653. Condition monitoring with signal processing in wind turbines

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Abstract. Renewable energy sources will come at the beginning of the future energy resources. In particular, wind power is among the most discussed sources in Turkey and all over the world. In this study, a model of the three-blade horizontal-axis wind turbine was designed. Analysis of fault, which may occur as a result of a possible blade deformation, was performed with the model. Comparison is provided between generator rotor speeds and torques for the states of healthy and damaged blades. Continuous wavelet transform (CWT) approach was adopted as the analysis method. The state of the healthy blade and the broken one were clearly identified by means of the CWT.

Keywords: wind turbines, continuous wavelet transform, condition monitoring.

1. Introduction

Nowadays, the use of wind energy as one of the renewable energy sources is increasing [1]. However, the largest difficulties are associated with financial aspects of utilization of renewable energy [2]. When wind turbines are compared to fossil fuel systems in terms of cost, the cost of fuel plays an important role for the fossil fuel energy systems. Whereas the initial setup costs of wind energy systems are higher. In addition, maintenance costs play an important role too [3]. Variable load conditions and hard operating environments lead to faults of wind turbines, which increase the maintenance costs [4]. Furthermore, another reason of increment at operational and maintenance costs is installation of wind turbines at remote areas [5]. Prevention of faults and decrement of maintenance costs at wind turbines are extremely important for ensuring reliability with respect to conventional power systems and competition [6]. The most effective way of this is continuous condition monitoring which provide early fault detection, facilitates preventive responses, maximizing productivity while minimizing downtime [7]. Today condition monitoring systems such as vibration, temperature, oil and generator current analysis are used in wind industry. Wind turbine condition monitoring based on electrical quantities is more useful, more comprehensive, more simple and cheaper than other techniques since analysis based on vibrations leads to abundance of cables and sensors, oil analysis cannot detect faults outside gear box, while optical strain measurement method for the stability of blade is expensive [8].

Blades, which are key element for energy transformation in wind turbines, affect operation characteristics directly and detection of their faults is difficult [9]. Furthermore when a fault occurs at one of the blades, an accident may occur and this may cause great economic loss [10]. In recent years, signal processing techniques are employed to determine fault conditions in electrical systems. Analysis of transient conditions in power systems or detection of variability in a system is very easy with signal processing techniques [11-13]. Therefore, Continuous wavelet transform (CWT) was used to detect deformation of the wind turbine blade in this study. Model of three blade horizontal axis wind turbine was designed and then blade fault was created by breaking one of the model blades. Rotor speeds and torques were compared between normal operational conditions with healthy blades and fault operation conditions with broken blade. CWT technique was used as analysis method for comparison.

2. Wavelet Transformation

Haar firstly used wavelet method in his thesis in 1909. Haar wavelet function has not got continuous derivative. In the 1930-s, in the studies on variable sized base functions, Littlewood and Paley (1937), obtained functions that protect their energy while the scale change. In 1950-1960 Littlewood-Paley theory was applied to partial differential equations and integral equations [11-13]:

$$X(\omega) = \int_{-\infty}^{+\infty} x(t).e^{-j\omega t}dt \quad (1)$$

$$x(t) = R_0 + \sum_{k=1}^{\infty} R_k.\cos(kt + \theta_k) \quad (2)$$

Mathematically, the Fourier transform is expressed by (1). As a result, the transform X (ω) gives the Fourier coefficients. So that signal can be expressed as (2) [11-14].

