ECE 445

Spring 2021

Design Document

El Durazno Wind Turbine

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Group 12

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1 Introduction

1.1 Objective

El Durazno, a village in Guatemala situated high up in the mountains, has access to neither reliable, affordable power, nor water [2]. We propose installing a low-cost, easily maintained micro wind turbine, no taller than a person, in order to power an electric pump to draw water from further down the mountain. This turbine would have the sole purpose of providing enough power for the water pump to operate long enough each day to draw the village's daily required amount of water.

1.2 Background

El Durazno is a village of about 1,220 people living in 188 households, a relatively small community compared to some towns and cities around UIUC, however this is still over a thousand people without water [2]. According to the report on the project ours is following up on, each household would use about 194.7 L of water daily, and between the households in the village, about 38kL of water would need to be pumped from the sources daily [2]. Their current primary source of water comes from a community leader's property which has a seepage spring on it. Pools of roughly 1-2m^2 are dug and claimed by families for their use. This source is the closest that they have and is still an elevation difference of 200 feet down from the village.

There are plans to connect this source and another one about 173 feet further down the mountain (an elevation change of about 60 feet) to a collection tank for safe containment, protected from contamination [2]. This would give the village better access to more clean, potable water. The only problem is that this collection tank is still much further down the mountain than the village and the whole point is to give them easier access to the water. As the village does not have easily accessible power, this is not as simple as hooking a pump up to the grid and pay the utility [2].

This is where our turbine comes in. It will be powering a pump rated at 373 W, 127 V that will be used to draw water up through galvanized iron piping back to the village so that it can be used. This will operate for 8 hours a day, run via a battery hooked up to the turbine [2]. The reason that this must be a specially designed turbine when wind turbines of this scale exist [1] is that the people of this village are not engineers nor would any of them have the technical know-how to maintain such turbines, let alone get the parts up to their remote village. So our prototype needs to be constructed with easily-obtained materials and be easily assembled with little engineering knowledge.

2 Design

2.1 Physical Design

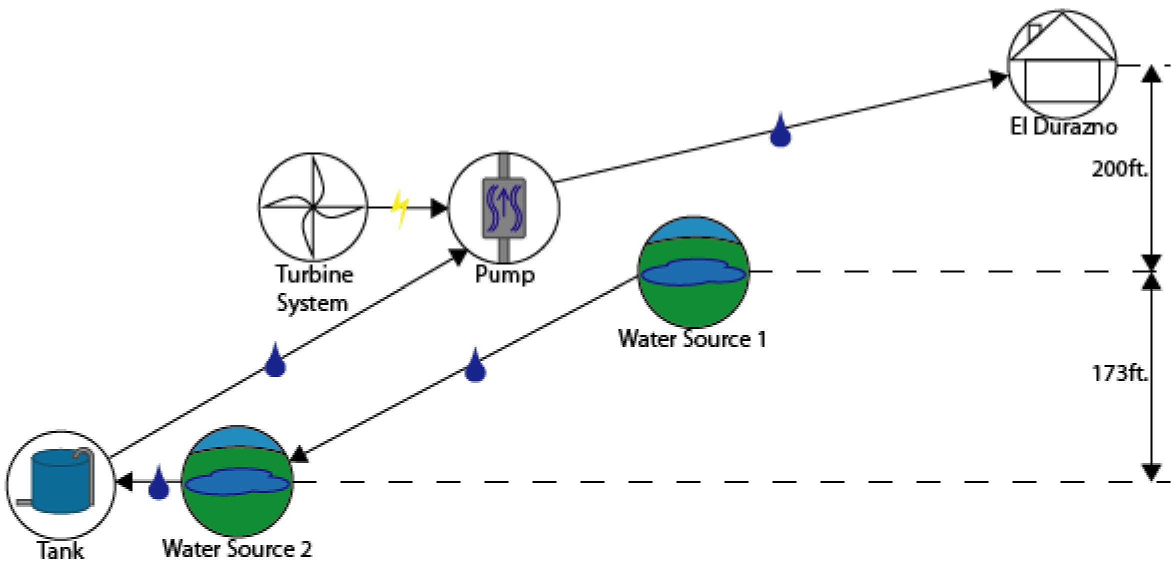


Figure 1: Visual Aid for Background.

2.2 High-level Requirements List

i. Our project must be able to generate enough electricity and power to operate a 373 W, 127 V pump via an inverter. The runtime goal for our pump should be able to operate for at least 8 hours a day so that the village would have access to water for enough time

ii. Our turbine should be made of used car parts as determined by our client

iii. Our project should be easy to operate and maintain so that the villagers could operate and run it even with no engineering support. The wind turbine should be easy to put together, following a set of instructions, without any need for additional wiring or work required. This means no custom ordered parts from the UIUC machine shop, and the parts we do use must be obtainable via our sponsor in Guatemala or obtained with relative ease by the villagers in other means. Quantifiably, if we can assemble it in under 30 minutes without having the instructions with us, it should be intuitive and simple enough that the villagers can do it in a reasonable amount of time with the instructions.

