A Review of the Conceptual Design Process and the Analysis of the Remote Wind PSU Turbine

Prepared for:
The DOE Collegiate Wind Turbine Design Competition
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1 Design Intro/ Overview

Figure 1: Deployed Market (M152) Turbine (Without Guy Wires Shown)

The Remote Wind Power Systems Unit (PSU) is the reliable solution to electricity demand in the event of a natural disaster or emergency. This 3-bladed, direct drive, downwind micro-turbine is designed for simplicity, durability, and most of all, adaptability by optimizing its performance and minimizing the number of moving parts. The Remote Wind PSU M152 is easily dispatchable due to its compact and lightweight design insuring quick response to an emergency situation. The ability to effectively store and transport this system makes it the ideal on-hand tool for first responders like local and state police and fire stations. Because of its durability and universal interface, the M152 creates new opportunities for organizations such as FEMA and Red Cross.

Unlike most micro-wind turbines on the market, the M152 is built into a compact and ergonomic carrying case for transport to virtually any location. To ensure that the system has a small volume the tower utilizes a telescoping arrangement reducing the height of 13 feet during use to 40 inches during transport and storage.

Once erected, the tower is stabilized by guy wires eliminating the need for bulky struts or limiting base area. The turbine itself is designed to operate in a downwind orientation on a horizontal axis to achieve the low cut-in wind speed of 4 m/s and have the capability to direct itself into the wind, allowing it to always maximize the windswept area without the need of a tail.

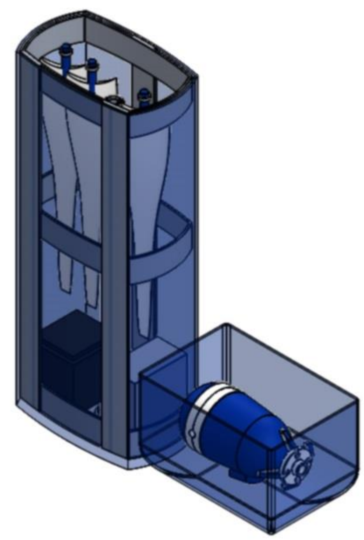


Figure 2: Stored M152 Design

Each blade of the micro-turbine can be detached for storage in a convenient carrying case, and when assembled, has a rotor diameter of 1.52 m. This allows the M152 blades to rotate at 650 rpm at rated wind speed of 11 m/s generating 441 W via a permanent magnet generator. While the wind is blowing, the power generated is stored at the base of the turbine in a 396 Watt hour (Wh) battery. The electricity produced can then be discharged through one USB outlets as well as two 12 V universal outlets.

2 Design Development

2.1 Wind Regime Analysis for Market Turbine

An important component in analyzing the product market of a wind turbine with respect to its aerodynamic performance is its intended wind regime of application. A Weibull distribution is used to statistically represent the distribution of wind speeds experienced at a representative location. A wind turbine product ought to perform flexibly in lieu of a defined location. In other words, in order for a small scale wind turbine to be profitable to a potential consumer, it must be able to extract a substantial amount of power from any wind regime.

Due to the scope of the competition, this product will be analyzed at a particular locale via a specified average wind speed. At that wind speed, we will then be able to calculate how much power and energy the wind turbine can produce for a given blade length. Before designing the turbine we estimated a coefficient of performance for the resulting wind turbine product.

A wide variety of wind regimes were considered for the market turbine, assuming a shape factor of 2 (Rayleigh distribution). Figure 3 shows the estimated daily energy availability under a variety of scale factors (λ, and thus annual average wind speeds) for varying length turbine blades. This chart was used in conjunction with the market analysis to identify the best scale of the market turbine product.

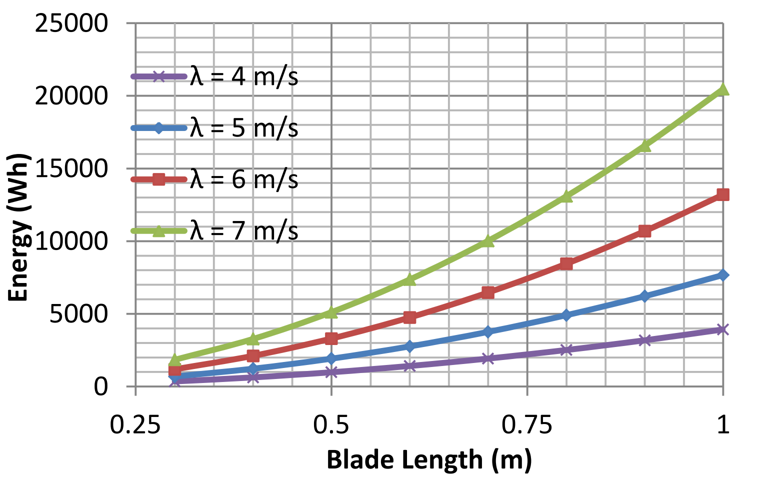


Figure 3. Daily Energy Available

Since the market turbine is ultimately focused primarily on a wind regime with an average wind speed of 4.5 m/s and a blade length of 0.762 meters, the wind turbine is expected to produce an energy output of approximately 600 to 700 Wh daily. This is important because we are then able to discuss the feasibility of the device with respect to supplying power to contemporary appliances.

A plot of a Rayleigh distribution for a 4.5 m/s annual average wind speed (~ 10 mph) will show that a wind turbine could be cut out (shutting down) at wind speeds approaching 15 m/s, because there are rapidly diminishing returns on available power above this wind speed.

2.2 Tower Design

The tower portion of our market turbine employs a telescoping design. There are five sections of tower, each an aluminum tubular section three feet long of varying diameters ranging from two to one inches. These sections can fully collapse such that each section is encased by the one immediately larger and then this is stored within the container structure for the turbine. When fully extended, the sections are held in place by steel pins that rest in holes drilled through the aluminum. The extended height of the tower is thirteen feet in total. To help with the stability of the tower, three guy wires will be used. These wires will attach to the top section of the tower via a schedule 80 PVC flange. The flange will slide over the top (smallest diameter) section of the tower and come to rest on the next lowest section. Carabiners will connect the wires to the flange. Stability of the tower is obtained by the 6” overlap between telescoping sections and tight clearances between the tower section diameters.