2.1. Continuous Wavelet Transform

Time-frequency diagram of signals which have variable frequency according to time are obtained with continuous wavelet transform as optimal [11]. Wavelet transform firstly was used in quantum mechanics and as a statistical approach. Signal processing has found place in first application areas of Wavelet transform. Window function in short term Fourier transform used before wavelet transform is fixed width during scan, this caused to not classification exactly in time changes of fast-changing high-frequency signal. As a solution to this problem, instead of fixed-width windows, usage of wide window functions for slow changes in signals and usage of narrow window functions for fast changing ones were introduced and, consequently, the wavelet analysis has emerged [14]. CWT function is shown as follows:

$$SDD_x^{\psi}(\tau,s) = \psi_x^{\psi}(\tau,s) = \frac{1}{\sqrt{|s|}} \int x(t)\psi^*\left(\frac{t-\tau}{s}\right)dt \quad (3)$$

$$\psi_{\tau,s} = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right) \quad (4)$$

3. System Model

There are two main turbine structures: horizontal and vertical axis. Horizontal-axis wind turbines (HAWT) with wind direction parallel to the axis of rotation are the most common. Horizontal-axis wind turbine is now widely used due to advantages such as being more cost-effective. Modern HAWTs are two or three bladed designs [15]. For these reasons, three-bladed horizontal axis wind turbine is simulated in this study (Figure 1) and the output values are examined. Example system model was taken from Mathworks [16].

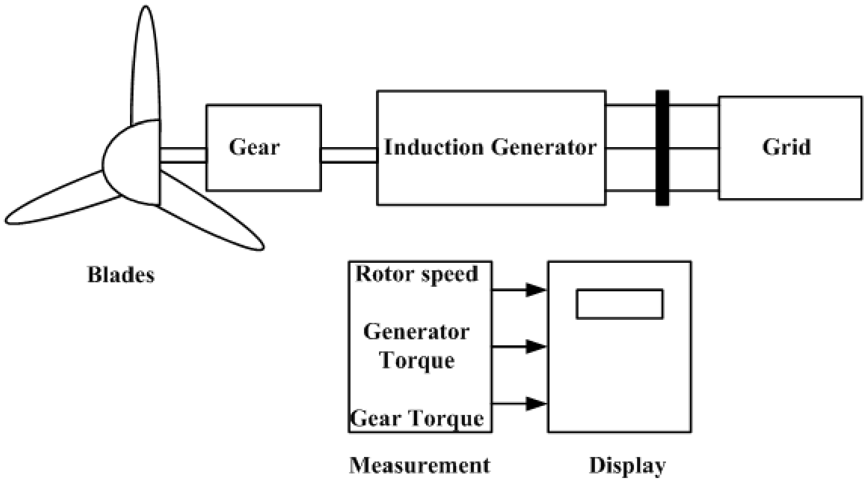

Fig. 1. System model

A fracture is created in one of the blades of the system model under the considered working conditions (Fig. 2). Turbine output values are also examined for the created fault condition.

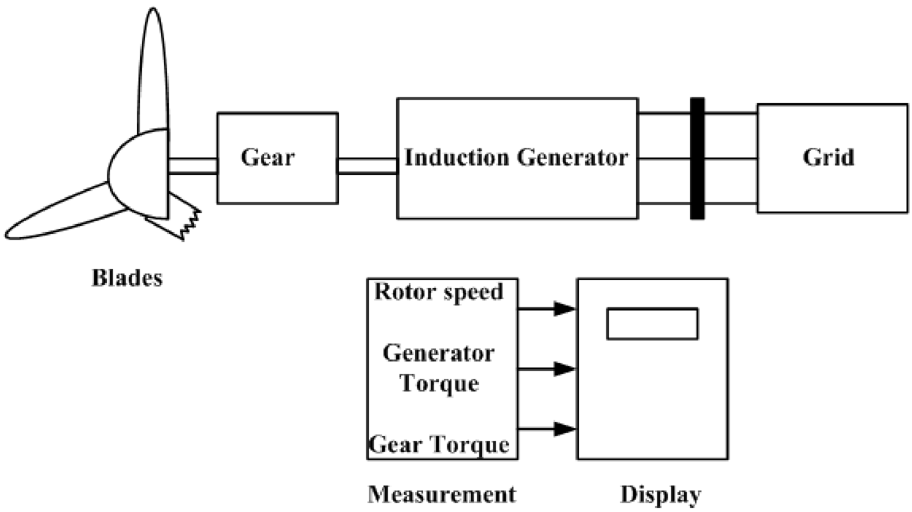

Fig. 2. Model of a faulty system

4. Fault Condition Analysis

Simulations for wind turbine are carried out under normal operating conditions and for the case of a damaged blade. In order to understand whether there is not significant relationship, comparisons are made between the healthy and faulty conditions. The comparisons with the scope of this aim are presented as rotor speeds in Fig. 3, generator torques in Fig. 4 and gear torques in Fig. 5.

