



Project Number: P12401

WIND ENERGY COLLECTION TO ENERGY BANK (WECEB)

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ABSTRACT

In this document, we present a transportable charging solution for a sealed lead acid battery. This was accomplished by using wind power as a renewable energy source. The purchased wind turbine and battery were chosen in order to supply enough power to the Charging Dock and Power Control (CDPC) sister senior design team. The resulting power that is stored within the WECEB system and consumed by the CDPC team will eventually be used to power future RIT Mechanical Engineering Undergraduate Course projects.

For the purposes of this project, an off-the-shelf wind turbine and lead acid battery was purchased. A 10 foot turbine stand was designed and built by the WECEB team. This stand has been engineered to exceed the survival wind speed of the wind turbine as well as the highest sustained wind speed the Rochester area sees near ground level. In order to monitor the state of charge of the battery the WECEB team also designed a printed circuit board. This circuit board contains LED's which display the battery's present charge. This will not only protect the battery from being discharged too much, but it will also let the CDPC team know when it is or is not capable of drawing power from the WECEB battery.

While indoor and outdoor wind testing did not yield thorough results, spinning the hub of the wind turbine with a power drill exceeded the power generation requirements. Systems integration between the WECEB and CDPC projects also proved successful in the transfer of electrical energy.

NOMENCLATURE

CDPC - Charging Dock and Power Control
HAWT – Horizontal Axis Wind Turbine
KGOE – Kate Gleason College of Engineering
LED – Light Emitting Diode
LVE – Land Vehicles for Education
MCU - Microcontroller
MPPT – Max Power Point Tracking
MSD - Multidisciplinary Senior Design
PCB – Printed Circuit Board
PCBA – Printed Circuit Board Assembly
SESE – Sustainable Energy System for Education
SLA – Sealed Lead-Acid
WECEB – Wind Energy Collection to Energy Bank
WOCCSE – Wireless Open Source / Open Architecture Command and Control System for Education

INTRODUCTION

Over the past several years, the desire and push to be “green” has increased at an astronomical rate. Hybrid-electric vehicles, biofuels, renewable energy, and sustainable systems are being implemented in every

environment imaginable. With RIT’s goal to be one of the most innovative, cutting-edge institutions, it comes as no surprise that they are expanding their reach into the field of sustainability. This is not only evident with the new construction projects throughout campus, but also the SESE family of projects in the MSD program. The goal for the SESE family of projects is to design, develop, build, test, and deliver interchangeable sustainable energy technological solutions. These technologies will be used by future senior design teams and undergraduate engineering class projects in the KGCOE, beginning fall semester 2013. The SESE projects should represent an integration of the six core technologies that make up a sustainable system: Capture/Collection, Conversion, Storage, Transmission, Management/Control, and Consumption. With these core functions, opportunities exist for various technological solutions to allow for the execution and integration of numerous modular SESE systems and elements. All work produced is in an open source/open architecture format, encouraging the use of these technologies by others. This project, P12401: WECEB, is one of the first projects defined in this groundbreaking family.

The WECEB project is intended to have a wind collection system that will take the potential power out of the wind and store it in an energy bank. The energy bank’s power will be consumed by the sister team, P12402: CDPC. As a result, interfacing between the two teams is essential. Safety is of utmost importance for the people who will be installing, using, and performing maintenance on the system. The WECEB was designed to be modular so subsystems can be replaced or added and the system will remain functional.

Systems related to the collection of wind energy, commonly consist of a bladed wind turbine that transmits electrical power to a battery bank. The power stored by the system can then be used whenever it is needed. Due to design specifications and time constraints, the WECEB team decided to go with the commonly seen set-up of a pre-manufactured wind turbine and a sealed lead acid battery. The power generated and stored within the battery will allow RIT to power future undergraduate projects such as the LVE with sustainable energy.

