Scaled Offshore Horizontal-Axis Wind Turbine

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Abstract

National increasing energy demands require innovative methods for electrical generation. Annually, the U.S. Department of Energy hosts the Collegiate Wind Competition to introduce undergraduates to wind power. Of the three contests, the current focus is turbine design and testing. Competition guidelines specify a scaled offshore-compatible turbine capable of generating up to 48 volts at varying wind speeds between 0-22 m/s. Elements were separated into subsystems – blades, pitching, brakes, nacelle, and anchor. Three Onyx blades with a Blade Element Momentum Theory informed airfoil cross-section are adjusted by the actuator-controlled pitching system to create lift with an optimal angle of attack. Rotor-disc brakes housed within the nacelle halt shaft rotation via an Arduino that monitors generated power to prevent runaway. A ferrous sheet-metal anchor stabilizes the turbine in an aqueous environment per the offshore requirement. Each system has been iteratively designed to approach optimum functionality, integration, manufacturability, and minimize size. The scope of this project has implications on the renewable energy domain at large as fresh perspectives on generative machinery may inform future mainstream products.

Requirements

The turbine is constrained by several design requirements provided by the Department of Energy.

Dimensional:

- Whole turbine profile: 61cm x 122cm
- Rotor and non-rotor volume: 45cm3
- Anchor: ≤ 30cm2 profile
- Anchor-sand penetration: ≤ 20cm
- Tower diameter < 15.8cm

Operational:

- Turbine braking capability by button, at loss of power, at ≥ 48V via PCC
- Power control for 11-14m/s wind
- Power may not exceed ±10% of average per wind speed
- RPM control for 11-14m/s wind

Other requirements focus on ease of use and safety principles:

- Turbine must be of an original design – no component reuse
- Design is safe and durable
- Full turbine can be quickly assembled
- Design is weight conscious

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Design Process

Used an iterative design process to solve subsystem specific challenges.

- Individual turbine design theory research
- Mathematical analyses on rotor torque, airfoil selection and component strength
- Utilized SolidWorks and QBlade software to model/analyze design iterations
- Subsystems were each reflected in at least three prototypes
- Dozens of revisions based on assembly

