Wake Modelling and Design Optimization of Wind Farms

Mechanical & Industrial Engineering
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Background

Wind energy in Canada is currently generating 5% of the domestic electricity demand. Most of this energy is supplied by large wind farms. The goal of wind farm layout design is to maximize energy production while minimizing environmental impacts.

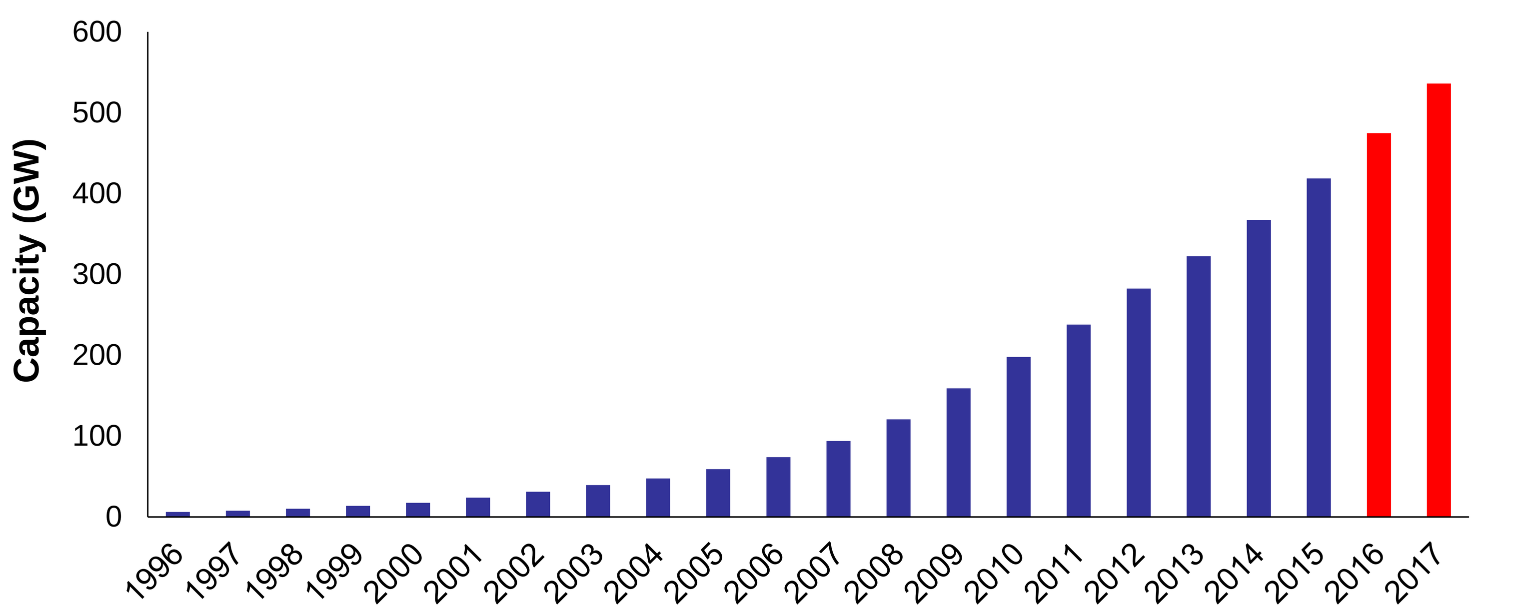

Fig. 1: Global cumulative installed wind capacity

Motivation

As the kinetic energy is extracted from the wind, a wake is generated behind the rotor, affecting energy production of turbines downstream. These wake losses can diminish annual energy production by 10 – 20% in large offshore wind farms. Thus, optimizing the turbine placement in a wind farm is crucial to reduce these losses. Accurate and low cost wake models are required for correct predictions of wake losses during the design optimization process.

Fig. 2: Photograph of the wake interactions in Horns Rev wind farm.

(Retrieved from: C.B. Hasager, L. Rasmussen, A. Peña, L.E. Jensen, P.-E. Réthoré, Wind Farm Wake: The Horns Rev Photo Case. Energies, 2013.)

Flat Terrains

The CFD simulations of wind turbine wakes are strongly influenced by the choice of turbulence model, as an inappropriate model can lead to inaccurate predictions in energy production. This work investigates the influence of different turbulence models on CFD wake simulations. The results show that wind direction uncertainty should be quantified when comparing CFD simulation and experimental results.

