5/1/2016

MBE Broncos- Boise State University

Wind2Water Filtration System

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Executive Summary

The MBE Broncos set out on a beaten trail to tackle one of the leading causes of death in third world countries; unsafe drinking water. Roughly 780 million people do not have access to safe drinking water; and while there are a great many of nonprofits and NGOs tackling this issue, there is still plenty of opportunity to bring safe drinking water to rural communities. People that live outside of the major cities in these countries might have to walk five to ten miles to retrieve a few gallons of water for their family to cook with, clean with, drink and wash. To take on this issue, the MBE Broncos have created the Wind2Water filtration system; a standalone wind powered water filtration system that can be set up in remote locations.

The idea is to bring the ability to have clean, particulate free, bacteria free water closer to rural villages. In order to achieve this, the team has designed a small, 80W wind turbine, pictured in Figure 1 to power two submerged water pumps. One pump will move water from an unsafe source to a settling pond, while the other will move water from the settling pond to the black water tank in the system. The filtration system consists of three 568L tanks on a tiered steel structure, which you can see in Figure 2. The top tank contains the black water, the middle tank contains the filtration media, and the ground level tank contains the filtered water. The filter media is a slow sand process that is able to remove 99% of bacteria, 99% of particulates, and 91-99% of viruses. Since the filter selection is not able to remove all viruses, boiling the water before use will be paramount.

Figure 1. Full scale view of wind turbine.

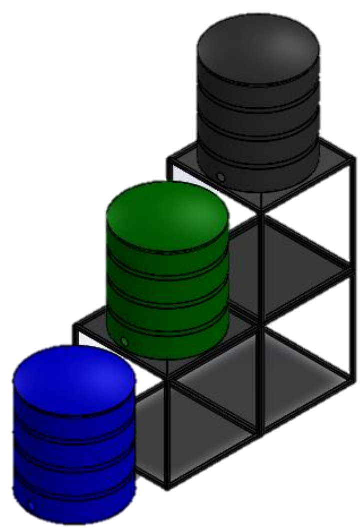

Figure 2. Full scale view of filtration system.

The team built and tested a prototype wind turbine at ¾ scale along with a prototype water filtration system. The prototype wind turbine exceeded the team's expectations operating at an average power coefficient of 0.27. The rated power of the prototype wind turbine is 19W. Given the application it was extremely important to keep the scale small in order to appeal to smaller scale customers. With a price point of $6,795 installed and a capacity to provide up to 50 people with an adequate amount of clean water each day, the system is very affordable and scalable when multiple systems are needed.

Another aspect of the prototype that the team felt was really important was the cut-in speed of the wind turbine. In order to achieve a lower cut-in speed without sacrificing power was to implement a clutch gearing system. The clutch feature that can be seen in Figure 3 is a centrifugal locking system where it will allow the blades to spin freely without engaging the gear. Once the rotor speed reaches 100 RPM the clutch engages and is held in by centrifugal force until the blades come to a complete stop. With this mechanism the prototype turbine was able to achieve a cut-in speed of 4 m/s. This is an important feature because it allows the full scale product to be used in a wider range of wind speeds.

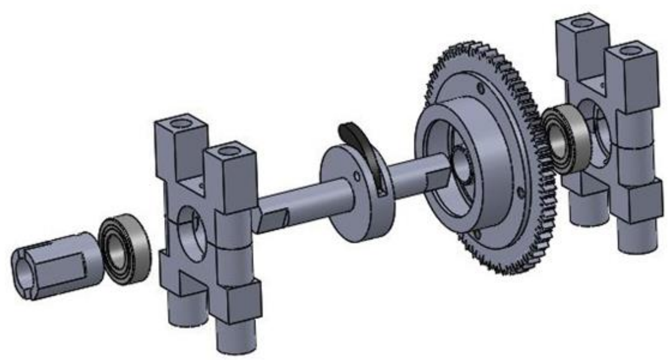

Figure 3. Exploded view of the clutch assembly.

One of the greatest aspects of the Wind2Water filtration system is its simplicity. From the slim design of the bare components to the slow sand filter, it is an easy system to learn and maintain. The filter media is easy to maintain and lasts as long as regular maintenance occurs. One of the most important aspects of presenting products like the Wind2Water filtration system to small villages is getting the buy-in of those that are going to be using it. Ultimately, it will be their responsibility to use and maintain the system, which creates an opportunity for social entrepreneurship and ownership of the life saving device. The team believes that this could be a great step forward in bringing safe drinking water closer to those who need it, and create an opportunity for communities to come together.

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Business Plan

Business Overview

Vision

Wind2Water will help rural communities in developing countries gain access to clean water, through the use of a wind turbine pumping filtration system, while instilling a feeling of ownership and pride.

Product Overview

The product is a three blade wind turbine system capable of providing filtered water for up to 50 people (568 liters (L)) on a daily basis. The system uses wind energy to provide power to two pumps that draw water from an undesirable water source. This water is then gravity fed through a slow sand water filter, which gathers the filtered water in an adjacent storage tank for use. This source of filtered water will benefit rural communities that may otherwise have to travel extreme distances for access to a clean water source.

The wind turbine filtration system will enable the local community to utilize wind energy storage. The product can take advantage of peak wind times and store clean water for use during times of reduced wind speeds. The filtration system will integrate slow sand filter technology. This process filters out particulates, dirt and debris from otherwise undesirable water sources. This is achieved by a two stage filter consisting of a small, bottom layer of gravel followed by a larger layer of sand. The water drains through at 22L to 25L per hour and is then stored in a reservoir water tank to be used as needed. The finished product will also include basic tools and replacement blades to ensure product longevity.

Value Proposition

Humans need at least 10L of water per day for survival (United Nations High Commissioner for Refugees). The turbine will be able to provide an estimated 568L of clean water per day, providing rural communities with a means to access a precious resource through an environmentally sustainable system. The product will allow rural communities to utilize a local water source that would normally be unsatisfactory. This, in turn, limits or eradicates the need for people to travel to obtain clean water.

Business Model Overview

Wind2Water will be established as a non-profit organization. The initial target users live in Virol, Haiti, a rural community in Southern Haiti located just north of Jacmel and south west of Port-au-Prince and near the rivers of Ravine Perdu Temps, Ravine Perdu Bien, as well as the Rivière Gauche. Future product installation sites would be focused on similar communities near the above mentioned rivers. After designing and testing the final product, materials will be sourced from retailers within Idaho, where possible, and construction will be carried out by members of the business. The system will be marketed and sold to non-governmental organizations such as the United Nations Development Programme or International Rotary Club. Product transportation will be intermodal, traveling by sea and land to our target location. In order to help ensure the system's effectiveness, individuals within the rural community will be educated on product functions and components while also instilling a "social entrepreneurship" approach. They will be trained in subjects such as the system's required maintenance and likely repair scenarios in order to instill a sense of ownership and to help ensure the product's useful life.

Market Overview

Product Offering

The Wind2Water system will provide filtered water to people with limited, or no means of obtaining water from a nearby clean water source. The product will significantly help reduce the local's traveling endeavors, which can require miles of walking to the nearest clean water source.

Customer Segment

The target demographics currently reside in rural "third world" communities who live near a source of unsatisfactory water. This could include, but not limited to, regions such as Eastern Africa, Central America, and Southern Asia. The first proposed product site will be in or near Virol, Sud-Est, Haiti, as mentioned in the "Business Overview" above.

The Haitian rural community has the lowest percentage of access to improved water sources in the entire Western Hemisphere. According to the CIA World Factbook (2016), the total population of Haiti is currently about 10.1 million people, with approximately two-thirds of those citizens living in rural areas. There is an average of 255 people per square kilometer, or 650 people per square mile, which is most heavily concentrated in urban areas, coastal plains, and valleys. When it comes to drinking water sources, 42.3% of the total population is subject to unimproved water sources. Rural communities on the other hand, have 19.2% of the population able to access improved drinking water, leaving the other 80.2% without reliable drinking water sources. These unsatisfactory conditions also promote a high degree of risk for major infections coming from food and waterborne illnesses, including but not limited to, bacterial and protozoan diarrhea, hepatitis A and E, cholera and typhoid fever.

Meeting the Needs of the Target Market

The turbine design will provide a cost-effective and easy-to-use solution for people living in impoverished areas who face daily water shortages. Currently in these rural areas, the opportunities to obtain clean water are limited. For those who are subject to unimproved drinking water sources in rural areas, 5% get their water from unprotected wells, 37% from unprotected springs, and 8% from rivers. These rural communities often rely on boiling methods or the addition of chlorine tablets to treat water sourced from wells and other unimproved sources. For those who live in urban areas, 20% get their water from "bottled water," 4% from carts with water drums, and 3% from unprotected wells (Water supply and sanitation in Haiti, 2016). Bottled and bagged water has been treated through reverse osmosis, and is sold by local private companies. They also import bottled water, especially in disaster times like after the 2010 earthquake.

With NGOs being the primary customer of Wind2Water's wind turbine filtration system, it is important that the product be aligned with the goals and visions of these organizations. By supplying rural communities with a source of filtered water, an opportunity to improve their mental and physical health arises. With access to a sustainable water resource, these communities will no longer have to spend precious time and energy to obtain a basic life necessity, ultimately improving their quality of life. These are just a few of the product benefits that will make Wind2Water's product a great addition to any humanitarian focused NGO.

Competitive Advantage

Our main differentiator and value proposition is based on our product's utilization of a renewable resource to operate a water filter. End users will be able to harness the inconsistent nature of wind to produce filtered water that can be stored and used for a later time. Our target market lives within geographical areas where infrastructure and reliable power are not readily available. By providing a sustainable solution, people living in these communities will have an alternative source of clean water available to them that will reduce their reliance on their region's unstable infrastructure. The needs of this segment are currently not being met, as shown in the "Competition Pricing" section below, since existing solutions only provide a water filtration solution without a solution to reducing or eliminating the task of transporting water long distances in hostile environments.

Pricing and Value Proposition

The product will initially be priced at $6,795 which includes one turbine, one tower, two pumps, three water tanks, slow sand filter components, water tank support structure components, three replacement blades, shipping, required tools for basic maintenance and repairs, as well as installation and training for the local community. This selling price will provide the necessary income to maintain business operations and future manufacturing processes. Since the product will be utilized in a humanitarian relief setting, a price point that allows enough revenue to maintain production and business operations will be most effective and desired. A low price point will allow for the purchase of the turbine system at a minimal cost, and be more attractive for humanitarian relief programs and non-governmental organizations to purchase and establish systems in regions most benefitting from additional access to clean water (Ex. Red Cross, Doctors without Borders, International Rotary Club, etc.).

Price Coinciding to Customer Value Proposition

The Wind2Water system will provide a means to reduce or eliminate the need to walk long distances to obtain clean water. A study in 2013 found that 783 million people worldwide are without clean drinking water (UNWater, 2013). The majority of these populations are located in rural communities that are required to travel to find a source of clean water.

The Wind2Water system will also coincide with non-governmental organizations' goals of helping societies. Most non-governmental organizations' missions coincide with the tasks that the product would help to solve by providing clean water to those in greatest need. This could lead to increased popularity, raising an NGO's ability to receive funding to progress their humanitarian efforts. It is expected that the knowledge that a person is directly helping to provide the establishment of long term water filtration abilities for communities in need will increase a person's likelihood of donating to an NGO.

Competition Market Overview & Pricing

There are several competitors currently operating in the renewable energy water purification product segment. Competitors offer an array of solutions ranging through small, medium, and large-scale designs.

