Design and Simulation of Small Scale Wind Turbine Blade for Wind Tunnel Wake Testing

Arash Hassanzadeh, Andrew Kirby, Rajib Roy, Jonathan Naughton
Wind Energy Research Center (WERC), Department of Mechanical Engineering, University of Wyoming, Laramie, WY, USA, ahassanz@uwyo.edu, Naughton@uwyo.edu

Abstract

Sub-scale testing of wind turbines in wind tunnels is necessary for better understanding the blade flows and wakes of wind turbines as well as for producing data necessary to validate computational models. For these experiments to have the most relevance, the wakes generated by the sub-scale turbine must contain the important characteristics found in modern utility-scale turbines. In this work, a new approach that has been developed to design the sub-scale turbine is discussed. The approach forces the normalized normal and tangential force distributions of the small scale blades to match those of the "parent" industrial scale wind turbine blades. To independently assess the blades designed using this approach, the "parent" industrial scale and geometrically scaled-down wind turbine rotors are modeled using the CFD simulations to validate the design.

Keywords: *Wake, Inverse Design, CFD Simulations, Validation*

Introduction

Sub-scale experiments that consider individual turbines as well as arrays of turbines are an expected outgrowth of efforts such as the IAE Wakebench[1] effort and the U.S. DOE Atmosphere to Electrons initiative[2]. The need to understand the complex physics of how a wake develops from the interaction between the wind and the blade is critical if modeling these blades is to be successful. In addition, high quality data from these tests is needed to validate computational codes that attempt to simulate individual wakes as well as wakes from multiple turbines and their interaction. However, sub-scale tests will not be effective in this role if they do not capture the relevant physics that govern the formation and evolution of wakes from modern industrial scale wind turbines.

Over the past two years, two independent efforts to design sub-scale blades for testing have been undertaken at Sandia National Laboratory [1, 2] and at the University of Wyoming [2]. In the Sandia effort, matching the relative circulation produced by the sub-scale blade to that of an industrial-scale turbine along the blade span was attempted.

This work describes the blade design approach and performance evaluation used by the authors. In contrast to the Sandia work, the University of Wyoming effort forces the normalized normal and tangential force distributions of the small scale wind turbine blade (2m diameter) to match those of an industrial scale wind turbine blade. To assess the blades designed using this approach, the industrial scale blade and the geometrically scale-down blade for the industrial scale blade are modelled using the CFD to validate the design.

Approach

A blade element momentum theory (BEM) inverse design approach is employed to determine the blade chord and twist angle distributions. To start the process, the normalized normal and tangential forces produced by the target industrial scale turbine are used as input to an inverse design approach that is used to determine the sub-scale wind turbine blade shape. The forces on the predetermined airfoils shapes are determined by the lift coefficient C_l and drag coefficient C_d of the airfoils, which were determined using XFOIL [3]. An iterative approach is then used to determine the chord length, and twist angle of each section along the blade. For details, see reference [2].

[1] http://www.ieawind.org/task_31.html
[2] http://energy.gov/eere/wind/atmosphere-electrons

Results

Using the forces obtained from FAST for the target wind turbine, the normalized force distribution design approach was applied to specify the sub-scale wind turbine blade geometry. The normal and tangential force distributions of the sub-scale blade are shown with the target force distributions in Fig. 1. These results demonstrate that the normal and tangential forces matching requirements have been met. Due to the constraints applied to the sub-scale turbine blade design, there are small gaps between the force distributions of sub-scale turbine and target values. In order to verify the design results, a CFD simulation has been performed to compare the wake structure at different downstream locations. Fig. 2 shows a contour of vorticity magnitude for the full-scale turbine (NREL WindPACT 1.5 MW).

Conclusion

The results show that it is possible to design a small scale blade that produces force distributions similar to that of an industrial scale turbine, which would not occur by simply geometrically scaling the industrial scale turbine blade. It remains to be demonstrated whether the similar force distributions produce similar wakes. The design approach will be employed to design a 1 m length blade that will be manufactured and instrumented for testing in a controlled inflow environment (e.g. in a large wind tunnel).

Acknowledgments

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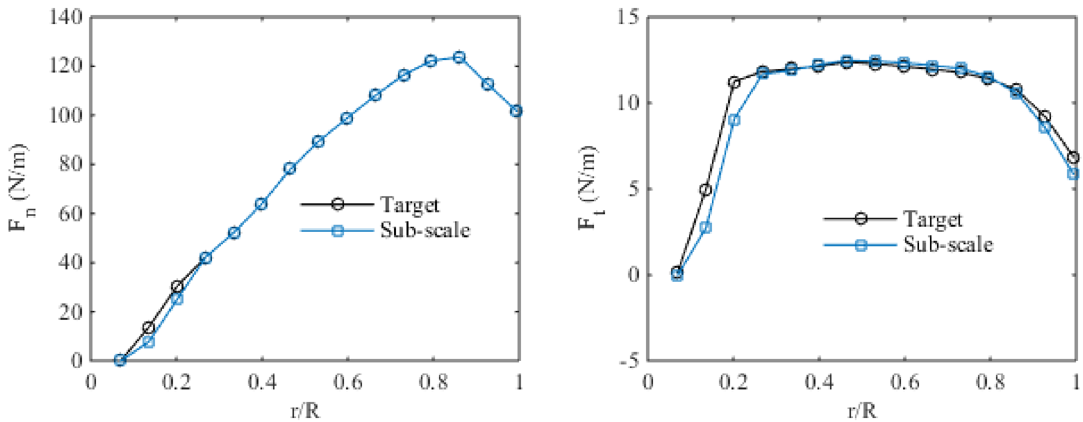

Fig.1 Normal and tangential force distributions for target and sub-scale blades

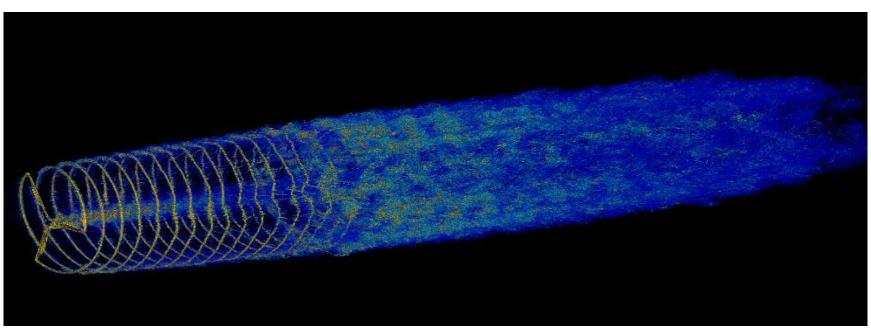

Fig.2 Contour of vorticity magnitude for the full-scale turbine