Better methods are needed to install, service and replace major components on large wind turbines

As wind turbines grow larger, SENSEWind's SENSE system could simplify installation and maintenance, reduce reliance on heavy lifting equipment and lower costs.

Larger turbines and more challenging wind farm locations are making turbine installation and maintenance increasingly difficult and expensive. Using current approaches, taller towers and heavier components require larger cranes and more specialised vessels, which are more expensive and less readily available. In turn, large cranes require modifications to infrastructure, including ports and roads, particularly at remote onshore sites and offshore projects far from shore.

Unplanned major maintenance brings particular difficulties when lifting equipment must be mobilised rapidly and can result in disproportionate costs. Replacing a blade, generator or complete rotor nacelle assembly (RNA) can involve expensive lifting equipment, lengthy mobilisation periods and revenue losses while the turbine is out of service.

For floating wind, major repairs can be even more complicated. One maintenance strategy involves disconnecting a turbine and towing it to port, where suitable cranes and facilities are available. This approach has been used at the Kincardine and Hywind Scotland floating wind farms. All five Kincardine turbines have been towed to Rotterdam for major component replacement (MCR) during 2022 and 2023, while all five Hywind Scotland turbines were towed to Norway for maintenance in 2024.

Kincardine subsequently demonstrated an alternative in 2024, replacing a generator offshore without towing the turbine to port. This early experience is leading the industry to question whether towing turbines to port is a practical and affordable long-term solution.

SENSEWind offers an alternative installation and service system which eliminates the need for ever larger cranes and crane vessels to install and service large turbines. Using SENSE (Self Erecting Nacelle and Service system), large turbines, for example 8 MW onshore and 20 MW offshore, could be installed using existing cranes and crane vessels.

How SENSE works

SENSE technology comprises a modular tower incorporating rails that allow specially designed SENSE carriages to travel up and down the structure to install the tower and turbine RNA and carry out service activities.

Rather than relying on a large crane to assemble the tower and lift the RNA in separate components to the top of the tower, SENSE sequentially installs tower sections to the required hub height. The RNA is then fully assembled at low level, including the blades, using much smaller lifting equipment.

The RNA carriage can also operate in reverse, allowing the complete assembly to be lowered and exchanged. This would be particularly useful when, for example, the gearbox or mainshaft bearings need replacing. Such an operation is relatively straightforward using SENSE but very difficult, or potentially impossible, without bringing a large crane back to site.

SENSE has also been designed to enable the exchange of major turbine components using separate, smaller service and maintenance carriages. These platforms provide access for servicing, inspections and repairs throughout a turbine's working life.

For example, to exchange a generator on an onshore turbine, the service platform would be brought to site on a flatbed lorry. The lorry would reverse towards the tower base, allowing the service carriage to be attached to one of the tower rails.

For a shallow water fixed-bottom offshore turbine, the service platform would be lifted into position on the tower rail by a small crane vessel. This could be an existing small jack-up vessel.

An umbilical power and control cable is attached and the carriage climbs to the tower top. In advance of this, service personnel will have prepared the generator for removal by opening the RNA covers and loosening the necessary bolts and connections.

The integrated crane then hoists the generator onto the platform and transports it to the tower base. The replacement generator is lifted onto the platform, taken to the top of the tower and installed. The service platform again returns to the tower base and is removed.

Service personnel remain inside the RNA to undertake the work. The service carriage is operated remotely or automatically, and no personnel travel on it.