2.3 Container Design

The packaging was designed to encompass durability, functionality, and portability of the wind turbine. To some degree, the container is modeled after a golf bag, but with more structural support. The design for the package was optimized to utilize the space as efficiently as possible. Once the payload was determined, the outer shell was designed, and an aluminum frame was incorporated for structural stability. While a fabric shell is an option if weight optimization is critical, it is in our business model that composite paneling or an injection molded plastic will be used to insure the safety of the contents inside while minimizing weight penalty. The removable covering was integrated to allow for secure storage and

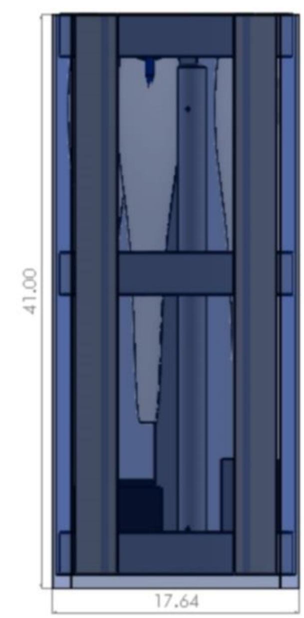


Figure 4. Diagram of M152 Container

tower access. The total weight of the package ranges from 30lbs to 50lbs due to dependence on the specific material properties.

Table 1: Comparison in Shell Materials for Container Design

Characteristic	***Material Comparison***	
	Composites ST94 - SPRINT	Plastics Liquid Crystal Polymer
Weight	~10lbs added to overall weight of package	~14lbs added to overall weight of package
Pros	High durability, low maintenance required, very light weight.	Much cheaper to create mold and low cost materials.
Cons	• High initial cost for mold. • Added material cost raise the price of overall product.	• Low durability, and ductile. • Heavier than composites

2.4 Generator Selection

For the test turbine, the generator was specified by the CWC organizers as an AMMO GPMG5225 motor. Because of the extraordinarily high speed requirements of this generator, and therefore the need for a gearbox to allow for a slower rotational speed on the wind turbine rotor design, a different generator was selected for the market turbine design. An extensive search was conducted for an optimal combination of rpm's on the order of 500, weight on the order of 10 lbs, and size less than 7 inches in diameter plus low potential cost of production. The machine which was chosen for the basis of the design of our market turbine's rotor aerodynamics was modeled after the characteristics of a MOOG AG-5250-C-1ES generator.

2.5 Aerodynamic Rotor Design

$$C_{p,r} = \frac{P_r/Eff_r}{0.5 * \rho * {U_r}^3 * \pi R^2} \quad (1)$$

$$\lambda_p = \frac{RPM_r * 2\pi}{U_r * 60} R \quad (2)$$

Utilization of Eq. 1 determines the extracted power coefficient from the blades, it takes in account for the rated generator power (P_r), generator efficiency (Eff_r), density (ρ), rated wind speed (U_r), and the swept area of the rotor (πR^2). With a given rpm, rated wind speed, and total blade length (R). Eq. 2 was used to determine the TSR at rated power. These functions combined, generate the resulting aerodynamic parameters based on the generator characteristics as shown in Figure 5 for the market turbine design.

By examining the radius and power coefficient curve the ideal design TSR was needed to produce the rated power of the generator and the optimum power coefficient. Using a cut-off design radius of 0.762 m (which was decided upon based on the initial market analysis results), and examining the power coefficient curve, it was found that an ideal design TSR for the market turbine is λ_p = 5.20, and $C_{p,r}$ = 0.40 shown in Figure 5.

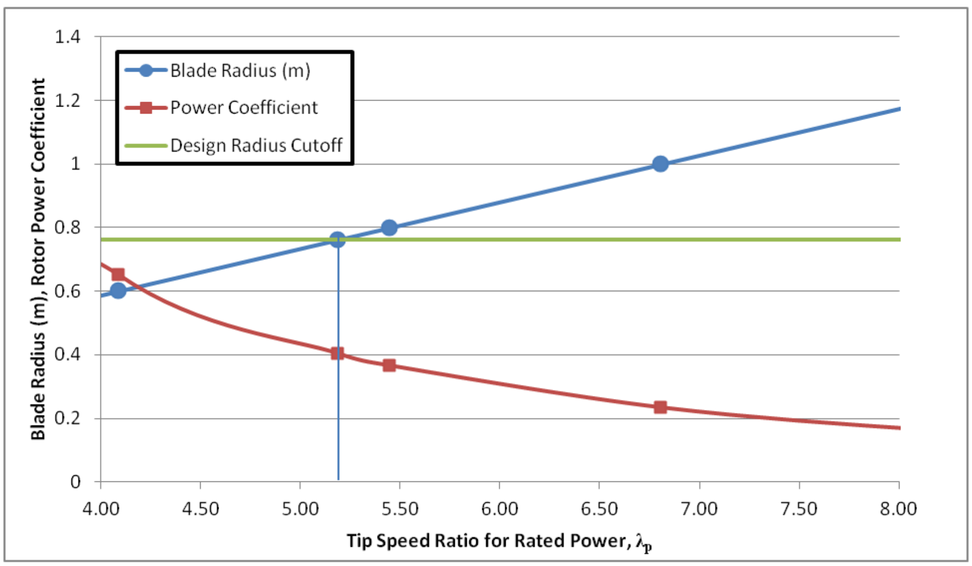


Figure 5. Variation in Power Coefficient and Blade Radius with TSR for Rated Power

These parameters were inputs for the blade optimization code used to determine chord and twist distributions. A TSR of six was selected from this analysis in combination with analyzing data from an ideal Betz rotor analysis and using an operating angle of attack determined from the C_l/C_d plots of our chosen airfoil, the Selig-S4094. A detailed breakdown showing the technical specifications for the two turbines is shown in Table 2.

Table 2. Technical Specification differences between the Test and Market-scale turbine.

