# El Durazno Wind Turbine

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## Abstract

Small wind turbines are usually used to power remote villages such as a village in Guatemala to get better access to water. Small wind turbines can be used to power remote communities and unattended operations. The project will encompass innovating a low cost wind turbine to help the village of El Durazno and build a prototype using used car parts, which can be recreated in Guatemala, to generate electricity in order to power the pump of a water transport system that will give the village better access to clean water. This report will go over the design considerations made by the design team in order to produce a working wind turbine, as well as the testing and verifications that led up to that point. The paper briefly covers the ethical considerations of this project regarding the IEEE Code of Ethics and the legal ramifications of renewable energy installation in Guatemala.

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# 1. Introduction

The goal of this project was to make a sustainable power source for a remote Guatemalan village in order to power a water pump in order to give the occupants better access to clean water for drinking, cleaning, bathing, and cooking. The closest water source to the village is 200 ft in elevation down the mountain, and then the other source the village uses is another 173 ft down [1]. Due to these elevation differences, access to clean, potable water is limited for the occupants of the village. So, a few years ago, an ABE senior design team devised a water system involving a gravity-fed tank and a pump to bring the water back up to the village [1].

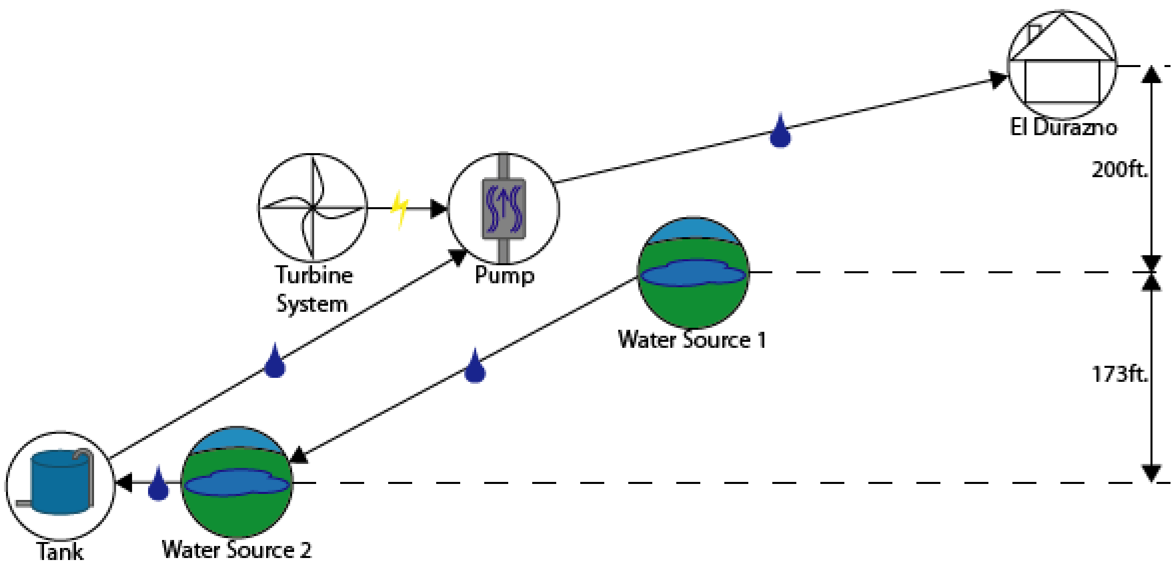


Figure 1: Visual Aid for background

Using the country's electrical grid to power such a pump is out of the question as the village is a remote place roughly 1.5 kilometers up in the mountains, preventing easy access to the country's grid. In light of this, the ABE team at the time brought on an ECE student to assist with devising a relatively simple wind turbine and battery system to power the 373 W pump for 8 hours a day [2]. There was a specific design constraint however, as the whole project is sponsored by Cofiño Stal, a major automotive importer in Guatemala. The easiest and most affordable way to provide these turbines to the village would be to make them primarily out of scrap car parts. With this constraint in place, the mechanical system for the turbine was devised and constructed, but the team could not get power from the alternator the turbine was being used to spin. This is where the original project left off.

This last semester, it has been this team's job to make the turbine prototype functional and improve upon the design choices made by the original team in order to make it more efficient. From the very start, we needed to be able to get the prototype spinning and generate a voltage at speeds normal for the area, around 15 mph [3], use that electricity to charge a battery and have that battery be able to charge something. On top of this, the general construction needed to be relatively simple and easy to construct, not requiring any engineering knowledge besides its initial setup.

# 2 Design

## 2.1 Design Procedure

Our initial mechanical system consisting of the rotor blades, hub and shaft were given to us. However, we worked with the ECE machine shop to custom design the rotor, gear ratio and fan belt.

