New Products and Technologies of Mitsubishi Wind Turbines

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In order to prevent global warming caused by CO_2 emission, the renewable energy is drawing attention and has come to be used in a large scale. Mitsubishi Heavy Industries, Ltd. (MHI) launched its development program of wind-turbine power generator in 1980, and has recently developed a new 1 000 kW wind turbine (MWT-1000A) for use in low speed wind areas, and a 2 000 kW wind turbine (MWT-S2000) with a synchronous generator. MHI has also developed new concepts for airfoil and for reducing load, which improve the performance of wind-turbine power generator.

1. Introduction

Renewable energy is drawing attention and its application is expanded more and more in order to prevent global warming caused by CO_2 emission. **Fig. 1**[(1)] shows the CO_2 emission levels of several power generation systems. In the case of power generation system using renewable energy including wind power, the fossil energy is consumed only at the manufacturing stage of the equipment, after which the fossil energy consumption is almost nil. Therefore, such system is effective for reducing CO_2 emission.

As for the world installed capacity of wind-turbine power generator, capacity of 33 400 MW has already been installed by the end of 2002, which corresponds to approximately 0.5% of the total demand for electricity[(2)]. In Japan, capacity of 553 MW has already been installed by the end of October 2003[(3)].

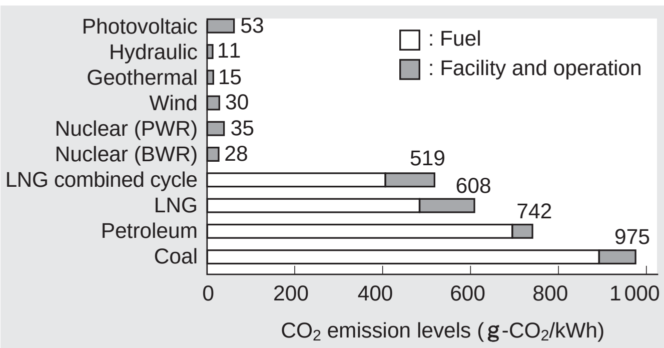

Fig. 1 CO_2 emission levels of several power generation systems
Renewable energies including wind power do not have CO_2 emission from fuel and are therefore effective to CO_2 reduction.

The use of wind-turbine power generation is expected to increase further in the future. In a proposal of "Wind Force 12"[(2)] published by European Wind Energy Association, installation of wind-turbine power generator of capacity for generating 1 260 000 MW in the world is called for by 2020, as shown in **Fig. 2.**, to cover 12% of the total demand for electricity.

2. Mitsubishi Wind Turbines

2.1 History of development[(4)]

MHI has paid attention to wind-turbine power generation since early time as a source of energy-saving and clean energy, and constructed, in 1980, an experimental 40 kW small-size wind-turbine power generator in Koyagi Plant, Nagasaki Shipyard & Machinery Works. Since

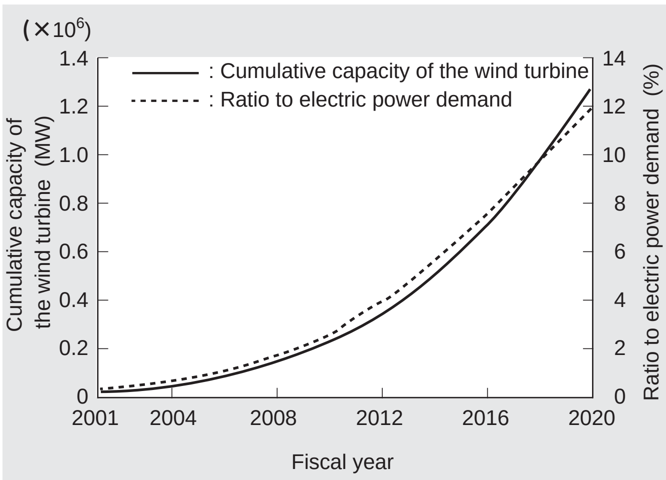

Fig. 2 Cumulative capacity of wind-turbne power generator vs. electric power demand according to "Wind Force 12"
The "Wind Force 12" calls upon to cover 12% of the world demand for electricity by wind by 2020.

