Mechatronics 21 (2011) 645–659

Contents lists available at ScienceDirect

Mechatronics

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

Robust and fault-tolerant linear parameter-varying control of wind turbines

Christoffer Sloth [a,*,1], Thomas Esbensen [b], Jakob Stoustrup [b]

[a] Department of Computer Science, Aalborg University, DK-9220 Aalborg East, Denmark
[b] Automation and Control, Department of Electronic Systems, Aalborg University, DK-9220 Aalborg East, Denmark

ARTICLE INFO

Article history:
Available online 5 March 2011

Keywords:
Wind turbine control
Linear parameter-varying (LPV) control
Fault-tolerant control
Robust control

ABSTRACT

High performance and reliability are required for wind turbines to be competitive within the energy market. To capture their nonlinear behavior, wind turbines are often modeled using parameter-varying models. In this paper we design and compare multiple linear parameter-varying (LPV) controllers, designed using a proposed method that allows the inclusion of both faults and uncertainties in the LPV controller design. We specifically consider a 4.8 MW, variable-speed, variable-pitch wind turbine model with a fault in the pitch system.

We propose the design of a nominal controller (NC), handling the parameter variations along the nominal operating trajectory caused by nonlinear aerodynamics. To accommodate the fault in the pitch system, an active fault-tolerant controller (AFTC) and a passive fault-tolerant controller (PFTC) are designed. In addition to the nominal LPV controller, we also propose a robust controller (RC). This controller is able to take into account model uncertainties in the aerodynamic model.

The controllers are based on output feedback and are scheduled on an estimated wind speed to manage the parameter-varying nature of the model. Furthermore, the AFTC relies on information from a fault diagnosis system.

The optimization problems involved in designing the PFTC and RC are based on solving bilinear matrix inequalities (BMIs) instead of linear matrix inequalities (LMIs) due to unmeasured parameter variations. Consequently, they are more difficult to solve. The paper presents a procedure, where the BMIs are rewritten into two necessary LMI conditions, which are solved using a two-step procedure.

Simulation results show the performance of the LPV controllers to be superior to that of a reference controller designed based on classical principles.

1. Introduction

Motivated by environmental concerns and the depletion of fossil fuels, increasing attention is being paid to wind energy, which is one of the most promising sustainable energy sources. From a control point of view, a wind turbine is a challenging machine, since it is driven by a stochastic input, which is poorly known. A modern wind turbine is controlled not only to maximize power production, but also to reduce loads, minimize acoustic noise emissions, and meet power quality grid codes.

Wind turbines inherently exhibit nonlinear dynamics, motivating the use of advanced control techniques such as gain-scheduled control to continuously adapt to the dynamics of the plant. Since many wind turbines are installed at remote locations, the introduction of fault-tolerant control is considered a suitable way of improving reliability of wind turbines and lowering costs of repairs. Finally, the lack of accurate models must be countered by robust control strategies capable of securing stability and satisfactory performance despite model uncertainties, see [1].

In this paper a three-bladed horizontal-axis, variable-speed, variable-pitch wind turbine is considered. The aerodynamic properties of the wind turbine are functions of the pitch angles of the blades, the speed of the rotor, and the wind speed. The wind exerts torque and thrust on the rotor. The aerodynamic torque is transferred to the generator through a drive train, which upscales the rotational speed of the rotor, and the aerodynamic thrust is transferred to the tower-top.

In terms of control, the wind turbine operates in two distinct regions, illustrated in Fig. 1. At low wind speeds, in the partial load region, the turbine is controlled to maximize the power output. This is achieved by adjusting the generator torque to obtain an optimum ratio between the tip speed of the blades and the wind speed. At higher wind speeds, in the full load region, the wind turbine is controlled to reduce loads by producing a rated power output at a constant rotor speed, which is obtained by pitching the blades to adjust the efficiency of the rotor, while applying a constant generator torque. In this paper only operation in the full load region is considered.

* Corresponding author.
E-mail address: csloth@cs.aau.dk (C. Sloth).
[1] Supported by MT-LAB, a VKR Centre of Excellence.

0957-4158/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mechatronics.2011.02.001