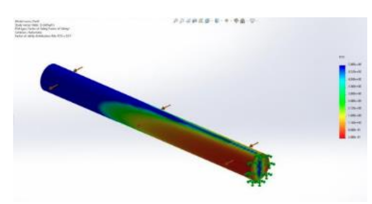


Figure 1. FEA Analysis


Figure 2. Brake Disc Iterations

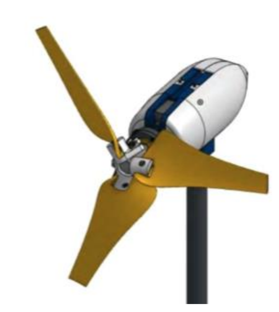


Figure 3. Previous Design Serving as Inspiration

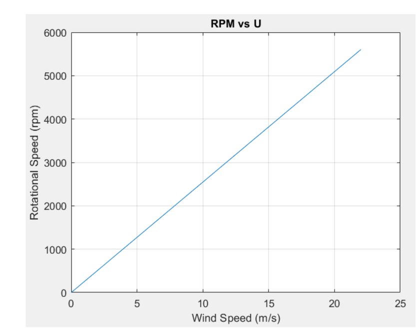


Figure 4. Relationship Between Angular Velocity and Wind Speed

Results/Conclusions

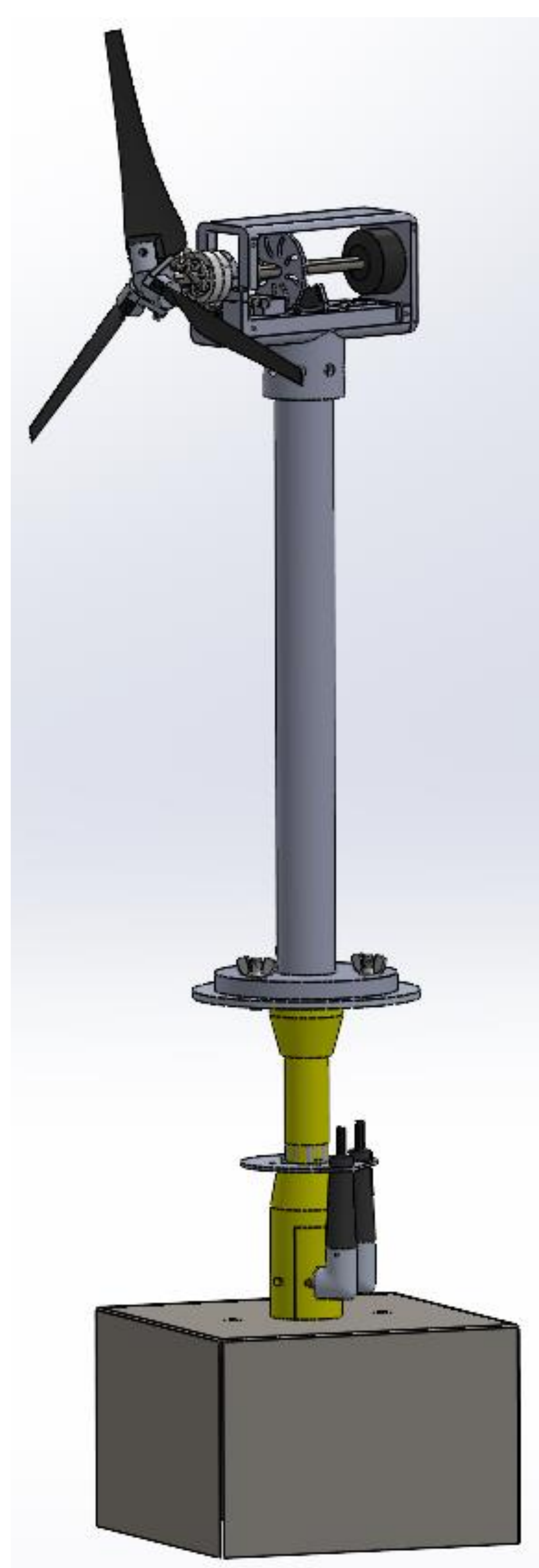


Figure 16. Final Design (CAD)

The finalized CAD model and completed assembly are presented in Figures 16 &17.

- Pitching mechanism adjusts blade interaction with the wind to regulate rotor RPM and power production up to 100° of rotation
- Disc-brake system employs guide rods and a linear actuator for controlled braking up to 1 N*m (max at Betz) via an Arduino microcontroller
- Blade design inspired by RC airplane airfoils optimized for low Reynold's numbers
- Nacelle components designed modularly for flexibility during testing
- Anchor ensures stability in offshore conditions with a max deflection of 2°
- Generator selected through dynamometer testing for efficiency and low cogging torque


Figure 17. Final Design (Physical)

In operation, the turbine is always connected to a resistive load, built by the EE subteam, to dissipate the generated power.


Figure 18. MAD Motor Utilized as a Generator

References

[1] J. F. Manwell, J. G. Mcgowan, and A. L. Rogers, *Wind energy explained : theory, design and application*. Chichester, U.K.: John Wiley & Sons, Ltd, 2011. Available: https://www.wiley.com/en-us/Wind+Energy+Explained%3A+Theory%2C+Design+and+Application%2C+2nd+Edition-p-9780470015001

[2] U.S. Department of Energy. *U.S. Department of Energy Collegiate Wind Competition 2024.* 19 Sept. 2023.

Subsystems

To maximize design efficiency, the turbine was separated into subsystems, each the focus of one team member. Apart from these components, both the generator and the resistive load essential aspects to the project as they are what ultimately allow the turbine to translate mechanical energy into electrical energy.

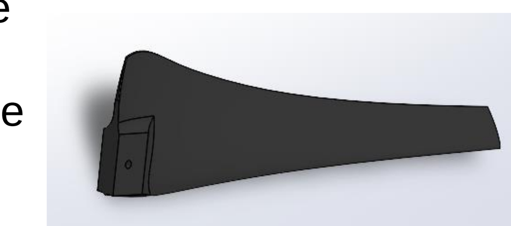


Figure 5. Blades: Captures Kinetic Energy From the Wind

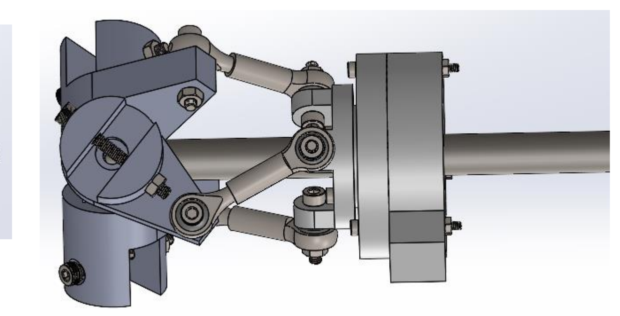


Figure 6. Pitching: Adjust Blade Orientation for Optimal Angle of Attack

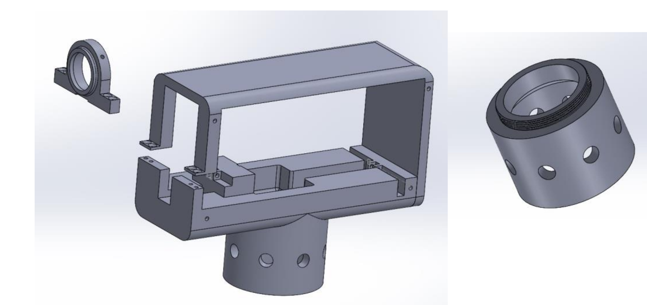


Figure 7 & 8. Nacelle: Housing for Internal Components (shaft, generator, etc.)