4.1 Fault Condition Analysis with CWT

Continuous wavelet analysis for rotor speed of healthy turbine is provided Fig. 6 and continuous wavelet analysis for rotor speed of the faulty turbine is shown in Fig. 7.

Normally, when rotor speeds are compared, difference is difficult to understood because of difference is not enough to be noticed visually as it may be observed from the rotor speed comparison chart in Fig. 3. Whereas when time, scale and coefficient relationships are examined, low-frequency high coefficient section is obvious as rotor speed chart of faulty wind turbine in Fig. 7 (the first hill section in chart). This difference is remarkable with high frequency sections in first hill in Fig. 6.

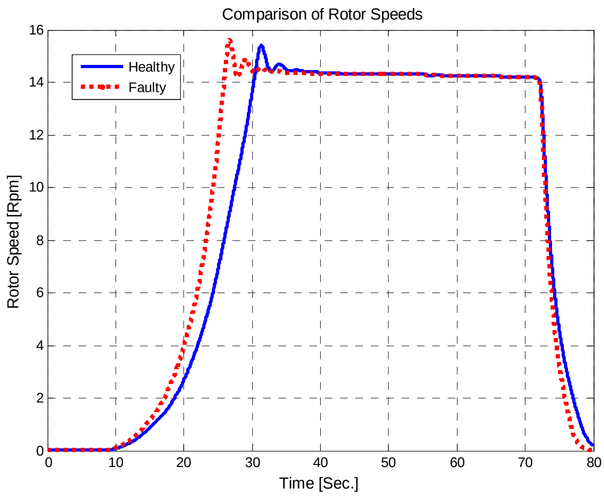

Fig. 3. Comparison of rotor speeds of healthy and faulty turbines

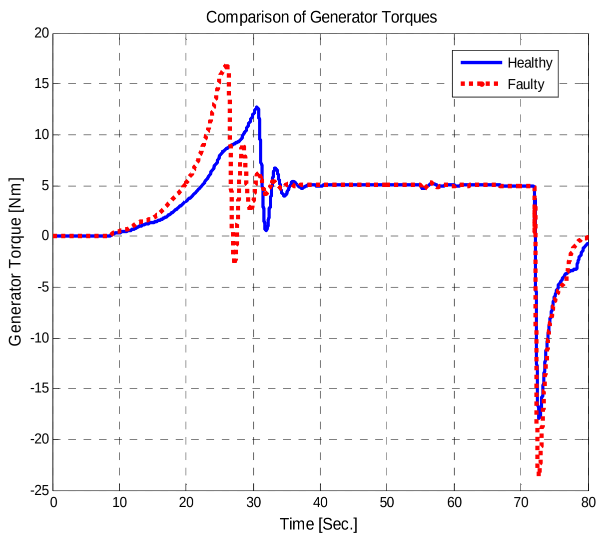

Fig. 4. Comparison of generator torques of healthy and faulty turbines

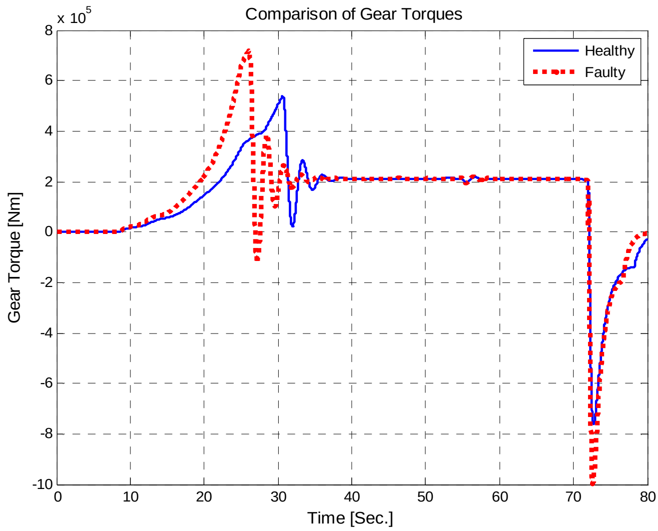

Fig. 5. Comparison of gear torques of healthy and faulty turbines

