Development of 2-MW Downwind Wind Power Generation System

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OVERVIEW: Renewable energy is being introduced throughout the world. Installation of wind power generation systems in particular is anticipated to expand further in Japan, driven by factors such as the ability to install in mountainous terrain and the prospect of offshore wind farms, and also by the introduction of feed in tariffs in July 2012. Hitachi, Ltd. and Fuji Heavy Industries Ltd. have already jointly developed a 2-MW downwind wind power generation system[1], [2]*. By combining the two companies' downwind turbine technologies with Hitachi's existing technologies for power control, Hitachi has established the capabilities to deliver total solutions that extend from generation to systems for the supply of stable electric power.*

INTRODUCTION

ATTENTION has been drawn to renewable energy in recent years against a background of growing international awareness of the environment, and growth is anticipated in the market for wind power generation. The Global Wind Report 2011 of the Global Wind Energy Council (GWEC) stated that the world's total installed capacity had reached 237,669 MW in 2011, an approximate 20% increase over the previous year. Along with this growth has come progress on making wind turbines larger, most notably in the case of offshore wind turbines.

Most large wind turbines use the upwind configuration whereby the rotor is located on the upwind side of the tower. Downwind turbines, with the rotor located on the downwind side, meanwhile, are a promising technology for reasons that include the performance advantages they offer in complex terrain.

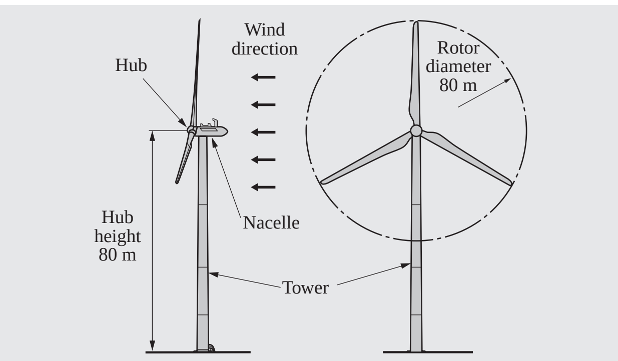


Fig. 1—2-MW Downwind Turbine.
The downwind turbine design has the rotor on the downwind side of the tower.

As a result of the merger of wind power generation system businesses with Fuji Heavy Industries Ltd., Hitachi has adopted the downwind turbine developed by Fuji Heavy Industries Ltd.

This article describes the specifications and technical characteristics of the 2-MW downwind wind power generation system, which is able to cope with difficult conditions such as typhoons or complex terrain.

SPECIFICATIONS OF WIND POWER GENERATION SYSTEM

Fig. 1 shows an overview of the 2-MW downwind turbine and Table 1 lists the main specifications of the wind power generation system.

DOWNWIND TURBINE TECHNOLOGY

Generation Output in Complex Terrain

The downwind rotor is given a negative tilt angle to maintain clearance between the rotor and tower (see

TABLE 1. Main Specifications of Wind Power Generation System
The table lists the main specifications of the 2-MW downwind wind power generation system.

Rotor diameter	80 m
Hub height	80 m/60 m
Rated output	2,000 kW
Rated wind speed	13 m/s
Operating wind speed	4–25 m/s
Tilt angle	–8°
Type of power control	Variable speed/pitch control
Yaw control	Active yaw (when generating power) Free yaw (when idling in strong wind)

$$P=\min\left\{P_{Rate},\ \left(\frac{\cos(\gamma+\alpha)}{\cos\gamma\cdot\cos\alpha}\right)^3\cdot P_0\right\}$$

[P_{Rate}: rated power, P_0: power curve (for horizontal wind direction), γ: inclination, α: tilt angle]

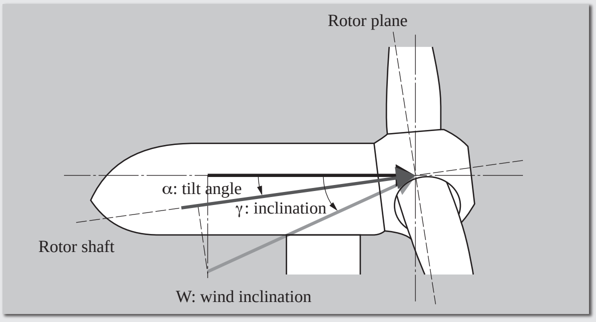


Fig. 2—Relationship between Downwind Rotor and Wind Inclination.
Power generation increases because of the smaller angle between the rotor shaft and wind inclination.

Fig. 2). As this reduces the angle between the rotor shaft and wind inclination, it increases the amount of power generated[3].

