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Technical Report

UNIVERSITY OF MARYLAND'S COLLEGIATE WIND COMPETITION TEAM

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Executive Summary

TERPine Industries aims to utilize renewable wind energy to transform the world's most important industry, agriculture, for some of the most underserved populations. TERPine Industries' goal is to develop a disruptive innovation in off-grid power production which revolutionizes the way the world farms. TERPine Industries is an ideal candidate for investment because of its end-user focused business, unique technical innovations, and demonstrated technological readiness. In this report, key information about the business, the product, and the path to deployment are presented.

The Business

The business model is designed to support a triple-bottom line: to be financially viable, provide a social benefit, and improve the environment. To achieve these goals, the business is designed around providing a sustainable asset to small business people as well being a replacement for conventional fossil fuel power sources. Irrigation and access to water are critical for farmers around the world. Often, farmers without reliable access to power are unable to pump water to properly irrigate their crops or they have to turn to expensive and pollutant producing power sources such as a diesel generator. These generators represent an off-grid power source which are easily replaced by a wind turbine.

TERPines Industries surveyed countries with large agricultural sectors with economic water scarcity and strong wind resources to deploy its product. The ideal initial target market, for reasons discussed in the business plan, is India, particularly in the high wind resource states with large agricultural sectors, notably Gujarat and Andhra Pradesh.

Figure 1: CAD rendering of TERPine Industries' flagship product.

The Product

The wind turbine developed is designed to be safe, reliable, and efficient which makes it ideal for being deployable in rural off-grid markets. The turbine is a 2.2 kW three-bladed horizontal-axis upwind turbine, with passive flow augmentation, yaw control, and a monopole structure shown in Figure 1. Beyond the current state of the art in wind turbine technology, additional technologies and analysis techniques have been and are being developed for this turbine.

TERPine Industries' turbine has been developed using advanced aerodynamics, computational fluid dynamics, and finite element methods, in addition to traditional engineering methods. The engineering analysis was applied to the implementation of a small scale, "competition" turbine to test the validity of the design. Through wind tunnel tests of the resulting turbine, the team demonstrated an exceptional amount of technological readiness for the engineering design.

The turbine features a performance enhancing shroud encompassing the perimeter of the rotor. Computational studies were developed to analyze shrouded turbines and this analysis has indicated that a shroud provides a marked increase in efficiency. Further, scaled model wind tunnel testing has supported the conclusions of these studies. This increase in efficiency allows for a smaller rotor of equivalent power output resulting in less material used and lower costs. Additionally, the shroud promotes safety by protecting the rotor and people around the turbine in the event of extreme conditions, thus increasing the longevity of the turbine.

The turbine also features a robust, easily deployable structural design. The turbine's structure can be put together with only two tools, allowing simple installation in rural areas by farmers without previous experience. The turbine is also designed to be easily raised and lowered in the event of required maintenance or typhoon-like conditions.

Additional research is being done to develop a passive blade pitching mechanism for the deployment turbine. This mechanism, described in more detail in the technical report, will improve cut-in speed without any active control, and has not been implemented on any existing turbines. Lower cut-in speed will enable deployment and power production in a wider range of environmental conditions.

The Path to Deployment

India is a rapidly industrializing country with well-developed transportation infrastructure and an increasingly skilled workforce. TERPine Industries' first steps are to incorporate within India and develop a headquarters within Gujarat to support local development and to keep transportation costs low. Additionally, being close to the target market makes it easier to work with stakeholders and plan deployment of individual turbines.

Every stage of marketing, from initial contact to seeing through the end of the turbines life, will be done by working closely with the end-users and organizations which work closely with these farmers. One such organization is One Prosper, which works to teach farmers about irrigation. TERPine Industries is looking to partner with that organization to find customers within its first year. Wind TERPines will work with customers to ensure that the turbine is deployed in a suitable location and meets all governmental regulations.

Predisposition for Achievement

This past year, TERPine Industries has developed a 45 cm turbine prototype for the Department of Energy's Collegiate Wind Competition which demonstrates the ability of its engineering team to create an energy efficient machine. The knowledge gained from this turbine has been extended to a design for the product, or the "deployment turbine." With the advances made in just a single year, TERPine Industries has proven to be an agile and innovative company which has the potential to make a meaningful impact. Investment in this company will help launch its manufacturing facilities and get the product in the hands of its beneficiaries. This report provides evidence of the viability of the business and product design, and demonstrates the potential this company has for success.

Business Plan

Business Overview

TERPine Industries' mission is to empower farmers in India by providing them with an effective, efficient and environmentally friendly source of power for irrigation for their farms. Some of India's staple crops, such as rice, sugarcane, and cotton are very dependent on the waters from the monsoons. It is estimated that as much as 79.5% of India's farmland relies on flooding during monsoon season.[1] The monsoons typically only last from June to September as shown in Figure 1.1. By providing an irrigation power source, the growing season can be extended and farmers can improve their crop yields and earn more money. In turn, the whole nation of India will benefit from increased food security.

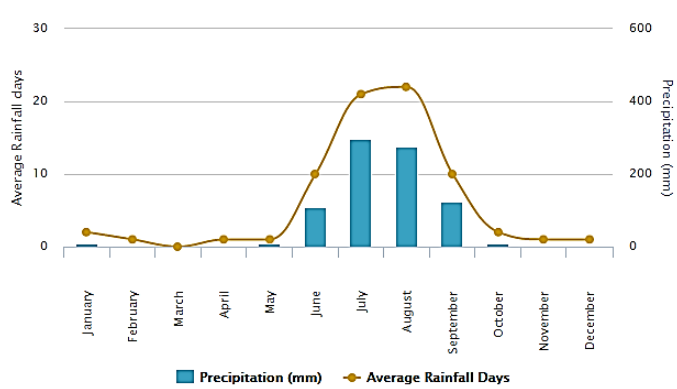

Figure 1.1: Average rainfall map for Gujarat.[2]

Many farmers in India have left their farms as "rain fed" farms, because of the heavy rainfall that traditionally accompanied the monsoon season. With the onset of global warming and climate change, the monsoon season in India has been drastically changed. As can be seen by the Figure 1.2, India is experiencing a large variability in monsoon rain, receiving nearly 25% less rain than usual in years such as 2009.[3] As climate change continues to unfortunately increase around the world, there will be more and more poor rain years that will have devastating effects on India's farming culture. However, these farms will not continue to flourish due to the erratic rainfall that global warming and climate change brings. TERPine Industries aims to help these farmers increase their crop yields now and in the future by providing them with a reliable source of irrigation.

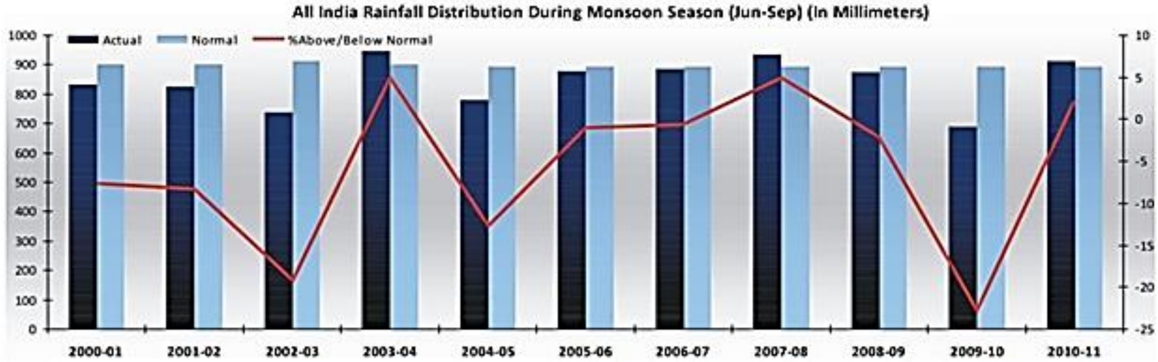

Figure 1.2: Monsoon season unpredictability.[3]

There are many countries which could benefit from a renewable energy irrigation power source, and TERPine Industries plans on penetrating these markets after having had a sizable impact on India's irrigation practices. However, the company firmly believes that India is the best place to start. Their rapidly growing population is highly dependent on its agricultural sector. Furthermore, unlike many Latin American and African countries, India does have one of the world's largest democracies. This in turn ensures that there is a more favorable business environment as opposed to say, in Nigeria, in terms of political and economic stability. Additionally, India has a strong wind resource in many of its regions.

The wind map in Figure 1.3 shows that there are higher wind resources around certain coastal regions, which include Andhra Pradesh, Gujarat, and lesser but still significant winds in Karnataka. Andhra Pradesh and Gujarat have wind power densities of 400 W/sq. m in some areas, while Karnataka has a wind power density between 200 and 300 W/sq. m in most regions[4]. TERPines' target areas are ideal for wind turbine usage for agricultural purposes, which makes the product being sold a perfect fit.

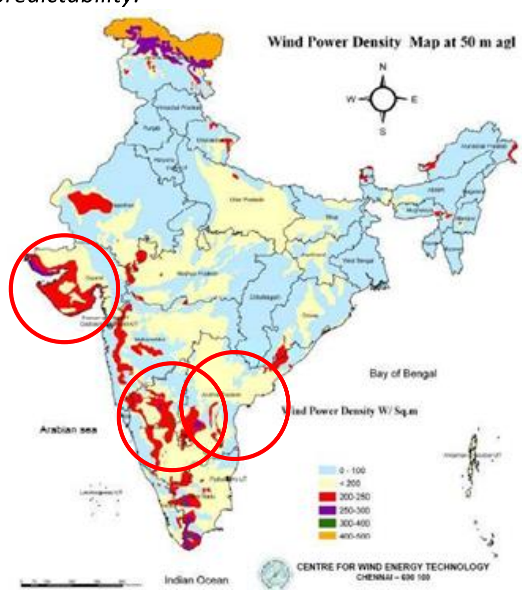

Figure 1.3: India wind resource map with Gujarat, Andhra Pradesh, and Karnataka circled.[4]

Market Opportunity

Target Market Size and Growth Opportunity

According to the All India Agricultural Census, there are total 398,980 acres of Indian farmland. In Gujarat and Andhra Pradesh there are 24,745 and 35,733 acres of farmland respectively.[5] In Gujarat, 59.97% of the farmland is completely unirrigated, and negligible percentages of the farmland use a diesel-powered irrigation system or have a well with no pump. In Andhra Pradesh, 54.41% of the farmland uses no irrigation, and negligible percentages of the farmland use diesel-powered irrigation or no pump, as seen with Gujarat. TERPine Industries plans to tap into these two markets in year one, and plans to expand into the Indian state of Karnataka by the beginning of year 4. In Karnataka there are approximately 30402 acres of farmland and 70.5% lack any irrigation and again a negligible number do use outdated diesel pumps or have wells with no pump systems. The company hopes to capture 25% of the market from all three regions including Karnataka by Year 5. This means that the turbine will be in use for 14,370 acres out of the 56,150 acres of farmland which could benefit from the product offering. This equates to selling approximately 2808 turbines by year 5.

Product

TERPine Industries' product is a wind turbine which produces electricity to allow farmers to power pumping and irrigation equipment for their farms. The wind turbine is designed with the end-user in mind. It is designed to be simple yet innovative. One of the driving factors is safety and reliability so any maintenance that has to be done can be completed relatively quickly, so as to not inconvenience the final consumer. Images and translated instructions will make it easy to understand for those who do not speak the same language as the manufacturers. The turbine is also multi-purpose because any electrical product could be powered by the turbine.

TERPine Industries' robust, deployable design offers it a competitive advantage over competitors, as it will not only be quick to assemble, but will also be easier to understand by potential customers. Assembling the turbine on-site will allow for customers to gain knowledge of how the turbine works and the maintenance required. Maintenance will be low because the turbine is built from durable materials, and because of the modular design, parts can also be easily replaced. The high efficiency of the rotor also means that maintenance costs will be lower because replacement blades are small. The unique shrouded design will attract customers with its safety and innovative design, meaning customers will be more likely to choose TERPine Industries' turbine over other wind turbine products.

Required Power

TERPine Industries is focusing its efforts on farmers who produce sugarcane, cotton, soybeans, rice, and lastly, maize, in this order. The reason for this is that sugarcane is the highest grossing crop traditionally grown in India, while rice, though more water intensive, is one of the lowest grossing crops in the country, as seen in Figure 1.4. Focusing on sugarcane farmers first will allow the turbine to be priced such that it can generate enough profit to expand into markets that might not be as profitable. According to the World Wildlife Fund's Global website page, 35 million farmers grow sugarcane, and another 50 million farmers depend on the employment generated by the production of sugar in the country. In the last ten years, sugarcane production in India has fluctuated between 233 million and 355 million tons, with the average-sized farm producing 40 tons annually.[7] Such low yields per farm paired with the variability of rainfall will make it very hard for farmers to meet the growing demand,

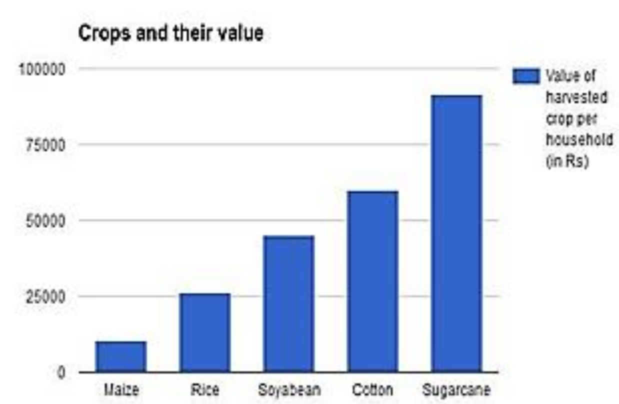

Figure 1.4: Value of crops in India.[6]

both domestically and globally, in the market for sugar. Sugarcane farmers will have to turn to new methods of farming.

In order to appropriately size the turbine, the power required by farmers to irrigate their land needed to be calculated. According to the FAO's (Food and Agriculture of the United Nations) Water Development and Management Unit, it takes 25,000 cubic meters of water per hectare to grow the average sugarcane yield in India over a year.[8] The water table is assumed to be 10m, and to pump the 25,000 cubic meters of water from the ground, the required power is 680.6 kWh. The turbine would be required to provide most of its power during the approximately 5 months of the growing season. This translates to an average of 78 watts an hour per acre, meaning that a 5 acre farm (an average size for medium farms) would use about 500 watts an hour. The turbine has been designed for this average power. Farms whose water table is lower or require more water may need an additional turbine, and farms which are smaller or require less water and power are encouraged to form collectives to better utilize the produced power.

