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Adding feedforward blade pitch control to standard feedback controllers for load mitigation in wind turbines ☆

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ABSTRACT

Combined feedback/feedforward blade pitch control is compared to industry standard feedback control when simulated in realistic turbulent winds. The feedforward controllers are designed to reduce fatigue loads, increasing turbine lifetime and therefore reducing the cost of energy. Two feedforward designs are studied: collective-pitch model-inverse feedforward using a non-causal series expansion and individual-pitch gain-scheduled shaped compensator. The input to the feedforward controller is a measurement of incoming wind speed, which could potentially be provided by LIDAR. Three of the designs reduce structural loading compared to standard feedback control, without reducing power production.
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1. Introduction

Current commercial wind turbine blade pitch control algorithms are typically feedback only, as shown in Fig. 1. Blade pitch is often controlled by a simple proportional-integral (PI) based collective blade pitch controller, which receives its input signal from the error in generator speed. Recent work [1–4] has verified that more advanced feedback controllers can reduce structural fatigue loads. These advanced controllers typically employ individual pitch control and may be based on signals from strain gauges and position encoders in addition to generator speed.

LIDAR (Light Detection and Ranging) can be used to remotely measure wind speed. Recent improvements in LIDAR size, cost, and reliability have made it realistic to obtain accurate wind speed measurements upstream of the turbine. When wind speed measurements are available, we can make use of this additional information through disturbance feedforward control. This feedforward control can be combined with either standard or advanced feedback control, as shown in Fig. 2. The use of these wind speed measurements to reduce turbine fatigue loads is an area that is being actively researched. Harris et al. [5] have studied disturbance accommodating control with inputs from a Lidar simulator. Laks et al. [6–8] have studied combined feedforward/feedback MIMO control with preview wind speed inputs. Schlipf and Kühn [9] have studied feedforward control added to standard feedback control, where the feedforward controller is a gain-scheduled static gain with a low pass filter.

In this study, a feedforward controller is also added on to a standard feedback controller, but the two types of feedforward controllers studied are different than the design in [9]. The results are compared to the standard feedback controller alone. This study also includes individual pitch variations of combined feedforward and feedback control. Simulation results in realistic turbulent wind fields will show that when the feedforward control is added on, it can reduce fatigue loads without reducing power capture.

This paper is organized as follows. In Section 2, we describe the wind turbine model, baseline controllers, and wind fields used in simulations. Feedforward blade pitch control designs are described in Section 3. Section 4 presents simulation results. Finally, Section 5 contains a summary of conclusions and future work.

2. Simulated turbine and turbulent inflow

2.1. 5 MW turbine model and baseline control

All simulations are performed using a full non-linear turbine model provided by the FAST [10] software code developed at the US National Renewable Energy Laboratory (NREL). FAST is an aeroelastic simulator that models a turbine as a combination of rigid

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