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Transformation algorithm of wind turbine blade moment signals for blade condition monitoring

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A B S T R A C T

To simplify signal analysis on wind turbine blades and enable their efficient monitoring, this paper presents a novel method of transforming blade moment signals on a horizontal axis 3-blade wind turbine. Instead of processing 3-blade moment signals directly, the proposed algorithm transforms the three sinusoidal signals into two static signals relative to the center of blade rotation through vector synthesis and coordinate transformation, and eliminates frequency components due to blade rotation from the obtained signals. Moreover, as an alternative to a rotational sensor, a blade rotation angle estimator is introduced. Its effectiveness was confirmed through simulations and field tests on an actual wind turbine.

1. Introduction

Wind energy has taken center stage because of its clean, safe and practical aspects, and plenty of wind farms have been constructed as a means of replacing fossil power plants. Though wind turbines are generally designed to operate for over 20 years, a Condition Monitoring System (CMS) is required to enhance wind turbine reliability and availability.

The main function of the CMS is to detect turbine faults at their early stage, and thereby to prevent the risk of turbine accidents. The CMS can be mainly classified into three types according to the kind of used sensor or monitoring object: vibration-based monitoring, oil debris-based monitoring and blade monitoring [2,3]. Among these, the blade monitoring has been generating much interest recently and has been actively studied, because blade failure accounts for a substantial proportion of total failures from the aspects of downtime and costs as shown in Fig. 1. As part of this trend, Germanischer Lloyd (GL) guideline for the certification of CMS recommends monitoring wind turbine blades as well as other main components such as a main bearing, a gearbox and a generator [4].

Several research studies on wind turbine blade monitoring have been in progress to secure wind turbine blade integrity. Papasalouros set up a wind turbine blade health monitoring system using Acoustic Emission (AE) sensors on a wind turbine of NEG-MICON NW48/750 [5] as shown in Fig. 2. Apart from this method, various monitoring techniques have been introduced to monitor the integrity of wind turbine blades, such as power characteristic monitoring [6,7], spectral analysis and order analysis [7], strain monitoring-based algorithms [7], inertial sensing [8], optical coherence tomography [8], bicoherence based on electrical power [9] and AE based on pattern recognition [10,11].

Especially, a Fiber Bragg grating (FBG) sensor has been recently applied to structural health monitoring of wind turbines, because it has the advantage of a direct physical correlation between the measured Bragg wavelength and strain, and has immunity to lightning and electric shortage, and moreover, uses far fewer cables and channels [12]. However, large amounts of its measured data and much computational load in implementing monitoring algorithms including frequency analysis require a high-speed data transmission unit and a high-speed data processing unit, respectively.

To solve the problems aforementioned, the KEPCO Research Institute developed a novel signal transformation algorithm that is very effective in monitoring turbine blades in real time. The proposed algorithm first synthesizes three raw moment signals into two orthogonal signals relative to the rotating blades, and then, transforms the two orthogonal signals into two final transformed signals relative to the center of blade rotation in order to eliminate rotational components with a fundamental frequency from the obtained signals. When performing this transformation, the

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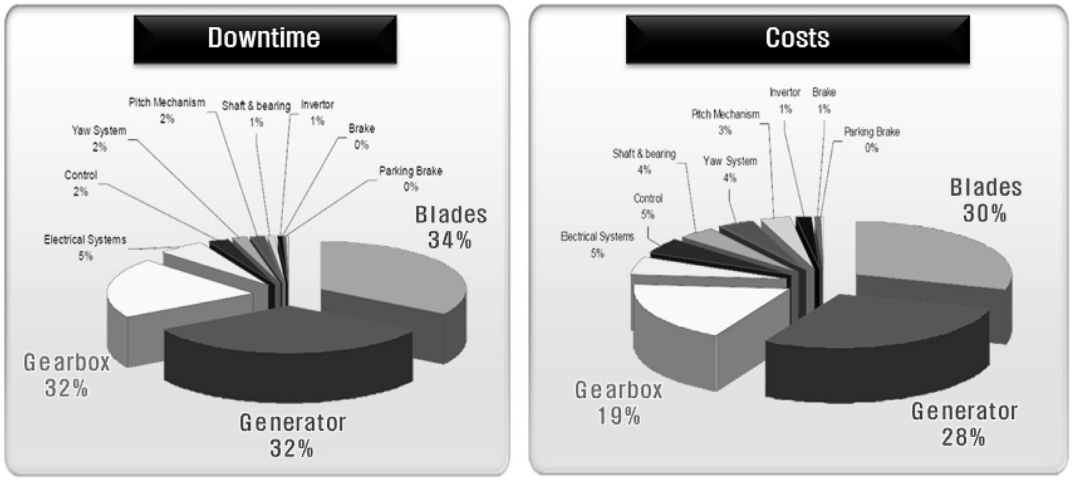