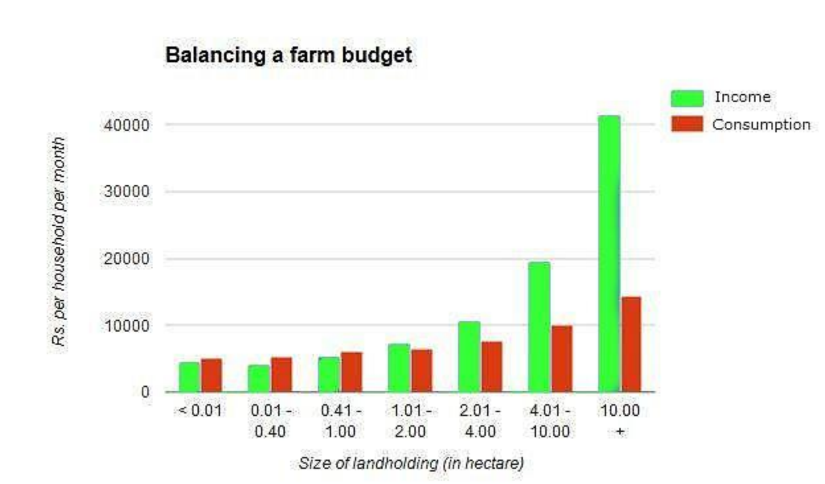

Figure 1.5: Average farmer income by size of land.[6]

Price

The breakdown of what a farmer makes in India depends on the size of his or her farm. In Figure 1.5, the blue bar represents income for farmers while the red shows their consumption. Farmers of smaller and average sized farms spend more than they are earning. For this reason, TERPine Industries is targeting farmers in the 5 acre (approximately 2 hectares) farm range. The farmers in this range are generating more income than they are consuming at this time and have disposable income. Furthermore, TERPINE Industries will also plan to try and sell to farmers collectives. The company believes that their turbine can sufficiently provide irrigation power for a 5 acre farm. Therefore, 5 neighboring farms of one acre each could come together and pool their resources in order to purchase the turbine. The company will be pricing the product offering at $2200 USD. Ajay Kothari is one of the directors of WHEELS (Water, Health, Energy, Education, Lifestyle and Sustainability) Global Foundation, an organization focused on creating technological solutions for rural communities and the son of a Gujarati farmer. He was interviewed by TERPine Industries and believes that partnering organizations such as USAID, World Bank and WHEELS will sponsor approximately half the price for these farmers.[9] As a result, the farmers will be paying only approximately $1100 out of pocket for TERPine Industries' product.

Place

In addition to reasons detailed in the Business Overview, India's public and private entities have a commitment to renewable energy. One of the country's biggest conglomerates, Ratan Tata, is a part of the Gates Breakthrough Energy Coalition. Additionally, the Indian National Institute of Wind Energy (NIWE) provides a testing facility and network of wind turbine manufactures. This existing infrastructure will help reduce the risk associated with operating in India. Furthermore, Prime

Minister Narendra Modi has an aggressive renewable energy plan to make sure that 100GW in India are produced through renewable energy sources.[10] Though his plan is focused mostly on solar energy as of now, TERPines is certain that India will embrace wind energy in addition to solar. Finally, there are tax breaks that India has in place for renewable energy companies that operate in India. These reasons make India an ideal market.

Promotion

To better reach the target market, the business will focus on grassroots marketing, and on working with farmers to develop solutions to their agricultural needs. This strategy has been determined to be the best approach to marketing, since most customers are typically going to be lower-income farmers, who may not have regular access to electricity and technology, and therefore have limited access to sources of traditional promotion media used in the US. Marketing research will be done to see if there are enough people with battery-operated radios to advertise in that manner. Additionally, since the turbine represents a significant investment on the part of the farmers, the business will work on an individual basis to create financing plans and warranties. For such technology to be bought by farmers, they would first have to be comfortable with the technology. For this reason, TERPine Industries will also focus on educating farmers on how wind turbines work.

As an important part of the business is in the social benefit, TERPine Industries would like to partner with non-profit and government organizations which have expressed support for and can help TERPine Industries, such as the Sustainable Sugarcane Initiative (SSI), which works with sugarcane farmers in India to introduce new farming technology and methods. Another organization that TERPine Industries would like to partner with would be OneProsper International, which partners with some innovative grassroots in India to promote, create, and scale drip irrigation programs.[11] OneProsper has a system where donors can select a small farmer to empower, fund a drip irrigation kit, and then see their impact. OneProsper's organization aligns exactly with TERPine Industries' in-country operations, making the company a good fit to work with OneProsper International.

A community ambassador program will also be important in terms of marketing in true grassroots fashion because it creates a point of contact for farmers and for TERPine Industries. The ambassadors will be the local contacts that live within the communities TERPines works with, and will help to educate the people in those areas on the products, sell them, and help people to use them. The ambassadors would be more trustworthy than a foreign company that locals are unfamiliar with, and because the contacts would be people who live in the areas where TERPine Industries wishes to sell its products, TERPine Industries would be able to grasp a better understand the people of the regions.

Revenue Model

TERPine Industries will sell direct to consumer in order to generate revenue. However, since the business plans to sell to farmers who may lack available capital, one risk may be that it is difficult for the turbine to be financed by the farmers. As a result, the team hopes to subsidize the product for their end user by forging public and private partnerships. The team hopes to get their product subsidized by governmental agencies since it will empower their farmers and aims to improve food access in India. It is worth noting that there are tax incentives for wind energy equipment companies in India, allowing companies to lower their prices, so it is clear the Indian government wants to help make renewable energy more attainable for consumers. Furthermore, TERPine Industries aims to forge a partnership with Ratan Tata, a very large Indian corporation and major investor in Bill Gates' clean energy fund, the Breakthrough Energy Coalition. Since that company had demonstrated a commitment to helping out and furthering clean energy in the Indian community, TERPine Industries believes that they will likely support their mission. Furthermore, TERPine Industries also aims to partner with organizations such as USAID which was a major partner in helping a similar business that use wind turbines to power water pumping in Afghanistan,[12] as well as the World Bank and WHEELS foundation. Through these partnerships, TERPine Industries aims to get the price of their offering down to a figure that is manageable enough for their end consumer to pay.

The proposed venture will initially be capitalized by investments, sponsorships from large companies, some of which have been previously mentioned, and through partnerships with nonprofits that have access to large amounts of funds, either from grants or their own revenue stream. TERPine Industries will also write grant proposals of its own to both U.S. and Indian governments and organizations.

Competition

In India, there are already a couple of renewable energy companies that aim to solve the irrigation problems in India through technology. An example of one of these companies is Spitzen Energy, a company that provides both wind and solar solutions. They provide wind and solar energy for a variety of situations, including water pumping for small farms. However, Spitzen's turbine only produces 1.4 kW at its peak,[13] whereas TERPine Industries' turbine on the other hand is projected to produce nearly 2.2 kW. In addition, TERPine Industry's innovations such as the shroud and consumer focused business model makes for a better value proposition.

Another direct competitor would be Xzeres 3.7 Skystream turbine.[14] The peak power of that turbine is much closer to TERPine Industry's at 2.6 kW, but they focus on providing power to residential consumers. However, their turbines cost between $8,000 and $11,500. Since the target market has such small disposable income, they would not be able to afford this product unless it was very heavily subsidized.

Finally, TERPine Industries also views solar irrigation companies as its main substitute and a fierce competitor. This year, the Indian government actually plans to subsidize nearly 26 million solar powered pumps to replace the inefficient diesel ones as of now.[15] However, wind turbines have a number of advantages over solar panels. Wind TERPine's turbine will take up far less space as opposed to solar paneling. Furthermore, with the proper maintenance, a wind turbine can successfully produce power for a longer time than solar panels. Finally, the wind turbine in particular is likely cheaper than solar paneling. A solar panel that produces a max of 2 kW costs approximately $4020 in India,[16] more than twice as much as TERPine Industries' product offering for a slightly lesser output.

Competitive Advantage/ Barriers to Entry

The establishment of manufacturing facilities is a large capital expense, which is a significant risk that deters a lot of entrants. Additionally, there are also restrictive trade policies that TERPine Industries might face when trying to do business in India. Paying taxes and doing business across borders have also been noted as factors that make it relatively difficult to do business in India. To eliminate that risk, the company plans to incorporate in India and create jobs within the country, and set up warehouses and factories near its target market. This strategy will ensure that the Indian government is more welcoming to the company. By overcoming these difficulties and eliminating these risks, TERPines Industries will gain a competitive advantage in that these barriers exist for other potential entrants.

One of the company's main competitive advantages, other than its highly efficient and safe turbine design, is that the company has social impact at its core for the people of India. Government and investors may want to support TERPine Industries (whether through sales or partnerships) because of the good the company hopes to bring to many Indian communities that would otherwise go unserved.

Management Team

The members of the TERPine Industries Board of Advisors will be Dr. James D. Baeder, Dr. Nagaraj, Mr. Jay Smith, and Dr. Ajay Kothari. These advisors have been chosen because they each hold extensive knowledge in areas ranging from business operations, to turbine engineering, to renewable energy in India. Dr. Baeder and Dr. Nagaraj are aerospace engineering professors at the University of Maryland College Park. Mr. Jay Smith is the Director of the Entrepreneurship and Innovation Honors Program at UMD. Ajay Kothari is director of WHEELS and President and founder of Astrox, an Aerospace R&D company. He holds a PhD in Aerospace Engineering from the University of Maryland College Park and is willing to help current students. His strong background in aerospace engineering ensures that he can help decide on the best designs for the wind turbine. Additionally, he has grown up in Gujarat and has been back himself in order to help low income people with healthcare and water resources.

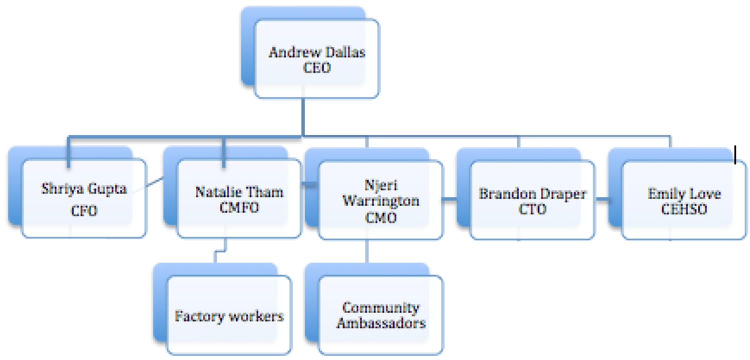

Figure 1.6: TERPines Industries organization chart.

Due to the strength of the current research team's members, TERPine Industries' C-suite will be drawn from current members. The positions and who will fill them are as follows: Chief Executive Officer-Andrew Dallas, Chief Financial Officer-Shriya Gupta, Chief Marketing Officer-Njeri Warrington, Chief Environmental Health and Safety Officer-Emily Love, Chief Manufacturing Officer-Natalie Tham, and Chief Technology Officer-Brandon Draper.

External positions will include the hiring of a law firm with an emphasis on tax consulting and intellectual property protection. The legal aspects of the business will be handled externally because none of the members of the research team/Board of Advisors have legal experience, specifically not as it pertains to India or the wind turbine manufacturing industry. The legal team to which TERPines outsource will have the knowledge and resources to mitigate any legal risks that the company may encounter when doing business in India.

Development and Operations

The development and manufacturing of the product will rely on local producers for the majority of raw materials and manufactured assemblies, and imported products for everything not readily available in India. Village associations and governments, regional competition for distributed energy, and regional government will all be important resources in the development of a concrete distribution strategy for the product. The company will be based in the Gujarat region, and will focus on developing relationships with clients, suppliers, and partners in the region first. Eventual expansion to the rest of India is expected with company growth.

Manufacturing

Manufacturing is expected to take place in-country. This provides a large risk reduction for TERPines in terms of supply chain processes, legal regulations, and governmental issues. Manufacturing in-country would reduce the risk of having product parts damaged in ocean transport, and removes the risks of having to deal with customs and paperwork. The transit time of the parts is lowered significantly by being produced in factories close to the target markets, which lessens the likelihood of parts being damaged in the trucks whilst on their way to being assembled on a farm. Producing in India will also help TERPines in the legal realm as the company will only have to abide by India's laws instead of the laws of two different countries. Risk is also managed by becoming better known with the local government, which could lead to connections and business protection. A list of suppliers will be produced by the engineering team and the business team to get an idea of where to begin supplying. As the intention is to supply primarily from local vendors, some changes may be necessary over time, as new suppliers are discovered and as relationships develop. Ultimately, one of the major challenges with manufacturing will be ensuring an adequate and reliable supply of important parts from regional sources. Sourcing within close proximity also reduces supply chain risks of not being able to get materials transported in time, and increases flexibility in the supply chain. Some external sourcing will likely be necessary, and a list of potential external supplies will be assembled.

The use of common manufacturing materials in the design will go far in preventing lack of specific materials from preventing the construction of the turbines. Generally speaking, the construction materials are readily available in the Indian market. The support tower will be constructed from galvanized steel. Sheet aluminum will be used to create the outer casing for the Nacelle. Various screws, bolts, and fixtures will be made of steel. The turbine blades will be injection molded and that manufacturing process will be outsourced. The electronics and controls materials -- permanent magnet generator, wires, control electronics, and sensors -- will be sourced from outside the region if they are not available within India. Outsourcing some manufacturing processes helps reduce capital expense and production quality risks.

Indiamart is an Indian wholesale distributor of a various construction and manufacturing components, similar to Alibaba in China.[17] Prices and availability vary depending on the seller, and specific information on these details will be determined based as needed. A variety of sellers based in the region are included in the Indiamart database which can be used by TERPine Industries, including:

- Pollux Global Steel, Shreeji Engineering Works, and Chitra Engineering Solutions for galvanized steel
- Shri Navkar Metals, Ajanta Metals, and Bhavesh Metal & Engineering for aluminum
- Krishna Trading Co., Harshdeep Industries, and Madhu Glasstex Private Lmtd. for fiberglass.

Ultimately, the quality, availability, price and other details for all of these suppliers will need to be determined, as they will change depending on scale of purchase, timing, regional demand, and a variety of factors. TERPine Industries hopes to find supply businesses with a broad range of products and reliable history to form partnerships with as the company grows in size.

As stated before, the manufacturing of the wind turbine will also take place in the Gujarat region. Once all the parts and materials are acquired, the majority of the manufacturing will be in constructing the nacelle and shroud, as well as assembling internal components and preparing the components for shipping. Aluminum will be used to form the nacelle and shroud supports. Additionally, fiberglass will be shaped to the shroud using a vacuum former. Once the nacelle and the shroud are assembled, the electronics and generator will be installed in the nacelle before it is sealed. The nacelle, blades, shroud, and support tower will be shipped using a flat-bed truck to clients in the region. The shipper will assist in the assembly as part of the delivery service including raising the tower, and wiring the turbine.

Product Distribution

TERPine Industries is looking into partnering with companies such as Amazon, which has a rapidly growing shipping service in India, or Indian company Ratan Tata, which has a very large shipping network in India. Raw materials will be shipped to the TERPine Industries company warehouse, where the turbine & shroud will be assembled. Delivery to local clients will be carried out in a flatbed truck owned by the company and will assist in the assembly of the support tower and guy lines, and in the installation of the turbine. More deployment details are included in the Deployment Section.

