Visionaries 2014

The Wind from the Future

—Fukushima Floating Offshore Wind Farm Demonstration Project—

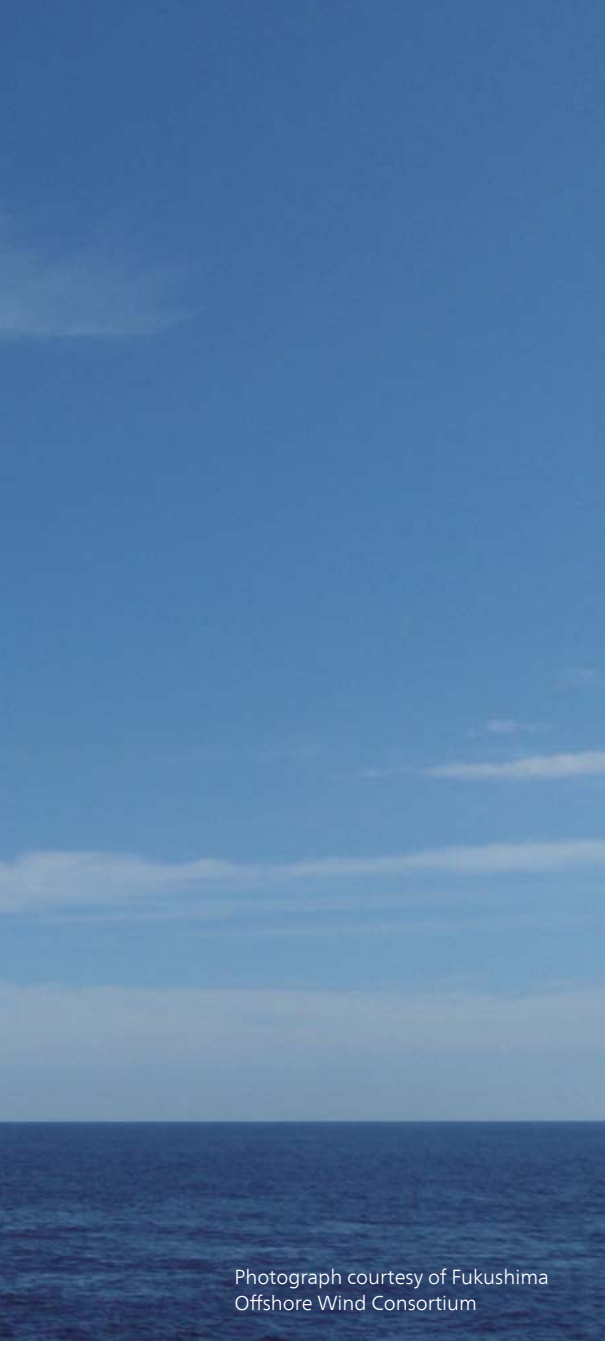
As use of renewable energy increases around the world, interest is growing in the harvesting of wind energy from off the coast of Japan. Unfortunately, numerous technical challenges stand in the way of achieving this goal of generating electric power from floating wind turbines. Hitachi is participating in a consortium that is taking on this challenge through a demonstration project, with roles that include the manufacture of a downwind turbine and the development of a world-first 66-kV offshore substation*. The wind turbine and substation are moored approximately 20 km off the coast of Fukushima Prefecture and commenced floating offshore power generation in November 2013.

Extensive Wind Energy Resources Waiting Offshore

The shortage of power generation capacity afflicted a wide area of Japan, including the Tokyo region, after many power plants were damaged in the Great East Japan Earthquake of March 2011. Subsequently, along with ongoing efforts by households and businesses to save power, there was also an acceleration of moves to encourage the wider use of renewable sources of energy such as photovoltaic or wind power.

As a mountainous country with limited flat land, Japan has a shortage of favorable sites for wind power and is seen as lagging behind Europe or China in its adoption of this form of power generation. Also, whereas offshore wind turbines in Europe tend to use fixed-bottom configurations

* The floating offshore wind power generation system is part of the FY2011 Fukushima floating offshore wind farm demonstration project (Fukushima FORWARD) funded by the Ministry of Economy, Trade and Industry.



