.

As the industry begins to deploy floating wind farms at scale in more distant locations, asset faults will have complex decision-making requirements. For example, deciding whether to action a repair on a single cable immediately or waiting for other cable issues to occur before initiating an offshore campaign, leading to a potential overall saving on operational expenses.

Floating wind turbines also present new technical challenges compared to fixed-bottom foundation turbines due to being an array of dynamic assets in more dynamic deep water environments. This introduces multiple new risk vectors and new components that have the potential to fail. It is anticipated the cost to perform remedial works in floating offshore wind will be greater than that currently seen in offshore wind sites with bottom-fixed foundations.

As well as accommodating all of these new technical risks, any floating wind farm O&M approach, including condition monitoring, must support a project developer's aims of achieving site bankability and mitigating insurance costs.

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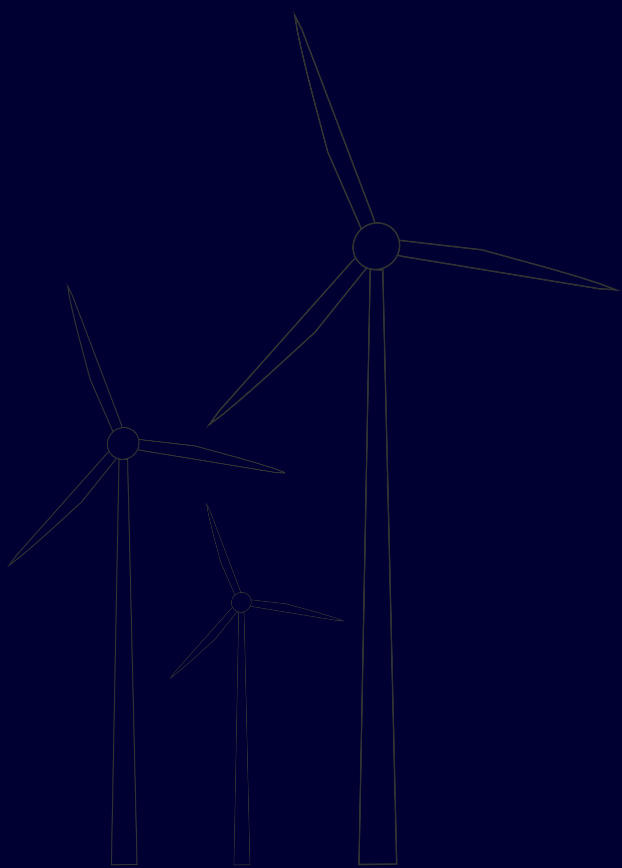

Definitions

Abbreviation	Definition
AHRS	Attitude and heading reference system
AI	Artificial intelligence
AUV	Autonomous underwater vehicles
CTV	Crew transfer vessel
DAS	Distributed acoustic sensing
DTS	Distributed temperature sensing
FOWT	Floating offshore wind turbine
GNSS	Global navigation satellite system
GPS	Global positioning system
HAUV	Hybrid autonomous underwater vehicles
IMU	Inertial measurement unit
IoT	Internet of things
IRM	Inspection, repair and maintenance
LCoE	Levelised cost of energy
MEMS	Micro-electro-mechanical system
MF	Medium frequency band (19-34 khz)
O&M	Operations and maintenance
OSV	Offshore support vessel
ROV	Remotely operated vehicle
SCADA	Supervisory control and data acquisition
SV	Sound velocity
TDP	Touchdown point
USBL	Ultra-short baseline
USV	Uncrewed surface vessel
VIV	Vortex-induced vibration

The opportunity to make a difference is now

The floating offshore wind industry can benefit from asset management lessons learned in other offshore energy industries, while still being innovative and mindful of cost drivers.

For several decades, we have been advancing the state-of-the-art for connected wireless subsea solutions in the offshore energy sector. These years of hard-won experience on subsea technology development - from ourselves and others - can be applied to jump-start the process of monitoring floating wind farm assets.

This whitepaper will look at how in-situ sensors, particularly wireless instruments, can contribute to monitoring solutions for subsea assets and their environments, to achieve the following:

- Better industry-wide component design
- Better understanding of real-world cause and effect, leading to broader simulated modelling, and digital twins of sites
- Optimisation of inspection, repair and maintenance (IRM) planning
- Better understanding and estimation of the expected life of wind farm subsea components
- Improved warranty and financing processes

All of these aspects combine to both reduce the levelised cost of energy (LCoE) of floating offshore wind, while providing the wind farm operator with a better understanding of the risks associated with their asset.

Mitigating risks on subsea assets

Any offshore wind farm operations manager requires critical information about an asset before taking action. Obtaining that knowledge can incur variable or unplanned cost, particularly when inspection data is acquired periodically by manned or remotely operated vessels. Therefore, implementing a monitoring solution offers a lower-cost, but constant, insight into the environment and components. Monitoring systems also help focus planned remotely operated vehicle (ROV) or hovering autonomous underwater vehicle (HAUV) inspections by identifying and targeting critical components, reducing the overall cost and increasing the effectiveness of inspection campaigns.