2.3 Block Diagram

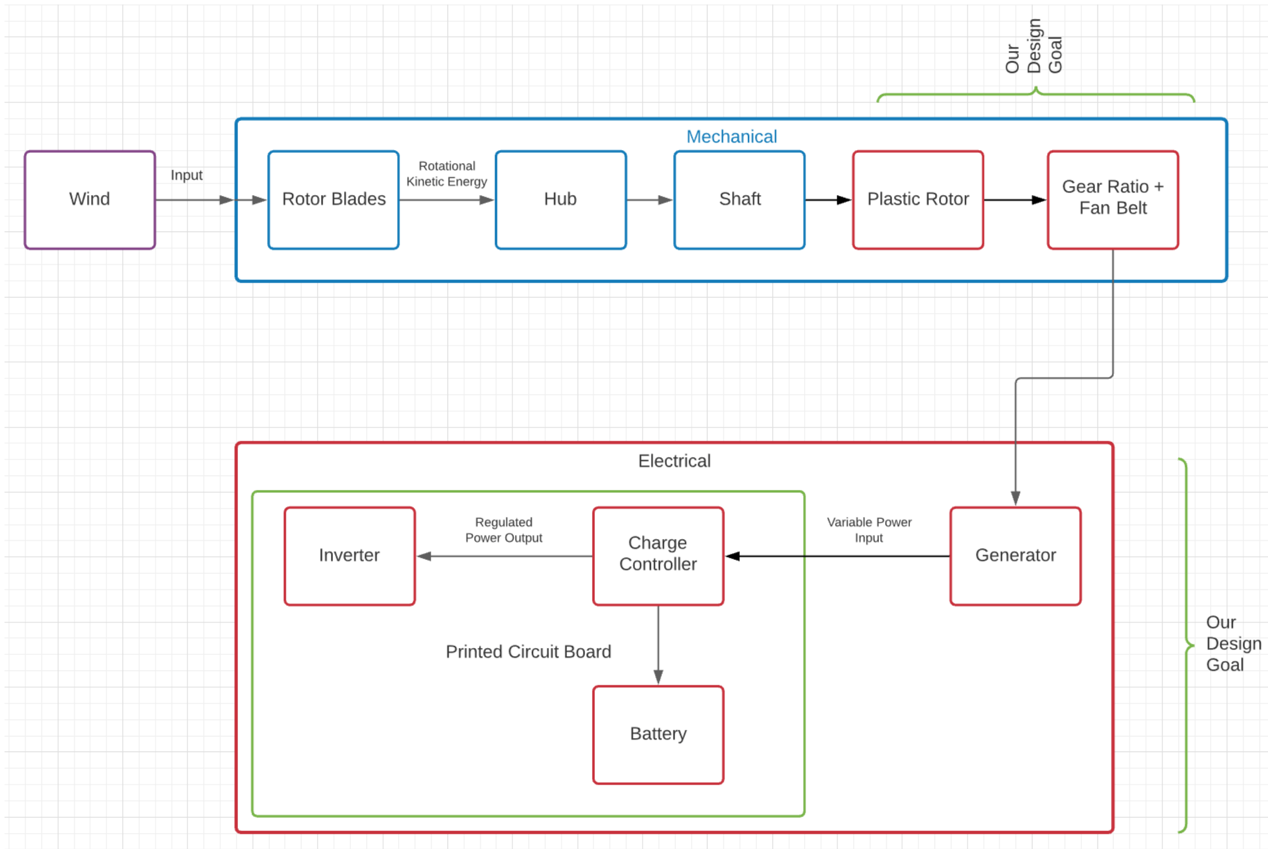


Figure 2: Mid-Level Block Diagram of Wind-powered System

We have two design goals. One is to complete the plastic rotor and Gear belt ratio with the fan belt by cutting a plastic sheet circularly with holes in the center for shaft and long the periphery for the lugnuts and by stretching the fan belt to connect to gears at a distance. This means the larger gear is attached to the plastic rotor while the smaller gear is attached to the generator.

The second design goal is to complete our electrical system consisting of a generator appropriately running with a charge controller, batter and inverter that are interconnected via a printed circuit board.

As the wind spins the rotor blades, it converts wind energy into rotational kinetic energy, causing the hub to rotate around the shaft. As the mechanical system spins, it moves the coils of the generator around its internal magnetic, converting rotational to electrical energy. This electrical energy passes through a charge controller that produces a steady DC output to charge the battery, while passing it to an inverter to show AC output.

