A Preliminary Evaluation on the Performance of Diffuser-Augmented Vertical Axis Wind Turbines

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Abstract. Computational Fluid Dynamics (CFD) was used to assess whether adding a stationary diffuser, known as wind lens, can improve the power performance of vertical axis wind turbines. Transient, two-dimensional simulations were conducted using a dynamic mesh and the Shear-Stress Transport (SST) $k-\omega$ model to calculate the generated torque. Blades were set to rotate at a constant angular velocity to maintain an optimal TSR (tip speed ratio) at the studied freestream wind speed. The product of this angular velocity (in rad/s) and the calculated torque (in Nm) was assumed to be the mechanical power harvested by the turbine. The simulation setup was validated using experimental data. It was found that a properly designed wind lens enhances power production in two ways. First, it collects and guides a larger air flow into the turbine (the inlet effect). Second, it induces a flow separation along its trailing edge, which leads to a reduced pressure zone downwind of the outlet of the lens (the outlet effect). The enhanced pressure difference between upstream and downstream regions drives a larger flow into the turbine, which increases power generation. It was also found that if the throat of the diffuser is not sufficiently large, the shear caused by its inner walls decelerates the blades. This negative impact can dominate the above-described inlet/outlet effects, which leads to a net reduction in power production. Although no rigorous optimization was conducted to identify an optimal geometry for the diffuser, the proposed lens was found to improve power production of the turbine by more than 400%. It is shown that substituting the augmented turbine with a large open turbine with a swept area equal to the maximum cross-sectional area of the lens is a more effective strategy (increases power production by 600%), however, it may cost considerably more.

Keywords: Vertical axis Wind Turbine · Diffuser augmented · Wind lenses · Static vanes · Renewable energy · Computational Fluid Dynamics · Fluent

1 Introduction

The global wind energy industry is rapidly expanding its capacity. According to a report by the U.S. Department of Energy (DOE), approximately 20% of the United States total energy is expected to be produced via wind power by 2030 [1]. The contribution of wind

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Table 1. The average moment and power production of wind turbines with and without lens.

Style	Average moment (Nm)	Average power (W)
Small turbine (no lens)	0.0033	0.1980
Small turbine with lens	0.0161	0.9660
Large turbine (as large as the lens)	0.11	1.98

4 Conclusions

Although augmenting a VAWT with a diffuser (wind lens) increases the power production, making a large turbine of the same size as the lens is a more effective strategy to enhance the annual energy production. For the turbine and non-optimal diffuser proposed here, the lens-augmented turbine harvests 440% more power than the unaugmented turbine. Substituting the unaugmented turbine with a scaled-up version of the same size of the lens, however, results in harvesting 640% more power. On the other hand, the costs associated with equipping an existing VAWT with a lens is significantly less than substituting the turbine with a large-scale version. In other words, wind lenses should be viewed as inexpensive and effective aftermarket options to improve performance of existing VAWT. In a comprehensive economic exploration of Diffuser Augmented Wind Turbines (DAWTs) by the DOE in 1981 [26], there was a positive reaction to this concept for smaller scale HAWTs. With the trend towards bigger turbines, the concept fell by the wayside. For the small scale VAWTs, however, the diffuser has its place to shine. Broader research could provide a more accurate comparison between augmenting an existing VAWT with a wind lens and utilizing a scaled-up VAWT with a rotor area equal to the cross section of the lens. This includes identifying the optimal geometry of the lens, calculating the aerodynamic forces acting on each setup, and finally, investigating the costs associated with each strategy.

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