DESIGN PROCESS

In order to choose the correct wind turbine design, the wind availability in Rochester had to be assessed. According to Betz Law, no wind turbine can extract more than 59% of the energy present in the wind. Wind speed increases as height increases by the Power

Law Profile which can be seen in Equation (1) below. [1]

$$\frac{V}{V_0} = \frac{h}{h_0}^\alpha \quad (1)$$

Where V is the velocity of the wind, V_0 is the initial reference velocity at some known height, h is the height at velocity V , h_0 is the initial height at which V_0 is the velocity, and α is a friction coefficient. This friction coefficient is different for urban settings, flat land, tree surroundings etc. As an example, α is equal to 0.25 for trees and bushes surrounding the area of a wind turbine. A usual α is around 1/7, meaning that wind speeds are double at a 50 meter height than at a 10 meter height.

Wind Analysis

Wind information was sourced from AWS Truepower windExplorer™. [2] AWS Truepower was used by the previous P11401 team for their analysis, as well as the Renewable Energy Systems course offered at RIT.

The AWS Truewind site allows you to select a location and get average wind speeds at various heights. The results are shown below in Fig. 1 for a location within RIT’s campus. Moving the chosen point around RIT’s campus changes the wind speed values minimally.

Estimated Wind Resource and Annual Net Energy

Wind Resource	80 ft (24.4 m)	100 ft (30.5 m)	120 ft (36.6 m)
Average Annual Wind Speed	10.02 mph	10.63 mph	11.16 mph
Annual Net Energy	80 ft (24.4 m)	100 ft (30.5 m)	120 ft (36.6 m)
Rotor Diameter 5-10 ft	200 kWh - 800 kWh	300 kWh - 1000 kWh	300 kWh - 1200 kWh
Rotor Diameter 10-20 ft	800 kWh - 3300 kWh	1000 kWh - 4100 kWh	1200 kWh - 4800 kWh
Rotor Diameter 20-30 ft	3300 kWh - 7500 kWh	4100 kWh - 9100 kWh	4800 kWh - 10800 kWh
Rotor Diameter 30-40 ft	7500 kWh - 13200 kWh	9100 kWh - 16300 kWh	10800 kWh - 19200 kWh

Figure 1: Average wind speeds for RIT’s campus

With these given average wind speed values, the friction coefficient (α) could be found by using Equation (1). V and V_0 being any of the two given average wind speeds, and h and h_0 being the respective heights of those wind speeds. Since alpha is the only unknown, it can be solved for. It came out to be 0.2611, which is typical for a low woodlands, slightly hilly area.

$$\frac{4.47 \text{ m/s}}{4.74 \text{ m/s}} = \frac{24.4 \text{ m}}{30.5 \text{ m}}^\alpha$$

$$\alpha = 0.2611$$

Then, with one given average wind speed, its respective height, and the calculated alpha, any user input height could be put to the same equation. Now

the only unknown is the velocity at the user input height, which can be solved for.

$$\frac{V@3m}{4.74 \text{ m/s}} = \frac{3 \text{ m}^{0.2611}}{30.5 \text{ m}}$$

$$V@3m = 2.59 \text{ m/s}$$

The 2.59 m/s value is the average annual wind speed at 3 meters above the ground for the RIT area.

To check this information, the probability of wind speeds at various heights can be generated. Assuming a Rayleigh case of the Weibull probability density function, this probability is defined as Equation (2).

$$v_{wind} = e^{-\left(\frac{v_1}{c}\right)^2} - e^{-\left(\frac{v_2}{c}\right)^2} \tag{2}$$

Where $c = 2 * Avg / \sqrt{\pi}$, v_1 and v_2 are wind speeds, and Avg is the average wind speed at any given height obtained Equation (1). [3]

The probability of each wind speed can be multiplied by the total number of hours per year (8760) to yield the total hours that each wind speed value is expected to occur each year. Figure 2 shows the expected wind speed distribution in Rochester at a hub height of 3 meters. This height was chosen to determine values at low-end wind speed results.

