Featured Articles

Core Technologies for Developing Wind Power Generation Systems

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OVERVIEW: Wind power is a mainstay of renewable energy, with new wind farms being installed around the world in recent years. Use of offshore wind power, in particular, is expected to expand in the future. Even more so than onshore wind turbines, large offshore wind turbines require high reliability and easy maintenance. To meet this demand, Hitachi is utilizing technologies for reliability assessment and various types of analysis to improve the reliability of the drive train, generator, and other components in its HTW5.0-126 5-MW offshore downwind turbine, which is currently under development, and is developing a cooling system that takes advantage of its downwind configuration. Hitachi is also seeking to develop blade design techniques for improving the reliability and increasing the output of the next generation of wind turbine blades.

INTRODUCTION

INTEREST in renewable energy has been growing in recent years because of its role in overcoming environmental problems such as global warming. Along with photovaltaic power generation, this interest is focused on wind power generation in particular, with wind farms being installed throughout the world. Offshore wind power is expected to be developed further in the future, with offshore sites enjoying better wind conditions than those on land. Being located offshore also facilitates the adoption of larger wind turbines by alleviating problems such as noise and having to transport large components. On the other hand, offshore locations place greater demands than before on things like reliability and ease of maintenance.

This article describes the technologies used in the development of the drive train, permanent magnet generator, and cooling system for the HTW5.0-126, a large 5-MW offshore wind turbine that is currently being developed by Hitachi, the progress of that development, and the potential for using blade design techniques to increase power generation.

TECHNOLOGIES FOR IMPROVING RELIABILITY OF DRIVE TRAIN

Two Bearing – Outer Rotating System

Hitachi is considering the use of a “two bearing – outer rotating system” to improve the reliability of the drive train for large 5-MW wind turbines. This design ensures that only the torque from the wind energy delivered from the blades is transmitted through the hub, rotating main shaft, and gearbox to the generator, with the wind load and the weight of the blades being supported by the static main shaft. Also, a low-rigidity design is used for the rotating main shaft to absorb the effects of misalignment. Structural analysis was used during the structural design of component parts to check their strength, and the reliability of the components was subsequently verified by testing.

Fig. 1 shows a precise one-fifth scale model of the hub, rotating main shaft, static main shaft, and bearings that were manufactured and used for drive train testing. This included using a hydraulic cylinder to apply axial and radial loads, and adjusting the height of the rotating main shaft support structure to introduce misalignment. This allowed the deformation behavior of the shafts in particular to be assessed and verified.

Back-to-Back Testing

For testing of the full-size drive train, two sets of generators, gearboxes, and power conditioning systems (PCSs) were operated back-to-back and measurements were taken of vibration, stress, and other parameters under a wide range of conditions in order to verify reliability (see Fig. 2). By shifting the position of the gearbox, this setup also allowed the characteristics to be determined for different levels of misalignment(1).

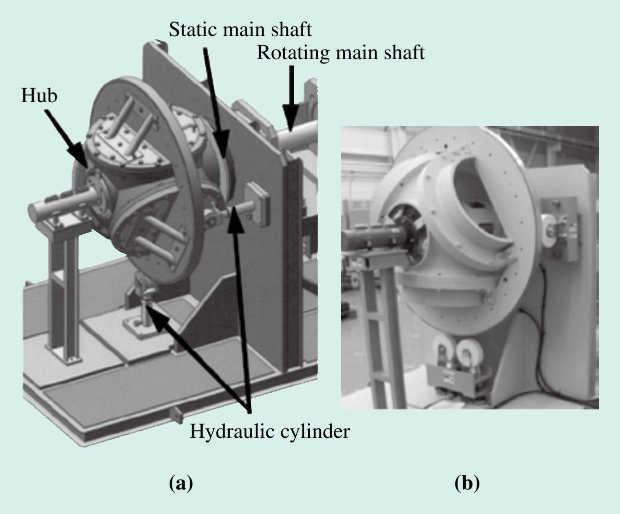

Fig. 1—Testing on One-fifth Scale Model of Drive Train.
The figures show a schematic diagram of the test rig (a) and a photograph (b). The design consists of a rotating main shaft that transmits the torque used for generating electric power and a static main shaft that supports the wind load and the weight of the blades.

