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3 MW class offshore wind turbine development

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ABSTRACT

This paper introduces the design and development of a 3 MW class offshore wind turbine (WinDS3000). The design has been carried out by considering high reliability, availability, maintainability and serviceability (RAMS) for the wind class TC Ia. An integrated drive train design, which has an innovative three stage gearbox, has been introduced to minimize nacelle weight of the wind turbine and to enhance a high reliability for transmission. A permanent magnet generator (PMG) with fully-rated converter has been introduced for its better efficiency in partial-load operation, thus it is grid-friendly and can adapt itself to either 50 Hz or 60 Hz grid connection. A pitch-regulated variable speed power control with individual pitch system has been adopted to regulate rotor torque while generator reaction torque can be adjusted almost instantaneously by the associated power electronics. It is expected that the blade and system load can be reduced by using individual pitch control. The wind turbine also has been equipped with condition monitoring and diagnostic systems in order to achieve maintainability requirements.

1. Introduction

In this century, environmental concern such as Kyoto Protocol and exhaustion of fossil fuels have raised as one of the most important issues in the world. Wind energy is considered as the most practical substitute energy to replace the fossil fuel, due to its competitive cost of electricity (COE) and maturity of technology. Furthermore, wind energy market has dramatically grown, especially in USA and China [1].

As well known, the current trends of wind energy are large wind turbine and offshore wind farm. In these streams, major companies of wind turbine are competitively developing large scale wind turbine up to capacity of 6–7 MW. Furthermore, many offshore wind farms are developed and planned in several countries. In Korea, the necessity of large scale wind turbine and offshore wind farm is also an issue, since Korea has sufficient offshore wind resources. Wind turbine development and wind resource assessment for the offshore wind energy are an on-going process in Korea. Doosan Heavy Industries and Construction Co., Ltd., which has been well-known as a power plant provider and construction company, is developing offshore wind turbine.

The developing status of a 3 MW class offshore wind turbine named as WinDS3000 is introduced in this paper. WinDS3000 has been manufacturing and assembling. The design concept of WinDS3000 has focused on high RAMS and low COE. A prototype WinDS3000 will be installed for type certification in Jeju Island on August of 2009 [2].

2. Design criteria

2.1. High RAMS

WinDS3000 has a three-blade upwind rotor and integrated drive train with permanent magnet synchronous generator. Table 1 shows general specifications of WinDS3000. For the power control, it is operated by torque controller with variable speed below-rated wind speed and by pitch controller at rated wind speed. Through these controllers, WinDS3000 operates along the optimistic power curve and generates electricity with high efficiency.

The concept of high RAMS is applied to the WinDS3000. High RAMS is the key factor for the development target of Doosan and it is expected that WinDS3000 will be competitive in wind energy market. WinDS3000 is carefully designed in the first stage of design in order to meet high reliability. Reliable components were adopted, and their design and safety were proven by several analysis and co-work with its manufacturers. Using a PMG with full power converter helps WinDS3000 to be a grid-friendly system. In the grid conditions of either 50 Hz or 60 Hz, WinDS3000 can be easily used due to its fully rated frequency converter. To enhance maintainability, effective maintenance crane is equipped and can handle every component in the nacelle. Finally Doosan's customer service infra which has been achieved in the power plant business will be applied for WinDS3000.

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Table 1
General specifications of WinDS3000.

Rated power	3000 kW (offshore)	IEC class	Ia
Rotor diameter	91.3 m	Gearbox	3-Stages (2 planetary/1 parallel)
Generator/converter	PMG/full power converter	Rated wind speed	13 m/s
Cut-in wind speed	4 m/s	Cut-out wind speed	25 m/s
System design lift	20 years	Certification guideline	Germanischer Lloyd

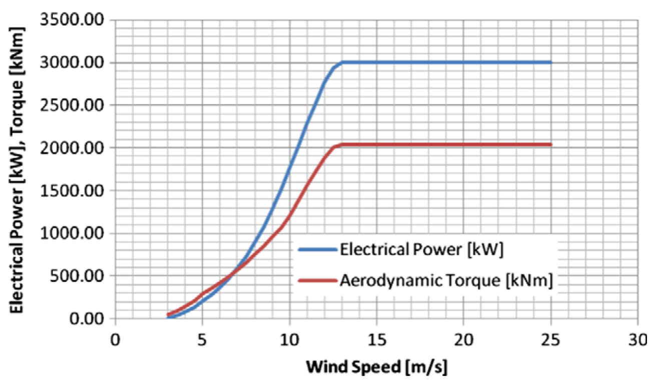

Fig. 1. Power curve of WinDS3000.