We had two choices for the rotor design. The first was to cut and thread a plastic plate into the shape of the rotor with a hole in the center to pass the shaft through and holes on the periphery to place lug nuts and screws. A larger gear would be attached to this plate. However, the machine shop suggested a simpler method to cut the existing metal rotor into a smaller circular disk and thread its periphery to attach to the fan belt's teeth. This approach reduced the cost of the design as we no longer needed a larger gear. With appropriate calculations, we worked with the machine shop to purchase a smaller gear that fit the spindle of the Minertia P Motor and can fit the fan belt's teeth. By placing the motor 12 in away from the metal rotor and connecting their teeth with a fan belt and their base with a custom harness, we were able to achieve a 1:10 ratio as shown in equation 1 below. In other words, the generator would spin 10 revolutions for every single revolution of the rotor, making it perfect for low wind speeds at El Durazno.

Furthermore, we identified the right machine to use among three motors available: a low voltage DC motor, the Minertia P Servo motor and the car alternator. Our test results showed that the car alternator was burnt off as its coil resistance measured to 65000 ohms on a digital multimeter. However, we were able to produce power characteristic curves using a dynamometer and labview for the Minertial P servo motor and low voltage DC motor. We understood that the typical wind speed in El Durazno ranged from 8 to 13 miles per hour, indicating around 100 RPM on average. Hence, our machine needed to produce 12 V and 2.5 A to power the charge controller, recharge the battery and light up the bulbs or use the inverter when rotating at 1000 RPM. Our low voltage DC motor only produced 9V and 1.5 A at 1000RPM while our Minertia P servo motor produced 12.5 V, 2.3 A and 1000 RPM, indicating that the latter machine is the perfect generator. These characteristic curves are shown below.

By calculations and discussions with teaching assistants and professors, we determined a 12V , 2.1 A lead acid car battery, 300 W car inverter and the Renogy Wanderer 10 A charge controller were the right components to purchase and connect.

Finally, we designed our printed circuit board twice. The first version had simply 3 screw terminal pins to connect the charge controller, battery and generator. In our second improved version, we inserted a reverse diode connecting the generator to the charge controller, preventing the battery from discharging into the generator when the wind turbine is not spinning.