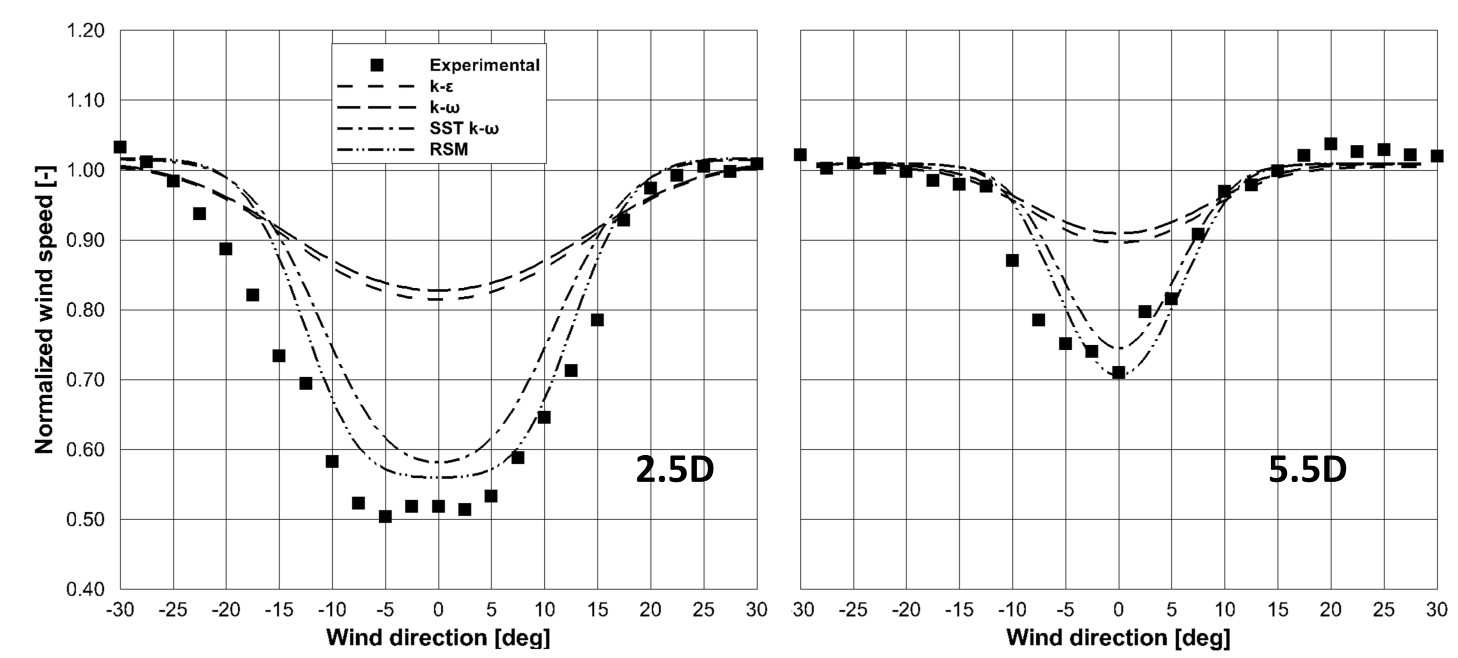

Fig. 3: Normalized wind speed downstream a stand-alone wind turbine as a function of wind direction

Complex Terrains

Energy production of onshore wind farms is strongly influenced by terrain topography. Although high-fidelity CFD wake models have been developed for complex terrains, these models remain too expensive for design optimization. The aim of this work is to develop a low cost wake model capable of accurately simulating wakes on complex terrains.