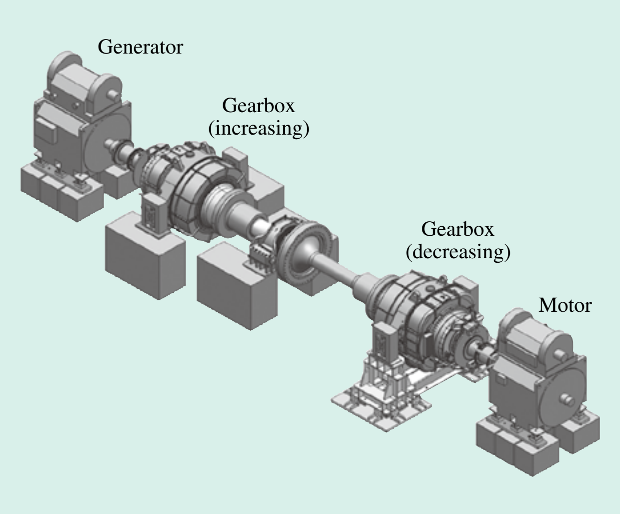

Fig. 2—Back-to-back Testing Configuration.
The drive system on the right (in which the generator operates as a motor) turns the generator system on the left to perform reliability testing under a variety of different operating conditions.

TECHNOLOGIES FOR IMPROVING RELIABILITY OF LARGE PERMANENT MAGNET GENERATOR

Clover Leaf Structure for Better Cooling

Generators for large wind turbines require a high output density to ensure small size and light weight. As a result, permanent magnet generators have increasingly been chosen for this purpose in recent years. However, because permanent magnets become demagnetized at high temperatures, temperature management (cooling) is required during operation.

Dysprosium, a rare earth element, is typically added to neodymium magnets to improve their thermostability. These magnets are located in the rotor, and Hitachi has designed a clover leaf structure that incorporates ventilation grooves into the rotor to improve cooling performance(2).

The clover leaf structure has a number of ventilation grooves located between the poles along the axis of the rotor, with improved cooling being provided by the air that passes through these grooves. Hitachi designed a 2-MW permanent magnet generator using computational fluid dynamics to perform an

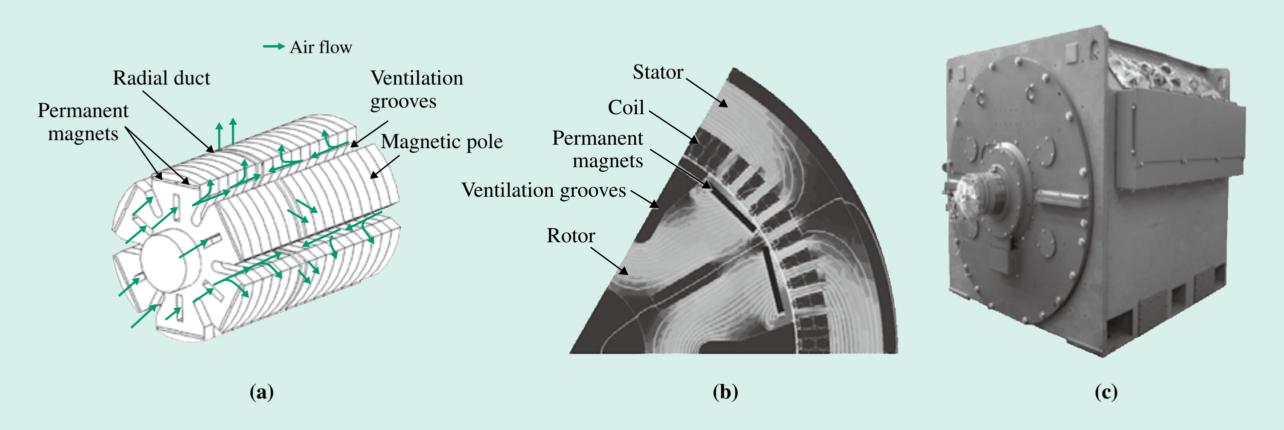

Fig. 3—Permanent Magnet Generator with Clover Leaf Structure.
Fig. (a) shows the flow of air through the rotor and Fig. (b) shows the magnetic field line diagram obtained by electromagnetic field analysis. In addition to conventional radial ducts, the rotor design also includes ventilation grooves that run in the axial direction to improve cooling around the magnets. Fig. (c) shows the newly developed 5-MW generator in which these techniques were applied.

analysis of air flow and associated losses, and an electromagnetic field analysis to predict the generation performance of the new structure. It also performed prototype testing. This succeeded in reducing the size of the generator by 30% compared to the previous doubly-fed induction generator [see Fig. 3 (a) and (b)].

Permanent Magnet Generator for 5-MW Wind Turbine

Hitachi developed a large permanent magnet generator for use in the HTW5.0-126. The version for use with a medium-speed drive train has 36 poles, a rated speed of 440 rpm, and an output of 5,460 kW. Although it requires better rotor cooling performance because it runs at lower rpm than the existing 2-MW HTW2.0-80 wind turbine, this problem was solved by using the clover leaf rotor design.

The development included additional study of the number of poles and of how to position the magnets in order to accommodate the higher capacity, as well as measures for making the generator easier to assemble [see Fig. 3 (c)].

