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Fault-tolerant sensorless control of wind turbines achieving efficiency maximization in the presence of electrical faults☆

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Abstract

This paper proposes a sensorless fault-tolerant control strategy solving the tracking problem of the maximum delivered power characteristic for a wind energy conversion system equipped with a permanent magnet synchronous generator. A previously published control scheme ensuring the maximum power efficiency of the wind turbine, not requiring feedback information about rotor speed and position, and about wind velocity, is here extended to make the control scheme fault-tolerant with respect to possible electrical faults affecting the equations of the permanent magnet synchronous generator (PMSG) in the original (α, β) frame. The control law is based on a number of interconnected nonlinear observers. Closed loop asymptotic vanishing of the observation errors is proved. The proposed control solution has been validated on the National Renewable Energy Laboratory (NREL) 5-MW three-blade wind turbine model.

☆ A preliminary version of this study has been presented in [1].

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1. Introduction

Among currently available wind energy conversion systems (WECS), variable-speed wind turbines (WTs) are continuously increasing their market share, since they allow to track changes in wind speed by adapting the shaft speed and thus enable the turbine to operate at its maximum power coefficient over a wide range of wind speeds [2–4]. As well known, to achieve the goal of power efficiency maximization, the turbine tip speed ratio should be maintained at its optimum value despite wind variations. Recently, in order to improve reliability, efficiency, and reduce maintenance costs WECs are equipped with directly-coupled permanent magnet synchronous generators (PMSGs) [5], which are receiving growing acceptance in industrial applications and energy conversion systems because of their desired features: fast dynamical response, high torque to weight ratio, high efficiency, low noise, and robustness [5–10].

The problem of WECS power efficiency maximization has been approached in recent years by different control strategies (for a comprehensive overview of variable speed wind energy conversion systems see [2,11,12]). In particular, the feedback schemes known as direct torque control [13,14] and field oriented control (FOC) [14,15] have been largely used. To account for the nonlinear behavior of the electrical and mechanical parts, and to deal with the recognized problem of mechanical parameter variations, different nonlinear and/or robust control techniques have been applied, such as, for instance, gain scheduling [16], fuzzy logic control [17], integrator backstepping [18], feedback linearization technique [19] and neural networks based control [20,21]. In the framework of robust control techniques, methods based on sliding mode control (SM) [3,22–26] have been largely used, since are computationally simpler than other robust control approaches.

All the cited control algorithms do require, as well known, feedback information about rotor position and, for wind power transfer optimization, of rotor speed and wind speed. Nevertheless, position or speed sensors of wind turbines are usually physically inaccessible, particularly for large size devices, and the associated circuitry may be poorly reliable. It follows that WECS performances in terms of energy transfer, and ultimately cost of energy, may be affected by sensors inaccuracies and/or faults, though extra costs added by rotational transducers are rather limited. For these reasons, the so-called *sensorless control* attracted the industrial interest, and induced an intensive research activity in the control community. Indeed, a number of contributions on this topic have recently appeared for different types of electrical machines. With specific reference to PMSGs [27], classification of sensorless techniques is done according to three main threads: motion electromagnetic force (EMF) based, inductance based and flux linkage based (see [28] for a review). Adaptive sliding mode observers have been also proposed [29], and extended Kalman filtering has been applied to estimate the state vector [30].

Recently, the tracking problem of the maximum delivered power (MDP) characteristic has been solved by a sensorless control algorithm using the FOC architecture reported in Fig. 1 coupled with a sliding-mode based robust observer of the aerodynamic torque [31]. In that paper, the control scheme is made independent of mechanical measurements and does not require any feedback about wind speed, making use of electrical measurements only. The key contribution offered by the present paper w.r.t. the previous work [31] consists in making the control scheme fault-tolerant with respect to possible electrical faults affecting the equations of the PMSG in the original (α, β) frame. The price paid for achieving such fault tolerance is some complexity of the control scheme, based on a number of interconnected