Small-scale solutions are available through both artisan and commercial producers. Handmade solutions produced by groups like Potters for Peace manufacture ceramic pot filters in Nigeria. The ceramic pots filter 1.5L to 2.5L per hour and sell for around twenty dollars, offering replacement clay filters for an additional five dollars (Ceramic Water Filter Project). Another inexpensive filter product developed by Australian scientist, Tony Flynn, is made from natural ingredients such as clay, coffee grounds, and manure and produces only 0.63 L an hour (Thomas). Vestergaard, the commercial makers of the LifeStraw, a portable filtration "straw", has products ranging from $20 to $330. These products have filtration volume life cycles ranging from 1,000L to 80,000L, after which they either require a replacement filter or in some cases a new product entirely. In addition to their product line, Vestergaard sets aside a portion of their sales to provide schools in developing countries with access to clean drinking water through their "Follow the Liters" program (LifeStraw).

An example of a medium scale solution is a product called Slingshot, invented by Segway developer Dean Kaman. This machine can reportedly purify up to 1,000L of clean water per day and costs approximately $1,000 to manufacture (Lazarus). Although this product is relatively inexpensive, the technology still requires the use of fuel to remain functional as well as a way to get the dirty water into the device, unlike Wind2Water's sustainable wind powered filtration system. Another medium scale product is the Eole Water turbine system. The product condenses water from the air, and then purifies it. The Eole Water turbine is estimated to produce 1,000 L of water per day (supports ~100 people) and initially costs $790,000 (Boyle, 2012).

Large systems, built commercially, can sell from $50,000 to $100,000. One example is the Hydra, a mobile power plant and water purification system. It uses a 2.88 kW solar panel to power its pump and push water through its "self-cleaning filtration system". At full capacity it can produce 87,000L of drinking water a day (Singh). Another comparable product is sold by Trunz Water Systems. They offer a variety of solar and wind, water purification and desalination systems, for application in disaster relief and developing countries. They offer a product costing approximately $60,000 that is capable of providing up to 650L per hour, or roughly 15,000 per day (supports ~1,500 people) (Water Shop Concept) .

Wind2Water will be capable of producing around 568L of clean water per day, which is comparable to other medium sized systems. Other Wind2Water product differentiations and benefits include:

- Eliminates the need to travel to a clean water source, in addition to providing filtered water.
- Utilizes wind energy storage by the process of storing clean water during peak wind conditions that can be later consumed during less than ideal wind conditions.
- Reduced costs compared to some of the large and expensive equipment needed for large-scale systems.
- Low cost and relatively simple maintenance processes.
- Can install multiple units to serve larger communities and reduce per-unit installation costs.
- Provide local communities with autonomy, self-reliance and pride of ownership.

While many of the competitors' systems are well designed and effective, many currently cost a significant amount of money. Although some produce a larger quantity of water, the Wind2Water unit sells for a fraction of the price of just $6,795 installed. This as a result, places a lot less risk and financial burden on a prospective NGO buyer. The design is also capable of accommodating multiple, equally priced turbines, to create a connected system to adapt to a region's specific needs. This could allow for increased clean water production, while still remaining reasonably priced.

Incentive Programs

With a humanitarian relief focused product, access to funding routes and partners are readily available. Such opportunities are provided on both a state and federal level. Within Idaho, the Idaho Nonprofit Center currently offers several grants within the environmental umbrella. There is also the Association of Fundraising Professionals (Idaho Chapter) that provides information and possible support.

The Department of Energy lists several options for renewable energy companies that can take advantage of tax credits. IRS administers Clean Renewable Energy Bonds (CREBs) that help finance renewable energy projects. The Renewable Energy Production Incentive (REPI) provides annual financial incentive payments of 2.2 cents per kWh for electricity generated and sold by new qualifying renewable energy generation facilities for the first 10-year period of their operation.

Sources of Capital

In order to sustain a humanitarian relief business model, the appropriate 501(c) (3) tax classification will be filed. After doing so, future plans would include applying for grants and other financial aid, either state or federal, that caters toward sustainable/renewable energy focused businesses.

Management Team

Team

The current business is comprised of twelve individuals, each with growing skills and expertise in the areas seen as necessary to execute the current business plan. These necessary areas include product design and development, business strategy, financial planning, assembly, sales, and operations.

Management Structure

The team is comprised of three main cores (business, electrical, and mechanical). Each of these groups have a selected team representative that are responsible for overseeing the progress of their respective groups. The current representatives for each group are as follows:

Lead Manager & Mechanical - Dennis Twitty

Electrical - Joe Fercho

Business - Carson Heagen

In addition to the core teams, a collection of strategic advisors are available to provide support and guidance. These individuals include Dr. John Gardner, Sandy Cardon, Lynn Catlin, Brian Higgins, and Kent Neupert of Boise State University. The experience and background of the advisors includes, but is not limited to engineering, business, and renewable energy products and services. Each is deeply knowledgeable in their respective fields and are motivated to find a solution to an ongoing global issue.

Development and Operations

Product Research Process

Initial research processes began by searching for a need within a market that could utilize the renewable energy produced by wind turbines. This process led to many different concepts and applications, such as universal USB chargers, vehicle-mounted power generators, naval radio transmitters, and heaters that could be used for camping and refugees. Ideas were narrowed on product concepts that could be used both for commercial as well as humanitarian-focused products. Due to the common location of wind farms in remote and rural locations, we focused on the needs of the populations living close to these areas. It was quickly discovered that one of the largest problems faced by this specific demographic is the high percentage of rural communities that go each day without access to clean water. By combining the off-grid power generated from a wind turbine and the ability to store filtered water for later use, a product concept had been conceived.

Location Research Process

In order to find a suitable location for deployment, efforts have been focused on finding the greatest need for clean water based on the percentage of the population lacking access to improved water sources. Initial locations were focused on the developing countries in Eastern Africa. After some research, it quickly became clear that the implications of shipping and deploying a product halfway across the globe were far too great. In order to find a suitable location, efforts were focused on finding a location closer to the United States. This is when the idea of the product being utilized in Haiti came about. The region of Southern Haiti is capable of providing ideal wind speeds, and has a large population that lack a consistent source of safe drinking water. Since each product is designed to provide enough water for a maximum of 50 people, small rural communities are ideal. Areas surrounding the rivers Ravine Perdu Temps, Ravine Perdu Bien, and Rivière Gauche will be targeted. These communities are ideal since they reside far enough away from urban water resources such as in the city of Jacmel, Haiti. On the other hand, these communities are within a close enough proximity of major cities to support product transportation needs.

Development Process

A prototype will be constructed to provide a proof of concept for the turbine design. Prior to full-scale design, research by the design team will include controls and reliability, design methods, tools and standards, energy analysis, testing, modeling, and simulation.

Raw Materials

Materials for the product will be sourced from local retailers, within the state of Idaho, whenever possible with the exception of the concrete needed for the base of the turbine. Materials that are not able to be sourced locally will be purchased from various online retailers. Raw materials will be initially stored at a "garage" of private residence. Future production demands could eventually give way to the need for a larger storage facility. In this event, a storage warehouse would be the best choice of action as it would provide a much larger space to maintain efficient operation.

Manufacturing

Manufacturing will take place in the "garage" of a private residence. Due to the lack of available equipment, heavy machining will take place at a local community machine shop that costs $100 a month for unlimited use. These locations help meet strategic "Lean Startup" guidelines to reduce operation costs during the beginning stages of the business. Future expansion would move assembly to a manufacturing warehouse to allow a larger workspace for manufacturing as well as storage.

In order to make the transport and assembly process more efficient, the product will be partially assembled prior to shipping and require final assembly at the product's destination. Initial assembly will be carried out by a team of mechanical and electrical engineers. Final assembly will be overseen by project engineers and completed by the local community who will be using the product. This ensures quality build standards are upheld and provides educational, hands-on training for the local community. This strategy will better enable the community to perform required maintenance and repairs so the product will perform consistently.

Company Partnerships

Relationships within the International Rotary Club are currently being formed. Locally, efforts have given way to a valuable contact who was previously the district 5010 Rotary Club governor, Gayle Knepper. Through this connection a line of communication has been established with Rotarian representatives nearby Virol, the first proposed product site. One of these contacts is, Voltaire Emmanuel, President of the Jacmel Rotary Club.

Shipping Process and Implications

Shipping will be required for turbine blades, pump, clutch assembly, and three 150 gallon water tanks. A shipping container will be used to transport the product to Haiti. This was found to be the most efficient and cost-effective method. Through the use of an online shipping calculator called Searates.com, it is estimated that $2,500 will be needed to transport the product to the intended location. This cost has been included in the product-selling price. Costs would include vehicular transportation to the Port of Lewiston Idaho and shipment by sea to Port Au Prince. Once the container arrives in the port in Haiti, a truck capable of carrying a container will be provided by a partnering NGO to make final delivery to the proposed product site. Future product sites will use the same transportation processes to deliver the product to specific villages.

The process for shipping the product will involve securing a shipping container and coordinating a delivery schedule. The turbine will remain fully assembled, excluding the detachable blades, and will be packed securely within the container.

There are a variety of potential risks that could affect the distribution plan. The first major risk is the possibility of the product becoming harmed in transit. Securing a shipping container from a reputable company is the first step that will be taken to prevent anything happening to the product. The second most important step is properly packaging and securing the turbine within the shipping container. Turbine blades will need to be individually wrapped and boxed as these are the more fragile components of the product. The remaining product components, tools, and replacement blades will be wrapped, boxed, and secured within the shipping container. The water tanks, being the least fragile portion, can be securely fastened within the shipping container without the need for additional packing processes.

Another reason to choose a reputable shipping company is to help ensure on-schedule product arrival. Any delay would be costly, and could perhaps put installation plans in jeopardy. To reduce this risk, the container will be shipped a minimum of two weeks before necessary in order to make certain it is there well before installation. An early ship date will help to ensure that, in the event of unexpected issues, installation schedules can still be met.

Another major implication is overseeing the successful installation of the turbine once in Virol, or other potential product sites. In order to perform proper installation, it will be essential to have the correct equipment and resources on-hand. In order to mitigate this risk, all of the basic tools and a ladder necessary for installation will be included within the shipping container and later given to the local community. This is to ensure successful installation, but also to provide the local community with the necessary tools to perform maintenance and/or repairs long-term. The required concrete platform will be constructed by local tradesmen with expertise and knowledge relating to the Haitian soil and terrain. Concrete materials will be sourced in Haiti and will be tested for quality standards prior to final product installation. It will be crucial that the first-sold systems are installed without major implications. Proper planning and proactive approach will help to mitigate these distributional risks.

Operational Risk

Environmental

Due to Haiti's location within the Caribbean, the region is susceptible to hurricanes. There is an average of 10.1 named storms in the Atlantic every year. In order for a storm to be named, it has to be categorized as a severe tropical system. Of these 10.1 named storms, an average of 5.9 become hurricanes and 2.5 develop into major hurricanes (Atlantic hurricane season, 2016). Not all of these storms have an effect on Haiti though. Since 1851, only six major category 3 or stronger hurricanes have struck Haiti. The strongest hurricane to hit Haiti was Hurricane Cleo in 1964. Although 2008 was a more active Haitian hurricane season than usual, when four separate systems passed through killing nearly 800 people, leaving more than 300 missing, and injuring nearly 600 (Masters, 2016).

