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Sliding Mode Based Control for a Flexible Wind Turbine

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Abstract

Control of wind turbines has been the subject of intense research activity these last decades. Among the main pursued objectives, one finds the need to deal with the design of the controller with the flexibility of these installations that can be the cause of significant perturbations. Such advanced controller can enhance the performance of electric energy production from the wind, reduce fatigue loads and limit the cost. Using an analytical mechanical model that integrates flexibility of a wind turbine in terms of drive train torsion, tower flexure and blades out-of-plane flexure, a sliding mode controller was developed in this work. The control law was synthesized and stability of the controlled system was proven by using Lyapunov criterion.

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Keywords: Wind Turbine; Sliding Mode Control; Flexibility; Stability; Lyapunov method.

1. Introduction

Control of wind turbines is being the subject of vast research activity. Most of the published works describe the wind turbine dynamics as being associated to that of its drive train, thus neglecting other flexible structural modes [1,2]. The drive-train consists of the low-speed shaft and the high-speed shaft which are coupled by a gearbox. A two-mass flexible model of the drive train was also introduced to account for some flexibility of the system [3]. Flexibility is an important factor in practice because of the need to deal with actual variable-speed wind turbines having such a large structure. Other concerns are related to the objective of driving down the costs by enhancing the

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system performance [4,5]. The design of a realistic controller that is able to take into account the effect of loads on the structure and that does not generate excessive loads by the control action is then essential.

Using a linear one degree-of-freedom structural model of the wind turbine, many wind turbines control systems have been designed [6,7]. Using a two mass model for the wind turbine the nonlinear dynamic state feedback controller with estimator (NDSFE) was introduced [2]. This controller is based on a nonlinear methodology and uses a special wind speed predictor. Based on a fuzzy integral sliding mode control, an optimal control loop for the wind power system was designed [8]. An integral sliding mode control (ISMC) for maximization of extracted power at below rated wind speed was also proposed [9]. A hybrid controller based on SMC and Radial Basis Neural Network control was recently proposed [10].

Much progress has been made in the last decades in the developing of complex simulators for wind turbine systems, providing accurate predictions of loads and performance . However, the complexity of these models cannot be handled for control purposes and lower-order linearized models are usually required. To avoid these difficulties ad direct four degrees-of-freedom modeling of a horizontally axis flexible wind turbine was proposed [11]. This modeling takes into account drive train torsion flexibility as well as tower and blades flexure.

From this model a linearized model is derived in this work and will be used in the framework of Sliding Mode Control (SMC) of the wind turbine. Considering the partial loading region of variable wind speed turbine, where the objective of control is to track the maximum power, a SMC based controller is proposed. This controller takes advantage from SMC which is known to achieve better efficiency. Stability of this controller will be proved by using Lyapunov energy criterion.

Nomenclature

a	Length of the nacelle
B_t	Damping of the tower
B_p	Damping of each blade
B_s	Damping of the transmission
B_r	Rotor external damping
B_g	Generator external damping
I_t	Inertia of the tower
I_p	Inertia of blades
J_r	Inertia of the rotor
J_g	Generator inertia (low-speed side)
H	Height of the tower
H_g	Distance to the mass center of the tower
k_t	Stiffness of the tower
k_p	Stiffness of each blade
k_s	Stiffness of the transmission
m_t	Mass of the tower
m_p	Mass of each blade
n_g	Gearbox Ratio
R	Length of blades
R_g	Distance to the mass center of the blade