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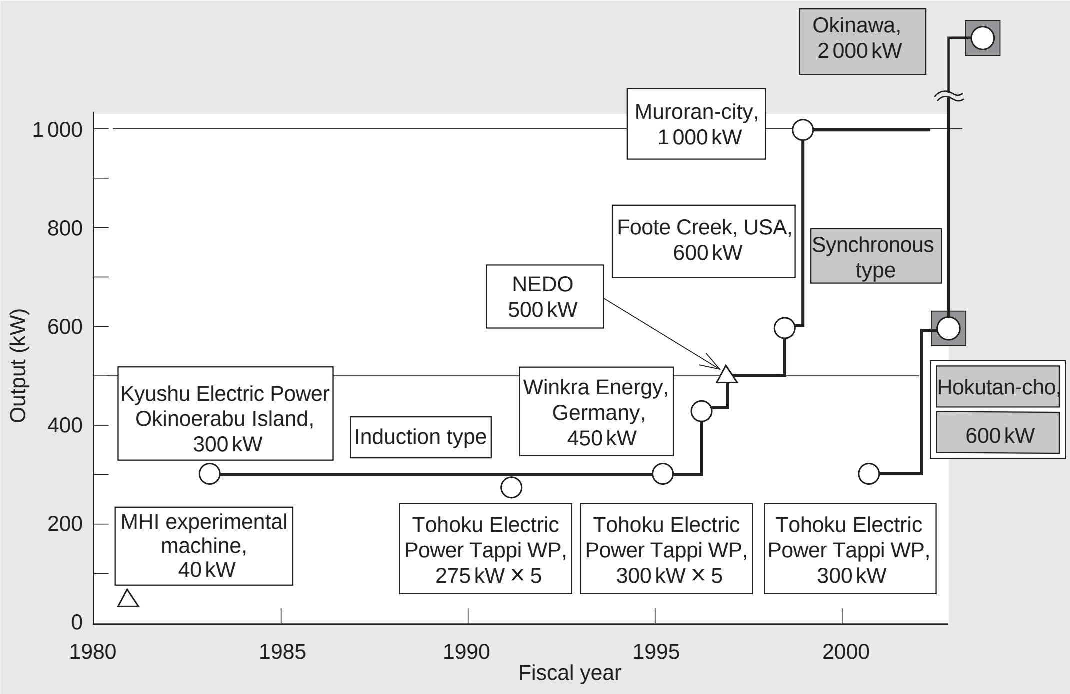


Fig. 3 History of development of MHI wind-turbine power generator
Development began from the production of experimental machine in 1980, and so far 1000 kW-class induction type and 2000 kW-class synchronous type have already been developed.

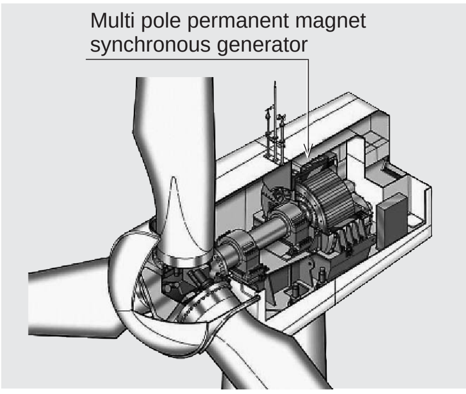


Fig. 4 Structure of MWT-S2000
Synchronous generator is used, needing no gear and inflicting little influence to electric power utility system because of variable-speed operation.

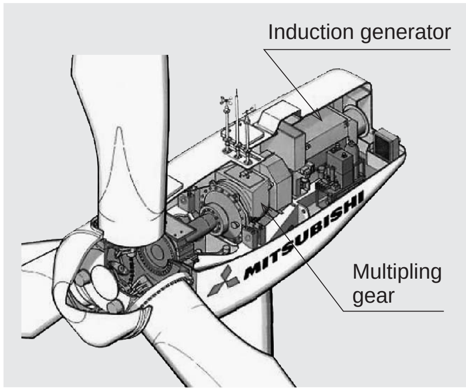


Fig. 5 Structure of MWT-1000A
Induction generator is used. The revolution of blade accelerated by gear before being transmitted to the generator.

then, the company has successively developed large-size generators as shown in **Fig. 3**.

Further, MHI has developed variable-speed gearless wind-turbine power generator using permanent magnet synchronous generator, with Mitsubishi Electric Corporation since 2000. The adoption of synchronous generator and AC-DC-AC converter allows variable-speed operation of wind-turbine power generator in the fluctuating wind, mitigating the power fluctuation caused by wind fluctuation and leading to reduction of the influence to the electric power utility system. Further, the use of synchronous generator makes it possible to transfer the revolution of wind turbine directly to the power generator without using a multiplying gear (**Fig. 4**), contributing to the elimination of noise caused by gear and saving the labor needed for the maintenance of the gear.