With these hurricanes comes seasonal flooding of most of the island's rivers, extreme wind and flying debris. In order to combat these risks, the product will be bolted to a solid concrete platform anchored to the ground. Sensitive components such as the motor assembly and blades will require removal and storage in the event of a hurricane. Due to the size of the product, this process can be accomplished with a ladder and basic tools. The wires can be easily disconnected within the housing of the turbine, after which four setscrews can then be removed to detach the entire turbine assembly from the top of the mounting pole. Other major components such as the water tanks and turbine mounting pole will be expected to withstand moderate hurricane conditions.

Haiti can also have frequent dust storms due to deforestation that could potentially cause wear on the turbine's blades from the abrasive dust and sand. In order to mitigate this risk, an extra set of blades will be provided for replacement, in the event of damage.

Social

Haiti is riddled with extreme levels of crime in regions across the island. The highest rates are within higher populated areas such as Port Au Prince. Although actual crime statistics are difficult to come by, the most frequently reported crimes against Americans include robbery and aggravated assault. Vehicle break-ins and thefts are common (Haiti 2015 Crime and Safety Report, 2015), and the country has the presence of a growing "rebel" force that has caused tensions within the communities (Hutson, R. 2016). In order to protect the product from these threats, the local community has to feel responsible and invested in the product to want to protect it from potential threats.

Haiti is one of the most impoverished countries in the Western Hemisphere, with 80% of the population living under the poverty line and 54% living in abject poverty. The 2010 earthquake only further escalated the issue by inflicting $7.8 billion in damages (The World Factbook: Haiti, 2016) Over one million people were displaced initially by the earthquake, with approximately 500,000 still homeless today (Hillestad, 2014). By giving the rural community a sense of well-being through maintaining and utilizing a valuable product and resource, it is expected that the overall mental and physical health of the community will improve.

Technical Constraints to Implementation

Feasibility

For building the product locally, without having our own equipment, the team will be subject to the scheduling and limitations of the local community workshop. Constraints for installation would include minimal ground preparation for the product, lack of access to larger diggers for the settling pond, and adverse weather conditions.

Technical Design

The technical constraints for the turbine and filtration design are as follows:

Turbine Design:

- Having a lower cut-in speed to take advantage of a wider range of wind speeds. Since wind is not always consistent it is important to be able to supply at least 568L per day of wind to the filtration system.
- Removability of the turbine can be difficult due to the wiring that will inevitably need to be disconnected when the weather is poor and reconnected once the weather has calmed.

Filtration Design:

- In many third world countries where the water source is most likely some type of natural water source, silt in the water can cause it to clog quickly. The design must overcome this in order to avoid constant maintenance and unsafe water conditions.
- Being limited in the amount of head that the selected pumps can overcome, the filter design is limited to being within 30 feet of the water source.
- The current filter design is roughly 3m tall which poses a big risk when the black water tank is full. The tanks will need to be fastened securely to the structure to avoid tipping during bad weather.

Design Features to Overcome Technical Constraints

The ways in which the technical constraints will be overcome are as follows:

- Fragile components of the turbine, such as the blades and drivetrain assembly, will be removable in the event that the weather becomes detrimental to the product.
- Blades will be produced from a high grade, flexible plastic to withstand higher wind speeds during lesser storms.
- A settling pond will be dug to provide the necessary means for the silt in the water to be neutralized.
- Filtration system will be fastened to a weighted steel structure to prevent tipping during high winds.

Impact and Opportunities

Technical

The current design of the turbine and water filtration system leaves some opportunities for improvements and/or additions. Future iterations may include components that are capable of filtering bacteria and pathogens out of the water. An explored alternative that was capable of sanitizing the water included the addition of a UV Filter. By using a more sophisticated water purification system like a solar purifier or a vapor compression system, we would be able to filter out disease-causing bacteria, viruses and other pathogens, reducing the need for further purification by those consuming the water. In order to adapt and expand to other locations, additional turbine units can be installed to the filtration system to provide a larger power source for the pumps. This would allow locations with lower wind speeds to benefit from our product by using a series of connected wind turbines to produce the required power for the water pumps.

Social

The most significant social impact and opportunity will come through the social entrepreneurship program. This will allow the community for which the turbine system provides water to be involved. The local people will be taught how to operate and care for the system, which in turn should provide a sense of ownership and pride. These feelings will help provide the necessary care and security needed to ensure that the system remains operational.

Environmental

There is very little environmental impact with the use of the turbine system. The system uses an existing water source, such as a river, lake or pond. At the same time it takes the water that was previously unacceptable for use without filtration and makes it usable. It also uses a renewable energy source, the wind, to power the system thereby reducing the need for any external power source.

Market Expansion Opportunity

Currently, Wind2Water's company vision and focus is the on the humanitarian market segment. Future expansion and success could give way for the company to expand into other product channels that could benefit from the wind turbine filtration system. These could include but are not limited to:

- Wind powered water filtration needs for off grid private residences.
- Water stations for remote hiking trails, such as the Pacific Crest or Appalachian Trails.
- Provide a source of water for remote campsites and recreational locations that lack the access or infrastructure to provide clean water to its visitors.

Financial Analysis

Required Capital

The final product will cost Wind2Water $5,610 to manufacture, as described in Appendix I. This estimate includes all the materials needed to construct a finished turbine, water filtration system, as well as the shipping and installation expenses. An additional $2,000 in capitol will be required to purchase related tools and equipment for manufacturing.

Sources of Capital

Required capital needed to finance the first full-scale system will be acquired through applying for federal renewable energy grants. Once a viable product is assembled, partnering with NGOs who have existing relationships within our target regions will be required. These relationships will be essential to selling the wind turbine filtration system, as well as reducing the cost of transportation and installation. Efforts will be focused toward establishing long-term relationships with these region specific NGOs, as their commitment will play a crucial role in Wind2Water's business model.

Key Assumptions

The biggest key assumption is being able to produce the finished product, installed, for well under $10,000. It is believed that this price would be attractive to both grant agencies and key partners. In terms of economic assumptions, it is believed that once a functioning full scale design is constructed, costs could be reduced by increasing purchasing volume and standardizing parts. Since this product is only capable of providing water for up to 50 people, multiple units will be required to sustain larger communities. This will require customers to purchase the amount of units required to sustain their target community or town, but the shipping and installation costs per unit go down dramatically with multi-turbine installations.

The second largest assumption is that there will be enough attraction from individuals within the target location to engage with the company and product. As outlined, this is a vital step towards ensuring the success and high-level impact that Wind2Water hopes to achieve with the benefiting community.

Pro Forma Financial Statements

Pro Forma financial statements can be found in Appendix I. Below is a high level summary of each statement.

Statement of Financial Activities (Appendix I, Section A)

Sales are forecasted to be two turbine systems in the first fiscal year. This assumption was formed based on market research, the outlook of renewable energy demand, and on the logistics of the product offering. One of the largest expenses will be the costs associated with sourcing, building, and shipping the final product. For the first year, business members will not be taking compensation. With a 501(c)(3) tax filing, the business will not have to pay taxes. First year of business operations are forecasting a net loss of $2,330.

Statement of Cash Flows (Appendix I, Section B)

It has been forecasted that the sole source of revenue for 2017 will be sourced from the sale of the turbine products. In terms of expenditures, there will not be allocated funds for rent since assembly is to take place in a private residence's garage. $2,000 will be allocated toward equipment, needed supplies, a ladder, various power and hand tools, an industrial post digger, and a forklift or skid steer if the situation permits. Ending cash flow activities for the first year will net a loss of $2,330.

Balance Sheet (Appendix I, Section C)

It is estimated for the date of August 31, 2017, that Wind2Water will have no cash assets on-hand, account receivables totaling $13,590, and $2,000 of equipment assets. This will bring current and fixed assets to a total of $15,590. Total liabilities will amount to $13,220, leaving an additional $2,370 of unrestricted net assets to bring the total of liabilities and net assets to $15,590.

Company Valuation

While the company is still in a preliminary stage of development and production, the team has spent a significant amount of time related to research and design of the product. Given the business's current technical designs assets, market research knowledge, and humanitarian contribution, the value of Wind2Water is estimated at $18,000 to $20,000.

If a decision is made to search for funding from accredited investors, it is believed that the specialized team and unique idea would create a very intriguing opportunity for potential investors. The massive market opportunity for sustainable water purification combined with the potential of the current product and market application is expected to elicit outside interest.

Technical Design

Design Overview

Design Objective

The team set out to design a turbine that would operate within a range of wind speeds from 6 to 11 meters per second for six hours per day (WeatherUnderground). The turbine would need to power two 36 watt pumps during that time. This means that the turbine design will need to supply 160 kWh per year to operate at design specifications. The pumps were selected based on maximum head versus flow rating. Maximum head for the system was determined to be 10 meters, which will provide a flow rate of roughly 30L per minute.

Haiti is one of many countries that suffer from a lack of clean water. For this reason a slow sand filter was determined to be the most economical system available to suit the need for clean water. Slow sand filters are cheap because the filtration media is easy to collect and prepare which means no waiting for costly filter media to be shipped for replacement. The population density in rural Haiti averages 255 per square kilometer; with each person consuming an average of 10L of water per day. In order to remain economical and flexible for smaller villages, the filtration system will need to filter 568L/day to provide for 50 people.

Design Component Support

The wind turbine rotor will be 61 cm in diameter while the structure will stand 3 m tall. The lack of trees in Haiti due to deforestation provides a better opportunity to harvest wind at lower heights. These parameters will provide a minimum of 200 kWh per year production.

The water filtration system will consist of a tiered steel structure supporting two 568L water tanks, with one additional 568L water tank sitting at ground level. The top tier will contain black water, the second will house the slow sand filter which provides storage of up to 340L above the sand, and the third tank will be filtered water. The entire system has a capacity of roughly 1,476L of water storage for filtration during turbine down-times. Slow sand filters are great for removing particulates and bacteria removing up to 99% of both; however they can only be guaranteed to remove 91% to 99% of viruses, which is a big issue with the water quality in Haiti. For this reason under the current design, those that use the water from these filters will still need to boil their water as they have been accustomed to doing. Further iterations of the design may include solar water purification or vapor compression distillation, however more research and testing is needed to provide a low cost option.

Mechanical Design Details

Mechanical Design Overview

Rotor

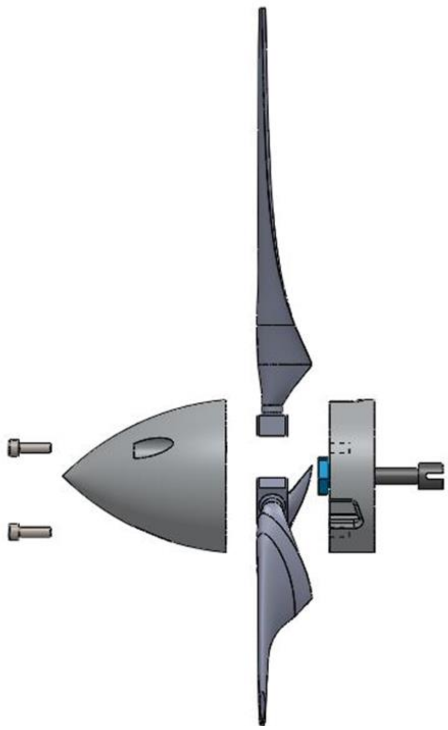
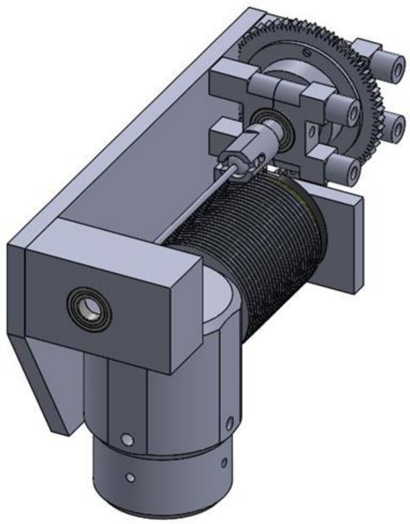


Figure 4. Exploded view of hub and blade assembly.

