Wind turbine wakes for wind energy

KEYWORDS
actuator disk; actuator line; atmospheric inflow; Blade Element Momentum theory; CFD; individual pitch; Lanchester-Betz-Joukowsky limit; orography effects; Particle Image Velocimetry; rotor modelling; system identification; trailing-edge flaps; turbulence modelling; wake; wake aerodynamics; wake interaction; wake meandering; wake turbulence; wind energy; wind farm; wind farm production; wind speed measurements; wind speed forecasting; wind tunnel modelling; wind turbine; wind turbine control; wind turbine load; wind turbine production

During recent years, wind energy has moved from an emerging technology to a nearly competitive technology. This fact, coupled with an increasing global focus on environmental concern and a political desire of a certain level of diversification in the energy supply, ensures wind energy an important role in the future electricity market. For this challenge to be met in a cost-efficient way, a substantial part of new wind turbine installations is foreseen to be erected in big onshore or offshore wind farms. This fact makes the production, loading and reliability of turbines operating under such conditions of particular interest.

The key in understanding the above-raised issues is to identify and model the *wind farm wind climate*, which is known to deviate significantly from the wind climate faced by solitary turbines. This is due to the creation of wind turbine wakes and their mutual downstream interaction.

This special issue of *Wind Energy* (WE) contains selected papers from Euromech Colloquium 508 on 'Wind Turbine Wakes' held at the Universidad Politécnica de Madrid on 20–22 October 2009. The colloquium was organized under the auspices of the EU TOPFARM project, chaired by Antonio Crespo, co-chaired by Gunner Chr. Larsen and coordinated by Emilio Migoya.

The colloquium was organized in 10 sessions addressing a variety of wake aspects, and a total of 47 papers were presented. The *first session* was about wake models. Different existing models were analysed and compared, and possible improvements were discussed. The *second session* dealt with turbulence closure models associated with both elliptic and parabolic computational fluid dynamics (CFD) approaches. The *third session* was dedicated to CFD work on turbine aerodynamics and the near wake, including actuator surface, actuator line and actuator disc approaches. The theme of the *fourth session* was the influence of topography and atmospheric characteristics on wakes and the modification of the atmospheric boundary layer caused by very large arrays of wind farms. *Sessions 5* and *6* were about experimental work including analysis and interpretation of full-scale and wind tunnel measurements. *Sessions 7* and *8* dealt with wake meandering. This is an important topic that highlights the need for non-stationary modelling of wind farm wind fields when wind turbine loads are to be assessed. *Session 9* was about large offshore wind farms. Both the flow fields within and behind large wind farms were addressed, including the interference of an upstream wind farm on the power output of a downstream wind farm. Finally, *session 10* included contributions on wind farm and wind turbine control strategies, wind turbine fatigue loading within wind farms and wind farm layout optimization.

The selected eight papers included in this WE special issue cover a breadth of topics, ranging from theory and numerical modelling to measurements and interpretation of such.

Troldborg *et al.*[1] analysed wake interaction between two wind turbines using the actuator line technique in combination with full unsteady Navier–Stokes computations. Various ambient turbulence intensity levels, turbine inter-spacings and types of wake interaction are considered, and main deterministic and stochastic flow field characteristics are extracted and discussed.

Espāna *et al.*[2] studied the wake meandering phenomenon using physical modelling in a boundary layer wind tunnel. Based on particle image velocimetry, quantitative information on the meandering process is achieved including the instantaneous wake width and wake meandering envelope as a function of downstream distance. It is concluded that the *mean* wake width is primarily dictated by the meandering process.

Cabezon *et al.*[3] introduced an elliptic actuator disc CFD model and assessed the model in terms of wind speed deficit and added turbulence intensity. Different turbulence models are considered, and the performance is validated through comparison with full-scale experimental results and results from alternative CFD-based wake models.

Sanderse *et al.*[4] reviewed the state of the art of the numerical calculation of wind-turbine wake aerodynamics. Various CFD techniques for modelling the rotor and the wake are discussed.

Sørensen and van Kuik[5] analysed the 'free vortex' model of Joukowsky. In its classical formulation, this model relies on an approximate momentum consideration, which can be justified for high tip speed ratios only. Taking into account the influence of the pressure on the lateral boundary of the control volume, however, remedies this problem. Furthermore, neglecting expansion, they show that the use of the momentum equation is circumvented, and contrary to the classical formulation, a power coefficient distribution that never exceeds the Lanchester–Betz–Joukowsky limit is obtained.

Jiménez *et al.*[6] have analysed full-scale measurements from complex terrain and from observations, subjected to wake flow effects. Compared with conventional design code specifications, a modified spectral shape was suggested to be applied in case of wake operation and moreover modified ratios of standard deviations and turbulence length scales among turbulence components in cases where the complexity of the terrain and/or wake effects are significant.

Markou *et al.*[7] explored and compared the potential of two different control approaches for load alleviation of turbines operating under wake conditions: (1) full-blade 'individual-pitch controllers' acting as wake compensators and (2) controllers using trailing-edge flaps. The analysis is based on full aeroelastic simulations of turbines operating in a non-stationary flow field influenced by upstream emitted wakes.

Knudsen *et al.*[8] developed innovative models for forecasting wake-affected inflow velocities applicable in a wind turbine control context. Based on standard turbine full-scale measurements such as rotor speed and power production, an estimation of the wind field averaged over the rotor disc is achieved. With the use of a system identification approach, this in turn opens for innovative wind speed predictions at neighbouring turbines, with a separation of more than 700 m and up to 1 min ahead.

The colloquium chair and co-chair served as Guest Editors for this special issue. We thank the editors of *Wind Energy* for hosting this special issue, especially Paul Veers, for his invaluable help and guidance through all phases of the process.

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