Photograph courtesy of Fukushima Offshore Wind Consortium

in which the turbine foundations are on the sea floor, Japan's lack of shallow offshore seabed means it has limited sites suitable for this approach. On the other hand, compared to onshore sites, the sea around Japan is known to have more reliable and strong wind conditions. This means that, surrounded as it is by a broad expanse of ocean, Japan has extensive offshore wind energy resources waiting to be tapped. In other words, offshore floating wind turbines are an appropriate form of power generation for Japan's geographical conditions.

Professor Takeshi Ishihara of the Graduate School of Engineering at the University of Tokyo was among the first to recognize this situation and engage in research into floating offshore wind power generation.

Grand Project Gets Underway off Fukushima

Wataru Saito (Chief Project Manager, Power & Industrial Systems Division, Power Systems Company, Hitachi, Ltd.), who has participated in the work of Professor Ishihara explained the situation as follows.

"Having recognized the potential of floating turbines, Professor Ishihara had undertaken some work on his own initiative in collaboration with construction companies and others, with practical investigatory work having only just begun when the Great East Japan Earthquake struck. This led to the Fukushima floating offshore **wind farm**[(a)] demonstration project."

The project was able to start in earnest when money was budgeted as part of the post-earthquake recovery and reconstruction work. Hitachi then formally joined the demonstration project in December 2011 after invitations to participate were announced by the Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry. It was through this process that the grand project to build a world-first offshore wind farm several tens of kilometers off the coast of Fukushima Prefecture got underway.

This project to aid recovery in Fukushima and

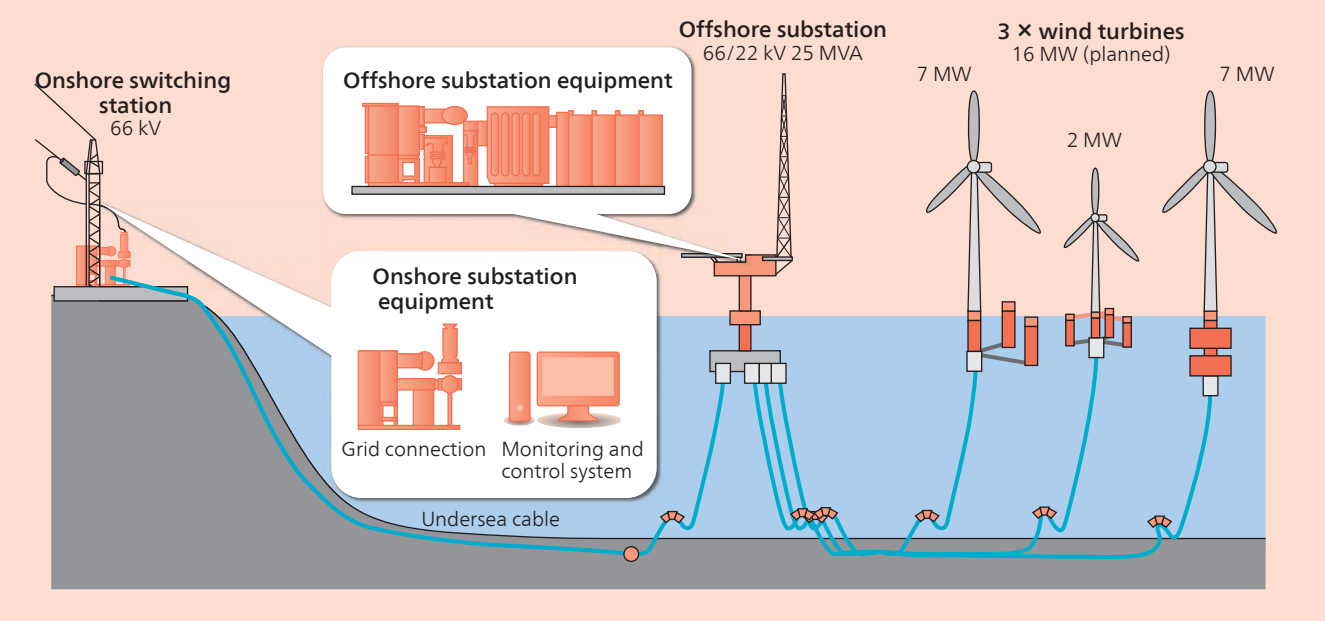
Wataru Saito

(a) Wind farm
A group of wind turbines used for power generation and also called as wind park. Installing a number of wind turbines (up to several dozen) in the same place can reduce the construction and operating costs per unit of output.