2.4 Functional Overview

Note: Multiple Requirements are difficult to quantize exactly. Requirements are quantified when possible, but several would require much further explanation than is suitable for this section, and are better left as a kind of "trial and error" requirement. A good example is the length of the steering column that functions as the shaft of the turbine. It just needs to be large enough to fit all the components.

2.4.1 Mechanical System

Rotor Blades:

The blades are straight with bent ends made from a used car's door side panel. As the rotor blades spin due to the wind direction, the hub they are attached to moves the shaft of the system. The turn clockwise or anti-clockwise and can operate even in the maximum wind speed at our site location.

- Requirement 1: The blades must be concave along the short axis in order to catch the wind efficiently.

Hub:

We are using a Toyota wheel hub or bicycle wheel hub that connects the turbine vanes together. The hub rotates along with the rotor blades and steering column creating a synchronous movement. This movement is what provides the rotational energy for the system.

- Requirement 1: Wide enough to interconnect steering column, rotor blades, and brackets.
- Requirement 2: Sturdy enough to withstand the changing wind speed

Shaft:

The shaft is a steering column to which the hub and blades are attached to. It spins and provides the appropriate balance to keep the system intact. The column is closed on either ends with PVC pipe caps or plugs. By drilling the cap, steel tube and column, we put a bolt and secured the column with a nut.

- Requirement 1: The steering column representing the shaft should be long enough to centrally connect all components of the turbine
- Requirement 2: It should be resistant to moving sideways while spinning and requires greasing often to prevent this fiction.

Plastic Rotor:

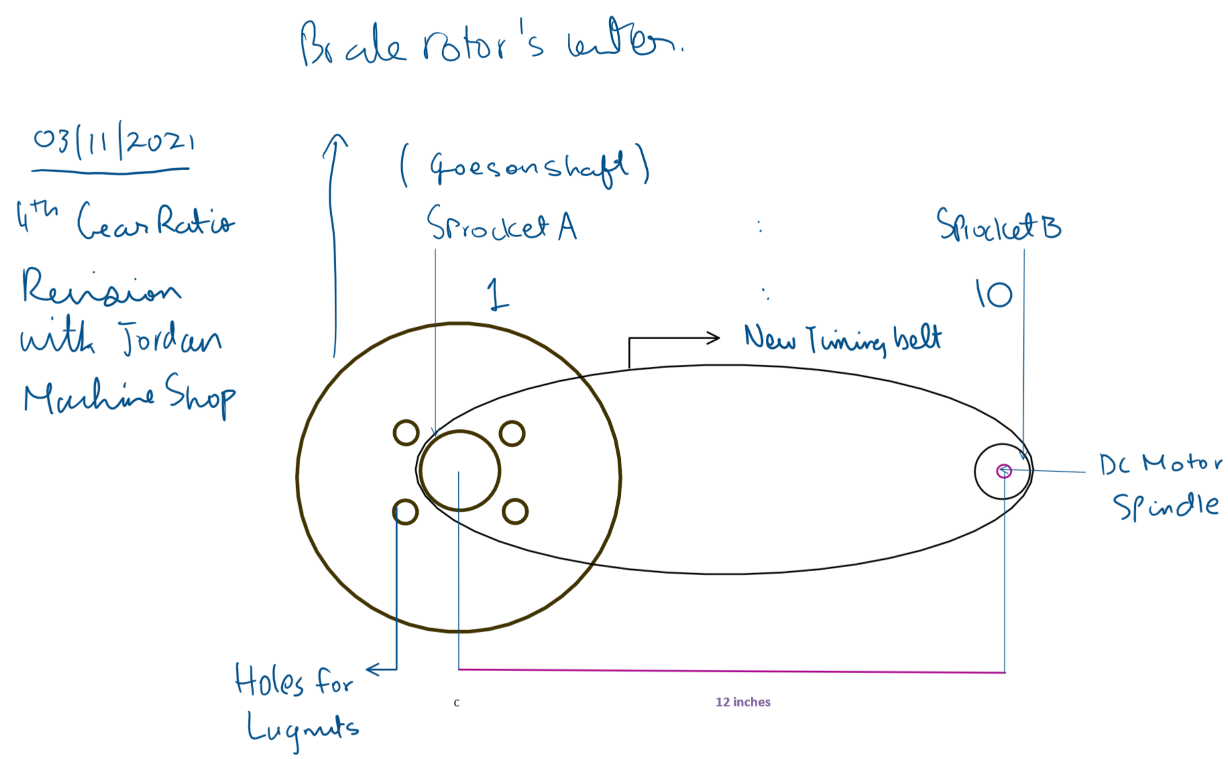
With the help of the machine shop, we are planning to perform this operation using an existing plate we have. The brake rotor is Plastic Plate cut in a circular shape to fit the diameter of the previous rusty rotor. It will have the appropriate holes along the periphery to screw lug nuts and a hole in the center to allow the shaft through.

