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Regular and nonlinear dynamics of horizontal axis wind turbine blades subjected to fluctuating wind loads

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Abstract

This research investigates the nonlinear behavior and diagnosis of the nonlinear behavior of the horizontal axis wind turbine blades under fluctuating wind loads. Geometric nonlinearity of a blade and the nonlinear rotation of the blade subjected to the combined excitations of aerodynamic forces, elastic forces, and inertia forces including Coriolis forces are considered in the investigation. Various types of responses of the blades are found, including periodic, nonperiodic, quasiperiodic and chaotic vibrations, corresponding to the fluctuating wind loads. The influences of different external excitations due to the wind loads on the nonlinear responses of the blade are examined. The nonlinear responses of the blade are quantitatively characterized with the newly developed Periodicity-Ratio (P-R) method and the results are compared with that of Lyapunov Exponent method. The present approach shows efficiency and accuracy in comparing with the other approaches of nonlinear vibration characterizations.

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Keywords: nonlinear vibration; wind turbine blades; chaos; Lyapunov Exponent; Periodicity-Ratio; HAWT wind turbine; wind power.

1. Introduction

Horizontal Axis Wind Turbines (HAWT) are becoming an increasingly important source of green and renewable energy and have attracted great attention from researchers and engineers in their development and applications. In the past decades, the wind turbines have been built larger and larger in size and the blades of the wind turbines have

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become lighter, longer and more flexible. This causes the concerns of nonlinear vibrations of the blades, as the nonlinear vibrations may lead to large deflections or fatigue failures of the blades and gear boxes of the turbines. The nonlinear vibrations also produce instability of the wind turbine blades therefore cause difficulties in controlling their operations and bring negative effects on the quality of the electricity generated by the wind turbines.

Vibratory responses of wind turbine blades, especially those of large scale blades, have attracted attentions of numerous researchers and engineers [1]. With the increasing demand for large scale wind turbines and for the high efficiency and controllability of the operations of the turbines, comprehension of the nonlinear behavior of the wind turbine blades become all the time more important. Several theoretical and numerical investigations on the nonlinear behavior of the blades are seen in the current literature [2]. However, due to the complexities of the wind turbine blades under dynamic wind loads, not many systematic studies on nonlinear behavior of the blades are found in the field and a thorough comprehension of nonlinear behavior of the blades are still in lacking. This research intends to study the nonlinear behavior and to diagnose the nonlinear behavior of the wind turbine blades under fluctuating wind loads. The influences of different external excitations due to the wind loads on the nonlinear responses of the blade are to be examined. The nonlinear responses of the blade are quantitatively characterized with the newly developed Periodicity-Ratio (P-R) method and the results are compared with that of Lyapunov Exponent method. With the present approach, the global responses of the wind turbine blades can be quantified and accurately diagnosed corresponding to large ranges of system parameters, geometric dimensions and loading conditions. A periodic-nonperiodic-quasiperiodic-chaotic region diagram is to be created for quantitatively and graphically evaluating the nonlinear behavior of the blades. This research is significant for HAWT wind turbine blade designs with considerations of nonlinear vibrations of the blades and provides an efficient and accurate tool for analyzing and characterizing the nonlinear responses of the blades.

2. HAWT turbine modeling

A sketch of HAWT turbine considered in this research is shown in Fig. 1 (a) and the blade of the turbine is illustrated in Fig. 1 (b). For the sake of clarity, the blade is considered as cantilever beam. In Fig. 1, OX_0Y_0 represents the inertial coordinate system for the blade, and the *OXY* is the rotating coordinate system moving with the blade under the wind load.

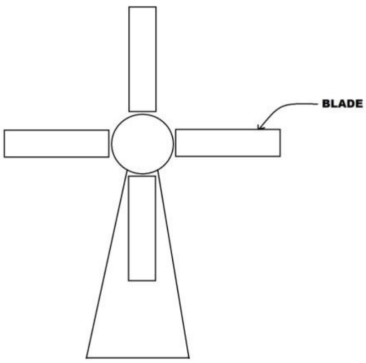

Fig. 1 (a) Sketch of Horizontal Axis Wind Turbines (HAWT)

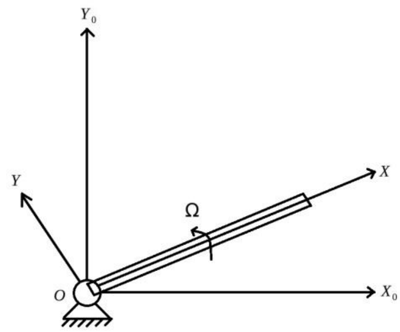

Fig. 1 (b) Blade of turbine

The speed of the blade is considered as varying with time and can be expressed as:

$$\Omega = \Omega_0 + A\cos\omega t \quad (1)$$

where Ω_0 is the average angular velocity, A is amplitude and ω is the frequency for blade rotation.
The wind speed is divided into the long period and short period parts [8].The varying velocity of the fluctuating