Consortium members	Main role
Marubeni Corporation (project integrator)	Feasibility study, approval and licensing, O&M, collaboration with fishery industry
The University of Tokyo (technical advisor)	Metocean measurement and prediction technology, marine navigation safety, public relation
Mitsubishi Corporation	Coordination for grid integration, environmental impact assessment
Mitsubishi Heavy Industries, Ltd.	V-shape semi-sub (7 MW)
Japan Marine United Corporation	Advanced spar, floating substation
Mitsui Engineering & Shipbuilding Co., Ltd.	Compact semi-sub (2 MW)
Nippon Steel & Sumitomo Metal	Advanced steel material
Hitachi, Ltd.	**Floating substation**
Furukawa Electric Co., Ltd.	Large capacity undersea cable
Shimizu Corporation	Pre-survey of ocean area, construction technology
Mizuho Information & Research Institute, Inc	Documentation, committee operation

O&M: operation and maintenance

Roles of consortium members. The project draws on the knowledge and technologies of each company.



Overview of demonstration project. The electric power generated by the wind turbines will be stepped up to 66 kV for transmission to the onshore switching station. The 66-kV floating offshore substation used for this purpose will be a world first.

trial a floating offshore wind farm was contracted by the Ministry of Economy, Trade and Industry to a consortium of 10 companies and one university. The first stage involves the installation of a single floating offshore wind power generation system with a 2-MW **downwind turbine**[(b)], a world-first 25-MVA floating offshore substation, and an undersea cable. The second stage will see the installation of two 7-MW floating offshore wind power generation systems.

There is a certain significance in Fukushima being chosen for the site of this project. Mitsuru Saeki (Senior Project Manager, Power Systems Company, Hitachi, Ltd.), who was involved in reconstruction work at the time, recalls the decision as follows.

"Fukushima Prefecture had a strong desire to pursue renewable energy. Whether or not this project would provide direct assistance for the recovery, we felt that this was not something that could be ignored."

Installation at a Floating Site

Hitachi's responsibilities in the project included the 2-MW offshore downwind turbine, a world-first 66-kV floating offshore substation, and its monitoring system.

Most wind turbines used for power generation have an upwind configuration in which the rotor is oriented upwind of the tower. As Mr. Saeki explained, the reasons for choosing a downwind configuration for this project included factors specific to a turbine floating at sea.

"We believe that a downwind design will have particular advantages for a wind turbine mounted on a floating platform that is subject to tilting, such as higher generation efficiency. The way a downwind turbine naturally tracks changes in wind angle when it blows from the side can be thought of as a match for the floating platform."

The downwind turbine was developed for use in Japanese conditions where there is little flat land available. In addition to selecting the transformer, power conditioning system (PCS), and other electrical components with consideration for the swaying that occurs on a floating platform, the system also incorporates a stability mechanism that controls the pitch of the blades to minimize this swaying.

Another feature of this project is the construction of a world-first floating substation. Typically, the longer the distance electric power needs to be transmitted, the greater the losses. To minimize losses over the long distance from the offshore wind turbine to the shore (approximately 20 km), an offshore substation that raises the transmission voltage from 22 kV to 66 kV was part of the project plan from the earliest stages.

(b) Downwind turbine
A wind turbine in which the rotor is oriented downwind of the tower. This configuration reduces the load on major components during sudden gusts due to a control mechanism that allows the rotor to freely orient itself downwind. Downwind turbines are suitable for difficult environments such as complex terrain.


Mitsuru Saeki

The electrical conversion equipment is installed on the top of this floating substation.

Toshiyuki Takada (Department Manager, Wind Turbine Business Department, Power & Industrial Systems Division, Power Systems Company, Hitachi, Ltd.), who has responsibility for this work, commented as follows.