The rotor design is a five piece modular system that consists of three blades, one cone and one hub, as shown in Figure 4. This design was implemented instead of a one piece design to make shipping easier and safer on the rotor assembly because the full scale version will be shipped out-of-country. Also with the modular design, if the user has damage to one blade they can replace one rather than the whole system. The blades will show wear over time due to abrasion, but the hub and cone will last the entire life of the turbine in normal operating conditions. For both the prototype and the full scale, the hub is pressed on to the spindle using a light 0.025 mm press fit. The press fit was chosen as a light fit that will keep the hub concentric on the shaft. The hub is then held onto the spindle by the hub nut. The blades are put into the hub and then the cone is installed. The cone has multiple purposes; the most obvious reason for the cone is its aerodynamic improvements that will be covered later in this report. The cone also holds the blades in place. The last job the cone has is to keep the hub nut from backing out. The cone was designed to act as a safety measure with minimal clearance, preventing the hub nut from backing out.

The actual blade profile was designed by the Boise State 2015 team, however the root was redesigned by the 2016 team. The profile consisted of a combination of three other profiles stitched into one blade. The stitching method used caused some discontinuity between the blade profiles which increased drag. The 2016 team re-modeled the blades and the discontinuity was fixed. 2015 had a one-piece 3D printed blade assembly that made it hard to ship safely and also had a very rough finish due to the 3D printing process. The casted blades used this year are smooth to reduce parasitic drag and, due to the modular design, they are easily shipped to locations such as Haiti. . The full-scale blades will be manufactured using the same method as the prototype blades, known as “plastic casting “The material used is a high impact resistant plastic called “Task 3” with a tensile strength of 45 MPa. For the purpose of the prototype, the hub and cone were 3D printed using PLA as the material, however the full scale version the hub and cone will be cast in the same method as the blades. This method offers great results and repeatability. The whole rotor assembly will increase in size by a factor of ¼, yielding a final diameter of 61 cm.

Drive Train



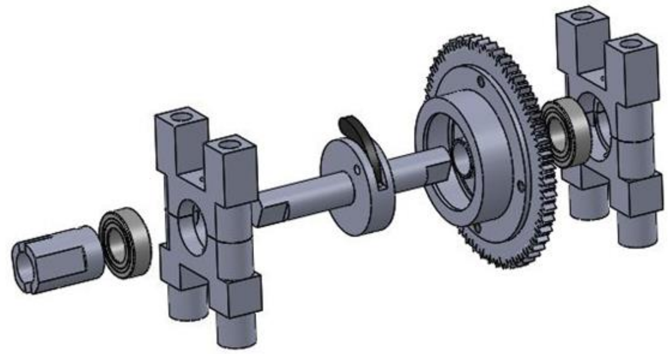


Figure 6. Exploded view of clutch assembly.

Figure 5. Drive train assembly.

The drive train design of the full scale turbine will be an exact replica of the prototype scaled up by a factor of 1/4. The first component of the system is the spindle, on which the hub is pressed. The spindle rides on two low friction ceramic bearings. Ceramic bearings were chosen because of their low rolling resistance and their ability to run without the need of lubrication (low maintenance). From the spindle, a "dog bone" style drive shaft was used to transmit power to the transmission assembly. This style of drive shaft was chosen because it was noted if there is no allowance for misalignment; the drive shaft can bind which will induce more system friction.

The transmission assembly consists of a positive engagement centrifugal clutch and one gear reduction. Using a tip speed ratio of 6 and a rotor diameter of 45 cm, it was determined the optimal wing tip velocity at an 11 m/s wind is 66 m/s thus a rotor speed of around 3000 RPM will give the desired wing tip velocity of 66 m/s. With the desired operating voltage of 3 V, the team was able to use the specs given by the generator manufacture of 2050 RPM/V to determine that in a perfect system the gearing combination would be a 1:2.1 ratio. Due to unexpected frictional losses, three gear sets were purchased. Tests were performed to determine the gear ratio that would yield the correct voltage. Tests were also completed to ensure that the selected gear ratio would not bring cut-in the speed to an unacceptable level. The gear ratio of 1:2.5 was the set that achieved the best results while testing, and therefore was chosen for the prototype.

The type of clutch desired for this turbine design is one that is either fully engaged or fully disengaged. As a result, a positive engagement centrifugal clutch, a clutch that engages a pawl on the bell housing as opposed to a clutch that has clutch shoes that slip on friction plates, was chosen for this application. The purpose of the clutch is to allow the rotor to free-wheel at low wind speeds then, once the rotor reaches 200 RPM, the clutch will engage and start spinning the spur gear. The RPM built up while the clutch is not engaged allows the turbine to use the momentum generated by the rotor to overcome the initial cogging torque of the generator. Tests were performed and the use of the clutch lowered the cut-in speed by 2.5 meters per second, on the prototype.

Aerodynamic Considerations

The entire drive system was rotated 180 degrees from previous iterations of the design to allow the generator to be tucked behind the pylon, which thinned the entire system down, as shown in Figure 7 and Figure 8. As mentioned above, a cone was added and the nacelle was designed to cover all the components downstream of the rotor. In Figure 9 and Figure 10 it is clear that these design choices will dramatically affect the performance of the turbine. Figure 9 shows the turbine without the aerodynamic add-ons, which produces multiple pockets of slow, stagnant air as well as turbulent air, which will induce vibrations and lower performance. In Figure 9, the turbulent air is drastically reduced. The nacelle on the prototype is cut short in order to meet the specifications of the wind tunnel but the full scale version will be longer and have a stabilizing fin at the end. This fin will act as a passive yaw system. The drivetrain mount on the full scale version will be attached to the pylon with a bearing allowing it to rotate. The nacelle for the prototype was 3D printed to visually replicate the full scale version. The full scale version of the nacelle will be made out of fiberglass for cost savings and manufacturability.

Figure 7. Side view of turbine with nacelle installed.

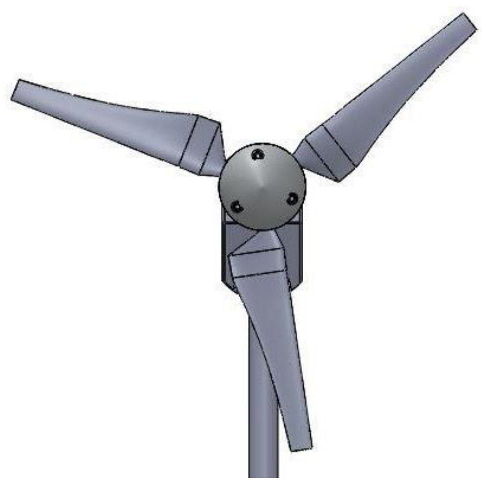


Figure 8. Front view of turbine with nacelle installed.

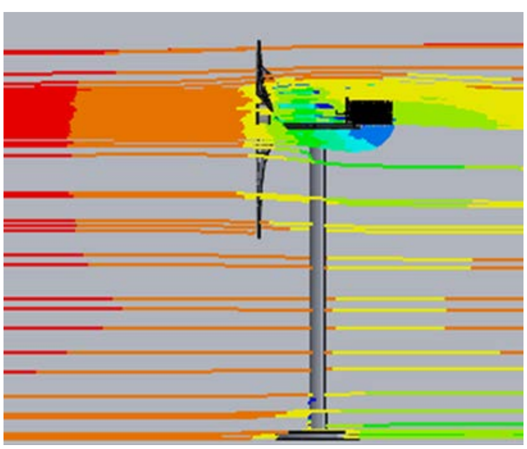


Figure 9. Air flow analysis without nacelle installed.

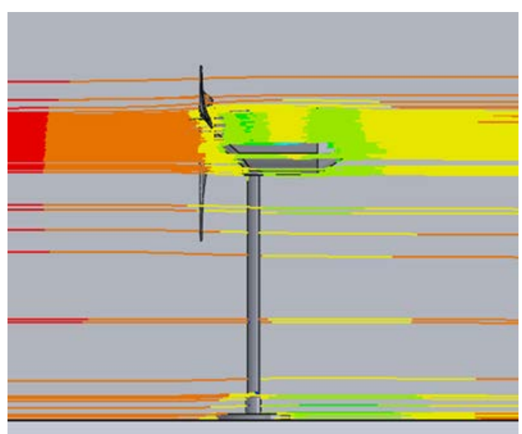


Figure 10. Air flow analysis with nacelle installed.

Static Performance Analysis

Cp-Lambda Report

The performance of a turbine is based on the Cp-Lambda curve generated from testing data. The coefficient of performance, Cp, is a measure of the efficiency with which a turbine extracts energy from the wind and Lambda is representative of tip speed ratio.

As can be seen from Figure 11, the maximum Cp was found at 10 m/s, with a value of 0.31. At the rated wind speed of 11 meters per second, the Cp was found to be 0.27. There is still room for optimization, however the performance of this turbine exceeded expectations and should function well enough to power the water filtration system.

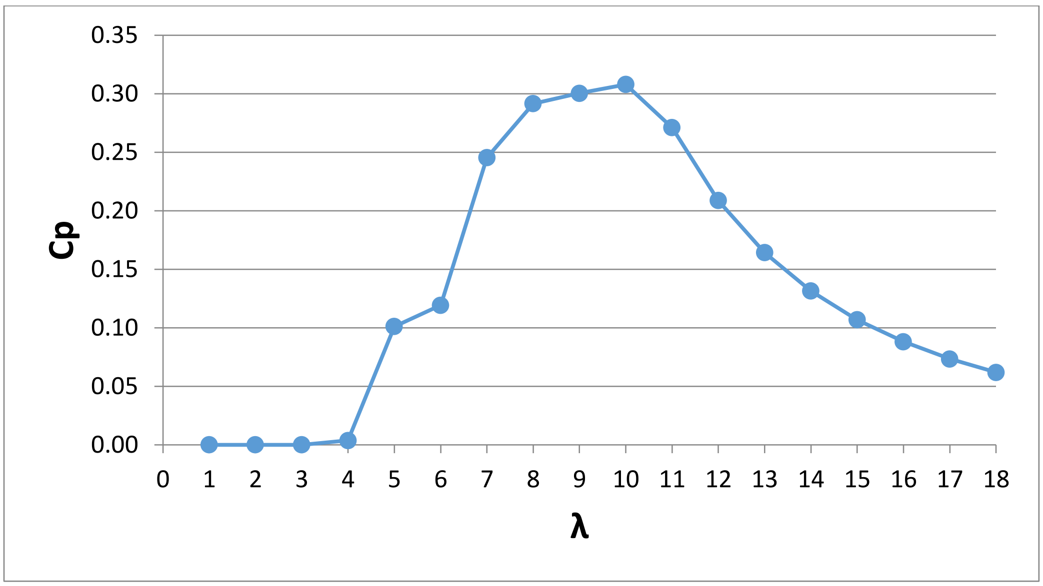


Figure 11. Graph of Cp vs. Lambda.

