Development of Next Generation 2MW Class Large Wind Turbines

YOSHINORI UEDA*1
MASAAKI SHIBATA*2

Wind power generation has come to be used widely in the world as a key role for preventing global warming. Accordingly, the wind turbines are getting larger rapidly and higher in performance. Mitsubishi Heavy Industries, Ltd. (MHI) is also developing a new type high-performance wind turbine MWT92/2.4. Its rated output is 2400 kW and diameter is 92 m. The new first turbine is expected to start in operation next year in Yokohama. Described below is the new technology applied for MWT92/2.4. The main purpose is to reduce the load exerted on the wind turbine.

1. Introduction

Wind power generation is drawing attention as a key role to prevent global warming. The wind power in the world reached to 40.3 GW at the end of 2003 (**Fig. 1**). And wind power in Japan reached to 730 MW with about 800 units (**Fig. 2**).

With the increase of wind power, the wind turbines get larger rapidly mainly in Europe to reduce construction costs (**Fig. 3**). The rated output increased to double in about 4 years during these ten years. This shows a rapid increase of several times in terms of the conventional thermal power generation. The introduction of 2 MW-class wind turbines started in Japan in March 2003, and 15 units of them are already in operation (**Table 1**).

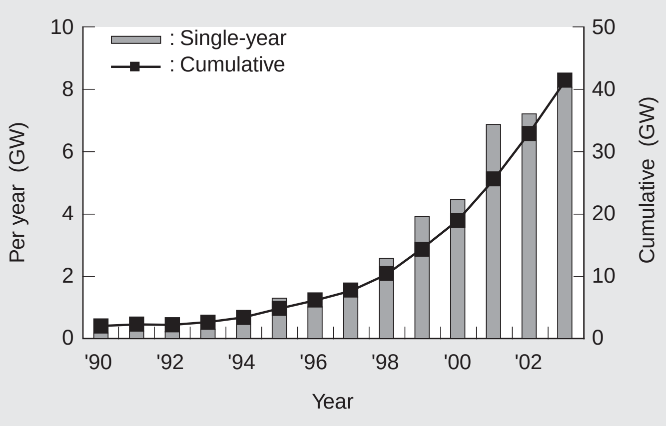

Fig. 1 Installed wind power in the world

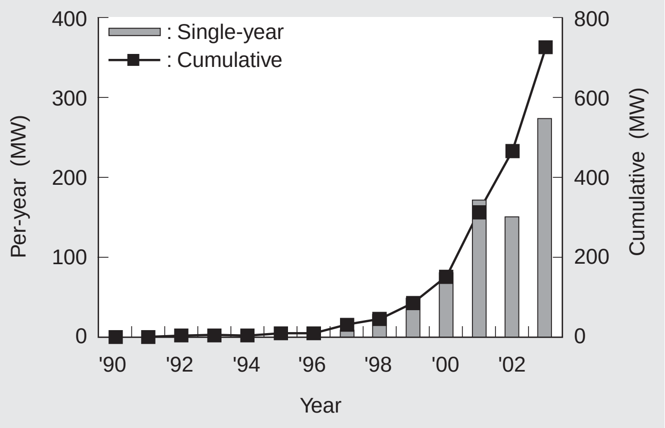

Fig. 2 Installed wind power in Japan

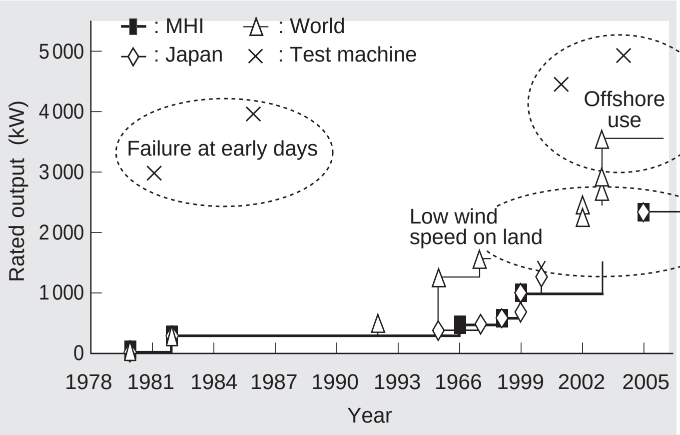

Fig. 3 Transition of wind turbine becoming larger in size

Table 1 2 MW-class wind turbines in Japan

Start of operation	Rated output (kW)	Unit number	Place of installation
2003/3	1 950	1	Gushikawa-city, Okinawa
2003/3	1 900	1	Ryuyo-cho, Shizuoka
2004/1	2 000	8	Sakata-city, Yamagata
2004/3	1 980	1	Chinzei-cho, Saga
2004/3	1 980	1	Tahara-machi, Aichi
2004/3	2 000	1	Nandan-cho, Hyogo
2004/3	1 950	1	Koto-ku, Tokyo
2004/3	1 950	1	Omaezaki-cho, Shizuoka
2005/4	2 000	(10)	Misato-city, Mie
2005	2 400	(1)	Yokohama-city, Kanagawa

( ) The items in parentheses are under construction.

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*1 Power Systems Headquarters
*2 Nagasaki Shipyard & Machinery Works

There are two ways for wind turbines to become larger: (1) Super-large 5 MW-class wind turbine for offshore wind power generation with good wind conditions. The machine size is not restricted by transportation and installation. (2) High-performance 2–3 MW-class wind turbine for on-land low wind speed regions. (IEC Class II, average wind speed of 8.5 m/s)

