Aerodynamic optimization of large-scale VAWT - elements of multi-parameter analysis

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1 Introduction

Vertical Axis Wind Turbines, unlike their horizontal axis counterparts, still do not form a well-developed industry. Due to that fact, optimal designs for many cases have often not been developed and many researchers, producers and enterpreneurs are still trying to develop the aerodynamic side of their design from a seemingly random starting point, with no reference to the many factors that influence a lift-based vertical axis rotor's efficiency.

2 Stages of multi-parameter analysis

Initial simulations were performed in ANSYS Fluent, using k-omega SST method on a 2-dimensional wind turbine model with 3 wings, a rotor diameter of 22.5m, a wing chord of 1.5m, a tower diameter of 1.5m, and a surface roughness height Ks=0, using NACA0018 as the wing airfoil. All simulations were conducted for an inflow speed of 9m/s, chosen as the optimal wind speed for this scale, based on Polish wind conditions. Firstly simulations for a selection of rotation speeds were analysed for different angles of wing attachment, leading to selecting the initial optimal attachment angle at 3 degrees. Optimal chord value was ascertained. After choosing the optimal parameters at that point, a series of simulations for a range of rotation speeds were made for all symmetrical NACA foils with thicknesses between 9% and 23% with an additional class of asymmetrical airfoils developed for use in vertical axis wind turbines.

Figure 1: Airfoil m1510 set at a 3 degrees angle

Optimal angles of attachment were once again tested for the NACA symmetrical airfoil offering the highest aerodynamic efficiency – NACA0013, as well as the custom airfoil offering the highest aerodynamic efficiency overall, dubbed m1510 and presented in fig. 1. For both abovementioned airfoils the optimal angle of attachment was 3 degrees. Separately, the effect of changing tower diameter on aerodynamic efficiency of the standard NACA0018 scenario was calculated. Afterwards, for the standard values of 1.5 tower diameter, 22.5m rotor diameter, 3 degrees angle of wing attachment and NACA0018 airfoil; simulations of optimal chord values for 2, 4, 5 and 6 wings with uniform spacing were performed. Worth noting is the sudden drop in maximum achievable aerodynamic efficiency of the 6-wing scenarios as compared to those achievable in optimal 2-5 wing scenarios. For optimal chord values of 2, 4 and 5 wing turbine models a check of performance for wing attachment angles in the range of 0-5 has been made for a range of rotation speeds, for each case showing highest aerodynamic efficiency at an angle of attachment of 3 degrees. Finally, simulations of influence of scaling of the 3 wing turbine with 1.5 tower diameter, 22.5m rotor diameter, 3 degrees angle of wing attachment and NACA0018 airfoil were made, at scales of 1:40, 1:10, 1:4, 1, 4 and 10.

Table 1. Aerodynamic efficiency of 3-wing turbine at different scales for a range of Wing Speed Ratios

	Aerodynamic efficiency [%] scale					
WSR	1:40	1:10	1:4	1	4	10
1.75	0.3%	2.3%	5.3%	10.6%	15.7%	18.6%
1.85	0.5%	3.1%	7.1%	13.3%	19.0%	23.0%
1.96	0.8%	4.2%	9.1%	16.8%	24.5%	29.0%
2.07	1.2%	5.6%	11.3%	22.5%	29.6%	38.5%
2.18	1.9%	7.3%	13.7%	26.9%	43.1%	49.8%
2.29	2.7%	9.7%	19.4%	38.9%	50.6%	53.7%
2.40	3.7%	12.7%	27.7%	46.7%	53.6%	55.8%
2.51	5.4%	17.8%	37.2%	49.8%	55.3%	57.1%
2.62	7.0%	25.7%	42.7%	51.7%	56.4%	57.9%
2.73	9.7%	31.9%	45.6%	52.9%	57.1%	58.4%
2.84	15.1%	36.1%	47.3%	53.4%	57.5%	58.6%
3.05	25.5%	40.3%	49.6%	54.6%	58.0%	59.0%
3.27	29.0%	42.0%	50.1%	54.3%	57.5%	58.5%
3.49	29.2%	41.9%	49.5%	53.4%	56.4%	57.5%
3.71	28.0%	41.1%	48.2%	51.8%	54.9%	56.1%
3.93	26.0%	39.3%	46.1%	49.7%	53.0%	54.3%

Table 1. shows the aerodynamic efficiency of a 3-wing turbine at different scales for a range of Wing Speed Ratios. It is important to note that despite the clear tendency of efficiency growing with wind turbine scale, the maximum efficiency of an optimally designed wind turbine will not change identically as shown above. As lower scales have higher optimal chord-to-diameter proportions, aerodynamic efficiency of smaller designs can be raised by increasing chord length. The problem of both tunnel testing of scaled models and exploitation of small designs is however, that even the lowest WSR simulated for the examples, relating to very low efficiencies, corresponds, for a 67.5cm rotor diameter (1:40 scale), to over 440 rotations per minute. For very large scales, further chord and profile optimization might even lead to simulated results reaching beyond the 59.3% HAWT Betz Limit.