To VAWT or not to VAWT?

Feasibility of Vertical-Axis Wind Turbine Sublayers

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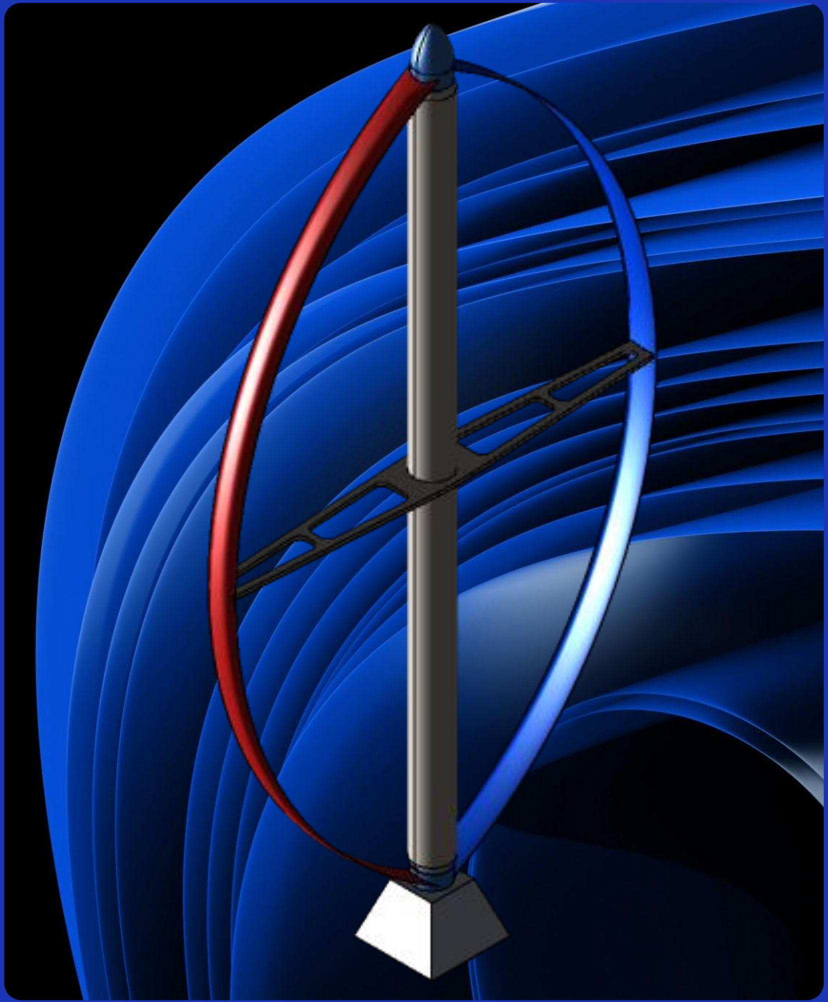
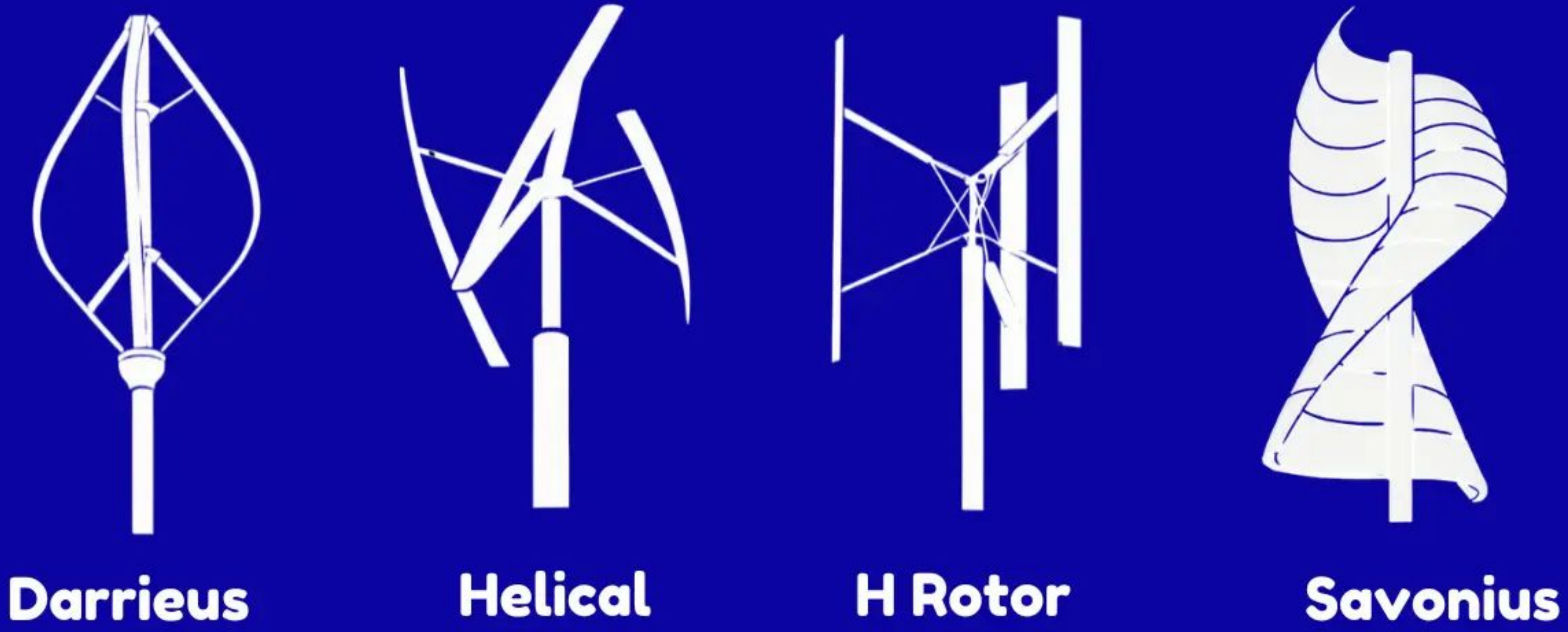
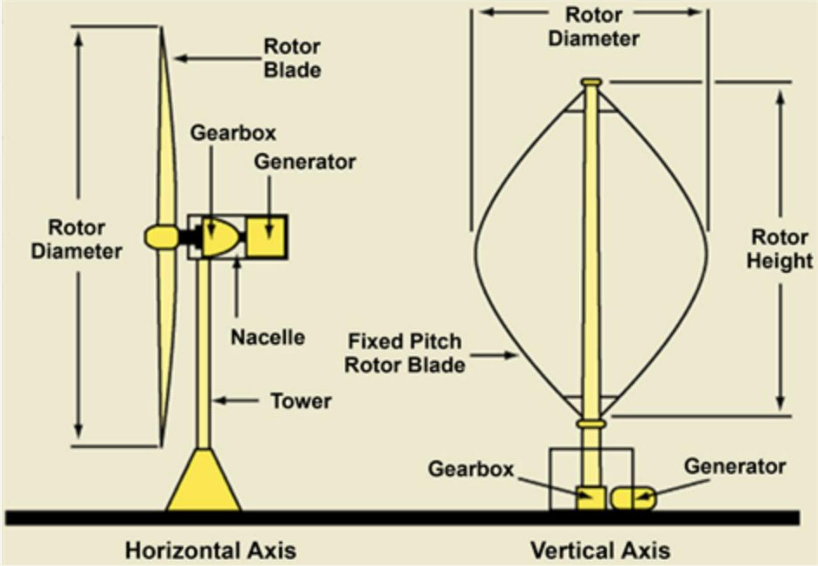


