

## Development of 2-MW Downwind Turbine Tailored to Japanese Conditions

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*OVERVIEW: Wind turbine systems play a key role in reducing use of fossil fuels and the emission of greenhouse gasses such as carbon dioxide. Turbines used in wind farms for commercial production of electric power need higher reliability, enhanced efficiency, and cost effectiveness. Especially in Japan, there is a surge in demand for systems that can tolerate storm loads, are protected against lightning, do not cause logistical problems, and can produce a stable electricity output. Hitachi and Fuji Heavy Industries Ltd. have developed a 2-MW downwind turbine tailored to Japanese conditions. The first model for commercial production of electric power has successfully been built at Hitachi Chemical Co., Ltd. Kashima Works, about 100 km east of Tokyo, and successfully operated by Wind Power Ibaraki Ltd. The operation has met the design specifications.*

### INTRODUCTION

THE characteristics required of wind turbines include greater capacity, better reliability, greater efficiency, quick installation, and lower maintenance costs. Demand for wind turbine generation systems

is growing strongly because they help reduce carbon dioxide emissions and prevent the greenhouse effect.

Hitachi and Fuji Heavy Industries Ltd. have developed a 2-MW downwind turbine called the “SUBARU 80/2.0.” This pitch-regulated

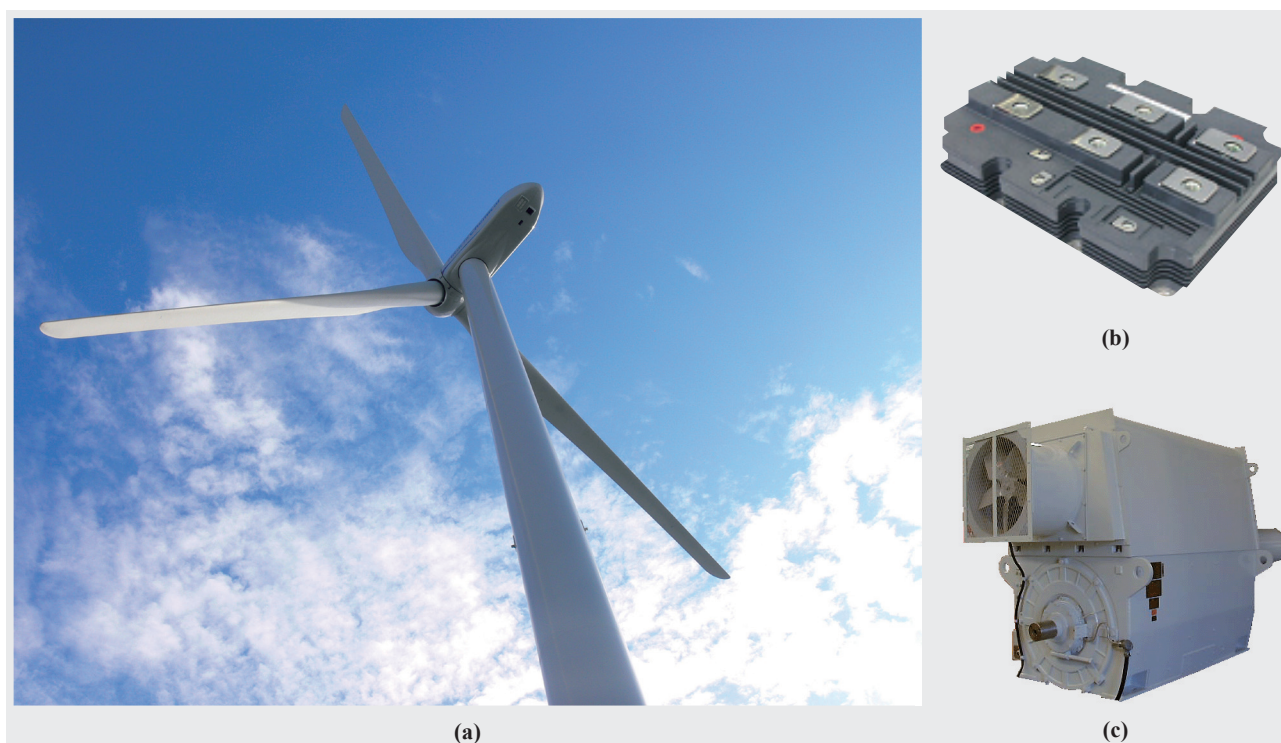


Fig. 1—First SUBARU 80/2.0 2-MW Downwind Turbine to Commence Commercial Production of Electric Power (a), IGBT (b), and Generator (c).

