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Implementation of a torque and a collective pitch controller in a wind turbine simulator to characterize the dynamics at three control regions

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ABSTRACT

As the capacity of wind turbines has increased, the loads on crucial components such as a gearbox, a generator, and blades are significantly increasing. An intelligent online monitoring system is indispensable to protect the excessive load on core components and manage a wind farm efficiently. In order to verify new online monitoring and diagnostic methods for such a monitoring system in advance, a wind turbine simulator is essential. For this purpose, we developed a simulator that has similar dynamics to an actual 3 MW wind turbine, and is thereby able to acquire a state of operation that closely resembles that of the 3 MW wind turbine under a variety of wind conditions.

This paper describes the implementation of a torque and a collective pitch controller, which is used for a new type of simulator with the intention of exploiting online monitoring and diagnostic methods. The torque and the collective pitch controllers were developed to facilitate variable speed-variable pitch control strategies in the wind turbine simulator. Experiments demonstrated that three control regions were successfully deployed on the simulator, and thereby the simulator was operated at all control regions in a stable and accurate manner. Moreover, the strain and vibration measured from the blade and the gearbox showed different trends at three control regions. Therefore, a new type of simulator is an effective means to develop diagnostic and prognostic algorithms as well as online monitoring methods reflecting the dependency of dynamic characteristics on the control regions.

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1. Introduction

The demands for sustainable and clean energy have recently accelerated the development of renewable energy. Wind energy is one of the most promising sustainable energy sources due to its high energy density, small restriction of scale, and high technological advances. Especially, significant enhancement in aerodynamic technology has recently made possible the development of high-efficiency, low-cost, and large-scale wind turbines. Consequently, the economic feasibility of wind energy has been established, and demands to develop large-scale onshore/offshore wind farms are growing consistently [1–4]. As large-scale wind farms are constructed, it becomes more and more significant to develop real-time condition monitoring and fault diagnosis for wind turbines to decrease the maintenance cost, especially for offshore wind farms due to the severe environmental conditions of the ocean.

Large capacity horizontal axis wind turbines (HAWTs) were successfully deployed on a commercial scale [5]. However, HAWTs require long downtime for repair or replacement, as well as the use of expensive and heavy equipment, if unexpected failures occur on major components such as a gearbox, a generator and blades. Considering the breakdown and downtime of wind turbines as important factors that can hinder the economic feasibility of a wind farm [6], intelligent Operation & Maintenance (O&M) is essential to improve the economic feasibility of wind farms. Efficient O&M can be achieved by applying a condition monitoring system (CMS). Through real-time online monitoring, predictive maintenance, and diagnosis of major components with CMS [7–11], it is possible to decrease O&M costs, eventually increasing the economic feasibility of wind farms.

Vigorous research has been conducted on the diagnostic and prognostic algorithms, which introduce various sensors and signal processing techniques to increase the efficiency of wind farm

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operation and maximize economic efficiency [12–18]. As there are high risks involved in applying and field-testing unproven algorithms on commercial wind turbines, reliable verification of the proposed methods should be carried out with a wind turbine simulator in advance before the field tests.

A variety of research has been conducted on simulators for wind turbines [19–21]. To create a controlled test environment for the drivetrains of wind turbines, a wind turbine simulator with an inverter-controlled induction motor applied has been developed [22]. A real-time hardware simulation system has been developed to analyze a grid-tied wind turbine equipped with a permanent magnet synchronous generator (PMSG) [23]. This research has provided a useful foundation to design and verify the wind energy conversion system. However, existing simulators control the rotational speed of the motor for stable operation, although the motor torque has to be controlled for realistic simulation. In addition, they omit blade pitch control due to space constraints and difficulty in implementation. As a result, since the existing wind turbine simulators do not completely implement the variable speed-variable pitch control strategy of an actual wind turbine, they have limits in verifying a health monitoring algorithm for the gearbox and blades under various operating conditions.

To develop an experimental platform for exploiting online monitoring methods and intelligent maintenance algorithms, Korea Electric Power Corporation (KEPCO) Research Institute developed a wind turbine simulator suitable for this purpose [24]. A torque and a collective pitch controller were implemented so that the simulator can be operated under actual three control regions. The proposed control logics were validated through experiments. Experiments demonstrated that three control regions were successfully implemented in the simulator with the torque and the pitch controller, and thereby the simulator operated at all control regions in a stable and accurate manner. Moreover, vibration and strain measured at the gearbox and the blades clearly showed different tendencies of the dynamics at each control region. To develop an intelligent monitoring system, the characteristics of dynamic behavior at each control region were identified for an efficient management of wind farms.

