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Controller design for a wind farm, considering both power and load aspects

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ABSTRACT

In this paper, a wind farm controller is developed that distributes power references among wind turbines while it reduces their structural loads. The proposed controller is based on a spatially discrete model of the farm, which delivers an approximation of wind speed in the vicinity of each wind turbine. The control algorithm determines the reference signals for each individual wind turbine controller in two scenarios based on low and high wind speed. In low wind speed, the reference signals for rotor speed are adjusted, taking the trade-off between power maximization and load minimization into account. In high wind speed, the power and pitch reference signals are determined while structural loads are minimized. To the best of authors' knowledge, the proposed dynamical model is a suitable framework for control, since it provides a dynamic structure for behavior of the flow in wind farms. Moreover, the controller has been proven exceptionally useful in solving the problem of both power and load optimization on the basis of this model.

1. Introduction

Wind farms help reduce the average cost of wind energy compared to individual turbines located far from each other [1]. Furthermore, the strategy of extracting maximum power of each wind turbine does not result in maximal power capture for the entire farm [2]. The reason is that the upwind turbines slow down the wind that reaches downwind turbines, by extracting too much power. Therefore, a controller should be designed for the farm to adjust the power extraction. Design of controllers for wind farms presents a challenge to prognosticate the effect of the wake formed behind a wind turbine on the other wind turbines. This challenge originates in the significant decrement in mean wind speed reaching downwind turbines, and the increment in turbulence. The increase in turbulence intensity in wakes behind wind turbines can result in a substantial increase in fatigue [3].

The research area of wind farm control can chiefly be divided into two main categories. The first is the quality control of the generated electrical power, which is not the subject of interest in this paper. The second is the coordinated control of power generated by each individual turbine such that the aerodynamic interactions between turbines are minimized [2]. In spite of some results on aerodynamic interactions in a farm [1,4], the subject is still immature.

There are numerous research in modeling and control of wind farms. An overall wind farm control that maximizes energy capture has been proposed in [4]. An optimization method to maximize the production of farms based on limitations of the physical system, e.g., voltage, voltage stability, generator power, has been proposed in [5]. Advanced controllers for wind farm electrical systems have been developed in [6,7]. The focus of [7] is the coordinated control of wind farms in three control levels: central control, wind farm control, and individual turbine control. A comparison of three control strategies for control of active and reactive power is provided in [8]. In [9], a concept with both centralized control and control for each individual wind turbine is presented. In this approach, the controllers at turbine level ensure that relevant reference commands provided by the centralized controller are followed. Despite these control methods and many research efforts on fatigue load reduction in single turbines [10–13], results on combined optimization of power and fatigue load are lacking.

In large wind farms, the upwind turbines extract most of the power from wind and increase the turbulence intensity in the wake reaching other turbines. Thus, the fluctuations and vibrations of the downwind turbines are greater than upwind turbines and results in more fatigue loads on them [14]. Therefore, the lifetimes of turbines that most frequently are in the downwind location are shortest. This fact results in reduction of the effective lifetime of the whole farm. In conclusion, wind farm controllers should employ proper strategies to reduce the extreme fatigue loads. Indeed, this can be performed by power set-point adjustment. This is possible since the wind farm controller is responsible for distribution of the power set-points between the turbines and for ensuring that the total time varying power reference commanded by the operator is satisfied.

In this regard, the aim of the present work is to develop a wind farm controller which aims at optimal distribution of power references among wind turbines, while it lessens the structural loads.

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