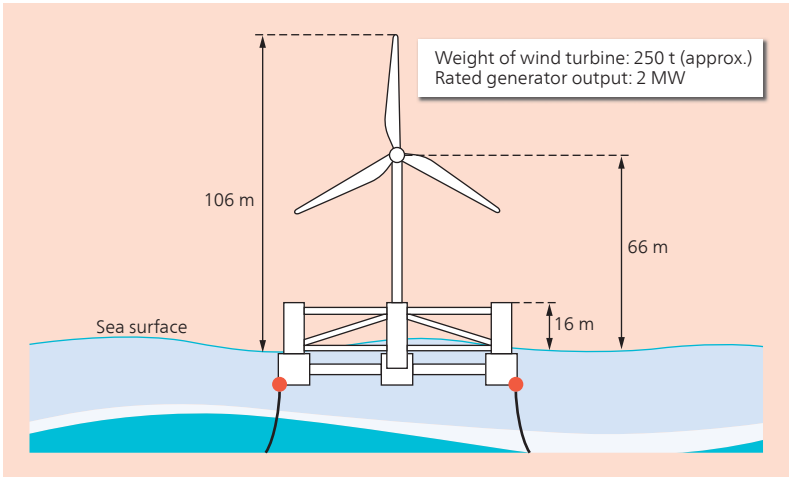
"While I had some concerns when we were only given two months to prepare our proposal to the Ministry of Economy, Trade and Industry, I spent considerable time at the factory discussing the work with the transformer designers and other staff as we settled on how we wanted to proceed."

However, substation equipment is built on the assumption that it will be installed on stable ground. If inclined, the coils, core, or other internal parts of a transformer can be left bare of transformer oil, compromising the insulation that is vital to its operation and potentially causing a fault. This meant that the major challenge was how to deal with the swaying and inclining that would result from the large waves of the Pacific Ocean.

Futoshi Asaka (Engineer, Industrial Systems Engineering Section, Power Systems Company, Hitachi, Ltd.), whose work included transformer testing, describes the situation as follows.

"We had no experience of building high-voltage (66 kV) substation equipment for use in a swaying environment and this left us wondering how we could go about testing it. What we ended up doing was to test the 25-MVA transformer inclined at angle up to 35° to verify its ability to deal with the swaying of the floating platform."

The 66-kV gas-insulated switchgear (top) and 22-kV vacuum-insulated switchgear (bottom) installed in the substation. These can safely disconnect the current flow if necessary.



Main specifications of the 2-MW offshore downwind turbine. The wind turbine has been designed for floating use and manufactured to cope with the swaying that occurs.

Kazutaka Yokoyama (Manager, Electrical Systems Engineering Department, Electrical Solution Business Division, Power Systems Company, Hitachi, Ltd.), who had experience in technical developments that dealt with swaying, added the following comment.

"As Hitachi has had experience in building a wide variety of transformers, including manufacturing large transformers that need to be robust enough for transportation over long distances to overseas sites and new designs that consider seismic performance, we had the know-how to deal with this new challenge. I believe that our success in building the 66-kV floating offshore substation was due to this experience."

A number of measures were adopted, including raising the height of the oil tank, increasing the quantity of transformer oil, and adding a number of bolts to ensure that the core and coils would not

Inclination test of transformer. Because the transformer will be installed on a floating platform, it needs adequate measures for dealing with swaying.

Toshiyuki Takada

Futoshi Asaka

Kazutaka Yokoyama

become dislodged by the swaying. A program of detailed testing was then performed to confirm that the equipment could cope with swaying and inclination.

Collaboration between Consortium Partners

The project still faced the difficult tasks of docking the wind turbine and substation to the floating platform, towing them to the installation site approximately 20 km off the coast of Fukushima, and then getting the system to operate as intended.

After they were fabricated, the tower, nacelle, and other parts of the wind turbine were separated, the blades loaded onto trucks in one piece, and transported to a **dry dock**(c) at the Chiba Works of Mitsui Engineering & Shipbuilding Co., Ltd.

Hideyuki Mimura (Senior Engineer, FH Wind Turbine Business Department, Power & Industrial Systems Division, Power Systems Company, Hitachi, Ltd.), who was responsible for the wind turbine and acted as the technical liaison with Mitsui Engineering & Shipbuilding Co., Ltd., described the process as follows.

"The dock provided a stable location for placing the wind turbine. However, a certain amount of coordination was required to prepare a schedule

(c) Dry dock
A facility used for the construction or repair of ships. It consists of a trench dug deep into the ground that can be filled or emptied of water. The dry dock is emptied of water to allow work to proceed. When the ship is ready to depart, the water is then pumped back in to raise the water level in the dry dock up to sea level.

Trial of Floating Offshore Wind Power Generation System off Goto Islands

While the Fukushima floating offshore wind farm demonstration project is making steady progress, another trial of floating offshore wind power generation has commenced off the Goto Islands in Nagasaki Prefecture, Japan. A small (100 kW) prototype wind turbine was installed 1 km off Kabashima Island, part of Goto City, in June 2012. This was followed later by a larger demonstration model.