Energy Production

A turbine's power curve is a determining factor of its performance. The filtration system will require a minimum of 150 kWh per year production from the full scale wind turbine. As you can see in Figure 12, the expected annual energy output for average wind speeds of 7 m/s will be around 204 kWh per year. The team expects the full scale turbine to meet the needs of the filtration system, given that the turbine will see typical Haitian wind speeds between 6 m/s and 11 m/s.

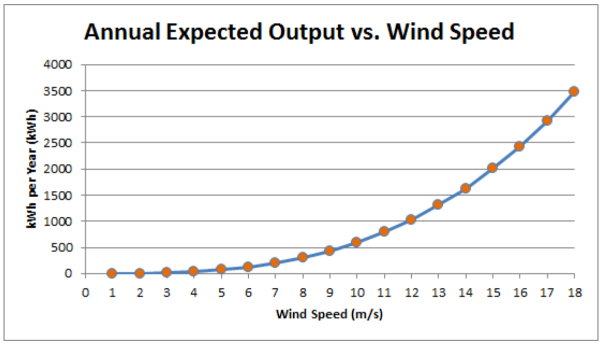


Figure 12. Annual expected output in kWh/year for a range of wind speeds.

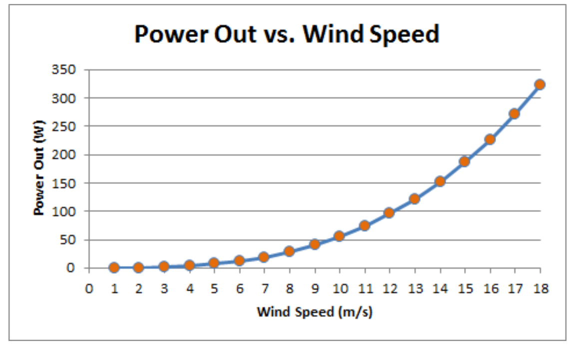


Figure 13. Expected power output over a range of wind speeds.

The output power for the prototype was measured at various wind speeds and the resulting power curve can be seen in Figure 14. A consistent, positive power was achieved as low as 4 m/s which is two m/s lower than the lowest average wind speed in our target area of Haiti. The turbine has been rated for 11 m/s as per competition rules so the power production levels out at the higher wind speeds. At 18 m/s the turbine will shut down completely to avoid any damage or runaway situations.

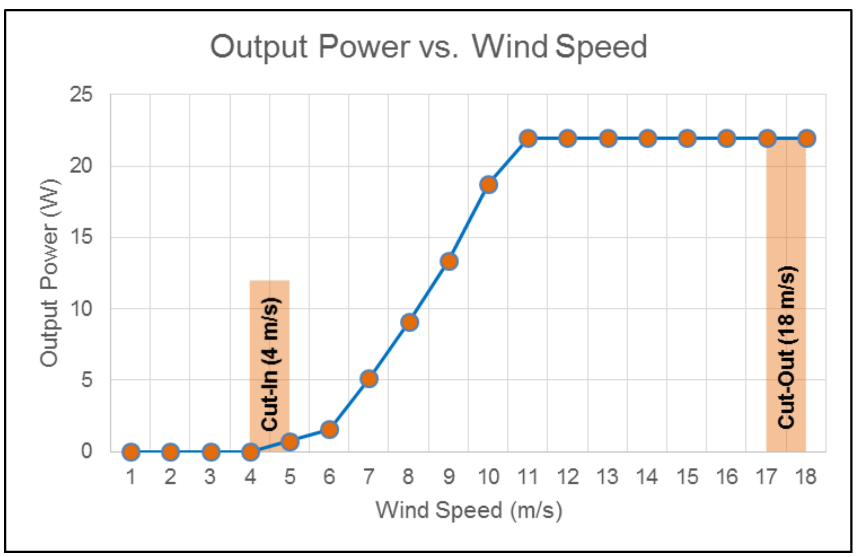


Figure 14. Tested output power versus wind speed.

Expected Load Analysis

Analysis of Expected Loads on the Turbine

From the wind power equation, shown in Appendix II as equation 1, it is calculated that a wind turbine with a rotor diameter of 61 cm will produce 220 W at wind speeds of 18 m/s. For these wind speeds there will be a 16 N-m torque applied to the rotor. From the torque it was determined that the drive shaft needed to have a minimum diameter of 2.32 mm, the final product will contain an 8 mm diameter shaft which will be able to sustain the drive train. Using a drive shaft of hardened 4140 steel, the critical speed was calculated to be 517,000 RPM, while the operating speed for the turbine will be approximately 2,900 RPM. The shaft will experience minimal vibrations because the operating speed is much lower than the critical speed. Given that the critical shaft speed is 178 times the operating speed, we do not anticipate the rotational velocity to approach the critical speed, even in the event of a runaway situation.

The blades will be casted with Task 3 Plastic, which has a tensile strength of 45.8 MPa. Figure 15 demonstrates three locations on the hub/blade that were analyzed for centrifugal forces and stresses. The blade location at distance 1 had the highest centrifugal force of 655 N with a stress of 1.35 MPa and associated safety factor of 35. Distance 3 has the lowest centrifugal force of 330 N with a stress of 3.00 MPa and safety factor of 15. Examples of these calculations can be found in Appendix II - Calculations, where it also demonstrates that the lift and drag forces on the blades are minimal.

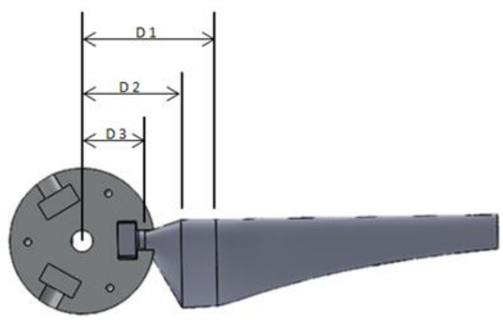


Figure 15. Critical locations of interest on blade and hub assembly.

A tubular tower constructed of 304 stainless steel was chosen for the full-scale design. The tower will stand 3 meters tall, have an outside diameter of 76.2 mm and a wall thickness of 1.65 mm. Because the turbine will be taken down in case of extreme wind speeds the maximum wind speed the turbine will see is 18 m/s, at these wind speeds the tower will deflect ± 5.63 mm and will experience stresses of 23 MPa. It was calculated that at these wind speeds the tower will have a safety factor of 9.35. The steel pole could see up to 70 m/s during a hurricane, which will give roughly 2,700 N/m^2 of pressure. That pressure will be considered negligible when compared to the yield strength of the material.

Analysis of Expected Loads on the Water Filtration System

The two pumps selected for the water filtration system each require 36 Watts of power to operate and will overcome the 10 m head pressure necessary for the system. Calculations were made to ensure that the setup of the water filtration system has the required hydraulic head. Loading forces were calculated for the weight of the tanks, water, sand, and steel structure. The supporting steel structure will withstand the total weight of the contaminated water tank with 125 gallons, which was calculated to be 500 kg. It will also support the weight of the green tank that contains 260 kg of sand and 378 kg of water. The supporting steel structure will be constructed of 304 stainless steel and will support the 4.9 kN force exerted by black tank and the 6.3 kN force exerted by the green tank. Figure 16 demonstrates the setup of the slow sand filter, where the black tank acts as a storage for the contaminated water, the blue tank stores the clean water, and the green tank will contain the sand filter.

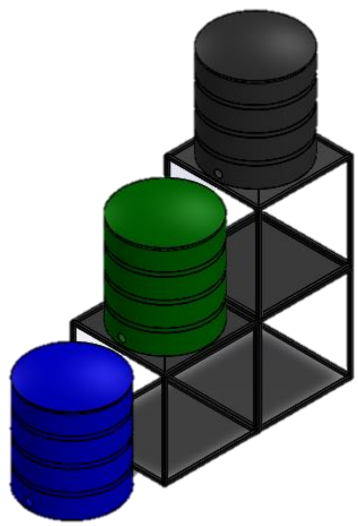


Figure 16. Full scale view of filtration system.

Electrical Design Details

Electrical Overview

The electrical system for the turbine is used to convert the mechanical energy of the wind into electrical energy for the water pump. It does this by boosting the small voltage, yet high current 3-phase power into to direct current power. The microcontroller provides the processing and logic behind this system. There are multiple safety features built in to minimize risk to the users of the turbine.

Each block in Figure 17 represents the circuit elements necessary to implement the electrical design. The blocks show the inputs and outputs of each circuit element. The red blocks represent power generation, conversion, and storage. The green blocks represent control system. The blue blocks refer to the safety and braking system. Dashed lines represent PWM signals. Each block is discussed in more detail in the following sections.

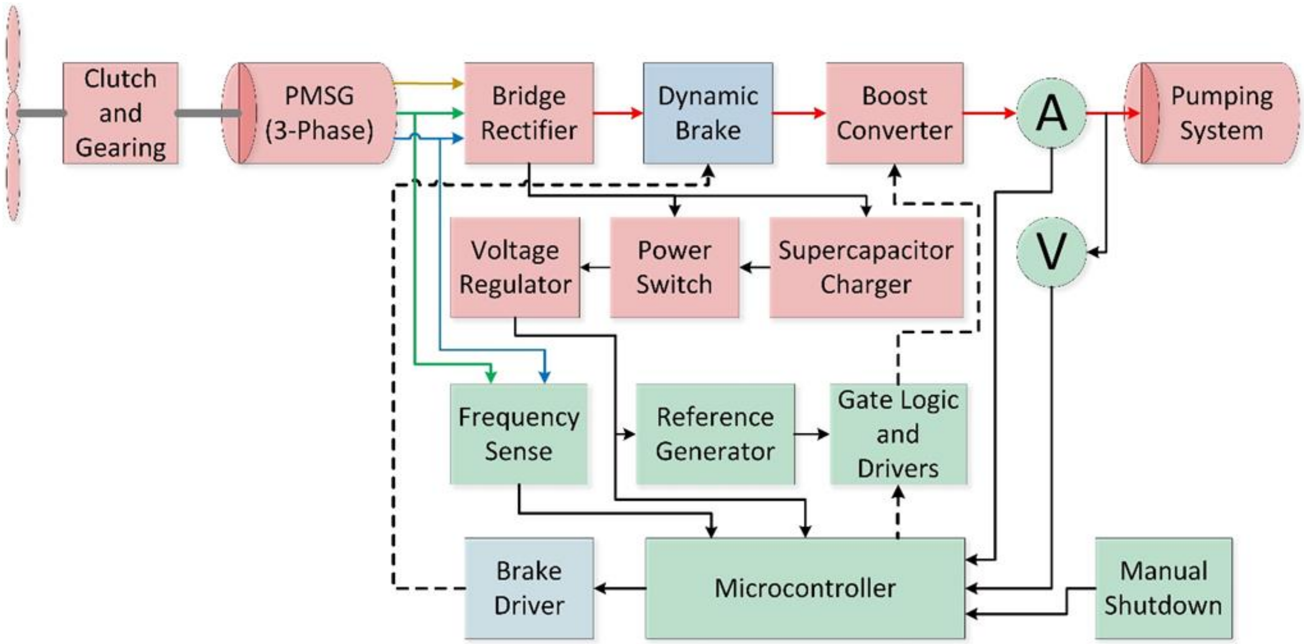


Figure 17. Electrical system block diagram.