## 2.2 Block Diagram Breakdown

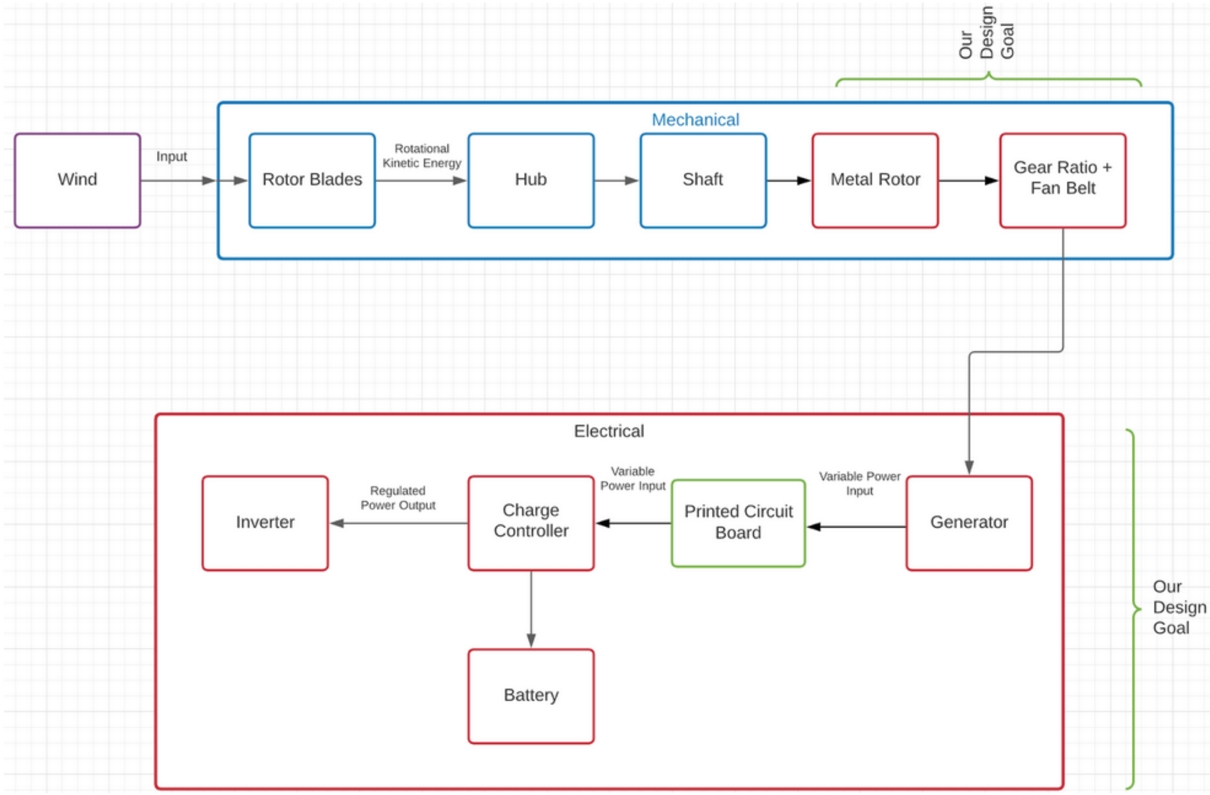


Figure 1: Project BlOck DIagram

Our Mechanical system consists of the rotor blades, hub, shaft, metal rotor, gear belt and fan belt. Our rotor blades are made from a used subaru car's door side panel. The rotor blades turn clockwise or anti-clockwise and can operate even at the maximum wind speed at our site location. We used a Toyota wheel hub that connects the turbine vanes together. As the hub rotates along with the rotor blades and steering column creating a synchronous movement it provides the rotational energy for the system. It moves the shaft which is a steering column to which the mechanical parts are attached to. The column is closed on either ends with PVC pipe caps or plugs. By drilling the cap, we can put a bolt and secure the column with a nut. We cut our existing metal rotor into a diameter with threading to fit a purchased fan belt and create 1:10 gear ratio. Next, we bought a stretchable fan belt to connect the two gears together. The cut metal rotor acts as a larger gear, while a smaller gear is attached to the DC Motor's Spindle. This allows low wind speeds to effectively run the DC motor at a high enough RPM to generate power.

Moreover, Our electrical system consists of the Minertia P Motor[4] as the generator connected to the printed circuit board with reverse diode. This PCB is wired to the Renogy Wanderer Charge Controller that has its battery terminals attached to a 12V, 2.1 A lead acid battery. Lastly, our battery is connected in parallel to an AC/DC converter and two 12 V 9.6 Watt fluorescent bulbs. We noticed our phones can charge via the USB port of the inverter and the bulbs brighten up when the battery is at 12V.

## 2.2 Design Details

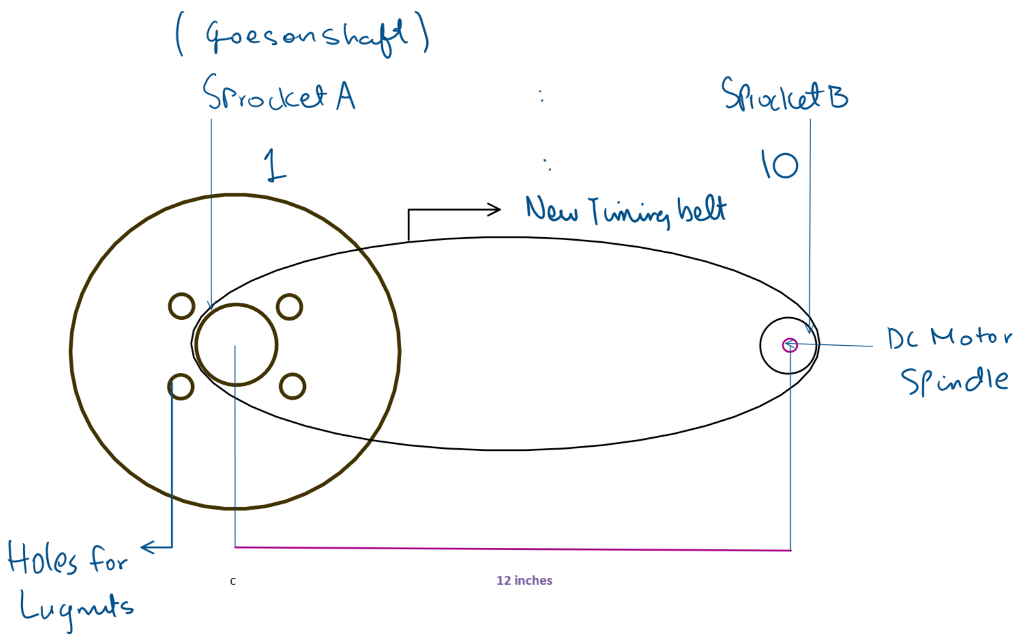


Figure 3 Gear Ratio

This is the fourth revision of our gear ratio with the ECE machine shop. The two sprockets were found online on McMaster Carr and the mental rotor was cut to a diameter whose radius satisfied the equation below.

$$Generator\ Rotational\ Speed\ = \frac{Rotor\ Radius}{Generator\ Radius} *\ Rotor\ Rotational\ Speed$$

Equation 1 Gear Ratio Formula [5]

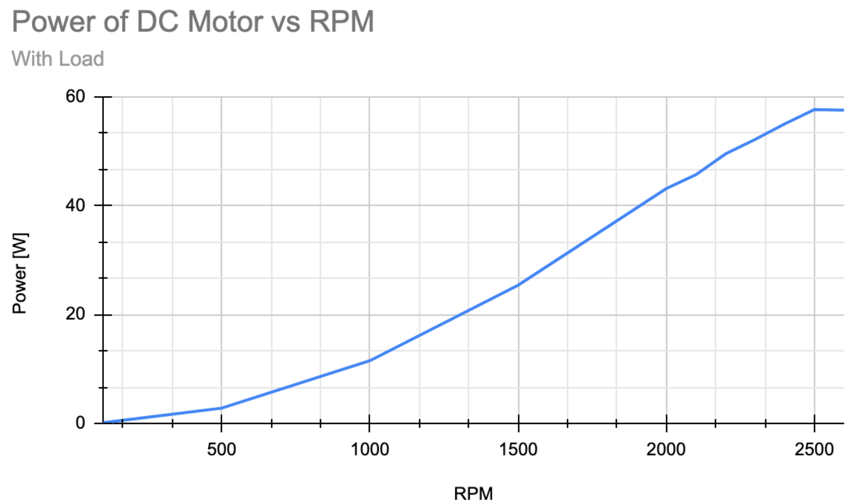


Figure 4 DC Motor Characteristics [6]

We can trace from 1000 RPM to just 18 Watts of power, revealing the DC motor was operating at half of its rated 100 W capacity.

