Large Wind Turbine System and Smart Grid

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OVERVIEW: Demand for renewable energy is growing as a way to help improve the global environment. Significant numbers of large wind turbine systems are being installed, mainly in Europe, the USA, and China, and this trend is expected to continue. A large 2-MW downwind turbine system jointly developed by Hitachi and Fuji Heavy Industries Ltd. commenced operation at two sites in Japan during 2010 and 2011. Since the generator controller employs technology for minimizing output fluctuations, a feature of the wind turbine system is that it contributes to grid stabilization even as use of wind power generation rises as a proportion of total grid capacity. Hitachi supplies total solutions regarding to not only generation systems themselves but also total grid systems for next-generation power systems able to cope with increasing use of renewable energy.

INTRODUCTION

DEMAND for use of renewable energy sources such as wind, photovoltaic, and hydro power is growing because of their role in improving the global environment. Wind power generation, in particular, is recognized for emitting less CO_2 (carbon dioxide) than other types of electric power generation during construction, operation, and maintenance, as well as emissions associated with the extraction, transport, and refining of fuel. The amount of wind power generation capacity being installed is growing, primarily in Europe, the USA, and China. According to the Global Wind Report 2010 published by the Global Wind Energy Council (GWEC), global installed wind power capacity increased by 24% during 2010, and the cumulative installed wind power capacity reached 197,039 MW.

Meanwhile, a scenario published by the European Renewable Energy Council (EREC) in May 2011 set targets of having renewable energy supply 20% of end-user power consumption in the European Union (EU) region by 2020 and 45% by 2030. For these reasons, it seems likely that use of wind power will continue to grow.

This article describes the specifications of Hitachi's large wind turbine system, examples of its use, what the company is doing in preparation for the future widespread adoption of wind power, and its deployment as part of a smart grid.

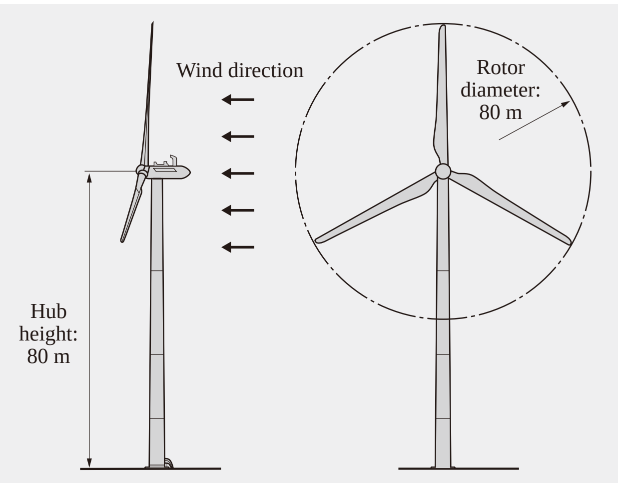

Fig. 1—Large Wind Turbine System.
The wind turbine rotor is located on the downwind side. Both the rotor diameter and hub height are 80 m.

LARGE WIND TURBINE SYSTEM

System Features

Fig. 1 shows the SUBARU 80/2.0, a large 2-MW downwind turbine system jointly developed by Hitachi and Fuji Heavy Industries Ltd. Table 1 lists the key specifications[(1), (2)].

Although most large wind turbines use an upwind configuration with the rotor on the windward side of the tower, the SUBARU 80/2.0 uses a downwind design in which the rotor is on the downstream side. This configuration provides the safer and stronger system that lightens the load on key mechanisms caused by gusts during typhoons and other storms. It is also expected to improve output of wind turbines sited on mountainous or steep terrain.

Because the generator is totally enclosed and its windings are not cooled by ambient air directly, it is particularly suited to coastlines where the wind carries a high proportion of salt.

TABLE 1. Key Specifications of Large Wind Turbine System
The generator is a four-pole air-cooled model with windings on both the rotor and stator, and the power conditioner controls the rotor magnetic field.

Category	Item	Specification
Basic	Rotor diameter	80 m
	Hub height	80 m/60 m
	Rated output	2,000 kW
	Rated wind speed	13 m/s
	Cut-in	4 m/s
	Cut-out	25 m/s
Generator	Type	Doubly-fed
	No. of poles	4
	Frequency	50 Hz/60 Hz

Fig. 2—Wind Power Kamisu Offshore Wind Farm.
This offshore wind farm was constructed 50 m off the shoreline in the Kashima Harbor district of Kamisu City in Ibaraki Prefecture. (Photograph courtesy of Wind Power Ibaraki, Co., Ltd.)

Example Installations

The following sections give an overview of the Wind Power Kamisu Offshore Wind Farm and Omaezaki Wind Power Station, both of which have commenced commercial operation.