2.2 Latest models of Mitsubishi Wind Turbines

(1) New 1 000 kW wind turbine MWT-1000A for use in low speed wind areas

Up to now, wind-turbine power generators were assumed to be installed in areas with strong wind having the average annual wind speed of 8 – 10 m/s. MHI has developed a wind turbine for use in low speed wind areas to ensure substantial power generation and excellent cost performance even in places with comparatively weak wind with the average annual wind speed of 6 – 8 m/s[5]. The specifications of the newly developed MWT-1000A are given in **Table 1**, and its structure in **Fig. 5**. The wind-turbine uses a rotor of diameter 61.4 m, tower of height 60 or 68 m and an induction generator.

To develop MWT-1000A, conventional 1 000 kW wind turbine MWT-1000, which has excellent past records and high reliability, was employed as the base. The blade length was increased from 26.8 m to 29.5 m, the rotor diameter from 57 m to 61.4 m and the power at low wind speed region up to 25%, ensuring an improvement of approximately 23% in annual power generation for annual average wind speed of 6 m/s.

The first MWT-1000A started its operation in White Deer Site in Texas State, U.S.A in December 2002, while in Japan the first MWT-1000A started operation in Seto Wind Hill in Ehime Prefecture in October 2003. MWT-1000A was acknowledged to have high performance, and orders received so far have been more than 300 units.

With its outstanding economic performance, the MWT-1000A is expected to contribute largely to the reduction of CO_2. This was highly evaluated, and brought MWT-1000A the Nikkei Superior Products & Services Awards (Nikkei Business Daily Awards) for 2003, the Chairman Prize of Japan Machinery Federation Award for Energy Conserving Machinery.

(2) Synchronous 2000 kW wind turbine, MWT-S2000

The MWT-S2000 is the latest model of wind-turbine power generator (S-series) using synchronous generator. The specifications are given in Table 1 and the structure in Fig. 4. MWT-S2000 has the rotor length of 75 m and tower height of 60 m.

This is not only a 2000 kW-class large wind turbine developed by a wind turbine manufacturer other than the European makers, but also the largest commercial wind turbine in the world using multi pole permanent magnet synchronous generator. Verification tests have started on the MWT-S2000 constructed in Gushikawa-city in Okinawa Prefecture for Okinawa New Energy Development Company, Incorporated, since February 2003, and second MWT-S2000 started operation in Nandan-cho, Hyogo Prefecture in April 2004.

Since the technical creativity and the advantage of inflicting less influence to the electric power utility system were highly evaluated, the synchronous wind turbines (S-series) including MWT-S2000 received "Minister of Economy, Trade and Industry Prize" of the New Energy Award 2002" from the New Energy Foundation in February 2003.

3. New technologies

3-1 Optimization of wind turbine airfoil

Various technologies developed by MHI are applied to the MHI wind turbines. Some of them regarding the development of wind turbine airfoils[6] are introduced below.

The airfoil (MHI airfoil) developed independently by MHI is used on the inboard part of blades employed for the latest models MWT-1000A and MWT-S2000. The aerodynamic performance of the airfoil was assessed by using the method of computational fluid dynamics (two-dimensional imcompressive Navier-Stokes solver) and the optimum airfoil was pursued by using the genetic algorithm method adopted for optimization.

Figure 6 shows the calculation results of flow analysis around the optimized airfoil. In Fig. 6, the wind speed

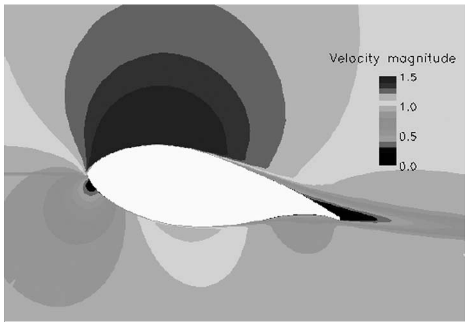


Fig. 6 Flow around the optimized airfoil
Result of computational fluid analysis for aerodynamic performance assessment of the airfoil. The figure shows dimensionless speed distribution.

