Brigham Young University
2022 Collegiate Wind Competition

Technical Design Report

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3. Executive Summary

The project objective was to develop a scale model offshore wind turbine by April 2022 that maximized power output for a wind speed range of 5 - 11 m/s. The turbine, anchored in submerged sand, will remain upright and stable without sinking, turning, or significant shaking. To focus efforts on critical design elements, the team identified key success measures and critical subsystems.

Last year's design was the base on which the new design was made, however due to poor performance of the old turbine, most subsystems would be redesigned. The only component directly reused with no modifications was the pitch control system.

After testing available market devices, the team selected a corkscrew design for the foundation. Estimates of the forces on the turbine and FEA indicate this design will be able to hold the turbine steady during both power curve and durability testing of the turbine. A cheap mockup of the competition sand tank was made using a trash can, and tests performed in a wind tunnel show that the base is sturdy, agreeing with the calculations made.

The blades used from last year were modified to increase their max power coefficient from 0.35 to 0.4. Nylon PA-12 was ultimately selected as the material for the blades, which were 3D printed using selective laser sintering. Calculations performed using QBlade, the software used to design the blades, showed they should be able to survive the loads experienced during testing in a wind tunnel. Destructive testing with an Instron supported these results. QBlade simulations reported an AEP of 60kWh.

The nacelle was designed to support the critical electronics and protect them from the high wind speeds, while also holding the generator and blades in place. The nacelle can be pointed into the wind after installation but has no other yaw capabilities.

A new generator was selected based off the data from blade simulations, a Maxon 268193 graphite brushed motor. An initial electronics system was developed that met competition requirements, but limited power output to a fixed 2.5W. A new system is being developed that fixes the restrictions of the initial system, allowing for higher power output.

The controls system uses the RPM sensor in the motor to determine what state the Arduino should be in. Interrupt pins on the Arduino check for either the emergency stop or load-disconnect triggers to switch to the emergency stop state.

The final system was assembled throughout the year, allowing the team to perform multiple mock competitions and refine the design. The power output of the turbine was not as high as the team hoped for. Several suggestions are made for what next year’s team can focus on to improve the power output of the turbine.

4. Technical Design Report

4.1. Design Objectives

The project objective was to develop a scale model offshore wind turbine by April 2022 that maximized power output for a wind speed range of 5 - 11 m/s. The turbine, anchored in submerged sand, will remain upright and stable without sinking, turning, or significant shaking. The team recognized that evaluation depended on three primary criteria. These were the power generation system, the emergency stop and safety system, and the ferrous base or foundation. The following subsystems were identified as necessary to maximize the effectiveness of the design at fulfilling the judging criteria: A nacelle to house the turbine components, blades made of nylon PA-12, a foundation made of steel, the electrical generator and other electronics, and the blade pitch and controls systems.

The requirements of the competition were integrated into a requirements matrix to help organize goals and allow the team to visualize specific objectives of the project and can be seen in the appendix as RM-001 Requirements Matrix. The most critical competition outcomes were then selected as key success measures for the project and placed into Table 1. The table shows the four selected key success measures, the range of target values for each measure, and the final measured value. The selection of these key success measures allowed the team to focus development efforts into systems that directly impacted the critical elements of the project, and helped limit wasted development time on non-critical subsystems.

Table 1- Summary of key success measures from overall requirements matrix, RM-001.

Key Success Measure	**Stretch**	**Excellence**	**Good**	**Lower Limit**	**Measured Value**
Minimize mass of base	< 2.5 kg	2.6 kg to 4.5 kg	4.6 kg to 6.5 kg	(No limit)	**1.5 kg**
Withstands wind speed of 22 m/s with minimal displacement	0 cm	+/- 2 cm	+/- 5 cm	> 5 cm	**0 cm**
Maximum power reached within 5-11m/s wind speed range	12 W	7 to 11.9 W	1.1 to 6.9 W	1 W	**2.5 W**
Time required for emergency stop	1 s	1.1 to 3 s	3.1 to 8 s	8.1-10 s	**1.25 s**

4.2. Changes From Last Year's Design

Last year's team focused their design work on minimizing the cut in speed of the turbine. Consequently, they optimized their blade design to be lightweight and produce power at lower wind speeds. Their motor was selected primarily for low starting torque and minimal resistance. Additionally, they pursued a turbine design with two sets of blades, to aid in starting at lower wind speeds. Figure 1 shows an image of last year's final design.

Figure 1 - View of last year's final turbine design

When tested in a wind tunnel, last year's turbine produced a maximum power output of 1 W between 5-22 m/s. Because this project is managed by a senior capstone team, no team members from last year were available to assist with troubleshooting. Attempts to fix the system were unsuccessful, and the variable load system was identified as a major source of unreliability. It was decided that all primary components would be reevaluated and replaced as needed during the turbine development. Ultimately, only one system was not redesigned.

The blade pitch control system was the only components reused from last year's design. Last year's team used a SAB 3 blade tail system (1), intended for use in Goblin RC Helicopters, as the pitch control system for the main turbine blades. It is very compact and easily converts linear motion into rotating the blades to a specific angle, and worked perfectly, so there was no need to change it. As part of the nacelle redesign, the mount for the linear actuator was moved, and the connection between the linear actuator and the sliding pitch control was redesigned to allow for a more robust connection.

This year's team has left extensive documentation and troubleshooting tips for each component, as well as personal contact information, so that next year's design team will not need to similarly redesign the whole turbine.

