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Aerodynamic Optimization of a Vertical Axis Wind Turbine Equipped with a Two-Element Airfoil

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Abstract

A Darrieus vertical axis whose blade is made up using a two-element airfoil is considered. The geometry of the main airfoil is fixed whereas the size and the position of the slat is optimized acting on four different decision variables: the position with respect to the quarter of chord, the distance between the two airfoils, the chord length and the pitch angle. Starting from a baseline configuration, a univariate optimization is performed, aiming at improving the total rotor power production in a target tip speed ratio. The results for the optimization are presented and the problem appears to be well defined with respect to the adopted optimization routine and decision variables.

Methods

The aerodynamic optimization of Darrieus vertical axis wind turbines is a largely debated theme in the scientific literature due to the inherent complexity of the rotor unsteady behavior. Different approaches have been exploited, considering advanced optimization tools as genetic and evolutionary algorithms and simulation routines including algorithms based on the Blade Element-Momentum theory and Computational Fluid Dynamics (CFD) solvers for the Unsteady Reynolds Averaged Navier Stokes (URANS) equations. While semi-empirical algorithms are generally the best choice for the traditional geometries involving a single-airfoil blade, the simulation of more complex geometries requires advanced computational tools based on the CFD techniques. On the other hand, genetic algorithms perform an efficient optimization activity but involve a large number of fitness evaluations. In the present work, a Darrieus vertical axis whose blade is made up a two-element (main and slat) airfoil is considered. The size and the position of the slat is optimized fixing a layout of the main airfoil.

The size and position of the slat airfoil is varied considering four different decision variables, as shown in Figure 1: the position with respect to the quarter of chord, the distance between the two airfoils, the chord and the angle of incidence. Starting from a baseline configuration, the slat position and geometry are optimized by considering a univariate optimization algorithm to improve the total rotor power production in a target tip speed ratio $\lambda = 1$. The rotor efficiency is numerically estimated by means of a CFD software implementing a URANS k-ω SST solver. The simulation is conducted considering a validated 2D mesh representing a large testing field, where the boundary conditions are imposed far enough not to influence the rotor aerodynamics. The rotor should be operating at low wind and rotational speeds: the target operational conditions are imposed to be 4 m/s for the wind speed and 100 rpm for the rotational speed.

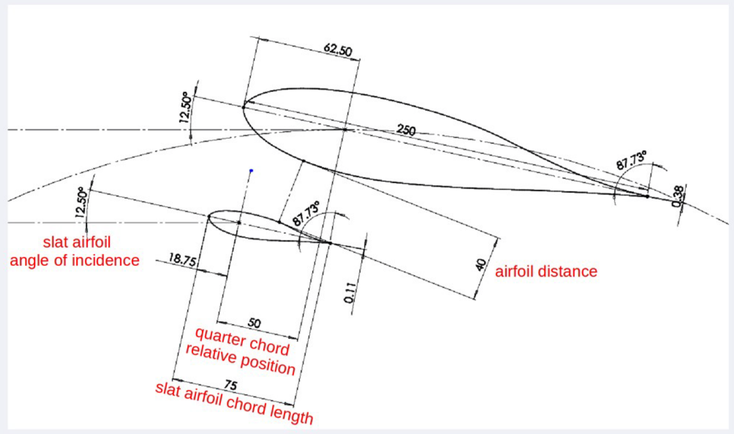

Figure 1: scheme of the double airfoil blade with the decision variables marked in red.

Results and Discussion

1. Airfoil Distance

The airfoil distance is the first parameter to be varied. Starting from the baseline configuration showed in Figure 1, distance values between 10 mm and 60 mm with a step of 10 mm are considered and the simulation is performed. The power production for the different configurations is showed in Figure 2. The optimal distance is 30 mm.

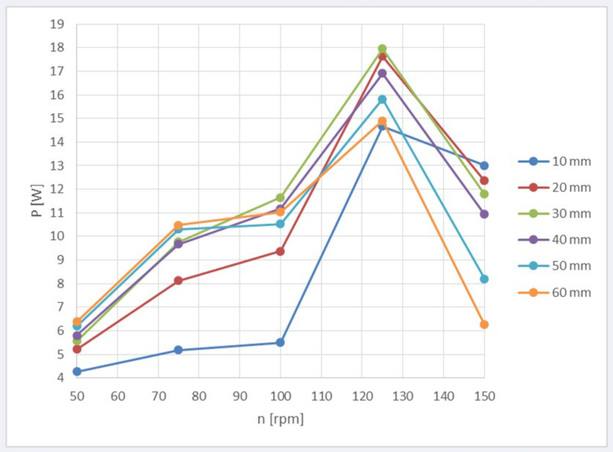

Figure 2: aerodynamic power production considering different airfoil distance.

2. Quarter Chord Relative Position

The quarter chord relative position is the second parameter to be varied. Starting from the optimal configuration from Figure 2, values between 10 mm and 70 mm with a step of 10 mm are considered and the simulation is performed. The power production for the different configurations is showed in Figure 3. The optimal value is 70 mm.

Figure 3: aerodynamic power production considering different quarter chord positions.

3. Slat Airfoil Angle of Incidence

The angle of incidence of the slat airfoil is the third parameter to be varied. Starting from the optimal configuration showed in Figure 3, angles between 11.0° and 32.5° are considered and the simulation is performed. The power production for the different configurations is showed in Figure 4. The optimal angle is 17.5° .

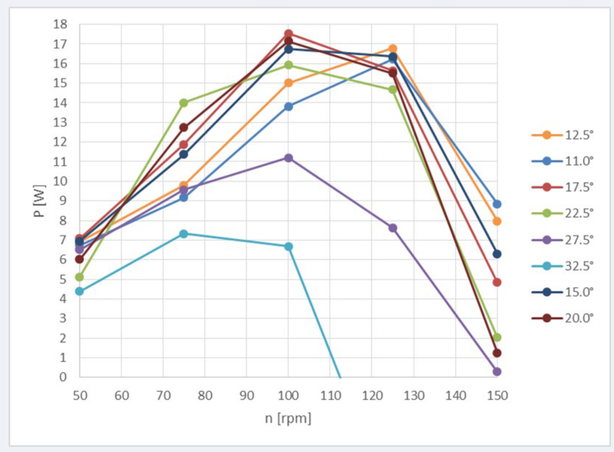

Figure 4: aerodynamic power production considering angles of incidence for the slat airfoil.

4. Slat Airfoil Chord Length

The chord length for the slat airfoil is the last parameter to be varied. Starting from the optimal configuration from Figure 4, values between 65 mm and 145 mm with a step of 10 mm are considered and the simulation is performed. The power production for the different configurations is showed in Figure 5. The optimal value is 95 mm.

Figure 5: aerodynamic power production considering different chord length for the slat airfoil.

Conclusions

The optimization activity successfully provided an optimal configuration for a Darrieus rotor whose blades are equipped with a slat airfoil. This airfoil presents an optimal chord length of 95 mm and pitch angle of 17.5° , whereas its position is fixed by a quarter chord position of 70 mm and airfoil surface distance of 30 mm. The slat airfoil is located in the proximity of the leading edge and on the suction side, in order to widen the airfoil efficiency range and enhance the production in the upwind rotor section. The simulations are of particular interest because, beside the performance increase, show the variations of the optimal working conditions with respect to the different geometrical configurations.