Featured Articles

Development of 5-MW Offshore Wind Turbine and 2-MW Floating Offshore Wind Turbine Technology

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OVERVIEW: To date, Hitachi has received orders for a total of 137 of the 2-MW downwind turbines it developed for use in Japan's demanding conditions such as tyhoon gusts and wind turbulance in its mountainous regions. The first seven offshore wind turbines mounted on fixed seabed foundations to be built in Japan commenced operation in 2010, with an additional eight turbines added in 2013. Hitachi is now drawing on this experience to develop a 5-MW downwind turbine for offshore use. Hitachi has also, as a member of the Fukushima Offshore Wind Consortium, supplied a wind turbine to the Fukushima Floating Offshore Wind Farm Demonstration Project sponsored by the Ministry of Economy, Trade and Industry. Similarly, it has installed a 2-MW downwind turbine for the Floating Offshore Wind Turbine Demonstration Project led by the Ministry of the Environment, with Hitachi being part of the group contracted to undertake the project.

INTRODUCTION

VARIOUS forms of renewable energy are being developed and commercialized around the world in response to the increasing environmental demands that accompany progress. Of these, wind power generation, in particular, has reached a stage where its output and cost are close to traditional forms of power generation using fossil fuels and nuclear power. It is growing in both scale and sophistication, being installed at various places around the world, not only in Europe, which is the leading early adopter of the technology.

Hitachi began developing its HTW2.0-80 2-MW downwind turbine in 2003, using the SUBARU22/100 to conduct quantitative testing of the differences between upwind and downwind configurations[1]. Subsequently, seven offshore wind turbines built on fixed seabed foundations, Japan's first, commenced operation in 2010[2], with an additional eight wind turbines entering service in 2013. Drawing on this experience, Hitachi is now developing the HTW5.0-126, a 5-MW downwind turbine for offshore installation.

As a maritime nation, Japan is surrounded by large areas of ocean that have much greater potential for wind power generation than on land. However, if wind turbines are to be situated offshore, they need to be capable of generating power reliably from floating platforms ("floaters") without fixed seabed foundations. Hitachi has supplied one HTW2.0-80 to the Fukushima Floating Offshore Wind Farm Demonstration Project sponsored by the Ministry of Economy, Trade and Industry, and another to the Floating Offshore Wind Turbine Demonstration Project led by the Ministry of the Environment. Through this testing, Hitachi aims to verify the viability of floating offshore wind power generation.

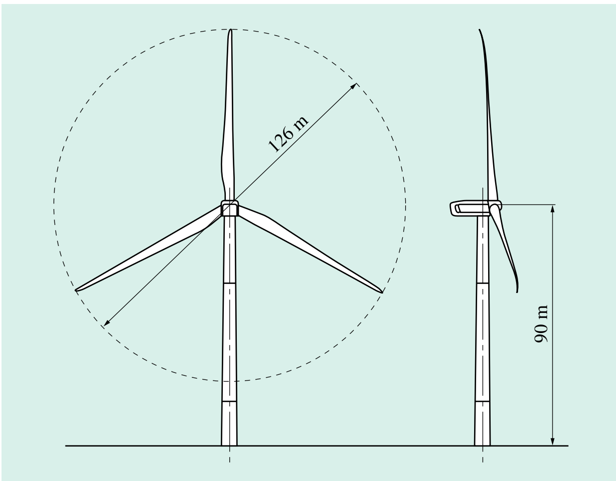

Fig. 1—HTW5.0-126 Wind Turbine.
The HTW5.0-126 has a rotor diameter of 126 m and is designed to withstand gusts of 70 m/s or more.

Table 1. HTW5.0-126 Specifications
An output voltage of 33 kV was selected to improve the economics of the undersea cable used to connect to the onshore grid.

Parameter	Specification
Rated output	5,000 kW
Rotor diameter	126 m
Hub height	90 m or more
Number of blades	3
Rotor orientation	Downwind
Tilt angle	−8°
Coning angle	5°
Output control	Pitch, variable speed
Brake	Blade feathering (independent pitch)
Yaw control	Normal operation: Active yaw When shutdown in high winds: Free yaw
Speed	6.4 to 12.7 rpm (min^{-1})
Gear ratio	1:40 (approx.)
Generator	Permanent magnet synchronous generator
PCS	Full converter
Turbine output voltage	33,000 V
Cut-in wind speed	4 m/s
Cut-out wind speed	25 m/s