The main markets of Mitsubishi wind turbines are USA and Japan. Unfortunately, the demand for offshore wind power generation is low in USA and Japan. Then, MHI has set developing target to the high-performance wind turbine for low wind speed areas. This type of turbine features in large rotor diameter as compared with rated output.

Fig.4 shows the background of Mitsubishi wind turbines in terms of size.

2. Problems in enlargement wind turbine

2.1 Basic principle

The wind energy is directly proportional to the cubed wind speed and the rotor swept area.

$$P=\frac{1}{2}mV^2=\frac{1}{2}(\rho AV)V^2=\frac{1}{2}\rho AV^3$$

where,

P: Wind power energy (W)

ρ : Air density (1.225 kg/m^3)

A: Rotor swept area (m^2)

V: Wind speed (m/s)

Hence, supposing the wind turbine efficiency to be conventional 43% and wind speed at rated output to be 11–12 m/s, the relationship between the turbine rated output and rotor diameter (Fig. 4) will become as follows:

Rated output (kW)   0.3 × (Rotor diameter m)^2

The wind turbine for offshore use falls in the category of higher output (top) above the parabola expressed by broken lines, while the wind turbine for low wind speed region in the category of larger rotor diameter (at the right of the parabola).

2.2 Handicap of wind power

(1) Low energy density

The generated power is approximately 0.3 kW/m^2 at usual wind speed of 8 m/s (cf. solar power generation: approximately 1 kW/m^2).

(2) There is a theoretical upper limit called Betz's limit in power production efficiency (16/27 = 59%). Therefore practical efficiency is approximately to 43% even in the case of the latest model wind turbine. This is a characteristic of a wind turbine, a turbo machine without casing. A turbine generates energy by reducing the speed of the wind that blows in. However, if the deceleration is increased, the wind tries to avoid blowing into the turbine, causing the wind flow to get decreased, thus creating an upper limit to the efficiency.

(3) It is difficult to design the wind turbine strength. Typhoon load is several hundred times larger than the normal use. (normal wind speed: 6–9 m/s, instantaneous wind speed at the time of typhoon: 60 m/s(7); and the wind load is proportional to the square of wind speed)

2.3 Difficulties in wind turbine enlargement

As can be deduced from the aforesaid limitations, the wind turbine mandatorily becomes larger in size against the rated output than the power generating machines like thermal power generation and diesel power generation, etc. Further, since the energy density cannot be condensed, there is simply no other way than to increase the rotor diameter in order to get larger output. Here, the following problems arise when a proportionate extrapolation design is carried out.