Power Generation and Conversion

3- Phase Generator

The generator used for the turbine is an ElectriFly Ammo 28-56-1530 brushless permanent magnet synchronous generator. This motor was chosen for its low cogging torque, known voltage and current characteristics, as well as its efficiency. The generator has a cogging torque of approximately 4 mNm. This will allow a lower cut-in speed for the turbine. This generator produces 1V at approximately 2050 RPM and can handle a maximum continuous current of 23A. This current rating far exceeds the maximum current necessary for scale performance, which peaks at approximately 3.20A. The generator outputs power in a 3-phase system, which allows a higher generator efficiency of up to 89%. The LT Spice model seen in Figure 18 was used to model the generator. The model was fully parameterized based on the wind speed, V, and as well as the open circuit voltage of the motor, V_{OPEN}. The internal resistance of the generator is modeled by R_S.

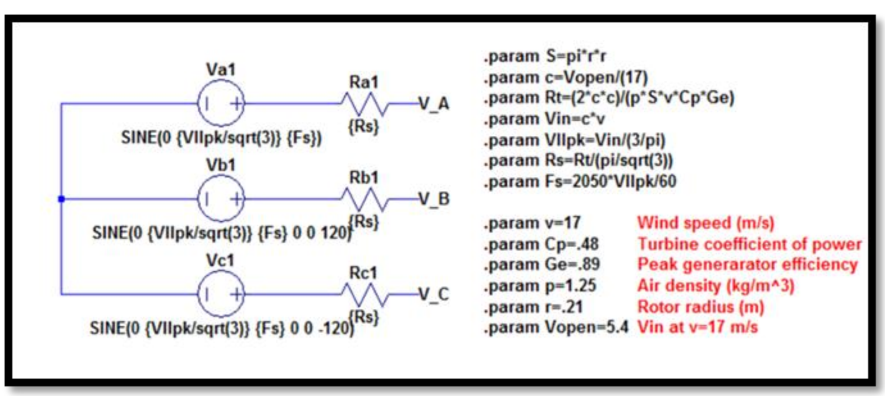


Figure 18. 3-phase generator model.

For the full scale turbine, the WindZilla 12 V DC permanent magnet generator will be used. The WindZilla generator is designed to operate as a generator instead of a motor. It is also designed specifically for wind turbines with a low operational RPM of approximately 400 RPM. The larger blades and different gearing system of the full scale will provide the torque necessary to reach this RPM for this more powerful motor.

3-Phase Bridge Rectifier

The 3-phase bridge rectifier is used to convert the output on the 3-phase generator into a DC signal. It operates by connecting one of three phases of the generator to both the anode of one diode and the cathode of another. This set of diodes is then put in parallel with the other two phases, which are configured in a like manner. The schematic for this topology can be seen below in Figure 19. The rectifier is the first sub-circuit in the primary power path. Due to this, the diodes this circuit is comprised of must have a low forward voltage in order to minimize excessive power loss at high currents. The Vishay VS-STPS20L15DPBF were chosen to comprise the 3-phase rectifier for this reason. These diodes have a forward voltage drop of 300mV at 3 amps, the current expected at maximum wind speed. Aluminum heat sinks were affixed to these devices in order to dissipate the lost power as heat. The DC output of the bridge rectifier has a 1mF aluminum capacitor in order to provide voltage smoothing.

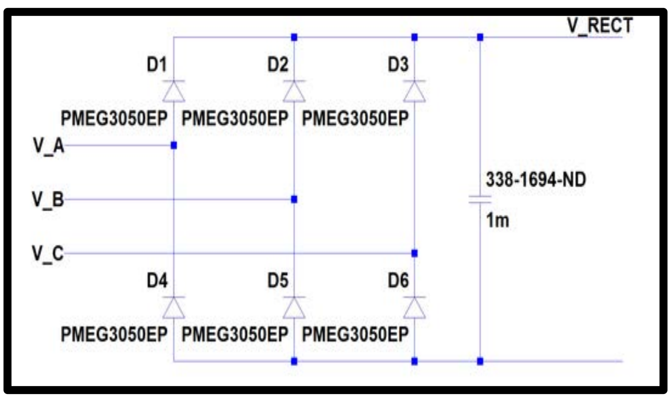


Figure 19. Diagram of 3-phase rectifier.

For the full scale version, an active rectifier using MOSFETs will be used. This topology is up to 90% efficient compared to the maximum 80% efficiency of the passive system. An active topology provides the benefit of increased power efficiency at the expense of more slightly more complex control logic. The logic is comprised of 6 comparators in order to determine when to enable or disable each gate. In parallel with each gate will be a diode that essentially provides a passive bridge rectifier in parallel with the active rectifier. This will allow power to be generated before the logic voltage is able to be regulated. After that, the active rectifier will operate on its own without need for logic input from the microprocessor.

Synchronous Boost Converter

The synchronous boost converter converts the low DC voltage from the rectifier to a higher DC voltage for the load. It is comprised of an inductor, low-side NMOS, high side PMOS, and a Schottky diode. The synchronous boost converter works by switching the NMOS to draw current from the inductor. When the NMOS is switched on, high current is drawn through the low resistance of the device. The NMOS is then switched off, forcing the inductor to continuously conduct high current, but instead, force it through the diode and PMOS in parallel. After the NMOS is switched off, The PMOS is switched on at the correct time in order to provide a low resistance path for the current to flow. The timing of this is explained in the gate driver section (Pg. 27). When both the NMOS and PMOS are switched off, the current is allowed to flow into the load via the Schottky diode in order to ensure that breakdown voltages of either MOSFET are reached. All 4 devices were chosen for their power and efficiency characteristics. The schematic for this subcircuit can be seen below in Figure 20. The inductor, TT Electronics HA55L-3623220LF, was chosen for its high saturation current of 26A and low resistance, 3.35 mΩ. The low side NMOS, STMicroelectronics STP150N3LLH6, was chosen for its low on-state resistance of 3.5 mΩ. The high-side PMOS, Infineon Technologies IPD90P03P4L-04, was chosen for its low on-state resistance of 4.1 mΩ as well. The Schottky diode is the same diode chosen in the 3-phase rectifier.

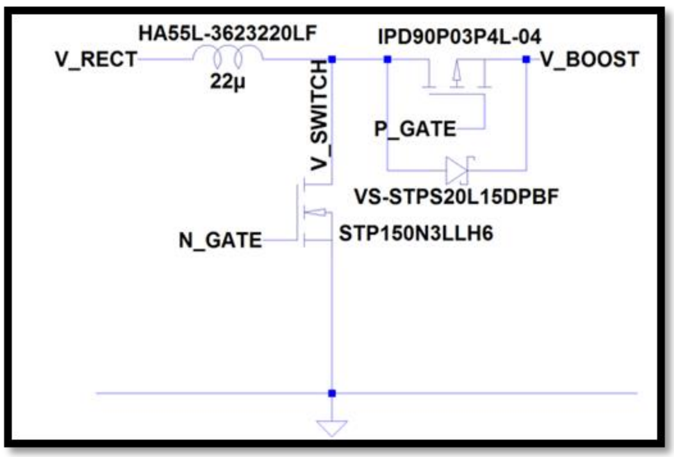


Figure 20. Diagram of synchronous boost converter.

With the more powerful generator, reaching the operation voltage of 12 V DC will be easily achieved. Because of this, a Buck-Boost circuit topology will be used to regulate the output 12 volts. The components will need to be changed to accommodate for the increased voltage and current. The inductor will be upgraded to the TT Electronics HA55L-3623400LF. It is similar to the current inductor, except that is higher rated model capable of higher currents. The capacitor will be upgraded to the United Chemi-Con EKZN500ELL102MK35S. This due to its higher voltage rating, as well as its higher ripple current rating. The MOSFETs as well as the diodes necessary for this new topology will stay the same.

Control system

Microcontroller

The control loop for power regulation and braking are implemented on a Texas Instruments MSP4305529 Launchpad development board. The development board attaches to the wind turbine via a 40 pin header. The MSP4305529 microprocessor and the associated development board were chosen for the following reasons:

- The processor was designed for ultra-low power designs, offering a variety of low power and sleep modes.
- The development board has an integrated USB hub and debug module, which can be disabled via jumpers when not in use (to reduce power demands).
- The microprocessor has an integrated multi-channel 12 bit ADC. The ADC is used to measure voltages that are directly proportional to the output current as well as the output voltage.
- The microprocessor has an integrated comparator. The comparator is used for level crossing detection along with one of the timers to sense the frequency.
- The microprocessor has four 16 bit timers. The timers are used in the design to determine frequency, apply averaging, and wake up the processor as necessary.
- The microprocessor has two UART interfaces, one of which is implemented via the development board's USB interface. This feature allows for rapid development of debug GUI which will be used to characterize the wind turbine.
- The development board provides all necessary pin-outs to interface with the ADC, comparator, and GPIOs.

The same microcontroller will be used for the full scale turbine. Only the microcontroller IC and not the development board will be used. The development board contains the microprocessor IC as well as many other peripheral features that are not need needed for operation of the turbine. In order to minimize unnecessary power usage, the microprocessor IC can be purchased and implemented separately with only the features required for operation of the turbine.

Power Management

Power for the control circuitry is handled through a voltage regulating IC. The regulator is powered by either the rectifier voltage or a supercapacitor for backup. A switch IC automatically determines the power source based on available voltages. The voltage regulator is DC-DC buck-boost voltage regulator, the Linear Technologies LTC3127, which was chosen for its wide range of voltage inputs. The switching circuit, Linear Technologies LTC4415, was chosen for its ideal diode characteristics. It uses internal logic to provide power O-ring from primary and secondary power supplies. The supercapacitor charging circuit, Linear Technologies LTC3355, inputs power from the rectifier in order to charge the backup power supply. The supercapacitor is charged using an internal buck converter to maintain charge on the supercapacitor. Charge is then conducted from the supercapacitor through a boost converter to the secondary input of the power switch. This IC was chosen for its simple and automatic power transfer upon loss of input power. Prior to competition all capacitors must be void of stored charge. In order to do this, a push button and bleed resistor will enable safe removal of residual charge from the capacitor.

The full scale turbine will have a similar backup power configuration. It will use a power switch, voltage regulator, and supercapacitor charging circuit to maintain backup power. All three ICs would need to be redesigned though in order to account for the higher input power. Another change would include the voltage regulator being set to an output 5V instead of 3.3V though. This would allow a broader range of more powerful control circuitry to be implemented.

Current Sense

The load current is measured using a shunt resistor and current sense IC. The IC then outputs an analog voltage that can be read by the ADC on the microcontroller in order to determine maximum power output. The IC used is the LT6105. This IC was chosen for its source voltage and low power requirements.

Current sense is critical to the control system and will be implemented in the full scale turbine. Another IC will be chosen though. This is due the full scale system not being under the lower source voltage constraints.

Voltage Sense

The voltage sense system uses a voltage divider and a secondary ADC channel to measure the voltage. The voltage divider is used to bring the output voltage down to a voltage that the ADC can read without damaging the microcontroller. 1% tolerance resistors were used for this in order to ensure accuracy of the readings. A similar voltage sense system would be used in the full scale turbine.