The Hitachi Chemical Co., Ltd. Wind Power Station operated by Wind Power Ibaraki Ltd. (a), an IGBT (insulated gate bipolar transistor) module (b) and a 2,000-kW doubly fed generator (c) are shown.

downwind turbine has active yaw control, a three-blade rotor, gearbox, doubly fed generator, and power conditioning system (see Fig. 1). The 80-m rotor diameter makes possible a high level of efficiency. The nacelle is located at the top of a 60-m or 80-m high tower. The design specifications for the downwind turbine were set at a higher level than required by IEC (International Electrotechnical Commission) regulations. The resulting characteristics (described below) mean the turbine can be constructed and operated under typical Japanese conditions.

- (1) Downwind rotor with increased output and stability
- (2) Heavy-duty system that satisfies IEC Wind Class 1
- (3) Protection against severe positive lightning (95% coverage)
- (4) Active power control simplifies connection to the grid.
- (5) Easy component transportation through use of a modular nacelle
- (6) Light nacelle and easy maintenance

## HISTORY OF 2-MW DOWNWIND TURBINE

Hitachi and Fuji Heavy Industries started testing a prototype of the 2-MW downwind turbine system at a demonstration site in 2005. The site at the tip of the Inubo Peninsula faces east toward the Pacific Ocean and is about 100 km east of Tokyo. Subsequent testing used a commercial model.

In 2008, the first 2-MW downwind turbine to be used for commercial production of electric power was delivered to Hitachi Chemical Co., Ltd. Kashima Works. The turbine is sited about 3 km west of the prototype and is operated by Wind Power Ibaraki Ltd.

Both turbines have supplied electric power to a utility company during the one to four years since their delivery.

## PERFORMANCE AND EQUIPMENT COMPOSITION

### Wind Turbine System

The 2-MW downwind turbine is an HAWT (horizontal-axis wind turbine) with the specifications shown in Table 1. It includes the following components.

#### Downwind rotor

The 2-MW downwind turbine uses a downwind rotor which means that the turbine is positioned downwind of the tower (see Fig. 2). A downwind

TABLE 1. 2-MW Downwind Turbine Specifications  
*With a blade tip height of 120 m, the commercially produced model will be one of the largest wind turbines in Japan.*

Category	Item	Specification
Turbine	Diameter	80 m
	Hub height	80 m
	Rated output	2,000 kW
	Cut-in	4 m/s
	Cut-out	25 m/s
Generator	Type	Doubly-fed
	No. of poles	4
	Frequency	50 Hz or 60 Hz
System	Speed control	Variable velocity
	Output control	Pitch control
	Emergency brake	Pitch control
	Yaw control	Active yaw
Lightning	Protection level	250 kA

turbine configuration has the following advantages because the wind force keeps the turbine in line with the wind direction behind the tower.

- (1) The blades do not need to be rigid because a rotor can never hit the tower.
- (2) The nacelle naturally aligns itself with the wind direction even during black-out conditions.