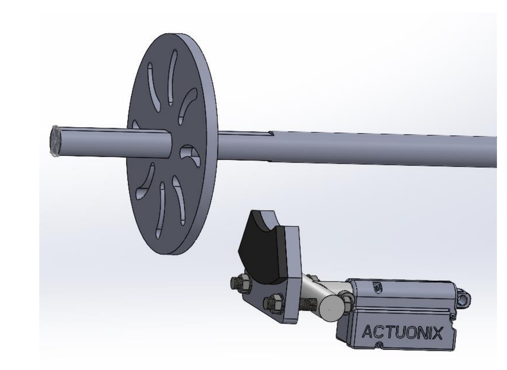


Figure 9. Rotor-Disc Brakes: Emergency Stop to Halt Shaft Rotation

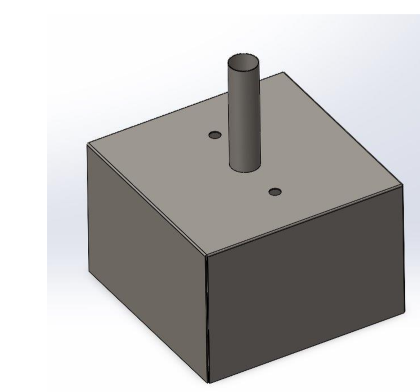
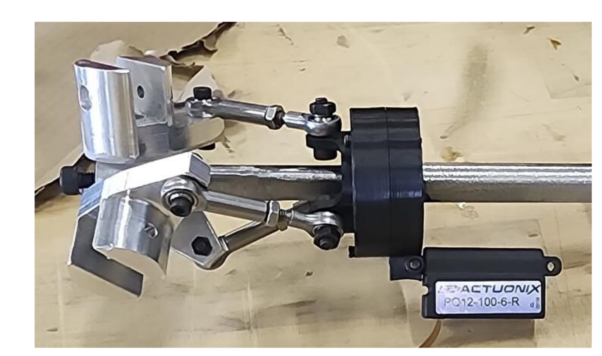


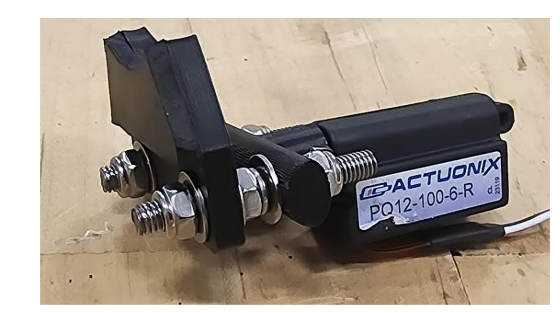
Figure 10. Anchor: Stabilization for the Turbine in an Aqueous Environment

Manufacturing

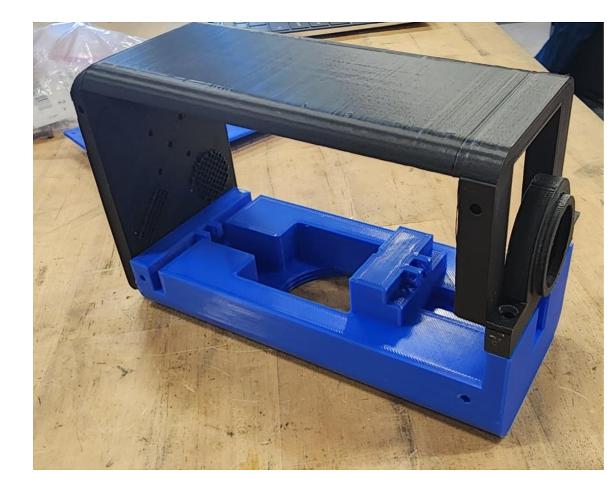


Figures 11. Pitching System


Figures 14. Tower & Baseplate



Figures 12. Braking Assembly


Figures 13. Nacelle


Figures 15. Anchor

CAD models were physically produced with both sourced and self-manufactured parts. Utilizing the CNC Vertical Mill, the brake disc and blade connectors for the pitching system were made from 6061 aluminum. The carbon steel shaft was milled into a Triple D profile to prevent free rotation of the swashplate and the brake disc. The nacelle was 3D printed in PLA, sheet metal was bent and welded for the anchor, and the steel tower was welded to the baseplate.

Acknowledgements

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