Collegiate Wind Competition 2021

Design and Testing of a Micro-Scale Wind Turbine

Northern Arizona University

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COLLEGIATE WIND COMPETITION
U.S. DEPARTMENT OF ENERGY

Energy Club at NAU

NAU's Team Website

Abstract

In modern times the need for renewable energy has become increasingly apparent. To combat the effects of the deteriorating environment as well as supply the country with efficient energy, the United States Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) employ several programs nationwide. One of these programs is the Collegiate Wind Competition with the goal of introducing undergraduate students to the physics and engineering required to fabricate a wind turbine. Northern Arizona University has the great honor of participating in this exclusive event through a mechanical engineering senior capstone project.

Problem Definition

The project involves the design, fabrication, and testing of a micro-scale wind turbine. The turbine must fit within a 45x45x45 cm volume. The DOE defines startup wind speeds as 2.5 m/s to 5 m/s. In order to score points in this category, the turbine must produce a positive current for over 5 seconds. The rated wind speed on the turbine is 11 m/s. Regarding the cut-out wind speed, the DOE requests that the turbine be designed to withstand up to 22 m/s, but will not be tested above 13 m/s. At any point in testing, the output voltage cannot exceed 48 VDC. Along with these tests that rate the turbine's ability to produce power, there are also utility-based challenges such as yaw rates up to 180°/s and braking to park in several scenarios within 10 s.

In addition to all the rules and constraints listed above, as an effect of COVID-19, the in-person competition has been cancelled and will be replaced with reports of extensive inhouse testing. In order to remain competitive in the competition, the group has assembled a data acquisition system to record values such as ambient pressure, temperature, wind speed, rotational velocity, current, and voltage. The conditions for the design and testing of the turbine mentioned above have been summarized below in Tables 1 and 2.

Table 1: Engineering Requirements

Requirement	Target
Turbine Size	45x45x45 cm
Cut-in Wind Speed	2.5 – 5.0 m/s
Operating Wind Speed	11 m/s
Cut-out Wind Speed	22 m/s
Yaw Rate	180°/s
Brake Time	10 s
Maximum Voltage	48 VDC

Table 2: DAQ Variables

DAQ Variables
Wind Speed
Temperature
Ambient Pressure
Rotational Velocity
Current
Voltage

The Team's Design

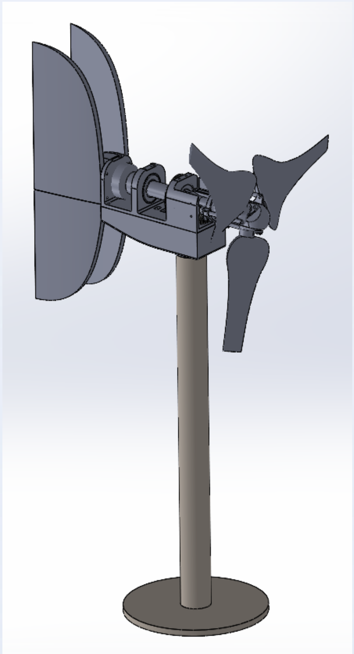

Figure 1: Turbine CAD Model

Figure 2: Turbine Assembly

Many subsystems must be fabricated to accomplish the tasks depicted in the problem statement. Figures 1 and 2 are representative of the summation of these subsystems.

Rotor

Horizontal axis wind turbines, while slightly lacking in startup capabilities, have proven more efficient than their vertical counterparts. With the inclusion of a pitching system, the group can compensate for this weakness while not sacrificing performance.

Pitching

This mechanism allows the control system to alter the angle of attack experienced by each blade. This allows for the optimization of forces at both low and high wind speeds, utilizing the characteristics of startup or stall.

Brake

Despite the presence of the pitching system that will drastically reduce the lift forces on the blades, a brake disk assembly will act as a clamp to ensure parking capabilities.

Yaw

A passive yawing fin will be implemented to ensure that the turbine's axis of rotation is always parallel to the oncoming flow field.

