Iowa State University

Business Plan and Wind Turbine Technical Report

AdVentus

Team Members

Siting Challenge	Structure	Blades	Electrical/ software	Business
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1. Executive Summary

In this report, ***AdVentus*** will explain the overall business plan, including marketing strategy and supply chain approach, as well as the financial analysis in regard to this proposed company. In order to promote and expand green energy in the RV industry, ***AdVentus*** would like to introduce an innovative product that provides an alternative solution for RV communities through the utilization of a clean and renewable wind energy source. The product, a portable wind turbine, will address concerns about portability, reliability, cost and environmental impact that arise with gas powered generator options. As seen in Figure 1, based on the market research conducted, 36% of RV owners were found willing to spend on a renewable energy product. Consequently, between the two major renewable energy products, solar and wind, ***AdVentus*** will go forward in manufacturing a portable wind turbine because the company believes this would be a marketable product, especially because of the Midwest's wind source.

Figure 1. AdVentus Device Mounted to Camper

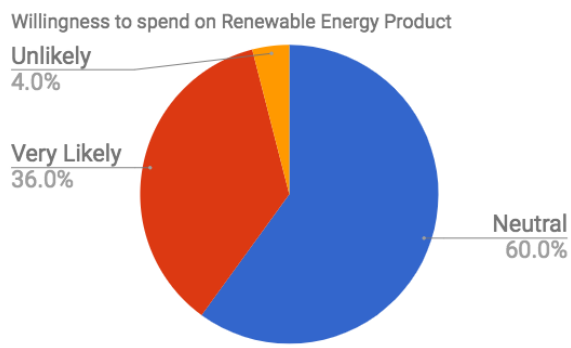

Figure 2. General Willingness to Spend on Renewable Energy Product

The company would like to seek a total investment of $350,000 for the first year and $50,000 on the second year. Thus, angel investors will hold a 41% of equity in the company. The whole team has manufactured the prototype and it appropriate testing has been conducted.

AdVentus will target two different consumers, which include millennials and the baby boomers. The company's wind turbine will not only provide an additional energy source for their RVs, but the product itself will also have a mobile application which contains various features of the turbine's system. At the same time, the product package will contain a portable battery for customers who would need an extra power source during camping or tailgating events.

In order to collect an accurate result, the company has analyzed the RV industry itself by conducting first-hand research by attending a tailgating event to retrieve information about RV owners. Furthermore, ***AdVentus*** also conducted interviews with camper sellers specifically in Iowa, such as Autorama Inc., Bob & Jo's, and Imperial. The purpose of the first-hand research was to gain insight about how the business would work within the current and future industry. ***AdVentus*** would like to go forward with the company by using an emergent strategy, which means that the company will have full control on the innovation, but at the same time continuously work together with consumers to create the most environmentally and societally friendly machine for its consumers. The company is confident that the primary research further strengthens this business proposal.

Through extensive testing, the team has attempted to provide a sample model to this type of turbine. Full SolidWorks and systems modeling are provided throughout the latter half of this report to further provide sample modeling into the company's product. The Iowa State University Collegiate Wind Competition Team attempted to integrate the Midwest's passion for renewable energy into a technically efficient product, which is the core of the ***AdVentus*** business methodology.

2. Business Plan

2.1 Business Overview

Since the initial idea phase for ***AdVentus***, the "founders" of the company have taken on a clear and focused path to lay the foundations and future success of the company. ***AdVentus's*** founders sought to combine the necessity of renewable energy with the commonality of outdoor exploration and activity that is native to the Midwest. The main idea for ***AdVentus's*** business strategy and product creation stemmed from the founders' collegiate experience at Iowa State University, where tailgating for university football games is traditionally a profound activity in which a vast majority of the school's student body, surrounding community, and even regional and national alumni take part. This fact spreads throughout the Big XII conference for not only football games, but also other major sporting events, such as basketball, baseball, and other NCAA events as well. That being said, camper and RV tailgating maintain deep roots within the company's home state of Iowa. With over 3,900 wind turbines (> 7.3 GW installed capacity) already installed in the state, Iowans are taking on the challenging task of spreading renewable energy past their state lines [1]. Therefore, with the ability to obtain mobile methods of wind energy, ***AdVentus*** developed a vision to expand the reach of clean energy through the use of its RV- and camper-compatible turbines.

As stated previously, the vision of ***AdVentus*** originates from wanting to provide outdoor and nature-lovers with the ability to harness nature's power while enjoying the beauty that Earth has to offer without harming it. For this reason, the company aims to provide an alternative solution for camping and RV communities that uses a renewable wind energy source and addresses concerns about portability, reliability, cost, and environmental impact that arise with current gas-powered generator options.

The ***AdVentus*** vision is to become the leading renewable wind energy company in United States The ***AdVentus*** shared values or philosophy are embedded in the company's culture and the core of the company's business operation. The values are integrity, innovative, cohesiveness and sustainability.

2.2 Market Opportunity

*Table 1. **AdVentus's** Business Model Canvas*

<table>
<tr>
<td rowspan="2"><u>KEY PARTNERS</u>
-Material company
-RV companies that offers green energy prep (Solar or Wind Turbine prep)</td>
<td><u>KEY ACTIVITIES</u>
-Buying some parts from key partners to reduce cost.
-Manufacturing of parts that would be more cost effective (and competitive with present technology) to manufacture ourselves.
-Assembly
-Packaging
-Distributing</td>
<td rowspan="2"><u>VALUE PROPOSITION</u>
-Clean Energy
-One time purchase ("fuel" is wind)/self sufficient
-Additional energy source besides a generator
-Easily stored
-Provides energy anytime, anywhere.</td>
<td><u>CUSTOMER RELATIONSHIP</u>
-1 year warranty
-Customer support (we can provide/link them to spare parts)</td>
<td rowspan="2"><u>CUSTOMER SEGMENTS</u>
-Individuals
-25-75
-RV Owners
-Interested in RV camping
-RV Sellers</td>
</tr>
<tr>
<td><u>KEY RESOURCES</u>
-Marketing/ sales staff
-Shipping
-Assembly team
-packaging team
-Techs for warranty</td>
<td><u>CHANNELS</u>
-At tailgate, demonstration.
-Social media
-Newspaper, magazine, print stuff
-Company website</td>
</tr>
<tr>
<td colspan="2"><u>COST STRUCTURES</u>
-Materials and marketing will be the most expensive
-Research and Development
-Maintain factory</td>
<td colspan="3"><u>REVENUE STREAMS</u>
-Comparable to generators
-$600</td>
</tr>
</table>

Table 1 demonstrates ***AdVentus***'s Business Model Canvas that will be used as a guideline to identify how the company would like to innovate. This will provide overall guidance to ***AdVentus*** throughout its execution of the product lifecycle to minimize disruptions in the market.

2.2.1 Value Proposition

Camping is associated with appreciation of the outdoors and connecting to nature. The company's initial idea phase stemmed from this fact, and yielded a product that would be able to power necessary camping equipment with a renewable source that has little impact on the environment. The product design is portable, durable, and self-sufficient. When there is no wind, customers can still power small electronic devices easily through the power storage system design. The cost of the system is comparable to or less than other model turbines with different functionalities. In addition, this product significantly reduces the amount of gasoline purchased and worry over charging up batteries before leaving home. ***AdVentus*** plans to sell the product, consisting of the full assembly, storage device, and spare parts, to RV sellers for a price of $500; they can then sell them to end users for $600 to $700 and remain within a profitable margin. ***AdVentus*** will maintain a $600 selling price on the company website. Through lower, affordable pricing in the market and an attempt to fulfill the customer's needs and requirements, ***AdVentus*** prioritizes the maximization of the camping experience for their customers (both the RV sellers and the second-tier customers, such as outdoor enthusiasts and tailgaters who own RVs).

The ***AdVentus*** founders also proposed a portable battery that can be used by the campers to store energy for later use (perhaps when sufficient wind is not available). ***AdVentus*** believes that the portable battery would be very important for the camping experience, so the customer would not be without power if they needed it to power small electronic devices, such as cell phones and tech accessories.

AdVentus has been putting forth the effort to be a strong competitor in the RV industry and will prioritize growth. In order to be the leading company in the RV industry, ***AdVentus*** will maintain a good partnership with a range of companies in the industry, especially the RV sellers who are attempting to improve/upgrade their campers with renewable energy solutions. Having these companies partnered with ***AdVentus*** to promote green energy would presumably give ***AdVentus*** a competitive advantage towards other renewable energy businesses, such as solar panel providers.

2.2.2 SWOT Market Analysis

Strengths

One of the strengths of ***AdVentus's*** product is that it will be a pioneer within the RV industry. The company will be entering into a unique market that is, simply stated, a composite of both the RV industry and portable renewable energy product industry. In financial terms, although the upfront cost of purchasing a wind turbine may be high, ownership can actually prove to be cost-saving in the long term. Hence, by purchasing a one-time product, a consumer could save on their RV expenses through elimination of electrical hook-up or reduction of gas consumption. Passionate employees and good communication by having the majority of operations within a single manufacturing plant will also aid in success of operations.

Table 2. SWOT Analysis

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Employees are passionate about the environment • Strong communication within departments • Unique product	• First of its kind • Lack of experience	• Iowa has strong wind resource • Cheaper real estate market in Iowa • Numerous benefits for renewable energy	Solar Panel • High market popularity • More reliable

Weaknesses

Although the fact that ***AdVentus*** would provide the first high-production turbine of its kind is the company's largest strength, it could also be considered the main weakness. It is a risk for investors to buy in on this, because the success rate of such a product is unknown, with minimal data to back up the proposal. Another potential weakness is the lack of the company's employee experience. As a new business on the market the company has a limited idea of how the industry functions in terms of business cycle and trends, except through ***AdVentus's*** research, observations, and analysis of the customers who would be potentially purchasing this product.

Opportunity

Basing a wind energy company in Iowa provides a great range of opportunity, as a state with a strong available wind resource and legal and financial benefits. As of the end of 2017, Iowa is ranked third among the states in terms of installed capacity and ranked seventh among the states for wind energy potential due to strong average wind speeds [1]. This provides a good wind resource for campers within the state and creates a renewable-friendly climate in which to market a wind energy product. Iowa also has traditionally set a good example for other states in that it encourages use of renewables, through such actions as being the first state to pass a Renewable Fuel Standard in 1983 [2].

Additionally, Iowa has one of the cheaper real estate markets in the country, which could help financially when building a headquarters building and factory. Iowa's central location provides a more cost-effective opportunity to ship the product to a larger range of locations in the country. Iowa also offers some rebate programs for use of renewable energy such as the Small Wind Innovation Zone Program and Model Ordinance, which would make the market for the product more welcoming [3]. Within the research the company has performed, it has been determined that no other company has created a wind energy product exclusively designed for the camping and RV market. Therefore, ***AdVentus*** would have a greater market opportunity due to it being in a "first-mover" status position with no direct small-scale wind energy competition.

With the projected expansion of the company's customers across the United States, wind resources in popular camping areas offer an opportunity for continued use of the product. Yellowstone National Park has a wind speed range from 0-40 mph with higher averages in the late spring to early summer (around 6 mph) and a yearly average of 5.1 mph for 2017 (as displayed in Appendix A). Many popular camping areas are located in the western part of the United States, from the Rocky Mountain National Park, Arches National Park, Zion National Park, and Canyonlands National Park.