4.3. Foundation Design and Testing

Multiple ideas were explored on how to provide a secure foundation for the turbine. The team wanted a foundation that would maximize surface area in contact with the sand, since the sand would serve as the primary support for the weight of the turbine. However, the foundation needed to be easy to install, and require minimal contact with the surface of the water. The team tested multiple several off-the-shelf products intended for anchoring in sand. After initial tests performed with a force gauge, it was determined that a corkscrew design would maximize surface area of the foundation, while allowing for easy installation and being light weight. Figure 2 shows a render of the initial design of the corkscrew foundation. Our base was initially tested by pulling laterally with a force gauge until it was dislodged from the sand. Later testing was performed with the turbine installed in the wind tunnel.

Figure 2 - Render of initial corkscrew design

To run simulations of the base performance, basic calculations were performed to determine roughly how much force the wind in the wind tunnel would exert on the turbine. The force imparted on the turbine by the flow of wind was calculated using the fluid linear momentum equation, $\sum F = \frac{\partial}{\partial t}\int_{CV} u\rho \, dV + \int_{CV} u\rho v \cdot \hat{n} \, dA$. The greatest force should occur when the speed of the air is highest, so the flow was assumed to be steady at 22 m/s, and if the wind came to a complete stop against a flat plate, so the blades of the turbine were modeled as a flat, square plates. This simplifies the equation to be $\sum F = -\rho A v^2$. To accurately represent the forces, it was assumed the blades covered 1/2 of the 45cm x 45 cm square representing the front face of the turbine for an area of 0.10125 m^2. using values of 1.23 km/m^3 for the density of air, and a velocity of 22 m/s, the force imparted by the wind is 60.28 Newtons.

To determine the safety of the base an FEA analysis was run using ANSYS. The base was modelled as steel. To increase the factor of safety of our results, the calculated force was doubled to 121 N and applied as Force B, as shown in figure 3. Moment C was calculated using the distance from the top of the base to the center axis of the turbine shaft.

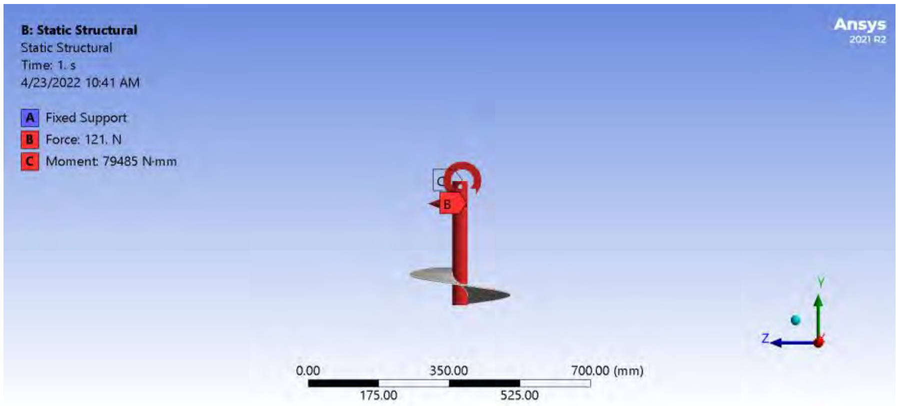


Figure 3 - FEA Analysis of the foundation

The sand was modeled as a box around the foundation, with a fixed support, A, at the bottom face to mimic the bottom of the tank, as shown in Figure 4. The sand was modelled as a linear elastic material. Since the maximum stress in the sand was 60.4 Pa, it was judged to be unlikely to fail, or shift, during testing. The analysis showed that the base would move a maximum of 0.258 mm. This was judged to be an acceptable amount of deformation.

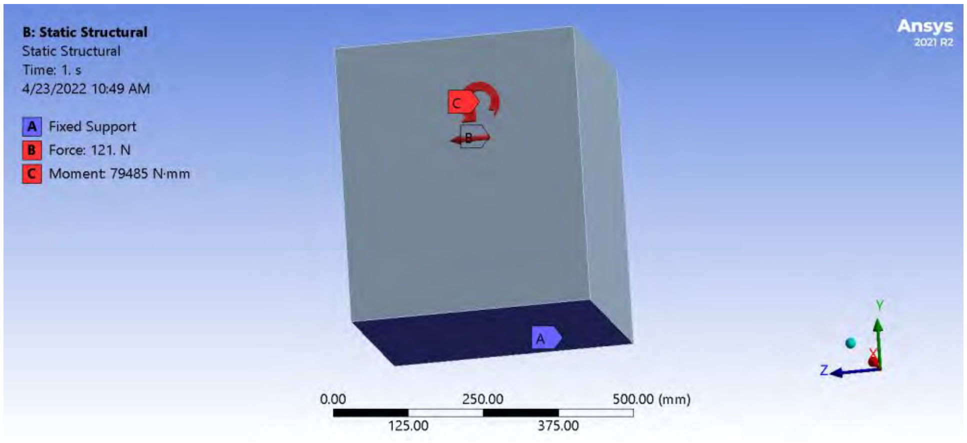


Figure 4 - The sand as modeled in ANSYS

The steel corkscrew prototype was manufactured through shearing, forging, and welding. A 25cmx25cm steel plate was cut into a circular shape to be more compatible with the auger shape. This steel circle was heated to a high temperature and then hammered into an auger shape. The auger blades were then welded to the 1.5” diameter steel pipe to create the final base prototype. The finished prototype can be seen in Figure 5.