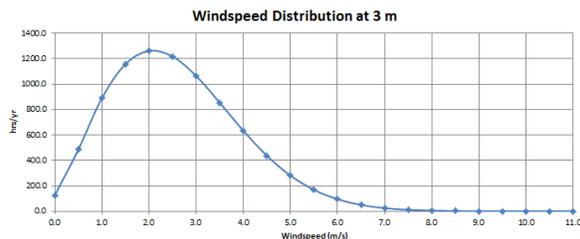


Figure 2: Rochester wind speed distribution at 3 meters above ground level

This analysis shows that the most probable wind speed for Rochester is about 2 m/s at a hub height of 3 meters. Finding the average of all these wind speeds will result in a value of 2.59 m/s, verifying the earlier calculation. In order for the wind turbine to be able to operate in these sorts of conditions, one had to be sourced with a low start up speed and enough wattage output at low sustained wind speeds.

Turbine Selection

The Nature Power 400 Watt Wind Turbine was the purchased turbine assembly for this project. The manufacturer’s website can be found in the following link. <http://www.naturepowerproducts.com/product->

[details.php?id=83](http://www.naturepowerproducts.com/product-details.php?id=83). An image of the wind turbine can be seen in Fig. 3. The diameter of the blades is roughly 4 feet (1.22 meters) and the total weight is around 20 pounds (9.07 kg), so it will help keep this system at a transportable level.



Figure 3: Nature Power 400 Watt Wind Turbine

The entire Nature Power kit includes a turbine along with a max power point tracking charge controller (MPPT). This additional unit will protect the SLA battery from overcharging or over-discharging as well as preserving the turbine. In high wind speeds, it will brake the turbine by the means of short circuiting. A stop switch that is included will also be put within the system for much simpler manual shut down.

Power output from the turbine can be seen in Fig. 4 below. The blue plot is the given power curve for a 12 volt nominal system from Nature Power. It displays a wattage output from the turbine at various wind speeds.

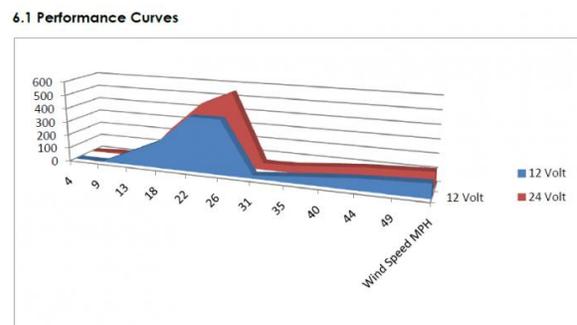


Figure 4: Nature Power Wind Turbine power curve

A scatter plot in Microsoft Excel was created to simulate the Nature Power 12V curve in order to produce a best fit line. From this, average wind speeds could be put into this best fit equation in order to find average power output.

From various calculations in initial design and wind analysis, it was determined the WECEB system needs to average 20.64 Watts in the average annual wind speed of 2.59 m/s in order to charge the SLA battery in an acceptable time, per the engineering specifications. Inputting the average annual wind speed into the best fit power curve equation deems that the system will be able to produce more power than the 20.64 Watts needed. Roughly 24-25 watts should be output at a wind speed of 2.59 m/s. These calculations showed this turbine is capable of meeting our specifications. One may also notice that the Watts generated (24-25) versus the Watts needed (20.64) are very close to each other. This leads to the conclusion that the Nature Power wind turbine chosen is correctly scaled to the overall integrated system of the WECEB and CDPC teams.

An initial choice was to use the Southwest Windpower Air-X wind turbine. It is the #1 selling small-scale turbine available, but it is rather costly compared to the team's budget constraint. As a result, a cheaper substitute, the Nature Power turbine, was found and selected for the project.

Another noteworthy topic is the height of the tower that the turbine will be installed on. A height of 3 meters (or roughly 10 feet) was deemed reasonable for a transportable system. Unfortunately, wind speeds are relatively low and turbulent at this height. Ideally, the system would be installed in an open field or on a high platform to remove as much turbulence as possible.

Finally, the team opted to buy a turbine instead of source parts and building its own. After seeing last year's P11401 team's output, the WECEB team realized that would not be adequate for the engineering specifications. The WECEB system needs to send enough power to the CDPC team and ultimately deliver enough power for 8 LVE battery packs to be charged. Since that is one of the customer needs, to supply power for future RIT projects, it was necessary to ensure the WECEB project produced sufficient power. From the calculations within this section, the Nature Power 400 Watt turbine appears to be very capable to meet the power demands of the two systems.