(1) Wind Power Kamisu Offshore Wind Farm

Constructed in Kashima Harbor off Minamihama in Kamisu City, Ibaraki Prefecture, this is the first open sea full-scale offshore wind farm in Japan (see Fig. 2). It was built and is operated by Wind Power Ibaraki, Co., Ltd. The offshore wind turbines are built on mono-pile foundations (length: 24.5 m, design water depth: -5 m). The turbines entered service on July 1, 2010.

Although subjected to significant vibration and impacted by the tsunami during the Great East Japan Earthquake on March 11, 2011, a full inspection found no serious damage to the power generation equipment. All turbines were back in normal operation three days after the earthquake and working without problems since then[3].

Fig. 3—Omaezaki Wind Power Station (Chubu Electric Power Co., Inc.).
The 11 turbines are spread along approximately 10 km of coastline facing the Enshu Sea at Omaezaki City in Shizuoka Prefecture, Japan.

Fig. 4—Installation Work.
Hitachi constructed the Omaezaki Wind Power Station under a full turnkey contract.

(2) Omaezaki Wind Power Station

This wind farm was constructed and is operated by the Chubu Electric Power Co., Inc. Located on the coastline facing the Enshu Sea at Omaezaki City in Shizuoka Prefecture, Japan, the wind farm consists of 11 turbines spread along approximately 10 km to the east and west of the Hamaoka Nuclear Power Station. All turbines entered commercial operation on January 28, 2011 (see Fig. 3).

Hitachi was awarded a full turnkey contract for the construction of the wind farm, and was responsible for everything from transport and foundation work to commissioning (see Fig. 4).

MITIGATING FLUCTUATING OUTPUT OF WIND POWER SYSTEMS

It is known that the wind speed often varies with both short periods of one to two minutes and long periods of 12 to 15 hours or even 100 hours. These cause corresponding fluctuations in the output of the wind power system.

There are concerns that, if the installed capacity of wind turbine systems increases in the future, fluctuations in generation output may lead to instabilities in grid voltage and frequency. The following section describes what can be done in the wind turbine system itself to mitigate these output fluctuations.

Use of Active-power-based Control to Minimize Short-term Output Fluctuations

A wind turbine system works by using the wind energy generated by the blades to drive the rotor in the generator which then transforms this rotational energy into electric power. Accordingly, changes in wind speed cause the speed of the generator rotor to vary. Because the generated electric power is proportional to the product of the torque and rotor speed, use of conventional torque control tends to result in a fluctuating output of generated electric power as changes in wind speed cause changes in rotor speed. If such a system were connected to the grid, the problem is that short-term fluctuations cause voltage fluctuations such as flicker.

The control technique used on the large wind turbine system described above is active-power-based control which works by controlling the active power (generated power)[(2), (4)]. This technique measures the active power of the system which consists of the grid-side converter and generator stator and performs the fast response control of the electric power converter to keep the measured active power equal to the active power command calculated from the wind speed (see Fig. 5).

Changes in the input wind energy due to the varying wind speed are absorbed into (or released from) the rotational energy in the blade, gear, and rotor to generate the steady level of electric power output specified by a command. Fig. 6 shows actual data from a wind turbine system that uses this control technique. The generation output is maintained despite sudden changes in wind speed by varying the rotor speed. The result is a “grid-friendly wind power system” that minimizes the disturbance of the grid power system.

Other Methods for Minimizing Output Fluctuation

Other measures that could be implemented at the wind turbine system that are under consideration include installing batteries alongside a wind turbine to buffer changes in its output[(5)] and techniques for smoothing the output of an entire wind farm by combining control of individual generator output with coordinated control of multiple wind turbines[(6)].

Furthermore, the smoothing effect of having a lot of wind generators spread over a wide area minimizes the short-term fluctuations in generated electric power from the perspective of the overall grid. This happens because the short-term fluctuations at each turbine tend to occur independently of each other, being caused by unsteady wind speeds due to the terrain and other local factors. On the other hand,