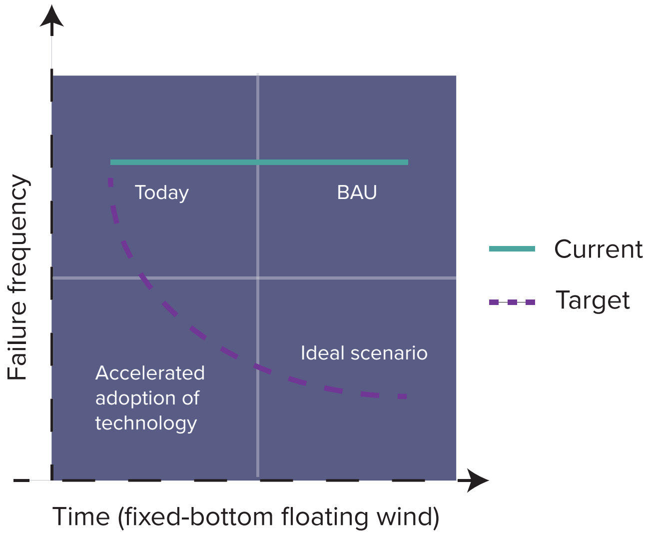

Figure 1: Graph denoting the current and target trajectory of failures in offshore wind

Placing monitoring instrumentation on above-water turbine components has historically far outweighed that of below the water line. This is due to the significance of many interdependent moving turbine parts that are critical to sustaining power generation. Above water, a typical turbine installed on a bottom-fixed foundation may contain upwards of 500 sensors, whereas the infrastructure below the surface hosts far fewer sensors and, in plenty of cases, none.

Cables are inherently dynamic due to their structure, the ancillaries attached to them and seabed mobility. They remain an industry challenge, accounting for a significant portion of insurance claims on bottom-fixed foundation sites, highlighting the significance of introducing dynamic mechanical elements to a floating offshore wind farm. Subsea component failures on floating wind farms have the potential to be even greater than for bottom-fixed foundation sites. Introducing dynamic array cables, mooring lines and bend stiffeners to offshore wind farm infrastructure cements the need for better information gathering. Higher fidelity information about the subsea structure can also lead to better life expectancy prediction and potentially support life extension campaigns towards the end of the asset's lifetime. Without intervention and implementation of monitoring solutions, understanding why and when systems fail will remain uncertain. Therefore, a change is required to reach an ideal bankable scenario.

Specifying a suitable monitoring system for a floating offshore wind farm is a crucial exercise and should be deep-rooted in a philosophy of risk-based predictive maintenance. It should be a forward-looking system that supports the operations manager by prioritising inspection and maintenance activities based on the severity and likelihood of a risk. It should also accommodate any future artificial intelligence (AI) capabilities.

Before specifying any technology, we should always seek to understand aspects such as:

- Criticality of components and what level of in-situ monitoring is required.
- Known requirements for planned O&M, site access or interventions (See A risk-based hardware specification)
- Failure modes of subsea assets (See *Failure modes*)

The role of an operations manager

An operations manager has a complex task and is frequently overloaded with decisions to make about offshore campaigns and asset interventions. They must manage:

- Operations: Operational site activities, planned preventative maintenance, health and safety inspections, condition monitoring and operations related to the base, port facility, operation support vessels (OSVs) and/or crew transfer vessels (CTVs).
- Unplanned Service: Proactive service in response to predicted failures or reactive service in response to unexpected systems failure and any related vessels or logistics.
- Other: Ongoing aspects such as community engagement or ongoing environmental monitoring campaigns.

With such a high number of tasks, it is critical to reduce this complexity and provide easy-to-understand information that enables decisions about whether to take action. An example would be that seen in Figure 2. This information can also be enhanced by incorporating simulated data that models the likelihood of failures, based on real world data (discussed further in *Data digitalisation techniques*).

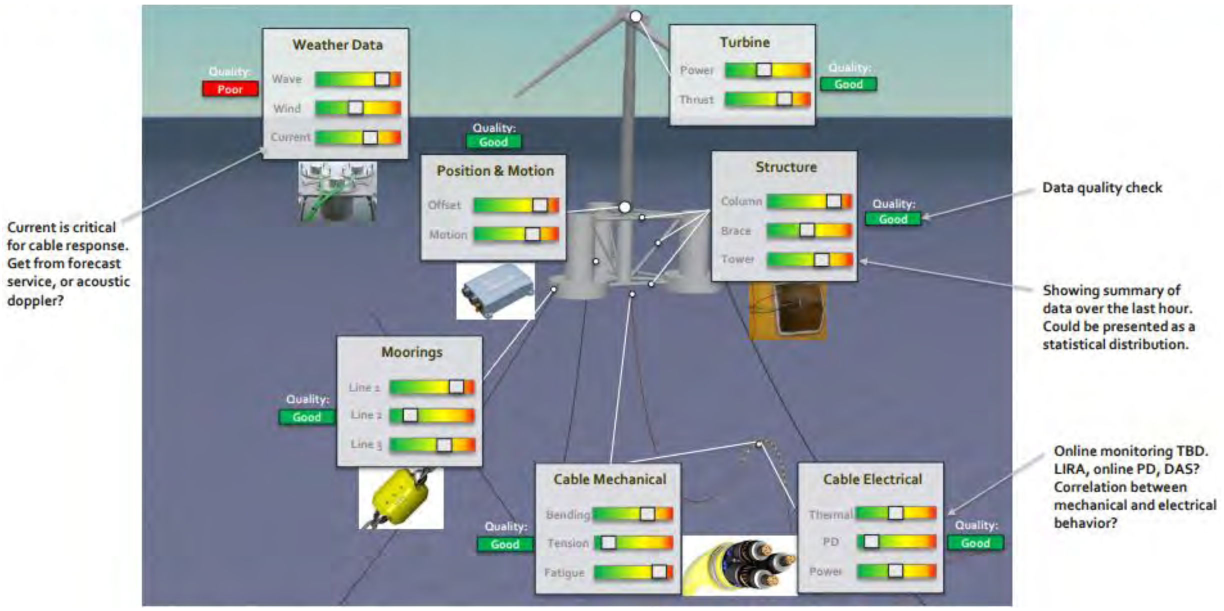

Figure 2: Diagram outlining component and environment variables on and around the floating turbines that could require monitoring, indicating levels of magnitude in a scenario suitable for observation with the operational control room. (provided by the ORE Catapult)

Failure modes

Failure modes identify the pathways for a potential failure of a component or the overall system. Understanding these failure modes enables an engineer to specify what must be measured, which ensures the correct information flows to the operator.