	Test Turbine	***Market-Scale Turbine***
Rated Power (W)	30	441
Rated Wind Speed (m/s)	14	11
Rated Speed (rpm)	1600	650
Rotor Diameter (m)	0.45	1.52
Type	Downwind rotor with stall regulated control	
Rotation Direction	Clockwise looking upwind	
Blades	Solid Concepts PolyJet HD	Fiberglass Injection Moldeing
Max Tip Speed (m/s)	70.5	80.0
Alternator	AMMO GPMG5225	MOOG AG-5250-C-1ES
Yaw Control	Passive	
Battery Charging	5V	12V
Braking System	Passive Stall Regulation with Relay Switch Controls	Electronic Stall Regulation with Relay Controls
Cut-In Wind Speed (m/s)	5	4
Survival Wind Speed (m/s)	20	25
Tower Type	N/A	Guyed Tubular
Tower Height (m)	N/A	3.5

2.5.1 Blade Design Optimization

A blade optimization code, from the book *Small Wind Turbines* written by David Wood, was used to determine the chord and twist distributions of the blade. Several inputs were required to run this code. One of the more important inputs is an airfoil data file, which includes coefficient of lift and drag values at different angles of attack for a variety Reynolds numbers. Other input variables include design wind speed, cut-in wind speed, tip speed ratio, number of blades, and blade radius. The most important variable, is the fitness score, A, varying from zero to one. The closer the value is to one, the more the code will design for power output. If the value is closer to zero, the code will design for startup time.

The code operates by randomly creating an initial blade population. Then new blades are bred based on the more fit blades of the previous generation. The more fit blades are then kept while the less fit are eliminated from the population. This goes on for the specified amount of generations, and the result is a "best blade." There are in reality a few "best blades" and the mean values between each blade are taken to determine the distributions of chord and twist.

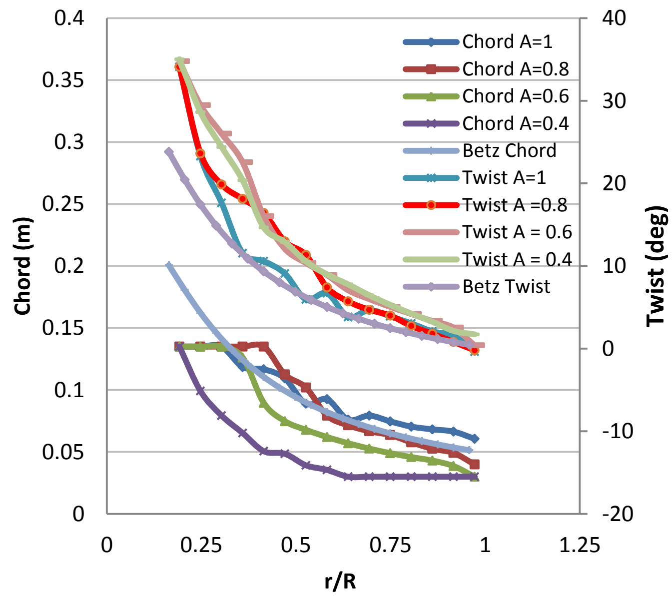


Figure 6. Chord and Twist Distribution for a variety of A values and Betz Optimum Chord and Twist Distribution

The code was run for a variety of *A* values. These distributions were then plotted against one another, as well as a Betz optimum distribution. The chord and twist distributions can be seen in Figure 6. By analyzing the results for the different *A* values, a blade design can be chosen based on chosen parameters, such as power output, startup time, and production cost.

The main focus of the design is to optimize the amount of outputted power and achieve a low startup speed, so a midrange value of *A* is preferred. However, production cost is an almost equally as important factor. The higher values of *A* are generally thicker than the lower values, which increases the production cost. A thicker inboard section of the blade is also needed to ensure that it does not break due to bending moments as well as generating enough lift to have a low start up time. Due to these constraints, the chord distribution that was chosen was the one where *A* is equal to 0.6. This distribution allows for a high power output compared to the other values of *A* as well as limiting the production cost. The corresponding twist distribution was also the one chosen to be used.

The same process was done for the market turbine, however power output was deemed more important. A higher value of *A, 0.8,* was selected because of this. The resulting output for the chord distribution was more constant than the market blade design. The higher relative torque for the test turbine is greater, which results in a thicker blade being needed throughout the entire radius.

2.6 Test Turbine Drivetrain & Electrical Configuration

While the aerodynamic design process was nearly identical for the test and market turbines, the drivetrain design for each turbine was quite different due to the decision to make the market turbine a direct drive machine. The following section breaks down the approach to designing the drivetrain and electrical configuration to achieve 5 V and 10 W of power output for the test, or competition turbine.

The subsystems that make up the electrical system are the AC to DC conversion, the breaking control, and the voltage regulation. The first stage, AC to DC conversion, was accomplished through testing several methods of rectification. To test several designs, multiple rectifiers were constructed and tested with a dynamometer (Figure 7). A three-phase rectifier was built, tested, and proved to be the best design in terms of meeting the size limitations and had a reasonable efficiency.

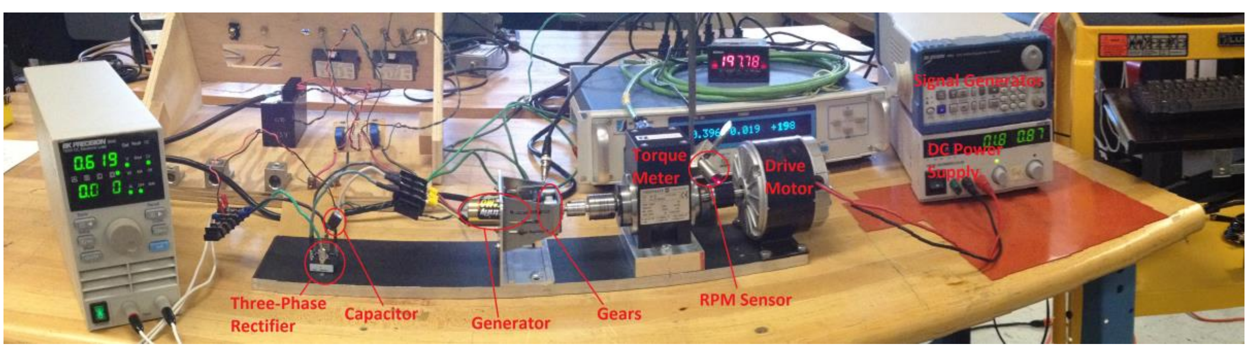


Figure 7. Dynamometer Testing Unit

The dynamometer was also used to determine the power required to turn the motor at varying gear ratios and rotor speeds. By recording the current and voltage load, Eq. 3 was used to calculate the load power, P_{load}, while the recorded torque was used to calculate the mechanical power, P_{mech}, via Eq. 4. Using an applied load and a gear ratio of 3.1:1, the desired voltage output of 5 V was not achieved (see Figure 8).