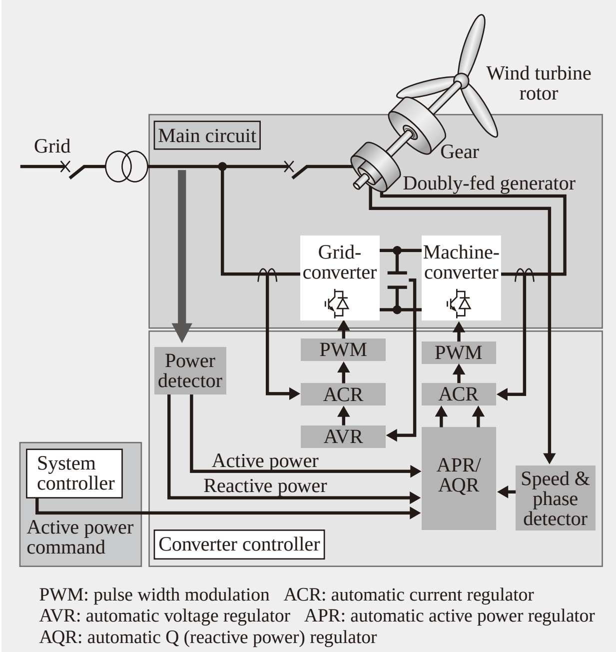

Fig. 5—Configuration of Power Conditioning System.
The generator (rotor) current is controlled so that the system active power measured in the main circuit is kept equal to the active power command from the wind turbine controller.

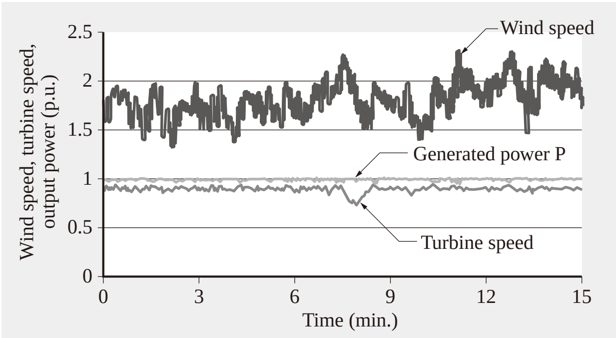

Fig. 6—Effect of Active-power-based Control.
The system is able to draw down the energy in the rotating parts to keep the generated power (P) constant when there is a drop in wind speed.

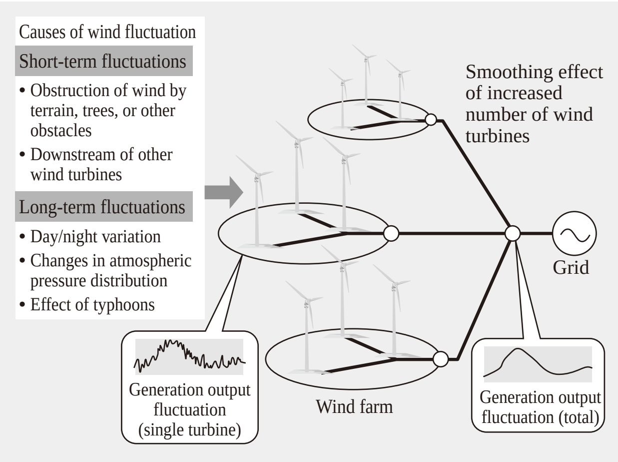

Fig. 7—Smoothing Effect on Generated Power across Wind Farms.
Short-term fluctuations in generation output due to changes in wind conditions are averaged out as the number of wind turbines increases.

long-term fluctuations resulting from changes in weather conditions or hours of daylight are strongly correlated between sites and therefore are much harder to smooth(7) (see Fig. 7).

SMART GRID

The Japanese Prime Minister at the time, Naoto Kan, announced at the Group of Eight (G8) summit held in May 2011 that renewable energy would exceed 20% of national electric power generation as early as possible in the 2020s. The next generation of electric power systems (smart grids) face the challenge of balancing a more variable supply environment due to the greater use of renewable energy sources, with demand environments characterized by more complex loads (see Fig. 8).

As can be seen in Fig. 8, the increase in the connection of large-scale power plants driven by new energy sources such as wind or photovoltaic powers will take place in sub-transmission systems. The short-term fluctuations (several tens of seconds to several minutes) in the level of power generated by these new energy sources can be smoothed by the methods described before and also compensated for by using governor-free operation at thermal power plants. For long-term fluctuations, on the other hand, the effective way of smoothing is to use electric power storage in the form of pumped storage hydro or large-capacity batteries.

Like large-capacity batteries, adjustable-speed pumped storage hydros are able to buffer electric power over a wide range of time periods (from less than one second to many hours) and this means that, compared to other pumped storage hydro systems, they make a strong contribution to the capability of the overall grid to balance supply and demand(8). As the proportion of capacity supplied from renewable energy source increases, measures that will be important in the future include the conversion of existing pumped storage hydro power plants to adjustable speed operation or increasing the ability of pumped storage hydro systems to minimize fluctuations in ways that can be combined effectively with use of new energy sources.