Tables 1 and 2 provide a breakdown of potential mechanical failure modes for floating wind farm dynamic cable and mooring systems subsea components, along with measurement requirements to monitor for these failures. The tables outline various in-situ sensor types and data for developing a subsea monitoring system. Sensor density (number of sensors) and configuration topography will vary depending on site characteristics, the type of floating foundation, subsea infrastructure type, project specification and budgetary constraints.

*Note that a separate set of sensors would be required if thermal and electrical failure modes were to be monitored. These sensors can benefit from being coupled with the mechanical sensors, as thermal, electrical and mechanical failure modes are closely linked – electrical loads heat up cables, hot cables are weaker mechanically, and cable mechanical loads can accelerate electrical and thermal degradation. This element of monitoring is not included in this paper.

	Measurement requirement	Why? (Failure mode)	System responses		Probable sensor type
Dynamic cable system	**Sag and hog clearance to seabed/surface**	1) Biofouling weighing down cable. 2) Loss or degradation of buoyancy modules. 3) Mis-calculated buoyancy ballast.	Cable moving too close to seabed	=	Depth sensor
			Cable moving too close to surface	=	Depth sensor
			Vessel motion, vessel position, metocean or water property change	=	Correlate with holistic floating foundation and environment behavioural detection
	Cable movement including bend radius	1) Cable conductor and component fatigue. 2) Floating foundation movement leading to heavy loading upon cable resulting in excess of max bend radius (inline). 3) Subsea currents leading to heavy loading upon cable resulting in excess of max bend radius (lateral and inline). 4) Third party intervention e.g., trawler snag. 5) Floating foundation ballast change leading to anomalous behaviour of cable.	2D inline cable flexing	=	Inclinometers at >2 location
			2D lateral cable flexing	=	Combination of dual axis inclinometers and XY acoustic position of >2 known points
			Vortex induced vibration across the cable	=	MEMS triaxial accelerometer
			Vessel motion, vessel position, metocean, scientific change	=	Correlate with holistic floating foundation and environmental behaviour detection
	Tension/ Compression	1) **Cable tensions** caused by excessive platform motions due to environmental loads or mooring failure, stretching the windward line. Particular concern in deep water >500m	Tension near hang off	=	Sheath strain gauges at single points
		2) Axial* compressions caused by excessive platform motions, which compress the cable against the seabed or platform connection. Particular concern in shallow water (<100m). **Different to radial compression - squeezing of the cable by the buoyancy modules and tether clamps causing cable insulation deformation. Difficult to monitor.*	Compression near hang off and seabed touchdown	=	Sheath strain gauges at single points. Integral fibre optic strain sensing
	Touchdown point migration	1) Strong currents and/or high drag causing TDP excursion. 2) Sediment shift/scour resulting in free span.	2D lateral cable movement	=	Acoustic XY position at TDP
			3D cable movement	=	Acoustic XYZ position at TDP
			Vessel motion, vessel position, metocean, scientific change	=	Correlate with holistic floating foundation and environmental behaviour detection

	Hang-off/Bend stiffener fatigue loads	1) Heavy loading from floating foundation movement causing fatigue. 2) Excessive loading from currents causing fatigue. 3) Bend stiffener latching mechanism failure due to design issues.	Vortex induced vibration across the bend stiffener	=	MEMS triaxial acceleration
			Strain and displacement of the bend stiffener and/or latching mechanism	=	Strain gauge and two axis inclination
			Vessel motion, vessel position, metocean, scientific change	=	Correlate with holistic floating foundation and environmental behaviour detection
	Tether line tension	1) Excessive tension and fatigue loading cycles, in combination with radial compression, at the tether line resulting in breakage.	In-line tether cable tension	=	Integrated load cell/strain gauge and MEMS triaxial accelerometer
			Tensions at the tether line to cable connection and clump weight	=	Integrated load cell/strain gauge
			Vessel motion, vessel position, metocean, scientific change	=	Correlate with holistic floating foundation and environmental behaviour detection

Table 1: Mechanical failure mode table for dynamic cable system on a floating offshore wind farm

	Measurement requirement	Why? (Failure mode)	System responses		Possible sensor type/information
Mooring system	**Mooring tension**	1) Mooring line fatigue resulting in line breakage. 2) Floating foundation movement leading to extreme loading at connections/bridle resulting in fatigue. 3) Floating foundation ballast change or unexpected motion response leading to anomalous behaviour of mooring. 4) Excessive relative motions between mooring components, causing large-scale wear 5) Excessive corrosion beyond design allowance	In-line mooring line/chain increased tension	=	Integrated load cell/strain gauge and MEMS triaxial accelerometer at separating points
			Mooring line break/slackens	=	High resolution depth sensor and/or inclinometer
			Tension at floater and anchor connection points	=	Integrated load cell
			Vortex induced vibration across mooring line	=	MEMS triaxial accelerometer
			Vessel motion, vessel position, metocean	=	Correlate with holistic floating foundation and environmental behaviour detection
	Catenary geometry	1) Catenary response not as designed. 2) Seabed contact damage of fibre rope and other sensitive components. 3) Third party intervention e.g. trawler snag. 4) Synthetic rope creep, causing loss of design pre-tension and slack lines	3D mooring line movement	=	Acoustic XYZ position or depth
			Mooring tension	=	Inclinometers, in-line load cell or strain gauge at separating points
			Vessel motion, vessel position, metocean	=	Correlate with holistic floating foundation and environmental behaviour
	Anchor position and orientation	1) Failure of soil resistance. 2) Trenching due to line movement. 3) Drag or partial displacement. 4) Overload of anchor structure. 5) Fatigue of anchor structure.	Anchor excursion and displacement	=	Acoustic XY position and inclination monitoring
			In-line mooring line/chain increased tension	=	Inclinometers, in-line load cell or strain gauge at separating points
			Tension at floating foundation and anchor connection points	=	Load cell
			Vessel motion, vessel position (change in expected tension vs position could indicate anchor movement or failure)	=	Correlate with holistic floater and environmental behaviour detection (See note 1 below).

