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ScienceDirect

Procedia Computer Science 125 (2018) 398–404

Procedia Computer Science

www.elsevier.com/locate/procedia

6th International Conference on Smart Computing and Communications, ICSCC 2017, 7-8 December 2017, Kurukshetra, India

Robust Control of Variable Speed Wind Turbine Using Quasi-Sliding Mode Approach

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Abstract

In this paper, a robust controller is designed for variable speed wind turbine (VSWT) system. The VSWT is an uncertain system having nonlinear dynamics. The irregular behavior of wind makes the system unstable. To overcome this problem, a nonlinear robust controller is designed using quasi-sliding mode approach (QSMC). The chattering effect is almost eliminated from the overall system. The obtained results are validated through simulation studies. The simulation results are compared with the conventional sliding mode controller to show the superior performance of the proposed control scheme.

Peer-review under responsibility of the scientific committee of the 6th International Conference on Smart Computing and Communications.

Keywords: Nonlinear system; quasi-sliding mode control; robustness; uncertainty; variable speed wind turbine

1. Introduction

Due to shortage of energy as well as environmental concern for the mankind, the wind energy conversion system (WECS) has been considered as the fastest growing renewable energy resource [1]. According to wind speed, the variable speed wind turbine (VSWT) operates into two regions [2]. These regions are namely torque control region (TCR) at partial-load and pitch control region (PCR) at full-load, where the VSWT operates at optimal and rated speed respectively. In the TCR, the maximum energy is extracted from the wind at the optimal rotor speed, where

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1877-0509
Peer-review under responsibility of the scientific committee of the 6th International Conference on Smart Computing and Communications
10.1016/j.procs.2017.12.052

generator torque is used as control variable [3]. Similarly, in the PCR, the pitch angle is used as the control variable to limit the generator output power at the rated rotor speed. In this paper, the main focus is on the torque control design of the VSWT.

For the extraction of maximum output power from the wind, there are several linear/nonlinear torque controllers has been proposed in the literature [4]-[11]. The proportional-integral-derivative controller for the torque control of VSWT is designed in [4]. A linear model predictive control (MPC) for torque control of VSWT is proposed in [5]. Similarly, a linear quadratic Gaussian controller (LQG) has proposed for torque control of VSWT in [6]. The VSWT operates at both partial-loads as well as full loads under a wide range of varying wind speed. Thus, these linear controllers are providing only local stability for the VSWT. Also they require online tuning of the control parameters to deal with hard nonlinearities present in the system due to the stochastic nature of wind speed. The nonlinear and intelligent controllers proposed for the torque control of VSWT are feedback linearization control (FLC) [7], sliding mode control (SMC) [8], Backstepping control [9], neural network control (NNC) [10], and fuzzy based control [11] etc. For a permanent magnet synchronous generator (PMSG), a DC-link voltage controller is designed through FLC to control the grid power of wind power system [7]. In order to deal with the problem of power generation and stability of VSWT, a higher-order SMC approach has been reported in [8]. The obtained results indicate the achievement of smooth torque and better power regulation. Similarly, a Backstepping and NNC approach for VSWT has been implemented to track the optimal speed and maximum power extraction in [9] and [10] respectively. By controlling the rotor speed of VSWT using an adaptive fuzzy controller, the maximum power has been achieved [11]. Among the above nonlinear control techniques, quasi sliding mode control (QSMC) has been proven to be an effective and efficient robust control technique to deal with nonlinearities, uncertainties and chattering effects. In the literature, not much survey available on the torque control design of VSWT using QSMC. The QSMC based torque controllers designed for VSWT are reported in [12], [13].

In this paper, QSMC based approach is applied to control the VSWT. This work presents the torque control of VSWT using QSMC, where the high wind speed acts as the disturbance. The performance of the proposed controller is evaluated with a conventional SMC with and without disturbances. Also the robustness issue is addressed in the presence of external disturbances. Rest of the paper is organized as follows. In Section II, the mathematical modeling of VSWT is briefly presented. The problem statement is formulated in Section III. In Section IV, the robust controller for VSWT is designed using SMC and QSMC approach. Section V demonstrates simulation results of the proposed control scheme with a comparative analysis. Section VI concludes the work presented in this paper.

2. Mathematical Modeling

The mathematical modeling of considered wind turbine consists of aerodynamic model, rotor speed dynamics model and elastic tower fore–aft motion model. Overall, the dynamical model of VSWT with its physical parameters is represented in Fig.1 [3].

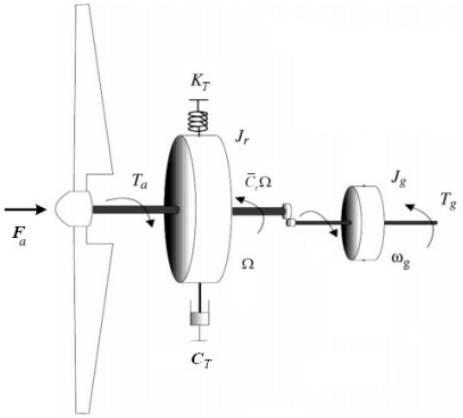

Fig.1. Wind turbine dynamical model [3]