Figure 5 - Finished corkscrew prototype

To test the base, a large trash can was purchased from Home Depot and filled with the appropriate sand. Water was added until the sand and water were at the levels specified in the competition rules. The trash can was large enough that the team estimated the sand would be the only element reinforcing the foundation, and the sides and bottom of the trash can would not be adding any structural support during testing.

The corkscrew met the team requirements of easy installation. A bar is inserted into the holes at the top of the foundation, and the corkscrew is twisted into the sand. The 'droop cables' required for the internal turbine electronics would be threaded through a hole on the side of the foundation now, before it is inserted into the water. A bubble level can be used to ensure the foundation is inserted straight into the sand. Additional testing showed that by using a wireless massage gun to vibrate the corkscrew during installation, the sand compacted around the base and held the foundation better than just screwing the base in on its own. This process requires less than 5 minutes for complete installation. When tested in the bed of sand with a force gauge, the prototype could hold up to 80 N of lateral force without moving. Using the above calculations of wind force for 60 N, that gives us a safety factor of 1.33. The corkscrew had a mass of just under 1.5 kg. A second prototype is being tested with holes cut in the shaft of the foundation. We expect the second prototype to hold the same force without moving but weigh less than the first prototype.

4.4. Blades

The blades were designed using the open-source program QBlade (3), the same software used by last year's team. This software allows a user to easily design a blade based off basic airfoils and provides useful analysis tools. Using the built-in simulation tools of QBlade, the final blade design was seen to have a better C_p-Lamba curve than the previous design. The previous blades had a maximum C_p of just over 0.35, while the new design is just under 0.4.

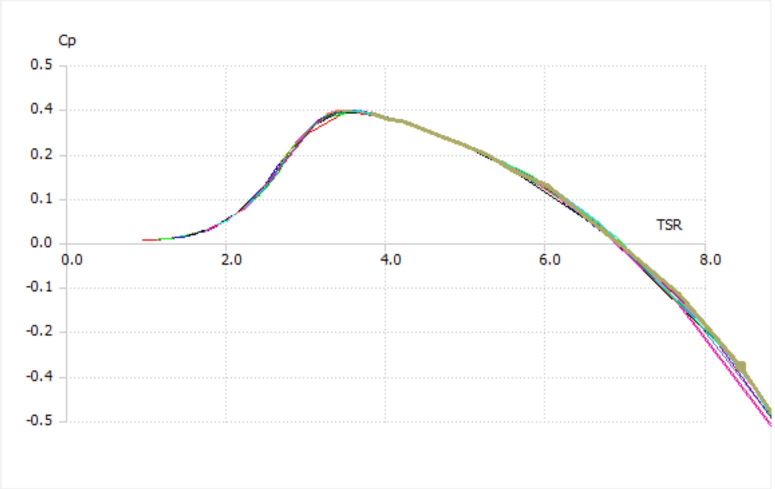


Figure 6 - Cp vs Lamba for the new blade design at various rotational speeds

Figure 6 shows that the final blade design has a peak Cp of approximately 0.4 at a TSR of 3.5. QBlade also allows the user to calculate an approximate annual energy production. It does this by using a Weibull distribution to approximate the probability of wind speeds for a year. The average power produced between two wind speeds is then multiplied by the probability of a wind speed occurring between those values, and then summed to find Annual Energy Produced. When using Weibull settings of k = 2.0±2.0 and A = 7.0±3.0, the annual yield of the turbine with this blade design was calculated to be 60 kWh. The Weibull probability of a certain wind speed occurring can be seen in Figure 7.

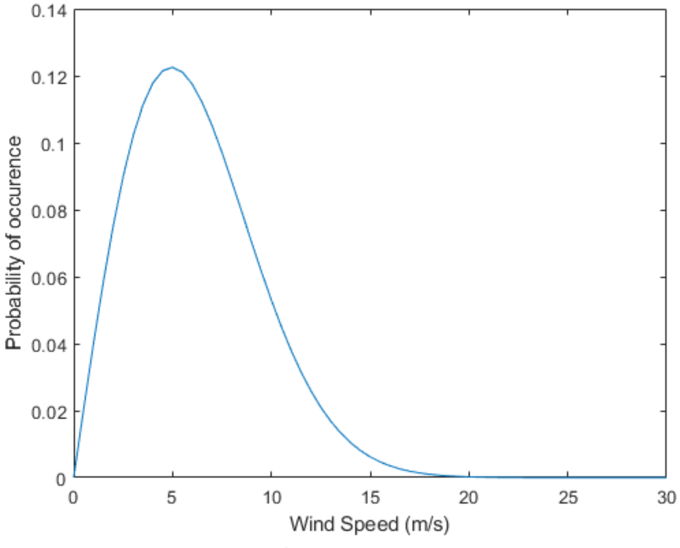


Figure 7 - Weibull probability distribution for wind speed used in QBlade AEP calculations

The blades were initially made by 3D printing an STL exported from QBlade. We used an FDM printer, and polylactic acid (PLA) for the blade material. However, initial testing of these blades showed they consistently failed after 10 minutes of continuous use at high speeds in the wind tunnels. By analyzing the failure points of the blades, it was determined they were failing due to high cyclical loads, as evidenced by beach marks found along the failure plane. The beach marks can be seen in figure 8.