Table 1 Comparison between latest and conventional wind turbines

Model		MWT-S2000 (Large turbine)	MWT-1000A (used in low speed wind areas)	MWT-1000 (Conventional-type)
Rated output	(kW)	2 000	1 000	1 000
Generator type		Multi pole permanent magnet synchronous generator	Induction generator (4-pole/6-pole)	Induction generator (4-pole/6-pole)
Estimated annual power generating capacity (for average annual wind speed 6 m/s)		Approximately double	22% up	Standard
Rotor diameter (blade length)	(m)	75 (36)	61.4 (29.5)	57 (26.8)
Tower height	(m)	60	60/68	60
Revolution	(rpm)	8 – 24	19.8/13.2	21.0/14.0
Rated wind speed	(m/s)	13.0	12.5	13.5
Cut-in wind speed	(m/s)	2.5	2.5	3.5
Wind Class Reference average speed	(m/s)	Class I 10.0	Class II 8.5	Class I 10.0

distribution is normalized by the free flow speed. The aerodynamic performance of the obtained optimum airfoil was verified by conducting wind tunnel test. A model blade with chord length of 930 mm and span length of 2700 mm was used.

Figure 7 shows the comparison of the lift-drag ratio (CL/CD) between the conventional blade profile and the optimized blade profile. For the optimized airfoil, it can be found that the lift-drag ratio has been improved in the range of attack angle from 2 to 14 (deg) including the operating range of the wind turbine and that at the attack angle of 8 (deg) the lift-drag ratio is 26, which is about twice of the value of 14 for the conventional airfoil.

Through adoption of the newly developed blade profile, the MWT-1000A and MWT-S2000 could successfully realize higher performance than the conventional type.

3.2 New concept for reducing load at extreme wind condition

The wind power generating equipment is designed taking account of loads under different conditions such as at normal operating state, at extreme wind condition e.g. typhoon, etc. Particularly, the blade and tower are exposed to a large load at the time of strong winds e.g. typhoon, etc., so that these make an important condition for determining the size and strength of the blade and tower.

The wind power generating equipment is generally designed to take a stand-by position with the power generation stopped and the blade facing to the upwind direction and set to the feathering position in order to reduce the load when strong wind blows.

In recent years, power failure is also taken into account in addition to the extreme wind condition in order to ensure safety. In this case, the drive motor for yaw control cannot be used unless an uninterruptive power supply is available, and the wind turbine fails to yaw to the upwind, which means that it is subjected to the winds from all directions, causing an unexpectedly large load to act on the turbine.

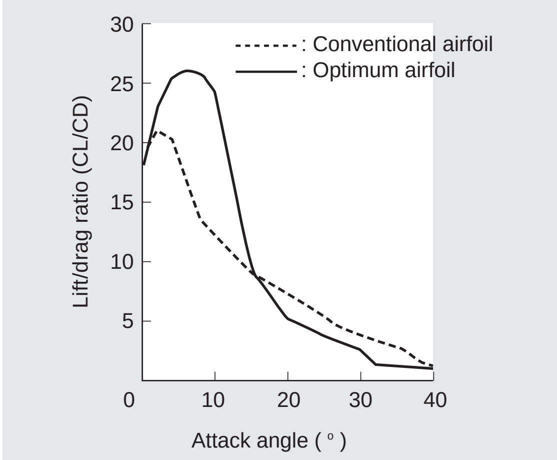


Fig. 7 Measured values of aerodynamic characteristics of conventional and optimum type airfoils
The lift-drag ratio (CL/CD) of optimum airfoil was improved by the range of elevation angle 2 - 14° including the wind turbine operating range.

In order to solve this problem, MHI has come up with a new concept called Smart-Yaw Concept (patent pending) for reducing the load at the time of strong winds(7).

Yaw refers to the direction of wind turbine, and the Smart-Yaw concept makes use of the general characteristics of the wind turbine of facing down wind direction on receiving the wind (**Fig. 8**). Facing downwind brings about reduction of load next to facing upwind, and is therefore a suitable direction to keep the wind turbine at stand-by state in times of strong winds.

As shown in **Fig. 9** (a), the wind turbine is faced upwind for operation by using yaw motor and hydraulic yaw brake at the time of normal power generation. In times of strong winds, however, the hydraulic yaw brake is released, which naturally turns the wind turbine to downwind direction based on the principle of wind vane. However, the brake installed to the yaw motor is applied with appropriate frictional force to prevent generation of excessive yawing rate in the wind turbine.