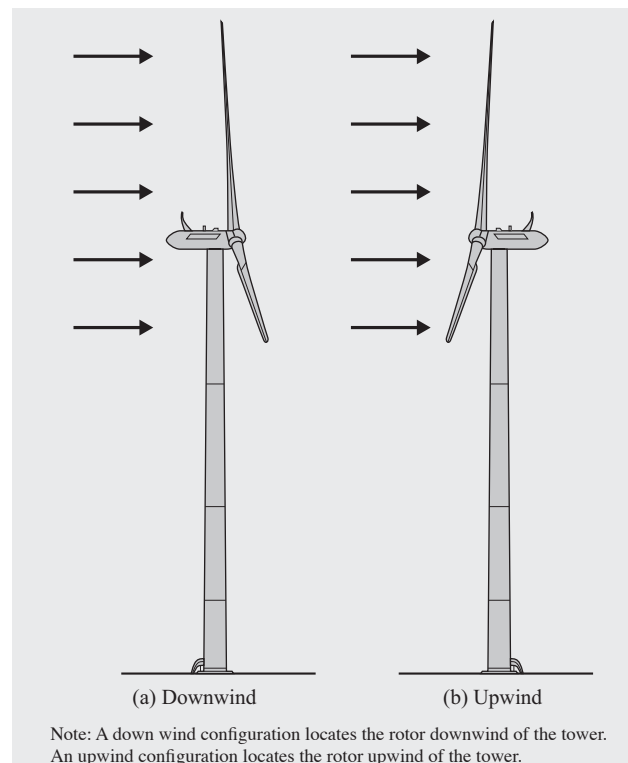


Fig. 2—Comparison between Downwind and Upwind Configurations.

*The 2-MW downwind turbine takes advantage of its downwind configuration to obtain high efficiency and stable output.*

(3) The rotor orientation aligns with updrafts and this provides high efficiency.

However, a downwind turbine configuration also has the following concerns due to the turbulence produced by the tower.

(1) The tower wake may cause cycle-fatigue in the blades.

(2) Interference between blade and tower may produce low-frequency noise.

Accordingly, use of a downwind turbine configuration requires special design considerations to ensure best use is made of the advantages while also dealing with the concerns.

An advanced aerodynamic design is used to address these issues of blade fatigue and noise caused by the tower wake. Field testing was conducted to demonstrate that the blade can successfully avoid the tower wake. The distance between the blade and tower provides a significant reduction in the overall cycle fatigue behavior of the blades. Fig. 3 shows a three-dimensional analysis used to determine the stress on the blade at a distance from the tower of three times the tower diameter. Although the results show a significant amount of stress, the level is within the design requirements. The testing demonstrated that the turbine successfully met all the environmental and stress requirements.

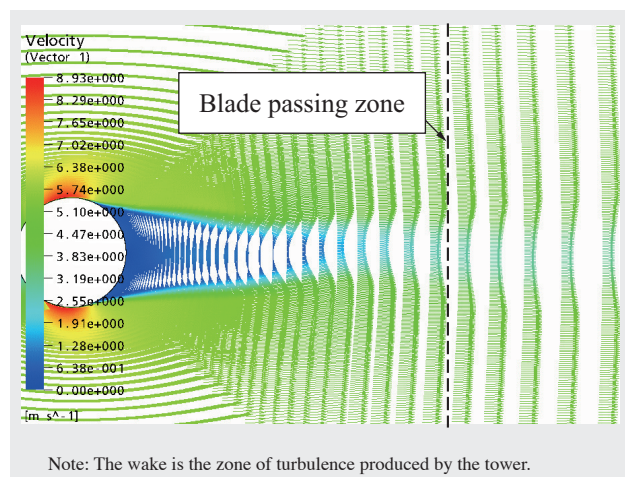


Fig. 3—Tower Wake Analysis <sup>(1)</sup>.

The 2-MW downwind turbine has enough distance between tower and blade to avoid the tower wake.

#### Hub and blade structure

The hub is mounted on the gearbox and connected by the main shaft which transmits the wind power to the generator. The rotor has an independent pitch control system which uses electrical actuators to keep

the blade at the optimum pitch angle.

The blades are made of GFRP (glass fiber reinforced epoxy resin). Two GFRP ribs are encased in two shells. The blades are designed to minimize mechanical losses.

#### Nacelle

The nacelle (see Fig. 4) contains the main shaft, gearbox, generator, and associated components. The nacelle bedplate has a girder structure. The gearbox is attached to the bedplate and transmits the torque from the main shaft to the generator. A roller bearing is used for the yaw system together with electrical actuators and a hydraulic brake system. The step-up transformer and power conditioning system are not located in the nacelle. This was done to keep the nacelle weight down and to make these components more easily accessible for maintenance.