Research and Development

Research is at the core of TERPine Industries. The core product offering has been developed as a result of significant research on the part of the engineering team. Success for the business relies on keeping the product offering on the cutting edge of wind technology. As such, the manufacturing facilities developed for deploying the product, will also serve as a lab for research under the guidance of the Chief Technology Officer. Research will be focused on the most cost effective innovations in order to keep research costs low. Additionally, TERPine Industries will partner with the University of Maryland, which has already expressed support for renewable energy through a Sustainability Fund Grant given to the team.

While significant development has been done optimizing the structural, mechanical, and aerodynamic design of the turbine, one of the biggest areas needed for research, as indicated by the generator testing done on the prototype turbine is a generator that matches the characteristics of the rotor. While the initial product offering will incorporate a purchased generator, research concentrated on developing a better generator to both improve system efficiency and decrease a major cost of the turbine. Further research will also be done on a passively pitching hub which will enable a lower cut-in speed for the turbine, and make the turbine more suitable for low wind environments.

Additionally, in order to diversify the company's product portfolio, development will also be done on modifying the current product to better adapt it to the needs of other markets and applications. Simple configuration changes such as alternate structures or control algorithms could make the turbine more suitable for higher wind environments. The deployable design makes the turbine suitable for application in other markets as well, such as for disaster relief efforts. Additional electric equipment could make the turbine also be easily modified for charging battery banks or even powering home appliances.

Developing larger or smaller models would take more resources, but could enhance the ability of the company to meet the needs of a more diverse consumer base. As the company generates more revenue, it can expand its manufacturing capabilities to larger turbines which typically have higher profit margins. It can also expand to smaller sized, high volume, and lower profit margin turbines to meet the needs of the large number of extremely small farms.

Financials

The expected pro forma for the businesses formational years can be found in Appendix I. This section will detail some of the assumptions that were made for those documents projections.

Balance Sheet

TERPine Industry's main assets were manufacturing machinery and flatbed delivery trucks. The majority of assets and capital expenditures that that TERPine Industries has comes in the first year on their balance sheet, as the company believes that these assets will be somewhat under-utilized when purchased and will approach maximum utilization by the end of the initial five year period. According to a website found about depreciating assets in India, assets such as machinery were generally depreciated at approximately 15% each year for 6.67 years.[18] Another main asset that TERPine Industry has is its accounts receivable. Since the company is selling to farmers in India who do not have a lot of money, the company is letting them buy the product on some credit. According to research mentioned previously, partners such as USAID, World Bank, WHEELS, and other various NGOs are likely to pay 50% of the up-front cost for the turbine while the farmer is responsible for the other 50%. In order to install the turbine, the company is only asking for 20% prior to installation. The rest of the turbine will be paid off in the next two years with 20% being paid off one year after the turbine's installation and 5% being paid off two years after the turbine's installation. As a result, there are a high amount of accounts receivable that TERPine Industries has on its books each year.

The primary liability that TERPine Industries has on its balance sheets is debt. Negative numbers exist on the income statement each year and debt is necessary to make sure that TERPine Industries' suppliers for their materials are paid for on time. As a result, they take out $300,000 of debt in the first year and $100,000 more in the next year. The debt is paid off in 2020 and 2021 with $100,000 being paid out in 2020 and the remaining $300,000 being paid off in 2021. Unfortunately due to this great amount of debt in the first two years, there is negative owner's equity on the balance sheet in the first two years. However, this is not a problem as the executives of the company are getting salaries of $40,000 in the first two years in order to cover their needs.

Income Statement

For the Income Statement, TERPine Industries made some additional guiding assumptions in order to project their revenues, costs and profits for the next five years. In the target analysis it was found that 2,800 turbines would be required to irrigate 25% of the farmland in Andhra Pradesh, Gujarat, and Karnataka. It is anticipated that approximately 100 turbines would be sold in the first year. In the second year, demand doubles as the business spreads and the name becomes known around Gujarat and Andhra Pradesh. Then in the third year, demand increases by 70%. In the fourth year, TERPine Industries plans on expanding to Karnataka and expanding their business once again. Therefore, demand again nearly doubles this year. In the fifth year and the final year that the company made projections for, the demand for the product once again increases by a more modest 70%. Under these growth rates and assumptions, the total number of turbines sold at the end of five years comes to 2798, in line with the estimated 2800 turbines that TERPine Industries plans to sell through its target market analysis. TERPine Industries then multiplied out their expected demand for each respective year by 2200, since the product is expected to be priced at approximately $2200, to forecast revenue for each year.

TERPine Industries has forecasted out their cost of goods sold based on the materials, labor, and delivery that the turbine would require. With the elements detailed in the Income Statement added up, the turbine costs approximately $1184.70 in order to manufacture and deliver. Delivery costs were made upon the assumption that the delivery distance on average would be approximately 15o miles, since the warehouses and factories are located in rural areas in each respective state. On average, a flatbed truck gets nearly 8 miles per gallon. This means that the truck would take approximately 18.75 gallons of gas to get to their destination. Currently, diesel in India is approximately at around $2.25 a gallon, however gas prices are fairly volatile and change rapidly. Since gas prices globally are so low right now, the company decided to forecast the delivery price assuming that the average cost for diesel would be around $2.67 as an average for the coming years. This as a result put the delivery cost at approximately $50 for each turbine. However, someone would also have to be paid in order to deliver that turbine. Driving 150 miles on average will take approximately 3 hours in rural India. Assuming the driver is paid a fair sum of approximately $10 an hour, this would amount to delivery costs of nearly $80 per turbine. In order to find gross margin then, this price was multiplied out by the forecasted demand for a year and then subtracted by the revenue estimates for that respective year.

The three major fixed costs that TERPine Industries plans to incur is the rent on their manufacturing floor, executive salaries, and marketing. Electricity cost is expected to be minimal because TERPine Industries actually plans to offset their power consumption from their factories and warehouses with their very own turbines. Furthermore, marketing costs associated with the company are kept at a minimum since OneProsper and volunteers are being used in order to conduct marketing for the product. In estimating how much the manufacturing floor rent would cost, renting space in a rural part of India for manufacturing would cost about $600 a month for a 4000 square foot facility.[19] In the first three years, the company plans to have a primary manufacturing site in Gujarat and a supplemental warehouse in Andhra Pradesh measuring a total of 8,000 square feet. Using the price per square foot estimates, TERPine Industries will pay approximately $19,200 in manufacturing floor costs per year. However, in 2020 TERPine

Industries plans on expanding to Karnataka and establishing another 8,000 square foot factory and warehouse in that area. As a result, manufacturing floor costs double in 2020 and 2021. Executive salaries are expected to be $40,000 for each executive from 2017-2019 and increase to $60,000 in 2020-2021 as the business expands. Since the company plans on having five executives, this amounts to $250,000 in 2017-2019 and $350,000 in 2020-2021.

Cash Flow

In TERPine Industry's payment plans, their partners pay for approximately half of the turbine's cost up front, and the farmer pays 20% of the cost of the turbine up front. In the calendar year following installation, the farmer pays the other 30% of the cost of the turbine. This means that in the nascent years of the business, TERPine Industry's cash flow is fairly unimpressive and even negative in year 2. However, it grows rapidly as demand grows and farmers pay off the turbine in subsequent years.

According to the cash flows that TERPine Industries has for the first five years *alone*, the discounted cash flow, assuming a cost of capital of 5%, leads to an impressive valuation of nearly $400,000 for such a young company.

Engineering Design

Design Overview

Turbine Views and Specifications

Figure 2.1: Competition turbine CAD (left) and implementation (middle) and deployment turbine CAD (right).

	Competition	Deployment
Configuration	Diffuser Augmented Wind Turbine (DAWT)	Diffuser Augmented Wind Turbine (DAWT)
Rotor Specifications		
Blade Diameter	0.42 m	3 m
Swept Area	0.1385 m^2	7.069 m^2
Rated RPM	2400	336
Number of Blades	3	3
Tower Specifications		
Tower System	Aluminum Monopole	Steel Monopole
Hub Height	60 cm	18 m
Number of Divisions	1	6
Mechanical Specifications		
Braking System	Mechanical Friction Element Disc Brake	Back-EMF Brake

Table 2.2: Turbine Specifications

Turbine Configuration Selection

The TERPine Industries engineering team began the wind turbine design process by determining the design objectives for the turbine. Three main focuses were identified: 1) Wind Tunnel Test Performance; 2) Marketability; and 3) Ease of Manufacture.

The team then selected 5 potential turbine configurations: a standard horizontal axis wind turbine (HAWT), a diffuser augmented wind turbine (DAWT), a Darrieus wind turbine, a drag-powered wind turbine, and a vertical axis cycloturbine. Using the HAWT as a baseline, each configuration was evaluated against 21 criteria using a Pugh matrix. The 21 criteria included performance criteria (e.g. power curve and cut-in speed) and other aspects (e.g. ease of manufacturing and safety). The team assigned weights on a scale of 0 to 10 for each criterion for both the competition turbine and the deployment turbine. Each configuration was then subjectively assigned a score between -2 to 2, with negative scores indicating the configuration is worse than the HAWT baseline and positive scores indicating the configuration is better than the baseline. Each score was multiplied by the weight of the category to determine the configuration's final score in each category. The most important criteria were those of safety and reliability, and efficient capture of wind, due to the distribution of the points. Additional categories such as life cycle environmental sustainability and appearance were included to consider the needs of a deployment turbine. The DAWT best satisfied the most important criteria, and its score from the Pugh matrix was highest. Ultimately, the DAWT still proved to be the best option to score the most points in the turbine testing at the competition as well as meet market needs. The spider chart shown in Figure 2.3 provides an overview of the scores and how each configuration was scored against the various criteria.

The wind turbine design was divided into the following subsections: aerodynamics (turbine blades, hub, and shroud), structures (tower and base), mechanical components (nacelle, generator, gears, braking system, and RPM sensing system), and electronics (microcontroller, power conversion electronics, and miscellaneous electronics). The first section will detail the design of the competition turbine, and then the transition to the deployment turbine will be discussed.

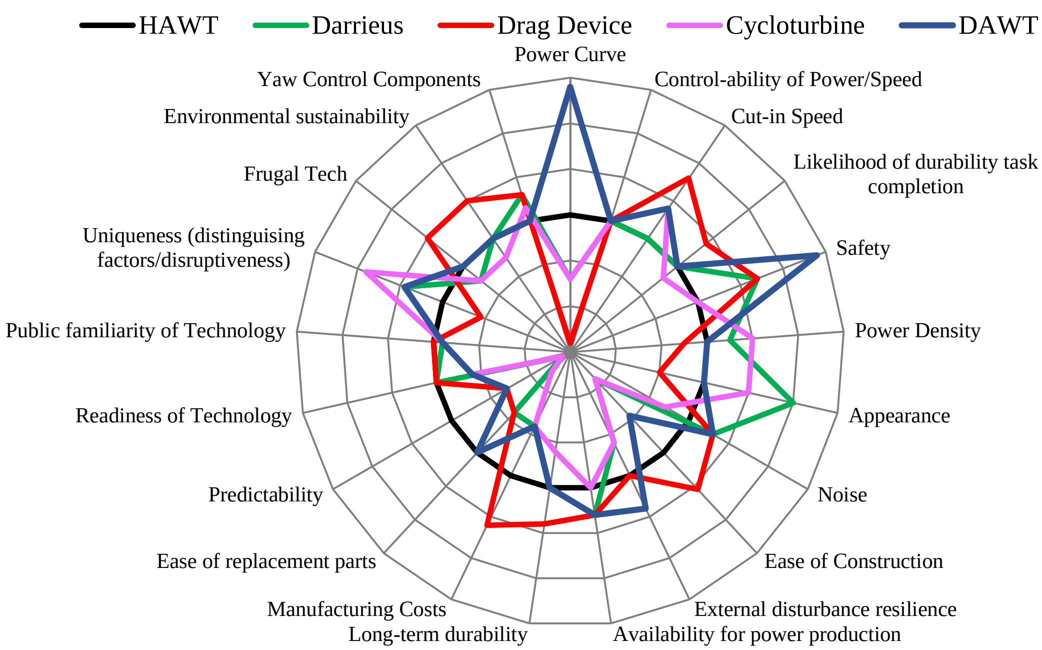

Figure 2.3: Spider plot of configuration analysis scores.

Aerodynamics

Blade Design

The turbine blades were designed to optimize power production and ensure structural strength. Three major design parameters were identified: blade diameter, blade airfoil, and blade tip speed ratio, which is the ratio of the blade tip's tangential speed to the incoming wind speed. The blade's tip diameter was set at 42 cm, which was the maximum possible size when taking the competition restrictions and the shroud into account.

There were three main objectives for the selection of the blade airfoil. The first was that the selected airfoil has a high lift to drag ratio, to maximize power generation. The second was that the airfoil exhibits gentle stalling behavior at high angles of attack. The third was that the airfoil be thick enough to provide structural stability to the blade.

Using the first two objectives, the SG6043 airfoil was selected due to its high maximum lift-to-drag value, superior lift performance, and gentle stalling at high angles of attack. In addition, as long-term durability is an important aspect of the design, a thicker airfoil, the SG6041, was used for the root of the blade to the 30% radial station. This airfoil is designed specifically to be used at the root of turbine blades. The SG6043 airfoil was used from the 40% radial station to the tip of the blade. The profiles for both airfoils are shown in Figure 2.4.

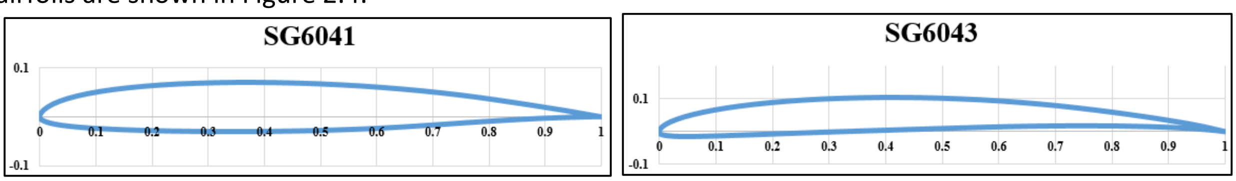

Figure 2.4: Airfoils selected for rotor.

The third design parameter, the tip speed ratio, was determined once the blade airfoils were selected. The SG6043 airfoil, which comprises a majority of the blade, has a maximum Cl/Cd ratio of about 39.7 at the operating Reynold's Number according to XFOIL data. Using this value, a design tip speed ratio of 4.61 was calculated.[20] The team decided to slightly lower the tip speed ratio to 4.5 to increase the blade torque to achieve a lower cut-in speed. This results in a maximum RPM of 2400 at a wind speed of 11 m/s. With these design parameters, the blade was then created using blade element momentum theory to optimize the twist and chord distribution for maximum power output. Based on this tip speed ratio and blade element momentum theory, the final twist and chord distributions were determined and are shown in Table 2.5. The final design is shown in Figure 2.6.

r/R	r (m)	Chord (m)	Pitch (deg.)	Airfoil
0.2	0.038	0.058	26.259	SG6041
0.4	0.076	0.043	10.620	SG6043
0.6	0.114	0.032	4.799	SG6043
0.8	0.153	0.025	1.599	SG6043
1	0.191	0.013	-2.030	SG6043

Table 2.5: Final blade parameters.