VERTICAL AXIS WIND TURBINES



Lower Practical Efficiency of VAWTs

- Cyclic variation in angle of attack, leading to ***dynamic stall***
- Blade-wake interactions as blades pass through their own wake
- Structural limitations on tip speed ratio



(Ahmad 2020)

Research Timeline

Darrieus 1925

Darrieus VAWT

Darrieus VAWT design was patented by Georges jean Marie Darrieus.

1970s

VAWT Popularity

The development of vertical axis wind turbines (VAWTs) began to gain momentum.

Xie 2016

Vertical Sublayer (VS)

Benefits of collocating vertical-axis and horizontal-axis wind turbines in large wind farms.

Dabiri 2020

The Future...

Arrays of VAWTS may be able to exceed the Betz limit for the array as a whole, due to beneficial wake.

Existing Literature

VAWT vertical sublayers (VS) are a highly under-researched topic with only one other paper being found on the niche...

Benefits of collocating vertical-axis and horizontal-axis wind turbines in large wind farms

Xie et al. 2016

Benefits of collocating vertical-axis and horizontal-axis wind turbines in large wind farms

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ABSTRACT

In this study, we address the benefits of a vertically staggered (VS) wind farm, in which vertical-axis and horizontal-axis wind turbines are collocated in a large wind farm. The case study consists of 20 small vertical-axis turbines added around each large horizontal-axis turbine. Large-eddy simulation is used to compare power extraction and flow properties of the VS wind farm versus a traditional wind farm with only large turbines. The VS wind farm produces up to 32% more power than the traditional one, and the power extracted by the large turbines alone is increased by 10%, caused by faster wake recovery from enhanced turbulence due to the presence of the small turbines. A theoretical analysis based on a top-down model is performed and compared with the large-eddy simulation. The analysis suggests a nonlinear increase of total power extraction with increase of the loading of smaller turbines, with weak sensitivity to various parameters, such as size, and type aspect ratio, and thrust coefficient of the vertical-axis turbines. We conclude that vertical staggering can be an effective way to increase energy production in existing wind farms. Copyright © 2016 John Wiley & Sons, Ltd.

KEYWORDS

wind farm; HAWT; VAWT; large-eddy simulation

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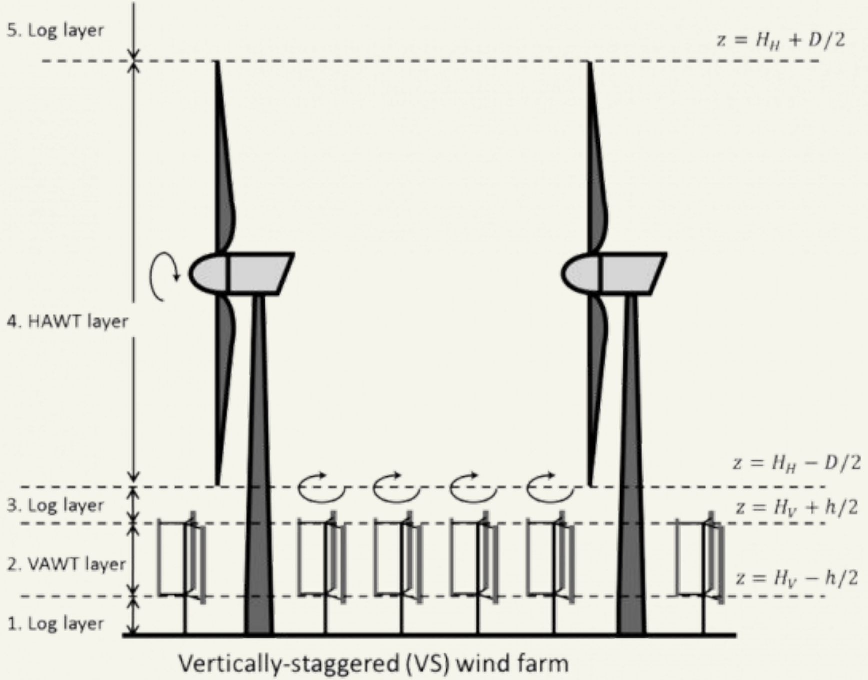
Existing Literature

Modified "Top-Down" Model Boundary Layers:

1. A log layer between the ground and the bottom of the VAWTs
2. A wake layer covering the rotor area of the VAWTs
3. A log layer between the top of the VAWTs and the lower tip of the HAWTs
4. A wake layer covering the rotor area of the HAWTs
5. A log layer above the HAWTs