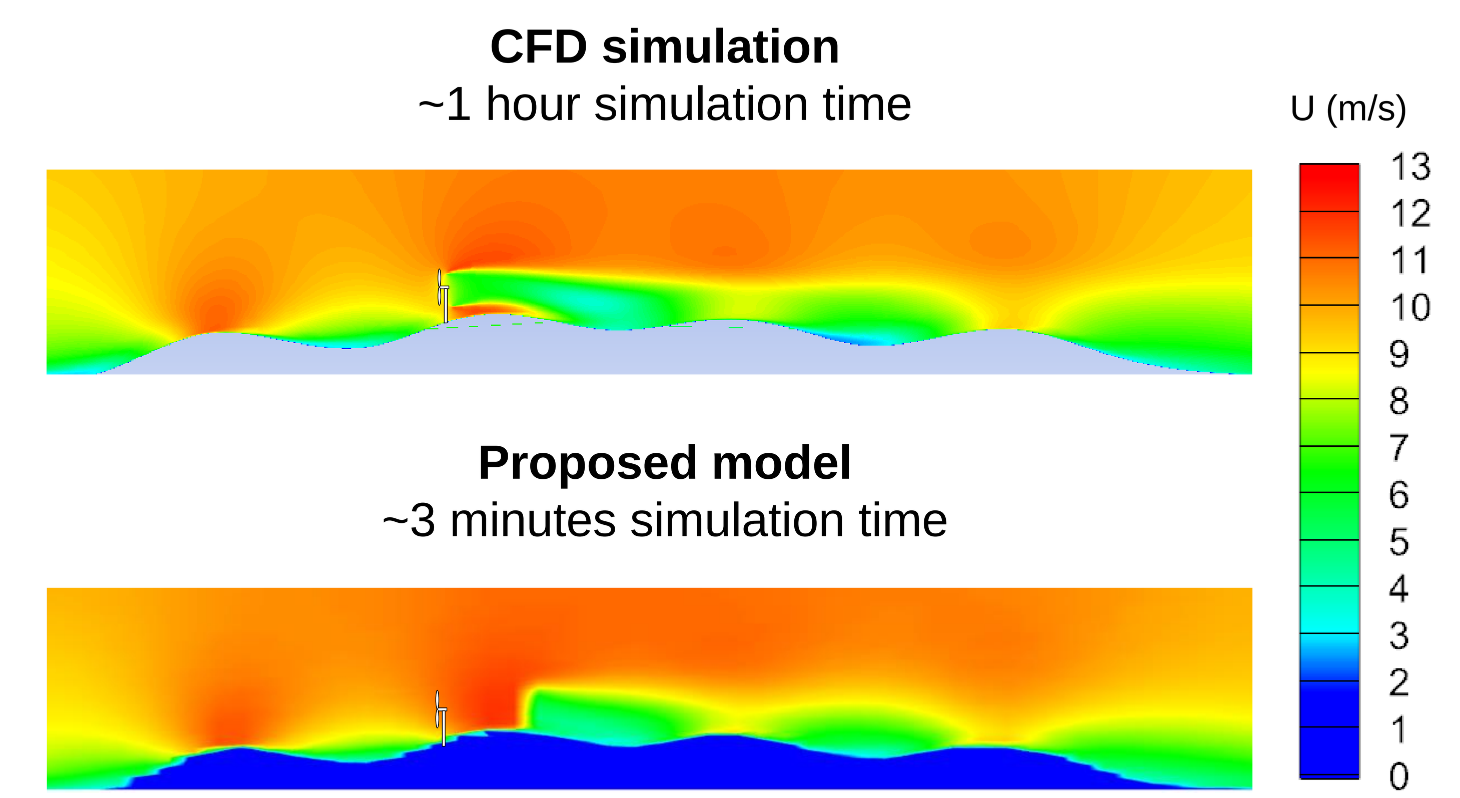

Fig. 4: Streamwise velocity contour (CFD vs proposed model)

Design Optimization

Evolutionary, deterministic and memetic optimization approaches have been developed for efficient turbine micrositing in flat and complex terrains.

A continuous mathematical approach has been introduced to solve highly constrained problems efficiently, and the results show its outperformance over state-of-art methods, consuming 1-2 order of magnitude less computational cost.

Land use constraints do not affect energy generation to the extent that they affect noise production.

Large-scale wind farms have been optimized considering infrastructure, produced power, and environmental aspects.