2.2.3 Partnerships

In order for ***AdVentus*** to be successful, partnerships with RV sellers will be crucial. After attending an RV expo in Des Moines, Iowa and performing research into the potential customers' suggestions for ***AdVentus***, the team discovered that many of the companies at the expo already embrace sustainability by offering solar prep services to their customers. For this reason, the team believes that these companies could sell ***AdVentus***'s turbines as an optional add-on to their RVs. ***AdVentus's*** main partnerships during the first year will be with RV sellers in the states of Iowa and Minnesota. RV sellers will have more variety of products to offer their clients and an enhanced brand image by embracing sustainability and renewable energy in a time when it has become very relevant. Finally, the company will, as part of the contract, guarantee the adjoining partners that warranties and liability for the product will be directly covered by ***AdVentus***.

2.3 Management Team

Chief Executive Officer: Azfar Kamarudin

As Chief Executive Officer, Azfar Kamarudin makes high-level managerial decisions. He manages the overall operations of ***AdVentus*** and makes sure it is well-resourced. As a main point of communication between the board of directors and corporate operations, it is crucial that he remains a viable contact for everyone. In addition to large-scope communication, Azfar is also responsible for daily management decisions, keeping in mind the company's short-term and long-term plans.

Chief Financial Officer: Aiyna Muhamad

As Chief Financial Officer, Aiyna Muhamad is responsible for all financial records—past, present, and future. She reports historical financial information that helps with company-wide decisions. Aiyna also evaluates the present economic climate to determine which financial direction ***AdVentus*** should take. On top of that, she oversees the investment of ***AdVentus***'s finances and determines how the company can capitalize on areas of high efficiency. Key traits that Aiyna possesses that aid in her success are being timely and accurate.

Chief Operating Officer: John Ceriotti

As Chief Operating Officer, John Ceriotti is responsible for the daily operation of ***AdVentus***. ***AdVentus*** is striving for growth in every aspect of the company. This is done by implementing specific business practices, promoting a positive culture, and checking operations of both line management and executives. He will implement Lean culture into not only manufacturing operations, but also daily business operations, to make sure the company is maintaining maximum efficiency. John excels in his position because he has experience in this field and is a leader.

Chief Legal Officer: Lauren Wibe

As Chief Legal Officer, Lauren Wibe oversees all legal action within ***AdVentus***. Lauren's main goal is to minimize the legal risks within and imposed on the company. She is in constant contact with other leaders in the company to ensure laws and regulations are being followed. Lauren advises the other board members and chief officers on the risks their planned actions could cause. All in-house attorneys report directly or indirectly to the office of the CLO. Lauren is a strong leader who is able to draw the line between right and wrong.

Engineering Board Members: Scout Crow, Heather Vieger, Brendon Geils

The engineering board makes major decisions on issues and improvements regarding the product's design. They also oversee the manufacturing process of the turbines and make decisions on major investments and design changes. The board is composed of highly qualified professionals on structural, aerodynamic, and electrical systems.

Advisory Board: Dr. Sritharan, Dr. Krennrich, Nicholas David, Mathew Wymore, Juana Castelli

The advisory board is composed of professionals with expertise on different areas of the market and industry credibility. This board will only be required to dedicate a few hours a year to the company. They will contribute to the overall vision of the company and provide the company's employees (particularly those in business development) with networking opportunities. Given that these informal advisors share ***AdVentus***'s vision and passion for renewables and sustainability, compensation will be expected.

2.4 Mobile App Concept

AdVentus is proposing a mobile-app that will provide the wind turbine users with real-time data and a better understanding of the system. This will make the turbine more user-friendly and will allow the users to better understand their energy production and consumption. This app will compliment the cutting-edge technology of the ***AdVentus*** wind turbine as well as the company's vision of sustainability.

2.4.1 Functionality

- Wind Speed Data
- Power Generation
- Power Consumption
- Battery Percentage (percentage & total energy available)
- Weather Forecast (if the app is connected to the internet)
- Electronic Version of the Turbine Manual and Safety Procedures
- Blog Platform
- Smart Energy Predictions
  Customer Service

Figure 3. Mobile App Home Interface

2.4.2 Electronic User Manual

In order to embrace the concept of sustainability in all aspects of the product, the app will have an embedded electronic version of the user manual, warranty, and safety practices. Even though ***AdVentus*** will offer printed copies to those users who do not wish to use the app, this will still help the team reduce the number of paper copies. This manual will also be efficient for the reader, given that the user will be able to easily navigate around the different sections of the manual or use the search bar to find the topic he or she wants to read.

2.4.3 Wind Speed Data and Weather Forecast

The app will also provide the user with real time wind speed data and weather forecast (if the electronic device is connected to the internet). Wind speed data will be available for the turbine location in general, as well as from the turbine wind speed sensor that will provide a more accurate and immediately relevant measure. As internet access is at times limited in outdoor recreation areas, the app will receive data from an RF signal within the turbine if cellular or satellite data is not available to access the internet. In addition, if the weather forecast predicts extreme wind speeds or storms, the app will advise the user to shut the turbine down until it is safe to operate. Finally once the wind speed sensor detects dangerously high wind speeds, the turbine will automatically shut down for safety.

2.4.4 Energy Real-Time Data

Other real-time data display options include the current power generation of the turbine and the power consumption of the user. ***AdVentus*** believes that is important for the users to be aware of and familiar with their turbine’s power production capabilities. Moreover, given that the turbine will allow the user to remove the battery and take it with them while they hike or explore, it is important that they are aware of how much power they have left in the battery. For this reason, the app will provide the user with real time data about the battery including percentage, total power available, and charging status.

2.4.5 Smart Energy Predictions

The proposed app will have the ability to provide analysis and predictions of the power consumption and production. The app will have an algorithm that takes into consideration current energy consumption, battery charge, current power production, and predicted winds in order to determine the available use hours given the current (or recent past) consumption rate. In this way, if the algorithm determines that power demand will outstrip production and battery charge, then the app will suggest that the user reduce the power being drawn from the turbine and its battery. In addition, as internet or cellular data access may be limited, the app will utilize averaged past wind speeds from the turbine's sensor, although this would mean that the program would assume the wind pattern would not significantly change.

2.4.6 Customer Service

The company understands the importance of providing good customer service. For this reason, in addition to having a customer service phone line, ***AdVentus*** will give its customers the option to live chat with a representative at all times and to provide feedback on the service received in order to keep improving it. This will create brand awareness, will build trust with the customers, and avoid problems.

2.4.7 Blog Platform

The app will also have a social platform for turbine users to interact with each other. The platform will have a Q&A section that includes common questions and enable users to post pictures or comments. Additionally, the platform will feature a live chat feature.

2.4.8 Portable Battery

The wind turbine will incorporate a detachable battery. This component of the wind turbine will fulfill the portability feature of the product. Since ***AdVentus*** is focusing on the outdoor enthusiast community, ***AdVentus*** believes that the battery will be an essential gadget for users to carry with them, whenever they leave the campsite/turb site. It will be lightweight to accommodate the needs of hikers and hunters and waterproof for canoeing or kayaking. ***AdVentus*** cares substantially about customers’ experiences; hence, the company wants to create a product that can fit well with adventurous lifestyles. The battery itself can charge two different devices at once. Other than that, it also will have a small built-in ultra-bright LED light, which lasts approximately ten hours during continuous usage. Its lighting distance projects over 30 feet even during rain or fog.

2.5 Development Operations

2.5.1 Company Objectives and Development Phases

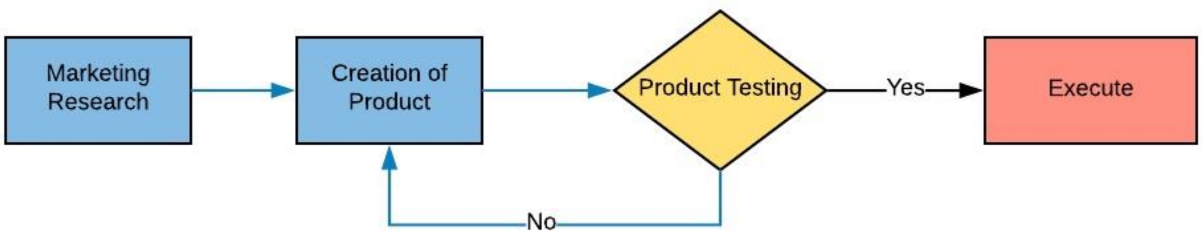

Figure 4. Overview of Company Phases

Phase 1: Marketing Research

Given the company's focus on renewables and sustainability, the ***AdVentus*** team initially researched issues in the mobile energy supply sector, specifically searching for market opportunities where wind energy could make a difference. The RV industry appears to be underserved in terms of available options, thus providing a good starting point for the development and sale of new wind turbine technologies. After designing an initial business plan, the team decided to survey prospective customers and suppliers in the RV industry.

The marketing research was divided into two parts:

1) Target market: RV/Camper Owners
2) Target market: Business Owners/RV Sellers

80 RV owners and 5 major RV companies participated in a survey that was brought to an Iowa State University tailgating event, where RV and camper owners/users are present. Based on the research, the team came to the conclusion that creating this market turbine will be beneficial to the target market. Based on Figure 5, ***AdVentus*** can conclude that the top 3 priorities that consumers look for before buying a renewable energy product are: 1) contains a good price (perceived value) (53.8%) 2) ease of use (15.4%) and 3) portability (14.1). Therefore, ***AdVentus*** will plan to create a wind turbine based on the consumer demands stated.

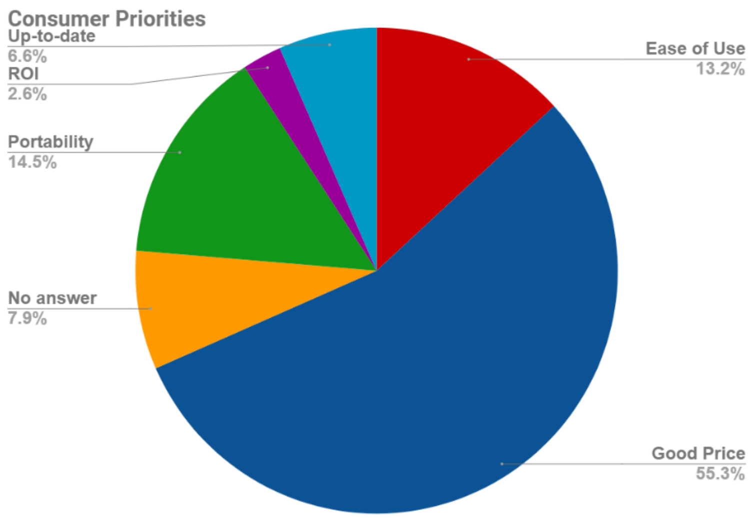

Figure 5. Consumer Renewable Product Priorities

Phase 2: Building and Testing the Prototype

Phase 2 includes building and testing the prototype of ***AdVentus***'s product. The bulk of the company's machines and materials will be outsourced, as will be reviewed in the financial and warehousing sections of this report. The manufacturing setting will include two main assembly lines for the tower structure and nacelle machining, with sequential areas to mold the blades and integrate electrical components. These main component manufacturing areas will flow (in an efficient spatial utilization method) to the main full unit assembly area. With the completion of assembly, the product will then be carefully packaged with the idea of ergonomic accessibility of the customer in mind for easy un-packaging. The prototype will then be shipped to consumers nationwide from the loading dock.

