Application of Modelling Methods in Wind Turbine Engineering

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Global energy demands and dwindling fossil fuels are making zero-head wind and water turbines increasingly important as renewable energy devices. Device efficiency is a key parameter in the economic viability, recovery of initial capital investment and long term profitability of such devices. Consequently, engineers world-wide have been looking at advancing free stream turbine performance to achieve economic competitiveness in the current energy market.

Significant effort has been invested in development of modelling methodologies in order to predict turbine performance. To determine a performance curve of an operational turbine, a range of aspects need to be taken into account. These include complex fluid dynamics, local topology and other environmental conditions, structural loadings and vibrations, transmission loads and generator dynamics. Furthermore, in most cases, turbines are installed in groups or farms. Flow interaction in a multiple turbine installation reduces the power output and thus has an important influence on economics of whole installations.

Betz and Glauert models were the first applications of mass and momentum balance principles to explain the turbine power output. Although, the theoretical background of these models is over-simplified and a lot of flow complexity is absent, they are still used for prediction of maximum theoretical turbine performance. Using the same principals, the actuated disc model and more complex blade element model were formulated. Both models require an empirical input to close the set of relations and to determine the turbine power output. A simple and flexible formulation, and the possibility to include an external input that describes additional flow complexity, makes these two models a very versatile and widely used tool for engineering modelling.

In comparison to the other, semi-empirical methodologies, Computational Fluid Dynamics (CFD) solves fluid flow differential equations for small discrete elements. Although, it requires substantial computational resources, the technique is able to capture complex flow physics (e.g. boundary layer separation) for most demanding operational conditions. Two-dimensional CFD simulations of blade segments can be performed to obtain lift and drag values for different flow speeds and incidence angles. This allows optimisation of different sections of turbine blades to maximize power output over a wide range of flow speeds. To capture three-dimensional flow
effects and their impact on turbine performance, a whole turbine and significantly large flow field surrounding the turbine need to be simulated. Such simulations require significant computational resources, but with falling costs of computational resources they are becoming more affordable. Furthermore, a CFD model can be coupled to a structural mechanics model to perform a fluid-structure interaction (FSI) simulation. This enables analysis of turbine deformations due to flow dynamic loading and their reversed effect on the performance of the installation.

Detailed CFD simulations of entire wind farms are still computationally too demanding. To reduce overall computational requirements, individual turbines can be modelled using the actuated disc or the blade element theory. In such simulations, different topological and meteorological environmental effects are described using CFD methods, whereas the effects of the turbines are modelled with momentum sources/sinks. Such hybrid modelling approaches have been used to predict performance of entire wind farms. In addition, advanced design search and optimisation techniques can be coupled with the simulation process to optimize the wind farm layout. Such an optimisation model was used successfully to identify a wind farm layout, which yields maximum power output for a given investment.

The described modelling methods are vital in planning, design and analysis stages as they significantly improve the energy yields, safety and reliability. They also help us to reduce the required investment costs and to avoid costly mistakes.