Figure 8 - Beach marks along failure surface of PLA blades

To avoid fatigue failures, the blade material was changed to Nylon PA-12. The blades were printed using a Selective Laser Sintering printer, with a print resolution of 0.05 mm, and excellent surface roughness. The nylon has a tensile strength of 41 MPa. Using these properties, an FEA analysis of the blades was done in QBlade. Using the force calculations from section 2.3, a distributed load of 1/3 the total force, or 20 N, was applied to the blade. The maximum stresses were concentrated along the center axis of the blade, close to where the PLA blades had failed. The max stress from a 20 N load was reported as 37.53 MPa, as seen in Figure 9, which falls within the limits of the Nylon material. This FEA also estimated the tip of the blade to deflect as much as 6.58 cm during testing, which was not consistent with what we saw during initial turbine tests. QBlade allows the user to import simulation data to estimate the forces on the blade at certain windspeeds. Using the QBlade estimated forces showed significantly smaller forces, closer to 1.3 N total force, with stresses no greater than 2.6 MPa. This tip deflection was estimated to be no greater than 3 mm, which was more in line with what we observed during testing, indicating that the calculations for force due to the wind on the front of the turbine were far greater than what we are seeing in our real-world testing.

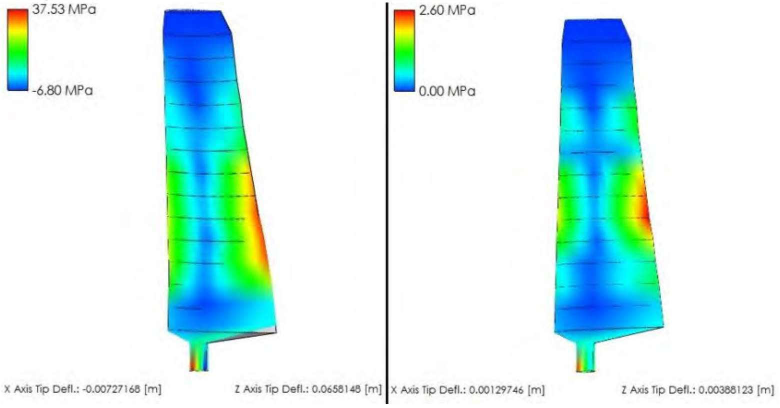


Figure 9 - FEA analyses of the blade from QBlade. The blade on the left shows the 20N load, while the right blade shows the QBlade estimated load

To further verify the strength of the nylon blades, we printed several to perform destructive testing. We used an Instron to test 2 blades each in a tensile strength test and a 3-point bend test. In the tensile pull test, the blades survived over 1500 N before failure. The 3-point bend test is more indicative of the type of loads we expect the turbine blades to experience. Of the blades tested in 3-point bending, only one failed. The other was able to withstand enough displacement and force that it slid out of the bending set up without breaking. The blade that did fail held 140 N before snapping. Even if each blade needed to support 20 N before failing, that would give us an approximate safety factor of 7.
Overall, the team feels confident that this year's blade design will be capable of producing high power over a range of wind speeds and is not at risk of breaking during the durability tasks of the competition. The nylon PA-12 material gives the blades a factor of safety of at least 7. Additionally, the Annual Energy production of the blades, according to QBlade simulations, is just over 60 kWh.

4.5. Nacelle

The nacelle serves primarily as the aesthetic and aerodynamic enclosure to hold all the important electronics in place and protect them from failure. This year's turbine does not require the incorporation of passive or active yaw capability, and as such was modified to have a small, streamlined shape, without large fins or other protrusions that would have been needed for stabilization. The nacelle is held onto the supporting post with a lock collar. The design was made so that next year's team could easily redesign the mount and incorporate bearings or a turntable.

The interior of the nacelle uses a modular system to allow for small electronics to be mounted anywhere along the edge of interior space. It also holds the generator and the axle using support posts. The axle transfers power from the blades to the generator, and its support post houses a bearing. The post has two heat-set threaded inserts, which allow a small 3D printed cap to screw on top of the bearing and hold it in during testing. The front post also holds the linear actuator which controls the pitch of the blades. Figure 10 shows the interior of the nacelle, with the generator, axle, and linear actuator all in their final positions. The assembly drawing of the final nacelle can be viewed in the Appendices as "Assembly Drawing of Nacelle."


Figure 10 - View of the interior of the 3D printed nacelle.

4.6. Electronics

At the heart of our power generation system is a DC motor. A DC motor simplifies the electrical circuitry by not requiring a rectifier and providing a much more constant output. After performing initial testing with the KV300 T-motor used in last year's design, less than 1W of power output was measured at up to 22 m/s of testing in the wind tunnel. Consequently, a new motor was selected to be the generator of the turbine. The blades have an optimum tip speed ratio of 3.5, and since the scoring of power output is weighted heaviest between 5-7 m/s wind speeds, it was decided that a motor should be selected that performs best near 5600 RPM. Maxon motors is known to be a high-end motor manufacturer, and so after speaking with a representative from Maxon, the team decided to purchase a Maxon 60W graphite brushed motor, part number 268193. (3) This motor also has an integrated motor encoder, which would allow the controls team to easily read the motor speed with the Arduino.

Due to team member constraints, we created a simplified and streamlined power-production circuit plan to use during initial testing. The output power is adjusted to be at 6 V with a buck converter. The 6 V output will also power the four internal components: Arduino, generator encoder, brake system, and linear actuator for pitch control. While this system, see Figure 11, is in line with the competition requirements, it also limited and "maxed out" our power production to about 2.5 Watts. Although we have measured up to 15 W produced from our turbine during generator testing over an 8-ohm load, using the simplified system limits the current and voltage reaching the load. Because we have a static load and are setting the voltage to a constant 6 V out of the buck the current, $I = \frac{V}{R}$, is also static. This led to a constant power output no matter what voltage and current our DC motor produced.