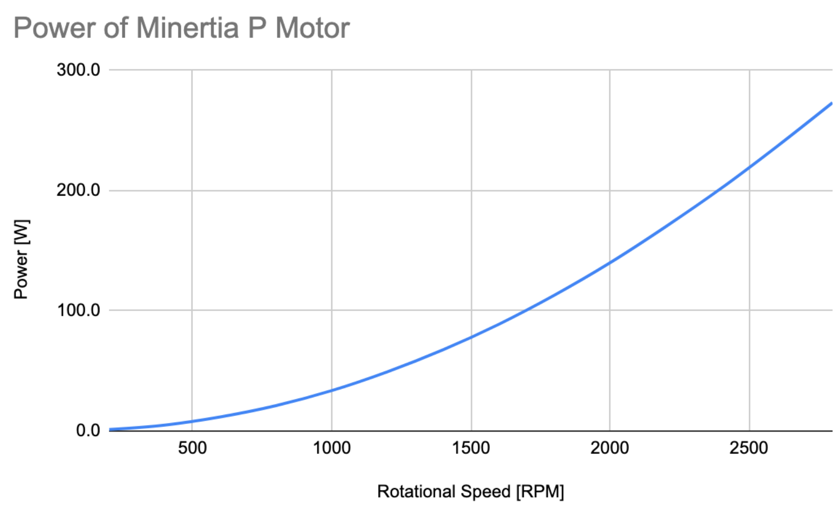


Figure 5 Minteria-P Motor Characteristic

The Minertia P servo motor allowed about 35 W at 1000 RPM, allowing 12 V and 2.3 Amps of current to flow. This suggested that its performance as a generator is exactly what we needed.

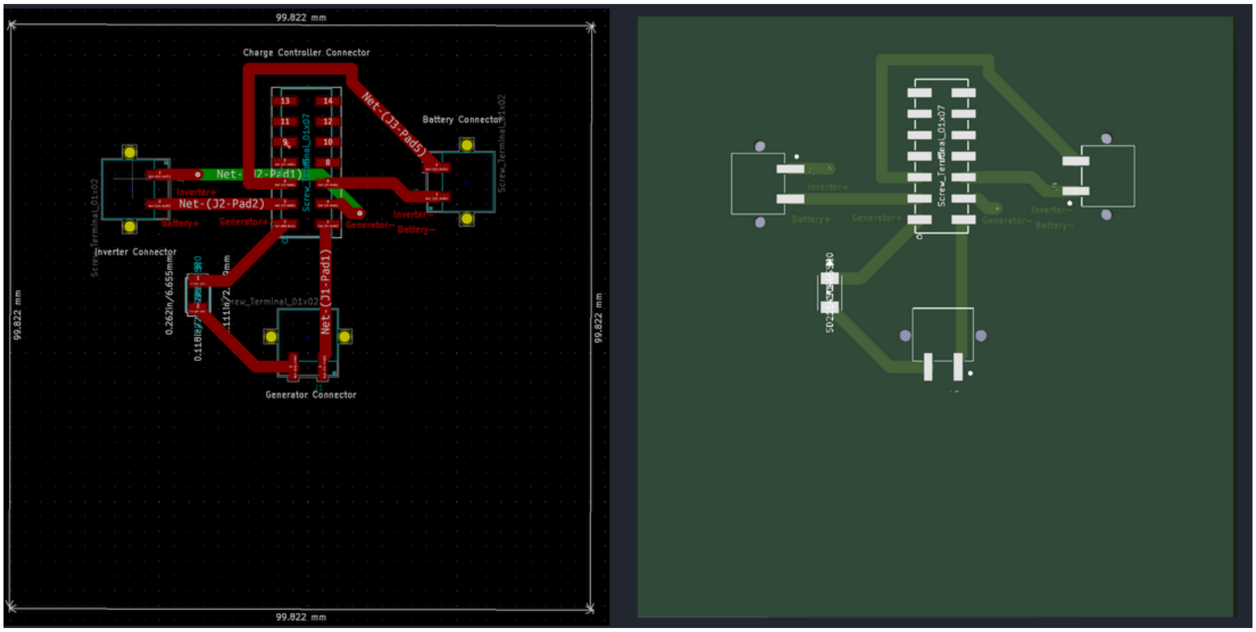


Figure 6 PCB Design using Kicad [7]

This is the second version of the PCB with the reverse diode attached on the left side. This trace width of 2 cm is appropriate to hold 5 A. However, when soldering, we reduced the components we used to just the generator connector, charge controller connector and reverse diode due to a sudden power surge of current in the charge controller trace.