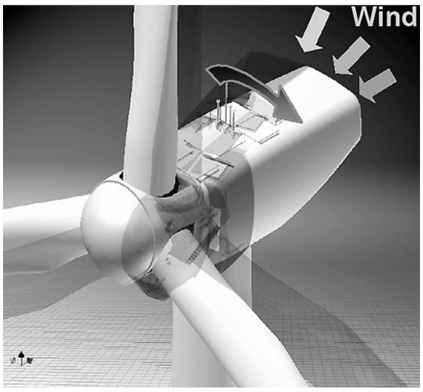
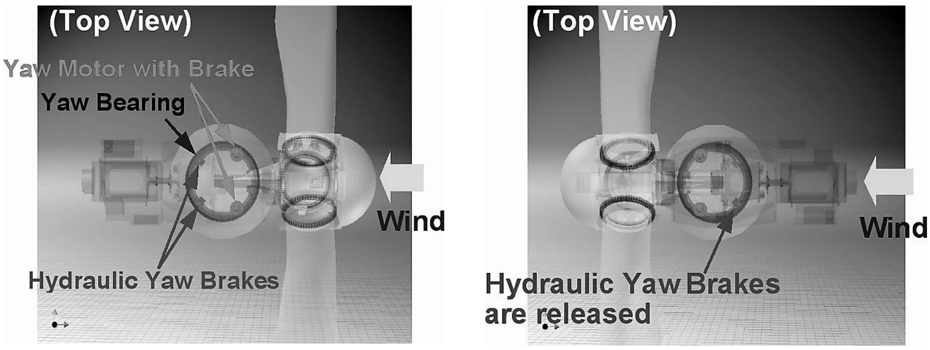


Fig. 8 Down wind directivity of wind turbine
The wind turbine generally tends to face down wind direction on receiving the wind.



(a) At normal power generation (b) In times of extreme wind condition

Fig. 9 Concept of Smart-Yaw operation, with (a) indicating the wind turbine faced up wind dirction for operation by using yaw-motor and hydraulic yaw brake at normal power generation while (b) indicating the wind turbine set to face naturally down wind direction by releasing hydraulic yaw brake in times of extreme wind condition.

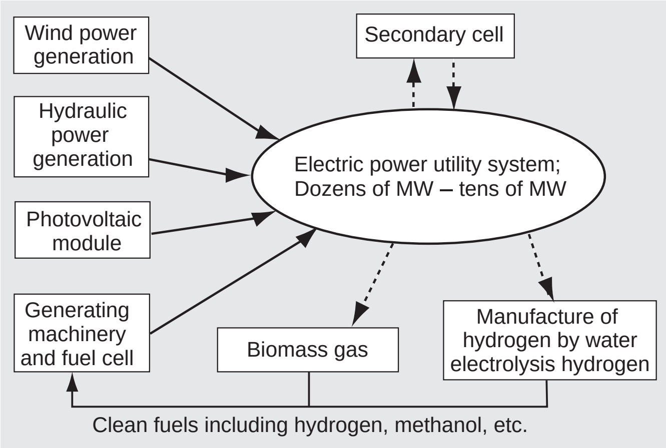


Fig. 10 Combined power system with various renewable energies used in combination and complementation

Further, since the yaw movement of wind turbine is not constrained, even if an excessive load acts on one of the three blades due to spatial turbulence of wind, the wind turbine carries out yaw movement due to the load difference between this blade and the other two. This motion results in the consumption of the excessively large load, which in turn contributes to the reduction of load.

With the Smart-Yaw concept analyzed and applied, the load acting on the blade in times of strong winds was found to get reduced by 25% and the load to the tower by 30%, which eventually led to reduction of blade weight by 15% and tower weight by 15%.

We are determined to apply these new techniques including Smart-Yaw concept to the development of highly reliable and rational wind turbines in the future so as to contribute to the spread of the use of renewable energy.

4. Future prospect

In order to make the effective use of the limited wind resource, the wind-turbine power generator is expected to become larger and larger in size. In Europe, 5 000 kW-class prototypes have already been constructed.

Further, operation of an offshore windfarm with power generating capacity of 160 MW started in 2002 in Europe. In Japan, the installation of wind turbines was conventionally limited to the land, but installation at port area and inshore (seabed installation type) has already started. It is considered that offshore wind-turbine power generation will advance. It is also expected that the development of floating-type offshore wind-turbine power generator will be studied.

In order to make more effective use of renewable energy, combination and complementation of various renewable energies is effective. **Fig. 10** shows a proposal of combined power system using renewable energies for the areas where demands for electric power are dozens of MW - tens of MW. Such system is considered effective as a distributed power source for power supply to a remote island or to a distant place.

5. Conclusion

In Japan, with the enforcement of RPS Law in April 2003, the development of wind power is getting accelerated aiming at the set goal of 3 000 MW for 2010.

With severe meteorological conditions including typhoons, narrow and steep geographical features, etc., Japan is surmounted with severe environmental conditions for wind-turbine power generators. Based on the technologies and experiences cultivated in the past, MHI is determined to carry on "development of new product" and "development of new technology" in order to offer wind-turbine power generator that can be applied at different parts of Japan and the world.

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