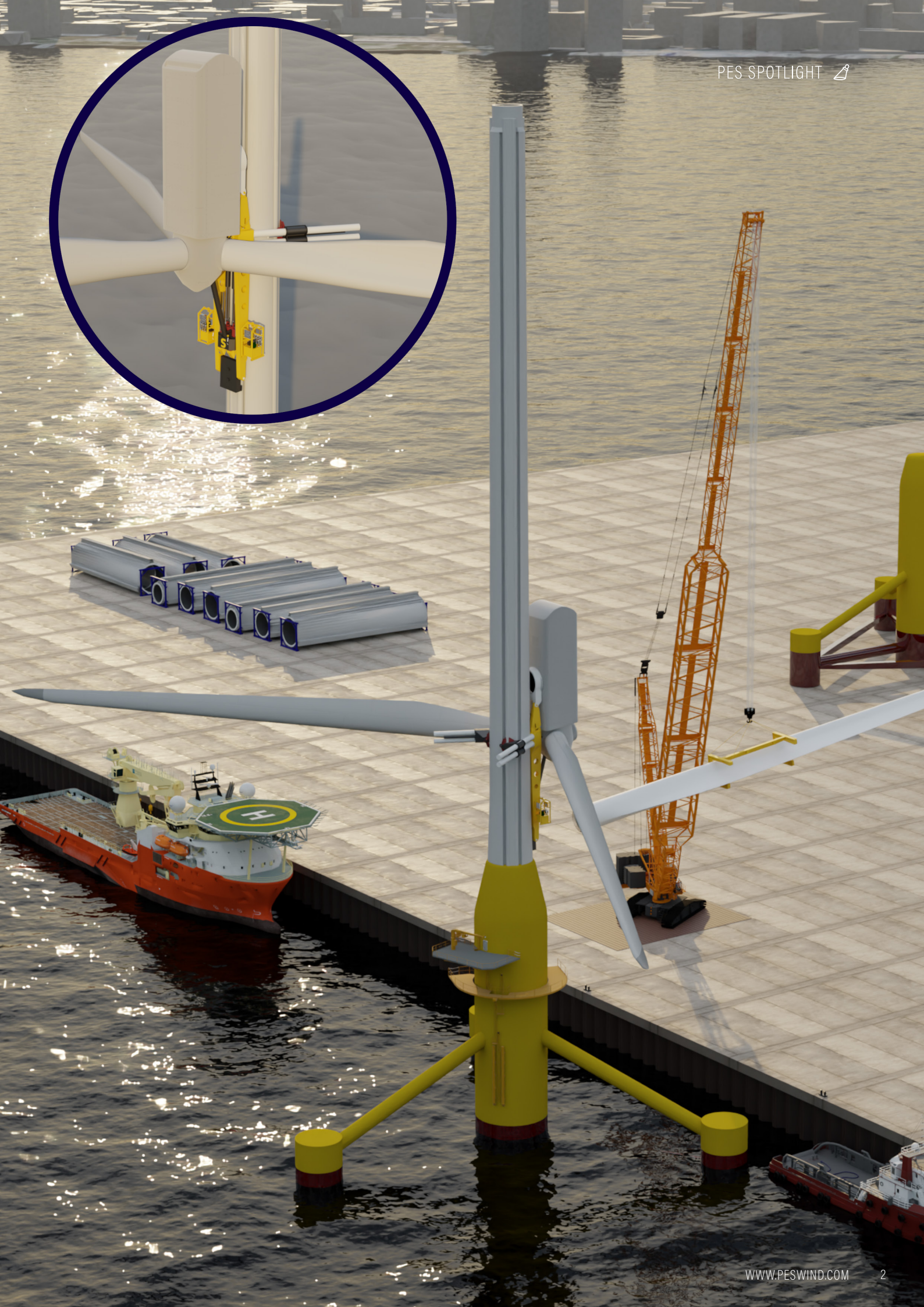
Floating wind major component replacement using SENSE

Replacing major components on a floating turbine presents particular difficulties. Any lifting operation must account for the movement of the floating foundation and offshore conditions.

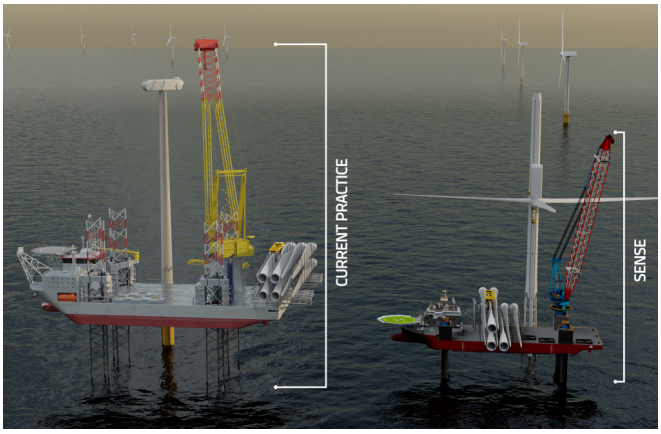
Towing to a port with calm, deep water access and sufficient space for a large ring crane remains an established option. But as Kincardine and Hywind Scotland have demonstrated, marine operations are not straightforward, suitable port facilities are limited, and this inevitably results in an extended period of downtime for the turbine and lost revenue. All of this is extremely costly.

