WindSTAR

Wind-Energy Science, Technology, and Research
Industry/University Cooperative Research Center

Development of a Computational Tool to Maximize Wind Farm AEP by Yaw Angle Optimization

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Recent studies have demonstrated promising results for control strategies such as intentional yaw misalignment to mitigate wake interactions and optimize wind farm efficiency (Figure 1). Most studies have been carried out in "idealized conditions," i.e. typically assuming fixed wind speed and direction. In a realistic scenario, wind speed and direction vary over time, including conditions where there is little to no value added for optimization (e.g., above-rated wind speeds). Therefore, the efficiency improvements obtained with idealized studies will likely be lower when measured in terms of annual energy production (AEP). In this project, we have developed a methodology to move beyond ideal studies and estimate the impact of yaw control on AEP.

The methodology is based on high-fidelity simulations and generalized polynomial chaos. High-fidelity simulations are used to minimize the uncertainties in predicting wind farm performance. Parameterizing wake deflection by yaw (which is the key mechanism for yaw control, a.k.a intentuional yaw misaligment) is still an open issue in wind energy research, and the use of low-fidelity models may result in uncertainties of the same order of the predicted performance improvement. Coupling the high-fidelity simulations with the polynomial chaos technique provide an accurate and computationally efficient surrogate model to compute wind farm power production as a function of wind speed and direction. The surrogate model is used to estimate AEP for different control strategies (in particular, baseline vs. intentional missaligments).

The procedure has been applied to relatively small wind farm consisting of 9 turbines (Figure 2). The wind farm is sited in a complex terrain, reproduced in the high-fidelity simulations, which significantly affects performance as a function of wind direction. A surrogate model for the baseline control strategy (i.e. no yaw control) is first obtained to compute the benchmark AEP. Nested extremum-seeking control is then used to find the yaw misalignment angles to optimize power production for each wind direction. The resulting surrogate model is used to estimate the optimized AEP, which provide an improvement of about 3% for this test case. In addition, the study reveals that the improvement on individual turbines may be larger than for the entire farm. This different sensitivity could be exploited for more advanced and tailored control approaches.

Calculation of optimal yaw angles using a genetic algorithm (GA) with the polynomial chaos surrogate model has also been performed to compare with the results from extremum seeking control (ESC). Table 1 shows the optimal misalignment angles of three turbines (T13, T14, T15 in Figure 2) optimized with ESC in the high-fidelity simulation and the same three turbines optimized with the GA on the surrogate model. While yaw angles are somewhat different, the total wind farm power changes with both optimizations are comparable.

Table 1: Comparison of intentional yaw misalignment angles for three turbines from Figure 2.

	T13	T14	T15	Total power change
ESC on high-fidelity model	-8 deg	-5 deg	-10 deg	+ 3%
GA on polynomial chaos model	-11 deg	-12 deg	-12 deg	+ 4%

The proposed methodology permits to assess the impact of yaw control in realistic conditions. This will ultimately enable operators to assess the benefit of the control strategy in terms of levelized cost of energy and thus make low-risk informed decisions.

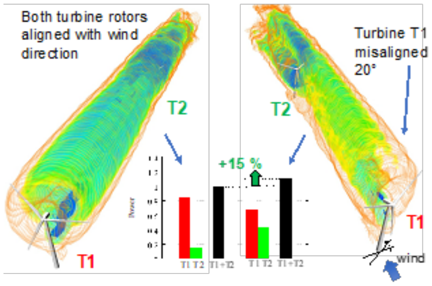

Figure 1: Intentional yaw misalignment to mitigate wake interactions. Visualizations of a two-turbine array (aligned with the wind direction) in baseline operating conditions (no yaw control, left) and with yaw control (right). With a 20° intentional yaw misalignment on T1, the trailing wake is deflected laterally, which reduces the wake interaction on T2. An improvement of 15% is obtained with yaw control for this wind direction.

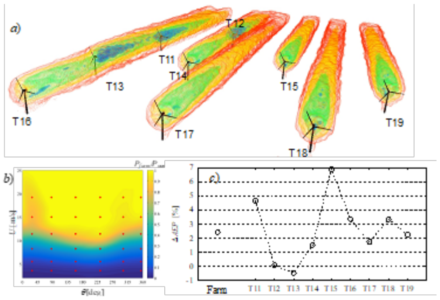

Figure 2: Application of the proposed methodology to estimate the impact of yaw control on annual energy production. Panel a): visualization of turbine wakes at the selected wind farm. Panel b): surrogate model obtained with high-fidelity simulations and polynomial chaos. For each wind speed U and wind direction ⊠, the model provides the power produced by the wind farm. Panel c): improvement of yaw control on annual energy production for the entire farm (≈ 3%) and the individual turbines.