Initial testing and evaluation of the prototype will take place within the grounds of the company site. Two designated T&E Engineers will be able to take on the task of performance analysis that will be needed to fit the customers' needs. This includes generator, electrical load, blade airfoil, and structural analysis. The company will be able to utilize the combined ability of the engineering team to ensure updated SolidWorks drawings and ANSYS evaluation on the different sections of the turbine.

While creating the turbine, the ***AdVentus*** Software team will develop the mobile app. Application design takes place in two phases: the front-end phase, in which the user design and interface are produced, and the back-end phase, which has to do with the more technical aspects of the application. According to the design firm ONEFIRE, experts estimate that it takes about eighteen weeks for the complete implementation of a mobile application. That being said, the total duration of time for the implementation of a mobile application project really varies from app to app. ***AdVentus*** believes that with the relatively straightforward and simple design envisioned for the ***AdVentus*** app, work could be complete in 10-13 weeks.

Figure 6. Application Development Timeline

The most important step before releasing the product to the public is testing the innovation itself. AdVentus will conduct wind tunnel tests on a laboratory prototype system to verify that the mechanical components do function well in collecting energy and producing steady power output. Simultaneously, the company will test mobile app integration with the product. AdVentus would like to identify if there are any possibilities of bugs or crashes.

The next step would be to build a field prototype at scale, which would undergo further testing in a wind tunnel as well as in the field. Finally, the company will release a number of products to the public for supervised beta testing with focus groups. The beta test will be conducted by our Quality Assurance team to ensure that we can meet customer demands and safety requirements. The company will compile feedback from the beta tests and refine the product, brochures, safety operating procedures, etc., to ensure that the product will be accepted in a "live" environment.

Phase 3: Marketing and Promotion

AdVentus can create awareness by publishing the news through social media channels such as Facebook, Twitter and YouTube. Since Facebook now has the option to create a live stream video, ***AdVentus*** can take advantage of this by demonstrating to Facebook users how the wind turbine will operate. Besides that, by doing a live stream video, it can create a two-way interaction where Facebook users and ***AdVentus*** can ask and respond to questions on the spot. ***AdVentus*** will also advertise through print ads and demonstrations. We will make the company present during Expo events that is related to RV as well as green energy.

2.5.2 Manufacturing Location and Production Processes

2.5.2.1 Company Location

Placing the business has been a concern to ***AdVentus***, since the company wants to be a cost-effective business in a strategic location. After considering several factors, ***AdVentus*** decided to place its headquarters in Urbandale, Iowa, within the Des Moines metropolitan area (Des Moines is the Iowa state capital). The main factor considered was that Urbandale and Des Moines are both growing hubs for startups. West Des Moines has experienced a rising number of automotive business in recent years. Many of the RV businesses, ***AdVentus***'s main customers, are similarly located in West Des Moines and are within a fifteen-minute drive from the ***AdVentus*** business office. This is an advantage for the company, as it creates a high level of market competency for ***AdVentus*** and reduces the costs of doing business. In addition, within the Des Moines metro area, Urbandale has a significantly lower tax rate, which makes the cost of doing business in the area approximately 15% lower than the national average.Going along with this fact, ***AdVentus*** is going to lease a steel warehouse that is priced at $156,816 per year on a 0.6 acre land at the price of $6 per square foot in Urbandale, IA. The headquarters will include office space, a factory, and a warehouse, which will be divided according to the space needed for each area. Leasing the steel warehouse and putting everything in one place will help ***AdVentus*** save on operational costs, helping the company meet its goal to build a strong, early stage financial statement.

2.5.2.2 The Headquarters Building

The building will accommodate both manufacturing and warehousing areas. The idea of focusing on a positive revenue stream and business growth is a priority for the first few years, and optimization of working space will contribute to this positive revenue stream. A combined facility will lower operating costs due to reductions in expenditures on construction and maintenance. In addition, the line management will have a better overview of the entire operation, since it is in one building. The space consists of offices on the second level, with manufacturing space and warehouse space on the first level. The manufacturing space consists of mechanical equipment specifically for metal materials machining, blade molding space, electrical component manufacturing, assembly, and packaging/shipping. The warehouse space consists of assembly production lines and storage space. The estimated cost of the simple equipment within the warehouse is $8,000.

The assembly lines begin with constructing the tower and nacelle. After structural assembly, the blades and electrical components are attached. Finally, the product proceeds to the packaging line.

2.5.2.3 Inventory Management

The company uses a chase strategy, which involves producing the precise number of units to meet the demand for units, in the production planning and scheduling to keep inventory low and reduce inventory holding cost [5]. In the first year, **AdVentus** forecasts sales of 5016 units. In addition to that, 500 units will be kept in the warehouse as safety stock. The company will manufacture the product only to match and meet the customer demand. As a startup company, it is very important to keep the inventory low so that the company can avoid stock liability, as it will cut holding inventory cost and help the company financially.

2.5.2.3 Transportation Strategy

Transportation must be integral for the business to flourish. A thoughtful plan will optimize the time and cost of shipments. The company will own three medium-size trucks. Each truck route will be designed to cover different parts of United States, specifically the west, Midwest, south, and east coast areas. Since wind turbines are not time-sensitive products, shipments will be made twice per month during early and mid-shipments are expected to take seven to fifteen days depending on customer location. RV companies in the Midwest States, such as Illinois, Iowa, and Wisconsin, present a big market opportunity for a company like **AdVentus**. The company will take the advantage by mainly focusing on the Midwest and the South due to a high concentration of RV sellers and other potential partners.

2.5.6 Technical Constraints and Risk Management

In regard to risk management and technical product constraints, **AdVentus** has applied a triple bottom line risk assessment approach. The key risks that come with the production of the market turbine are social, environmental, and economic. Table 3 below lists the primary risks and expected company action in response. Most notably, the company will: 1) need to focus on providing supply chain visibility in order to effectively communicate with suppliers and customers and 2) likely not meet its financial objectives in the short term. To mitigate these specific risks, **AdVentus** will need to establish appropriate and efficient lines of communication with members of the supply chain and perform continuous risk assessments in order to maintain and advance market position.

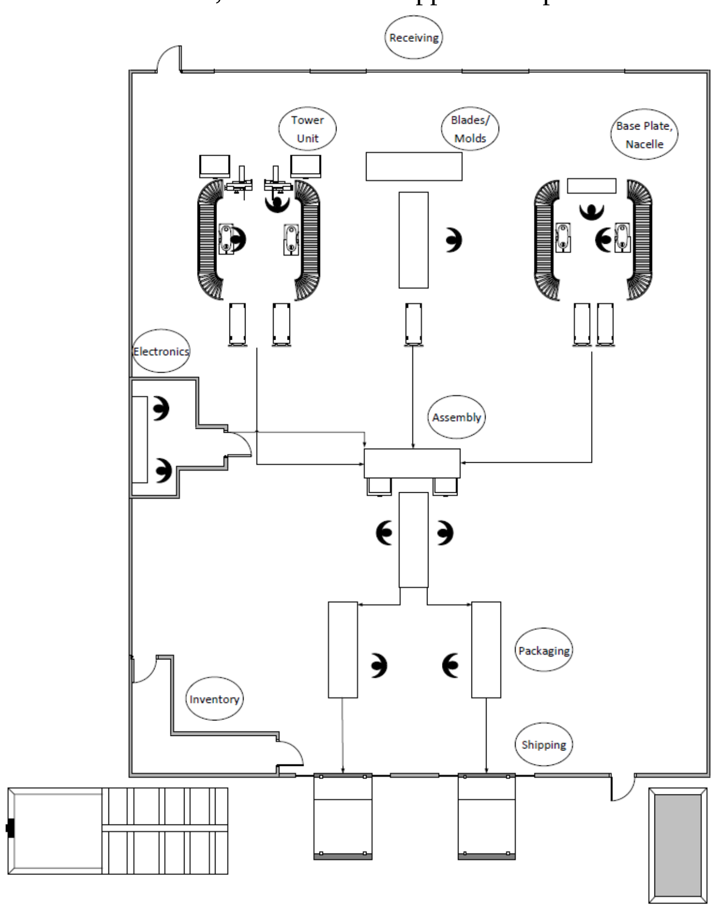

Figure 7. Warehouse Space Distribution and Assembly

Table 3. Risk Management Overview

Area	Priority	Title	Description	Probability of Impact	Schedule Risk	Cost Risk	Planned Risk Mitigation Actions
Social	LOW	Employees	-Employee Satisfaction maintained -Employee Work Conditions	LOW	LOW	LOW	-Establish employee benefit plan -Establish employee engagement and wellness plans -Maintain feasible schedules of work
	HIGH	Visibility of Operations	-Supply Chain Visibility -Communication amidst suppliers and 1st/2nd tier members	MID	HIGH	HIGH	-Utilize ERP system for better management of resources and better communication amidst suppliers/vendors -Provide information for direct contact between suppliers, vendors, and AdVentus
	LOW	Social Media	-Communication with Community and Customers	LOW	LOW	LOW	-Establish line of direct communication amidst all members of supply chain, including customers -Appoint employee to take on additional task of outreach and social media head
Environmental	MID	Energy	-Need to provide necessary power in all RV settings -Possibility of energy storage failure	MID	HIGH	MID	-Guidlines within Research and Development to maintain awareness of all energy needs within technical design -Test and Evaluation performed for various battery applications amidst range of environmental conditions
	LOW	Packaging	-Environmental sustainability in package design	MID	LOW	LOW	-Package material research and experimentation
	MID	Manufacturing Materials	-Sustainable materials utilized -Environmental impact in field use -Plant setting environmentally sustainable	MID	MID	LOW	-Research into proper materials and maintenance of adherance to environmental standards and regulations -Appointment of an employee to manage sustainability policies alongside a sustainability team
Economic	LOW	Transparency	-Publicity of business unit	LOW	LOW	LOW	-Continuous research into market status and evaluation of competitors
	MID	Economic Performance	-Risk of losses within business unit -Success of product	HIGH	LOW	HIGH	-Perform initial market research into RV unit to analyze customer interest -Perform testing on current RV models to ensure technical product performance
	HIGH	Financial Objectives	-Obtainability of financial objectives	HIGH	HIGH	HIGH	-Set obtainable financial goals for the intitial years of company startup -Failure plan and continuous risk analysis needed to maintain financial success
	MID	Marketing and Publicity	-Possible lack of marketing and outreach	MID	LOW	HIGH	-Establish margin of profits to be applied toward marketing, travel, and expo appearances
	MID	Loss of Continuous Improvement	-Manufacturing operations lose efficiency	MID	LOW	HIGH	-Establish LEAN principles within the manufacturing center and warehouse, along with standard work procedures to maximize employee and product line efficiency
	MID	Technological Advancement	-Competitors become more technologically advanced	MID	LOW	HIGH	-Establish R&D team to keep up-to-date and ahead of competitors who may produce new technology or product advancements

The main technical constraints in regard to turbine production and function are the power that needs to be produced and also the manufacturing of the product components on-time. With the unique load associated with RV and camper power necessities, the turbine, estimated for a rated power of 400 Watts, will need to fulfill that requirement when used in the field. This will be ensured through the test and evaluation phase (within Phase 2) of the business development. The other main technical constraint includes efficient manufacturing of all product components. With blades that will need cure time, the blades section of the assembly line will not be implemented as a one-piece flow line. The blades will need to be made in advance of assembly (the day before), and this may cause line backups. To counter this, as mentioned, blades will be materialized on a regimented schedule with ample time for curing before assembly.