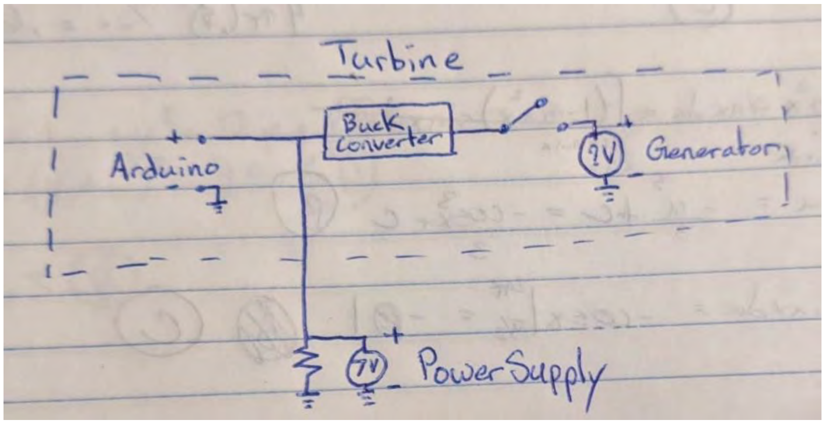


Figure 11 - Buck Convertor and Constant Wall Voltage

To overcome this significant power loss, we moved on to a more advanced circuit design, as shown in Figure 12 and Figure 13. This concept uses two relays, one on each side of the PCC, to control voltage and current flow. The two relays create two systems, a turbine powered system that drives the resistive load, and a wall powered system from the load side powering the internal nacelle components. Both systems (turbine-drive and load-drive) use the same wires that pass through the PCC and therefore meet the CWC cable constraints. Each switch is controlled by the nacelle Arduino, and the Arduino will communicate to the load side through an optically isolated comm-line. The comm-line is to make sure the Arduino, turbine, and the load sides are in the same performance-state. The performance-states are power production, load disconnect, emergency braking sequence, or restart. This system allows for the buck convertor to protect the nacelle Arduino input voltage while not limiting the voltage and current that pass through the PCC to the load. This system is still under development and testing.

In the spirit of simplifying designs, we are using a single constant power resistor, 8 ohms, for our load. With this setup the Arduino and all components can be in the housed in the nacelle.