The equation based on momentum theory shown in the figure is used to allow for the effect of the inclination on the power curve[4].

The capacity factor over the course of a year was calculated for a wind farm in complex terrain. Fig. 3 shows a graph of wind speed plotted against inclination.

The capacity factor was calculated for a downwind turbine and an upwind turbine with the same power curve (tilt angle +5°, coning angle 0°) (see Fig. 4). The calculation results indicated that the downwind turbine has a capacity factor (generated energy) approximately 7% higher than the upwind turbine.

Nacelle Yaw Measurement for Complex Terrain

A yaw sensor (wind vane) is located on top of the nacelle to control its orientation during generation (yaw control). Whereas the nacelle yaw sensors on upwind turbines are strongly affected by the rotor and nacelle, very little of this interference occurs on a downwind turbine (see Fig. 5).

Fig. 6 shows an example calculated using computational fluid dynamics (CFD). On the upwind turbine, interference from the nacelle and rotor upwind of the yaw sensor significantly deflects the air flow at the sensor position. The downwind turbine, in contrast, experiences very little of this interference. This means that downwind turbines are capable of more accurate yaw measurement in complex terrains, the benefits of which include a higher capacity factor (generated energy) and less fatigue damage[5].

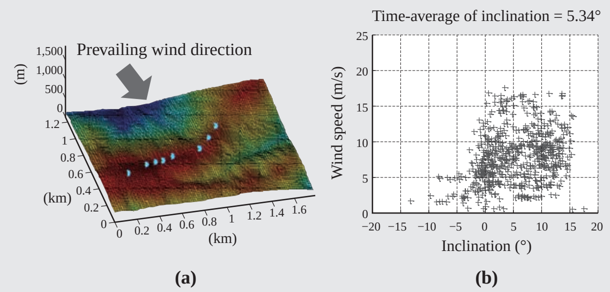


Fig. 3—Model of Complex Terrain.
The graph (b) plots the wind speed and inclination for the model terrain (a). Each point represents a particular timing (at 6-hour intervals) for one of the wind turbines.

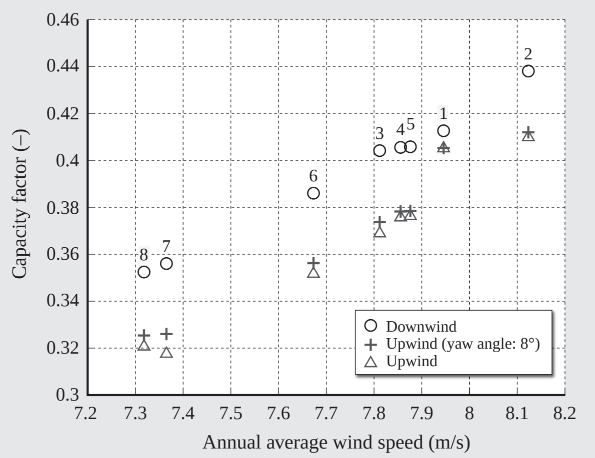


Fig. 4—Annual Average Wind Speed and Capacity Factor.
The capacity factor (generated energy) for the downwind turbine is approximately 7% higher than for the upwind turbine.

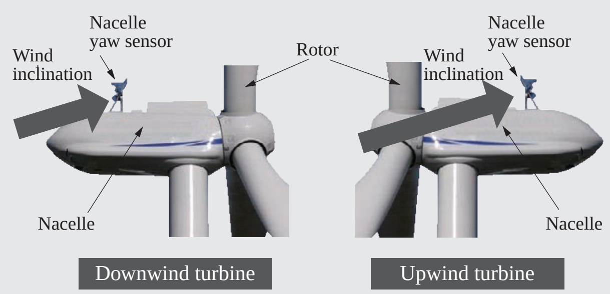


Fig. 5—Positional Relationship between Wind Inclination and Yaw Sensor.
On a downwind turbine, the rotor and nacelle do not significantly interfere with the nacelle yaw sensor.

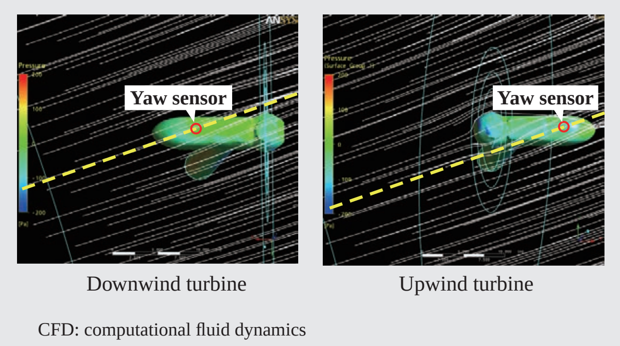


Fig. 6—Streamline Around Nacelle Yaw Sensor Calculated Using CFD (Wind Inclination: 16°, Yaw Angle: 16°).
Very little interference due to the rotor and nacelle occur on a downwind turbine.

