Annual Reviews in Control 000 (2015) 1–11

Contents lists available at ScienceDirect

Annual Reviews in Control

journal homepage: www.elsevier.com/locate/arcontrol

Fault-tolerant control of wind turbines with hydrostatic transmission using Takagi–Sugeno and sliding mode techniques[☆]

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ARTICLE INFO

Article history:
Received 15 June 2015
Accepted 2 August 2015
Available online xxx

Keywords:
Wind turbine control
Fault tolerant Control
Sliding-mode observer
Takagi–Sugeno systems

ABSTRACT

In this paper, a Takagi–Sugeno Sliding Mode Observer for actuator fault diagnosis and fault-tolerant control scheme of wind turbines with hydrostatic transmission are presented. It will be shown that sliding mode techniques have the advantages that several actuator faults of the wind turbine drive train can be simultaneously reconstructed with one and the same observer and directly applied for fault compensation. Furthermore, a simple compensation approach is implemented by subtracting the reconstructed faults obtained from the (faulty) inputs. These corrected inputs act on the system as virtual actuators, such that the originally designed controller for the nominal, i.e. fault-free situation, can still be used. The fault reconstruction and fault tolerant control strategy are tested in simulations with several faults of different types.

1. Introduction

Wind turbines with hydrostatic transmission are not yet available in commercial systems. Only recently, however, this drive train concept has been considered as an alternative to conventional wind turbines. There are several reasons for this: firstly over the rated power range between 1.5 and 10 MW, the existing gear-less direct-drive concepts cause an increase of weight around 25 percent and a cost increase of around 30 percent (Ragheb & Ragheb, 2010). Secondly, the conventional gearboxes of modern wind turbines at the Mega-Watt (MW) level of rated power are highly stressed by different load cases, where wind gusts and turbulence lead to misalignment of the drive train and a gradual failure of the gear components. This failure interval creates a significant increase in the capital and operating costs and downtime of a turbine, while greatly reducing its profitability and reliability (Ragheb & Ragheb, 2010).

In contrast, hydrostatic transmission allows mechanically decoupled operation of wind turbine rotor and generator over a wider range of wind speeds without the need of mechanical gearboxes and frequency converters. It permits the use of synchronous generators with low numbers of poles, which are cheaper than double fed induction generator for indirect drive (with gearbox) and multi-pole synchronous generators for direct drive (without gearboxes). Both drive-train configurations are commonly used in variable speed machines today. Furthermore, as a consequence of the omission of power electronics, the use of synchronous generator with an electrical voltage up to a range of 10 kV eliminates the need for voltage transformer. According to the investigation in Diepeveen and Laguna (2011), hydrostatic transmission also have a positive impact on power quality, since small rotor speed fluctuations due to wind gusts are absorbed.

Up to now, hydraulic transmissions are mainly used in construction and agricultural equipment. For these kinds of applications, condition monitoring, fault diagnosis and maintenance are easy to perform. However, for a reliable operation of hydrostatic transmission in wind turbines, fault diagnosis and fault tolerant control are indispensable especially for offshore applications. Only a few model-based fault-tolerant control approaches exist for wind turbines with conventional drive-trains. In Sloth, Esbensen, and Stoustrup (2011), passive and active fault-tolerant controllers are designed and considered with regard to accommodating altered actuator dynamics in the pitch system model. In Odgaard and Stoustrup (2012), a bank of unknown-input observers is used for fault diagnosis in the rotor and generator speed sensors of the fault detection isolation (FDI) benchmark model presented in Odgaard, Stoustrup, and Kinnaert (2009). In Sami and Patton (2012b), Sami and Patton (2014) active fault-tolerant control is achieved in the partial-load region of wind turbines by means of a sensor fault hiding approach. The fault-tolerant control (FTC) strategy uses a multiple integral observer and a fast adaptive fuzzy estimator, where the observer designs are based on a nonlinear Takagi–Sugeno (TS) model. In Sami and Patton (2012a), a passive sensor fault-tolerant control strategy is implemented using a sliding mode controller for the partial-load region that tolerates generator speed sensor faults and generator torque offset faults. In Rotondo, Puig, Valle, and Nejjari (2013), an FTC strategy using Linear Parameter Varying (LPV) virtual

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[☆] A shorter version of this paper was presented at the 19th IFAC World Congress, Cape Town, South Africa, August 24-29, 2014

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http://dx.doi.org/10.1016/j.arcontrol.2015.08.003

Please cite this article as: H. Schulte, E. Gauterin, Fault-tolerant control of wind turbines with hydrostatic transmission using Takagi–Sugeno and sliding mode techniques, Annual Reviews in Control (2015), http://dx.doi.org/10.1016/j.arcontrol.2015.08.003