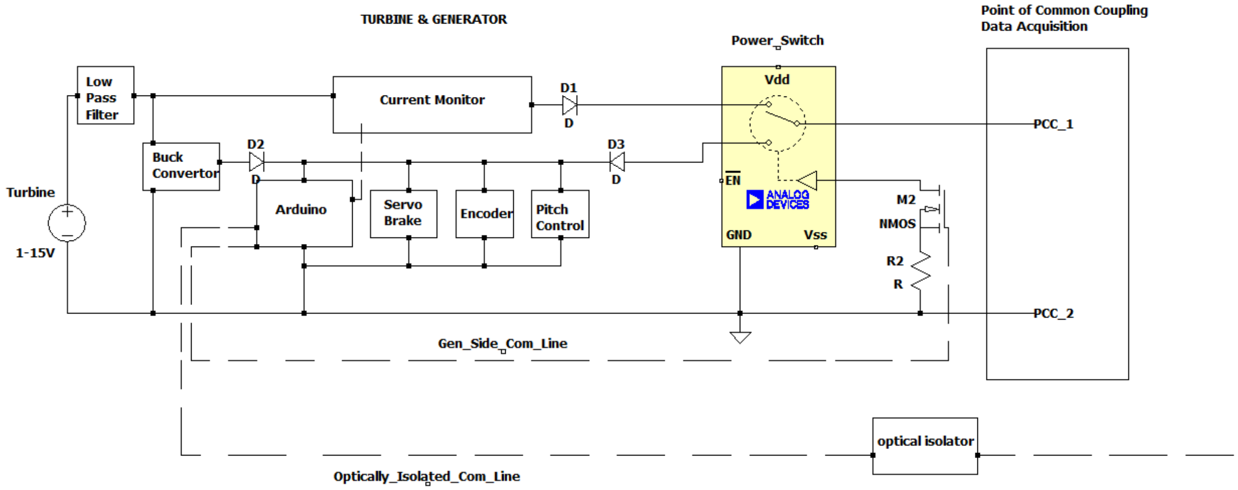


Figure 12 - One line diagram of the turbine side electronics

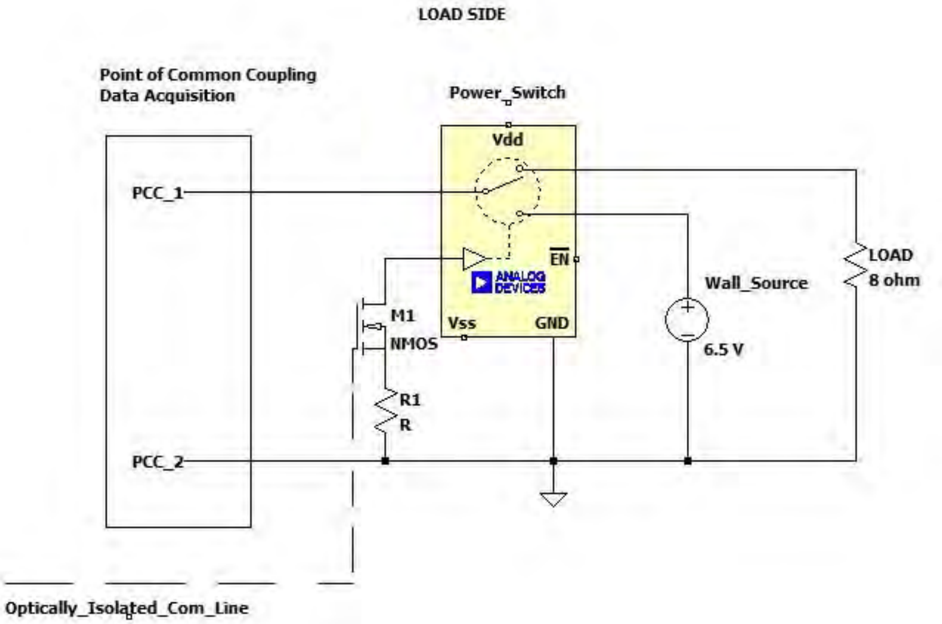


Figure 13 - One line diagram of the load side electronics

4.7. Software and Controls

An Arduino is used as the brains for the turbine. The first sensor monitored by the Arduino is a rotary encoder on the generator shaft which measures the rotation speed of the blades. With rotation data from the encoder, the Arduino monitors for abrupt changes in rotation speed to detect a load disconnect. There is also a pin reading the emergency-stop button. With this information, the Arduino can swap between the following states: startup, max rotation speed, rated speed, and emergency stop. A flow diagram of the states and triggers can be seen in Figure 14.

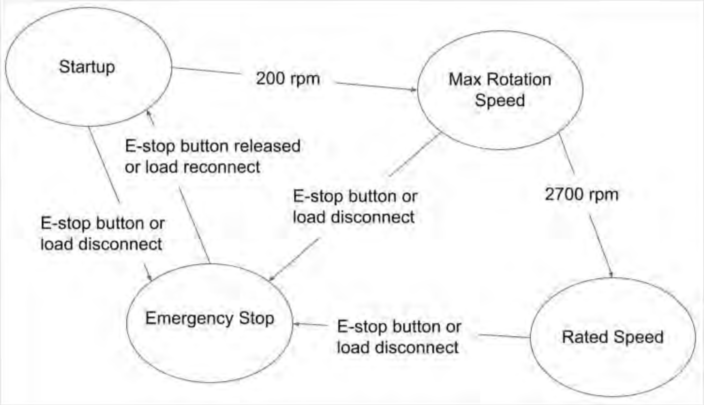


Figure 14 - Flow diagram for software states

During startup, the blades are pitched to an optimal angle for a low cut-in speed. Once the wind is fast enough to spin the blades above a threshold rpm, the state switches to pitch the blades and maximize the rotational speed. During testing it was found that it is best to keep the rotation of the blades less than 2700 rpm, which is reached around wind speeds of 11 m/s. When the generator reaches this rotational speed, the state is switched to rated speed such that the blades are incrementally pitched out of the wind to maintain speeds close to but below 2700 rpm. The final state, emergency stop, is triggered by the e-stop button or a load disconnect. The emergency stop state pitches the blades all the way out of the wind.

The generator encoder uses the encoder Arduino library and two interrupt pins to measure the rotations per second of the generator. The linear actuator used for changing the pitch of the blades is controlled with the servo Arduino library and uses a pin with a PWM signal to specify the position. The emergency stop button is read on a digital pin, where the high is released and low is triggered. A load disconnect is detected by monitoring for a significant change in the rotation speed, which we found to be very distinctive as seen in Figure 15.

