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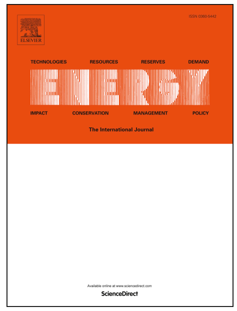

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Analysis and Optimization of Ducted Wind Turbines

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Abstract

Wind-lens turbines offer the potential for better energy efficiency and better suitability for urban and suburban environments compared to unshrouded or bare wind turbines. Wind-lenses, which are typically comprised of a diffuser shroud equipped with a flange, can enhance the wind velocity at the rotor plane due to the generation of a lower back pressure. In this article, the wind-lens efficiency is increased by designing the shroud and turbine shape as well as flange height through an optimization process that seeks to maximize the power while minimizing drag and thrust forces. The employed optimizer is a multi-objective genetic algorithm (MOGA). Bezier curves are used to define the chord and twist distribution of the turbine blades and a piece-wise quadratic polynomial is utilized to define the shroud shape. The power, thrust, and drag coefficients are calculated by solving the Reynolds-averaged-Navier-Stokes (RANS) equations with the $k - \epsilon$ turbulence model for the flow within and around the diffuser augmented wind turbine using the open source code software *OpenFOAM*. To reduce the computational cost, the turbine rotor itself is modeled by incorporating blade element momentum model body forces into the RANS equations. Realistic rotor data for the sectional lift and drag coefficients for all angles of attacks are utilized via look-up tables. Grid convergence studies for verification and comparisons with experiments for validation are carried out to demonstrate that the adopted methodology is able to accurately predict the performance of a wind-lens prior to performing shape optimizations. It will be demonstrated that the resulting optimal designs yield significant improvements in the output power coefficient.

Keywords: Ducted wind turbine, Wind-lens, Blade element momentum model, Betz limit, MOGA, simpleFoam, Shape Optimization.

1. Introduction

Modern wind turbines fail to achieve the Betz limit, which is the theoretical maximum power coefficient for conventional wind turbines, due to numerous reasons such as wake losses due to upwind turbines, drag as well as tip vortex losses. To overcome the Betz limit and mitigate some of the losses associated with the tip vortices, a number of studies have suggested that encasing the turbine with a shroud or ducted shape could be beneficial. The purpose of the shroud is to enhance the wind velocity of the air passing through the rotor plane since the power output is proportional to the wind velocity cubed. Another substantial aspect of shrouding a turbine is to reduce the cut-in speed, meaning that a turbine can remain operational during a larger part of the year, thus increasing the overall annual energy production. A recent study conducted by Takahashi, Hata et al. [1] concluded that ducted wind turbines also exhibit a significant reduction in wind noise due to the damping of vortices generated from the blade tips through the interaction with the boundary layer created by the diffuser shroud. Therefore, these turbines can be erected in or near

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