Figure 2.6: CAD of final blade design

Using blade element momentum theory, a C_P (coefficient of power) versus tip speed ratio graph was generated and is shown in Figure 2.7.a. The C_P is defined as the ratio of electrical power produced divided by the total amount of wind energy being captured by the turbine. The CP versus tip speed ratio graph gives a general idea for the efficiency of the turbine and the power it can generate (this graph was validated against experimental data obtained during wind tunnel testing). Using this data, the turbine's coefficient of power was calculated to be 0.38. Additionally, the generator efficiency was assumed to be 0.5 and the shroud augmentation factor was computed as 1.25 (these parameters are discussed later). In addition, the cut-in speed was estimated to be 3.5 m/s. Using the ideal efficiency and cut-in speed, the expected power output is shown in Figure 2.7.b.

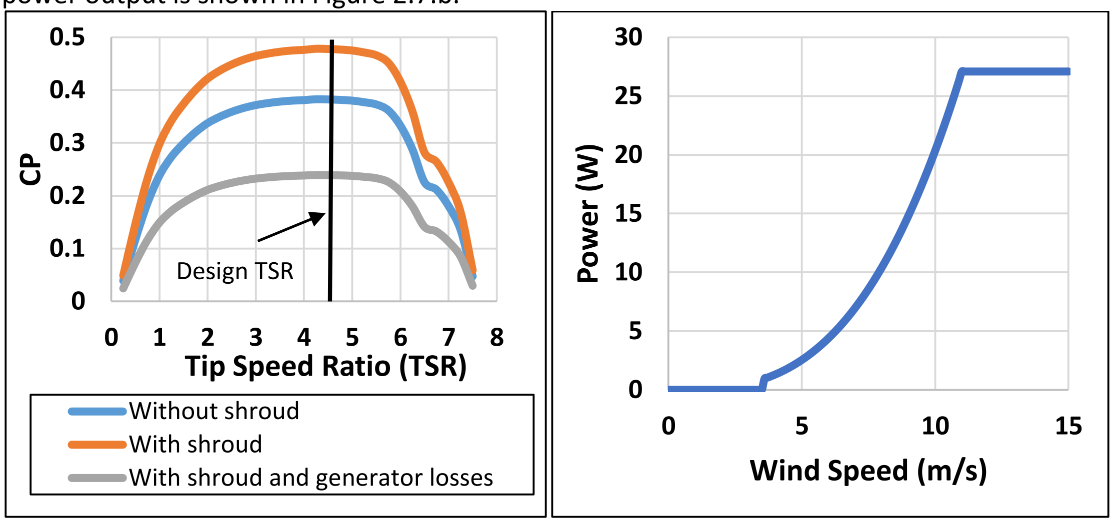

Figure 2.7: a. Coefficient of Power vs Tip Speed Ratio (left) and b. Power vs Wind Speed (right).

The maximum possible thrust generated by the rotor was estimated by the following equation:

$$T = \frac{1}{2}\, C_T \rho U^2 \pi R^2$$

Using a value of 8/9 for the coefficient of thrust C_T (which corresponds to optimum power production), 1.225 kg/m^3 for the air density ρ, a maximum wind speed U of 18 m/s, and a blade radius R of 0.21 m, the thrust was estimated to be 24.4 N. This force was used to calculate the stress on the turbine tower (see "Structures" below).

Centrifugal force was calculated to determine the tensile stress exerted on the blades. The stress was calculated to be 1.44 MPa at a rotational speed of 2400 RPM. The maximum stress exerted on the 3D printed material used for the blades was 7.78 MPa. This analysis verifies that the blades have a safety factor of at least 5.4 when stressed in tension during normal turbine operation.

Hub Design

The main objectives for the hub design were to develop a way to hold the blades securely and minimize the drag force on the turbine. The hub was printed in two separate pieces, the base and the nose cone, shown in Figure 2.8. They were printed separately because the nose needed to be printed hollow to reduce the moment of inertia about the drive shaft, while the base was printed solid to provide additional strength. The two pieces press fit together after printing and are not removable. On the underside of the base, there is space for a shaft collar to press fit into the base which secures the assembly to the hub. The blades are secured to the base by two bolts that pass through matching holes on the blades and are tightened with nuts.

Another hub was also printed that has the blade attachment points rotated so that the blades are pitched 10 degrees into the wind. This was fabricated to test the impact of blade pitch on cut-in speed. Work was done to determine if it would be possible to implement a system that used springs to change the pitch of the hub. The system was designed but determined impractical to manufacture due to the extremely small scale of the competition turbine. However, the system should be able to be used on the deployment turbine, so testing will carried out with this hub to determine the impact of adjusting the pitch of the blade.

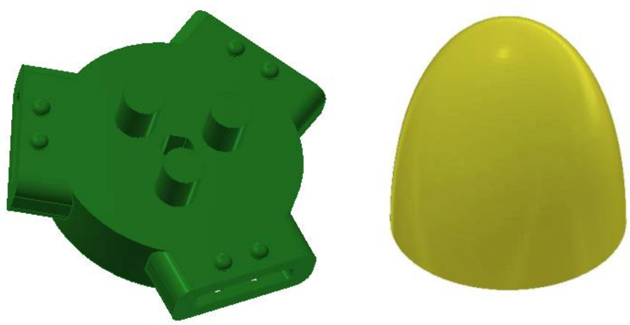

Figure 2.8: The hub base (left) and the nose cone (right).

Shroud

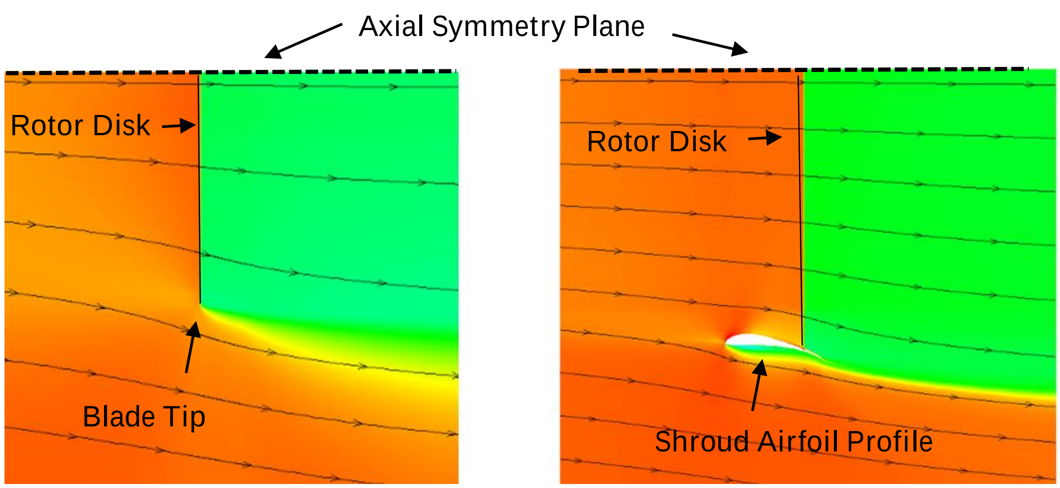

Figure 2.9: Computational fluid dynamics solutions of the flow as it passes through an unshrouded and shrouded rotor actuator disk approximation.

The primary purpose of a shroud is to improve the aerodynamic energy capture of a wind turbine. The shroud acts through two phenomenon, the increase of mass flow through the turbine and the elimination of tip vortices. The shroud can also serve as a protective covering providing a higher level of safety, both for the rotor and for people near the turbine. This safety improvement is both a physical and psychological benefit. Shrouds also have potential in serving as an aesthetic element and noise dampener.

Additional code was programmed into OverTURNS, the University of Maryland's in-house computational fluid dynamics solver, to simulate a wind turbine rotor in 2D. A cross-sectional view is taken of the rotor radius perpendicular to the plane of the rotor. Then, to add in the effect of the shroud, a cross-section of the airfoil of the shroud is added at the end of the rotor. A variety of shroud cross-sections were tested. Additionally, for each shroud cross section the parameters of the angle of attack, proportional size of the shroud to the rotor, and location of the rotor within the shroud were varied for a total of over 50 simulations. An example of the solution for an unshrouded and shrouded rotor is plotted in Figure 2.9. In this figure, the total pressure as it flows through a 2D representation of the turbine rotor is plotted. The darker colors in the shrouded case indicate that the flow is moving faster through the shrouded rotor, indicating that more energy is being extracted.

Given this approach, it was determined that the S1223 airfoil cross-section at 10 degrees of angle of attack would be ideal for the shroud. The results indicated an expected increase in power of 25.2% for the operating conditions of the prototype shroud. Using empirical data for this airfoil, the shroud can be expected to produce an additional thrust of 0.4 N, essentially negligible, therefore the structural performance was analyzed using just the thrust of the rotor.

One of the challenges that had to be overcome was the accurate construction of the shroud shape. To precisely produce the airfoil shape on a small prototype, the shroud was 3D printed in sections and a spar-and-rib structural design was used to keep the shroud light and strong. The ribs were then covered with Monokote to give the shroud an aerodynamic finish.

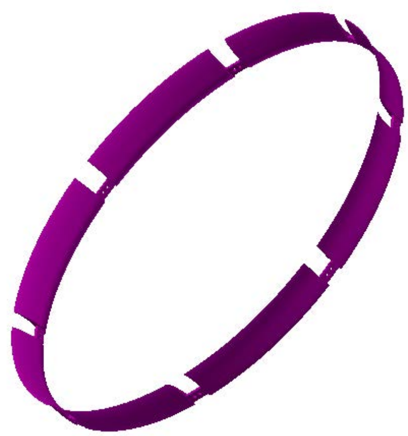

Figure 2.10: CAD model of the shroud.

Structure

The structure of the competition turbine serves as an interface for the competition wind tunnel and the power generation components of the turbine. The initial sizing of the turbine structure was based on the test wind tunnel dimensions. In order to analyze the structure, the tower and nacelle was modeled as a vertical cantilever beam fixed at one end and free at the other.

Aluminum-6061 was ultimately chosen as the primary material for the tower because it has a favorable strength to weight ratio and is easy to work with. A hollow aluminum tube with an outer diameter of 2.54 cm was used because it both satisfied the minimum calculated diameter necessary for structural soundness, and provided a way for the power wires to run down the length of the tower.

Loads experienced by the tower can be broken into two main categories: steady loads and dynamic loads. Steady loads refer to those loads produced aerodynamically by thrust, torque, and the weight of the machine. These include loads due to thrust and the weight of the turbine associated with bending and buckling. Dynamic loads encompass those that are cyclic (wind shear, blade weight), transient/impulsive (start/stop, short-duration), turbulence, and resonance-induced (excitation near resonance frequency). The primary dynamic load considered was resonance-induced.

The steady loads, namely buckling and crippling stress on the tower, were calculated using a length of 61 cm, a modulus of elasticity of 68.9 GPa, and a moment of inertia of $1.39*10^{-8}$ m^4. Thrust on the tower was determined to be 24.4 N as calculated in the Aerodynamic Section. The calculations for buckling stress and deflection were determined with the equations:

$$\sigma = \frac{Mc}{I} \qquad \delta = \frac{PL^3}{3EI}$$

The value determined for bending stress was 13.2 MPa, with a deflection of 0.174 cm. The ultimate bending stress for aluminum-6061 is 310 MPa, meaning the tower has a minimum Safety Factor of 24.

A calculation of the natural frequency of the tower was determined with the equation:

$$\omega = \sqrt{\frac{g}{\delta}}$$

δ refers to the deflection from the weight of the nacelle and the weight of the tower, which was found to be 0.529 mm. The natural frequency of the tower was found to be 1300 RPM, well below the operating frequency of 2400 RPM. The tower had to be designed so that the natural frequency does not coincide with the rotor excitation frequency or the blade pass excitation frequency. Both calculations for natural frequency and buckling stress were confirmed using finite element analysis (FEA). The deflection results from the FEA can be seen in Figure 2.11.

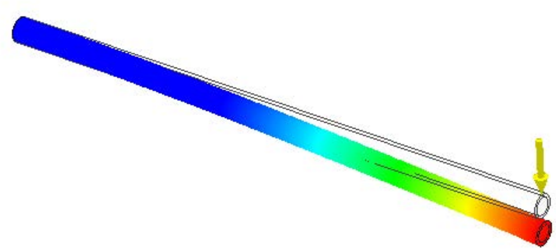

Figure 2.11: FEA of tower deflection.

Mechanical Design

The mechanical subsystem is integral to both the power production and safety requirements of the test turbine. More specifically, these subsystems, facilitate the conversion of energy from the kinetic energy in the wind and subsequent rotation of the rotor to the output electrical energy and allow the maintenance of a safe rotational speed and the shut the turbine down if necessary. Design decisions involving the mechanical subsystem of the prototype turbine are guided by the following: safety and durability, wind tunnel and test section space restrictions, and demand for shutdown. Subassemblies and functions deemed necessary to meet these requirements are as follow:

- Nacelle housing: connects to the tower and protect the mechanical and electrical components of the turbine
- Gear train: provides the required increase in torque or velocity from the rotor shaft to the generator for power production
- Braking mechanism: responds to the microcontroller’s commands and safely brake the turbine when necessary
- RPM sensing mechanism: reports the speed of the rotor to the microcontroller

Nacelle and Internal Components

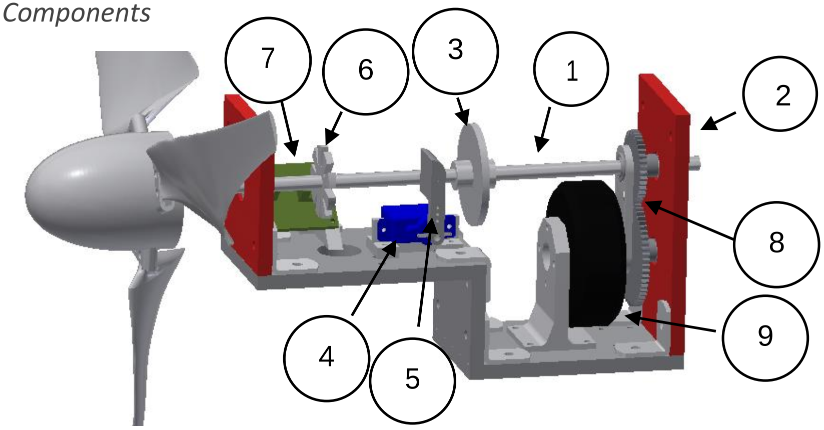

Figure 2.12: Uncovered nacelle design and component layout.