2.6 Financial Analysis

2.6.1 Key Assumptions

Creating the financial statements are a vital step for ***AdVentus*** because the company would like to know if it is profitable. ***AdVentus*** will begin with 20 full-time employees, including management in order to make the whole operation efficient. Part-time truck drivers will be hired for transportation. In addition to insurance coverage for equipment and facilities, the company will maintain commercial automotive, liability and workman's compensation insurance to cover accidents that occur on the job. ***AdVentus*** will be capitalized by two Angel Investors through a long-term investment vehicle that includes 41% equity. The company founders will retain control and ownership of the remaining 59%.

2.6.2 Financial Statements

Customer satisfaction derived from owning a best-in-class product will be a top priority for ***AdVentus***. Hence, ***AdVentus*** will utilize the company's capital to obtain advanced mechanical components. The three major products that the company will provide are the wind turbine, the mobile app, and the portable battery.

After conducting substantial research, the company decided to outsource the portable battery from Chinese firms, as they offer inexpensive, high-quality batteries, and develop the mobile app in house. For the latter, the primary associated expense (beyond developer time) will be the approximate $500 annual mobile app license fee. In this way, the company can reduce labor costs and focus more on the core of the business of manufacturing the wind turbine itself.

In the first year, ***AdVentus*** will target selling 4000 units at $500 each to RV retailers and 1016 units directly to end consumers. This will give the company a total revenue of $2,609,600. Based on the Bill of Material, shown in Appendix B, ***AdVentus*** estimates that the cost per wind turbine will be approximately $230. The company plans to buy materials in bulk as much as possible, in order to keep costs low.

Based on the Income Statement (Table 4), ***AdVentus*** predicts that the company will have a low income of $3,255 in Year 1, which is due to start-up investments heavily in the Plant & Equipment and marketing department. Marketing is a crucial step for a successful product launch. The company plans a large Year 1 campaign to establish the company name and product in the minds of consumers. Thus, the company estimates that it will cost around $40,000 for marketing, including advertisements in social media, such as Facebook and Twitter, through TV commercials, as well as conducting customer outreach through RV Expos in the U.S. Midwest and South regions.

Table 4. Income Statement

AdVentus					
Annual Fiscal Year Income Statement					
Year			**2018**	**2019**	**2020**
Revenue					
	Sales	Retailers	$ 2,000,000	$ 2,200,000	$ 2,420,000
		Consumer	$ 609,600	$ 670,560	$ 737,616
		Total Sales	**$ 2,609,600**	**$ 2,870,560**	**$ 3,157,616**
	Total Revenue		**$ 2,609,600**	**$ 2,870,560**	**$ 3,157,616**
Cost of Goods Sold					
	Raw Materials		$ 1,269,342	$ 1,396,276	$ 1,535,904
	Shipping		$ 50,160	$ 55,176	$ 60,694
	Tools		$ 15,687	$ 17,256	$ 18,981
	Insurance		$ 25,147	$ 25,147	$ 25,147
	Total Cost of Goods Sold		**$ 1,360,336**	**$ 1,493,855**	**$ 1,640,726**
Gross Margin			**$ 1,249,264**	**$ 1,376,705**	**$ 1,516,890**
Expenses					
	Administrative expenses		$ 96,482	$ 96,482	$ 96,482
	Salary and Wages		$ 432,125	$ 432,125	$ 432,125
	Rent Expense		$ 156,816	$ 156,816	$ 156,816
	Triple Net Expense		$ 78,408	$ 78,408	$ 78,408
	Equipment		$ 200,236	$ 42,505	$ 25,615
	Transportation Equipment		$ 33,557	$ 33,557	$ 33,557
	Advertising Expense		$ 40,000	$ 20,000	$ 20,000
	Other Expenses		$ 207,520	$ 227,520	$ 247,520
	Total Expenses		**$ 1,245,144**	**$ 1,087,413**	**$ 1,090,523**
Net Earning From Operation			**$ 4,120**	**$ 289,292**	**$ 426,367**
Interest Expense			$ -	$ 20,000	$ 20,000
Net Earning Before Tax			**$ 4,120**	**$ 269,292**	**$ 406,367**
Income Tax			$ 865	$ 56,551	$ 85,337
Net Income			**$ 3,255**	**$ 212,740**	**$ 321,030**

Based on the Income statements, the following tables, including Cash Flow and Balance Sheet could be derived (Table 5).

Table 5. AdVentus Balance Sheet and Statement of Cash Flow

AdVentus			
Annual Fiscal Year Balance Sheet			
Year	**2018**	**2019**	**2020**
Assets			
Current			
Cash	$ -	$ 414,347	$ 750,000
Account Receivable	$ 10,000	$ 11,000	$ 12,100
Inventory	$ 125,000	$ 137,500	$ 151,250
Supplies	$ 10,000	$ 3,000	$ 1,000
Total Current Assets	**$ 145,000**	**$ 565,847**	**$ 914,350**
Fixed Cost			
Equipment	$ 200,236	$ 42,505	$ 25,615
Transportation Equipment	$ 33,557	$ 33,557	$ 33,557
Total Fixed Assets	**$ 233,793**	**$ 76,062**	**$ 59,172**
Total Assets	**$ 378,793**	**$ 641,909**	**$ 973,522**
Liabilities and Equity			
Current/Long Term Liabilities			
Account Payable	$ 10,000	$ 11,000	$ 12,100
Loan Payable	$ -	$ 44,381	$ 44,381
Warranty	$ 1,317	$ 1,448	$ 1,593
Other Liabilities	$ 64,222	$ 19,085	$ 28,423
Total Liabilities	**$ 75,539**	**$ 75,915**	**$ 86,497**
Owner's Equity			
Common Stock	$ 300,000	$ 350,000	$ 350,000
Retained Earning	$ 3,255	$ 215,995	$ 537,025
Total Owner's Equity	**$ 303,255**	**$ 565,995**	**$ 887,025**
Total Liabilities and Owner's Equity	**$ 378,793**	**$ 641,910**	**$ 973,522**

Adventus			
Annual Fiscal Year Statement of Cash Flow			
	Year		
	2018	**2019**	**2020**
Cash Flow From Operating Activities			
Revenue Captured	$ 2,609,600	$ 2,870,560	$ 3,157,616
Advertising Expense	$ 40,000	$ 20,000	$ 20,000
Maintenance Expense	$ 13,000	$ 13,000	$ 13,000
Office Supplies Expense	$ 10,000	$ 3,000	$ 1,000
Salary and Wages	$ 432,125	$ 432,125	$ 432,125
Inventory	$ 125,000	$ 137,500	$ 151,250
Property Insurance	$ 2,000	$ 2,000	$ 2,000
Transportation insurance	$ 6,000	$ 6,000	$ 6,000
Rent and Utilities Expense	$ 33,557	$ 33,557	$ 33,557
Startup capital Expense	$ 20,000	$ -	$ -
Turbine Material Cost (BOM)	$ 1,269,342	$ 1,396,276	$ 1,535,904
Travel, Meals and Entertainment Expense	$ 15,000	$ 15,000	$ 15,000
Corporate Tax	$ 865	$ 56,551	$ 85,337
Net Cash Flows From Operating Activities	**$ 642,711**	**$ 755,550**	**$ 862,443**
Cash Flow From Investing Activities			
Vehicles Purchase	$ 33,557	$ 33,557	$ 33,557
Equipment	$ 200,236	$ 42,505	$ 25,615
Net Cash Flows From Investing Activities	**$ 408,917**	**$ 679,488**	**$ 803,270**
Cash Flow From Financing Activities			
Investment	$ 300,000	$ 50,000	$ -
Net Cash Flow From Financing Activities	**$ 300,000**	**$ 50,000**	**$ -**
Net Cash Flow	**$ 708,917**	**$ 729,488**	**$ 803,270**

Looking at the company's other financial statements, the company's pro forma has shown a good financial performance for the next three years. The company decided to make a $500,000 debt financing in the second year for expansion purposes. However, the Debt to Equity ratio, when calculated, stays below 1.0 for the next three years. Retained earnings will show a significant amount of increase according to the predicted 10% increase in sales every year. As in the company's Balance Sheet (Table 5), by the fiscal year 2020, the company can make a decision in issuing the dividend to the equity holders. ***AdVentus'*** cash flow statement (Table 5) also shows a healthy financial performance through the measurement of outflow in cash for the next three years. The cash outflow is mainly for the material cost of the turbine due to the predicted increase in demand over the years. A significant amount of cost incurred in the first year for the equipment is due to the investment for a startup company. Overall, the financial performance for ***AdVentus*** is seemed to be healthy for the next three years following the base case scenario analysis.

3. Technical Design

3.1 Design Objective

3.1.1 Prototype Turbine

The team had designed the prototype turbine with efficiency, simplicity and minimal maintenance in mind. The objectives taken into consideration were to be able to obtain a desirable cut-in wind speed, be able to turn the rotor into the wind, and reach maximum power output for wind speed ranging from 2.5 to 11 m/s and nearly constant rotor speed and power beyond 12 m/s. Finally, the turbine has to safely shut down if wind speeds are too high or if necessary for safety reasons.

The team needed to be able to control the power output from the wind's variable speed. Due to this, it was decided that in order to maintain that power output, the best way to do it was to be able to pitch the blades in order to change the angle of attack. When maximizing power output, the blades are pitched to the optimal angle corresponding to each wind speed bin. When maintaining power output, the blades will be pitched up or down in order to maintain the angular velocity of the rotor and prevent the blades from spinning uncontrollably. This pitch control design was preferred, which was designed by the team after extensive research and calculations. Calibration of the pitch control and reliable values are obtained from wind tunnel testing.

The team used light blades and a low speed shaft with a low moment of inertia by using a hollow cylindrical rod. This hollow rod also allows for the pitch control to be connected to the actuator through the low speed shaft.

In order to have an efficient yaw mechanism, the team chose a passive system and did research on how large the wind tail must be. According to Windynation, the tail length must be at minimum 5% of the swept area of the blades [6]. Taking this value into consideration and the given competition sizing constrains, the area was calculated in order to have the desired and necessary effect from the wind. Also, for this, the team designed a collar to be attached at the bottom of the nacelle, which facilitated the connection to the tower. In the collar, there is a low friction steel needle-roller bearing and below that, a needle-roller thrust bearing for the collar to spin on.