Gate Drivers

The gate driver circuit uses digital logic and bootstrapped gate drivers to quickly and safely switch the MOSFETs in the synchronous boost converter. The primary driver is the gate PWM signal. This signal is provided by the microcontroller. It is an 8 kHz signal with a variable duty cycle based on the output power. Also used are crossed, high side and low side output signals. Using inverters and an RC delay, these signals are implanted in such a way to ensure only one MOSFET can be switched on at a time. This, as well as instantaneous current sensing within the logic, prevents cross conduction. Also implemented is load overvoltage protection. Using a voltage divider and a comparator, the NMOS within the synchronous boost converter is unable to switch. This allows the load voltage to drop in order to protect the load. A control signal from the microcontroller can also disable and enable synchronous activity at will. This is done by forcing the PMOS to constantly be switched off. All of this logic then commands the gate driver ICs, Linear Technology LTC440-5. These ICs use the low level digital logic to drive a relatively high powered bootstrapped supply to drive the gates. This IC was chosen in order to be able to provide the current necessary to quickly charge and discharge the large power MOSFET gate capacitances.

The gate driver logic for the boost converter gates would be nearly identical in the full system. The gate driver IC's would be upgraded though to remove the need for the bootstrapped power supply.

Frequency Sense

The frequency of the generator will be sensed using level crossing detection. This is accomplished by sensing the line-to-line voltage and feeding the signal to a comparator and timer on the microprocessor. The line-to-line voltage is measured using an LMV822M op-amp in a differential configuration with an applied offset of 1.65V from the reference generator. The line-to-line voltage is attenuated to 30% of full signal to be compatible with the microprocessor comparator.

Frequency sensing would be done in a nearly exact manner for the full scale turbine. The signal would be attenuated a little more though, due to the higher input voltages.

Reference Generator

This module will be used to produce a fixed 1.65V from the 3.3V source voltage. It is to be used for many of the logic circuits. The LMV822M Op-Amp will be used to isolate, buffer, and maintain this voltage. This sub circuit would stay the exact same in the full scale, but the output would be 2.5V instead of 1.65V due to the change in source voltage.

Braking

Brake Drivers

The brake drivers will be used to provide the current necessary to quickly enable and disable the MOSFETs in the braking system. Buffers are used in parallel to quickly charge and discharge the large gate capacitances, in the switching dynamic brake. The buffer used is the Texas Instruments CD74AC244M96.

The brake drivers will stay the same in the full scale turbine. The same IC will be used as it is rated to operate with the new source voltage.

Dynamic brake

The dynamic brake is the first stage in the braking cycle. It is connected across the output of the rectifier and has the purpose of gradually slowing the wind turbine down. The brake is ramped on over the interval of about 7 seconds via a PWM signal sent from the microcontroller via a buffer. During the 7 second interval, the duty cycle of the PWM signal is ramped from 0% to 100%. It is comprised of a power sink resistor and N-Channel MOSFET. The brake is switched via the same type of MOSFET as the synchronous boost converter, the STMicroelectronics STP150N3LLH6. The 50 mΩ resistor is the Riedon PF2203-0R05J1.

For the full scale turbine, a similar electronic braking method will be used to slow the turbine. The primary difference lies in that a higher rated power resistor will be used. The new resistor will be the PF2205-0R05J1 by Riedon. This is a similar model to the resistor currently used except it has a higher power rating, 50W vs 35W. This resistor will also be attached to a larger heat sink in order to more effectively dissipate the heat.

Printed circuit board

PCB Board Layout

The focus of the PCB layout is to shorten the main power path and to eliminate switching noise. The orientation of the three phase rectifier and the braking system provides the electronics with enough room to place heatsinks in order to dissipate the heat produced. The main power path was also kept as short as possible, using as wide of traces as possible, in order to minimize losses. The gate drivers were placed as close as possible to the switching MOSFETs in order to ensure noise free switching. Switching signals were also kept separate from the sensing signals to reduce noise to the sensitive ADC. Both top and bottom planes of the board were also used as ground planes. The bottom went unused as much as possible to ensure a star ground board layout.

The circuit board for the full scale turbine will be designed using the same process and considerations as the prototype used in competition. It will be approximately the same size through use of the smaller microcontroller IC even though larger, higher rated power electronics will be used.

Load

DC Water Pump

The DC water pumps used for the load are rated to operate from 6V to 12V. Through testing, we've shown that they will operate as low as 1V as well. These water pumps are fully powered from the turbine's boost converter. The load is comprised of DC brushed motors that contain three main parameters to take into consideration when being modeled or operated. It contains internal resistance, internal inductance, and back EMF voltage. The back EMF is proportional to the speed of the motor and inversely proportional to the motor's back EMF constant. The back EMF constant was found empirically by measuring the torque outputted from the motor and dividing by the current drawn to do so. Our parameterized model for each pump is shown below in Figure 21.

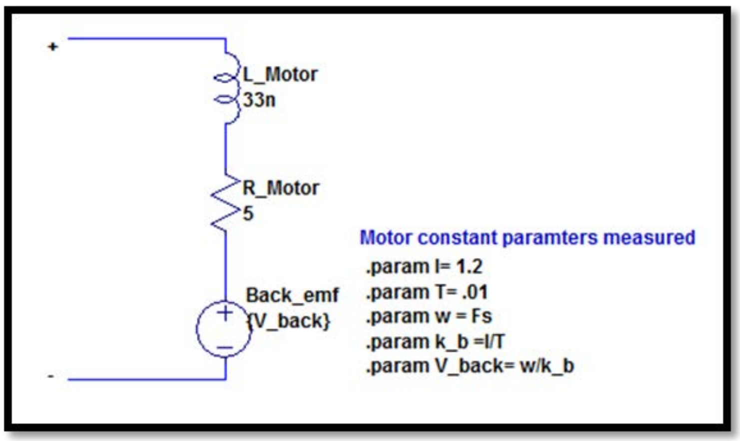


Figure 21. Simulation diagram of DC water pump.

In the full scale design, the Seaflo 12V 750GPH Automatic Electric Submersible Bilge Pump will be used. This is due to its higher flow capacity at 750 gallons/hour at 12 V The maximum recommended discharge head is 9.5m and the maximum delivery head is 10m.

Control System

The control system uses a hill climbing maximum power point tracking algorithm to determine the optimum boost converter duty cycle. The algorithm adjusts the duty cycle up or down while monitoring the output power then determines whether to maintain the direction of change or go the opposite direction based on the sampled output current. For a given wind speed, there is an optimal duty cycle that delivers the most output power. This control system is represented graphically in Figure 22 below.

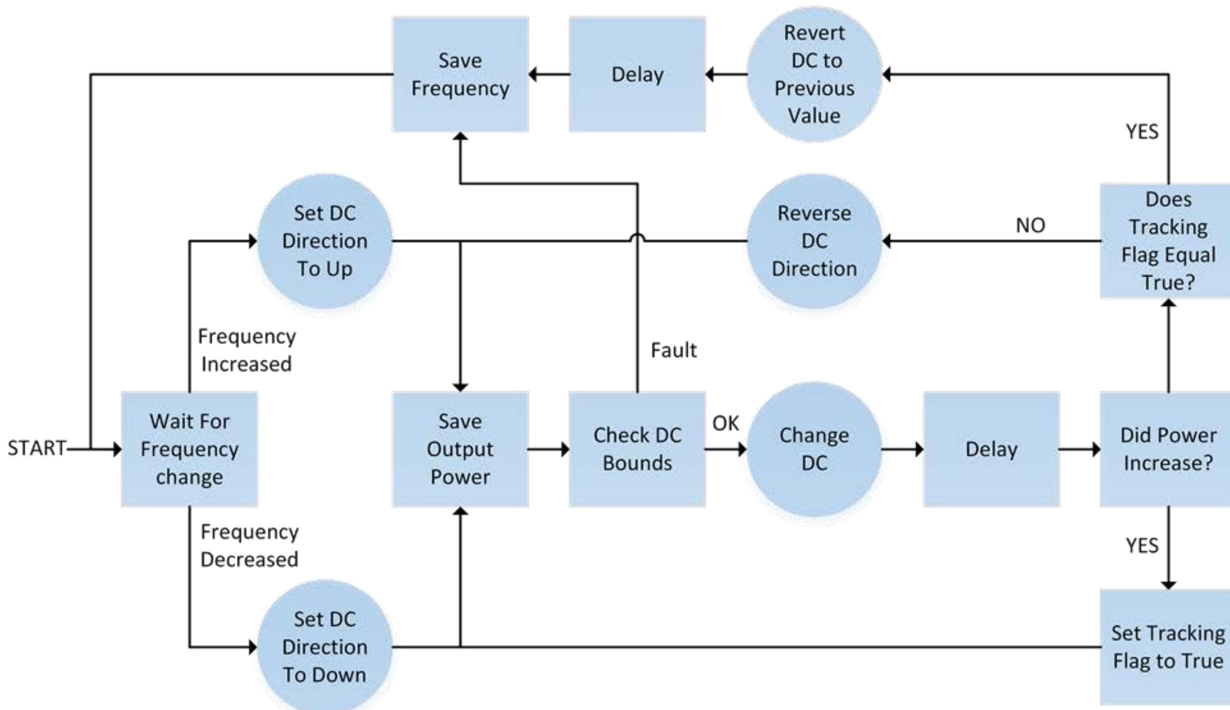


Figure 22. Graphical representation of the maximum power point tracking system where "DC" means Duty Cycle.

The same control algorithm will be used in the full scale turbine. The duty cycle and maximum current bounds would need to be updated in order to compensate for the higher power output.

Software

Software used

Multiple software packages were used to simulate, generate, and control the electronics for the turbine. In order to simulate the circuit and its subcomponents LTSpice by Linear Technologies was used. This package was used due to the fact it was free as well as the ease of use with Linear Technology's IC models. In order to create the PCB, EAGLE by CadSoft was used. This was due to the fact that it is a free package that could output the files necessary to have the board manufactured. In order to generate code for the microcontroller, Code Composer Studio by Texas Instruments was used. This program was used due to the fact that it allows deep integration with the hardware through the processor's registers.

The same software packages would be used to design the full scale turbine. The professional version of these packages would be paid for and used though to avoid limitations brought on by using the free versions.

Development process

The software development process was comprised more of adaptation and optimization instead of creation. This is due the fact that code was available from the BSU CWC2015 team. The code was adapted and optimized in order to work with different control hardware and signal levels. The software for the full scale turbine would follow a similar development process. The primary difference lies with it would be adapted from the CWC2016 team's work.

Deployment Strategy

Project Site Specifications

Environmental and Technical Suitability

The first turbine system would be deployed in the Southern portion of the country of Haiti. A small rural community by the name of Virol has been selected. This community is located north of Jacmel and south west of Port-au-Prince. This location represents just one of multiple possible locations in the region for the wind turbines. Other potential could include along the Ravine Perdu Temps, Ravine Perdu Bien, and the Rivière Gauche.

One of the main foreseeable issues with this region is that there is seasonal flooding of the rivers each year, which causes river bank erosion. This could be a major issue for the product if not taken into consideration. This circumstance will be evaluated when deciding exactly where to place the concrete platform supporting the turbine, filter, and storage tank. Finding an appropriate location will be a balance between product safety and ensuring the water pumps are able to operate at optimal efficiency. The turbine will require a reinforced foundation due to its size and weight specifications. The foundation will roughly be 2.4m x 2.4m x 0.15m and be able to withstand a load of up to 8.44 kN/m^2.

