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Active structural control for load mitigation of wind turbines via adaptive sliding-mode approach

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Abstract

This paper studies the load mitigation problem for wind turbines by using active tuned mass dampers. A state space model for the tower/nacelle system is established with the consideration of tower/blade interaction. The uncertainties that appear in the damping matrix and natural frequencies are also considered in the controller design. External loads acting on the tower including the drag force induced by winds and the absolute base shear induced by the rotating blades are involved, and shaping filters for online generating these loads are proposed which can be easily implemented in numerical simulations. An adaptive sliding-mode controller is proposed to handle the system uncertainties, external disturbances and hard constraint, and also to improve the overall performance of the wind turbine system. Numerical simulations are performed to demonstrate the effectiveness of the proposed control law.

1. Introduction

As one of the most promising renewable energy sources, wind energy has drawn increasing attention all over the world [1–7]. In particular, the horizontal axis wind turbines (HAWTs) have been the most-installed wind turbines nowadays, where the tendency is to design taller towers so that stronger winds can be experienced, and consequently, more power can be gen-

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erated [8]. However, these tall towers have also been more vulnerable to the wind excitations due to their very flexible and lightly damped structures. As a result, the significant vibrations experienced by the towers may slow down the wind energy conversion to electrical power, reduce the fatigue life of the systems, and reduce the annual wind turbine availability [9]. Therefore, the load mitigation problem for wind turbines is a vital design consideration to protect the structures from wind induced vibrations, to prolong the lifespan of wind turbines and to improve the overall performance.

Structural control has been demonstrated to be an effective way to suppress vibrations for wind turbines and other mechanical systems. An auxiliary spring mass system adhered to the primary structures, known as tuned mass damper (TMD) or dynamic vibration absorber (DVA), is a common device for structural control [13]. Generally speaking, the structural control devices can be classified into three categories, that is, passive, semi-active, and active control. For wind turbine with passive control, in [10], a passive TMD is installed at the nacelle to suppress the vibration of the wind turbine with the consideration of blade/tower interaction. In [9], the reliability of the wind turbine system is improved by using a single or multiple passive tuned liquid column dampers (TLCDs). In [14], active structural control with TMDs is investigated, and it demonstrated that active control can further reduce the load compared with passive control. In [11], active structural control via generalized H_∞ method is studied for offshore floating wind turbines. In [12], the problem of balancing power and structural loads using normal actuators in wind turbines is investigated.

This paper is concerned with the load mitigation problem for wind turbines by using active structural control with TMDs. The system uncertainties arising from the inaccurate estimation of the damping and natural frequencies are considered. To account for the tower/blade interaction, the tower and blade are modeled as discrete multi-degree-of-freedom systems, where a time-varying formulation for the blade is proposed. The shaping filters to online generate the wind excitations including the wind drag force and the rotationally sampled spectra for wind turbulence are designed. An adaptive sliding-mode control law is designed to handle the system uncertainties and the external disturbances.

The structure of this paper is organized as follows. In Section 2, the model of the tower/nacelle system is proposed and the overall problem is formulated. In Section 3, the adaptive sliding-mode controller is designed for the tower/nacelle system. In Section 4, the external disturbance to the tower/nacelle system induced by wind is introduced and methods to simulate these excitations are proposed. Section 5 presents the numerical simulation results with different settings. Conclusions are drawn in Section 6.

Notation

The superscript T denotes the matrix transposition; the notation $\mathbf{P} > 0$ means that $\mathbf{P}$ is symmetric and positive definite; $\mathbf{I}$ and $\mathbf{0}$ represent identity matrix and zero matrix; the notation $\| \cdot \|$ refers to the Euclidean vector norm. In symmetric block matrices or long matrix expressions, we use * to represent a block in a matrix that is induced by symmetry. Matrices, if their dimensions are not explicitly stated, are assumed to be compatible for algebraic operations. Scalar quantities are represented in the italic (sloping) type, while vectors and matrices are represented in the upright bold type. The space of square-integrable vector