PCS: power conditioning system

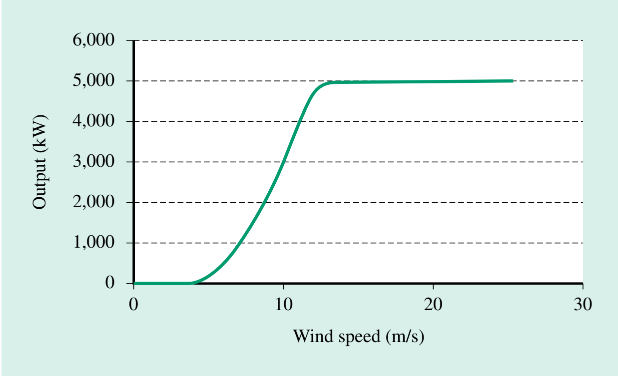

Fig. 2—HTW5.0-126 Power Curve.
The wind turbine has a capacity of 5 MW and uses monopile foundations, which have the lowest cost.

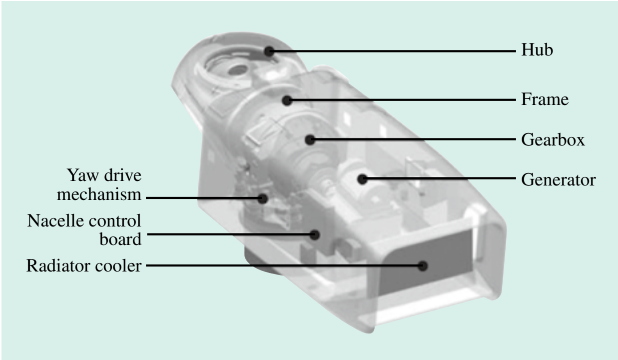

Fig. 3—Nacelle Design.
The nacelle has a two-stage gearbox to reduce weight and improve reliability.

This article describes the concept and features of the HTW5.0-126, the differences between mounting wind turbines on floaters and on fixed seabed foundations, an overview of two floating wind power generation systems, and the progress that has been made on testing these systems.

HTW5.0-126 5-MW DOWNWIND OFFSHORE WIND POWER GENERATION SYSTEM

In response to demand for larger offshore wind power generation systems, Hitachi plans to build a prototype of its HTW5.0-126 5-MW downwind offshore wind power generation system off the coast of Kamisu City in Ibaraki Prefecture. Fig. 1 shows a drawing of the HTW5.0-126 prototype, Table 1 lists its specifications, and Fig. 2 shows its power curve.

Compared to locations such as Europe's North Sea, Japan and nearby parts of Asia have not only a low mean wind speed in the 6 to 8 m/s range, but also experience gusts of up to 70 m/s during typhoons.

The specifications of the HTW5.0-126 were chosen to achieve good economics, reliability, durability, and scope for future expansion under these conditions. The rated capacity for the wind turbine was set at 5 MW because this allows monopile foundations, which is the lowest cost option, to be used. Use of a two-stage gearbox is being considered to reduce the weight of the tower head. The target weight of the tower head is 350 t. Fig. 3 shows the nacelle design.

Features of Downwind Turbines

A major feature of the HTW5.0-126 is that the rotor is located on the downwind side of the tower. This configuration ensures high reliability in environments such as Japan, where typhoons are frequent, even during power outages on the grid[3].

Because the large rotor required for higher wind turbine capacity means greater bending, locating the rotors on the downwind side eliminates the risk of bending causing the rotor to collide with the tower, facilitating the adoption of larger rotor diameters by minimizing the restrictions associated with longer rotor blades. Furthermore, the clearance between the blades and tower increases with increasing wind speed on a downwind turbine. Compared to an upwind configuration, where the opposite occurs, this improves safety by further reducing the potential for a collision between tower and blade[4].

The stability of the downwind configuration is also potentially valuable for floating offshore wind power generation, and it provides major benefits to the two floating offshore wind power generation systems described later in this article.

Reliability Improvements

Because offshore wind turbines are more difficult to access than land-based installations, they need to achieve higher utilization than on land in order to improve the economics of offshore wind turbines over their entire lifetime[5]. This means they require higher reliability.

Because it was designed specifically for offshore use, Hitachi has already incorporated, or is considering incorporating, a number of reliability improvements in the HTW5.0-126. The following sections describe the most important of these.