# 3 Verification

## 3.1 Mechanical System

Our first verification tests were done on the mechanical system. We ensured the rotor blades, hub and shaft were rotating smoothly without friction and detachments by exposing the system to a wind tunnel gushing wind out at 8-15 miles per hour.  During our testing, the fan belt never slipped, nor did the motor every stray from its place in the harness, which stayed securely fastened to the rest of the assembly.

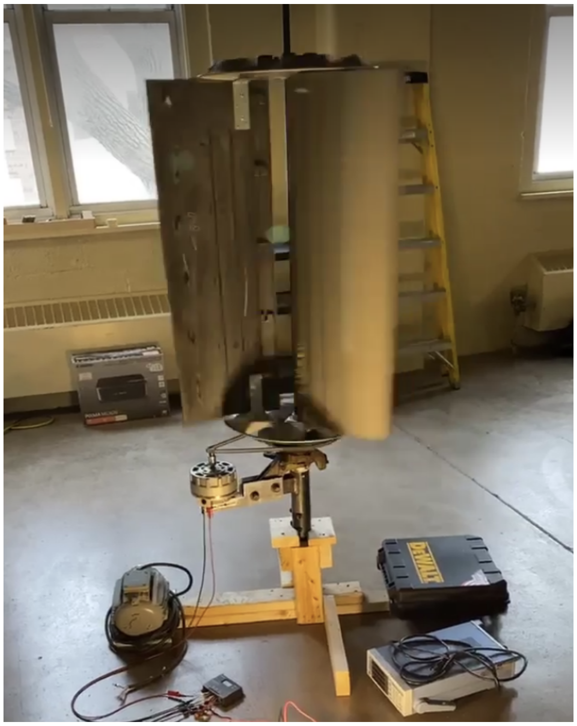


Figure 7 Wind Turbine Rotational Test

## 3.2 Electrical System

Furthermore, we tested the Minertia P Motor using a dynamometer and lab view in the ECE power lab across different loads to check if the desired voltage and current is produced for our system.

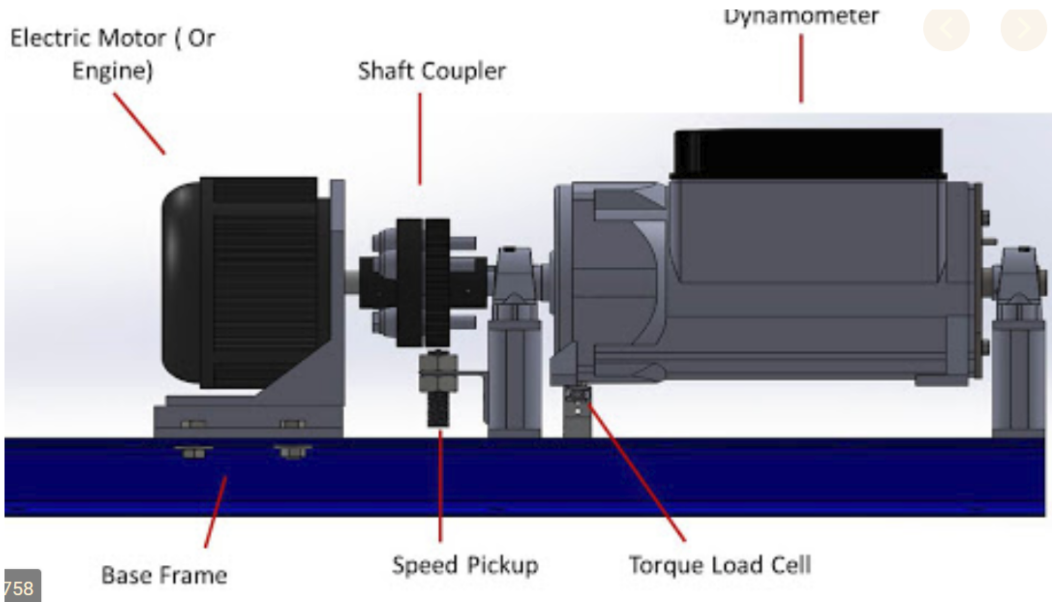


Figure 8 3D setup of Motor Testing [8]

The charge controller efficiency was also measured by using a Keithley DC supply as a power source. By checking the charge controller's display and attaching a resistive load to its battery terminals across a Yokogawa power meter, we determined the controller's efficiency to be 88% efficient.