Table 2: Mechanical failure mode table for a mooring system on a floating offshore wind farm

To optimise monitoring installations and underpin predictive modelling, it is also necessary to monitor the following additional floater and environmental conditions to derive the cause of the asset's behavioural output. Cause and effect monitoring is described further in data digitalisation techniques.

- Floater position (surge, sway, yaw) measured by a differential Global Navigation Satellite System (GNSS) unit, and/or hybrid Ultra Short Baseline (USBL)/ gyro (see section below).
- Floater motion (heave, roll, pitch) measured by a motion response unit (MRU) (separate or integrated into hybrid USBL).
- Turbine loads also measured to give complete external loading picture.
- Metocean (wave, wind, current magnitude and direction) from radar, wave buoy, acoustic Doppler current profiler (ADCP), LiDAR etc.
- Conductivity and temperature near surface and seabed components correlate to both metallic corrosion and polymer change.
- Bio measurements can be correlated with marine growth fowling of cables and moorings.

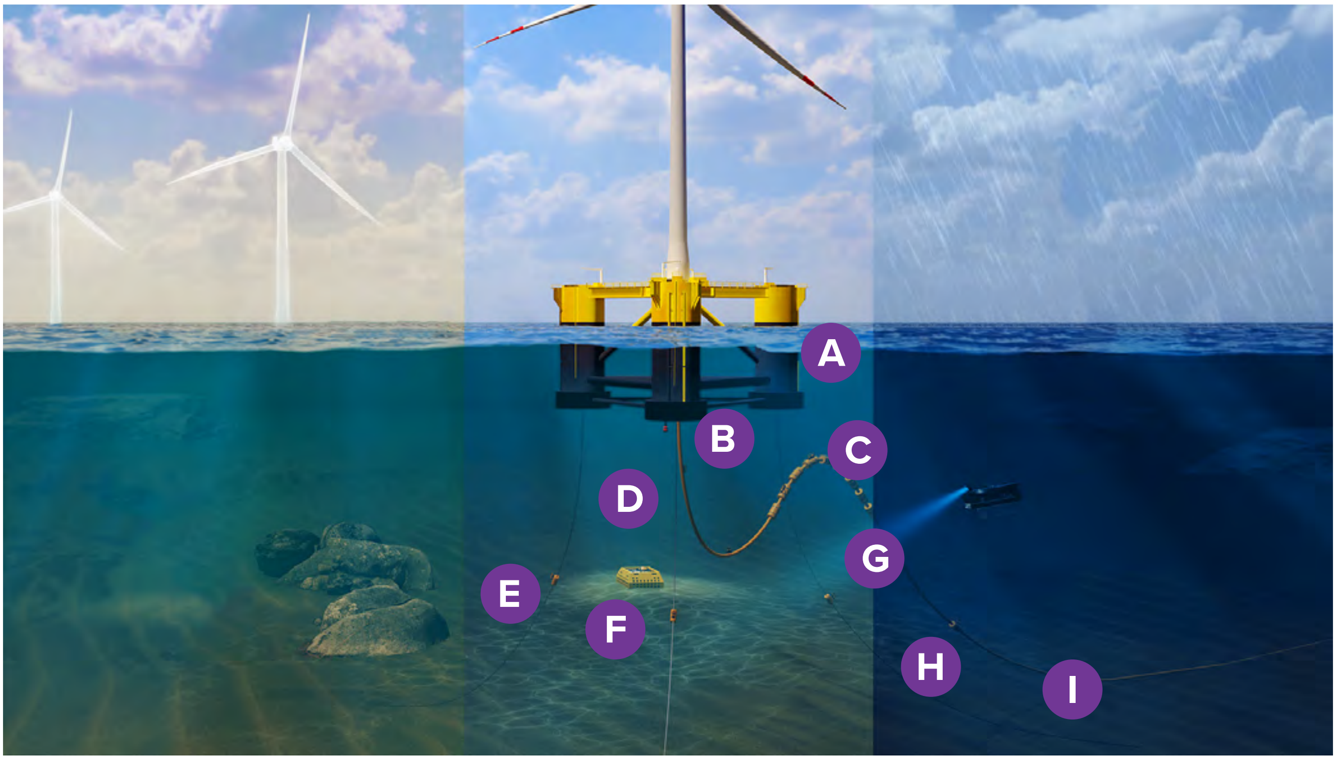

Figure 3: The graphic depicts the measurement requirements that can be cross-referenced with table 1.

A = Floater movement

B = Bend stiffener VIV

C = Bend radius

D = Time-synchronised telemtry

E = Mooring monitoring

F = Subsea monitoring of current and wave height

G = Cable hog and sag distances

H = Tether and anchor monitoring

I = TDP position

An interoperable ecosystem for data exchange

Figure 3 demonstrates how an interoperable ecosystem for exchanging data would look on a floating wind turbine. An ecosystem of in-situ monitoring installed on both the subsea infrastructure and in the surrounding environment can combine both wireless and cabled sensors, while also integrating with other sensors and condition monitoring solutions.

Instruments used in subsea operations with onboard Edge computing can process vast data at the acquisition point. This leads to more efficient use of the acoustic connection, better data management and battery conservation, optimised control and machine learning, and real-time threshold alerting and decision-making.