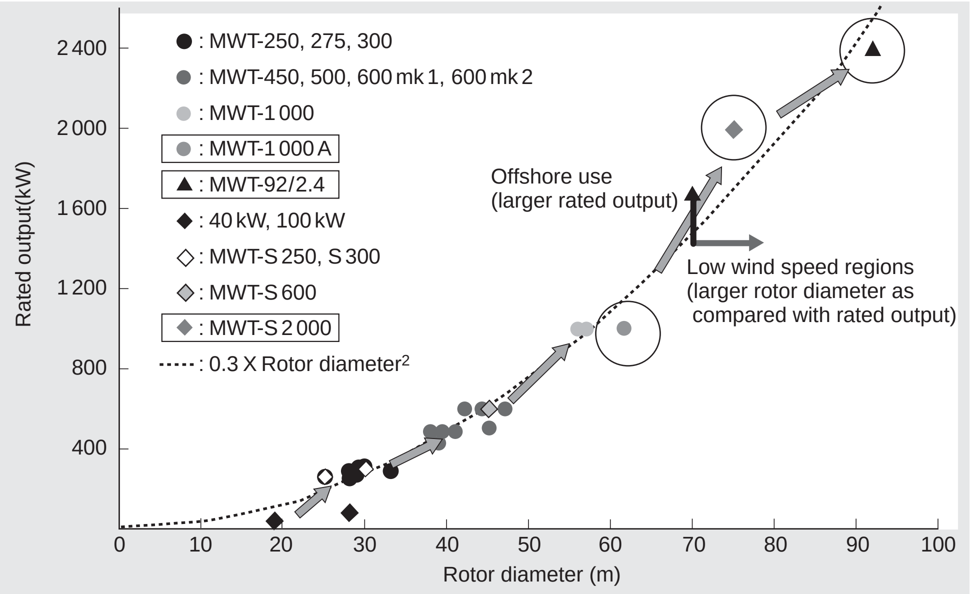

Fig. 4 Trends of Mitsubishi wind turbines

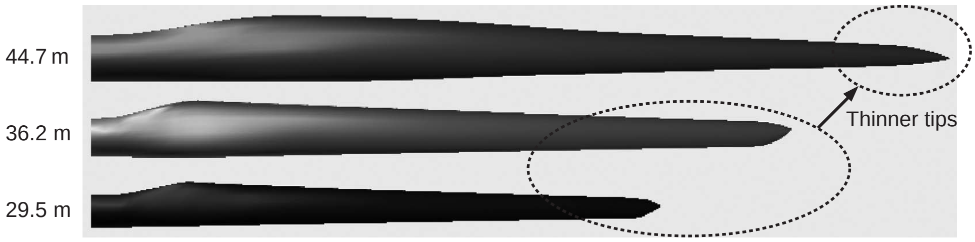

Fig. 5 Adoption of slim blade

(1) Output $\propto$ Rotor area $\propto$ (Blade length)^2 $\propto$ (Size)^2

(2) Strength $\propto$ (Load/Sectional area)$^{-1}$ $\propto$ (Size)$^{-1}$ $\propto$ (Output)$^{-0.5}$

Wind turbine blade tip speed has upper limit (approximately 60 m/s at wind speed 8 m/s) because the sound from blade tip is very keen to velocity. So rotating speed has to be restrained when the rotor diameter becomes large. This leads to the increase of torque, inflicting effect on the design of main shaft and multiplying gear.

(3) Main shaft torque $\propto$ Output/Rotor revolution $\propto$ (Output)$^{1.5}$

(4) Price $\propto$ Wind turbine weight $\propto$ (Size)^3 $\propto$ (Output)$^{1.5}$

This suggests that if the output is doubled, the main shaft torque becomes 2.8 times larger, the strength 0.7 times larger and the price 2.8 times higher (1.4 times higher in terms of kW unit price). The following two methods can be counted as effective countermeasures to these difficulties.