Turbine Stand

The turbine stand was modeled using SolidWorks. The stand was designed with ease of assembly and portability as the main factors. The stand was constructed using schedule 40 steel pipe available at any local hardware store. These stores will also cut and thread the ends at no extra cost. The outcome of the materials chosen result in an easy-to-assemble system. The user can assemble the system by simply threading the mast together and pinning the legs. This allows for the ability to quickly disassemble or reassemble the system, as well as the ability to transport it in pieces on foot around the RIT campus. Figures 5-7 show the overall design of the turbine stand.



Figure 5: Full turbine stand view

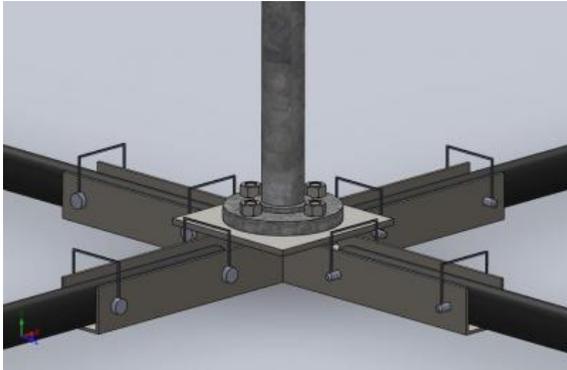


Figure 6: Close-up of the turbine base and leg assembly

The turbine mounts on 1-1/2" schedule 40 pipe, but in order to save weight for raising the mast, 1-1/4" galvanized steel schedule 40 pipe was used in the mast. This was used in conjunction with a 1-1/2" to 1-1/4" reducer and 1-1/2" nipple at the top of the mast which was adapted to the proper mounting size. There 1-1/4" fittings are also more readily found in local hardware stores than 1-1/2" fittings.

The base of the stand was designed to be made out of a small steel plate that the mast flange could be bolted to. The four sections of channel were welded together. The leg sub-assemblies simply pin into the steel channels of the base using two 5/16" safety pins each. The bolts that attach the galvanized flange to the base plate are designed to be left attached through basic assembly and dis-assembly; the mast will be threaded into the flange each time the system is assembled.

The legs are made using 1-1/4" black iron schedule 40 pipe to increase the weight of the base to prevent tip-overs. The guy wires permanently connect to the end of each leg through a hole using two (2) wire clamps each. The other end of each guy wire will have a hook to attach to the flange on the mast above the coupling. It will be removed each time the stand is disassembled. The stand is assembled pinning the end of the leg first, followed by hooking the guy wire, then using the leg as a lever to tension the wire and installing the second pin through the leg. This allows the stand to be assembled without using tension mechanisms for the guy wires.

Two wind loading cases were considered for the analysis of the stand. The loading of the wind turbine assumed that the entirety of the wind was deflected out and around the wind turbine. This overestimates the total force on the blades of the turbine. The wind speed of 25 m/s corresponds to the highest sustained wind speed per year based on Rochester, NY conditions at a height above the ground of 3 m. The

second case assumed a wind speed of 70 m/s, which is the survival wind speed of the turbine.

The SolidWorks stand model was imported into ANSYS workbench. The material properties were gathered from the materials library in SolidWorks. Galvanized steel pipe was used for the upright pole while ductile iron pipe was used for the base legs.

For the case of the wind speed of 25 m/s, the maximum stress over the two orientation scenarios was 21.79 MPa, compared to the yield strength of 203 MPa. This maximum value occurred at the location on the vertical pole at the point where the cables attach in the 45 degree orientation case. The model then indicates that for a moderately heavy wind, the stand should not see stresses close to yield. The stress corresponded to a maximum displacement of 0.00799 meters at the top of the stand.