Figure 6. Prototype Turbine Model Overview

3.1.2 Market Turbine

Simple, lightweight, and easily transportable are three main goals of the market turbine design. Consumers need to be able to assemble and disassemble the turbine in a reasonable amount of time. The blades are bolted on so they can be removed quickly. The nacelle can be set on top of the tower without any tools. The tower sections telescope and lock into place. It also needs to be compact enough that it can fit inside vehicles and light enough to be carried by hand. For this reason, the tower collapses within itself for storage and transportation. The entire wind turbine is lightweight so that it can be safely assembled and carried by hand.

The turbine needs to be lightweight to safely mount the nacelle to the tower and raise the tower. A lightweight nacelle also means the tower has to support less weight. When the low speed shaft reaches a specified rpm, the rotor brake on the low-speed shaft will be applied. This is to protect the generator and the system as a whole.

Figure 7. Market Turbine

The blades for the turbine will be geometrically similar to the prototype turbines, but dimensionally scaled up to the size of the market turbine. Both blades will have the same airfoils; however, the length of the market blade will be 0.7m in length, compared to approximately 0.17m for the prototype blade. There will also be differences in the twist and taper of the two blades, due to each of these properties being optimized for the length and use of the blade. The connection piece for the market turbine will be similar to that of a full-size turbine, which will allow for easy setup and tear-down..

A simple design will reduce parts, manufacturing time, costs and assembly time. This was accomplished with a passive yaw system and a fixed pitch. The passive yaw system is the same as the prototype, which consists of a roller bearing and a wind vane. When the wind applies a force the side of the wind vane, the nacelle will rotate about the tower until the force is negligible. A fixed pitch system eliminates the need for many expensive mechanical and electrical components, minimizing maintenance on the turbine.

3.2 Mechanical Design Overview

3.2.1 Braking System

An active braking system is being implemented for the market turbine. The braking system consists of a brakes caliper and brakes rotor. The purpose of the brake is to slow or halt a rotor by converting kinetic energy to heat energy. The brakes are capable of regulating speed and providing emergency stop. The rpm sensor is used to apply the brakes on the low speed shaft. The brakes system is chosen over the pitch control because of its simplicity. Since brake systems require less parts, simpler and minimal parts was determined to be more practical for mass production. For the prototype, the pitch control is used to stall the blades and slow down.

3.2.2 Gear Ratios

Prototype Turbine

The timing belt system is one of the core mechanical parts that runs inside the prototype turbine. The first component of the system is the pulley system. The pulleys are made of aluminum and they both vary in sizes. The small pulley has 20 teeth and the larger pulley consists of 60 teeth. Thus, the system uses a 3:1 gear ratio based on the Equations 1-4. The small pulley is placed around the high-speed shaft while the larger pulley is placed around the low-speed shaft. Both shafts are supported by aluminum bearings. Aluminum material was chosen because of durability and ease of manufacturing. The second component of the system is the belt. Since the belt length is not suitable for the distance between the two pulleys, the high speed shaft pulley has the ability to be manually extended away from the low speed shaft pulley in order to maintain tension in the belt. The high-speed shaft is placed on a t-slotted aluminum framing and bolted to the fasteners on both ends of the shafts. This allows the pulley along with the shaft to slide inward and outward. The linear velocity of the blade is determined by using the Equation 1. The belt drive system was chosen over the gear drives primarily due to several factors. In belt drive systems, the pulleys are made with less dense materials and required less input power to rotate them. Belts are also quieter during operation and if it fails at rotating, only the belt needs to be changed rather than changing both of the pulleys. This is convenient for our team to do inspection and lessen the time spent on maintenance.

Market Turbine

A gearing system is being chosen for the market turbine. It consists of a 20-tooth gear, which is attached to a high-speed shaft, meshed together with an 80-tooth gear that is attached to a low-speed shaft. The gears are kept in an acrylic gearbox filled with oil lubricant. The gear ratio of 4:1 was calculated using the following problem solving method, as seen in Equations 1-4, where

V_b = Velocity of blades, V_w =Velocity of wind, χ = Tip Speed Ratio, Ω = Angular frequency, RPM_b = RPM of blades, RPM_g = RPM of generator, and GR = Gear Ratio:

$$V_b = \chi \times V_w \qquad (1)$$

$$\Omega = \frac{V_b}{R} \qquad (2)$$

$$RPM_b = \frac{\Omega}{60 \times 2\pi} \qquad (3)$$

$$GR = \frac{RPM_g}{RPM_b} \qquad (4)$$

The purpose of the gearing system is to increase the rpm of the rotor so that it matches required generator rpm to produce specific power.

3.2.3 Tower Design

Prototype Turbine

The tower design for the prototype is a simple circular tower with a round base plate. The tower has a height of 0.6 m and is made out of an alloy steel. It has an outer diameter of 38.1 mm, inner diameter of 25.4 mm. and a thickness of 12.7 mm. The round steel base plate was machined according to the dimensions set by the Rules and Requirements of the competition. So, it has a thickness of 16 mm, with 3 holes each 120 degrees apart with a diameter of 15 mm. The diameter of the whole base plate is 150 mm and at its center is a 38.1 mm hole for the tower to be inserted through. Furthermore, a steel collar with an inner diameter of 38.1 mm. will be inserted over the tower and positioned right above the base plate. The collar has a 12.7 mm thickness and its purpose is to provide extra strength to the overall tower and to ensure its sturdiness while facing high wind loads.

Market Turbine

AdVentus's primary goal of providing clean energy to the camping community requires a tower that is structurally sturdy and portable. To achieve this, a telescoping tower was designed. The telescoping tower must be able to withstand strong winds as well as the gravitational loads from the weight of the nacelle and its' contents. To set up the tower with ease, three sections of round steel tubes of decreasing size is used. The tower can be extended to a full height of 3.66 m (12 ft) in a few minutes. The sections feature quick lock/release collars to extend the towers manually by pushing up the sections and fixing them in position

The telescoping tower works by loosen the knob on the top collar and push up the top tower section until it stops. Then, lock the collar by tightening the knob. Follow the same procedure for each tower section for the middle and bottom section. Furthermore, there are two connection pieces on the bottom section of the tower to attach the tower to the ladder of the RV.

Since the target customers are the camping community, the team conducted important surveys to see what the needs of the customers would be. As mentioned before, the tower needs to be sturdy and portable. So, the design of the telescoping tower is suitable for the market turbine because based on the customer surveys, the camping community would benefit most from a wind turbine that is small, portable and easily attached/detached to the ladder at the back of camping RVs.

3.3 *Expected Loads and Safety Factors*

Considering the prototype wind turbine, it is calculated that a rotor diameter of 0.38 m will produce 11.72 W power at wind speeds of 15 m/s. From that wind speed, an overall force of 15.63 N is applied on the wind turbine. Given the large tower steel tower selected for the prototype (with a thickness of .355 inches), our structural analysis resulted in a very high factor of safety of 33 for the tower (as expected).

The blades of the prototype tower are 3D-printed in Onyx, a light material with a tensile strength of 36 MPa. Based on calculations done on 1/4 of the rotor diameter, the centrifugal force of 34.27 N with a stress of 2792.5 Pa is obtained. Examples of these calculations can be found in Appendix C.

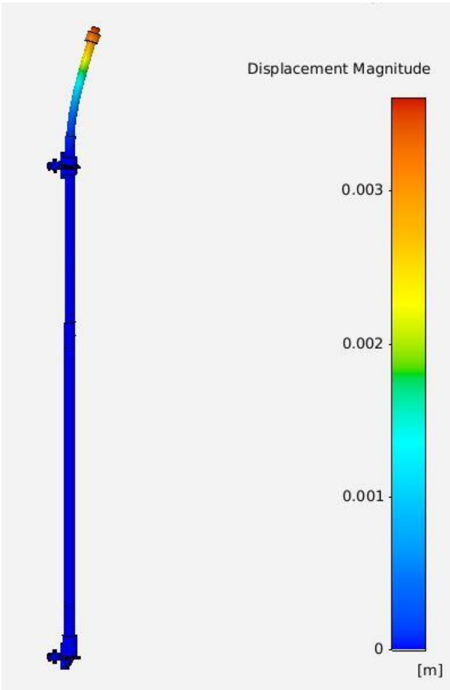

Figure 8. Tower Displacement Magnitude

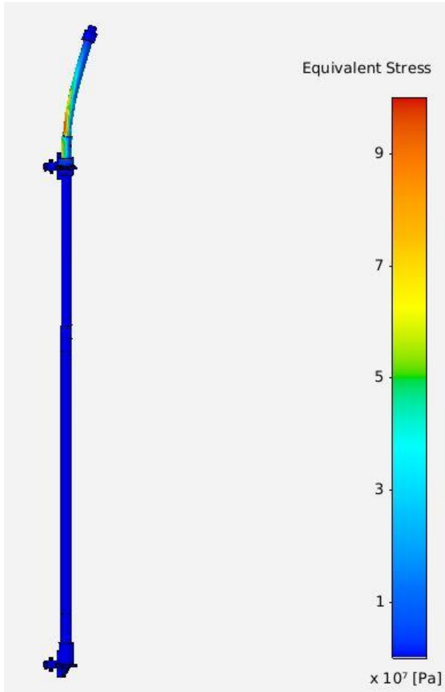

Figure 9. Equivalent Stress for Tower

For the market turbine tower, the team also did structural analysis by applying a load of 2220 Newtons to the top of the tower (as expected in extreme conditions) as well as the weight of the nacelle applied vertically downward. The turbine was constrained at the two clamps that attach the tower to the RV ladders (different points were tested). As seen in Figure 9, the maximum stress obtained is almost 100 MPa at extreme conditions, resulting in a factor of safety of 2.5. In addition, the maximum displacement at the top of the tower resulted in approximately .0035 meters.

3.4 Blades

The blades for the prototype blade were created through a series of design processes that ultimately lead to the final design. A MATLAB code was used in the beginning to assist in the airfoil selection, and then a wind turbine blade simulation software, Qblade, and SolidWorks were used for analysis. The final airfoils can be seen below in figure 10.

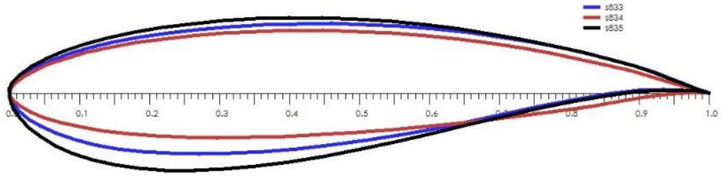

Figure 10. Airfoils Chosen for Prototype

Once the airfoils were selected the computer analysis began. This started with Qblade simulations, and gradually escalated to SolidWorks. The Qblade software simulations were able to output many different graphs for various properties, the most important being the power vs wind speed plot, which can be seen in figure 11 for the final design.

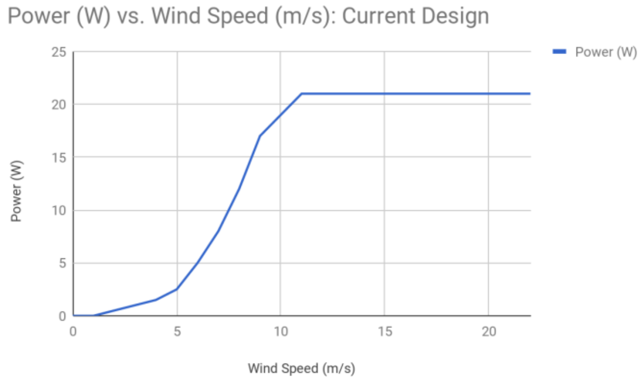

Figure 11. Power vs. Wind Speed Theoretical

After the analysis was done, manufacturing began and the first blade was printed. This blade was mainly printed to test the connection piece, which failed. An intermediate blade was then created, which had an updated connection piece and extended length, with valid twist. This blade was then updated due to changes in hub size and the connection piece. The SolidWorks model for this final blade design can be seen in Figure 12.