$$P_{load} = V_{load} * I_{load} \quad (3)$$

$$P_{mech} = \Omega * \tau * 2\pi/60 \quad (4)$$

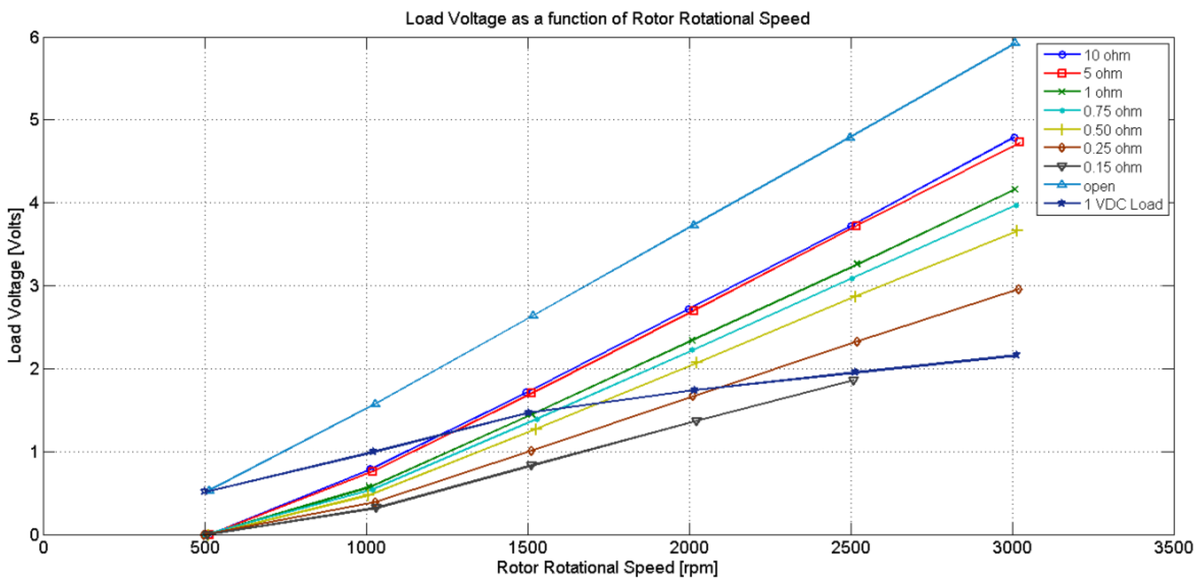


Figure 8. Voltage vs Rotor Speed

Because the goal of 5 V for the competition was not achieved by the stated gear ratio, two alterations were proposed and tested as possible solutions. The first solution was to incorporate a voltage booster to the electronics of the turbine. However, to withstand the amount of current associated with the 5 V requirements, six of the proposed voltage boosters configured in parallel would be required, decreasing the individual efficiencies of the boosters. In addition, the power required from the rotor would have to increase which was not acceptable. The alternative and most promising solution was to increase the gear ratio to a value much higher than initially designed. Ideally, increasing the gear ratio to a value higher than 3.1:1 would greatly increase the power output without increasing the power required from the rotor to an undesirable amount.

In order to achieve an output voltage, the generator must overcome a static resistance which was indicated by the specifications of the motor and gears as 0.03 N-m. A 6.94:1 ratio is currently what has been chosen for our design such that this resistance can be overcome but still achieve the 5V requirement, although this is still under test as of report submission. Results for the wind tunnel test of the final test turbine design will be discussed in section 4.

2.7 Performance of the M152 Market Turbine

The M152 turbine was analyzed with WT_Perf to gather performance data on the power output predictions through various wind speeds shown in Figure 9. Each solid line represents the predicted power output performance along varying RPM at particular wind speeds. The electro-mechanical curve represents the theoretical rotor input to the generator as the RPM increases.