For the case with a wind speed of 70 m/s, the maximum stress over the two orientation cases was 171.39 MPa. This was seen at the mounting point of the supporting cables, which was slightly lower than the yield strength of the material, 203.9 MPa. This was seen in the 45 degree orientation case. This model suggests the stand would survive the survival wind speed of the turbine. The model also over exaggerates the force on the turbine blades. This stress correlates to a maximum displacement of 0.062 meters, seen at the top of the stand.

From these simulated scenarios, the stand will survive wind speed conditions greater than the survival point of the wind turbine. This ensures that the more expensive and critical component of the assembly, the wind turbine, will not be compromised by the stand failing. By providing a stand that will fail after the wind turbine does, we made sure that the wind turbine would not fall to the ground and break in any condition which the wind turbine would have survived otherwise.

Battery Enclosure

The battery and electrical enclosure needed to be portable, inexpensive, and shield the components from the elements. It does not however have to be weather proof, or survive being outdoors for extended periods of time during adverse conditions. The design consists of an 18 gallon plastic tote with a simple 2x4 frame to set the battery and other electrical components inside of it. The MPPT, PCB, and other electrical control components are mounted on two separate sheets of acrylic. These sheets of acrylic are spaced out and stacked on top of one another to allow all critically accessible components to be on top and all

unnecessarily accessed components on the bottom. For transportation, the wiring and any other hardware can be stowed in the container. A 3D model of the battery enclosure is shown in Fig. 7.

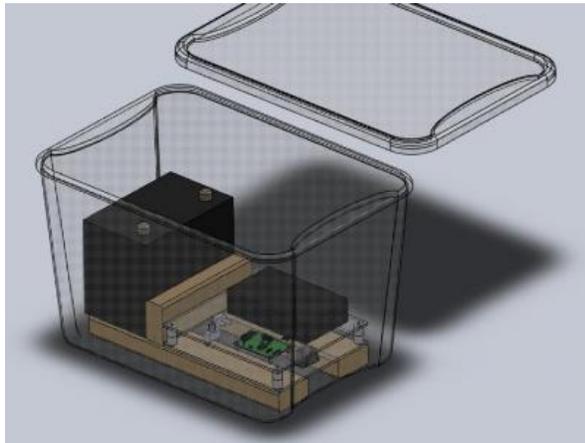


Figure 7: Plastic tote made transparent to show SLA battery, 2x4 wooden frame, and electrical components

Battery

The chosen battery for the WECEB project was the Amstron 12 Volt, 75 Amp-hour Deep Cycle Sealed Lead Acid Battery. In order to charge eight LVE batteries per the CDPC team’s requirements, it was calculated that a battery capacity of 68 Amp-hours or greater will be necessary. The battery purchased has a 75 Amp-hour deep cycle unit. It will be able to provide enough power to the charging dock while still maintaining a depth of discharge of 40%. The battery will last for approximately 1000 cycles at this depth of discharge. Deep cycle batteries are essential for wind based renewable energy systems due to the inconsistencies of available wind and resulting power generation. The change in battery voltage over time due to a typical CDPC power consumption can be seen in Fig. 8. The battery voltage range shown is a 100% state of charge down to 60%. These voltage values were used in programming the MCU which will be discussed more in depth later in this document.