(Xie 2016)

Findings

Nonlinear Power Increase

Top-down model analysis suggests nonlinear increase in total power with increased loading of smaller turbines

HAWT Power Increase

Power extracted by the large HAWTs alone increases by 10% in the VS farm

32% More Power

The VS farm produces up to 32% more total power than the traditional farm

Higher Energy Density

Concludes vertical staggering can effectively increase energy production in existing wind farms

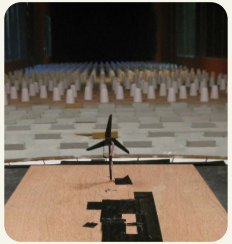
Our Methodology and Findings

1. *In-depth review of existing literature*
2. *Assumptions*
3. *1st level analysis*

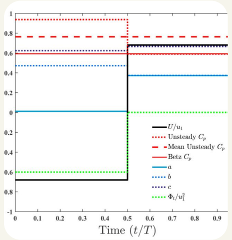
Other Reviewed Literature

We reviewed numerous papers from various lens' to establish a strong foundational understanding of VAWTs. This allowed our further work with the topic to be from a more comprehensive viewpoint.

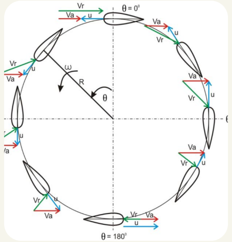
Ashwill 2012



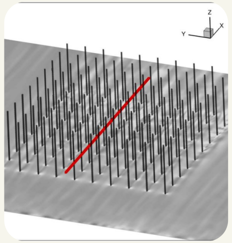
Barlas 2015



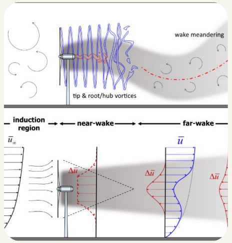
Dabiri 2020



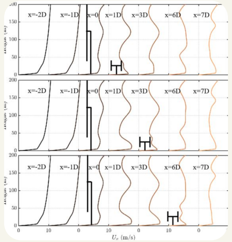
Kavade 2024



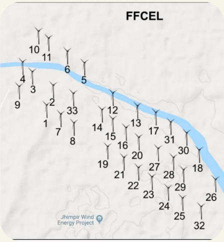
Pierce 2013



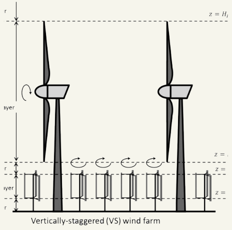
Porté-Agel 2019



Shao 2023



Syed 2020



Xie 2016

Assumptions

The Betz Limit Assumption

Assumption that wind speed is uniform and flow is constant

Blade Energy Momentum (BEM) Theory

Assume that flow is steady and the forces acting on the blade can be separated into drag and lift components

Additional Assumptions

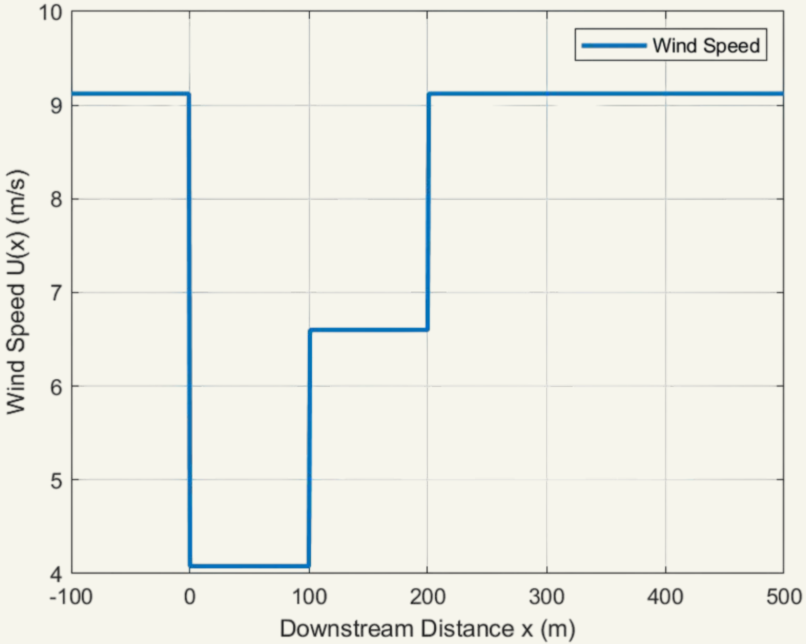
- ❏ Steady State Conditions
- ❏ Uniform Inflow
- ❏ Axisymmetric Wake
- ❏ Linear Wake Expansion
- ❏ Isotropic turbulence
- ❏ Constant Thrust Coefficient
- ❏ Complex wake interactions are not well represented