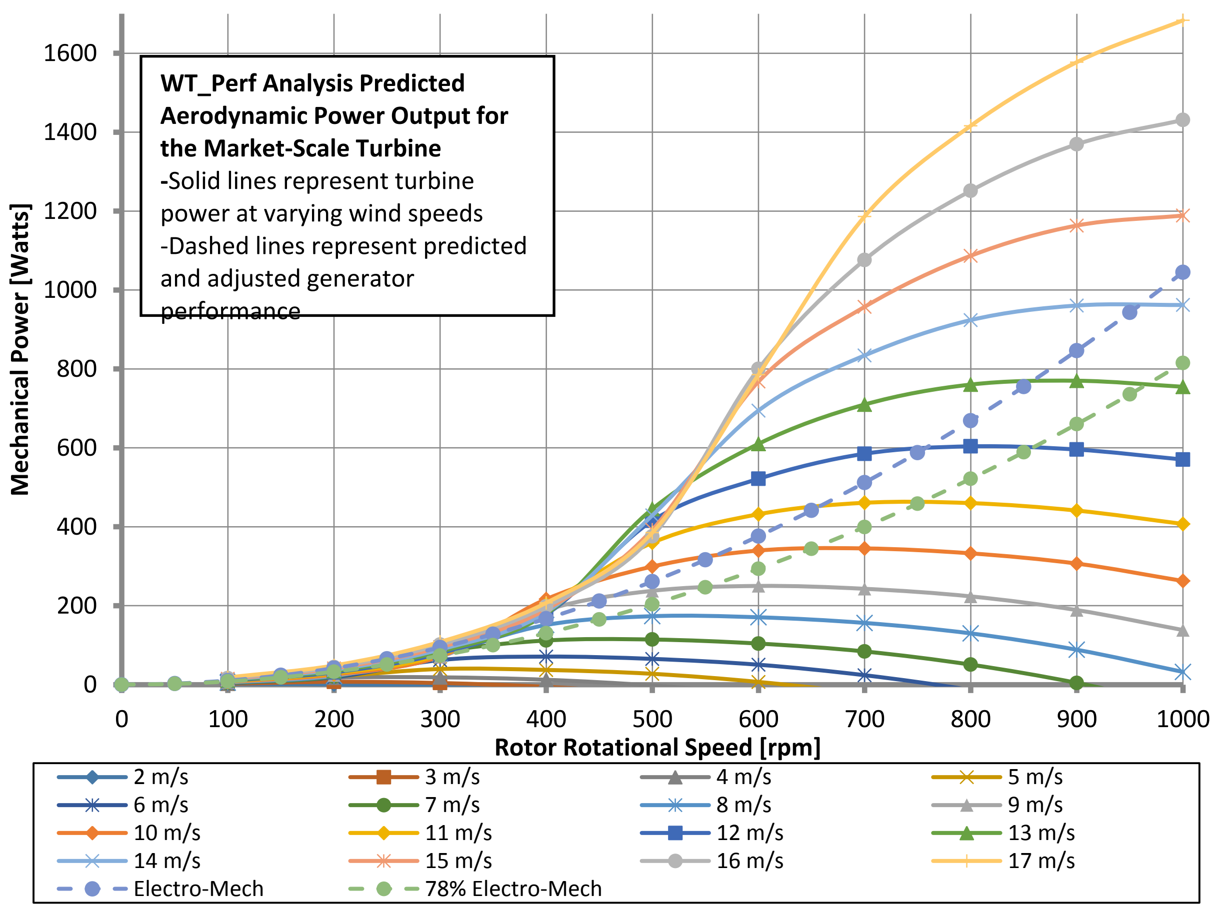


Figure 9: Predicted power output performance as a function of RPM at various wind speeds

The rotor was designed for a rotational speed of 650 RPM which corresponds to the 11 m/s power curve. The generator has an efficiency of 78% so the resulting power output produced at the rated RPM is situated at the peak of the 10 m/s design wind speed curve.

Figure 10 shows the power curve for the M152 turbine. The rated power for the market scale turbine was found to be 441 Watts at a wind speed of 11 m/s. This number was determined by co-locating points from Figure 9 to create a plot of power generated at varying wind speeds.

Data points on the generator curves were matched with corresponding wind speeds on the aerodynamic plot to determine the power curve data points. The wind speed of 11 m/s was used to conform to Small Wind Certification Council standards.

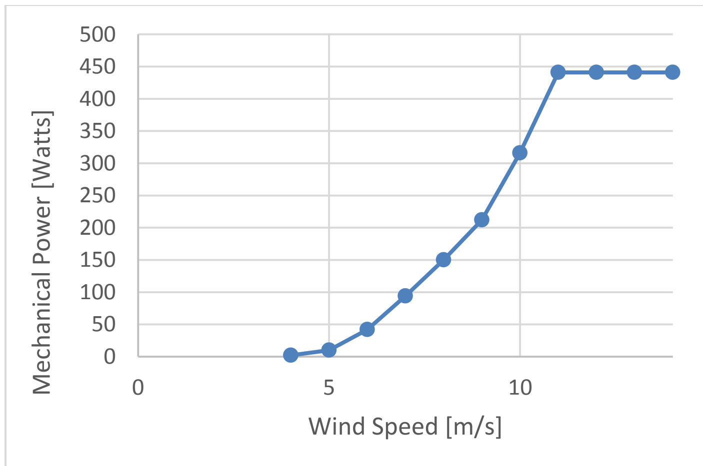


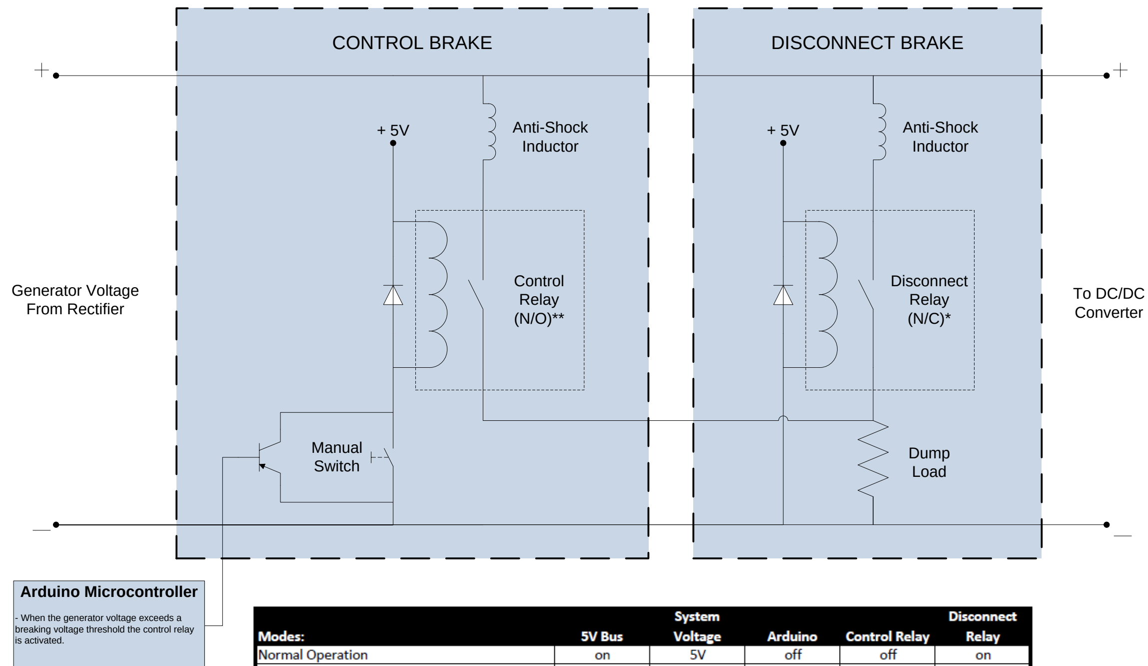
Figure 10: Predicted M152 Power Curve

2.8 Controls

The power control system is a major component of both the M152 and test turbine as it provides the functionality of converting power from variable power in the wind to regulated voltage for energy storage. In order to make our product competitive in the market, the M152 must utilize novel control approaches to ensure that the product is performing safely and efficiently at a reasonable cost.

To test the most basic components of the M152 control system several components were scaled for operation on the competition test turbine.

Power generated by the permanent magnet generator will be provided to the system as a 3-phase AC source. For battery storage this AC power signal must be converted to DC power using a three-phase rectifier. Coming out from the 3-phase rectifier, the DC voltage will be passed through an A/D converter controlled by an Arduino device. The controller then compares the measured voltage to voltages which would be consistent with a stable 5V DC load connection. If the load connection is outside of reasonable bounds then the disconnect brake relay will be excited; otherwise the wind turbine will operate normally. The test turbine will also operate a brake relay system which can be excited manually using a user switch. The switch state will be monitored by the Arduino controller which then provides excitation to the control relays when necessary. A more detailed representation of the control and disconnect brake systems are shown in Figure 11**Error! Reference source not found.**.