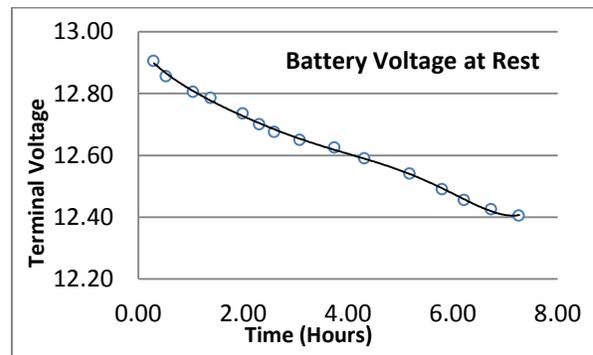


Figure 8: Amstron Battery Voltage versus Time based on CDPC power consumption

PCB Monitoring System

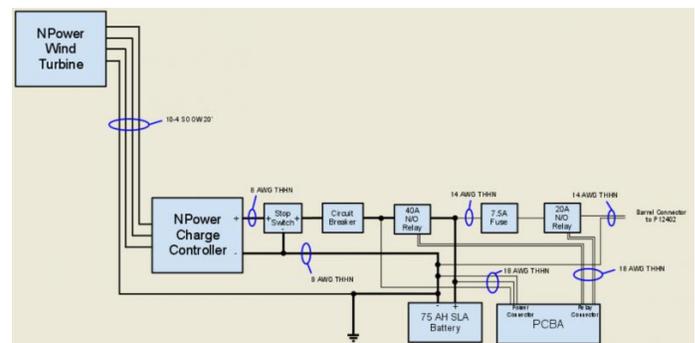


Figure 9: Overall System and Harnessing Diagram

The printed circuit board designed for this system will prevent permanent damage to the battery from over-discharging. Figure 9 shows how the PCBA will integrate within the WECEB and CDPC systems. It will also allow both projects to be used at the same time. This will allow for the battery to be charged while providing power to the CDPC team. When sending power to the CDPC team, the PCB will protect the charging dock system from high inrush current. It will additionally display the current capacity of our energy bank which will range from 60% to 100%. This tells the CDPC team how many LVE batteries can be charged.

To be modular, a future team will be able to utilize the spared pins off the MCU, as well as the I2C peripherals.

Relays

This system consists of two different relays, a 40A and a 20A normally open relay. The 20A relay is placed between the battery terminals and the output to the charging dock. This relay is needed to break the output connection in the event that the state of charge in the

SLA battery falls below 60%. This relay is also used to disconnect the load from the battery while testing the state of charge. The 40A relay is located in between the Nature Power charge controller and the terminals of the SLA battery. This relay is needed in order to ensure the battery is at rest when testing for the state of charge. The voltage of the battery, without the charge controller or load connected, needs to be tested in order to determine the state of charge. The circuit will open the both relays for 1 minute, disconnecting both the MPPT and output load from the battery, and test the voltage provided by the battery after 1 minutes rest. The circuit will then close the 40A relay and will either open or close the 20A relay, depending on the state of charge. This test will be performed every 17 minutes while the battery voltage is below 12.5 volts, every 34 minutes while battery voltage is between 12.5 V and 12.7 volts, and every 68 minutes while batter voltage is above 12.7 volts.

Safety Devices

The system, PCBA not included, contains one 7.5A fuse at the output of the battery and a circuit breaker and in between charge controller and battery terminal. The 7.5A fuse is placed in order to protect the CDPC. The circuit breaker will trip in the event that there is more than 40 amps through the 8 gauge wire connecting the MPPT to the battery terminals.

The Nature Power turbine also comes with a stop switch. Under normal conditions the stop switch will be in the ON position and will connect the positive Nature Power charge controller terminal to the positive terminals on the battery. When the stop switch is in the STOP position it will short the output wires of the MPPT and engage the brake. When the stop switch is in the OFF position the system will not charge the battery or engage the brake.

PCBA

The power to the PCBA is provided through two barrel connectors. The first connection provides power from the terminals of the battery and the second connection provides power from the Nature Power charge controller. The use of two power sources is necessary to power the PCBA in the event where an empty battery is inserted and there is not enough power to close the 40A relay.

The PCBA also controls the state of the relays. The PCBA outputs a signal of 12 volts to close a relay and outputs 0 volts to open a relay.

MCU

A TI MSP430G2231 MCU is used to measure the voltage of the SLA battery, control the relays and update the LEDs after a measurement. When the MCU powers up the it goes through an initialization stage. During this stage all LEDs are on and both relays are opened. This state is held for 4 seconds to let a user confirm everything is operational. Once the MCU is initialized properly the Analog to Digital Converter (ADC) of the MCU is setup to measure the voltage of the SLA battery. Voltage measurement interval of the SLA battery is 30 minutes and first measurement is taken 16 seconds after initialization. The measurement interval is lowered to 15 minutes if the voltage of the SLA battery is under 12.5V after a measurement and 1 hour if the voltage of the battery is above 12.7V after a measurement. In order to get an accurate measurement from the SLA battery both relays are opened to let the voltage of the SLA battery settle. After about 1 min the voltage of the SLA battery is settled and voltage measurement of the SLA battery is taken. The voltage level of the SLA battery is indicated by the five LEDs (1 red, 4 green). These LEDs are updated according to the following measured values. If the measured voltage is below 12.5V the red LED is on, if the measured voltage is 12.5V to 12.6V one green LED is on, if measured voltage is 12.6V to 12.7V two LEDs are on, if the measured voltage is 12.7V to 12.8V three LEDs are on and when measured voltage is 12.8V or above all four green LEDs are on. Once the procedure for measuring voltage is done the MCU goes into low power mode with interrupts. When the voltage of the SLA battery needs to be measured an interrupt will wake up the MCU and start the procedure.

