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A framework of an operational wind farm controller is developed in this work comprising solutions for power control and induction-control of wind farms, including measurement-processing procedures and integrated turbine control. The major advantages of the framework are faster prototyping, design flexibility and a common environment for the development of wind farm control. The measurement-processing unit comprises, amongst other, advanced procedures for the accurate quantification of wind conditions. Particularly, the measurement of turbulence was investigated with respect to the impact of the spatial variance of the second-order moment of correlated wind speeds. The first analytical solution for the quantification of the spatial variance was developed and successfully verified in this thesis. The mitigation of the impact of the spatial variance on wind farm control, the verification of wind turbine performance, and sensor verification is investigated. Thereafter, three, novel developments for power control of wind farms are presented. First, a control-oriented, dynamic, linear model of wind farm flow and operation is investigated. The developed approach allows to model the future, control-dependent evolution of wind farm flow for its use in power control. The engineering model-based state space system results in a computationally fast execution. The dynamic simulation of a two-turbine array illustrates the main characteristics of the model, and the application to a large-scale wind farm demonstrates its scalability and performance in a more realistic setting. Second, the first model-predictive dispatch for power control of wind farms is successfully developed. The approach performs flow model-predictive optimization of farm operation according to multiple objectives and uses closed-loop feedback control to track the reference total power. Dynamic simulations demonstrate reduced fatigue loads and power variability, and more accurate tracking of the reference total power, as compared to present, standard power controllers. Third, the mitigation of fatigue loads of wind turbines is investigated using a novel database-driven approach which accounts for the turbine operation-dependent aerodynamic interaction of wind turbines. The approach is incorporated into a model-predictive power controller. Dynamic simulations on an eight-turbine array show a significant reduction in the sum fatigue loads of wind turbines. Finally, the impact of induction-control in nominal operation is investigated with respect to fatigue loads and the effect of external conditions on power. Large eddy simulations show that a positive offset of pitch angle yields a beneficial reduction of the sum fatigue loads of a two-turbine array. The approach therefore allows for the trade-off between power production and fatigue loads in nominal wind farm operation. The investigation of a wide range of external conditions using the sDWM and recalibrated Larsen model showed the largest, potential power gain in low turbulence intensity and turbine spacing, and a wind direction aligned with the wind turbines. Even in the potentially most beneficial conditions, large eddy simulations showed a reduced total power production. In the ensuing chapter, a turbine controller is presented that can enable the use of induction-control in wind farms. The suitability of the developed turbine controller is successfully demonstrated on a single wind turbine, and in a wind farm set-up in interaction with the wind farm controller.

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