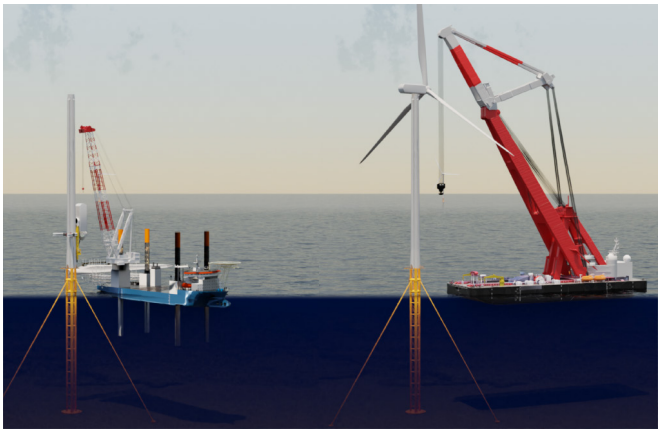
To maintain investor confidence in the growing UK floating wind sector, Great British Energy (GBE) is consulting the industry on developing a UK MCR hub somewhere around the UK coast. Developing a port-based MCR hub may provide confidence to floating wind investors in the short term, but SENSEWind believes that an in situ solution to MCR is essential in the longer term to keep costs manageable.

SENSEWind commissioned comparative studies of floating wind MCR using its SENSE system, based on two representative floating wind projects. In one modelled scenario











involving the exchange of generators on five turbines, the study estimated that using SENSE saved £21 million, a 67% reduction, compared with the tow to port method.

To exchange a generator in situ using SENSE on a floating or deep water offshore turbine, a floating crane vessel would deploy the service platform into position on the tower rail.

The estimated cost savings for the generator exchange come from avoiding the tow to port and the return journey, the associated complex port operations and the disproportionate use of a circa 3000 tonne ring crane to extract a component that may weigh only around 100 tonnes.

SENSEWind estimates an in situ generator exchange would take less than half the time, allowing the turbine to return to service sooner and reducing lost energy production and revenue.

Applications across the wind industry

SENSE is designed to be used across onshore, fixed-bottom offshore and floating wind projects, from installation to decommissioning.

For onshore projects, using the SENSE system could reduce the need for large cranes and the additional infrastructure required to transport and operate them, particularly at remote or island sites or where access is restricted.

SENSE could also be used for onshore projects which use refurbished turbines to reduce costs. This is a growing area of the wind industry. Installing SENSE equipped refurbished turbines on taller SENSE towers can significantly increase energy yield as well as reduce long-term operating costs and risks because major components could be exchanged using the SENSE system instead of bringing a large crane back to site.

For shallow water offshore projects, turbine sizes are increasing rapidly and conventional installation depends on ever larger jack-up crane vessels. Using SENSE would allow smaller existing crane vessels to carry out installation and undertake MCR more cost-effectively when required.

For deep water fixed-bottom foundations, the use of conventional jack-up crane vessels may not be possible. SENSEWind is exploring arrangements using smaller existing floating crane vessels to undertake both turbine installation and in situ MCR.

On floating turbines, the relative movement of the foundation and crane vessel makes conventional lifting operations at hub height particularly challenging. SENSE reduces this problem because lifting and assembly work is carried out at low level, where relative movement is significantly smaller for a given sea state.

When using the service platforms, there is no relative movement between the platform and the turbine because the platform is attached directly to the tower.

SENSE is also intended to support decommissioning. When a turbine reaches the end of its working life, the carriage arrangement could be used to lower major components or the complete RNA rather than relying on large and expensive lifting equipment. The decommissioning process is essentially the reverse of the installation sequence.

Levelised cost of energy reduction

Independent studies have modelled how SENSE technology could reduce the levelised cost of energy (LCoE) for different wind projects, with the following headline savings:

- **£90 million and an 8% reduction** in LCoE for a UK 350 MW onshore project using 6 MW turbines.
- **£1 billion and a 5% reduction** in LCoE for a UK 4 GW shallow water offshore project using 15 MW turbines.
- **£740 million and a 9% reduction** in LCoE for a 500 MW ScotWind deep water offshore project using 12 MW turbines.
- **£5.8 million and a 24% reduction** in LCoE for a UK 8 MW onshore project using refurbished 2 MW turbines, representative of a community wind project.

The savings come from both capital expenditure (CapEx) and operating expenditure (OpEx), although in different proportions for each application depending

on the project details, the lifting equipment required and the maintenance method used for comparison.