2.2. Low COE

COE is one of the most important issues in the wind energy. It depends on the cost of wind turbine including construction and power output related with wind turbine efficiency. WinDS3000 is designed to achieve high efficiency and low cost.

Fig. 1 shows the power curve and shaft torque of the WinDS3000. Those have been calculated using the BLADED software. Rated power is achieved at a rated wind speed, 13.0 m/s. The pitch control is used to limit rotor power at a range over the rated wind speed. The shaft torque also reaches a maximum value in conjunction with output power at rated wind speed. It gives a maximum power output from wind and low COE in generating electricity.

Main transformer, which transverses the voltage from generator side to grid side, is equipped in the nacelle in order to get the low cost of wind turbine. To define transformer positions, three types have been considered. The positions were tower base, outside under the nacelle and inside of the nacelle. Through the analysis of cost, electrical losses and design consideration, transformer is located in the nacelle. When the transformer is in nacelle, wind turbine cost is lower by 10–20% than other solutions with similar electrical losses. After optimization of nacelle layout, nacelle weight of WinDS3000 will be achieved to about 100 ton including transformer.

3. Main components

3.1. Blade

The EU90-2300 blade has been used as a baseline blade. WinDS3000 blade was a modification of the baseline and designed to satisfy structural and aerodynamic demand for TC Ia condition of GL regulation (Fig. 2). Because the design of EU90-2300 blade is based on the IEC class IIa, the aerodynamic shape of the new blade has been modified to slimmer blade, and structurally reinforced by spar cap and UD-mat.

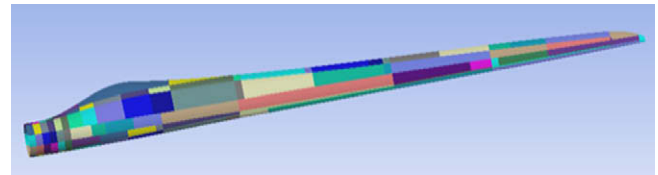

Fig. 2. Blade shape and laminate structure.

The new blade will be manufactured by means of vacuum infusion method. Because it has higher fiber volume fraction than hand lay-up method used in the baseline blade, the new blade has better structural strength per unit mass than the baseline. The length of a blade is 44 m and the weight is approximately 10.5 tons. It is manufactured with GFRP material excluding carbon fiber in order to avoid matching problem which takes place between heterogeneous materials. Fig. 3 shows a finite element model of the new blade.

3.2. Gearbox

The gearbox has been designed to consider light weight, compact size, high reliability and easy maintenance. Innovative design concept has been employed to achieve these design goals. The design characteristics of gearbox are as follows:

(1) Rotating planetary gear housing.
(2) Compound differential gear train.
(3) Multi-planets with flexible pin.
(4) Torque linkage suspension system.

The gearbox is composed of two planetary gear stages and one parallel gear stage. A differential gear between the 1st and 2nd stages has been employed to reduce the size of gearbox. In this rotating housing design, the input torque is provided by the coaxial gear housing that transmits the torque to the ring gear of the 1st stage and the carrier of the 2nd stage.

The rotating housing undergoes negligible deflection due to its large diameter and high bending stiffness. The compact size and weight reduction of 10% could be achieved by employing the differential gear and the rotating housing. Torque linkage suspension system has been employed using the elastic twist of the torsion bar in order to avoid possible damage coming from emergency stop or extreme load. In addition, flexible pin concept has been employed to solve load distribution on the gear teeth.

3.3. PMG

WinDS3000 has a PMG on two main reasons: one is good efficiency in partial-load operation and the other is a simple structure that could be potentially more reliable. Since PMG does not need an excitation current, rotor electrical loss is less than induction generator. Additionally, it results in simple and reliable design potentials, because PMG does not need any slip rings.

However, the PM may have a problem on the demagnetization. To overcome this problem, neodymium–iron–boron (NdFeB) magnet has been used. It has high energy product (Br × Hc) and high permanently demagnetization temperature.

A proper heating channel has been installed to prevent damage on the generator due to condensing water. The generator and the power electronics are cooled by a water–air heat exchanger. Skew of stator slot has been considered to reduce the cogging torque. A low voltage level has been selected considering cost of inverter switching device.