Regional Wind Suitability

The region of Virol, Haiti has, on average, a sufficient amount of wind to power the turbines, ranging from 6 m/s to 11m/s wind speeds (WeatherUnderground). Due to the remote location of the chosen site, detailed weather data is not available for the exact region. Considering information gathered from surrounding areas, it is believed the amount of wind should prove sufficient. From the months of May through October, the region of southern Haiti sees average wind speeds of roughly 6 m/s to 11 m/s. For the remaining months of the year, the area is mainly affected by tropical storm systems that provide varying wind conditions.

The product will need approximately 7 m/s winds for at least six hours each day in order to bring fresh water to a maximum of 50 people, or approximately 568L per day at 10L per person. This region is expected to provide enough wind to power the turbine for the required time each day.

Correlation with Target Market

Each product will be able to provide 10L per person per day of fresh water to a maximum of 50 people, or approximately 568L per day. The water provided from the turbine product will improve the lives of many Haitians living in the region. In relation to population and demographic data, the average family in Haiti has four to five members (Haiti, 2006). This would allow the product to provide enough water for approximately ten families each day. Also by placing the turbine system closer to the towns and villages, it will allow for easier access to water without having to travel and/or walk long distances. With communities that are plagued by starvation and disease, having access to clean water without the need to travel would provide the local people with a means to preserve precious energy and time. Women and children are generally the ones tasked with gathering water, often having to travel miles to get it (The 3 to 5 Days Approach to Sustainable Solutions, 2015). Reducing the distance required to obtain water, opens up more time for the women to not only take care of their household duties, such as cooking, cleaning and caring for children, but also for helping with agricultural duties. Particularly in rural areas, women work alongside the men to harvest and care for crops, as well as taking the cultivated goods to market (Gender in Haiti, 2011).

Economic Implications

Stakeholders Identified

There are several stakeholders involved with Wind2Water. The most important being the local communities, Haitian government, and non-governmental organizations working within Haiti, such as the International Rotary Club. Each group has an important role in making this company successful. For the local communities and governments, not only will they benefit from the clean water, but operations will not be successful without their cooperation. The non-governmental organizations also have a lot at risk, including their assets, reputation, and other contributions dependent on the product's success.

Communication with Stakeholders

It is strongly encouraged that an open line of communication be kept with the stakeholders. If a problem or need were to arise, there should be no hesitation to contact Wind2Water. In addition, regular reports and letters will be sent to all stakeholders updating them on current progress, problems, and plans for the future.

Required Permits for Operation

Obtaining all of the required operating permits will take approximately three months. This includes activities such as registering with the Ministry of Commerce and Industry, obtaining a tax ID, and notifying the Haitian Labor Ministry and the Insurance and Retirement offices (Starting a Business in Haiti, 2016). By partnering with an already established non-governmental organization, much of this process should be able to be bypassed and the wait time drastically reduced. Building permits also can take approximately 45 days to obtain once requested from the Municipality and Ministry of Public Works. The first 30 days are used for filing paperwork and studying the feasibility of the project. 15 days are then allowed for the process of payment for the permit. Once the permit has been obtained, a series of inspections, mostly handled by the municipality, occur throughout the construction process. Required inspections include a site inspection by an engineer, an inspection to verify the set-out and foundation, an inspection for the quality of materials used, as well as a final inspection (Dealing with Construction Permits in Haiti, 2016).

Regional Opportunities and Partnerships

Several NGOs operate in Haiti, such as the American Red Cross, World Neighbors, and GlobalGiving (Water Sanitation and Hygiene, 2014). Partnerships will be established with these organizations to help alleviate the process of establishing the product in a foreign country. A valuable contact by the name of Gayle Knepper, the past district 5010 governor from our local Rotary Club, has been working with us to help establish a potential partnership in Haiti. She helped us make contact with Voltaire Emmanuel, the president of the Jacmel Rotary Club. Current efforts are focused on establishing a business relationship to aid in the process to secure the potential deployment site. Other possible NGOs that we could partner with are still being considered as well.

Deployment Timeline and Project Lifecycle

Deployment is expected to begin in early 2017. By September 30, 2016, the potential partnering NGOs will be determined and contracts set in place. Production of the turbines will begin in early October. Shipping to Haiti will begin in January 2017. The shipping process will take approximately one month: two weeks at sea, and one week each way to and from the ports. The process for obtaining the building permits will begin during this same time. Once the building permits are secured, by early March 2017, construction of the pond and concrete pad will begin. Assembly and operation of the turbine is expected to begin in April 2017.

The lifespan of the project is expected to be long term. The average lifespan of a wind turbine is 20 years (Wind Turbines, 2016). Therefore the unit as a whole should not need to be replaced often. Replacement parts can be sent as needed, due to damage, malfunction or normal wear and tear. A partnering NGO will be in regular contact with the local community and will be able to make arrangements for replacement parts as needed. On average, the filter will need to be completely replaced every seven to ten years. The filter can be replaced more often if needed, due to the fact that components can be sourced locally.

Installation and Maintenance

Installation will be provided by Wind2Water with the help of our partnering NGOs. The maintenance will be taken over by the local people the wind turbine serves. By establishing a social entrepreneurship program, the local people will be encouraged to be involved, providing a greater value to the local community. Major components will be designed to be “plug and play”, making the installation process simple and efficient. The education/literacy level in Haiti is the lowest in the Western Hemisphere. Therefore having a system that is not overly complicated is would be best for the process of educating the targeted users. Workshops and classes will also be established to teach the local people how to care for the turbines, troubleshooting, and who to contact for help if needed.

Reliability and Risk Management

Risk is not something that can be completely avoided. One of the biggest risks Wind2Water will face by placing the product in Haiti is that of theft and destruction. Organized crime is a very big problem in Haiti. We hope to be able to mitigate some of the problem by establishing our social entrepreneurship system. When the community is involved, they will hopefully take a sense of pride and ownership in the product and therefore take extra measures to protect it.

Appendix I – Pro Forma Financial Statements

A.

Statement of Financial Activities Estimated for the year ended Aug. 31, 2017 - Aug. 31, 2019				
		8/31/17	**8/31/18**	**8/31/19**
Revenue				
	Sales	13,590	33,975	81,540
Cost of Goods Sold				
	Raw Materials	3,220	7,648	17,388
	Shipping	5,000	11,875	27,000
	Installation	2,000	4,750	10,800
	Tools & Replacement Blades	1,000	2,375	5,400
Total Cost of Goods Sold		**(11,220)**	**(26,648)**	**(60,588)**
Gross Margin		**2,370**	**7,328**	**20,952**
Expenses				
	Administrative Expenses	1,500	2,500	4,000
	Salary & Wages	0	0	0
	Rent	0	0	0
	Equipment	2000	0	0
	Other Expenses	1200	1200	1200
Total Expenses		**(4,700)**	**(3,700)**	**(5,200)**
Net Financial Standing		**(2,330)**	**3,628**	**15,752**

B.

Statement of Cash Flows Estimated for year ended Aug. 31, 2017 - Aug. 31, 2019			
	8/31/17	**8/31/18**	**8/31/19**
Operations			
Revenue	13,590	33,975	81,540
Cash Paid to Suppliers	(6,220)	(14,773)	(33,588)
Administrative Expenses	(1,500)	(2,500)	(4,000)
Operating Expenses	(1,200)	(1,200)	(1,200)
Other Payments	(5,000)	(11,875)	(27,000)
Net Cash Flow from Operations	**(330)**	**3,628**	**15,752**
Investing Activities			
Purchase of Equipment & Tools	(2,000)	0	0
Net Cash Flow from Investing Activities	**(2,000)**	**0**	**0**
Financing Activities			
Net Cash Flow from Financial Activities	0	0	0
Ending Cash flow	**(2,330)**	**3,628**	**15,752**

C.

Statement of Financial Position Estimated for 8/31/2017 - 8/31/2019			
	8/31/17	**8/31/18**	**8/31/19**
Current Assets			
Cash	0	13,590	20,385
Accounts Receivable	13,590	20,385	61,155
Fixed Assets			
Property	0	0	0
Equipment	2,000	1,800	1,600
Depreciation	0	200	400
Total Assets	**15,590**	**35,975**	**83,540**
Current Liabilities			
Accounts Payable	13,220	26,647.50	60,588
Total Liabilities	**13,220**	**26,647.50**	**60,588**
Net Assets-Unrestricted	2,370	9,327.50	22,952
Net Assets-Restricted	0		
Total Net Assets	**2,370**	**9,327.50**	**22,952**
Total Liabilities & Net Assets	**15,590**	**35,975**	**83,540**

Appendix II - Calculations

Power: $$P = \frac{1}{2}\rho_A A\, V^3 C_p = \frac{1}{2}(1.125\frac{kg}{m^3})(0.292m^2)(18\frac{m}{s})^3(.23) = 220\, Watts \quad (1)$$

Torque: $$T = \frac{1}{2}\rho_A A\, V^2 R = \frac{1}{2}(1.125\frac{kg}{m^3})(0.292m^2)(18\frac{m}{s})^2(0.305m) = 16.2\ N * m \quad (2)$$

Minimum Shaft Diameter: $$d_{min} = (\frac{T}{\pi\, \tau})^{\frac{1}{3}} = (\frac{16.21}{\pi(415MPa)})^{\frac{1}{3}} = 2.32mm \quad (3)$$

$$(d_{min=}2.32\ mm) < (d_{actual} = 8\ mm)$$

Critical Shaft Speed: $$\omega_c = (\frac{\pi}{0.0425m})^2 \sqrt{\frac{(9.81\frac{m}{s^2})(190\ MPa)(2.011x10^{-10}m^4)}{(5.07x10^{-5}m^2)(7600\frac{kg}{m^3})}} = 54{,}120\frac{rad}{s} \quad (4)$$

$$(\omega_c = 54{,}120\frac{rad}{s}) \gg (\omega_{max} = 591\frac{rad}{s})$$

Lift Force: $$F_L = \frac{1}{2}\rho_A A V^2 C_L = \frac{1}{2}(1.125\frac{kg}{m^3})(570x10^{-6}m^2)(18\frac{m}{s})^2(1.2) = 0.125\ N \quad (5)$$

Drag Force: $$F_D = \frac{1}{2}\rho_A A V^2 = \frac{1}{2}(1.125\frac{kg}{m^3})(0.0684m^2)(18\frac{m}{s})^2(0.2) = 0.0208\ N \quad (6)$$

Centrifugal Force: $$F_{Cf} = mr\omega^2 = (0.0494\ kg)(0.0532\ m)(354\frac{rad}{s})^2 = 329\ N \quad (7)$$

Shear Stress: $$\tau = \frac{F_{Cf}}{A} = \frac{329\ N}{110x10^{-6}\ m^2} = 3.00\ MPa \quad (8)$$

Safety Factor: $$\eta = \frac{45.8\ MPa}{3.00\ MPa} = 15.3 \quad (9)$$

Force: $$F = \frac{1}{2}\rho_A A\, V^2 = \frac{1}{2}(1.125\frac{kg}{m^3})(0.292\ m^2)(18\frac{m}{s})^2 = 53.2\ N \quad (10)$$

Deflection: $$\delta = \frac{Fl^3}{3EI} = \frac{(53.2\ N)(3.048m)^3}{3(190\ MPa)(46.96 * 10^{-6}m^4)} = 5.63\ mm \quad (11)$$

Stress: $$\sigma = \frac{My}{I} = \frac{(53.2\ N)(3.048m)(0.0381m)}{(\frac{\pi}{4})((0.0762m)^4 - (0.0729m)^4)} = 23.0\ MPa \quad (12)$$

$$\eta = \frac{215\ MPa}{23.0\ MPa} = 9.35$$

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