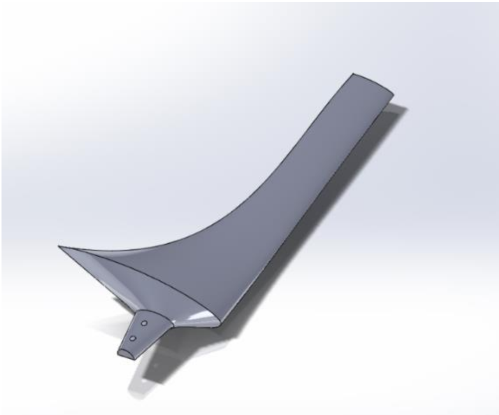

Figure 12. SolidWorks Model of Final blade design

There are two main properties that need to be taken into consideration when designing a wind turbine blade. They are the coefficient of power, Cp, and the tip speed ratio, TSR. These two properties are very important because they dictate how efficient the blade will be and how much power the turbine will produce. Figure 8 shows the blades Cp vs. TSR. This graph shows that the best TSR for the blade is around 2.0. A TSR of 2.0 is quite low for full-size turbines, but because of the small scale of this turbine, 2.0 will work well.

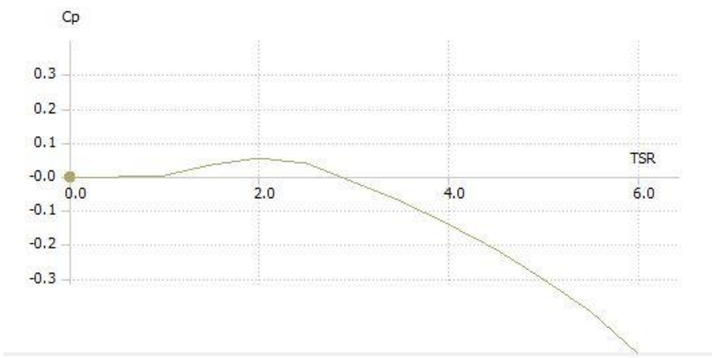

Figure 13. Cp vs TSR for Prototype Blade

3.5 Electrical System & Analysis

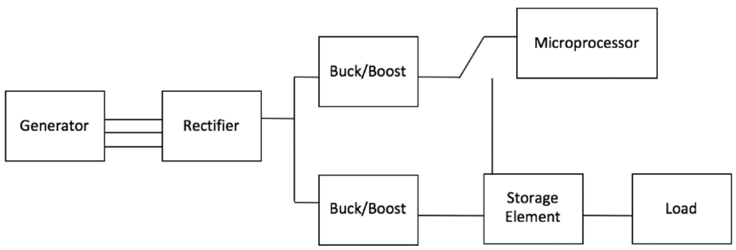

Figure 14. High-Level Electrical System Architecture

The electrical team decided on the circuit architecture in Figure 14 to meet the requirements set for the competition. Moving from left to right, power generation through manipulation and use was taken into account. The kinetic power from the spinning blades will induce a three-phase power after passing through our generator. The three-phase power will be rectified to DC using a rectifier. From here the rectified voltage will be passed to two buck-boosts. The top-most buck-boost will convert the voltage to turn on the microprocessor. The lower buck-boost will convert the rectified voltage to a proper charging voltage for the storage element. The storage element will then be connected to the load. The team also added in a relay as an additional power source to the microprocessor. This addition allows the team to switch power supplies to the storage element if the power from the generator is not enough to sustain the correct voltage across the microprocessor, and the storage element has a suitable amount of energy to provide the microprocessor with power.

The schematic level diagram in Figure 15 depicts the power flow in green lines, while the control lines are shown in blue. This diagram can be used to reference the integration of components.

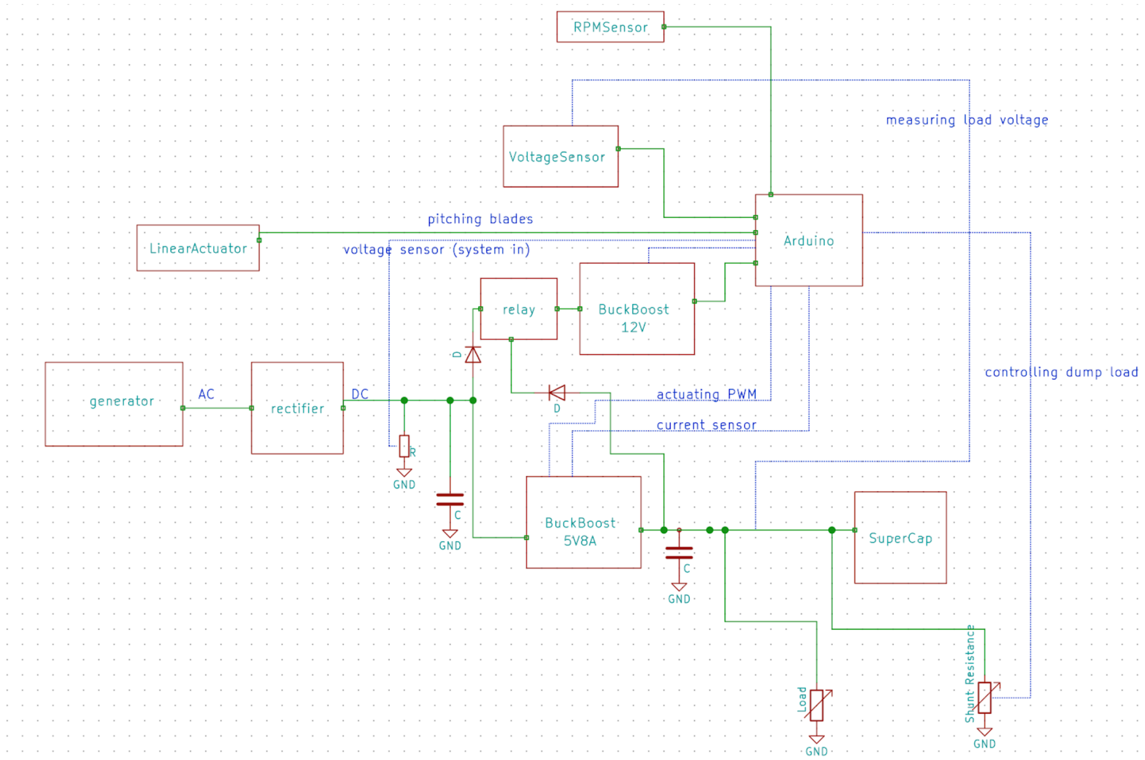

Figure 15. Schematic Level Diagram

3.6 Generator Selection

3.6.1 Selection Criteria

When deciding on the generator for the prototype wind turbine, the team took into consideration Kv (rpm per volt), power output, maximum current, maximum voltage and cost. After taking each of these into consideration, the team decided on the Multistar Elite 3508 from HobbyKing that has a Kv of 268, a power output of 330 watts, maximum current of 12 amps, and maximum voltage of 35 volts all at $37.97 at the time the team purchased it [7].

For deciding on the generator for our market wind turbine, the team took into account the weight of the turbine, since the turbine will need to be light enough to move on a telescoping tower. The size of the generator and the power output depended on the length of the blades of the wind turbine giving us a range of around 500 Watts. Again, taking all of these points into consideration, the team decided on the on the WindZilla 12/24V DC Permanent Magnet Generator [8].

3.6.2 Motor Analysis

After attaching the generator by pulley to another RPM controlled generator tests were done to determine parameters of the motor useful in creating simulations and operating regions. In order to test in a safe operating region the max RPM was derived using the following approach assuming it was running at full voltage.

$$8S(Full\ Voltatge\ in\ terms\ of\ LiPo\ Batteries) \times \frac{3.7\ Volts}{1S}\ (Nominal\ Voltage\ of\ a\ LiPo) \times 268\ \frac{RPM}{Volts} = 7932.8\ (Maximum\ RPM) \qquad (5)$$

Equation (5)

As a safety factor, the nominal voltage was used to represent the voltage per LiPo cell, but in actuality a LiPo cell can hold up to 4.2V.

3.6.3 Generator Laboratory Testing

After determining the upper bound for RPM, a variety of tests were performed. The first of these tests was confirming the number of poles in the motor. Utilizing the equation relating to mechanical and rotor speed:

$$r = P2 * rm ; r = 2f \quad (6)$$

The induction generator (used to spin the motor) would take an input of a percentage of full power and then RPM of the generator was measured along with Voltage and Period. The generator pole testing can be noted in Figure 16, which denotes an increasing linear trend in Rotor Mechanical Speed versus Rotor Electrical Speed.

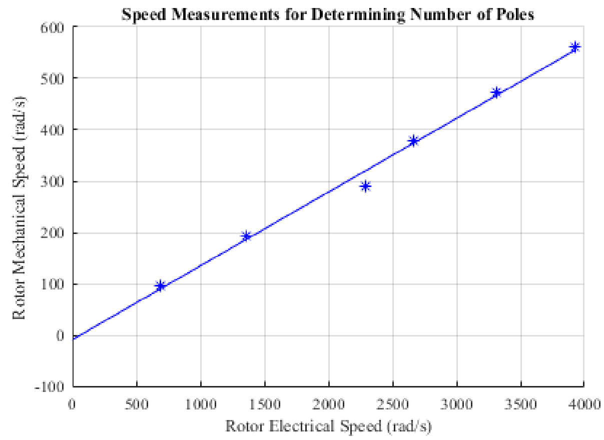

Figure 16. Generator Testing for Poles

3.6.4 Pole Laboratory Testing

Table 6. Tabular Results for Pole Testing

Input on Induction Generator	Line-to-Line Terminal Voltage (V)	Mechanical Rotational Speed, (RPM)	Period, T (s)	Calculated Frequency, *f* (1/T) (rad/sec	Calculated Electrical Speed (rad/sec)
.1	2.75	918	0.0092	108.7	682.9
.2	5.30	1830	0.0046	215.5	1354.1
.3	8.20	2773	0.0027	365.0	2293.1
.4	10.7	3625	0.0024	423.7	2662.4
.5	13.2	4505	0.0019	526.3	3306.9
.6	15.7	5354	0.0016	625.0	3927.0

Then the number of poles were found for each value of RPM and averaged leading to a final value of 14 poles. The results from the generator testing were formulated in Table 6 and were utilized to further the evaluation.