Fig. 1. Failure rate of wind turbine components [1].

proposed method uses the rotation angle estimated by the Phase Locked Loop (PLL) instead of using a sensor, thereby achieving additional cost reduction. Through the proposed algorithm, three sinusoidal signals can be finally simplified into two static signals, which can reduce computational burden in implementing monitoring algorithms and signal analysis. The effectiveness of the signal transformation algorithm is confirmed through simulations and field tests with an actual wind turbine.

2. Transformation algorithm of blade moment signals

The proposed algorithm presents the effective algorithm of moment signal transformation for a 3-blade horizontal axis wind turbine, which can be used for validating the integrity of its blades. The basic idea of this algorithm is to transform the 3-blade raw moment signals into 2-orthogonal signals, thereby making a blade monitoring process more simplified and efficient.

Fig. 3 shows the overall procedures of the moment signal transformation algorithm. First, the 3-blade raw moment signals are obtained by fiber optic sensors from the leading edge sides of the blade roots, which will be described in detail in Section 4. Second, instead of processing the 3-blade moment data directly, the signals are transformed into a reference signal and its orthogonal signal, which are attached to a rotating blade, by using the direct-quadrature transformation [13]. Third, the blade rotation angle estimator using the PLL estimates the angular velocity of the turbine blades that will be used for eliminating rotational components from the two orthogonal signals. Finally, the transformed signals for blade monitoring are calculated through the coordinate transformation using a rotation matrix. Each procedure will be explained in more detail in the following subsections.

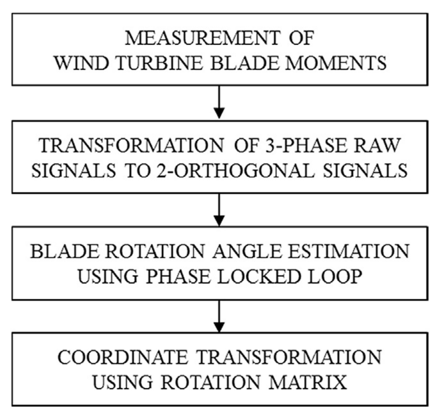

Fig. 3. Overall transformation algorithm of blade moment signals for blade monitoring.

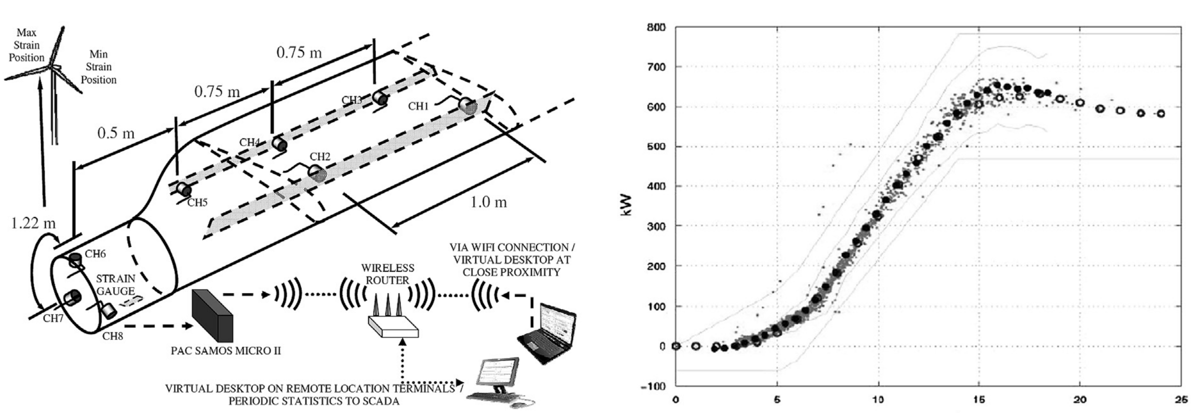

Fig. 2. Schematic illustration of structural condition monitoring using AE sensors and power characteristics.