- Improvement in specific strength of machine components
- Reduction of aerodynamic load exerted on wind turbine

In order to improve the blade specific strength, the internal structure, the blade root bonding method and the material strength were improved, the outline of which was based on the "Development and Operational Records of New Mitsubishi Wind Turbines (MWT-1000A and MWT-S2000)(1)."

3. Technologies for reducing aerodynamic load

The technologies explained below were applied for reducing the aerodynamic load in MWT92/2.4.

(1) Slim blade

In order to prevent the increase of thrust power caused by enlarged rotor diameter (long blade), the blades with slimmer tips (**Fig. 5**) were applied. In other words, the moment acting on the main shaft was effectively restrained by reducing the load at the blade tip as cantilever beam.

(2) Variable-speed operation

The short-cycle variation of wind was absorbed and leveled by controlling the rotor revolution through variable- speed operation of the wind turbine in order to reduce the fatigue load. This technology's effectiveness is proved from the experience of the variable-speed gearless synchronous wind turbines.

(3) Independent blade pitch control

Because of the ground surface friction, the wind speed has altitudinal distribution (wind shear), so that the wind turbine experiences fatigue load at every rotation. The blade pitch angle was slightly corrected so as to nullify the load variation in order to reduce the fatigue load (**Fig. 6**). Research is underway on precise load control by installing a stress sensor to the blade.

(4) Active vibration damping of tower

Based on the data from the sensor installed at the top of the tower, the blade pitch angle was slightly adjusted so as to nullify the tower displacement in order to reduce the load toward main wind acting on the wind turbine. **Fig. 7** shows the confirmed operation result of MHI 1000 kW wind turbine installed in Seto-cho, Ehime.