The next step was to determine the magnetic flux constant using the equation for the steady-state stator terminal voltage below where iqs = 0 because there is no current through the machine. This is displayed in Equation 7:

$$v_{qs}{}^{r} = \left(r_s \times i_{qs}{}^{r}\right) + \left(\omega_r \times \lambda_m{}^{r}\right) \quad (7)$$

Finding the slope between the stator terminal voltage and rotor electrical speed gives a magnetic flux constant = 0.0176

Next the L_q and L_d inductances were found using the following equations:

$$L_q = \frac{\int_{t_o}^{T} v_q(t) - r_q i_q(t) dt}{i_q(T)} \quad (8)$$

$$L_d = \frac{\int_{t_o}^{T} v_d(t) - r_d i_d(t) dt}{i_d(T)} \quad (9)$$

The q axis test was done by applying a step voltage between phases a and b, while c was short-circuited to b. Then, the voltage and current values were collected for different voltage steps (1V,2V,3V) and plotted.

Similarly, for the d axis the voltage step test was done from 1 to 3 volts where the setup was applying a step voltage between phases b and c while a was open-circuited. The outputs of the different resistances and inductances of the two tests were averaged leading to final values of:

- q-axis resistance, Rq = 0.3314 Ohm
- q-axis inductance, Lq = 0.00036 H
- d-axis resistance, Rd = 0.29137 Ohm
- d-axis inductance, Ld = 0.00021766 H
- Average per-phase resistance, Rs = 0.31139 ohm

These results are further displayed in Figures 17-19.

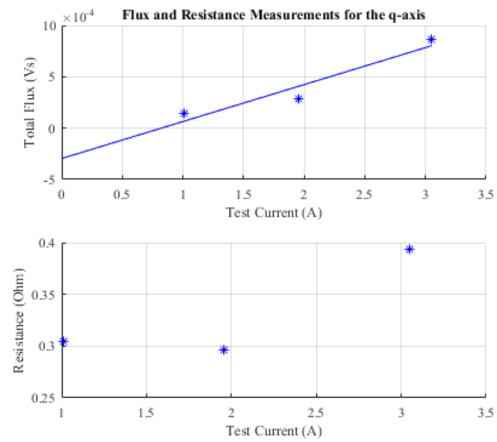

Figure 17. Flux and Resistance for q-axis

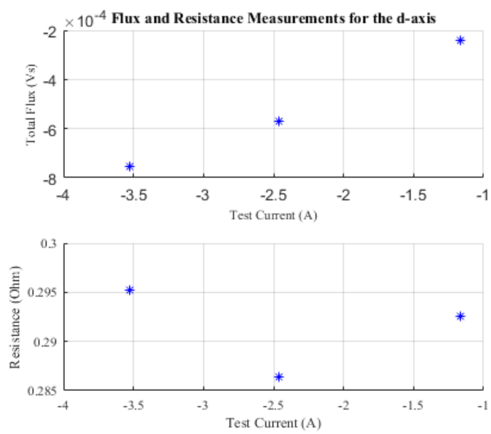

Figure 18. Flux and Resistance for d-axis

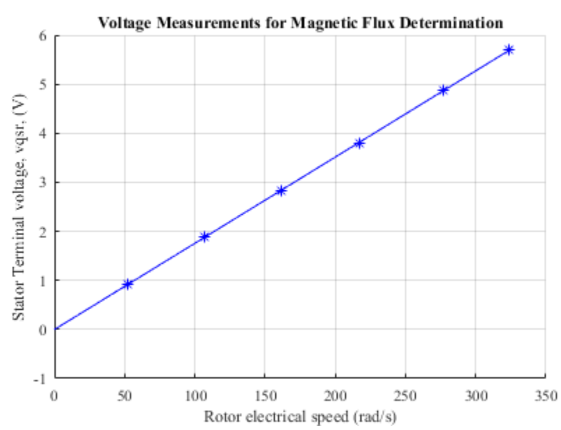

Figure 19. Voltage for Flux Determination

3.7 Power Electronics

3.7.1 Canonical Model

The electronics team designed a Simulink model in MATLAB to simulate the buck-boost power converter that would be used. When the switch is on, there is a rise in inductor current and when the switch is off, there is a decrease in inductor current. When the duty cycle is less than 0.5, it acts as a buck converter. When the duty cycle is greater than 0.5, it acts as a boost converter. The duty cycle of the converter is monitored through the output voltage and inductor current. By monitoring the inductor current, the duty cycle can be adjusted to control by comparing the actual current to the controlled current that was derived using the state space model and a PI controller. The output voltage shifts between 5-15 Volts and is regulated using another buck-boost converter to produce our 5V output. It should be noted that the output voltage is inverted across the capacitor.

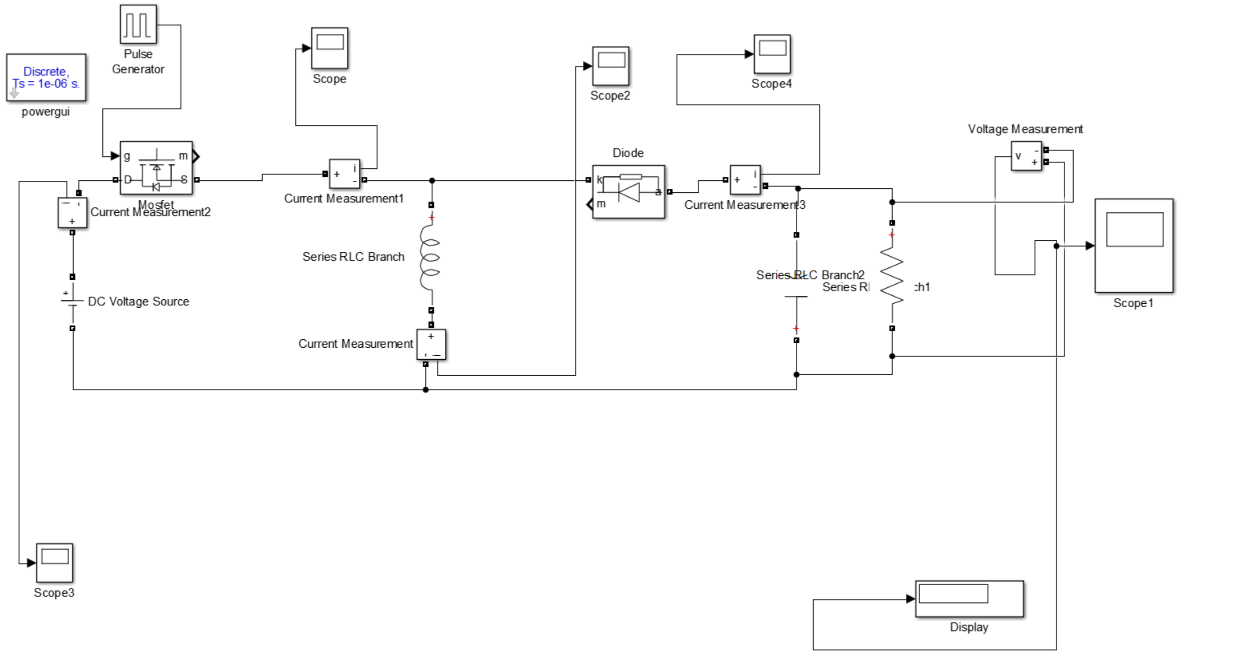

Figure 20. Canonical Model Built Using Simulink Power Electronics Library

3.7.2 Electrical Load Model

In the testing of the load, the team used a variable load generator to test the load capabilities of the wind turbine generator. The desired load was set at 40 W output, accounting for about 5 W for losses and to power the microcontroller. The tests show that the generator must have a minimum speed of 5,133 RPM which would produce a voltage of 15.37 V and current of 2.93 A of the rectifier. The test also showed the generator is not effective in maintaining a load at currents greater than 3 A. Figure 21 and 22 shows the relationship between the voltages at a set load.

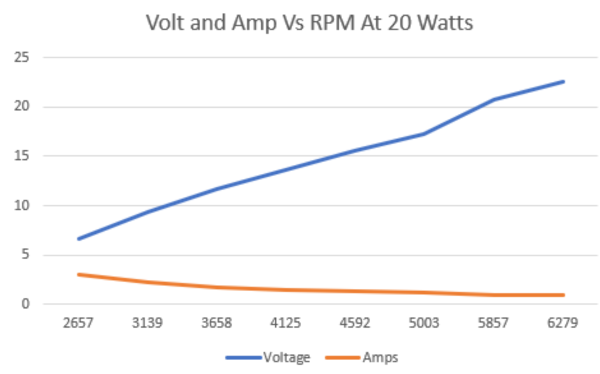

Table 21. Voltage and Amps at 20 W

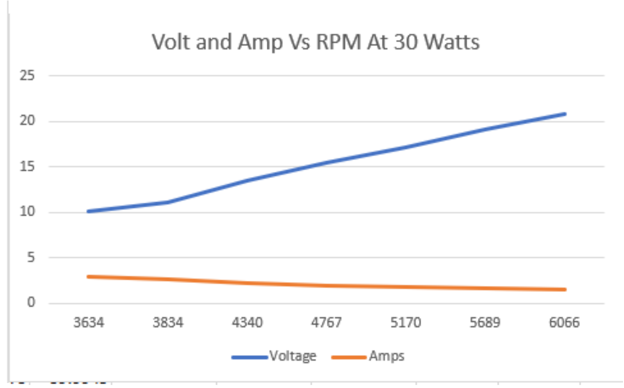

Table 22. Voltage and Amps at 30 W

3.7.3 Operating Voltage and Voltage Regulation

As mentioned earlier, the buck boost converter will take the rectified voltage from the capacitor at the input and change it to a 5-15 V range on the side of the load. The input range at the input is designed to be up to 25V Rectified DC Voltage limited by the rating of the capacitor. The current control method will insure that at no matter what power the turbine is producing, 5-15V will be coming out at the side of the load by adjusting the current accordignly. The control code has safety parameters to not continue if V_{out} is above 14V and if the current in the inductor gets above 10A.

3.7.4 Storage Element

The test model will store voltage in the supercapacitor at a voltage of 14 volts. The supercapacitor will be charged from a DC to DC power converter that will maintain the voltage and increase the current. The supercapacitor will take a charge time of 294.5 seconds with a supply voltage of 15 volts to the supercapacitor to dissipate once the turbine has stopped supplying power. The equation that the capacitor will discharge when the supercapacitor is charged to 14 volts as followed:

$$V_c = V_o \times e^{(\frac{-t}{RC})} \qquad (10)$$

3.8 Control System

3.8.1 Overview

The control system is used to pitch the wind turbine’s blades. The controls system consists of a single Arduino Uno taking an input of an RPM sensor and an output of a linear actuator connected to a push rod to push and pull the rotors to a desired angle. The desired angle is calculated by taking the RPM and voltage and getting a value from a lookup table in the Arduino we created during testing. The Arduino will also monitor voltage and current within the electrical system to make sure the system do not have excessive voltage within the system and interfere with competition rules as well as possibly damage components within our electrical system.

3.8.2 Software Utilized

Arduino – The electrical team programmed the controls systems using the Arduino language, utilizing Arduino standard libraries for servos and interrupts. Simulink and MATLAB were also utilized as advanced programming technology to test various parts of the control system.