RESULTS AND DISCUSSION

Testing has proved difficult for the system as a result of the difficulty in finding winds to consistently generate power. In-door testing has proven ineffective due to the inability to generate enough wind to spin the turbine blades. The final option testing option involves the use of a drill to spin the hub of the wind turbine. Even though the corresponding wind speed will not be known, making sure the turbine can output in excess of 20 watts is crucial. The drill test resulted in producing 51 watts at 1000 RPM. Assuming the Nature Power curve from Fig. 4 is correct, the 51 watts would correlate to a wind speed of 12 mph (5.36 m/s). While that wind speed is higher than average for Rochester, it is not uncommon. This wind turbine may very well exceed power requirements and expectations.

The turbine braking system also operates differently than expected. Instead of slowing the turbine to a

speed where power can safely be generated, the turbine nearly comes to a complete standstill before releasing the brake.

It was noted in the owner's manual that the turbine needs 60-100 hours of break in time for the blades to spin in the wind. This will allow the bearings to get worn in and produce maximum efficiency. The time constraints of this project will not allow the team to run the turbine for this long of a time.

Systems integration testing proved to be successful though. When plugging the WECEB system into the CDPC team's unit, the monitoring system lit up the correct LED's and sent power to the charging dock. This shows that with adequate wind, the project will be able to successfully create and store power for later use by other systems.

CONCLUSIONS AND RECOMMENDATIONS

A major limiting factor throughout the project was the group's budget of \$1,000. A Budget increase would have allowed for the purchase of a turbine with a better power output. Conversely, the project could have been scaled down and completed under the current budget. The project initially seemed like a great opportunity to build a wind turbine from scratch. However, the price of the components necessary limited our ability to do so. Another benefit of an increased budget would have been the ability to create a wind tunnel that could have been used for testing. Depending on nature to provide the appropriate conditions for testing proved frustrating and limited the amount of system testing that was able to be performed. Ideally, the group could have used additional funds to create a wind tunnel while concurrently creating the wind turbine.

Another area in which the group failed initially was communication with the customer, Dr. Hensel. During the initial design phase, communication with the customer was limited to when issues arose. Eventually a weekly meeting with the customer was scheduled. This proved to be effective, as the group was able to discuss design ideas with the customer and get feedback on whether it was an appropriate approach. Additionally, negotiations on customer requirements were able to be done easily and effectively. This allowed for the group to ensure that the project was still completed and performed in a manner that was acceptable by the customer. It would be recommended that future groups that expand upon our work involve the customer in the design throughout the duration of the project.

In relation to communication with the customer, discussions with possible additional sponsors could have been given more effort. A company in Pittsburgh, PA, Aquion, is currently developing Sodium-Ion batteries that are fully recyclable and would fit perfectly within the scope of this project. Due to the time constraints of actual design time, a Sodium-Ion was not sourced for the WECEB system. In the future, to expand on the modularity of the system, one of these Sodium-Ion batteries should be integrated.

In addition, one instance in which the group failed concerned a purchased part for the stand sub-assembly. The purchased part, a pipe flange, was assumed to have a mounting hole pattern gathered from one manufacturer, but in reality, the hole pattern was approximately 1/4" different. This led to having to slightly alter the manufactured parts to which the flange was mounted. In retrospect, the flange should have been inspected when it arrived prior to drilling out the incorrect hole pattern on the manufactured plate.

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