Modes:	5V Bus	System Voltage	Arduino	Control Relay	Disconnect Relay
Normal Operation	on	5V	off	off	on
Overspeed (Voltage too high)	on	High	on	on	on
Manual Shutdown	on	5V	off	on	on
Disconnect	off	0V	off	off	off
Disconnect with Manual Shutdown	off	0V	off	off	off

*disconnect relay is normally closed; a system voltage of 0V will close the relay (off) allowing current to pass through the dump load

NOTES:
*N/C indicates a normally closed contact relay
**N/O indicates a normally open contact relay

Figure 11. Break system configurations

The functionality of the test turbine control system provides the foundation upon which a more advance control system can be developed for the M152 wind turbine. With an appropriate control algorithm, the power output of the wind turbine can be optimized for various combinations of operational wind speeds and rotor rotational speeds; commonly called maximum power point tracking (MPPT). It is also necessary to minimize loads in high wind conditions which would otherwise cause damage to structural and electrical systems. Pulse width modulation (PWM) is the method most commonly used to provide MPPT and over speed protection.

The M152 has been designed to generate power up to a maximum wind speed of 17 m/s while maintaining a rated power of 441 W. When the wind speed exceeds 17 m/s, or the 500Wh battery is full, the smart controller switches the load to a diversion sink to manage excess power. If the wind turbine was to reach rotor speeds that may cause damage or compromise the safety of the user, the breaking system ensures that the system can safely shutdown..

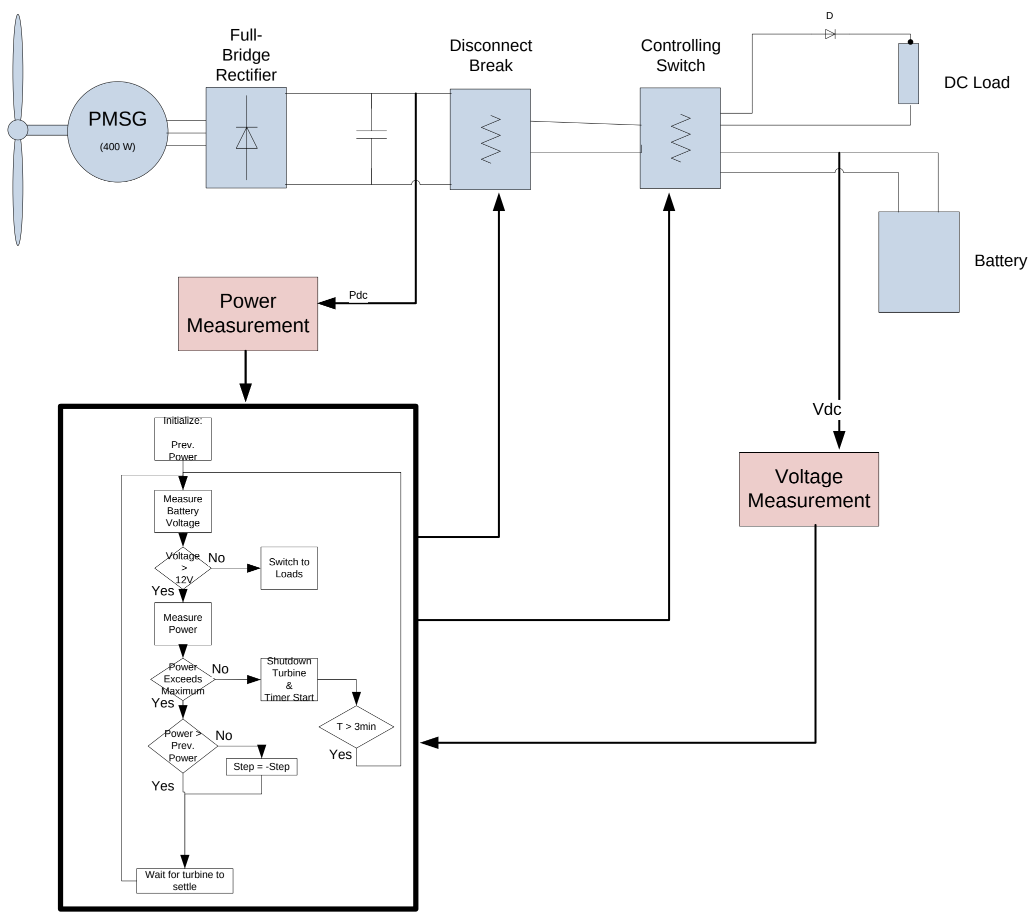


Figure 12. Overall configuration for the market product

Present in the Test Wind Turbine and the M152, a diode bridge rectifier is used to convert AC power to DC power. This conversion system is located in the nacelle of the turbine in order maximize the "plugand-play" functionality of the system. From the nacelle, the DC circuit is connected to a system of brake relays which are controlled by the control algorithm. Finally, the DC load switch, followed by the diversion load and batteries concludes the system.

The control algorithm will play three roles and the highest priority function is always related to safety. The controller will measure the power across the DC circuit after the rectifier and compare the power with the data stored in the memory. When the measured power is greater than what the turbine is generated at the cut-off wind speed, the braking relay will pulse-brake the circuit, slowing the rotational speed of the turbine. If a high output state exists for more than 30 seconds an over speed state will be entered and the turbine will shut down. At the same time a timer will start and count for 3 minutes. After 3 minutes, the controller will start the turbine again and see if the wind speed is still too high for the turbine to operate safely.