The nacelle layout is shown in Figure 2.12. The unique configuration is designed to position the RPM sensor and braking mechanism for shaft proximity and to take advantage of the tower's aerodynamic shadow for the placement of the large generator. The nacelle "hides" the generator profile behind the structural support shaft for improved aerodynamics, effectively decreasing the frontal area by 40%. Depicted in Figure 2.12 are the following components of the competition turbine and their corresponding functions:

1. Rotor shaft: connects the turbine rotor to the gearbox, generator, and braking mechanism
2. Nacelle walls: supports the weight of the rotor shaft and allow it to rotate with minimal frictional losses, provide protection for the nacelle components
3. Brake disk: provides a contact surface on the shaft for the braking mechanism
4. Brake servo: actuates the brake arm in response to the microcontroller output - either rpm control or emergency turbine shutdown
5. Brake arm: provides a resistive friction force that brakes the turbine
6. Rotational speed disk: indicates the motion of the rotor shaft for the photo-interrupt
7. Photo-interrupter: reads the rpm from the shaft via the rpm disk and output to the microcontroller
8. Gears: transfers the rotational energy from the rotor shaft to the generator shaft, either increase the rotational speed or torque as necessary to operate the generator
9. Generator: converts rotational energy to electrical energy for the turbine output

The wires from the various components are routed down the structural support shaft to the electronics.

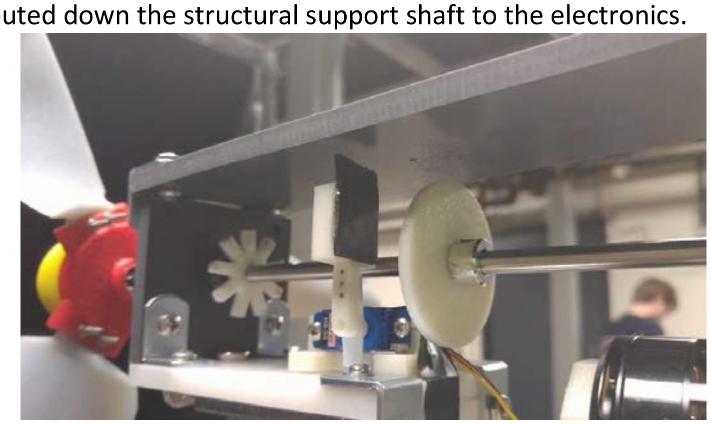

Figure 2.13: Nacelle assembly (without side walls) prior to a wind tunnel test.

The most likely point of failure of the nacelle is due to the thrust loads on the front and back walls of the nacelle. These walls are made of PVC and support the bearings that hold the main shaft of the turbine and the ceiling. Simple cantilever beam bending analysis was carried out on the walls to verify that they can withstand the bending load.

Using the maximum thrust, dimensions of the wall, and modulus of elasticity for PVC (2.4 GPa), the maximum deflection angle is calculated as 0.43 degrees for a total deflection at the bearing of 0.3 mm. This amount of deflection is very small and was determined to not affect the alignment of the bearings. Assuming all of the thrust was applied on the back wall, the safety factor due to the rotor thrust moment at the base of the wall was calculated. Using the ultimate stress of 52 MPa for PVC, a safety factor of 14.4 was calculated.

$$\sigma_{max} = \frac{Mc}{I} = \frac{24N \cdot 0.051m \cdot (0.0032m)}{0.1084 \cdot 10^{-8}\ m^4} = 3.6\ MPa$$

Gear Design

Due to the disparity between the chosen generator's operating conditions and the expected performance of the turbine rotor, a gearbox was chosen over a direct-drive configuration. The generator selected by the electronics team was the Turnigy HD 3506 Gimbal Motor. Using the measured cogging torque of that generator, and the torque on the stationary rotor Q_s calculated by the aerodynamics team, a range of possible gear ratios estimating performance was determined. Gear ratios including a 1:1 (a direct drive system), 2:1, and 3.5:1 were manufactured in order to test the effects of increasing rotational speed or torque through the gear interface. From testing, it was determined that a 2:1 gear ratio provided an ideal balance between cut-in speed and power curve performance. In the future, further gear box tuning may improve this balance.

Brake System

The prototype braking mechanism, shown in Figure 2.14, consists of a 1.75 inch diameter brake disk, an HS-55 sub-micro servo motor, a brake arm attached to the servo, and a mount for the servo. A 1/8th inch sheet of rubber covers the side of the brake arm that contacts the brake disk, attached to the ABS plastic brake arm with epoxy for a frictional element. Originally, the brake disk was left uncovered, however it has a maximum coefficient of friction of 0.46.[21] This configuration proved to brake the system within the allotted time frame up to 1800 RPM. To improve the braking performance, the brake disc was also covered with rubber which raises the coefficient of kinetic friction to 1.16.[22] A servo motor actuator was chosen over a hydraulic system in order to reduce the number of parts, ease and accuracy of control, and cost restrictions. This system will utilize the readings from the rotational speed sensor and the shutdown conditions to safely control the competition turbine's speed.

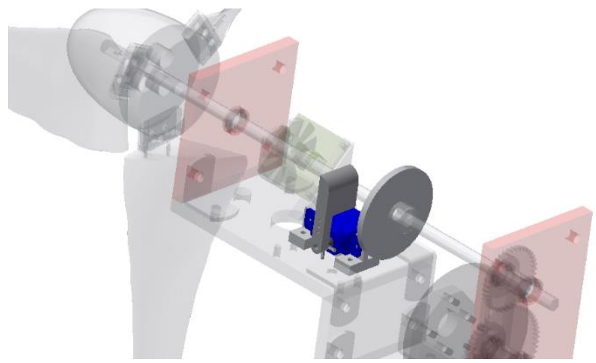

Figure 2.14: Braking mechanism.

Rotational Speed Sensing

In order to measure rotational speed of the turbine rotor, a photo-interrupter with a toothed disk was designed to measure RPM. The disk is placed such that it rotates through the photo-interrupter, mounted on a wedge in order to conserve space on the nacelle base. When the teeth of the slotted disk pass through the sensor, the sensor sends a signal to the microcontroller. The accuracy of the photo-interrupter increases with the number of teeth on the disk. Originally 36 teeth were used based on the maximum rotational speed of the turbine and the response rate of the sensor. Through testing it was found that the

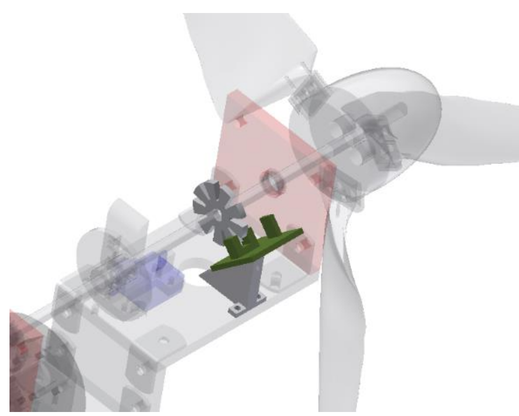

Figure 2.15: Disk for rotational speed measurements.

microcontroller had difficulty reading at higher rotational speeds. Therefore, 9 teeth were used for the disk as can be seen in Figure 2.15.

Shaft Analysis

Autodesk Inventor's finite element solver was used to analyze the competition nacelle shaft stresses and safety factors. In this analysis, the turbine shaft was modeled at the rated 2400RPM. Additionally, the rotor and shroud are expected to produce 54W before transmission and electrical losses. Therefore, the maximum force on the 20° pitch angle gear face was calculated below to apply to the model.

$$F = \frac{\tau}{r \cdot cos\theta} = \frac{P}{r \cdot \omega cos\theta} = \frac{54\ W}{2.5cm \cdot (2400 \cdot 2\pi/60)\cos(20°)} = 11.2\ N$$

The anticipated maximum thrust load was also applied. Fixed constraints were placed on the press-fit shaft bearing exteriors and a shaft collar was added to prevent the shaft from sliding out of the bearings. This analysis revealed that the minimum safety factor in the nacelle (6.25) occurs in the rear shaft bearing. An illustration which resulted from that analysis can be seen in Figure 2.17.

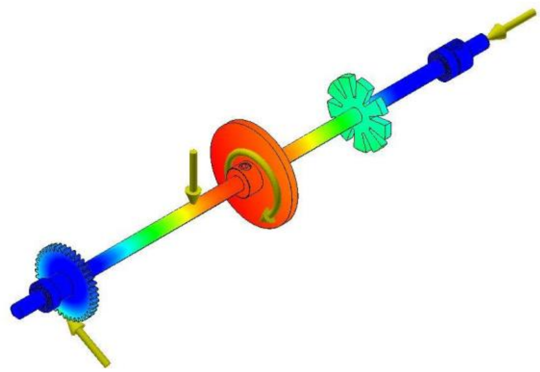

Figure 2.17: Results from the finite element analysis illustrating the forces applied and deflection magnitude. Maximum deflection is less than a tenth of a millimeter.

Electronics Analysis

The turbine electrical system serves two purposes. The first challenge for the electronics is to condition the output of the generator to form useable power. The second is to interface the software control strategy to the hardware. Reliability and efficiency were the guiding principles for the design of this subsystem. The electronics schematic which resulted from the design can be seen in Figure 2.19.

Power conversion is performed passively with a 3-phase rectifier. The output voltage of the turbine varies from 0 to 35 volts depending on the output power level. The output voltage is not regulated to a single value so that there are no additional losses on the turbine side. Once output voltage exceeds approximately 5 volts, a buck converter steps down the voltage internally for use by the control electronics. A buck converter was chosen as opposed to other regulators such as linear or Zener regulators because of its high efficiency. A boost converter could potentially be used to power the control electronics when the output is at lower voltage, but in that region the power produced is so low, it would not be sufficient to power the control electronics.

The microcontroller used is the Arduino Micro Pro. This microcontroller was selected because of the documentation and support for Arduino microcontrollers, low power consumption, and sufficient number of input and output channels. The Micro Pro operates at 8 MHz, half of the typical 16MHz of most other Arduino microcontrollers, but this speed enables operation at lower power.

The electronics utilize three different sensors to monitor RPM, current produced, and the shutoff conditions. The simplest sensor, the shutoff switch is a simply a normally closed switch with a pull-up resistor which is monitored by the microcontroller. This solution provides robust and low power operation. Current production is sensed with a Hall Effect current sensor. A Hall Effect sensor is used because it is efficient. The current sensor is used to both monitor if the load is connected and how much power is produced. The final sensor is the RPM sensor. There are several options for measuring RPM, but the one least prone to faulty operation is a photo-interrupter used with a slotted disk attached to the main shaft. A photo-interrupter uses an LED and phototransistor to determine when an object blocks the path between the two. The photo-interrupt has a quick response time, on the order of tens of microseconds, which makes rapid, accurate measurements possible.

Actuation is performed with a single servo for the mechanical braking mechanism. The mechanical brake consumes the most power of the system when in operation at around 0.5 Watts. Fortunately, the brake will only be in operation when the system is producing a significant amount of power, so the brake will not decrease power produced by a significant percentage.

Power consumption calculations estimate that the control electronics will draw just below 1 Watt in the worst case scenario as indicated in Table 2.18. This power consumption is 7% of the rated power found from wind tunnel testing. Electrical tests done on individual components indicate that 1W is a reasonable upper bound on power consumption.

Component	**Voltage (V)**	**Current (mA)**	**Power Consumption (mW)**
Arduino Micro Pro	3.3	90	300
RPM Sensor (Sharp Photo-interrupt)	3.3	45	150
Hall Effect Current Sensor (ACS722)	3.3	10	33
Servo (HS-55)	3.3	150	495 (stall)
Manual Shutoff	3.3	1.5	5
		Total:	983

Table 2.18: Worst case power consumption.

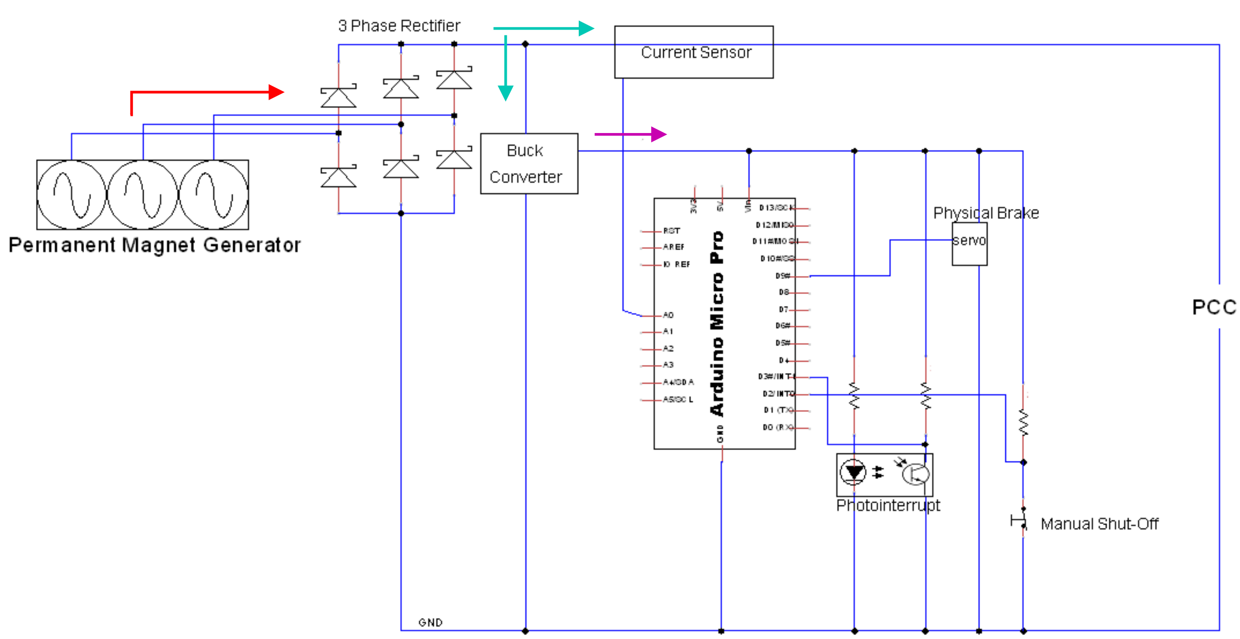

Figure 2.19: Test turbine electronics schematic. The red arrow represents three-phase AC power, the light blue represents unregulated DC power, and the magenta represents regulated 3.3V.

Load Electronics

For the competition, the load is just represented by a set of power resistors. Resistors were chosen for the load because it would limit the impact of the load on the performance of the turbine. Inductive loads like that of a motor would have a resonant effect on the turbines. Voltage and current sensing are used on the load to monitor and display power output.

Generator

Selection of the generator proved to be one of the most critical components of the design. In order to enhance performance in the competition, the primary goals of the generator were to maximize energy production efficiency and minimize cogging and parasitic torque.

Generators can be divided into two categories: synchronous and asynchronous. As the turbine is designed for an off-grid application, synchronous, or induction, generators would not work as they are dependent on a grid to provide a slip frequency. Additionally, these generators rely on excitation current at startup. Asynchronous, permanent magnet generators do not suffer from these disadvantages and they perform well in a wide variety of operating conditions.

Unfortunately, power generation and cogging torque data for generators at the scale of the competition turbine (below 50W), is not easily found. To make an informed choice on an appropriate generator, testing to characterize the performance of a variety of generators needed to be done.

