

Editorial

Wakes of Wind Turbines in Yaw for Wind Farm Power Optimization

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The application of wind-generated energy is increasing at a great rate, about 11% per year, with an installed capacity of 837 GW in 2021, and it is the primary non-hydro renewable technology; in many countries, it is the main source of electric energy. Wind energy is generated in vast wind farms that have many wind turbines that—because of the cost of land, civil works, and other infrastructures—tend to be closely placed. It is then necessary to adequately locate them in order to minimize interference effects, mainly associated with the wakes downstream of each turbine. In a wind turbine wake, the average velocity of the wind is smaller than its ambient value and the turbulent velocities are larger, so that a turbine that is in the wake of another one will produce less power and have larger unsteady fatigue loads that will shorten its lifetime.

An interesting method to avoid these deleterious effects is the control of turbine parameters, specifically the yaw angle. The thrust force produced by the wind is essentially normal with respect to the rotation plane, so that under yawed conditions the thrust will have a component perpendicular to the wind, and the corresponding reaction force will deflect the wake trajectory. The controlled turbine, working in yaw, will produce less power and its working conditions will not be optimal, but some downstream turbines will not be affected by the deflected wake, and this may result in an overall benefit for the wind farm. This topic has been extensively studied in the literature (see, for example, [1–3]).

In this invited Editorial entitled “Wakes of wind turbines in yaw for wind farm power optimization”, we provide an inclusive review of different problems associated with the wake modelling of yawed wind turbines and with the application of these models to wind farm control leading to optimization. As can be seen in the following, there is a wide variety of technical and scientific problems on this topic that have been addressed in various papers published in this journal that are indicated and discussed below.

This Invited Editorial includes seven papers of interest about yawed wind turbines that have been recently published in this journal. Four of them [4–7] are essentially about the analysis and study of yawed wakes, and the rest [8–10] are about the application of already existing yawed wake models for controlling wind farms and examining the corresponding effects on power production and load characteristics.

Below, there is a brief compilation of each selected paper:

Lin and Porté-Agel [4] proposed an actuator disk model with rotation (ADMR) to parameterize the forces of a yawed wind turbine and implemented it in a large eddy simulation (LES) model. The results were validated with wind-tunnel measurements and compared with the results of analytical wake models; in general, there was a good agreement, although a small overestimation of the wake deflection was detected. The predictions were improved when comparing them with results obtained from a standard ADM model without rotation.

Moreover, the turbulence properties and corresponding scaling laws of wakes developing within a turbulent boundary layer were studied by Stein and Kaltenbach [5]; in particular, they examined the self-similarity of different flow characteristics. They performed wind tunnel measurements of wakes immersed in two turbulent boundary layers



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of different roughness lengths, for various yaw angles. Due to the greater momentum transfer, within the rough boundary layer, the wind turbine wake was significantly less deflected compared to that of the smooth boundary layer. Interestingly, they present a model for the diagonal part of Reynold's stress tensor that can be easily combined with other wake models.

Two aspects of the wake models for wake-steering control were studied by Howland and Dabiri [6], namely, the comparison of different procedures of wake velocity deficit superposition, and secondary steering, that is, the wake deflection of an aligned turbine located in the wake of a yawed turbine. The various wake superposition models were compared using LES applied to a six-turbine array. They proposed a model for secondary steering that was tested and validated. Interesting conclusions were obtained regarding the influence of these effects on power production and on associated errors.

Wei et al. [7] provide a two-dimensional analytical model of the wake of a yawed turbine. The predictions of the proposed model were compared with wind tunnel measurements, with results of an LES model also included in the paper, and with results of other similar analytical models available in the literature, mostly showing favorable comparisons. Interestingly, appendices are included for each one of these literature models with detailed information of the differences from the proposed one.

Kuo et al. [8] proposed a random search algorithm for the optimization of the yaw angles and applied it to a specific wind farm. Interesting observations were made regarding the quality of solutions and the optimization process characteristics. Considerations of interest were made on the influence of the density of the wind farm on the potential for yaw optimization, as well as regarding the non-uniqueness and number of solutions; the sensitivity of optimal solutions to wind direction changes was also examined.

Van Beek et al. [9] applied the wind farm model FLORIS to the Lillgrund wind farm to investigate the possibility of minimizing wake losses by steering the wakes of yawed wind turbines. First, they calibrate the model; then, they make a sensitivity study, and finally they carry out the optimization while taking uncertainty into account. Optimization was applied to both a deterministic case and other cases with different uncertainties. An interesting discussion was provided about the influence of uncertainty on the optimized results. The paper emphasized the relevance of the number and quality of available data.

Finally, Kanev et al. [10] made a thorough study on the effect of wake steering on the fatigue loads of a specific offshore wind farm. The wake flow was calculated numerically using a two-equation turbulence model, and loads were obtained with an aeroelastic simulation tool. Interesting discussions were provided concerning the relative sensitivity of loads to flow characteristics and to yaw misalignment, and about the corresponding comparison between the wake loads and those due to misalignment. The overall result is that fatigue loads tend to decrease under wake control by steering.

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