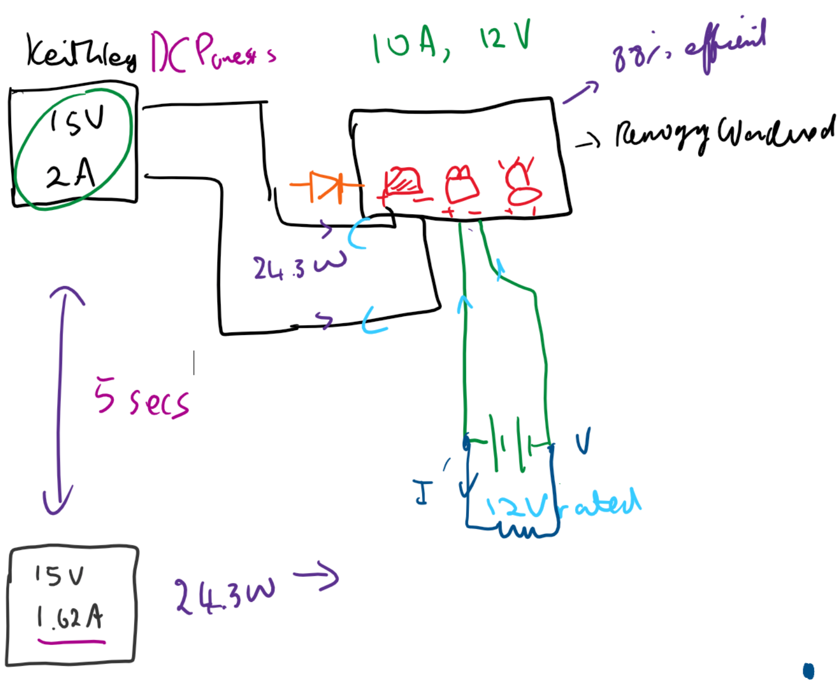

Figure 9 Charge Controller Testing

Next, we measured the charging of the battery by connecting it to the keithley DC power supply and injecting 14V and 2 Amps across a yokogawa power meter. Similarly, we discharged the battery by connecting it across a 5 ohm resistor connected across a yokogawa power meter. By filming the readings on the Yokogawa Power meter, we had data to later slow down the videos and plot for a specific time scale.

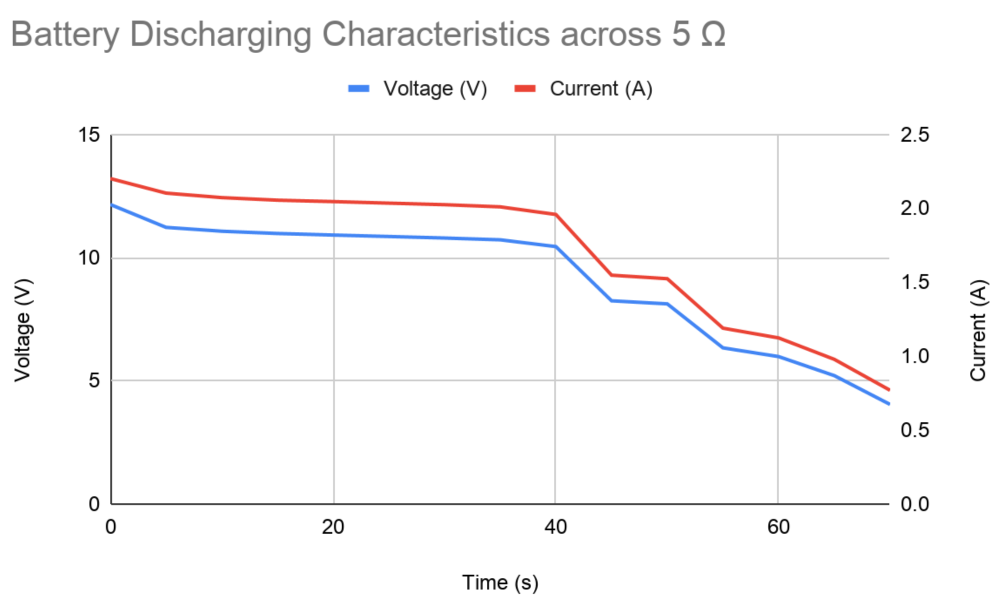


Figure 10 Battery Discharging Curve

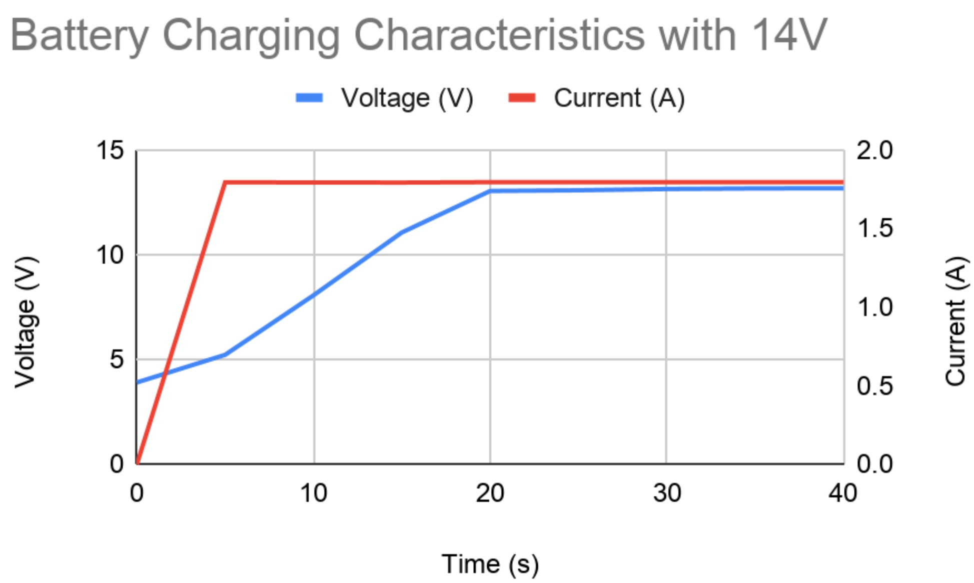


Figure 11  Battery Charging Curve

Lastly, we verified the battery is charging through our generator when the wind turbine is running as we saw the brightness of the bulbs increase and also measured the power coming in to the controller as 12.9 V and the power going out to the battery as 12.3 V.