Several motors were tested by driving them at a rotational speed typical of the turbine. The generators were connected to a 3-phase rectifier and the power across a load resistor was measured. The motor parameter which had the most influence on the power production was the kv rating. Figure 2.20 shows the variation of power production with kv rating. Based on these results, lower kv ratings are clearly ideal for power generation in the rpm range that is expected.

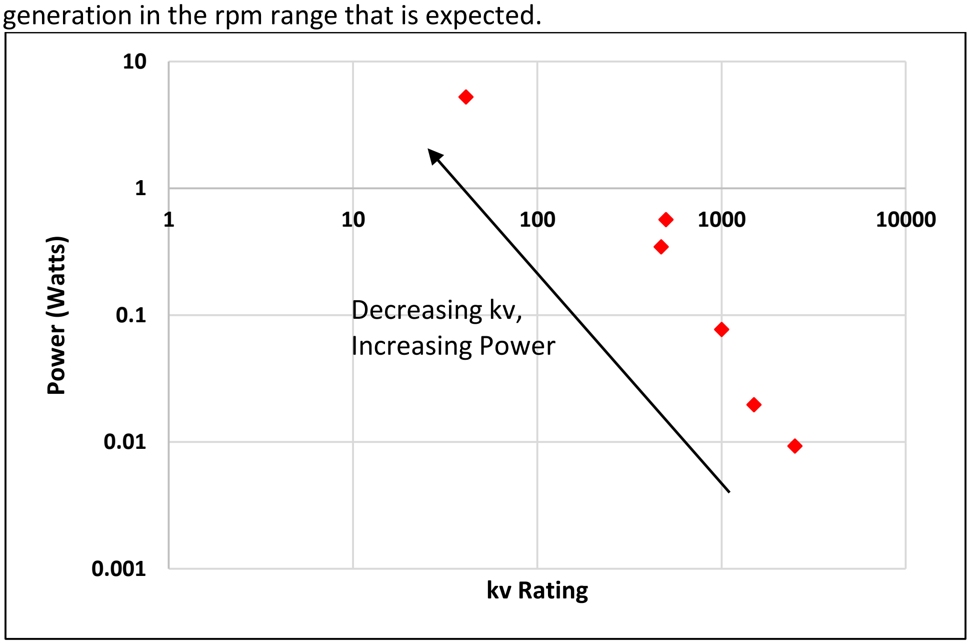

Figure 2.20: Generator power production vs. kv rating for a variety of Turnigy and Quantum branded BLDC motors.

A simple static torque measuring setup was developed to determine the cogging torque. A level arm was attached to the generator and loaded with weights until it began to rotate. From this, the torque required to start the generator was calculated. For the motor chosen from the efficiency test, this turned out to be 5.39 mN.

Control

Traditional turbine control is typically done through three methods, yaw control, rotor rotational speed control, and pitch control. Since the turbine is tested in a wind tunnel, yaw control is not necessary. Active pitching control on the scale of the turbine is unfeasible and adding additional components would negatively impact reliability, an important consideration for the deployed product. For these reasons, only active rotational speed control is implemented on the turbine.

The turbine operates in five distinct regions. The regions are as follows:

I – Idle (Below 3.5 m/s): No rotation due to low wind speeds.

II – Startup (3.5 – 5 m/s): The turbine begins producing power, but exhibits no active control or sensing.

III - Power Curve (5 – 11 m/s): As the turbine begins producing enough power to support the electronics, it begins sensing to ensuring rotational speed does not exceed that of the rated speed.

IV - Constant Rotational Speed (11 – 18 m/s): The turbine uses a proportional control strategy to maintain constant rotational speed.

V - Shutdown: The turbine transitions upon activation of automatic shutdown or loss of load until it returns to idle.

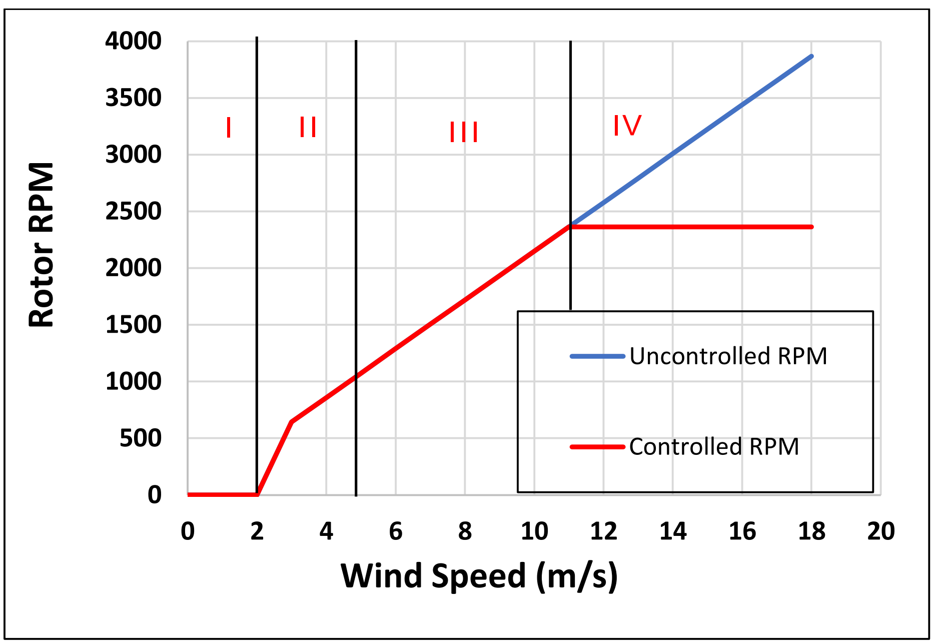

Figure 2.21: Designed control regions. Note that Region V is not pictured as it is a transition region.

The turbine subject to a constant input is a stable system as long as it is not operating at a natural frequency. As a result, the controller in Region IV can be implemented with a relatively simple system. An algorithm in which the force applied by the servo is proportional to the rotational speed above the rated speed is used for this region.

Software

The software design is meant to first prioritize response to urgent safety events, such as shutdown. The software's second priority is to maintain the turbine within its safe operating range. By focusing on these two priorities, the software can be kept as simple as possible to eliminate potential bugs. The Region III/IV control loop begins only after the turbine produces enough power to activate the microcontroller. The flowchart in Figure 2.22 is used to illustrate the decision making process of the software. Since responding to the shutdown requires quick response, the shutdown conditions are checked at the beginning of each control loop. Once either of these conditions is detected, the program enters shutdown mode. The shutdown also cuts off its power, but since the servo torque is reduced once the power is turned off, the turbine should not have any issues restarting. The servo brake is also used to keep the speed and power at the rated conditions.

Finally, the software is also designed to avoid the primary natural frequency of the tower and the blades. If the rotational speed of the turbine is at approximately 1300 or 1500 RPM, the tower or blades can become structurally unstable. There are two checks required to make sure the turbine is not just passing through the natural frequency. If the turbine is within 20 RPM of the unstable rotational speeds for greater than 0.5 sec, the controller will slightly apply the brakes.

The microcontroller is programmed using Arduino's development environment, in a derivative of C++. Arduino offers many tested prebuilt libraries which expands its functionality for sensing and control and limits the amount of coding required. Particularly useful are the interrupts, which are configured to activate the shutdown procedure. In the future, the two shutdown conditions will be wired to use only a single pin. The other interrupt pin is used for the rpm sensing.

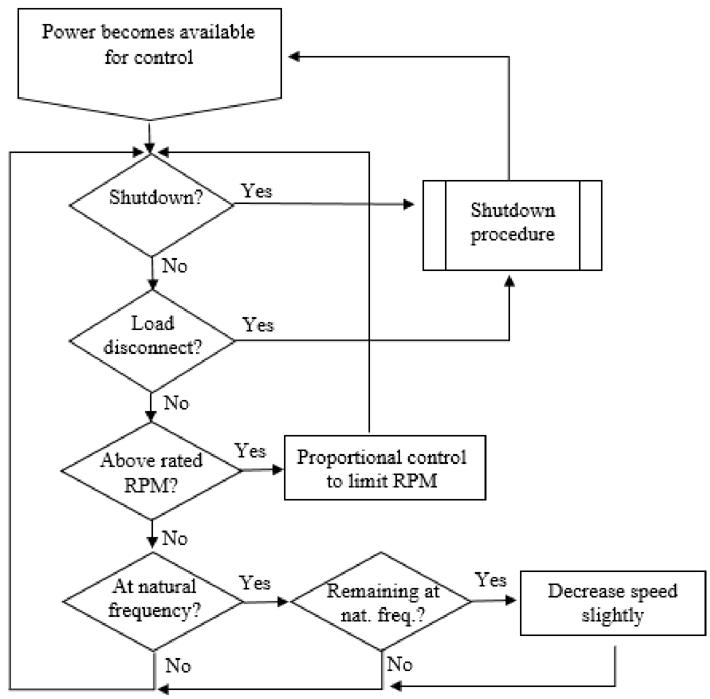

Figure 2.22: Software flowchart.

Testing

Wind Tunnels Used for Testing

Two different wind tunnels have been used for testing during the development of the turbine. A small wind tunnel was constructed by the team to measure performance at low wind speeds. The tunnel has achieved speeds up to 6 m/s, but the flow is not uniform which makes it difficult to produce accurate data. This tunnel has been used for preliminary testing when more effective wind tunnels were unavailable. The wind speed is significant enough for the turbine to generate a small amount of power and to ensure all of the moving parts and electronics are working properly.

The turbine has also been tested in a larger open jet wind tunnel at the university. The wind tunnel has a throat size of 30 inches by 30 inches and is capable of producing wind speeds up to 36 m/s. This wind tunnel was used for measuring power curves, measuring cut-in speeds, performing braking tests, and determining structural stability.

Data

To measure aerodynamic efficiency, a separate setup from the turbine was used. This setup relied on electromagnets to provide braking torque, as well as a torque sensor and tachometer that could be used to calculate the power produced by the rotor itself. Using this test setup, the data in Figure 2.23 was generated and compared against the calculated CP-Lambda graph. Since this test setup did not incorporate the generator or shroud, the data is compared against the expected performance of just the rotor. Due to the nonlinear behavior of the electromagnets, as well as calibration issues with the torque sensor, the results are not comprehensive and do not match precisely with the theory. Despite the lack of accuracy, this information is included for completeness and show that this base may serve as a valuable tool for future turbine tests.

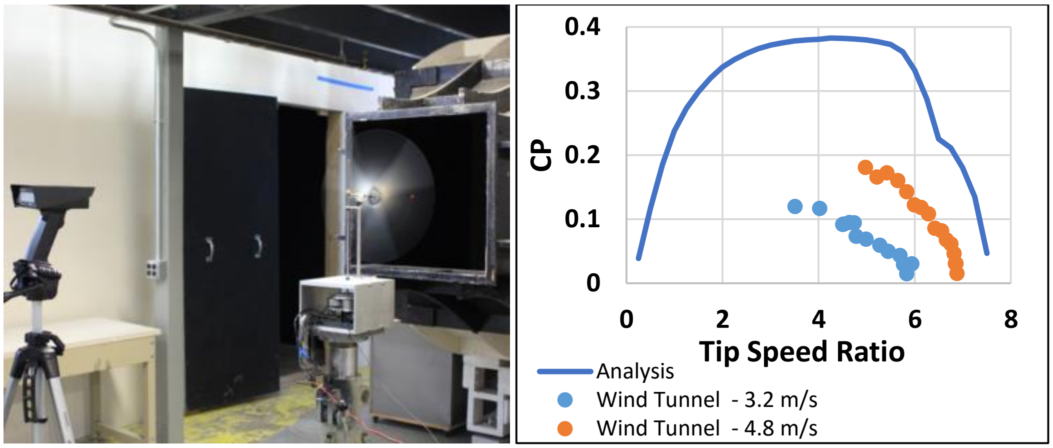

Figure 2.23: C_P-Lambda test setup and curve with unshrouded test data.

After the aerodynamic power tests were completed, the entire system was tested for its ability to produce electrical power. For these tests, the gear ratio and the inclusion of the shroud were varied. The results for several of the tests are shown in Figure 2.24. One of the important results from this testing was the proof that the shroud provided a performance boost. While the performance enhancement was not uniform for all wind speeds, the shroud gave a 22% increase in power production at some data points, which validates the conclusions from the CFD analysis. Other important results were the important of the gear ratio choice. The gear ratio which produced the best cut-in speed, performed fairly poorly in terms of the power curve peaking at 2.5 W at 10 m/s, nearly 8 W lower than that of the 1:1 gear ratio at the same wind speed. However, the 1:1 gear ratio performed poorly in cut in speed task, while not providing much of a power curve benefit over the 2:1 gear ratio. For this reason, the 2:1 gear ratio will be used for the competition.

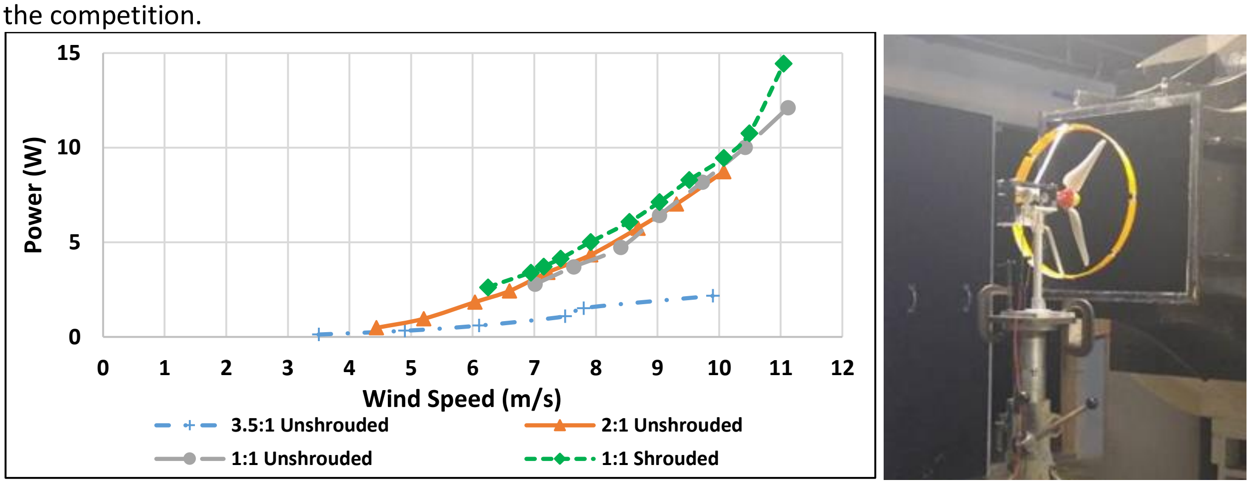

Figure 2.24: Power curve data from testing and experimental setup.

During the wind tunnel testing, the team also tested the frictional braking ability and the structural strength of various components. These tests resulted in some slight modifications to the design such as a stronger frictional brake material and shroud support adjustments.