Time synchroneity fuses real-time environmental data to deliver an accurate picture of the cause and effect of asset behaviour. Although a single turbine is presented, monitoring should be implemented at varying locations across the wind farm site. However, with cause and effect capability it would only be a requirement to instrument a small percentage of representative turbines. Predictive simulations can enable extrapolation of wider wind farm activity, while keeping costs down - further explored in *The adoption of digitised models*.

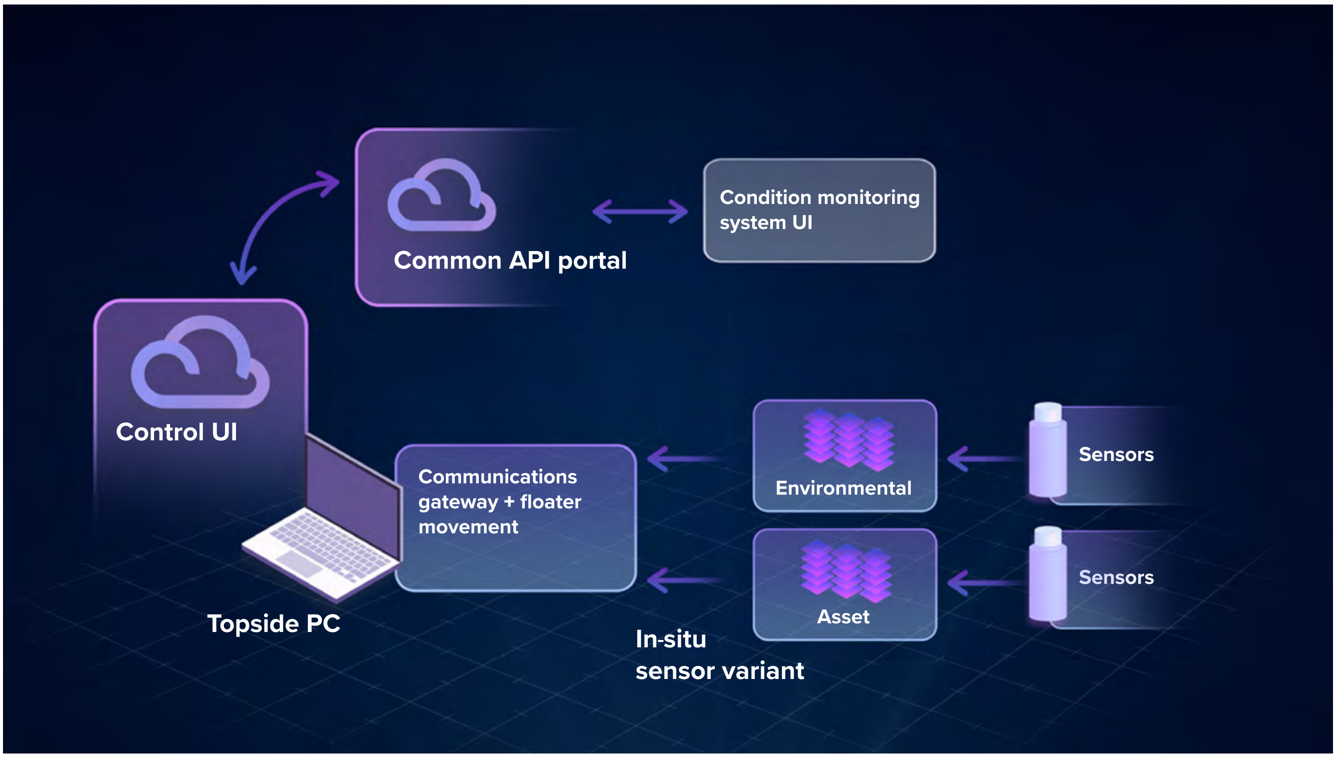

Figure 4: Interoperable ecosystem block diagram for FOW infrastructure

Communication gateway

All wireless sensor information below the waterline is delivered to a transceiver or modem, either fixed to the floating foundation platform or harvested from an alternative surface platform such as a CTV, OSV or resident uncrewed surface vessel (USV) used in the vicinity.

Please note that using an alternative surface platform means monitoring information cannot be acquired in near real-time, while a data gateway installed upon and connected to the floating foundation will. The floating foundation can be considered as a survey vessel, always on anchor, monitoring the assets and the subsea environment.

There are two ways of extracting and transmitting information collected by a gateway-installed floating foundation: via the fibre optic cable within the wind farm high voltage cables or by broadcasting data via an onboard transmitter using a satellite communication network.

Location and movement of the floating foundation across six axes

We have experience fitting intrusive and non-intrusive systems to floating offshore oil and gas drilling rigs, which face similar challenges to a floating offshore wind turbine platform.

In addition to being the surface gateway for all subsea sensor communication and positioning, our hybrid transceiver systems also register high-frequency motion outputs of pitch, roll, yaw, heave, surge and sway.

While corrected GNSS systems are used frequently for excursion monitoring of moored floating structures, the communications transceiver can also compute excursions with high accuracy using a known seabed position. This offers critical positional redundancy (e.g., recognising mooring line failure) from a system already being used for alternative applications.

Dynamic cable and mooring movement

There is a long distance between the subsea sensor and the floating foundation platform, and the end-user can choose from cabled or wireless sensors attached to the dynamic cable. A wireless sensor network can transmit to a topside transceiver through the water column using acoustic communications.

Sensors should be easily integrated between, onto or into the ancillary equipment on the dynamic cable (for example, buoyancy modules, tether clamps, or the cable sheath) and at points on the mooring line.