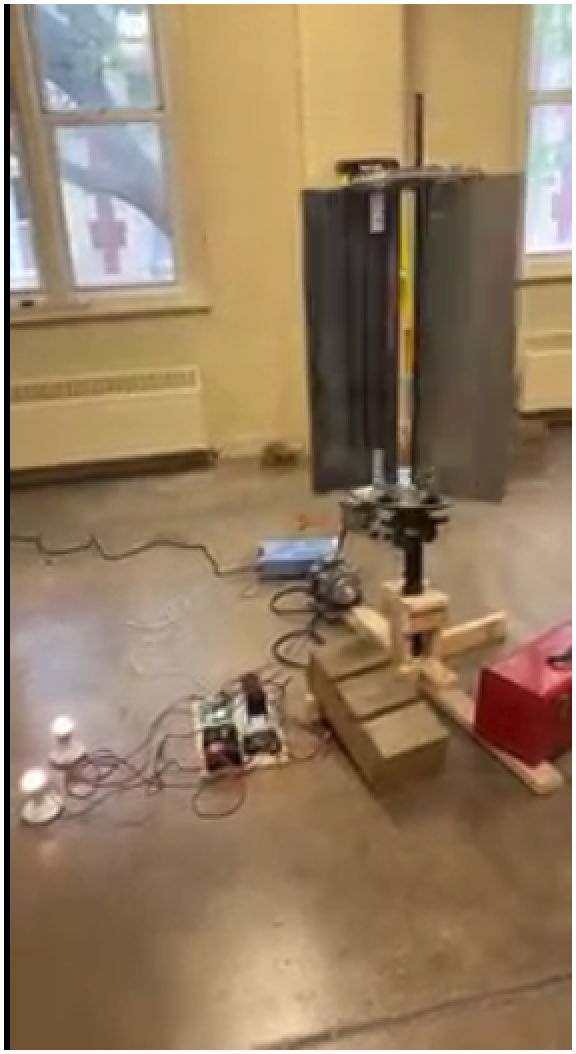

Figure 12  Generator Increases Bulb Brightness

Our Table 1 in  Appendix A carries more detailed data in table format to describe these verification tests.

# 4. Costs

## 4.1 Parts

**Table 1 - Parts Cost**

| Part | Manufacturer/ Distributor | Catalog Number | Cost ($) |
|---|---|---|---|
| Power Inverter | LP Direct | B08MT5ZF8L | 29.99 |
| 12 V, 7 Ah Lead Acid Battery | Chromebattery | B006LO9XHA | 21.95 |
| 14 Gauge Insulated Wire | Amazon | 14GA100-2RB | 16.95 |
| Charge Controller | Renogy Wanderer | B07NPDWZJ7 | 19.99 |
| Electrical Terminal Crimping Kit | Knoweasy | B07VZ4D2J4 | 25.99 |
| **Total** | | | 114.87 |

## 4.2 Labor

**Table 2 - Labor Cost**

| Labor | Number of workers | Hourly Pay ($/h) | Time Paid For (h) | Cost ($) |
|---|---|---|---|---|
| Project Team Work Hours | 3 | 30.00 | 96 | 8640.00 |
| Motor Testing | 3 | 50.00 | 2 | 300.00 |
| Fabrication | 2 | 50.00 | 2 | 200.00 |
| Welding | 1 | 100.00 | 1 | 100.00 |
| **Total** | | | | 9240.00 |

# 5. Conclusion

## 5.1 Accomplishments

This project was a huge success. We solved every problem that the design process threw at us and turned a spinning assembly of scrap plastic and metal into a working wind turbine. We were able to power two 12 VDC light bulbs as well as charge a phone using the inverter.

## 5.2 Ethical considerations

The people in the village would be in direct contact of the turbine. The operation and the maintenance of the wind turbine will be undertaken by the people so we need to make sure that the turbine is easy to maintain and operate. Furthermore, we have to ensure that the turbine is safe to use. The major hazard would be the electrical circuitry in the generator and the wires connecting the pump to the generator. The voltage of the generator would possibly be 120 VDC and it would need to be insulated properly to prevent it from causing harm to the operators. All the electrical equipment would be properly insulated. Any loose wiring would be removed or taped off to prevent shocks or loss of current.

Moreover, since this would be placed in an outdoor environment and on a mountain, it would also need to be protected from the weather. Different climates can cause the electrical circuits to short circuit or cause other problems. Proper monitoring should also be taken so that the production is not affected by the wind speeds and there are enough hours of operation for the pump. This matches with IEEE ethics code #1 to maintain the safety of the public [9]. The turbine will contain grounding down conductors in the blades and grounding down conductors in the turbine to protect from lightning.