PASSIVE COOLING TECHNIQUE UTILIZING NATURAL AIR FLOW

Because the HTW5.0-126 has a downwind configuration, its most upwind point is the tip of the nacelle. Hitachi has utilized this feature to incorporate a passive (fan-less) cooling system.

The radiator used to air-cool the cooling water from the generator and gearbox is located at the upwind end of the nacelle. This provides efficient cooling because it gets the full benefit of the natural air flow before the wind speed is reduced by the rotor blades [see Fig. 4 (a)].

Computational fluid dynamics was used to design the nacelle shape, which is important for ensuring sufficient air flow for cooling [see Fig. 4 (b)]. Locating the radiator inside the nacelle wind profile is also beneficial for reducing the wind load on the nacelle(1).

BLADE DESIGN TECHNIQUES

State of the Art for Wind Turbine Blades

Currently, in 2014, large wind turbines in the 7-MW class with blade diameters of about 160 m are being prepared for deployment in Europe. Furthermore, steady progress is being made in the development of larger wind turbines. The European Wind Energy Association (EWEA) predicted (in 2008) that wind turbines in the 10-MW class with blade diameters of about 180 m will enter service around 2015.

Among production wind turbines, meanwhile, improved models with long blades designed to be capable of generating power at low wind speeds have been released on the market. The trend toward larger blade sizes designed to increase the amount of power generated as much as possible is intended to maximize the return to the customer. This demonstrates the importance of customer-oriented product development in the wind power generation business.

Wind Turbine Blade Design

Blades generate torque from the energy of the air flowing over them. Fig. 5 shows a diagram of blade bending moment and torque.

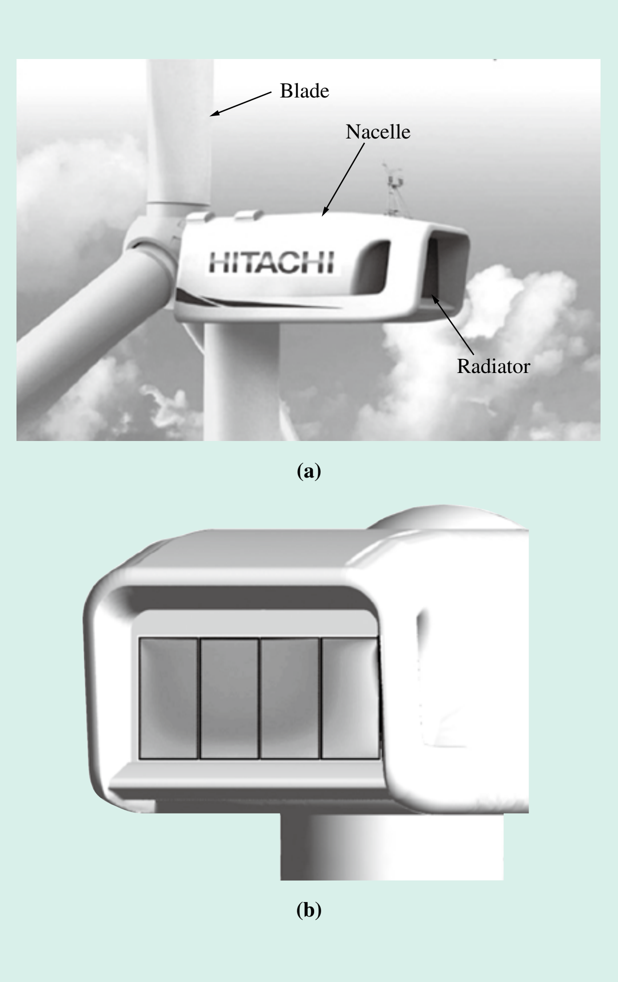

Fig. 4—Passive Cooling System.
Fig. (a) shows the nacelle where the radiator is located, and Fig (b) shows the air speed distribution in the radiator obtained by computational fluid dynamics. The shape of the nacelle was designed to provide good and uniform airflow without the use of a fan.

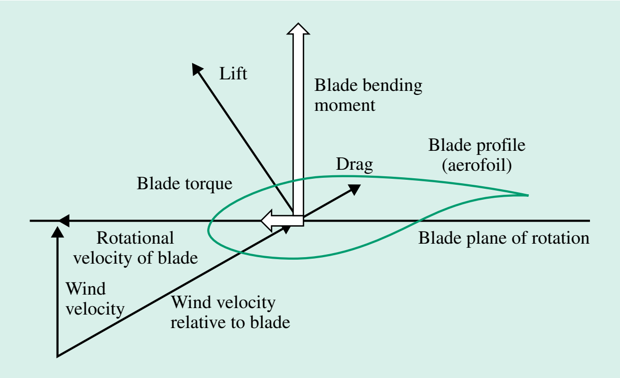

Fig. 5—Relationship between Wind Velocity and Forces with Respect to Wind Turbine Blade Profile.
Since the blade profile acts as an aerofoil, its design should maximize lift and minimize drag. Since the rotational velocity of blade is high relative to the wind velocity on large wind turbines, most of the lift acts to bend the blade in the downwind direction.

