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Performance of disturbance augmented control design in turbulent wind conditions

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ABSTRACT

This paper investigates the use of disturbance models in the design of wind turbine individual pitch controllers. Previous work has used individual pitch control and disturbance models with the Multiblade Coordinate Transformation to design controllers that reduce the blade loads at the frequencies associated with the rotor speed. This paper takes a similar approach of using a disturbance model within the H_∞ design framework to account for periodic loading effects. The controller is compared with a baseline design that does not include the periodic disturbance model. In constant wind speeds, the disturbance model design is significantly better than the baseline design at canceling blade loads at the rotor frequencies. However, these load reduction improvements become negligible even under low turbulent wind conditions. The two controllers perform similarly in turbulent wind conditions because disturbance augmentation improves load reduction only at the multiples of the rotor frequency in the yaw and tilt moment channels whereas turbulence creates strong collective bending moments. In addition, turbulent wind contains energy across a broad frequency spectrum and improvements at multiples of the rotor frequency are less important in these conditions. Therefore inclusion of periodic disturbance models in the control design may not lead to the expected load reduction in fielded wind turbines.

1. Introduction

Demand for renewable energy is increasing rapidly with many governments setting aggressive goals towards greener energy alternatives. Wind energy plays an important role in this development as a promising renewable energy source and its success depends on the competitiveness of its cost per unit energy. The economics of wind power generation has driven the wind power industry to turbines of enormous size. Several issues arise due to the large dimensions including increased flexibility of the tower and blades and increased coupling between the turbine modes. Advanced control algorithms can be used to address vibration and loading issues, especially at above-rated wind speeds, and thus result in better fatigue reduction and lower maintenance costs.

A wind turbine operating in above-rated wind speeds (Region 3) has the control objective of maintaining its rated power while minimizing structural loads on its blades, tower and the gearbox system. Turbulent wind conditions as well as persistent disturbances such as vertical wind shear, gravity and tower shadow are typical disturbances acting on the turbine. Conventionally, single-input single-output (SISO) classical control methods involving independent control loops are used for wind turbine control. A PID controller commanding collective blade pitch can be used to track desired constant rotor speed, while the generator torque is set accordingly to obtain rated power of the turbine. The generator torque command can be modified to add damping to the drive train torsion vibrations while collective pitch command can be modified to damp out tower fore-aft vibrations [1]. In addition to the SISO approaches, various multi-input multi-output (MIMO) control techniques such as Linear Quadratic Gaussian [2] and H_∞ [3] using individual pitch control (IPC) also have been investigated in the literature.

In addition to these methods, there are also MIMO controllers in the literature that are designed to eliminate the effects of persistent disturbances for load reduction. These controllers either use an observer to estimate the disturbances on the turbine in real time or include models of disturbances at the design stage of the controller. One common example of the estimator based approach is Disturbance Accommodating Control (DAC) [4–6]. DAC is an extension of LQR control that is based on estimating the persistent disturbances acting on the turbine. An example of the controllers that account for the effects persistent disturbances at design stage can be found in [7]. With this method, disturbance models are augmented to the plant output to model the effects of the disturbances on system outputs. Instead of estimating the disturbances directly, the undesired effect of disturbances on system outputs are considered and controllers are designed to attenuate these effects.

All these linear control approaches require a linear representation of the nonlinear wind turbine system. The turbine is subjected

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