The user can choose a sensor for a particular purpose based on the measurement required. Functions include measuring position, depth, inclination, temperature, motion and vibration. Transponders also facilitate the integration of ancillary sensors, such as strain gauges (see Table 1 - dynamic cable), across several communication protocols.

Environmental parameters

Well-established solutions for ADCPs exist, but the industry needs a tailored solution for floating wind farms due to the specific challenges of managing many dynamic assets over a vast area. A solution could consider:

- Current profiling in deeper waters
- Wave height measurement
- Temperature
- Conductivity
- Algae measurement for marine growth prediction

The number and location of subsea landers must be assessed strategically and will depend on the degree of change to site characteristics over the entire array.

A risk-based hardware specification

Reliability and survivability need to be prioritised when designing an interoperable ecosystem such as the one suggested in Figure 4, aiming to remove unnecessary turbine visits where possible.

Advantages of wireless sensors

A wireless condition monitoring system is a suite of configurable sensors with varying levels of capability offered to the end user. Deploying a subsea wireless network that follows an acoustic methodology enables data points to be fed from subsea to the operations team in most cases as effectively as fully cabled alternatives.

Benefits over cabled alternatives include:

- Standalone components. Removes the requirement for complicated subsea cabling and connections. Particularly over longer distances in corrosive, pressurised, and dynamic environments. Sensors attached to subsea assets can remain intact for decades as they are subject to fewer external stressors than cables.
- Additional functionality. Positioning of sensors and communication of data over the Wideband digital acoustic signal.
- Extended range. Wireless acoustic signals can achieve distances in the order of kilometres, so signals from sensors on a neighbouring turbine could also be received.
- High-speed data transmission. Acoustic technology currently achieves 9 kbps, with optical data transfer speeds of up to 100 Mbs over much shorter range.
- Hot-swap flexibility. Acoustic sensors are simple to retrofit/remove using ROVs and simple to configure by using the topside transceiver. This removes the requirement to run cables subsea. It is conceptually similar to placing IoT sensors into a home and configuring them wirelessly.

Disadvantages of wireless sensors

While wireless subsea technology does have certain advantages over cabled sensors, as set out above, it does also have some disadvantages:

- Surrounding environmental noise. Low signal-to-noise ratios, particularly in shallow water will affect the stability of the acoustic signal. We are able to mitigate this effect by using high bandwidth digital signals.
- Line of sight. Acoustic signals can be blocked by infrastructure. This can be mitigated by acoustic data hopping techniques, using neighbouring sensors.
- Battery power. Wireless sensors will be reliant on batteries for power and as a result are limited by battery life. This can be mitigated by onboard data management, additional battery packs, and the use of low energy acoustics.

Survivability of a monitoring system

Survivability of a monitoring system is crucial, given that a typical offshore wind farm targets an operational life of up to 30 years. The following are critical requirements for a monitoring system to survive and remain functional over extensive periods:

- Maximising battery power. As with any remote technology, battery life is a dilemma. Several of our transponders are able achieve a maximum battery life beyond ten years, while there are also available methods to overcome power consumption challenges, such as adjusting the signal power intensity. The data logging regime can also be optimised to prioritise power saving by using Edge computing. Battery life can in addition be communicated into the operation centre's broader monitoring or supervisory control and data acquisition (SCADA) system.

  A well-planned risk-based monitoring programme can be tailored to focus on early measurements over one to ten years, where battery life remains available. This allows the response of the floating system to be well-validated and understood without the need to gather decades of continuous data of diminishing value. Once confidence is built on the validated model after the first few years, a lighter touch on the monitoring system can be taken.
- Small but durable sensors. Although floating offshore wind farms still present shallow water conditions compared to many offshore oil and gas projects, sensors must sustain extreme offshore environments for extended periods. Housing materials can make a difference, but for projects ranging between 6 to 100 bar, it is more significant that sensor endcaps and any bulkhead connectors are secure enough to avoid water intrusion over decades.
- Redundancy is imperative to ensure a system can continue to operate in the event of a sensor failure. While implementing redundancy at a specific sensor location is challenging, it exists in a more holistic form.

  Each structural sensor is mechanically independent at a local level, so a monitoring system will still gather ample information if a sensor fails within the network.

  At the wind farm level, cross-site monitoring of more than one turbine provides the ability to emulate missing data points from a failed sensor by using that from a different turbine.

  Wind farm operational bases tend to use a variety of condition monitoring systems that utilise different technologies and capabilities. Within these systems, there can be information overlap between monitoring strategies, offering system redundancy and validation. For example, both GNSS and the USBL system can be used to calculate floating foundation excursion. Also, fibre optic strain (Bragg sensors) and external strain gauges can be integrated with the sensors each measure dynamic cable strain.

Functionality of a modular and integrable system

A modular system that blends different data sets, including alternative monitoring systems, can build a richer picture of the wind farm. This offers both contextualisation and redundancy across the whole system.

- Multi-system integration is possible with fibre-optic condition monitoring solutions, such as distributed temperature sensing (DTS) and distributed acoustic system (DAS) or Proserv's novel ECG™ holistic cable monitoring system, which additionally incorporates distributed electromechanical sensing (DES). These systems internally monitor a cable's ability to conduct power continuously, whilst Sonardyne's technology monitors the exterior mechanical behaviours and form of a dynamic cable, as well as mooring, anchor and floater movements.
- Modularity. Activating additional sensing, such as turning on a built-in accelerometer to detect vortex induced vibration (VIV), can be as simple as sending an acoustic firmware update to initiate an already in-built sensor.
- Ease of installation. It may, at times, or even as standard, be necessary to retrofit subsea sensors to floating offshore wind turbines post-deployment. For example, it is less costly than embedding into a component design, validating pre-front end engineering design (FEED) / FEED modelling, or meeting insurer requirements. Using proprietary detachable clamp designs for a sensor retrofit campaign allows the operator to utilise small work-class or larger observation ROVs, such as the Leopard, Valor, or Defender, already used for IRM operations in offshore wind. Increasingly ROVs deployed from USVs, and station-keeping HAUVs will undertake this task as the industry adopts more advanced autonomous technologies.
- Time Synchronisation. An interdependent wireless system must have time-synchronised in-situ sensors on both the floating foundation platform and infrastructure. As with any dataset from a wind farm sensor, this ensures that data can be accurately recorded and interpreted. An automatically managed acoustic link, data retrieval schedule, and clock synchronisation of each subsea device ensures data can be used for simulation or a digital twin.