Materials Testing

A blade was bolted into an oscillator to determine the natural bending frequency. The setup is shown in Figure 2.25. The blade was exposed to different frequency oscillations and the blade deflection was measured using an infrared distance sensor. As can be seen in Figure 2.25, the blade's first natural frequency is 24.97 Hz, which corresponds to 1498 RPM.

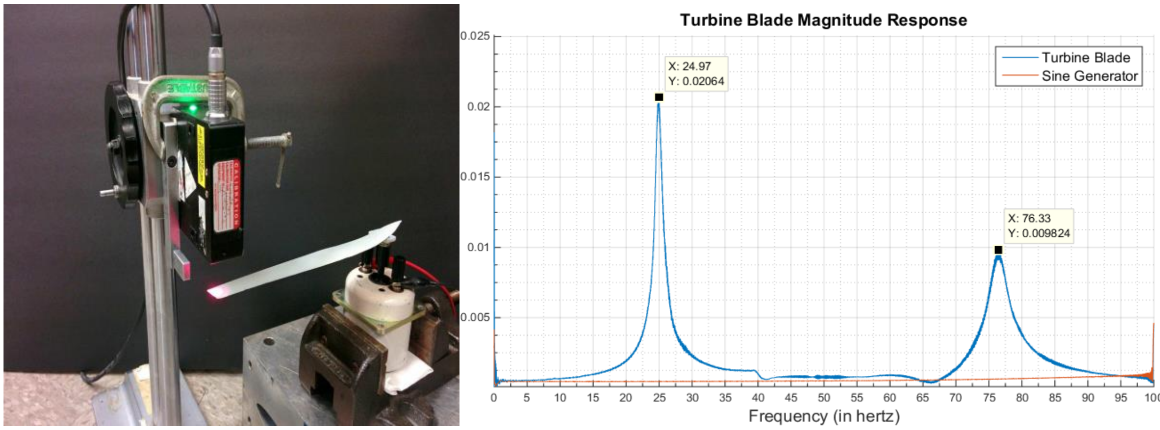

Figure 2.25: The natural frequency test.

The material the blades were printed from was also tested to determine its material properties. A .25" diameter 9" long rod was printed and loaded first in bending and second in both bending and torsion. The deflection was measured using an arm attached to a gauge which could measure vertical displacement. The Young's modulus was experimentally determined to be 229 MPa and the shear modulus was determined to be 42.8 MPa.

The hub base was tested in tension to determine if it could support the centrifugal force of the blades. The bolts used to attach the hub to the blades were inserted and a steel fiber was tied around both bolts. The fiber was then attached to a load which was increased up to 298 N, which is the equivalent of 4400 RPM giving a safety factor of 3.3 for the load experienced at rated RPM speed.

Extension to the Deployment Turbine

Aerodynamics

The most significant difference between the competition turbine and the deployment turbine aerodynamically is the size of the blades. In order to calculate the required blade radius, the required power needed to irrigate one farm was determined to be an average of 500W each hour calculated in the Market Opportunity: Required Power section. Based on NREL's Wind Resource Assessment of Gujarat, U_r was estimated to be 8 m/s for z_r = 80m. The wind speed at a reasonable deployment turbine height was extrapolated using the wind profile power law.

$$U = U_r \left(\frac{z}{z_r}\right)^{0.143}$$

U_r is the reference wind speed in Gujarat at the reference height z_r, z is the turbine height, and U is the wind speed at the turbine height. For z = 18m, U was determined to be 6.46 m/s. The required diameter of the wind turbine was then calculated from the following equation adapted from Manwell[20]:

$$D = \frac{3}{2}\eta_g A_s \frac{C_P}{C_{P,Betz}} \sqrt{\frac{\bar{P}_w}{\rho U^3}}$$

D is the diameter of the wind turbine, η_g is the generator efficiency, A_s is the shroud augmentation factor, C_P is the expected coefficient of power, $C_{P,Betz}$ is the Betz limit, $\underline{P}_w$ is the average wind machine power required, ρ is the air density, and U is the average wind speed. The derivation of this equation assumes a Rayleigh distribution for Gujarat, illustrated in Figure 2.26. Using $\eta_g = 0.8$, $A_s = 1.25$, $\underline{P}_w = 500$ W/hr, $\rho = 1.225\ kg/m^3$, U = 6.46 m/s, $C_P = 0.38$ (from C_P-Lambda graph), and $C_{P,Betz} = 0.593$, the required diameter was calculated to be 2.88m. This diameter was increased to 3m for the final deployment turbine design to account for wind speed variation.

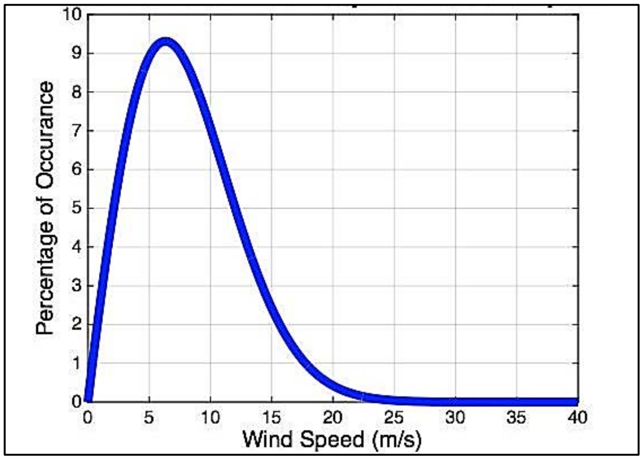

Figure 2.26: Example Rayleigh wind distribution based on Gujarat's mean wind speed.

These blades would be manufactured through fiberglass molding and would cost about $80 per blade.[23] Other possible steps to take to optimize the blade design for the deployment turbine include conducting a finite element analysis (FEA) to determine whether hollowing out the blade would achieve significant performance or cost benefits.

With these blades, the expected power can be calculated over the range of expected wind speeds. For wind speeds over 11 m/s, the rotor RPM would be controlled so that power output remains the same. The expected power versus wind speed is shown in Figure 2.27.a. Additionally, using the specifications of the turbine, the annual power output for a range of average wind speeds was calculated, as can be seen in Figure 2.27.b.

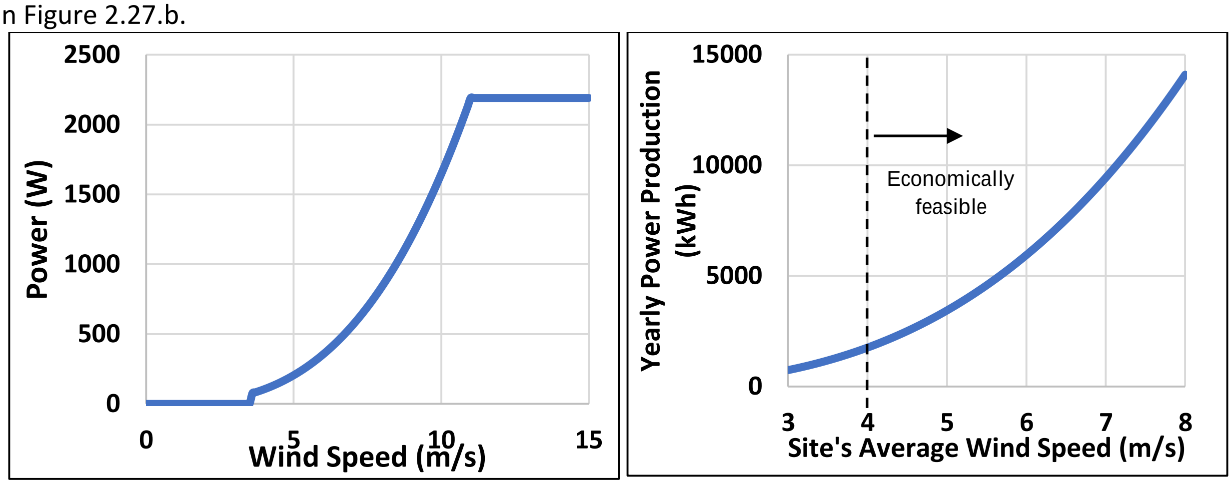

Figure 2.27: a. Expected power production for one deployment turbine as a function of wind speed. b. Expected yearly power production for a mean wind speed.

Using the data for expected annual power production, it can be determined what average wind speed is required to make the turbine an economically feasible investment. Assuming that the turbine lasts for 10 years with minimal maintenance costs, if the average power production is expected to be less than 2200 kWh, the price per kWh will exceed 10 cents, an approximate average cost for electricity. The turbine will produce less than this power for an average wind speed of approximately 4 m/s, so the turbine is not recommended for sites which experience these conditions.

Figure 2.28: Cutaway view of the deployment shroud, highlighting its strong and weight saving design.

The rotor hub will also be developed into a slightly more complex design to allow for passive pitch control. The hub will hold the blades with a curved slot and spring. When not rotating, the blades will be pitched into the wind to decrease cut-in speed. As the rotor turns, the centrifugal force will extend spring and the blades will pitch to their optimal operating angles.

As the turbine will be operating at higher Reynold’s Numbers, the shroud cross-section can be pitched at a higher angle of attack without the airfoil stalling than for the competition turbine. Since this change will induce more mass flow, the expected performance increase from the shroud will be even greater. However, in addition to the increased performance, a larger shroud comes with increased challenges. The biggest challenge is in the construction. The deployment shroud will utilize the same spar-and-ribs design as the competition shroud. However, the deployment shroud will be built out of materials more suited for long term durability. The backbone will be constructed of aluminum bent into a circle and lined with Acetyl resin ribs. These plastic ribs will be covered with a thin layer of fiberglass to give the shroud a strong, aerodynamic surface as shown in Figure 2.29.

The deployment turbine must also be yawed into the wind for ideal aerodynamic power production. The nacelle will be constructed with a tail fin to accomplish this task. The tail fin will allow for the turbine to automatically adjust its orientation and enable passive yaw control to align the rotor with the wind direction.

Structure

To make the transition to a production model, the tower needs to be scaled up significantly. The height of the deployment tower is 18m to take advantage of better wind resources farther off the ground. In the final design, the deployment tower design utilizes compartmentalized tube segments manufactured using galvanized steel. The tower was broken into six segments to increase ease of assembly. Each pipe section is a standard, size-6 galvanized steel pipe with a length of 3.05 m and wall thickness of 1.5 cm. Galvanized steel was chosen due to its high fatigue strength and resistance to corrosion, making it ideal for long-term performance. In addition, the tower is fixed at the base to a 5800 N concrete block weighing. The concrete is set in the ground and weighs enough to prevent tipping or sliding. Moreover, the deployment tower uses a gin pole mechanism to raise and lower the tower and turbine assembly, as detailed in the Installation and Maintenance section.

Figure 2.29: CAD design of structure including the gin pole at the base.

As with the competition turbine, the loads experienced by the tower break down into two main subcategories – steady and dynamic. A bending analysis was conducted based on the maximum steady thrust loads expected from the rotor. Using the yield strength of 200 MPa and elastic modulus of

200 GPa for galvanized steel, and the current dimensions of the tower, the safety factor for bending is 5.46. Other steady loads are much less in magnitude.

The natural frequency of the turbine must not coincide with the rotor excitation frequency or the blade pass excitation frequency to prevent resonant-induced loads. An estimation of the first and second natural frequency of the tower was determined using finite element modeling (FEM) of a rod in bending using the following matrices:

$$M = \frac{\rho AL}{420}\begin{bmatrix} 156 & 22L & 54 & -13L \\ 22L & 4L^2 & 13L & 3L^2 \\ 54 & 13L & 156 & -22L \\ -13L & -3L^2 & -22L & 4L^2 \end{bmatrix} \quad K = \frac{EI}{L^3}\begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix}$$

The FEM analysis showed the first two natural frequencies to be 0.348 and 2.18 Hz. The turbine has a rated rotational frequency of 5.6 Hz and blade pass frequency of 16.8 Hz. Therefore, the deployment structure is not expected to fail due to a vibrational overlap, even though the turbine must pass through the first two natural modes of the tower to reach rated speed.

Mechanical

One major change from the competition turbine will be to the braking system. If installed in the deployment turbine, the friction brake currently installed in the competition turbine will wear down over time. This system will be replaced with an EMF brake controlled automatically to control the turbine to rated speed and for emergency braking. This will prevent additional maintenance costs resulting from replacing the friction brake pad and increase up-time. A back-EMF brake has been deployed in other commercially available turbines and is a tested and reliable system for braking.

The gear system installed in the test turbine has additional risks due to the increased points of failure. The risk for damage to the gear system increases, and due to the difficulty in replacing the system in the deployed turbine, an alternative has been chosen. For the deployment turbine, a direct drive will be installed, so that the power generated from the spinning rotor will be directly transferred to the generator. The gear system in the competition turbine is used because the generator does not ideally match the aerodynamic characteristics of the rotor. A generator will be chosen that better matches the rated rotor speed and power to eliminate the need for this gear system.

Electronics

The majority of the electronic elements of the deployment turbine will remain functionally identical to their competition turbine counterparts. The deployment turbine will utilize scaled versions of a permanent magnet generator, three-phase rectifiers, and rpm and current sensors due to their successful implementation in the competition turbine.

The only major functional change for the deployment turbine is the replacement of the mechanical friction element brake with back-EMF braking. As the wires of the permanent magnet generator used for the competition turbine generator were very small, back-EMF was not used for the competition prototype as it could damage the generator over time, but more robust permanent magnet generators would not have this problem. This electronic braking will be operated with a MOSFET shorting the positive and negative ends of the rectifier circuit and operated using pulse width modulation.

The desired power production as previously stated is 2.2 kW. Research on the ideal generator of this size will be paramount to ensuring efficient and reliable operation and will be central to the continuing research efforts of the company. Additionally, the Arduino will be swapped out for a lower cost microcontroller and the electronics will be incorporated onto a single PCB and production outsourced, for low-cost high-volume production runs.

Control and Software

The control and software of the deployment will undergo the least amount of changes from its implementation in the competition turbine. As safety is the most important job of the control, the controller prioritizes responding to shut down conditions. Beyond the rated speed, the controller will also maintain rotational speed through a pulse width modulation control of an electronic back-EMF braking system, instead of the mechanical brake used in the competition turbine. Further functionality may be researched and developed into the software after the development of the initial model such as an incorporating more advanced data logging which could be used to optimize future turbines.

Deployment Plan

Site Suitability

Numerous factors are taken into account when determining site suitability of a small wind turbine. A strong soil foundation, access to wind, and nearness to the water pump are all important aspects of determining the best location for a wind turbine on a farm. The farmer's ability to purchase a wind turbine is another important consideration for site selection and is covered in the promotion strategy section of the business plan. This section covers the required topological and atmospheric conditions for optimal wind turbine placement on a small farm.

Wind turbine towers require sufficient soil compressibility and strength to prevent tipping during high winds and earthquakes. The most common type of soils in TERPine Industries' target market are alluvial and black soil, which can sometimes be somewhat soft. Where soft soils are present, concrete pilings are needed to secure the tower. These pilings carry the load of the tower to a deeper layer of Earth where the soil is more solid.