Fig. 4—Nacelle of 2-MW Downwind Turbine.

The nacelle is designed for light weight and with a streamlined shape to avoid disruption to the wind flow. The wind blows from right to left in the above figure.

#### Tower structure

The conical tubular-steel tower is made up of four segments to make transportation easier. A door near ground level permits access to the internal components and the nacelle is accessed via ladders or a service lift. The power conditioning system is mounted in the tower base. Bus bars are used to carry the power from the generator in the nacelle to the bottom of the tower. Optical glass fiber cables are used for all control signals to avoid any problems with electromagnetic interference.

#### Electrical system

An asynchronous 4-pole air-cooled doubly-fed generator with a wound rotor and wound stator







Fig. 6—Blade Being Attached to Hub at Top of Tower. Assembling the rotor in the air one blade at a time saves on ground space.

### PREDICTION OF DOWNWIND EFFECTS

Complex terrain like that often found on mountainsides in Japan is considered unattractive for wind development and is often excluded when selecting wind turbine installation sites. Complex terrain can cause the wind-flow to be concentrated resulting in updrafts and high wind speeds.

Mountain slopes and ridgelines often act to concentrate the wind flow resulting in updrafts and high wind speeds (see Fig. 7). An upwind turbine with a tilted rotor does not take full advantage of this effect due to misalignment with the wind direction. For downwind turbines, however, this misalignment is smaller and more power can be obtained. Downwind turbines are considered to be the best choice for large wind turbines located on mountainsides.

Because the 2-MW downwind turbine is located on flat terrain and therefore is not subject to updrafts, it was decided that an analysis method should be developed. A number of different approaches were considered and the following formula<sup>(4)</sup> chosen as being the most accurate.

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

Here,  $P$  is output power,  $P_{rate}$  is rated power,  $P_0$  is power from the power curve,  $\gamma$  is wind inclination and  $\alpha$  is the tilt angle of the main shaft (8 degrees for the 2-MW downwind turbine).

For an updraft inclination of +6.0 degrees, a downwind turbine can be expected to produce 7.6% more power than an upwind turbine.

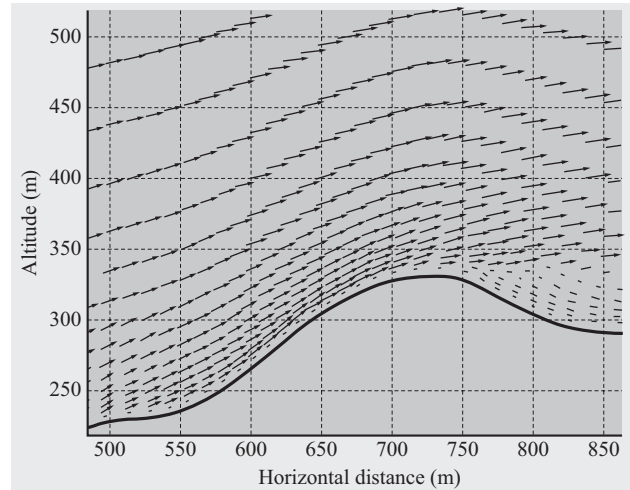


Fig. 7—Airflow over Mountain Slope<sup>(4)</sup>.

A mountain slope or ridgeline often acts to concentrate the wind resulting in an updraft and higher wind speed.

### CONCLUSIONS

This article has described the development of a 2-MW downwind turbine system for the commercial production of electric power. The experience gained during the analysis, construction, and commercial operation phases has proved valuable for future designs. Whereas mountainous areas with complex terrain like those found on mountainsides in Japan used to be overlooked and considered unattractive for wind development in the past, this development has solved some of the problems associated with installing wind turbines in mountainous areas. Hitachi and Fuji Heavy Industries Ltd. are aiming to make further improvements in the quality, reliability, and safety of the 2-MW downwind turbine system to encourage the growth of the Japanese wind energy business.

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