1st Level Analysis

Step Function of Wind Velocity Behind HAWT

Utilized the wind speed data from homework 1 and plotted it as a step function to gain insight on downstream mean wind speed variation with distance

Showed the area of high wind yield potential and thus the optimal locations in the HAWT wake region for a VAWT



1st Level Analysis

Total Kinetic Energy Profile of Wind Velocity With and Without HAWT

Definition of total kinetic energy (*TKE*):

$$TKE = \frac{1}{2}\left(\overline{u'}^2 + \overline{v'}^2 + \overline{w'}^2\right)$$

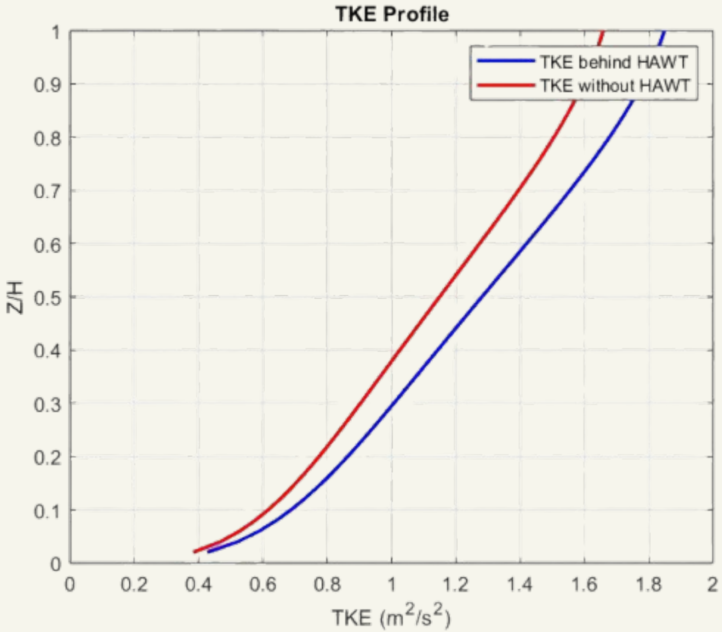
Related with turbulence intensity(I_z) and mean wind speed(σ_z):

$$I_Z = \frac{\sigma_Z}{U_Z} \Longrightarrow TKE = \frac{3}{2}\sigma_Z^2$$

Substituted terms:

$$TKE = \frac{3}{2}(I_Z U_Z)^2$$

Plot also gives information to help optimize turbine spacing and thus energy capture