This demonstration project was led by the Ministry of the Environment, with participants including Toda Corporation, Hitachi, Fuyo Ocean Development & Engineering Co., Ltd., Kyoto University, and National Maritime Research Institute. The 100-kW prototype installed in 2012 was the same unit that had been used off Izena Island in Okinawa 10 years earlier. In 2013, a 2-MW downwind turbine (demonstration model) supplied by Hitachi was installed, increasing the rotor size from 22 m to 80 m. Operation of commercial-scale floating offshore wind power generation commenced in October 2013. The plan from 2014 onwards is to collect data from the offshore site.

While the wind around Kabashima Island in the Goto Islands is strong, making it a good site for offshore wind power generation, the 100-kW prototype was vulnerable to the forces of nature. In FY2012, the region was struck by a one-in-50-year typhoon, one of the strongest on record. Although the wind turbine itself survived the typhoon, this led to changes in the construction of the 2-MW demonstration model, including a change to the maximum design wave height and revisions to parameters such as rotor vibration and angle of orientation.

The project provides an opportunity to gather valuable data on such questions as what form of wind power generation is suitable for regions of ocean like this that experience frequent typhoons. The data collected and analyzed from the Goto Islands will also provide valuable information for use in the wider adoption of offshore wind power generation.

Images courtesy of joint participants in Ministry of the Environment's demonstration project for floating offshore wind power generation

A demonstration project aimed at achieving wider adoption of offshore wind power generation is also being undertaken in Nagasaki Prefecture.

Docking the wind turbine to the floating platform (photographed at the Chiba Works of Mitsui Engineering & Shipbuilding Co., Ltd.) Time constraints meant work proceeded rapidly.

The substation fitted with electrical conversion equipment (front) and wind turbine (rear) are located about 2 km apart.

for completing the assembly work within tight time constraints in an environment that was open to the weather."

The substation was assembled at the Isogo Works in the Yokohama Shipyard of Japan Marine United Corporation.

Further arrangements were then needed for transporting the assembled wind turbine and the fitted-out substation to the sea off Fukushima. In particular, the 32-m draft of the substation during towing meant it was at risk of running aground in shallow waters.

"Together with Mitsui Engineering & Shipbuilding Co., Ltd., we held discussions with the relevant agencies on aerial identification during the period up until the power cables were connected out at sea," commented Mr. Mimura.

The wind turbine and substation were successfully towed to their intended positions off the coast of Fukushima and positioned approximately 2 km from each other. The undersea cable was then connected, allowing the operational trials to commence. However, because of the numerous typhoons that passed through the region, they encountered difficulties that prevented equipment adjustment from being completed on schedule.

Speaking about the collaboration between the companies that made up the consortium and that had to deal with these difficulties, Jun Kamoshida (Engineer, Switchgear Equipment Development Section, Switchgear Design Department, Power Systems Company, Hitachi, Ltd.) made the following comment.

"It seemed like we were only able to get out to the floating platform to perform work about one day in 10. I worked on the design of the integrated monitoring system and network infrastructure for the entire facility. Because the facility included equipment from the various different suppliers, there were cases when systems did not function correctly. Furukawa Electric Co., Ltd. was responsible for the undersea optic cable, and by calling on them, or others such as Hitachi Systems, Ltd., for help when problems like this happened, we succeeded in building a fast and highly secure network."

By overcoming the various problems that arose in this way, they succeeded in supplying power from the mainland to the substation and wind power generation system.

Hideyuki Mimura

Jun Kamoshida

Symbol of Reconstruction and the Future

The Fukushima floating offshore wind farm demonstration project commenced operation in November 2013.

Yuhei Sato, the governor of Fukushima Prefecture who attended the opening ceremony, said, "I see floating offshore wind power as a symbol of the future." The project's aims extend beyond research trials to include helping with the recovery of Fukushima by attracting new industries based around renewable energy and creating employment. The requirements for achieving these goals include an increase in generation capacity and an expansion in the scale of activity.

"It is thanks to the consortium participants and other parties involved that we have been able to achieve the results that we have from this demonstration project. I would like to express my heartfelt thanks," said Mr. Saeki.

The substation is inscribed with the words "*Fukushima kizuna*" (Fukushima links), and the floating platform for the downwind turbine with "*Fukushima mirai*" (Fukushima's future). It might be said that the wind that turns the giant blades off the coast of Fukushima is blowing from a future that people are creating for themselves.