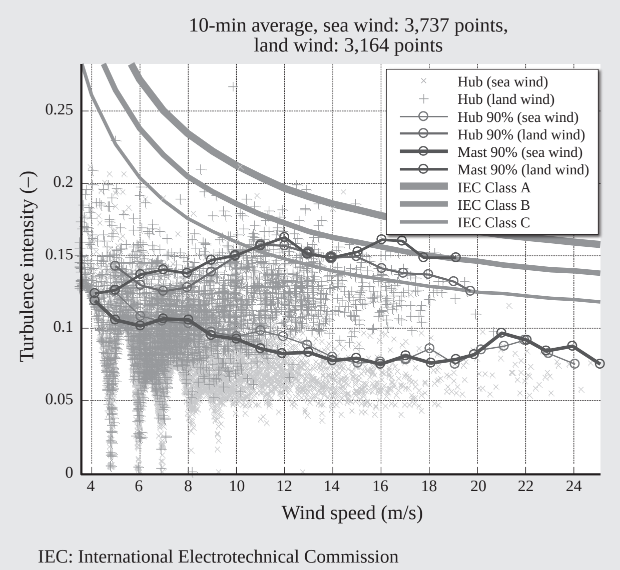


Fig. 7—Comparison of Turbulence Intensity Measurements from Mast and from Nacelle (Corrected).
The estimates from the nacelle wind vane are in good agreement with measurements from a meteorological mast.

Nacelle Wind Vane

Accurate measurements of turbulence intensity are required because of the strong affect it has during generation on factors such as turbine output and fatigue load. Because the nacelle wind vane on the 2-MW downwind turbine is located upwind of the nacelle and rotor, it is possible to estimate the turbulence intensity by adjusting appropriately for tower vibration(6). Fig. 7 shows measurements from a meteorological mast and the estimates from the nacelle wind vane. The results indicate good agreement for factors such as the effect of wind speed and the amount of turbulence intensity for land and sea winds.

* GH Bladed is a product name of Garrad Hassan & Partners Ltd.

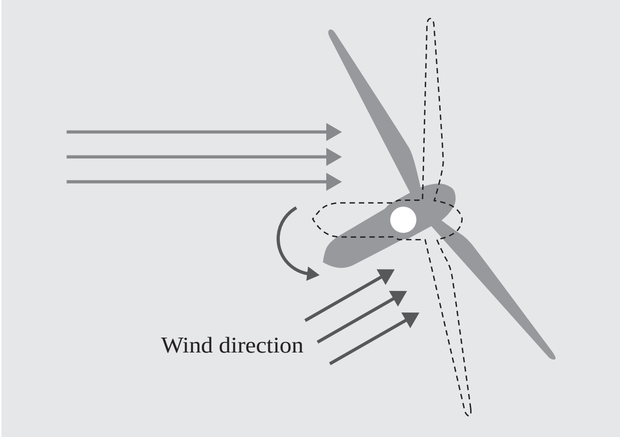


Fig. 8—Free Yaw.
With a downwind turbine, the rotor can be allowed to orient itself freely in the wind like a weathervane.

Free Yaw (Idling in Strong Wind)

Free yaw is a nacelle control method in which the rotor is allowed to orient itself freely in the wind like a weathervane (see Fig. 8). The ability to use it is one of the advantages of a downwind turbine. In Japan in particular, it is also a useful technique for reducing the load on the turbine during strong winds. The 2-MW downwind turbine uses free yaw control when idling in strong wind conditions.

Fig. 9 shows simulation results produced using the GH Bladed* aero-elastic simulation software for wind power systems(7). The simulation calculates the nacelle orientation over a 300-s time period during which the wind speed fluctuates about an average of 50 m/s and the wind direction changes from 0° to 90°. This confirms that use of free yaw control allows the nacelle to keep up with the changes in wind direction.