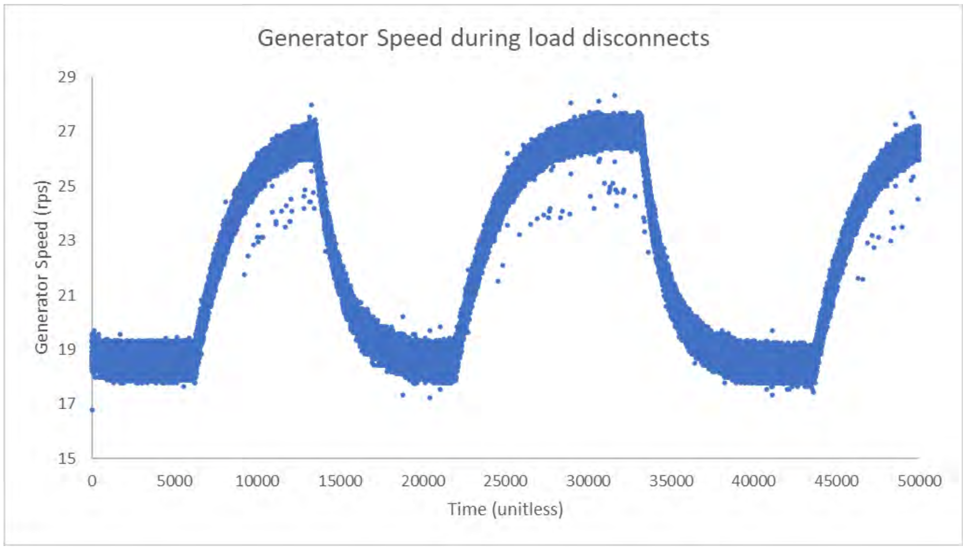


Figure 15 - Generator rotational speed during load disconnects

4.8. Installation Instructions and Checklist

- ☐Install foundation
  - ☐Thread droop cable through hole in corkscrew
  - ☐Ensure somebody holds the ends of the droop cable so connectors do not get wet
  - ☐Attach the bubble level to the corkscrew
  - ☐Use the installation rod to screw the foundation in, ensuring it stays level
  - ☐Use the battery powered massage gun to compact the sand around the foundation
  - ☐Tug on the foundation to ensure it does not come loose
- ☐Install the adapter stub and thread droop cable through it. Remove the wing nuts
- ☐Roll the table under the wind tunnel
- ☐Connect the droop cables to the turbine side cables
  - ☐Lightly tug on connectors to ensure they are secured
- ☐Mount the turbine to the adapter stub and secure using the wing nuts
- ☐Point the turbine into the wind by adjusting the lock collar in the nacelle
- ☐Use a multimeter to check for connectivity between PCC side and turbine side wires
- ☐Attach the droop cables to the PCC
- ☐Attach emergency stop wires
- ☐Connect the load side of PCC to load
- ☐Check that the blade pitch control is not locked
- ☐Connect load side electronics to wall outlet
  - ☐ Verify LED is on in load box to confirm the wall-system is prepped
  - ☐ Turbine side Arduino should power up and initiate start sequence
- ☐Check that all internal components of turbine are intact, secure, and communicating
- ☐Close the nacelle.
  - ☐ Ensure the nacelle is tightly shut
  - ☐Check the fit of nacelle halves are tight and will not come loose

4.9. Final Assembly and Performance of Turbine

Because of the somewhat iterative design approach used by the team, most of the systems had already been tested together prior to the final assembly of the system. Consequently, all systems assembled properly into the final turbine, and the team was able to spend a few weeks on mock competitions and refining the final system. The mock competitions allowed us to run multiple tests of all systems.

Installation of the foundation can be performed smoothly, with the cabling properly running through the adapter stub and the foundation without getting connectors wet. The turbine sits properly on the adapter stub and can be pointed into the wind as necessary with the adjustable mount. More importantly, the foundation remains stable during testing, with no visible movement up to wind speeds of 23 m/s, with one exception during emergency stop procedures, as discussed below.

The turbine performance also met our expectations. The cut in speed of the turbine was 3.7 m/s, below the starting wind speed for the power curve task. The turbine generated power consistently during testing, up to wind speeds of 23 m/s. When the emergency stop was triggered through the emergency stop button, the blades were able to pitch out of the wind, and the motor encoder reported the turbine rpm fell below the 10% of the speeds it had been running at. The turbine was able to start up again when the emergency stop was ended. When the blades pitch fully into or out of the wind, the entire system shifts as the force of the wind stops pushing on the blades. However, analysis of high-speed footage and force gauge testing shows that this motion does not compromise the stability of the system, and the foundation remains stable in the sand.

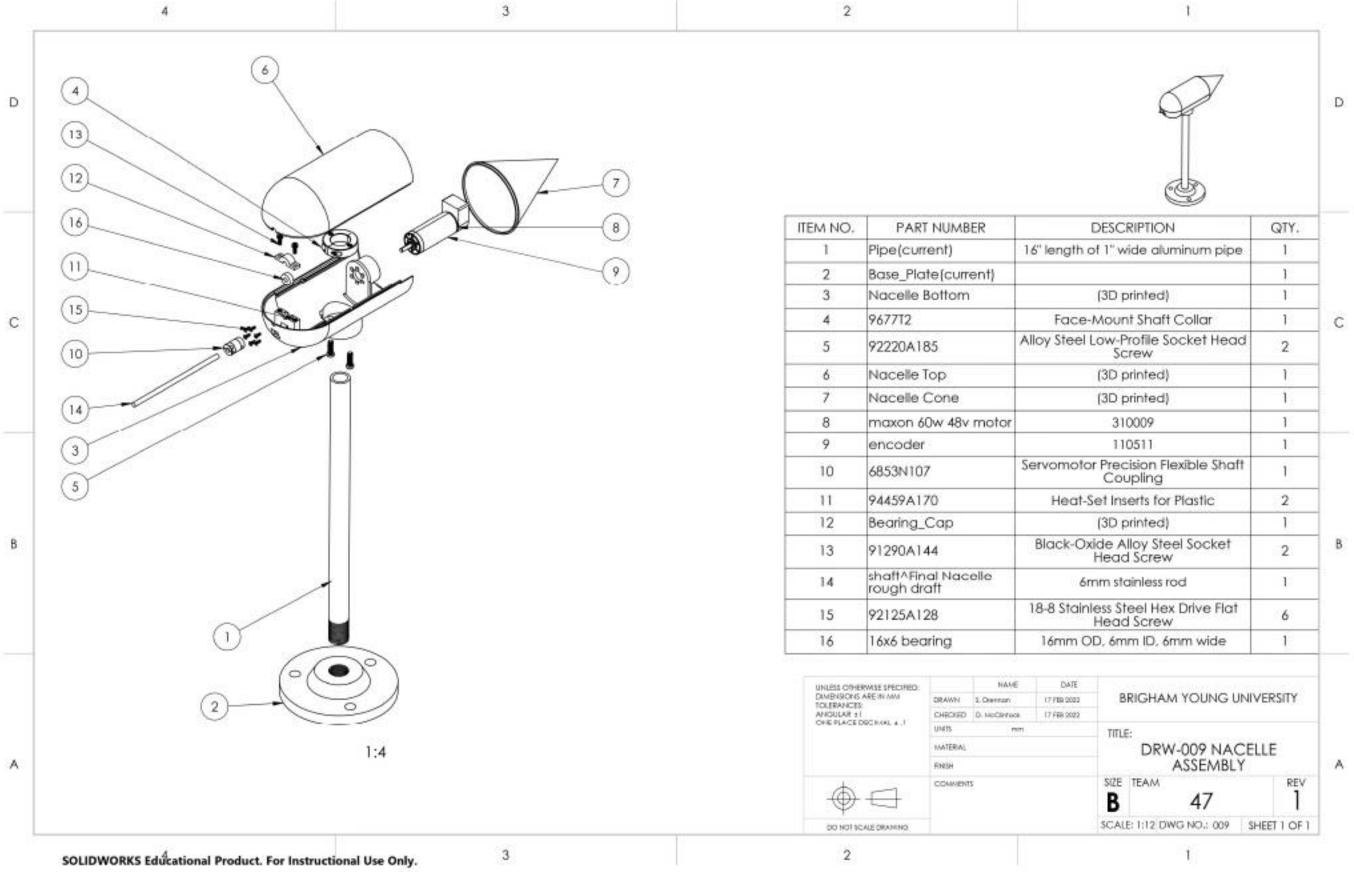
Total power output of the system is just over 2.5W. This value is not as high as we were hoping to achieve. We believe that the final circuitry is not as optimized as it could be and refining the system could significantly increase the power output of the turbine. Additionally, the selected motor can run at much higher RPMs than our blades spin at, so adding a gearbox to the existing design could potentially increase the power output. Finally, integrating a variable load system to the turbine would help with achieving optimal power output at specific wind speeds.