(1) Medium-speed gear drive

To reduce the potential for faults in the gearbox and generator, Hitachi is considering adopting a medium-speed gear drive consisting of a gearbox (with a gear ratio of approximately 1:40) in place of parallel gears, along with a 36-pole permanent magnet synchronous generator.

(2) Dual-bearing outer ring drive

Hitachi is considering the use of a dual-bearing outer ring drive system on the HTW5.0-126 in order to bear the higher loads associated with larger wind turbines (see Fig. 4). This system uses two shafts (fixed and rotating) to split the rotor load and transmit it to the rest of the structure. This design improves the reliability of the gearbox by transmitting a very pure torque load to it, with minimal loading other than the rotor torque component. Also, because the fixed shaft that bears loads other than torque does not itself rotate, it improves the reliability of structural components by reducing the fatigue load.

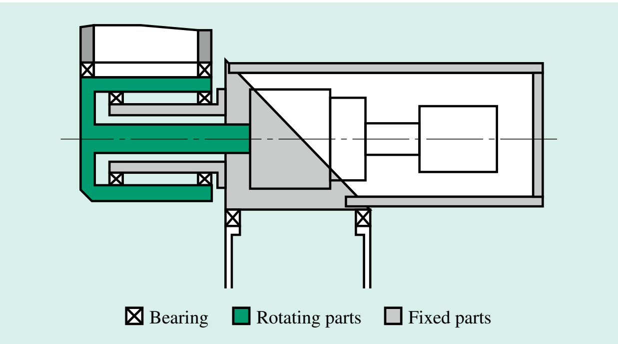

Fig. 4—Dual-bearing Outer Ring Drive.
Use of separate fixed and rotating shafts splits the rotor load and transmits it to the rest of the structure.

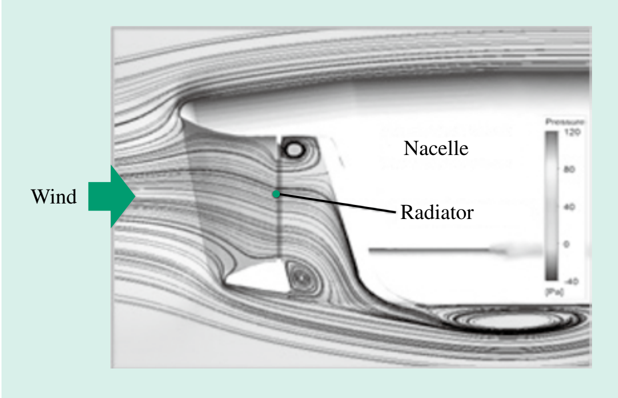

Fig. 5—Fluid Dynamics Simulation around Nacelle.
The figure shows a simulation of air flow through the radiator used in the design of the nacelle shape.

(3) Passive cooling

Because the HTW5.0-126 has a downwind configuration, the front side of the nacelle is the part that is furthest upwind. Hitachi has utilized this feature to incorporate a passive (fan-less) cooling system. Using computational fluid dynamics, it has designed the important parts of the nacelle shape to ensure the volume of air necessary for cooling (see Fig. 5).

HTW5.0-126 Development Schedule

The HTW5.0-126 prototype is currently being fabricated and is expected to be ready for construction in the summer of 2014. The power train is undergoing full power testing at the factory prior to nacelle assembly.

Fig. 6 shows an overview of full power testing, which includes measuring the power train behavior

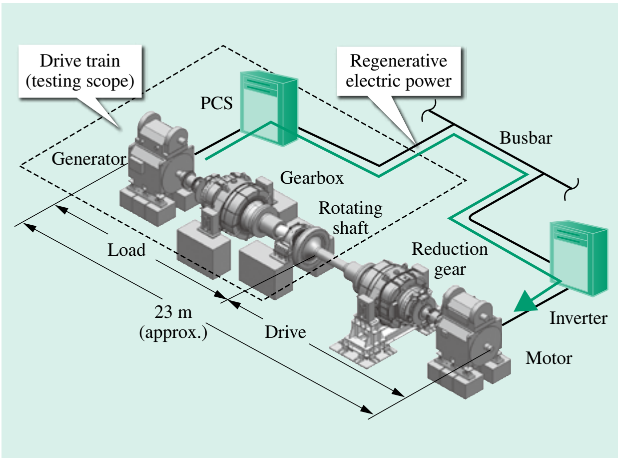

Fig. 6—Full Power Testing of Drive Train.
Two power trains were installed and tested using electric power regeneration.