Data digitalisation techniques

To maintain a cost-effective approach to O&M, while also servicing many assets over large areas, floating offshore wind farm developers will need to model component behaviour via simulation or through the use of digital twins.

- Simulation is the process of creating a model of a real system or process and using it to experiment and test different scenarios. It can be done using a combination of mathematical models and physical sensors. The goal of simulation is to understand how a system behaves under different conditions and to optimise its performance.

- Digital twin, on the other hand, is a virtual representation of a real-world system. It is a digital model that emulates the physical characteristics, behaviours, and performance of the real system in real-time. Using data from sensors and other sources to update its model, so it can accurately reflect the current state of the system. AI or simulated neural networks can take this a step further by analysing prior patterns in the data to provide a prediction and recommended course of action to the wind farm operator.

The key difference between simulation and digital twin is that simulation is a one-time process used to test a specific scenario, while a digital twin is an ongoing process that continuously updates the model based on real-time data. Simulation is a tool to predict a particular outcome, whereas a digital twin is a tool to understand and optimise the behaviour of a system in real-time.

In the context of floating offshore wind, engineers would use monitoring sensors on demonstrator turbines to run simulated behavioural tests to better understand the asset's behaviour at that point in time. The information is used to validate or calibrate the simulation models, and ultimately inform the execution of the FEED process for future floating systems.

Whereas digital twins take in data to continuously understand the behaviour of the asset, which can be used to inform risk-based decision making. This approach is typically best suited for use at scale over a fully developed site, where only a select few turbines are real-world monitored.

The adoption of digitised models

There are significant advances being made in the scientific field of simulation and digital twins for critical infrastructure, including for offshore wind turbines.

For example, the ROSEHIPS EPSRC[1] project will develop a formal mathematical approach for calculating a similarity score between structures, allowing information from one structure to infer what is happening on another. Branled et al (2020)[2] also developed a method to take sensor data from a single asset to estimate a state for a number of related assets.

Fugro and AS Moseley[3] demonstrated how remote monitoring combined with digital-twin methods can eliminate or reduce subsea inspections of mooring systems by modelling a Hywind Scotland floating offshore wind turbine (FOWT). From the study, modelled tensions calculated based on inputs from GPS and floater based attitude heading and reference sensors (AHRS) were within good correspondence to the load cell readings at the anchor points.

However, the study was inconclusive in its overall validation of the tension model, acknowledging that a more robust (high quality and high resolution) data set should be used for digital twin modelling, identifying Global Positioning System (GPS) noise and bias as detrimental to the overall data set.

While research and innovation is developing fast, so is industrial deployment of the technology. EIVA (a Sonardyne sister company) is an example of a company that can deliver both a simulated model or a digital twin. This can provide a wind farm operator with real-time and numerically modelled information underpinned by their in-situ sensors, all directly feeding into the operator's user interface. The approach that EIVA offer is comparable to the method developed by Branled et al.[2] to estimate the state of an asset.