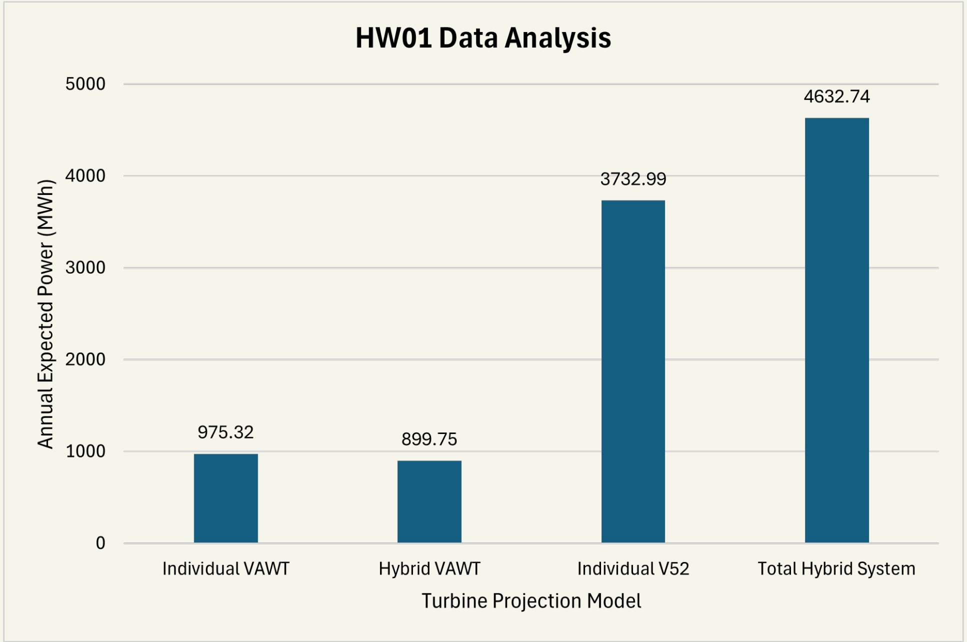


1st Level Analysis

Annual Expected Power (AEP)

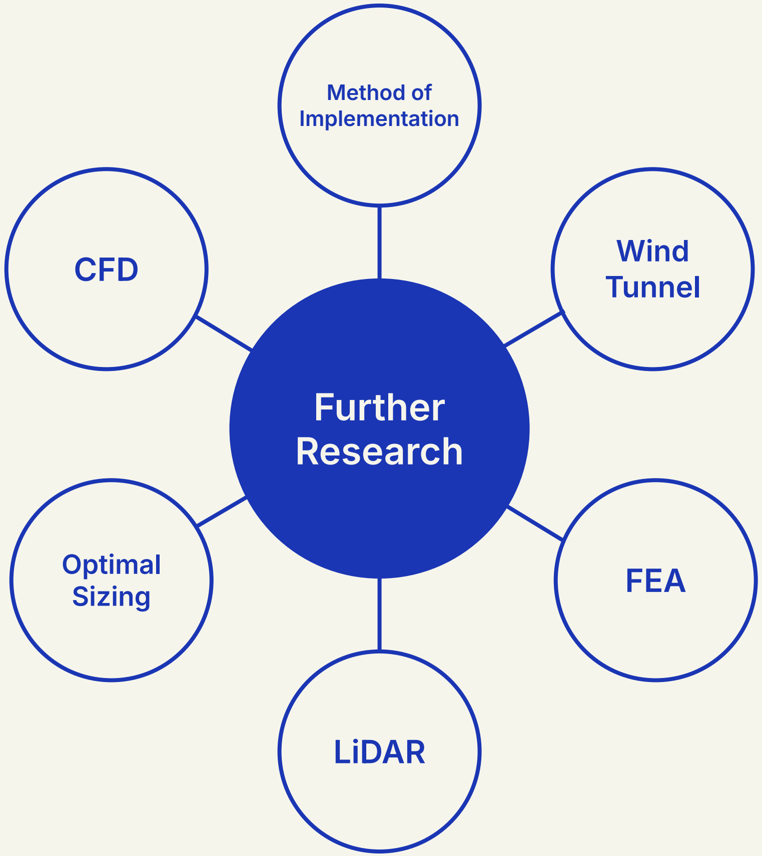
The AEP from different wind turbine systems was calculated utilizing methods and data from Homework 1 alongside a Gaussian wake deficit model.

This data illustrates the potential value in putting a VAWT in the wake region of a HAWT for higher power density.



Conclusion

- Wind after HAWT has significant power in wake region that can be used by VAWT in efficient way to be cost effective
- **Hybrid HAWT–VAWT systems necessitate further in-depth research due to their significant potential for value**



Thank you

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