Fig. 7—Full Power Testing.
This equipment was used to measure the power train behavior under variable torque and with alignment deviations.

under variable torque and with alignment deviations. Fig. 7 shows the test apparatus with which full power testing is conducted.

FUKUSHIMA FLOATING OFFSHORE WIND FARM DEMONSTRATION PROJECT

Overview of Fukushima Offshore Floater Project

The Fukushima Offshore Wind Consortium made up of Marubeni Corporation (as project integrator), ten companies (including Hitachi), and The University of Tokyo (as technical advisor) was contracted by the Ministry of Economy, Trade and Industry in March 2012 to undertake the Fukushima Floating Offshore Wind Farm Demonstration Project. The project involves the consortium building the world's first floating offshore wind farm off the coast of Fukushima Prefecture, and conducting testing to assess its safety, reliability, economics, and other characteristics, with each of the consortium members taking on a role that utilizes their respective technologies and other knowledge[6]. In addition to supplying the electrical conversion systems for the floating substation, Hitachi will also provide an HTW2.0-80 wind turbine modified to suit this purpose for the semi-sub floater supplied by Mitsui Engineering & Shipbuilding Co., Ltd. The wind turbine will be assembled on the semi-sub floater in a shipyard dry dock, which provides an environment similar to a land-based installation, and then towed all the way to the site. A feature of the semi-sub floater is its high level of stability (see Fig. 8).

Fig. 8—Wind Turbine off Coast of Fukushima.
The 2-MW downwind turbine (HTW2.0-80) is mounted on the semi-sub floater (photograph courtesy of Fukushima Offshore Wind Consortium).

Strengthened Tower for Floating Wind Turbine

A coupled analysis of the wind turbine and floater was conducted during the design stage to ensure the tower design could cope with the higher static and fatigue loads caused by swaying. To align with the diameter of the center column on the floater and deal with the higher tower bending moment, the diameter at the bottom of the tower is 5 m, the largest to date for a HTW2.0-80. The tower needs to be made as narrow as possible because of its wind shadow, which is a consequence of the wind reaching the rotor of a downwind turbine after passing around the tower. One way of satisfying these requirements for (1) strength, (2) weight reduction, and (3) shape restrictions associated with the tower shadow, is to incorporate measures to improve the fatigue strength of the tower on the floater by machining weld toes. The wind turbine tower can be built by forming a welded structural steel plate into a cylindrical shape and then joining it with a full penetration weld. This can satisfy the above three requirements.

Electrical Equipment Containers

Hitachi is considering mounting the power conditioning system (PCS) at the base of the tower. The PCS controls the frequency of the generated power to match the grid. This configuration requires the high-voltage panel, step-up transformer, special high-voltage panel, and other components to be located on the grid-side. The possibilities include

Fig. 9—Containers on Deck of Floater.
The extra-high-voltage panel container is on the left, the high-voltage panel container is in the center, and the step-up transformer container is on the right (photograph courtesy of Fukushima Offshore Wind Consortium).

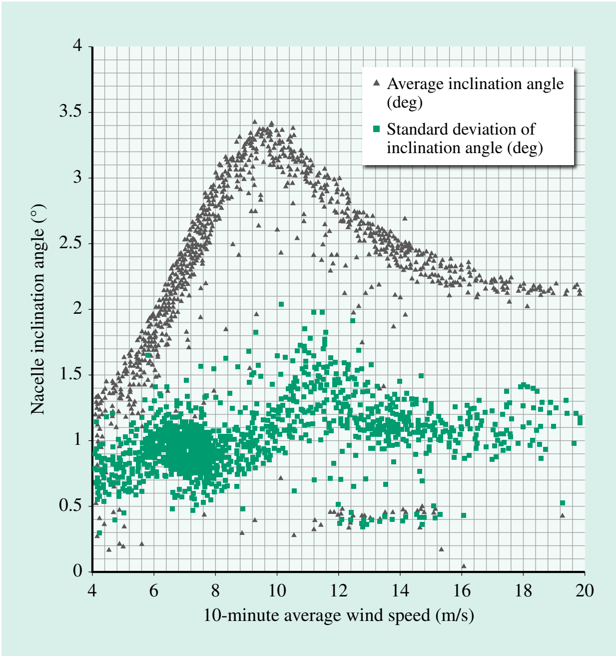

Fig. 10—10-minute Average Wind Speed and Nacelle Tilt Angle.
A tilting sensor was attached to the nacelle to take measurements on the floater.