We would we working with a team from the ABE department, as well as clients in both Champaign and Guatemala so we would constantly need to correct our design and work on the demands as mentioned in IEEE ethics code #7 [9].

Additionally, we would also need to adhere to Guatemala national energy laws such as the General Electricity Act [10]. This would have an influence on our design as well as building with respect to things such as tying in the turbine into the grid or having a backup energy storage to ensure that the pump is operational when needed. This project would set up a battery storage as well as have the possibility of letting the sponsor in Guatemala to tie the turbine into the grid, depending on their preferences and interaction with the Guatemalan government.

## 5.3 Future work

Future work that could be done with this project includes dealing with the flickering and instability of the instantaneous power flow from the generator to the charge controller. This would need a capacitive circuit to try to smooth out the voltage over time curve. This circuit would need to have a time constant somewhere around a second or so so that it actually smooths out the voltage noise. Something else that could be done is actually testing the turbine out by having it power a pump of a relatively small power rating to see how many turbines would be needed in the final implementation.

# References


[1] C. Abbamonte, "El Durazno Final Report", 2019

[2] "WINDExchange: Small Wind Guidebook", Windexchange.energy.gov, 2021. [Online]. https://windexchange.energy.gov/small-wind-guidebook#parts. Accessed: 18- Feb- 2021

[3] “El Durazno Monthly Climate Averages,” Neuvo Lan, MX, 2020-2021. https://www.worldweatheronline.com/el-durazno-weather-averages/nuevo-len/mx.aspx. Accessed March 4. 2021

[4] “El Durazno Monthly Climate Averages,” Neuvo Lan, MX, 2020-2021. https://www.worldweatheronline.com/el-durazno-weather-averages/nuevo-len/mx.aspx. Accessed March 4. 2021

[5] “Steps to calculate a gear ratio - Blog CLR”, CLR.es, Ibi, Alicante, 2021-2021. https://clr.es/blog/en/steps-to-calculate-a-gear-ratio/. Accessed May 5. 2021

[6] “Understanding DC Motor Characteristics”, Lance.mit, 2007. http://lancet.mit.edu/motors/motors3.html#speed Accessed March 4. 2021

[7] KiCad EDA: Schematic Capture and PCB Layout Software, Version 5.1.8, KiCad

[8] “Bench Type Dynamometer”, Focus Applied Technologies. 2019. FAT- Engine Dyno (focusappliedtechnologies.com. Accessed March 5. 2021

[9] “IEEE Code of Ethics.” Institute of Electrical and Electronics Engineers. 2020. https://www.ieee.org/about/corporate/governance/p7-8.html. Accessed Feb 18. 2021

[10] “Electricity regulation in Guatemala: overview”, Thomas Reuters. 2020. https://uk.practicallaw.thomsonreuters.com/w-009-9340?transitionType=Default&contextData=(sc.Default)&firstPage=true. Accessed Feb 18. 2021

# Appendix A Requirement and Verification Table

**Table 1 System Requirements and Verifications**

| Requirement | Verification | Verification status (Y or N) |
| --- | --- | --- |
| 1. Rotor Blade Proper Rotation | 1. Wind Tunnel Test 8-15 mph | Y |
| 2. Hub Sturdy and Spinning | 2. Wind Tunnel Test 8-15 mph | Y |
| 3. Shaft Spinning, no detachment | 3. Wind Tunnel Test 8-15 mph<br>a. Visual Inspection | Y |
| 4. Metal Rotor<br>a. Metal rotor cut and threaded correctly | 4. Machine Shop Precise Cutting<br>a. Fits fan belt diameter<br>b. Connects to fan belt teeth | Y |
| 5. Gear Ratio + Fan Belt<br>a. Gear Ratio accurately calculated<br>b. Find smaller gear b online<br>c. Rotor radius fits Gear A at 12 inches distance | 5. Machine Shop Conversations<br>a. 1:10 gear ratio using formula<br>b. Harness well built to keep motor at that distance<br>c. Fan belt connects well between motor and rotor | Y |
| 6. Generator<br>a. Reliable charging of battery<br>b. Produces 12V, 2.5A at 1000 RPM | 6. Lab View and Dynamometer Testing<br>a. Bulb brightness increases<br>b. Power characteristic curve of Minertia-P satisfies requirements | Y |
| 7. Charge Controller<br>a. Renogy Wanderer, 10A.<br>b. High Efficiency | 7. Yokogawa Testing<br>a. Yokogawa power meter readings show 88% efficiency<br>b. Part Found Online on Amazon | Y |

| | | |
|---|---|---|
| 8. Inverter<br><br>a. Operational converting 12V DC to 120V AC | 8. Multimeter Testing<br><br>a. Multimeter reading verified 120V Ac output when battery is at 12V DC. | Y |
| 9. Battery<br><br>a. Charging and Discharging should be appropriate for system<br>b. Low cost<br><br>c. 2 parallel bulbs charge<br><br>d. Inverter operable | 9. Multimeter Testing<br><br>a. Yokogawa readings show tolerable charging and discharging<br>b. Cost is 27$ within budget<br><br>c. Bulb brightness increases<br><br>d. Inverter charges phone through USB port | Y |