# Optimal Vertical Axis Wind Turbine Active Control Strategies

**Student:** Saskia van Nieuwstadt
**Supervisor:** Wei Yu
**Daily Supervisor:** Adhyanth Giri Ajay

## Background

Wind energy is an important current and future source of sustainable energy. Vertical axis wind turbines (VAWTs) are the subject of renewed research interest because they have several key advantages over conventional horizontal axis wind turbines (HAWTs) which could make them better candidates for future wind energy applications [1]. VAWTs have their generator at the base of the tower, lowering the turbine's center of gravity and easing maintenance. The turbines are indifferent to the incoming wind direction and rotate at slower speeds than HAWTs, which produces less noise. These characteristics lead to two main promising future applications of VAWTs: multi-megawatt turbines floating in deep water where the wind resource is better, and small-scale turbines in urban settings where the wind is highly turbulent. VAWTs can also be placed closer together, resulting in a higher power density per area in a wind farm [1], [2].

## Objective

This thesis project will contribute to the ongoing body of research into controlling VAWT aerodynamics—which are more complicated than that of HAWTs—by studying the impact of different active pitch profiles on the turbine's performance, loading, and wake. The blades of a VAWT can be pitched individually and dynamically throughout one rotation of the rotor. In this project, several active pitch control profiles will be devised and implemented in low- to mid-fidelity models (the 2D actuator cylinder model [3] and lifting-line vortex model). The goal is to optimize the angle of attack at each azimuthal position. The dynamic pitch angles will be modeled by varying the airfoil polars—that is, changing the lift ($C_L$) and drag ($C_D$) coefficients based on the angle of attack [4]. The pitch profiles will be evaluated based on the power coefficient, blade loading (bending moment), and wake recovery (wind velocity in the wake). The multiple objectives are to maximize the power output, minimize the load fluctuations, and maximize the wind velocity in the wake (to maximize the power produced by a downwind turbine). Previous studies have analyzed the effects of a fixed blade pitch offset [5]–[7], or only the power and loading under dynamic blade pitching [2], [8], and not the combination proposed herein. The impact of dynamic blade pitch control on the wake in particular is not well-understood, which is a gap this study aims to fill. Ultimately, the optimal dynamic blade pitch profile will be selected based on a balance of the turbine's own performance with that of a downwind turbine.

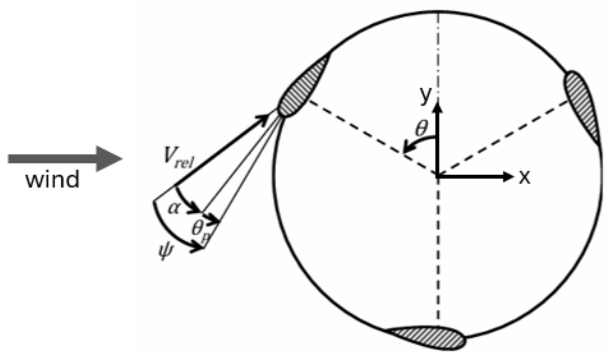


Figure 1: Top view of a VAWT. $\theta_p$ is the blade pitch angle, which can be actively changed throughout one rotation in order to achieve the optimal angle of attack $\alpha$ at each azimuthal position. Modified from [1] Figure 2.4.

# References

[1] D. de Tavernier, "Aerodynamic advances in vertical-axis wind turbines," Doctoral thesis, Delft University of Technology, Delft, the Netherlands, 2021. DOI: https://doi.org/10.4233/uuid:7086f01f-28e7-4e1b-bf97-bb3e38dd22b9. [Online]. Available: https://repository.tudelft.nl/record/uuid:7086f01f-28e7-4e1b-bf97-bb3e38dd22b9.

[2] S. L. Fouest and K. Mulleners, "Optimal blade pitch control for enhanced vertical-axis wind turbine performance," *Nature Communications 2024 15:1*, vol. 15, pp. 1–13, 1 Mar. 2024, ISSN: 2041-1723. DOI: 10.1038/s41467-024-46988-0. [Online]. Available: https://www.nature.com/articles/s41467-024-46988-0.

[3] H. A. Madsen, "The actuator cylinder - a flow model for vertical axis wind turbines," Doctoral Thesis, Institute of Industrial Constructions and Energy Technology, Aalborg University Centre, Jan. 1982. DOI: 10.13140/RG.2.1.2512.3040. [Online]. Available: https://www.researchgate.net/publication/281449635_The_Actuator_Cylinder_-_A_Flow_Model_for_Vertical_Axis_Wind_Turbines.

[4] L. Battisti, L. Zanne, M. R. Castelli, A. Bianchini, and A. Brighenti, "A generalized method to extend airfoil polars over the full range of angles of attack," *Renewable Energy*, vol. 155, pp. 862–875, Aug. 2020, ISSN: 0960-1481. DOI: 10.1016/J.RENENE.2020.03.150.

[5] B. LeBlanc and C. Ferreira, "Estimation of blade loads for a variable pitch vertical axis wind turbine with strain gage measurements," *Wind Energy*, vol. 25, pp. 1030–1045, 6 Jun. 2022, ISSN: 1099-1824. DOI: 10.1002/WE.2713. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1002/we.2713.

[6] M. Huang, A. Sciacchitano, and C. Ferreira, "On the wake deflection of vertical axis wind turbines by pitched blades," *Wind Energy*, vol. 26, pp. 365–387, 4 Apr. 2023, ISSN: 1099-1824. DOI: 10.1002/WE.2803. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1002/we.2803.

[7] A. Rezaeiha, I. Kalkman, and B. Blocken, "Effect of pitch angle on power performance and aerodynamics of a vertical axis wind turbine," *Applied Energy*, vol. 197, pp. 132–150, Jul. 2017, ISSN: 0306-2619. DOI: 10.1016/J.APENERGY.2017.03.128.

[8] M. Elkhoury, T. Kiwata, and E. Aoun, "Experimental and numerical investigation of a three-dimensional vertical-axis wind turbine with variable-pitch," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 139, pp. 111–123, Apr. 2015, ISSN: 0167-6105. DOI: 10.1016/J.JWEIA.2015.01.004.