locating the PCS inside the tower, inside the floater, or on the floater deck. Although the floating wind turbine is a prototype, its specifications have been designed with future commercial use in mind. Accordingly, Hitachi has mounted the equipment in three separate and independent containers in order to allow for replacement in the event of a fault (see Fig. 9). The two containers containing the special high-voltage panel and high-voltage panel are connected to the tower by a pipe, and there is a process for using a ventilation fan inside the tower to circulate air for cooling. For the step-up transformer, the possibilities include covering it with a coating to prevent salt damage and using a fan in the container ceiling to supply outdoor air and circulate internal air for cooling. One possibility is to attach the three containers to the deck of the floater by bolts, in which case it will be possible to detach and replace an entire container in the event of a fault.

Testing

The wind turbine has been generating electric power reliably and producing test data since November 2013. The stability of the floater has been particularly good. Although there is some perceptible swaying, the testing has found no problems with performing the sort of routine maintenance carried out on land. Fig. 10 shows the inclining angle of the nacelle when generating power. The horizontal axis represents the 10-minute average wind speed and the vertical axis represents the measurement from an incline angle sensor located in the nacelle.

The average incline angle increases until it reaches the range in which the blade pitch is adjusted, and then subsequently decreases. Hitachi plans to utilize this data for future study of the details, considering influences such as ocean currents.

Testing is scheduled to continue until the end of FY2015. Data will be collected during this time and used as feedback for the design process so that it can be applied to the development of future floating wind turbines.

MINISTRY OF THE ENVIRONMENT THE FLOATING OFFSHORE WIND TURBINE DEMONSTRATION PROJECT

In the Floating Offshore Wind Turbine Demonstration Project that began with a preliminary study in 2010[(7), (8), (9)] led by the Ministry of the Environment, a group of companies headed by Toda Corporation constructed a floating offshore wind turbine with a spar design off the Goto Islands in Nagasaki Prefecture. While a wide variety of designs have been proposed for floating offshore wind turbines, the project selected a spar design because of its excellent economics. They were able to improve its economics further by using a hybrid construction that combined prestressed concrete and steel components (see Fig. 11).

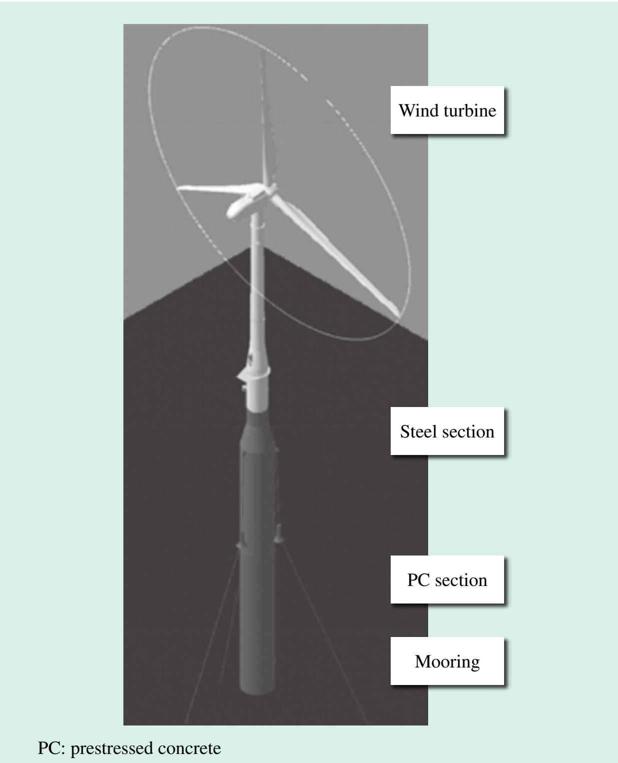

Fig. 11—Hybrid Spar Design.
Instead of an all-steel spar, a hybrid spar design incorporating prestressed concrete was adopted.

Fig. 13—2-MW Demonstration Wind Turbine.
This demonstration model was built by modifying a 2-MW onshore wind turbine and installing it on a floater.

To take advantage of the characteristics of the floater, it is necessary to work on things like the overall transportability, ease of construction, and durability, factors that arise from having an elongated shape with a simple structural design.

Hitachi supplied two separate wind turbines for testing: a 100-kW base model and a 2-MW model.

The small 100-kW prototype wind turbine was a SUBARU22/100 base model designed for offshore islands that formerly belonged to Izena Island in Okinawa (see Fig. 12).