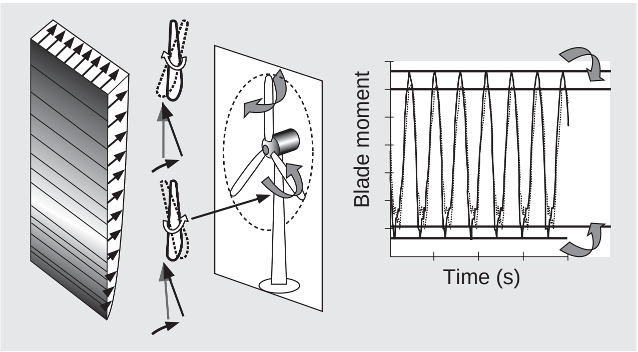

Fig. 6 Independent blade pitch control

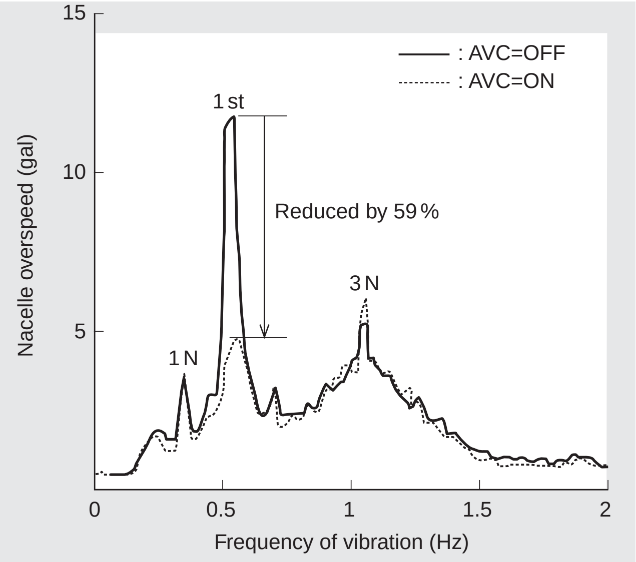

Fig. 7 Effect of active vibration damping of tower

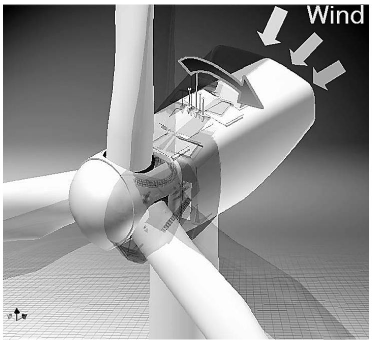

Fig. 8 Conceptional diagram of Smart Yaw at work

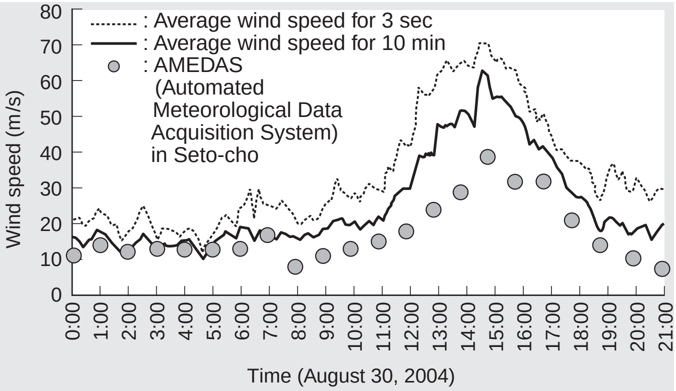

Fig.9 Wind speed trends during Typhoon Chaba (No.16) at Seto Wind Hill

(5) Smart Yaw system against typhoon (Down Wind Safety Concept)

The collapse of wind turbine in Miyakojima caused by Typhoon Maemi (No. 14) in 2003 has drawn attention to the countermeasure against gust at power failure(7). Smart Yaw system is a new technique ensuring wind turbine yaw control even during power interruption. The system carries out yaw control using the wind vane effect by changing the turbine stand-by position to downwind direction (**Fig.8**). Here, since the wind load acting on the rotor is used for driving the yaw, it is effective even at power failure. For details, refer to "New Products and Technologies of Mitsubishi Wind Turbines(2)." In spite of the Class II design, Mitsubishi 1 000 kW wind turbine MWT-1000A adopting the Smart Yaw system withstood the gust exceeding the maximum instantaneous wind speed of 70 m/s (measured by nacelle anemometer: **Fig. 9**) when Typhoon Chaba (No. 16) and Songda (No. 18) directly hit Seto-cho, Ehime on August 30 and September 7, 2004, respectively proving the efficacy of the system.

4. Conclusion

With the wind turbines becoming larger and larger rapidly, the wind turbine manufacturers are earnestly engaged in the development of new-type large wind turbines. Furthermore, the wind turbines are considered to be divided in two types in the future; i.e., wind turbines for on land and offshore use.

As for the wind turbines for on land use, the rated output of 2–3 MW and the rotor diameter of approximately 90 m are considered to be the upper limit for the time being because of following two restrictions; (1) Transportation of super-long blade exceeding 40 m, and (2) Crane capacity for lifting the nacelle in case of a tower with more than 70 m length. MWT92/2.4 wind turbine to be installed within the site of MHI Yokohama Dockyard & Machinery Works in 2005 by MHI (**Fig.10**) is expected to be the largest turbine for on land use.

Fig. 10 Estimated finished diagram of MWT92/2.4 wind turbine

As for the development of offshore wind power generation, the economic performance and reliability of the machine are in trial stage. If successful, wind turbines much larger size (5 MW-class) are expected to be produced since there will be no restriction of transportation and installation as in the case of land wind turbines, and economic performance will be higher than on land. In such case, MHI plans to catch up accordingly.

As the sole manufacturer of large wind turbines in Japan, MHI is determined to make incessant efforts in developing new technologies and providing new products in order to build up a bright future in harmony with man and environment.

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Yoshinori Ueda

Masaaki Shibata