SENSEWind considers these estimates conservative because they do not include the potential value of reducing project risk, particularly the high maintenance reserves that may be required for conventional MCR operations.

The studies use project-specific assumptions, assessed by the independent consultants. Detailed reports are available from SENSEWind under a non-disclosure agreement.

These potential cost reductions are possible because of two fundamental design choices made during the development of the SENSE system.

1. The SENSE tower design departs from the rolled steel tubular sections now dominant in conventional towers, but which are becoming increasingly challenging for very tall structures. Instead, it comprises three structural legs that also serve as the supporting rails for the SENSE installation and service carriages. This allows the tower to be modularised for ease of production, transport and assembly.

   For onshore applications, the lower tower sections can be a lattice structure, potentially allowing onshore hub heights of 200 m or more. For offshore applications, the tower structure is fully enclosed. In both cases, the tower can be self-installed using relatively modest lifting equipment.

2. The RNA is designed to be upended and attached to the carriage. This design choice presents a challenge for wind turbine original equipment manufacturers (OEMs), but SENSEWind's engineering work indicates that it can be achieved with relatively modest modifications to the RNA.

   A significant benefit is that the blades can be installed horizontally at low level, delivering potential improvements in both safety and assembly quality.

Engineering progress and looking ahead

Throughout the development and engineering of the SENSE system, SENSEWind has worked with partners who have extensive wind turbine design experience.

Blackfish Engineering and Houlder have contributed to the engineering of the RNA carriage, P.E. Concepts has provided specialist wind turbine tower design expertise and CREADIS has analysed the impact of SENSE installation on modern wind turbines.

DNV in Bristol has undertaken detailed aeroelastic modelling to provide installation load data.

This expertise has allowed SENSEWind to take an integrated design approach aimed at reducing the costs and risks of turbine installation and servicing, including consideration of the turbine design itself.

In 2021, SENSEWind built its first functioning demonstrator, installing a Vestas V27 turbine in Northern Ireland.

This prototype provided the practical experience and engineering confidence to upscale the SENSE system for a Vestas V80 2 MW turbine.

Building on this experience, SENSEWind undertook a substantial redesign during 2025 and early 2026, moving towards a 6 MW turbine, for which the company has now completed the design of all key aspects.

A turbine in the 6 to 8 MW range is now the preferred scale for demonstrating the SENSE system. The proposal is to install one turbine using SENSE as part of a larger onshore wind farm, with the remaining turbines being standard machines.

SENSEWind has identified a site through its main investor, a wind farm developer, and believes the project could be delivered in 2028 if the necessary investment is secured to take the design through manufacture, installation and testing, alongside engagement with wind turbine OEMs.

SENSEWind's longer-term development roadmap envisages incremental upscaling from 6 MW onshore to approximately 15 MW in shallow water offshore applications and 20 MW or more for deep water offshore projects.

The next step would be an offshore version for a turbine of approximately 15 MW in shallow water, deployed from a jack-up vessel.

The procedures for using SENSE from a jack-up crane would be similar to those for onshore use, so SENSEWind expects this upscaling to be relatively straightforward.

Subject to collaboration with industry partners, the design work could proceed in parallel with the onshore project, with a possible demonstration by 2030.

For deep water floating wind, a further upscale of SENSE for turbines of 15 MW and above could be used to assemble the turbine on its floating foundation in harbour or shallow water, removing the need for a large ring crane. SENSEWind believes this could also be developed by 2030.

SENSEWind aims to establish a technology and manufacturing base in the UK, working with partners Forsyths and Hutchinson for the manufacture of SENSE towers and SENSE carriages.

The immediate priority is to secure the development funding and industry engagement needed to build and demonstrate the 6 MW operational turbine installed using SENSE.

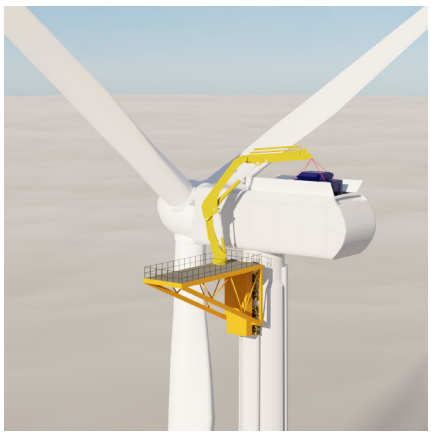
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Blade inspection and repair



Blade exchange



Generator exchange



RNA exchange