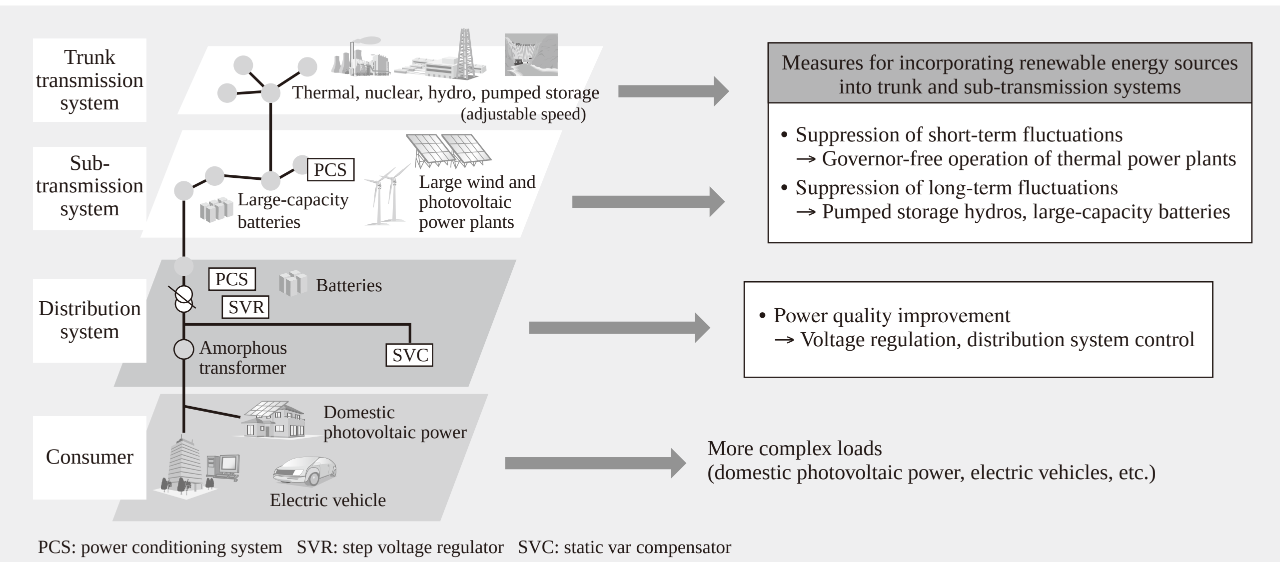

Fig. 8—Next-generation Power System (Smart Grid).
For environmental reasons, renewable energy is expected to provide a greater proportion of electric power generation. Measures are required at each level of the power system.

Furthermore, the use of large-capacity batteries to store electrical energy will require ways of planning battery operation based on wind climate prediction and demand forecasting in order to minimize the battery capacity required. Hitachi is continuing to work on the development of technologies such as electric power storages for grid stabilization and generation planning for renewable energy sources[6].

CONCLUSIONS

This article described the specifications of Hitachi's large wind turbine system, examples of its use, what the company is doing in preparation for the future widespread adoption of wind power, and its deployment as part of a smart grid.

Hitachi supplies total solutions that extend from generation to reliable electric power supply systems and is contributing to the creation of a new generation of electric power systems which will incorporate large quantities of renewable energy generations.

REFERENCES

(1) T. Nagao, "Development of Large 2-MW SUBARU 80/2.0 Wind Turbine," Journal of Japan Wind Energy Association **30**, No. 1, pp. 19–23 (2006) in Japanese.

(2) T. Matsunobu et al., "Development of 2-MW Downwind Turbine Tailored to Japanese Conditions," Hitachi Review **58**, pp. 213–218 (Oct. 2009).

(3) Y. Ueda et al., "Great East Japan Earthquake and Wind Power Generator Information, Parts 1 to 3," Journal of Japan Wind Energy Association **35**, No. 1, pp. 4–7 (2011) in Japanese.

(4) M. Ichinose et al., "Power Electronics Products for Renewable Energy," Hitachi Hyoron **90**, pp. 1,000–1,005 (Dec. 2008) in Japanese.

(5) K. Gomi et al., "System Stabilization Technology through Power Storage Approach for Power Network with Renewable Energies," Hitachi Hyoron **92**, pp. 234–237 (Mar. 2010) in Japanese.

(6) K. Imaie et al., "Power Stabilization Technologies for Next-generation Transmission and Distribution Networks," Hitachi Review **59**, pp. 106–110 (Aug. 2010).

(7) T. Nanahara, "Wind Power Output Fluctuation and its Effect on the Grid," Journal of Japan Wind Energy Association **29**, No. 4, pp. 76–82 (2005) in Japanese.

(8) O. Nagura et al., "Hitachi's Adjustable-speed Pumped-storage System Contributing to Prevention of Global Warming," Hitachi Review **59**, pp. 99–105 (Aug. 2010).

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