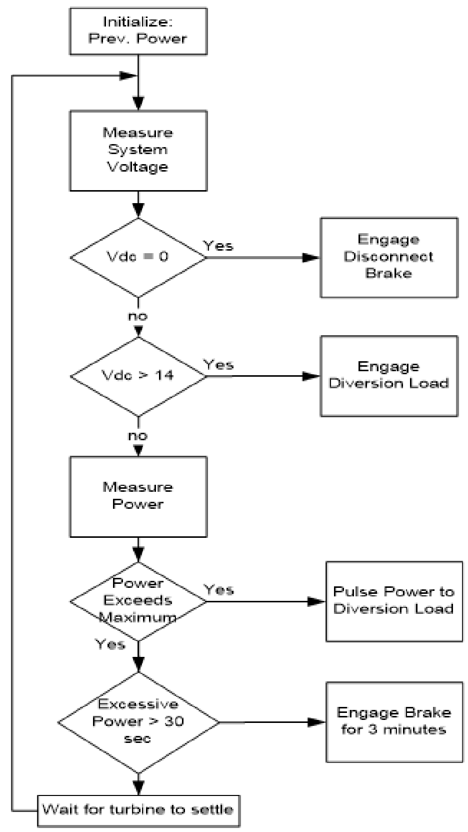


Figure 13. Flow chart for the control algorithm

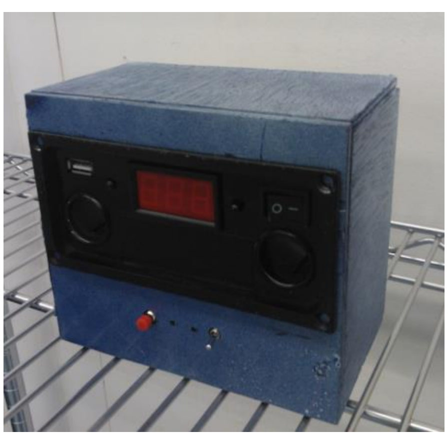


Figure 14. Control interface prototype

In addition to safety, operational efficiency is also very important. Since our product has a fixed pitch blade configuration, the only way to control the RPM is to vary the load in the circuit. Through utilization of the power measurement, the algorithm will compare the value with testing data and keep the turbine following the preferred power curve by switching on and off the DC diversion load. In addition to the functions on the controller of the test turbine, the controller on the market product will also measure the voltage of the batteries. If the batteries are fully charged, the controller will disconnect them and turn on the diversion load. The overall configuration for the market product and the flow chart for the control algorithm are shown in Figure 12 and Figure 13.

To allow users to easily access the power outlet, a user interface has been designed and a prototype has been built (Shown as Figure 14). Since 12 Vdc auto outlets and USB ports are both universal power outlets, the interface includes two 12 V power outlet and 1 USB port. In order to monitor system charge levels an LED voltage readout is included. The user may also monitor control states and turn-on/off the controller via a system of LED indicators and manual switches. The battery is rated at 33 Amp hours. Assuming a 15W load on the system and fully charged batteries the interface could charge all of these devices over a period of at least 11 hours.

2.9 Structure

2.9.1 Blade Structural Analysis

The International Electrotechnical Commission safety standard for small wind turbines (IEC 61400-2) was utilized to determine the fatigue load models for the market scale turbine. IEC 61400-2 defines a small wind turbine as having a rotor swept area of less than 200 m^2 which correlates to a rated power generation of less than 50 kW. IEC 61400-2 standard allows for the determination of turbine structural safety through three distinct methods: 1. The ‘‘Simple Load Model’’ (SLM) which combines straightforward equations for the main fatigue loadings while introducing high factors of safety. 2. Aero-elastic Modeling which uses more advanced computer modeling of wind turbine loads in response to a variety of stochastic inputs. Implementing this method can be very costly and time consuming, and is used primarily on large-scale instead of small-scale wind turbines. 3. Performing field testing to determine real-time load measurements, and predictions for extreme conditions.

We chose to incorporate the SLM method for our fatigue analysis because it is unique to small-scale wind turbine design as well as an inexpensive and effective alternative to Aero-Elastic modeling. The sacrifice to using the SLM method is the inherent inclusion of high safety factors. It should be noted that the SLM can only be implemented to horizontal axis turbines with two or more cantilevered rotor blades on a rigid hub. This approach was valid for our design since our product is a horizontal axis, three-bladed turbine. There were nine separate design load cases that were analyzed to determine the structural integrity of the market turbine, which are shown in Table 3.

We utilized an Excel spreadsheet that was included with Small Wind Turbine textbook (Wood, 2011) to run the calculations for each of the nine load cases. Parameters such as design rotational speed, wind speed, and shaft torque as well as maximum yaw rate and rotational speed were first determined from various user defined inputs, and the load calculations were then calculated and were presented on an individual pass/fail criterion.

Table 3: The Design Load Cases of the Simple Load Model (Wood, 2011)

Design Situation	Load Case	Description	Type of analysis
Power Production	A	Normal operation	Fatigue
	B	Yawing	Ultimate
	C	Yaw error	Ultimate
	D	Maximum thrust	Ultimate
Power Production plus occurrence of fault	E	Maximum rotational speed	Ultimate
	F	Short at load connection	Ultimate
Shutdown	G	Shutdown (braking)	Ultimate
Parked (idling or standstill)	H	Parked wind loading	Ultimate

These parameters determined the blade and shaft loads for fatigue, yaw, maximum thrust, and maximum rotational speed, shutdown braking, shorting, and parking [1]. These loads coupled with the shaft dimensions, root dimensions, material strengths and blade section inertia calculates the equivalent stresses for each of the blade and shaft loads. These stresses determine the fatigue damage during a given product lifetime (assumed to be 15 years for the market turbine). This fatigue damage determines if the wind turbine can sustain a given amount of fatigue during its tenure. If the fatigue damage is less than the material stress or fatigue damage limits, the turbine is designed properly; otherwise, it is must be redesigned to meet this requirement.

2.9.2 Tower Structural Analysis

For analysis of the tower, the design was simplified and modeled as a single tapered pole. Buckling of the pole was calculated using the equation:

$$P_{cr} = \left(\frac{d_b}{d_a}\right)^{2.67} \left(\frac{\pi^2 E I_a}{4L^2}\right) \quad (5)$$

Where P_{cr} is the critical load that induces buckling, d_b is the diameter of the pole at the base, d_a is the diameter of the pole at the top, E is the modulus of elasticity, I_a is the moment of inertia at the top of the pole, and L is the length of the pole.

A critical load of 358.56 lbs was calculated, which is more than sufficient to support the nacelle without buckling. The ground anchors were selected for their load capacity and small size. Each anchor has a vertical pullout resistance of 400 lbs in asphalt/hardpan and 200 lbs in dense sand or gravel. This load capacity will be sufficient for several types of soil with the calculated tension from the guy wires.