2. Torque controller

The most successfully deployed commercial wind turbines are the variable speed-variable pitch type. The rotational speed of the rotor varies depending on the wind speed, whereas the pitch angle of the blades is constant below the rated power to capture as much wind energy as possible. On the contrary, the pitch angle of blades varies depending on the wind speed, whereas the generated power keeps constant above the rated power to reduce the load exerted on a wind turbine. In order to realize this system, the torque corresponding to the rotational speed of rotor (wind speed) has to be estimated accurately, and applied to the drivetrain of the simulator so that the wind turbine simulator can operate at a variety of operational conditions of an actual wind turbine. To apply such a torque using wind, a large wind tunnel is required, which needs a large space and entails a high cost. In this study, a DC motor was installed in front of the simulator to apply mechanical torque to the drivetrain of the simulator (Fig. 1). The torque transmitted from the drivetrain is converted into electrical energy through the generator controlled by the inverter. The rotational speed of the simulator converges to a constant speed with induced motor torque and generator torque varying rotational acceleration, which is the same method for wind turbines adopting variable-speed control strategy. The key algorithm to facilitate a torque control strategy on the wind turbine simulator is the torque estimator, which calculates appropriate torques for the motor and the generator. Unlike wind turbines, which have slow dynamic response due to the large inertia of a rotor, the simulator has a small inertia; thus, major components

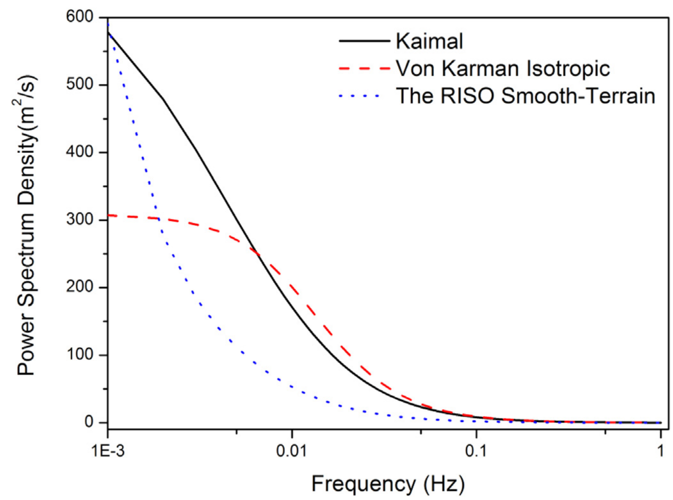

Fig. 2. Power spectrum density of three wind models.

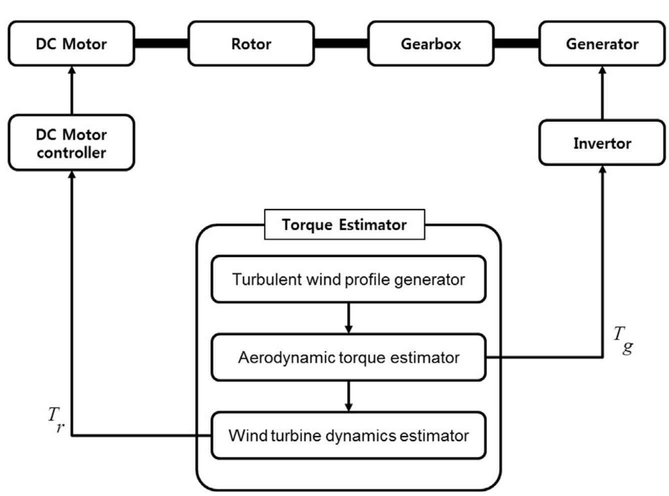

Fig. 1. Schematic diagram of torque control method for the simulator.

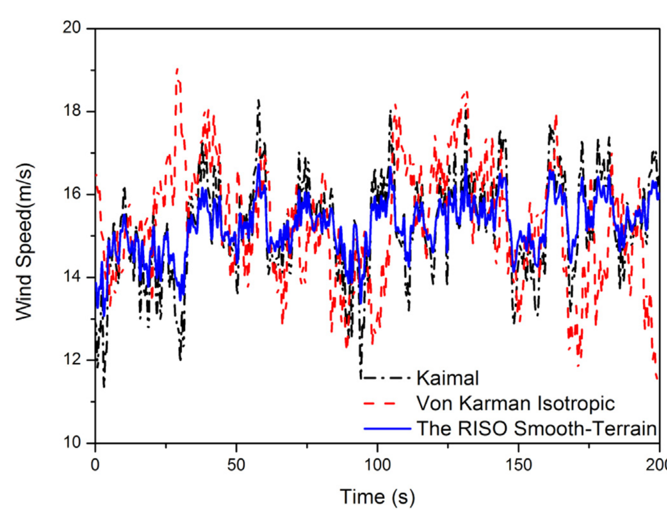

Fig. 3. Turbulent wind profiles in time domain.

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