3.8.3 Simplified Controls Logic Diagram

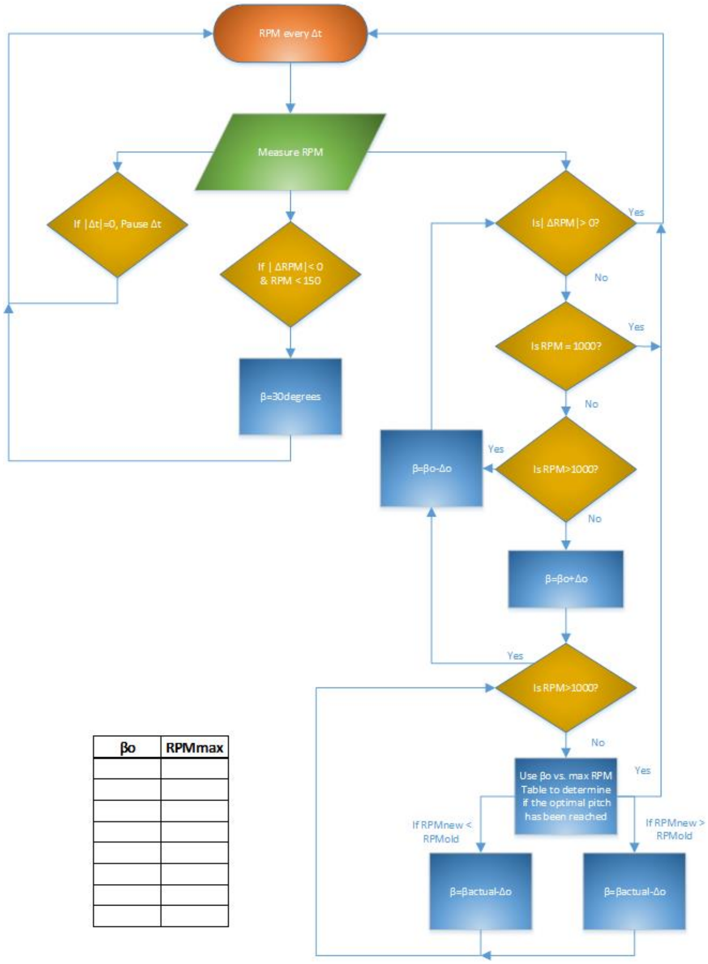

Figure 23. Pitch Control Simplified Logic Diagram

The above figure relates the overall control system for the various tests that will be performed on the turbine. The individual control steps in this process can be noted in Figure 23. This displays each step from the beginning of the test input to the individual reactional steps for tasks given.

In order to succeed in the Durability Test, another control system will be running to control the current running through the inductor. The control block diagram takes as input the voltage out and the RPM and with the help of a PI controller will output a duty cycle that will set our measured current across the inductor equal to the calculated current that in the diagram through a feedback loop.

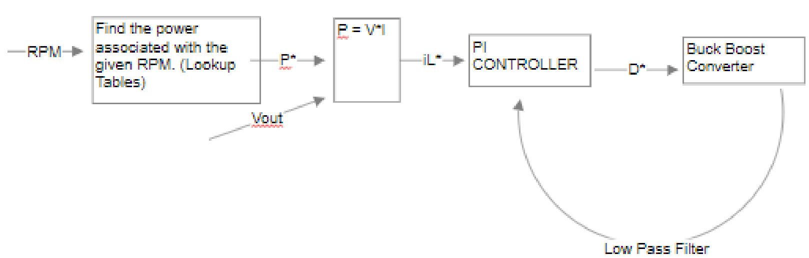

Figure 24. Controls System

The controller was created and then tuned to find Kp and Ki values that would allow a stable system. In order to find these values a state space average model method was used to determine a transfer function that represents the Buck Boost Converter System. The control is achieved by using Equation 11 that represents an average model of the current across the inductor and setting it equal to a commanded duty cycle d* that contains a controller and a feedforward term (Equation 12). Rearranging the terms gives a final transfer function (Equation 13). That represents how the theoretical current I_L^* will relate to the measured value I_L. In order to tune the controller, a Simulink model of the system attached with a feedback loop was run with different values of Kp and KI until the overshoot is minimized.

$$\frac{dI_L}{dt} = \frac{V_{in}\times d - V_{cap}\times(1-d)}{L} \qquad (11)$$

$$d^* = (I_L{}^* - I_L)\times\left(Kp + \frac{KI}{S}\right) + \left(\frac{V_{cap}}{V_{in}+V_{cap}}\right) \qquad (12)$$

$$\frac{I_L{}^*}{I_L} = \frac{\left(\frac{L}{V_{in}+V_{cap}}\right)\times S^2 + Kp\times S + Ki}{Kp\times S + Ki} \qquad (13)$$

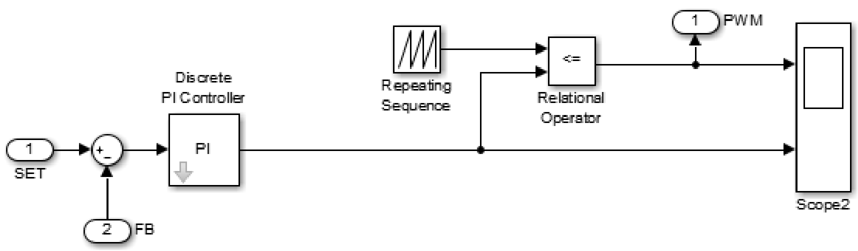

Figure 25. Controller with Feedforward

3.8.4 Elements & Analysis

RPM Sensor - The RPM sensor consists of a hall effect sensor and two magnets connected to the wind turbine shaft. Every time a magnet comes in range of the sensor it triggers an interrupt to increment a counter. This count is then utilized to calculate the RPM in a given period.

Linear Actuator - The function to move the linear actuator can take in a percent (0-100) and move the servo that far.

Current Sensor - Takes current from the circuit and converts an output voltage at a rate of 200mV per amp read through the sensor for the Arduino to read.

Voltage Sensor - A voltage divider consisting of two resistors to convert the input range of voltage to an output voltage of zero to five volts for the Arduino to read.

Buck/Boost Converter - Takes a voltage and either boosts the voltage up or bucks the voltage due to a programmed duty cycle.

Arduino - Reads inputs from voltage, current and hall effect sensors; sends duty cycle to the gate driver and a PWM signal to the actuator and relay as well as providing power to each one of the sensors, gate driver, actuator and relay.

Gate Driver - Switches between the two main buck boosts in the circuit given a duty cycle from the Arduino.

Relay - Electronic switch that will switch between the dump load and the supercapacitor that is controlled by a PWM signal from the Arduino.

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5. Appendices

Appendix A. Wind Energy Resources at U.S. National Parks

National Park	Average Wind Speed - 2017 (mph)
Zion	7.3
Arches	8
Sequoia	8.2
Rocky Mountain	6.1
Yellowstone	5.1
Canyonlands	8
Grand Canyon	9
Acadia	8.1
Everglades	8.8
Olympic	6.5
Grand Teton	7.8
Mesa Verde	7.9
Badlands	10.8
Joshua Tree	7.7

Death Valley	10.5
Bryce Canyon	9.2
Redwood	7.1
Great Sand Dunes	9
Big Bend	8.1
Glacier	6.9
Great Smokey Mountains	6.1
Hot Springs	6.6
Mammoth Cave	6.7
Shenandoah	6.7
Voyageurs	7.9

Appendix B. Market Turbine Parts List

Use	Part Name	Link	Price	Quantity	Total Price	Discount price (bulk -5%)
Yaw	2 inch Needle-Roller Thrust Bearing	McMaster Carr	$4.88	1	$4.88	$ 4.64
Keyed Shaft	1/2 inch Keyed Rotary Shaft	McMaster Carr	$62.06	0.1	$6.21	$ 5.90
Key	6061 Aluminum Machine Key Stock	McMaster Carr	$23.49	0.125	$2.94	$ 2.79
Yaw	Steel Needle-Roller Bearing	McMaster Carr	$11.92	1	$11.92	$ 11.32
Bearing for gearbox - HSS	Roller Bearing for 3/8" shaft	McMaster Carr	$5.14	2	$10.28	$ 9.77
Bearing for gearbox - LSS	Roller Bearing for 1/2" shaft	McMaster Carr	$5.76	2	$11.52	$ 10.94
Bearing for LSS	Mounted Bearing for 1/2" shaft	McMaster Carr	$3.70	1	$3.70	$ 3.52
20 Tooth Gear	36" x 36" steel plate	Online Metals	$180.95	0.000384	$0.07	$ 0.07
Low Speed Shaft gear 80 tooth	36" x 36" steel plate	Online Metals	$180.95	0.005102	$0.92	$ 0.88
High Speed Shaft	3/8" High Speed Shaft	McMaster Carr	34.15	0.035714	$1.22	$ 1.16
Coupler	0.375/0.5 Coupler ffor HSS	SDP/SI	$5.60	1	$5.60	$ 5.32
Generator		eBay	$119.00	1	$119.00	$ 113.05
Battery			$2	1	$2.00	$ 1.90
Gearbox shell	Clear Acrylic Sheet 48" x 96" x 1/4"	McMaster Carr	$187.74	0.02	$3.18	$ 3.02
Hub	6061 Aluminum 1/2" Thick, 5' x 12'	Midwest Steel Supply	$1,247.25	0.004167	$5.20	$ 4.94
Hub Collar	6061 Aluminum 1" Thick, 5' x 12'	Midwest Steel Supply	$2,457.91	0.000116	$0.28	$ 0.27
Base plate	6061 Aluminum 1/4" Thick, 5' x 12'	Midwest Steel Supply	$626.57	0.011111	$6.96	$ 6.61
Brake Rotor	304 Stainless steel	Midwest Steel Supply	$2,256.06	0.001302	$2.94	$ 2.79
Tower nacelle bearing housing	6061 Aluminum 1" Thick, 5' x 12'	Midwest Steel Supply	$2,457.91	0.001042	$2.56	$ 2.43
LSS Bearing Block	6061 Aluminum 1/2" Thick, 5' x 12'	Midwest Steel Supply	$1,247.25	0.000385	$0.48	$ 0.46
Brake Caliper	Cast iron	Iron Foundry	$0.37	1	$0.37	$ 0.35
Tower	structural steel (material)	Capital Scrap Metal	$38	1	$38.00	$ 38.00
Sum Total:					**$240.23**	**$230.12**

Appendix C. Sample Turbine Force and Power Calculations:

$$Power = P = \frac{1}{2}\rho_A A v^3 c_p = \frac{1}{2}\left(1.225\frac{kg}{m^3}\right)(0.1134m^2)\left(15\frac{m}{s}\right)^3(0.05) = 11.722\,W$$

$$Torque = T = \frac{1}{2}\rho_A A v^2 r = \frac{1}{2}\left(1.225\frac{kg}{m^3}\right)(0.1134m^2)\left(15\frac{m}{s}\right)^2(0.19) = 2.969\,N.m$$

$$Force = F = \frac{1}{2}\rho A v^2 = \frac{1}{2}\left(1.225\frac{kg}{m^3}\right)(0.1134m^2)(15^2) = 15.628\,N$$

$$Centrifugal\ Force = F_{cf} = mr\omega^2 = (0.05kg)(0.0625m)\left(104.72\frac{rad}{s}\right)^2 = 34.27\,N$$

$$Shear\ Stress = \tau = \frac{F_{cf}}{A} = \frac{34.27N}{0.01227m^2} = 2792.5\,Pa$$