3 Wind Tunnel Tests

Following our dynamometer tests, the next step was to go to a wind tunnel to perform testing, and the setup is shown in Figure 15. The test data recorded with higher gear ratios in the wind tunnel are shown in Figure 16. One feature that helps us significatly is that the blades can be pitched although this increases the feathering of the blades it is able to increase the torque that is produced. The figure shows that a gear ratio can be matched with the blade pitch to produce the systems optimal conditions, which is helped from data from our dynometer tests. As shown in the figure no matter what higher gear ratio or pitch that was used the 10 watts needed for the competition is possible. Therefore the criteria that is most looked at after that is start up wind speed. With the definition that we used for startup speed is the wind speed which power is started to be produced. Many of the configurations started at about 5 m/s and the most promising gear ratio and pitch is the 6.94:1gear ratio and pitch position +1. Although we are hoping to improve the startup speed from the current 5 m/s wind speed before the competition.

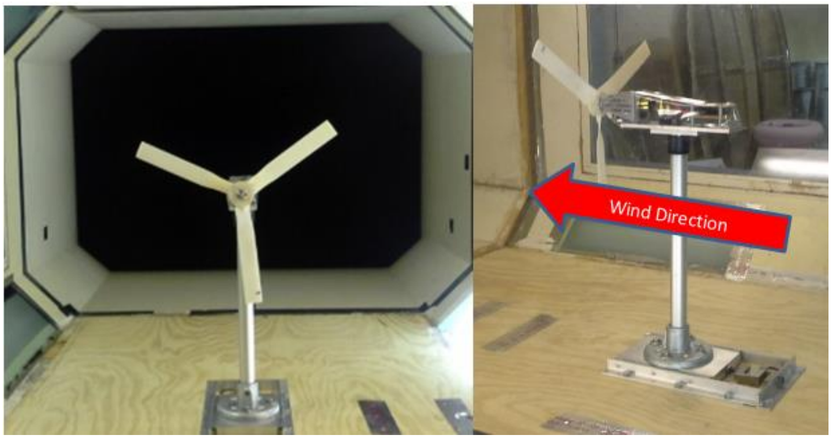


Figure 15. Wind tunnel view

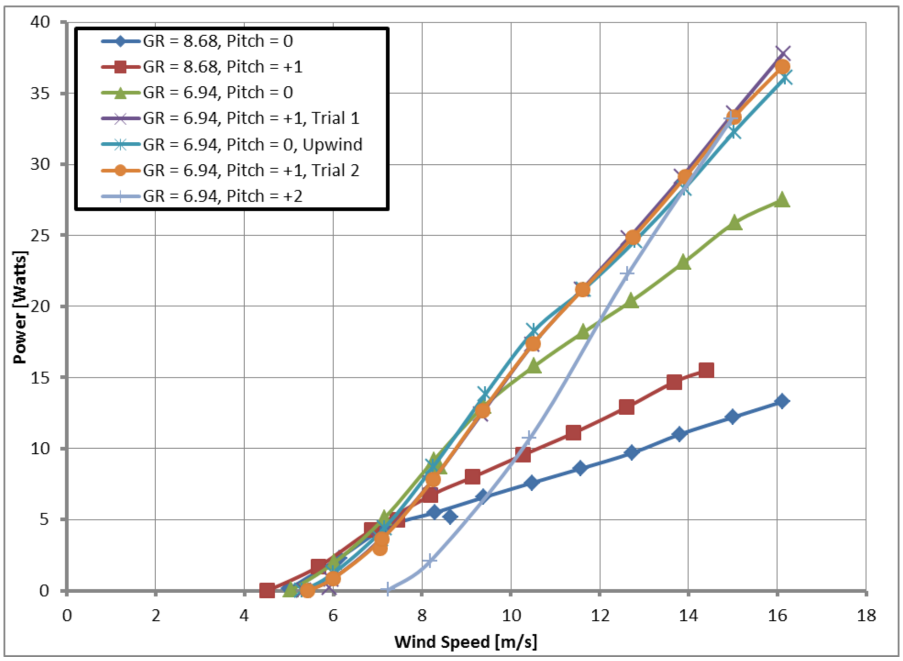


Figure 16. Higher Gear Ratio Power Curve

While there is a slight difference in the pitch positions with the same gear ratio, a major difference is that the gear ratio is changed, this can be seen from Figure 16. The changes in gear ratio allow a great difference in RPM that the motor is allowed to run at. However, the pitching position does impact this as well. Most of the difference in the pitching position is the start up speed and the top RPM speed at which the rotor can run. This is expected to occur since the pitch is increased throughout the blade with the higher pitch position, helping the startup RPM with some limitation. This pitching as mentioned before increases the feathering causing the blade to have to push more air as the RPM increases, decreasing the ability to produce extra power.

4 Design Team

The design team was organized into several subtasks which were managed by the PI and Co-PI as well as the Ph.D. student TA. These teams are summarized in the following table with the year and major of each team member noted.

Table 4: Remote Wind PSU Design Team Members

Rotor Aerodynamics			
	Mike Popp	senior	Aerospace Engineering
	Parth Patel	senior	Aerospace Engineering
	Steve Flinchbaugh	senior	Aerospace Engineering
	Jacob Lampenfield	senior	Aerospace Engineering
Test Turbine			
Structural Design & Integration			
	Greg Liptak	senior	Aerospace Engineering
Controls			
	Yande (Armstrong) Liu	senior	Aerospace Engineering
	Donghuan (Travis) He	senior	Electrical Engineering
Drivetrain			
	Grant Schneeberger	senior	Aerospace Engineering
	Kevin Knechtel	senior	Aerospace Engineering
	Jeremy Ogorzalek	senior	Mechanical Engineering
	Tryan Hammerschmitt	senior	Aerospace Engineering
	Russell Hedrick	senior	Engergy Engineering
Market Turbine (M152)			
Tower Design & Construction			
	Sahil Desai	freshman	Aerospace Engineering
	Jeremy Ogorzalek	senior	Mechanical Engineering
Concept Design and Integration			
	Ken Palamara	senior	Energy Engineering
Container Design & Construction			
	Path Patel	senior	Aerospace Engineering
	Greg Liptak	senior	Aerospace Engineering

As the concept for the market turbine came to fruition, and the lessons learned from the test turbine design also helped form the basis for some of the design considerations in the market turbine, many of these team members also contributed to the market turbine design. The entire rotor aerodynamics team applied the same design procedure which they had learned in the test turbine design to the market turbine design. We also had some additional team members concentrating specifically on the market turbine design, as shown in the table above.

The team brought a diverse set of skills to the design. We had two team members with significant CAD experience. We also had a team member with a structural internship experience and one has gotten is also working on another project on the design of a 50 ft guyed anemometer tower. He was often able to apply what he was learning from one group directly to our team.