Control System

The operation of a turbine is greatly optimized and made safer through the use of microcontrollers. Using several of the variables listed in Table 2, proper application can ensure the steady operation of each subsystem.

Assembly and Manufacturing

With COVID-19's prevalence through the project's life, the fabrication of the turbine was riddled with lead times and wait lists. However, the group utilized 3D-printing to manufacture complicated geometry such as the blades and nacelle housing. Although convenient, certain components of the turbine needed stronger material properties than what a hobbyist printer could produce. The shaft and tower are examples of these components that needed to be machined. Utilization of both on and off campus resources has allowed the group to include aluminum parts into the design. In addition to printing and machining, mechanically complicated and / or electrically intensive parts were outsourced, such as the generator and slip ring. These three tactics have resulted in the Team's Design seen in Figure 2.

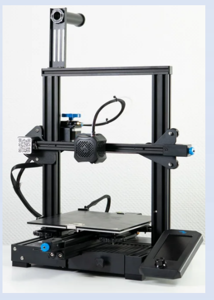

Figure 3: Ender 3 V2 Printer

Figure 4: Shaft Machining

Analysis and Simulation

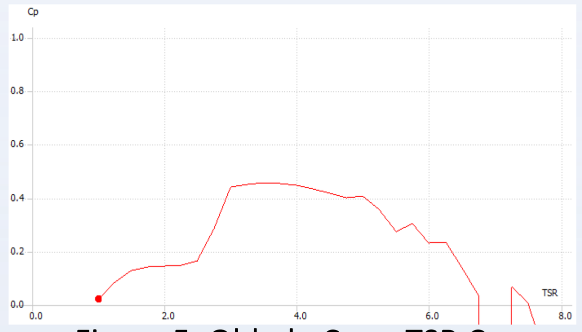

Figure 5: Qblade Cp vs TSR Curve

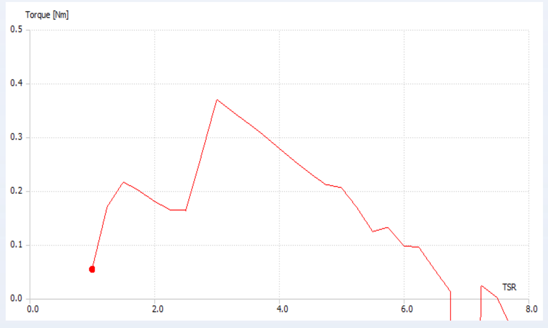

Figure 6: Qblade Torque vs TSR Curve

Table 2: MATLAB BEM Iterator

Radius	Shape	Chord	Solidarity	RE	Alpha	phi	Pitch
0.02	NACA2412	0.03623	0.86493	32688	8.75	39.357	30.607
0.04	NACA2412	0.033973	0.40552	41057	8.25	26.537	18.287
0.06	NACA1412	0.035227	0.28033	56120	6.25	19.37	13.12
0.08	NACA1412	0.028576	0.17055	57481	6.25	15.08	8.8299
0.1	NACA1412	0.023777	0.11353	58171	6.25	12.29	6.04
0.12	NACA1412	0.020256	0.080595	58553	6.25	10.349	4.0994
0.14	NACA1412	0.0176	0.060024	58788	6.25	8.9283	2.6783
0.16	NACA0012	0.020392	0.060854	77354	5	7.8455	2.8455
0.18	NACA0012	0.018239	0.048381	77495	5	6.9943	1.9943
0.2	NACA0012	0.016498	0.039387	77642	5	6.3082	1.3082