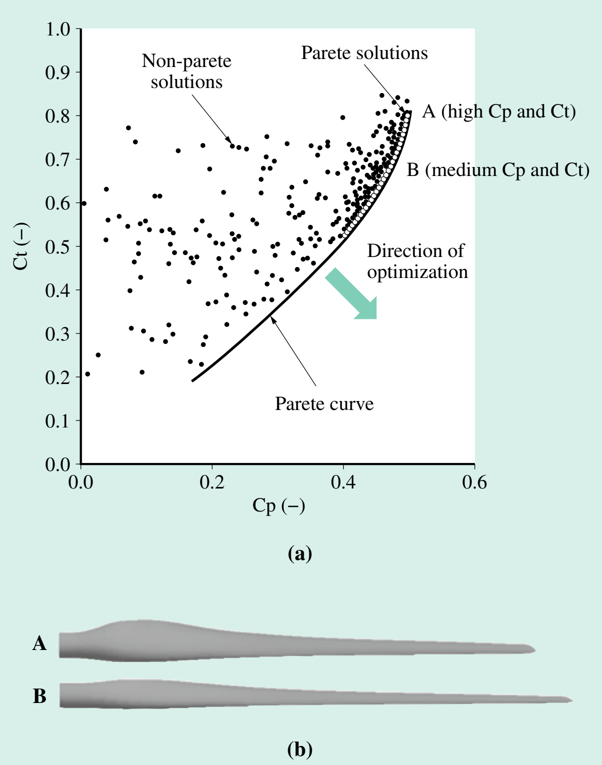

Fig. 6—Results of Optimal Design Search for Wind Turbine Blade.
The graph plots the results of a two-objective design optimization (design search) with an objective function that seeks to minimize the thrust coefficient (Ct), which influences reliability, and to maximize the power coefficient (Cp), which influences output. In these results, profile B has a similar bending moment to profile A under the same wind speed conditions. Profile B has a slender blade profile for which the lower Cp allows the aerofoil chord length to be shorter and the lower Ct allows the blade length to be about 10% longer.

Bending moment has a major influence on wind turbine reliability. It corresponds to the flexing of the blades in the downwind direction and is applied to the main shaft at the points where the blades are attached (the roots). Torque, on the other hand, is what causes the shaft to rotate. A higher torque produces a higher output. Because the return on investment is strongly influenced both by income from the sale of generated power and by savings on the cost of operation and maintenance (O&M), blades need to have both high reliability (through lower bending moment) and high output (through higher torque).

Blade design makes use of blade element momentum (BEM) theory(3). The design parameters include the blade aerofoil profile (cross section) from root to tip, and the associated performance tables, chord length, thickness, and lift. BEM theory is used to determine the aerofoil profile by identifying the design parameters that provide the required aerodynamic performance. Next, the forces to which the blades will be subjected are estimated for various different operating conditions, and the internal design that will provide the necessary static and fatigue strength is determined. Fig. 6 shows the results of a design search that sought to satisfy the requirement for both high reliability (low bending moment) and high output (high torque)(4). The design search was performed by coupling these calculations with an optimization system. Ct is a dimensionless thrust coefficient representing the bending moment, and Cp is a dimensionless power coefficient representing the output.

As shown in Fig. 6 (a), the design search found numerous solutions as the priority was shifted from output (high Cp) to reliability (low Ct). Fig. 6 (b), meanwhile, shows the blade profiles for point A, where the value of Cp is highest, and for point B, where the lower Ct means the bending moment remains roughly the same despite the blade being 10% longer. Because the benefit of longer blade length outweighs the reduction in Cp between points A and B, the total annual power generated by blade B over a year is about 7% higher than for blade A (assuming the same wind conditions and operation below the maximum output limit).

While this is just one example, Hitachi intends to establish a role for itself in the renewable energy sector by taking account of customer requirements when designing trade-offs between reliability and power generation.

CONCLUSIONS

This article has described the development of the drive train, permanent magnet generator, and cooling system for a large offshore wind turbine currently being developed by Hitachi, the technologies used in that development, and the potential for using blade design techniques to increase power generation.

Hitachi is also developing other technologies, including those required for instrumentation and monitoring, and for the system control of wind turbines. Hitachi believes that the use of these technologies in the development of highly reliable and efficient wind power generation systems will lead to greater use of energy sources that are conscious of the global environment.

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