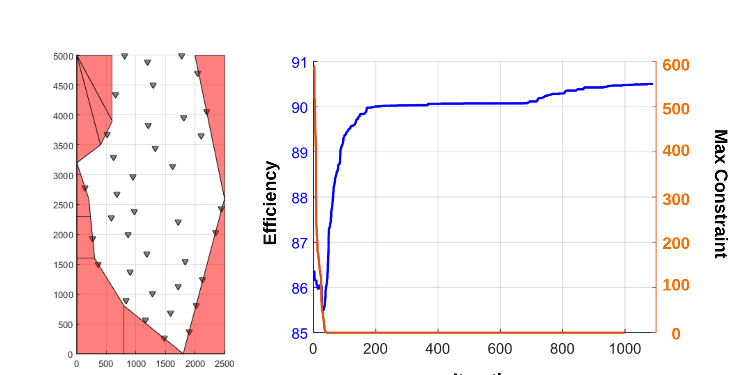

Fig. 5: Solved instance using IPM.

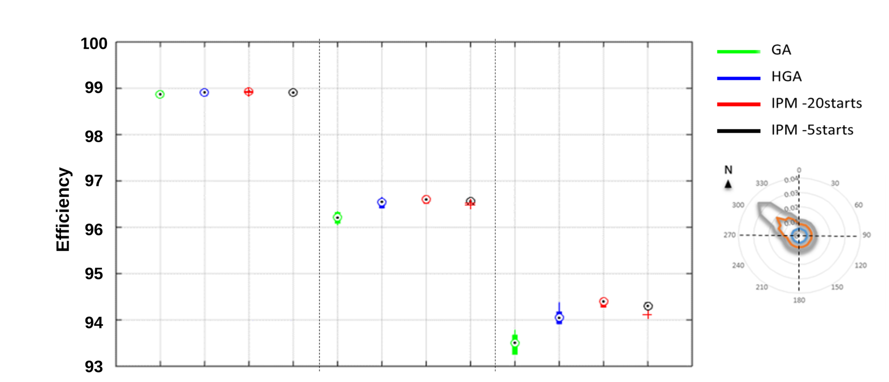

Fig. 6: Multi-start IPM vs. GA

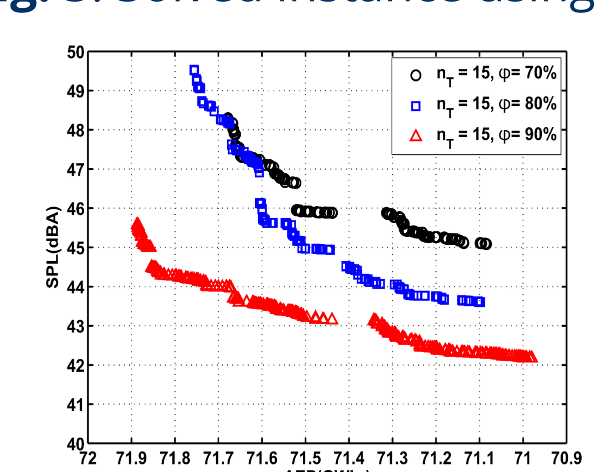

Fig. 7: Energy-noise trade-off for 15 turbines and different land availabilities.

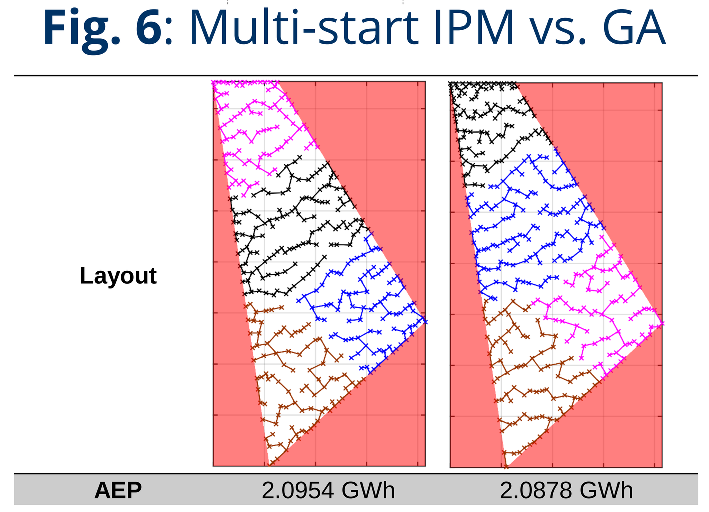

Fig. 8: Optimized large-scale farms considering output power and infrastructure.