5. Conclusions

In this study, modeling and analysis of widespread three-bladed horizontal-axis wind turbine was performed. Firstly, model of the turbine was designed and expected blade deformation, which may occur in real turbines, was simulated. Comparison was performed on the basis of data obtained from the simulations. Also healthy and faulty status of system were compared and examined with wavelet analysis, which demonstrated that faulty turbine has coefficients with higher amplitude than healthy turbine in 16-128 scales. This indicates that this method is a successful in detecting deformations in the system. It was confirmed that the method provides successful results for detection of faults and it is compatible with the conducted analysis.

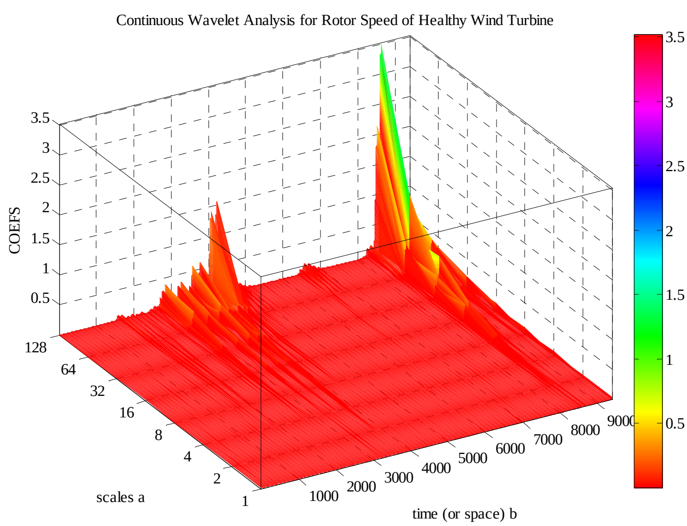

Fig. 6. Continuous wavelet analysis for rotor speed of healthy wind turbine

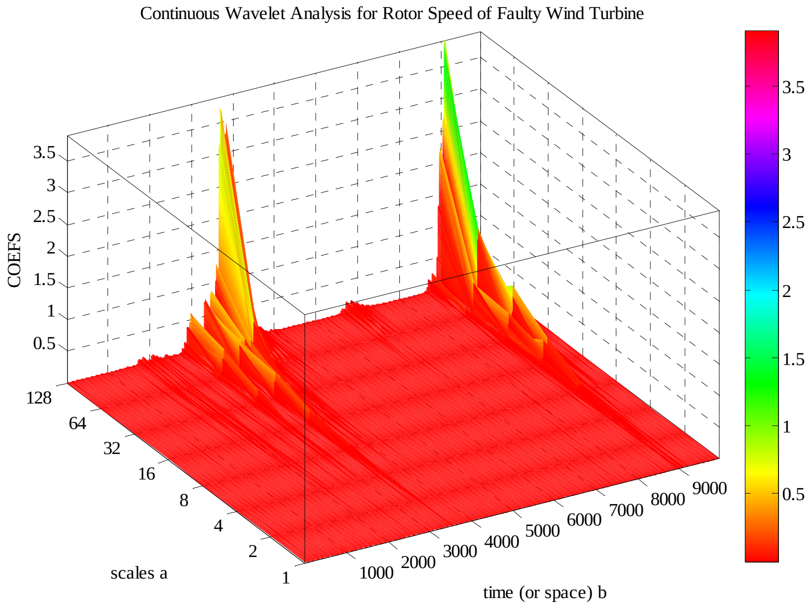

Fig. 7. Continuous wavelet analysis for rotor speed of the faulty wind turbine

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