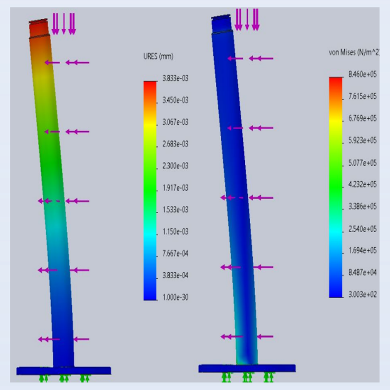

Figure 7: Solidworks FEA Tower Analysis

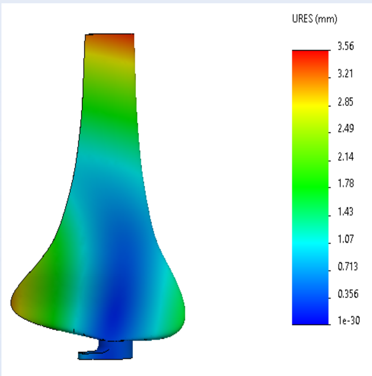

Figure 8: Solidworks FEA Rotor Analysis

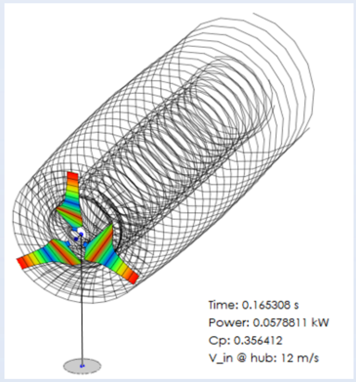

Figure 9: Qblade Performance Analysis

When creating a wind turbine, there are many design attributes that need to be considered, ranging the from calculating desirable aerodynamics through the computationally rigorous Blade Element Momentum Theory or the insurance of sufficient structural support investigated through a Finite Element Analysis. These crucial data sets were collected by the group in several different programs such as MATLAB, Qblade, and SolidWorks. The tables and figures shown to the left are examples of data the group used to converge on the most optimal design by ensuring values that will properly interface with the electronics of the system, display aerodynamic traits competitive with products available on the market, and prove enough structural competence to withstand the expected forces.

Testing and Performance

Even with proper manufacturing and educated analysis, there is no guarantee of an efficient system. Although Figure 5 reports a coefficient of power of nearly 44%, this value could be lower after considering electrical and drive train resistances. With no access to a wind tunnel, the experiments employed to confirm the data of the analyses presented above were *creative*. Many static experiments were performed, such as the loading of the stepper motor until failure to pitch the blades and loading of the nacelle to confirm a sufficient factor of safety for the tower connection. As for dynamic testing, Figure 10 displays the testing apparatus that allowed the group to mount the turbine to a vehicle and produce a flow field through relative wind velocity. The variables listed in Table 2 are recorded and monitored using LabView and the UI seen in Figure 11. The stalling mechanism allowed the turbine to remain stationary in flows up to speeds of 21 m/s. The yawing displayed a consistent response at speeds as low as 5.5 m/s. Subsystems worthy of further testing and development include the implementation of start up pitch, which did not display effective results until 6.8 m/s, as well as the use of the variable resistive load, which reduced power production up to 15 W when improperly incorporated.

Figure 10: Testing Apparatus

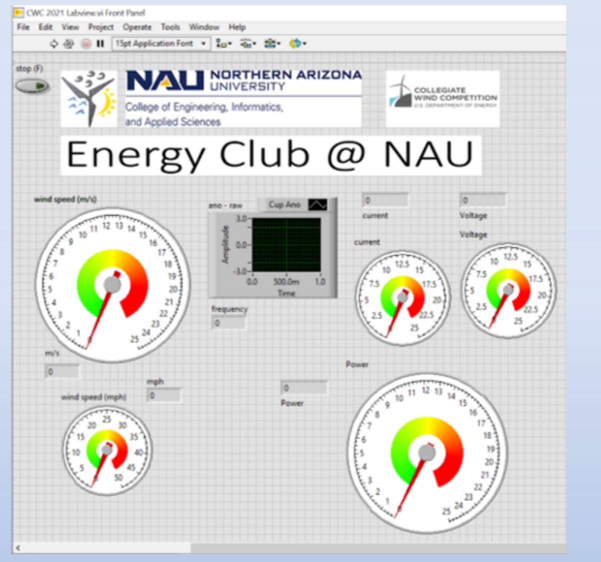

Figure 11: DAQ UI

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