5. Appendices

5.1. RM-001 Requirements Matrix

			Key Success Measures				Basic Measures					Constraints						
		Units	m/s	kg	W	s	unitless	unitless	cm	unitless	N/A	N/A	V	A	N/A	cmx cmx cm	cm	cm
		Performance Measures	Maximum survivable wind speed	Weight of base	Maximum power reached within 5-11m/s wind speed range	Time required to reach 10% speed when brake is engaged	Power curve score [1]	Maximize power coefficient (C_p)	Deflection in the horizontal direction	Tip-speed ratio (ratio of blade tip speed to wind speed)	Aesthetic quality	Shut-down and restart ability	Voltage output	Current output	NEMA rating for safety of electrical components	Turbine bounding box dimensions, excluding tower (height x width x depth)	Foundation height above water	Structure foundation diameter
	Market Requirements	Importance	1	2	3	4	5	6	11	12	13	9	14	15	16	17	18	19
1	Generates significant amount of power	9			X		X	X										
2	Power output can be controlled	8			X													
3	Withstands high wind speeds	6	X						X									
4	Meets CWC dimensional requirements	10		X												X	X	X
5	Interfaces with CWC equipment	10											X	X				
6	Produces power at low speeds	5			X		X											
7	Safe electrical components	7													X			
8	Safe voltage/current ouput	10											X	X				
9	Able to shut down safely at any time	8				X						X						
10	Durable	7	X						X	X								
11	Turbine maintains structural and civil stability during testing	9		X					X								X	
12	Aesthetically pleasing	1									X							
		Importance	4	7			9	5	3	8	1	8	10	7	10	10	2	5
Ideal Values	Lower Acceptable Limit		13	0	1	N/A	20	0.25	N/A	2	N/A	N/A	N/A	0.5	N/A	N/A	-3	N/A
	Ideal		22	0	7	1	50	0.44	1	4	Looks like a wind turbine	Shuts down after button press or power disconnection	< 48	1	Meet NEMA1 guidelines	< 45 x 45 x 45	-1	3.8
	Upper Acceptable Limit		22	N/A	11	10	N/A	N/A	2	8	N/A	N/A	48	3	N/A	45 x 45 x 45	0	3.8
Real Values	Target		18	4.5	7	1	40	0.38	1	6	Looks like a wind turbine	Shuts down after button press or power disconnection	<48	<10	Meet NEMA1 guidelines	<45 x 45 x 45	0	3.8
	Stretch		22	2.5	10	<1	50	0.44	0.5	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

5.2. Exploded View Assembly Drawing of Nacelle



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Pipe(current)	16" length of 1" wide aluminum pipe	1
2	Base_Plate(current)		1
3	Nacelle Bottom	(3D printed)	1
4	9677T2	Face-Mount Shaft Collar	1
5	92220A185	Alloy Steel Low-Profile Socket Head Screw	2
6	Nacelle Top	(3D printed)	1
7	Nacelle Cone	(3D printed)	1
8	maxon 60w 48v motor	310009	1
9	encoder	110511	1
10	6853N107	Servomotor Precision Flexible Shaft Coupling	1
11	94459A170	Heat-Set Inserts for Plastic	2
12	Bearing_Cap	(3D printed)	1
13	91290A144	Black-Oxide Alloy Steel Socket Head Screw	2
14	shaft^Final Nacelle rough draft	6mm stainless rod	1
15	92125A128	18-8 Stainless Steel Hex Drive Flat Head Screw	6
16	16x6 bearing	16mm OD, 6mm ID, 6mm wide	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR ±1
ONE PLACE DECIMAL ± .1

	NAME	DATE
DRAWN	S. Drennan	17 FEB 2022
CHECKED	D. McClintock	17 FEB 2022
UNITS	mm	
MATERIAL		
FINISH		
COMMENTS		

DO NOT SCALE DRAWING

BRIGHAM YOUNG UNIVERSITY

TITLE:
DRW-009 NACELLE ASSEMBLY

SIZE B
TEAM 47
REV 1

SCALE: 1:12 DWG NO.: 009
SHEET 1 OF 1

6. Bibliography/references

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