The turbine is small and features a mounting strategy that allows the tower to be lowered to the ground during episodes of extreme wind. The size and lowering capability of the tower means that the foundation does not need to be solid enough to withstand the intense winds of a monsoon, but must still provide ample support during regular wind and periods of high gusting.

The wind turbine tower is supported via a concrete block with dimensions of 0.5 m by 0.5 m by 1.3 m, with the 1.3 m dimension being the depth that is embedded into the ground. This concrete block will weigh around 5800 N, enough to keep the tower set in the ground during normal operation. Due to the 1.3 m depth into the ground, it can be assumed that the turbine is essentially fixed to the ground. Steel rebar reinforces the block, providing the additional strength needed to prevent the concrete from failing in tension.

The states in which the turbine is being deployed are chosen for their beneficial access to wind. In order to maximize wind potential, the turbine will ideally be located on top of a hill; however, the water pump will be located at a lower altitude to minimize the power needed to pump the water to the surface. Ground transmission wires will be utilized to transmit the power from the turbine to the pump. These lines will be no longer than 100 m, and will play a role in determining the optimal location of the tower.

Siting regulations within India are typically somewhat lax. One important law to consider when siting the turbine is that all non-airport structures be built at least 0.5 km away from any airport. This issue is somewhat of a special case though, and most of the time there will not be any legal regulations for the construction of the turbine.

The community ambassadors and marketing team will be trained to work with customers to find locations in which the wind turbine will be on a hard dirt or clay spot that does not experience regular water flow, such as the top of a hill, which will also allow for maximum wind access. Once a number of turbines have been deployed, data collection on power generation and site characteristics from these turbines will help inform future site selections.

Stakeholder Identification

TERPine Industries' primary stakeholders include clients, employees, and investors. Investors who donate money and time to the business are extremely important stakeholders, but the business will maintain a client-centered structure because the customers are at the core of TERPine Industries' mission. Keeping a client-centered structure ensures that the clients who purchase wind turbines are properly informed and their turbines properly maintained so that their investment will pay off long-term. Since TERPine Industries relies heavily on word-of-mouth marketing, client well-being is given maximum priority. Significant importance is also placed on employee satisfaction, and efforts will be made to certify that employees represent the company well to other stakeholders.

Secondary stakeholders include the media and government. These sources will take interest in TERPine Industries because of its principled mission and can provide the company with sources of subsidization and outreach. TERPine Industries will apply for government grants to subsidize the turbine price, and will seek out media coverage in order to help advertise the company. One important stakeholder in the India government is the Indian National Institute of Wind Energy (NIWE). NIWE develops regulations for wind turbines, but at this time only larger utility scale turbines are subject to those regulations. NIWE also offers a testing site which can serve as a potential resource for the company's future turbine development.

Deployment Timeline

The deployment timeline for TERPine Industries encompasses the time to meet with a customer, determine site suitability, ship the turbine, and install the turbine. Planning a meeting with a customer could happen in as quickly as four to five days or as long as one to two months depending largely on the customer's schedule. However, once the meeting occurs, the process can move relatively quickly. Determining the site suitability of one farm will take one to two days, as TERPine Industries' will need to research the area and survey the land before making any decisions to move forward. This process will ideally be done with the trained community ambassadors and at minimal cost. During the client meeting, soil and wind data will be measured. The wind data will be compared to expected data and wind data for nearby regions with long term data to make an estimate on the actual wind resource. While it would be ideal to measure the wind over a long period of time, an estimate is used in its place to keep costs low and the deployment turbine shorter. It is worth noting that as the company grows and becomes familiar with site suitability in a specific region, this process will go much faster. Once a site has been selected, the turbine will be shipped from the warehouse near Gujarat via flatbed truck and assembled at the site. Delivery and assembly takes place in one day, which is a major competitive advantage of the turbine. After the initial meeting with the customer, the process of deployment lasts about three days.

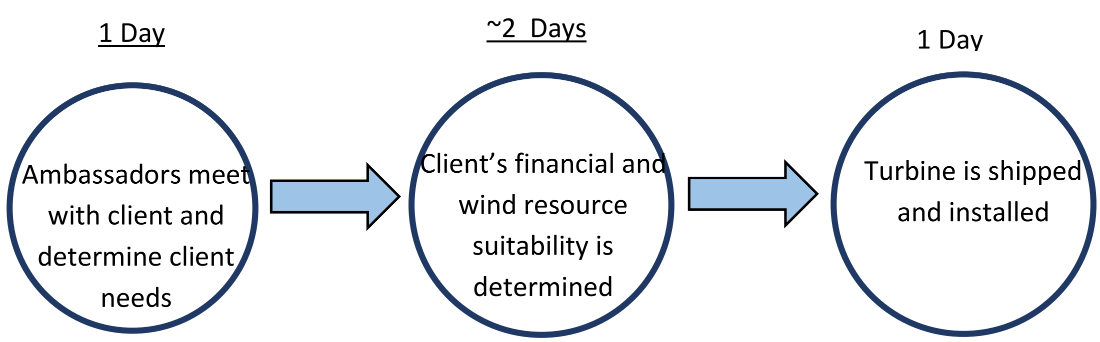

Figure 3.1: Deployment timeline workflow.

Installation and Maintenance

The wind turbine installation is straightforward and does not require skilled-laborer assembly. The turbine delivery includes assistance with installation. The deliverer will assist the farmer with assembling and installing the turbine. All bolts and nuts on the tower are the same size to facilitate a single-tool-assembly method for extremely simple installation and maintenance. Tower construction takes place in two steps: pre-installation and installation.

1. *Pre-installation*

Before installing the tower, a suitable location must be selected. The farmer works with TERPines Industries personnel to choose the optimal space based upon wind data, soil requirements, and farmer preferences. Once an installation location has been chosen, the farmer digs a square hole that is 0.5 m on each side and at least 1.3 m deep.

2. *Installation*

Once the hole has been dug, the turbine and tower arrives in pieces via a flatbed truck. The components that the truck brings include a pre-poured concrete foundation block, six tower poles, a gin pole, and the wind turbine rotor, shroud, and nacelle.

First, the concrete foundation block is unloaded into the hole dug by the farmer. This support block is reinforced with steel rebar and features attachment points for the turbine poles. These attachment points are designed to allow the tower to rotate from a lying-down position to an upright position so that the tower can be assembled lying down and then lifted into its final position. The gin pole and tower poles are unloaded in a line starting at the concrete foundation block. The turbine is unloaded at the end of this line.

The tower poles weigh about 100 kg and do not need to be lifted off the ground while being attached to one another. As such, two people can easily manipulate the poles and then they can be fixed together at the flanges. The gin pole is attached to the first pole, which is then attached to the concrete foundation block followed by each successive pole and ultimately the turbine.

Once assembled on the ground, the turbine must be raised. The truck is positioned to raise the tower, and a winch is attached to the gin pole of the tower. The winch is powered to raise the tower, which is then fixed into place using additional bolts. This process is shown in Figure 3.2. For subsequent raising and lowering of the tower for maintenance or preventative care, a bullock cart and at least two bullocks (oxen common in India) can take the place of the winch on the truck. A bullock weighs 300 kg on average, and is capable of pulling up to 900 kg for a short period. Two bullocks can easily lift the tower and turbine assembly, which weighs about 900 kg total.

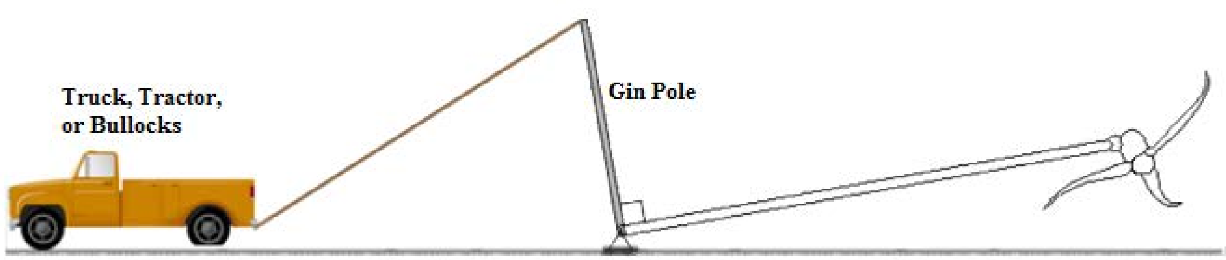

Figure 3.2: The gin pole is pulled via a tractor, a pair of bullocks, or a truck with a winch in order to raise the assembled tower into its standing position.

Preventative care and maintenance are important parts of tower security. When a monsoon with extremely high winds is expected, the tower should be lowered to prevent damage to the turbine. Additional preventative maintenance is occasionally required to check for rust at the flanges of the pipes and to inspect the turbine itself for signs of fatigue. This can be accomplished using the two-bullock method described above. The farmer is provided with simple maintenance documents that explain all of the suggested maintenance and preventative care procedures. If more than standard maintenance is required, then the company will repair the damage as long as it is covered under a warranty.

Risk Management

TERPines Industries has a comprehensive risk management plan to account for possible issues that the wind turbines may encounter during operation. A number of possible risks have been identified and mitigation strategies have been determined for each risk. The risk assessment matrix below summarizes both the risks and the response plans. Likelihood and severity of each risk is ranked using a three tier rating system (low, medium, and high). The customers will be informed of these potential risks and indicators. With proper operator education, major failures can be prevented.

Risk	**Impact**	**Likelihood (L,M,H)**	**Severity (L,M,H)**	**Action Trigger**	**Response Plan**
Moderately High Winds/Gusting	Damage to wind turbine blades, alternator, and tower	H	L	Turbine anemometer reads wind speeds in excess of 11 m/s	Turbine control system uses braking system to maintain constant RPM
Excessively High Winds	Damage to wind turbine blades, alternator, and tower	M	M	Turbine anemometer reads wind speeds in excess of 20 m/s	Turbine brake engages, shutting down turbine
Storms or Monsoons	Excessive damage to turbine	L	H	Weather forecasts	Turbines structure is easily lowered ahead of storm
Wear and Tear	Damage to turbine parts; turbine may not operate	H	L	Regular maintenance inspections	Maintenance office in Gujarat can repair turbine

Table 3.3: Risk management plan.

References

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Appendix I: Financial Statments

Starting Assets

Fiberglass Forming Tools	$3,900.00
Drill Press	$1,200.00
Slip Rolls	$700.00
CNC Milling	$8,480.00
VSR MIDI Lathe	$1,854.00
Flatbed Trucks	$16,000.00
Miscellaneous	$20,000.00
TOTAL	**$52,134.00**

Income Statement

	2017	2018	2019	2020	2021
Growth in demand		100%	70%	100%	70%
Anticipated Demand	113	226	384	768	1306
Revenue	$248,600.00	$497,200.00	$845,240.00	$1,690,480.00	$2,873,816.00
COGS					
-Pipes	$48,590.00	$97,180.00	$165,206.00	$330,412.00	$561,700.40
-Concrete	$8,136.00	$16,272.00	$27,662.40	$55,324.80	$94,052.16
-Fiberglass cloth/ Resin for Shroud	$2,169.60	$4,339.20	$7,376.64	$14,753.28	$25,080.58
-Plastic Injection Molded Blades	$27,120.00	$54,240.00	$92,208.00	$184,416.00	$313,507.20
-Aluminum	$4,350.50	$8,701.00	$14,791.70	$29,583.40	$50,291.78
-Electronics	$5,650.00	$11,300.00	$19,210.00	$38,420.00	$65,314.00
-Fasteners	$2,825.00	$5,650.00	$9,605.00	$19,210.00	$32,657.00
-Delivery	$9,040.00	$13,560.00	$23,052.00	$46,104.00	$78,376.80
-Labor	$39,550.00	$79,100.00	$134,470.00	$268,940.00	$457,198.00
TOTAL	$147,431.10	$290,342.20	$493,581.74	$987,163.48	$1,678,177.92
Gross Margin	**$101,168.90**	**$206,857.80**	**$351,658.26**	**$703,316.52**	**$1,195,638.08**
Manufacturing Floor	$14,400.00	$14,400.00	$14,400.00	$21,600.00	$21,600.00
Executive Salaries	$240,000.00	$240,000.00	$240,000.00	$360,000.00	$360,000.00
EBITDA	**-$153,231.10**	**-$47,542.20**	**$97,258.26**	**$321,716.52**	**$814,038.08**
Less Depreciation	$7,820.10	$7,820.10	$7,820.10	$7,820.10	$7,820.10
EBIT	-$161,051.20	-$55,362.30	$89,438.16	$313,896.42	$806,217.98

End of Year Balance Sheet

	2017	2018	2019	2020	2021
Assets					
-Current Assets					
-Cash	$54.90	$27,932.70	$70,778.96	$138,923.48	$497,960.76
Accounts Receivable	$74,580.00	$149,160.00	$253,572.00	$507,144.00	$862,144.80
-Gross Fixed Assets	$52,134.00	$52,134.00	$52,134.00	$52,134.00	$52,134.00
-Less Depreciation	$7,820.10	$15,640.20	$23,460.30	$31,280.40	$39,100.50
-Net Fixed Assets	$44,313.90	$36,493.80	$28,673.70	$20,853.60	$13,033.50
TOTAL ASSETS	$118,948.80	$213,586.50	$353,024.66	$666,921.08	$1,373,139.06
Liabilities					
-Debt Outstanding	$250,000.00	$450,000.00	$450,000.00	$450,000.00	$350,000.00
TOTAL LIABILITIES	$250,000.00	$450,000.00	$450,000.00	$450,000.00	$350,000.00
Owner's Equity	-$131,051.20	-$236,413.50	-$96,975.34	$216,921.08	$1,023,139.06
TOTAL L+E	$118,948.80	$213,586.50	$353,024.66	$666,921.08	$1,373,139.06

Cash Flow

	2017	2018	2019	2020	2021	
CASH RECEIVED						
-Cash from operations	$174,020.00	$422,620.00	$740,828.00	$1,436,908.00	$2,518,815.20	
-New current borrowing	$280,000.00	$150,000.00	$50,000.00	$0.00	$0.00	
TOTAL:	**$454,020.00**	**$572,620.00**	**$790,828.00**	**$1,436,908.00**	**$2,518,815.20**	
EXPENDITURES						
-Operating Expenses	$147,431.10	$290,342.20	$493,581.74	$987,163.48	$1,678,177.92	
-Other Expenses	$254,400.00	$254,400.00	$254,400.00	$381,600.00	$381,600.00	
Purchase of Assets	$52,134.00	$0.00	$0.00	$0.00	$0.00	
-Repayment of Borrowing	$0.00	$0.00	$0.00	$0.00	$100,000.00	
TOTAL:	**$453,965.10**	**$544,742.20**	**$747,981.74**	**$1,368,763.48**	**$2,159,777.92**	
Net Inflow	**$54.90**	**$27,877.80**	**$42,846.26**	**$68,144.52**	**$359,037.28**	
Net Present Value	$52.29	$25,285.99	$37,012.21	$56,062.67	$281,315.11	**$399,728.25**