Although this wind turbine had been installed on land, its specifications were suitable for offshore use because it had been designed for use on islands. For example, it had been treated with a coating to prevent salt damage and had a cooling system that worked primarily by recirculating the internal air. Other possible ways of adapting it for floating use include changing the rotor to a downwind configuration and

Fig. 12—Small 100-kW Prototype Wind Turbine.
This small prototype was built by modifying a 100-kW wind turbine designed for use on offshore islands and installing it on a floater.

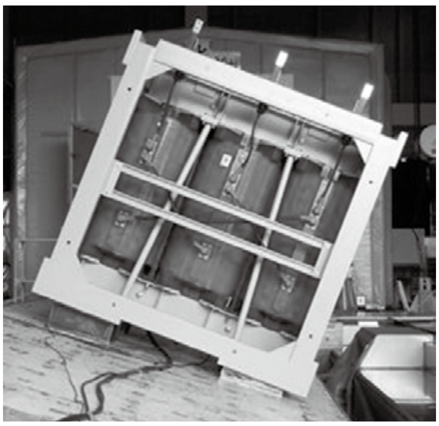

Fig. 14—Inclination Test of Step-up Transformer.
Because the step-up transformer will be installed inside the floating wind turbine, inclination testing was performed in accordance with standards used for shipping.

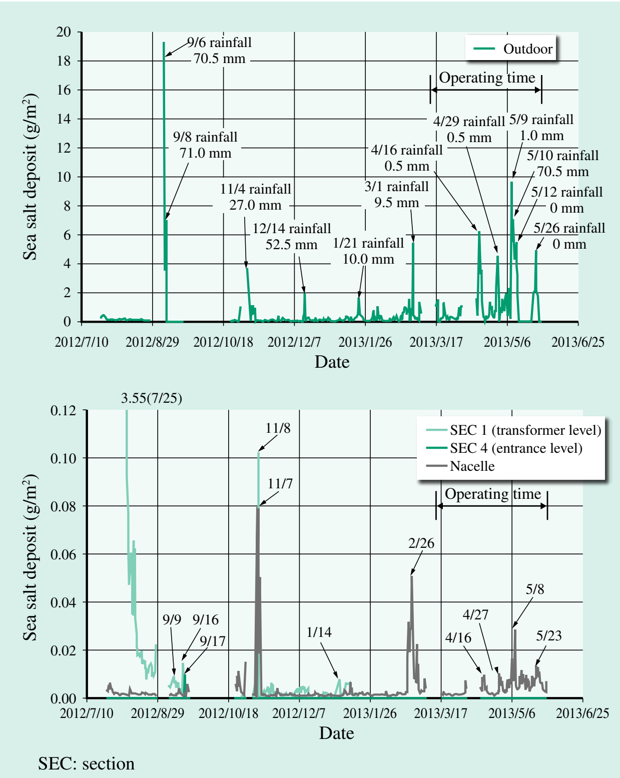

Fig. 15—Salt Level Graphs (One-hundredth outdoor level of salt).
A practical technique for measuring the level of salt in the air has only become available recently. The graphs show examples of how the technique was used for quantitative assessment of measures to prevent salt from getting into electrical rooms.

modifying the blade pitch control to dampen the swaying of the floater.

Additional modifications made to the 2-MW demonstration model to suit floating use included measures for dealing with the inclination, water or oil leaks, and humidity (see Fig. 13).

One measure for dealing with the inclination is to conduct inclination testing of components such as step-up transformers in accordance with standards used for shipping (see Fig. 14). Possible countermeasures against water leaks, meanwhile, include double-skinned housings for electrical components and waterproofing them at three atmospheric pressures.

Waterproofing also serves to prevent salt from getting into the equipment (see Fig. 15). It would also be possible to extend measures for minimizing swaying on the 2-MW demonstration model by equipping it with independent pitch control.

CONCLUSIONS

This article has described the development of technology for the 5-MW offshore wind turbine based on experience with the 2-MW wind turbine on a fixed seabed foundation, technology for wind turbines for the Fukushima Floating Offshore Wind Farm Demonstration Project, and a demonstration project for floating offshore wind power generation led by the Ministry of the Environment.

In addition to utilizing operational data from these two floating offshore wind turbines in future designs, Hitachi also aims to expand offshore wind power generation and help protect the global environment by utilizing testing of the HTW5.0-126 to make progress on commercializing offshore wind turbines.

ACKNOWLEDGMENTS

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