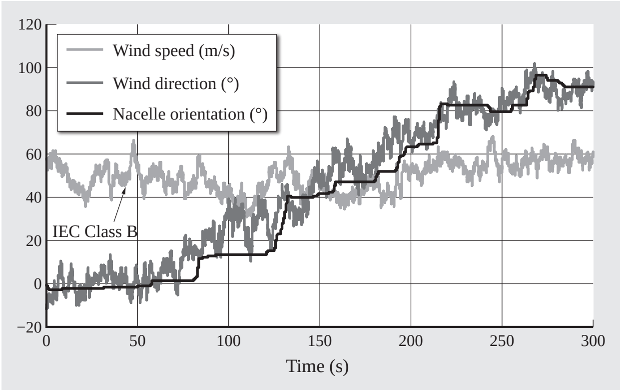


Fig. 9—Wind Speed and Direction and Nacelle Orientation (Free Yaw).
Use of free yaw control allows the nacelle to follow changes in wind direction.

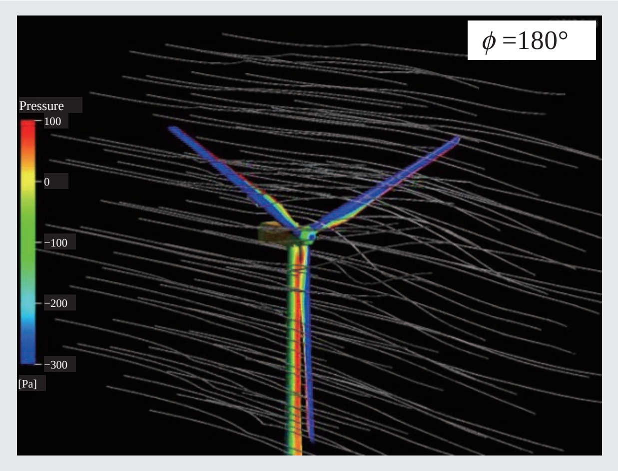


Fig. 10—CFD Analysis of Blade Passing through Tower Wake.
This simulation result shows a CFD analysis used during development that considers the aerodynamic interference that the blade imposes on the tower shadow.

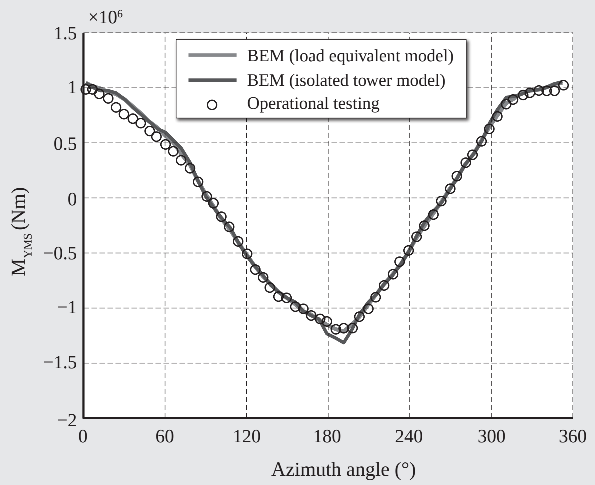
Tower Shadow Model

Because the rotor on a downwind turbine rotates on the downwind side of the tower, the blades pass through the wake of the tower once every revolution. The resulting aerodynamic interference between the tower wake and rotor is called the "tower shadow effect." As the tower shadow influences fatigue damage on a downwind turbine, an accurate calculation is required. However, the previous tower shadow model was based on the profile of the wake of an isolated tower, modeled by CFD and wind-tunnel tests, using this result as the air flow through which the rotor passed. What it didn't do was consider the aerodynamic interaction between the tower and the blades.

Accordingly, when developing the 2-MW downwind turbine, a simulation that combined CFD with blade element and momentum theory (BEM) was used to devise a load equivalent model that took account of this interference (see Fig. 10). The validity of the model was verified by comparing the amount of bending of the main rotor shaft during operational tests (see Fig. 11). It was also found that the previous isolated tower model had overestimated the tower shadow, so it was possible to develop the 2-MW downwind turbine with an acceptable level of load[(8), (9)].

CONCLUSIONS

This article has described the specifications and technical characteristics of the 2-MW downwind wind power generation system, which is able to cope with difficult conditions such as typhoons or complex terrain.



BEM: blade element and momentum theory
Azimuth angle: angular position of rotor blade

Fig. 11—Bending of Main Shaft Relative to Azimuth Angle (Wind Speed: 13 m/s).
The validity of the load equivalent model was verified by a comparison of main rotor shaft bending during operational testing.

The merger of wind power generation system businesses has facilitated the integration of the downwind turbine technology with Hitachi's existing technologies for power control, grid connection, and power system stabilization. In the future, Hitachi intends to continue to work toward the supply of total solutions that extend from generation to systems for the supply of stable electric power.

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