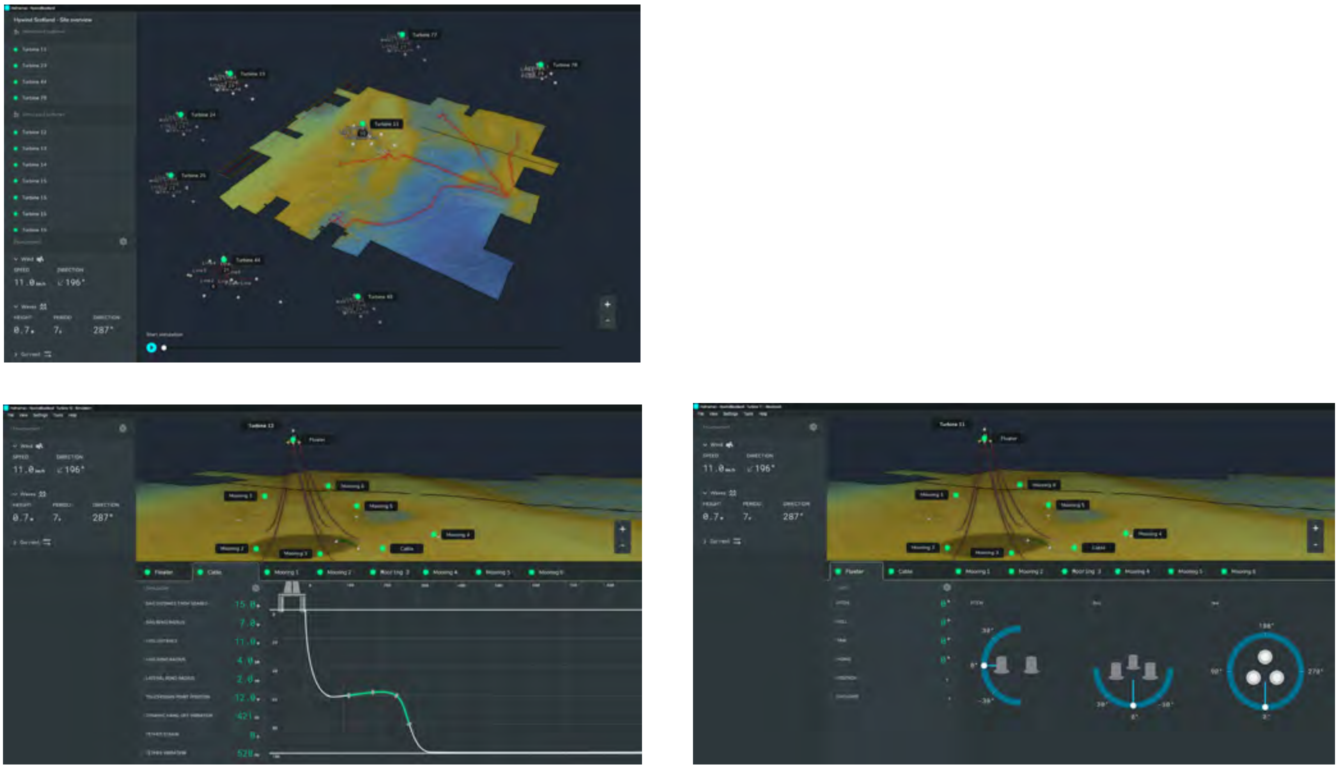

Figure 5: Concept screenshots of EIVA's NaviSuite software used for visualising and analysing a floating offshore wind farm digital twin

The strengths and weaknesses of simulation and digital twin

It is important to understand the strengths and weaknesses of simulation before deploying any technology.

Strengths

- Relatively low cost of implementation
- Covers wide geographical area and wide range of components
- Future predictions enable risk-based approach to inspections, maintenance and life extension

Weaknesses

- Inability to detect actual damage; problems can only be inferred from the system response
- Algorithmic complexity: accuracy of simulation and predictions can be hard to check, especially for systems with limited redundancy
- Reliance on modelled data rather than actual data

Important opportunity to learn from real-world behaviours and correct in advance of costly failures.

Robust systems (people and infrastructure) are needed to ensure the digital twin is used to its full potential over the decades; there are many examples of monitoring data being used only after a failure has occurred.

Bringing it all together: best practice for a floating wind project

A real-world baseline

By cross-correlating metocean data collected from monitoring systems like subsea landers or wave radars with in-situ asset sensor data (such as cable and mooring behaviour), a comprehensive understanding of the entire asset and its health can be gained.

This allows the wind farm operator to create a contextual picture of how external forces impact the behaviour of the floating platform, dynamic cables, and mooring systems. Consequently, real-world information can be used to improve digital numerical models, such as simulation or digital twins, through baselining.

Extrapolating datasets to simulate wind farm-wide behaviour

As previously discussed, a subsea monitoring system consisting of a floater, cable, and mooring sensors need only be installed on a select number of turbines for a fully developed wind farm. Simulation or modelled data can then provide data for what are essentially the soft sensors to provide behaviour patterns of the remaining turbine locations on site. It is important to approach each case individually to develop a feasible technical and commercial monitoring solution. The required number of in-situ sensors may vary significantly depending on the system, meaning a site with 50 turbines would not require 50 times the amount of monitoring compared to a single turbine site.

In addition, a well-calibrated and verified interoperable ecosystem system could use in-situ measurements and environmental forces to calculate loads and predict fatigue of cables and mooring systems using strain, load cell and other methodologies. Whilst a simulation strength could be measured by loopback validation methodology, whereby the simulations are compared against real-world information, providing the potential to emulate fatigue accumulation. This would facilitate better planning for life extension campaigns for turbine locations with limited or reduced monitoring datasets.

The user interface: turning hardware and data into useful tools

As an operations manager, having a visual representation of a floating asset in its environment and a dashboard with traffic light decision-making support tools can be transformative rather than just a desirable feature. The information displayed is crucial for decision making, and it should be user-friendly and easily intelligible, whether it is a standalone system or feeding into a broader SCADA system. Introducing more complexity and technology can increase operational risks and costs, so clarity is critical.

Our conclusion

Given the historic challenges with bottom-fixed foundation offshore wind farms, the move to floating offshore wind farms, at pace and scale, adds several more layers of complexity and risk that can be addressed if dealt with early in the development cycle. This white paper has emphasised the importance of understanding both the cause and the degree of impact of asset behaviour. All of this is possible with commercial condition monitoring and underwater communication technologies available today.

Our aim is to support offshore wind farm operators to de-risk operations, optimise IRM activities and improve workflows by utilising advanced digitisation techniques such as simulation, digital twins and AI. Before implementing any monitoring system or methodology, it is imperative that engagement is bi-lateral and collaborative, so that objectives can be set and a rational site-specific plan can be developed.

We help you understand your asset in depth

Our business is privately owned and based in the UK. It was founded in 1971 and has been dedicated to developing innovative underwater technology for over 50 years.

We engineer and manufacture subsea navigation, positioning, communications and monitoring solutions that transform what's possible in offshore energy, maritime defence and ocean science. And as part of a vertically integrated group, we can uniquely and effectively tackle subsea projects with our sister companies and strategic partners.

Delivering subsea monitoring and communications is at the core of what we deliver daily for offshore wind and wider offshore industries. We welcome discussions with the industry to help drive progress in this space and ensure the most advanced and appropriate technology is selected for use on sites for years to come.

Links

[1] https://www.theengineer.co.uk/content/in-depth/expert-q-a-protecting-national-infrastructure-assets

[2] https://iopscience.iop.org/article/10.1088/1742-6596/1618/2/022030/pdf

[3] https://ctprodstorageaccountp.blob.core.windows.net/prod-drupal-files/documents/resource/public/Fugro_ConditionMonitoring.pdf

About the authors

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