Optimization of wind farm power production using innovative control strategies

Wind energy has experienced a very significant growth and cost reduction over the past decade, and is now able to compete with conventional power generation sources. New concepts are currently investigated to decrease costs of production of electricity even further. Wind farm coordinated control is one of them; it is aimed at increasing the efficiency of a wind farm and decreasing the fatigue loads faced by wind turbines by reducing aerodynamic interactions between them. These objectives are achieved considering two different strategies: curtailing an upwind turbine to reduce the wind speed deficit caused by the wake downstream, or yawing the turbine to deflect the wake away from the downwind turbine. Simulation results found in the literature indicate that an increase in overall power production can be obtained. However they underline the high sensitivity of these gains to incoming wind conditions. It is therefore not known to what extent these gains can be reproduced in a real wind farm where wind conditions are very fluctuating. The French national project SMARTÉOLE constitutes one of the first attempts of implementing these strategies on a full scale wind farm. A ten month measurement campaign was realized in 2016 in which different scenarios were tested. In this master thesis the experimental data from this field test are analyzed and used to calibrate two different models. An optimization process is then performed based on these models to find the maximum power production of two aligned wind turbines.

The experimental results show that the scenarios implemented during the first measurement campaign did not achieve an increase in overall power production, which confirms the difficulty to realize wind farm power optimization in real operating conditions. In the curtailment field test, the down-regulation of the upwind turbine was probably too high to expect the downstream wind turbine to compensate for that loss. Total losses were quite low though, meaning that a significant part of the upwind turbine lost energy is regained downstream by the second turbine. Regarding the yaw offset strategy, no wake deflection could be detected at the downstream turbine and therefore no conclusion be drawn about the impact of yaw misalignment of the upstream turbine. In both cases, unfavorable wind conditions and an incomplete knowledge of the wind turbine behavior in the farm considerably reduced the amount of usable data in the wake sector.

However the data recorded during this campaign could still be used to calibrate models. First a wake deficit model was obtained by re-calibrating the well known Jensen model. Contrary to the original Jensen model, where the wake expansion coefficient is assumed to be constant for the whole wind farm, in this new proposed model it is calculated at each wind turbine based on the local measurement of turbulence intensity. In that way the wake added turbulence intensity can be taken into account and thus the wind speed deficit caused by wind turbines in the wake of other turbines further upstream is not over-estimated. This model proved to be in very good agreement with the measured power deficit in the wind farm. Second, a Ct model giving variation of wind turbine thrust coefficient during down-regulation could be derived from the analysis of guaranteed power curves and validated using experimental data.

The combined power production of two aligned wind turbines was finally maximized considering a curtailment strategy and using these two models. The results from the optimization process in full wake conditions show that the more important gains are obtained in the wind speed range 6 – 10 m/s, i.e. when both the Cp and the Ct of the wind turbines are high. The maximum expected increase in combined power production is found to be in the order of 2 to 3% for a particular wind speed bin, however when averaged over the complete wind speed range these gains represent only 0.3 to 0.5%. The width of the wind direction sector in which the coordinated control is profitable could also be assessed to 10°, centered on the full wake direction. These results confirm the high sensitivity of coordinated control to incoming wind conditions, and that gains that are to be expected considering two wind turbines only are small. New scenarios based on the results found during this thesis are supposed to be implemented during the second field test campaign of SMARTÉOLE planned for the second semester of 2017.

General information
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