- Requirement 1: The circular plate's diameter fits the length of the belt appropriately. Lug nut and shaft holes are accurately cut.
- Requirement 2: A large (>3in, <1.5ft) gear must be able to be fastened to the plate.

<u>Gear Ratio + Fan Belt:</u>

Our goal is to stretch the fan belt in order to connect two gears together. The larger gear, Gear A, is fastened on top of the plastic plate while the smaller gear, Gear B, 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.

- Requirement 1: Gear ratio must be 1:10
- Requirement 2: Fan belt must stretch by about 5% of its total length to accommodate the size of the gears.



<u>Figure 3: Final Gear Ratio Built with Machine Shop</u>

2.4.2 Electrical System

Generator:

Our generator will be 1 DC motor connected to an AC/DC converter. We are testing two different motors in the ECE lab to produce a Voltage vs Power Curve in order to understand how they produce power over a range of rotational speeds up to about 2400RPM. This is so we can select the more efficient one of the two.

- Requirement 1: The results from the test must produce 15V and at least 1A at at most 1200 RPM.
- Requirement 2: The machines have to be able to operate 8 hours reliably to allow the charge controller to recharge the battery.

2.4.3 Printed Circuit Board

Charge Controller:

We are buying Picasoleil’s 12/24 V charge controller that can take an input from 400-600W of power.

- Requirement 1: IP67 weather resistant and reliable to use
- Requirement 2: Cost below $40 and be easily wirable to battery, generator and inverter.
- Requirement 3: A reverse diode to prevent the battery from sending current back into the generator must be installed and working correctly.

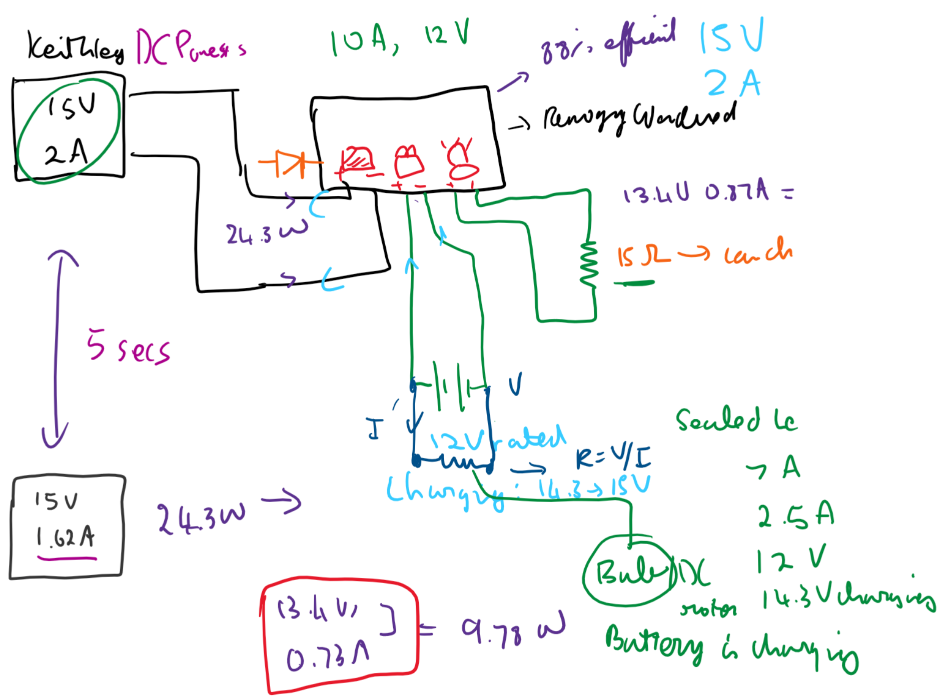


Figure 4: Charge Controller Testing Sketch

Inverter:

This inverter should prove we can produce an AC output using the charge controller. It takes voltage input of 12 to 24 V along with a 400-600W power range.

- Requirement 1: Tolerate wide AC input: wind speeds range from 9-13 miles per hour, meaning generated voltage can vary very quickly
- Requirement 2: IP 67 Waterproof and can survive hurricanes in El Duazno
- Requirement 3: Attachable to a PCB

Battery:

A small lithium ion rechargeable battery available to residents in El Durazno. It turns 12V to 110V at 600mAh and proves our ability to store and energy.

- Requirement 1: Cost below $40 and be readily available for plug and play use. No extra configuration needed.
- Requirement 2: At least 85% efficient..
- Requirement 3: Impedance must be contributing a load within 6 ohms.

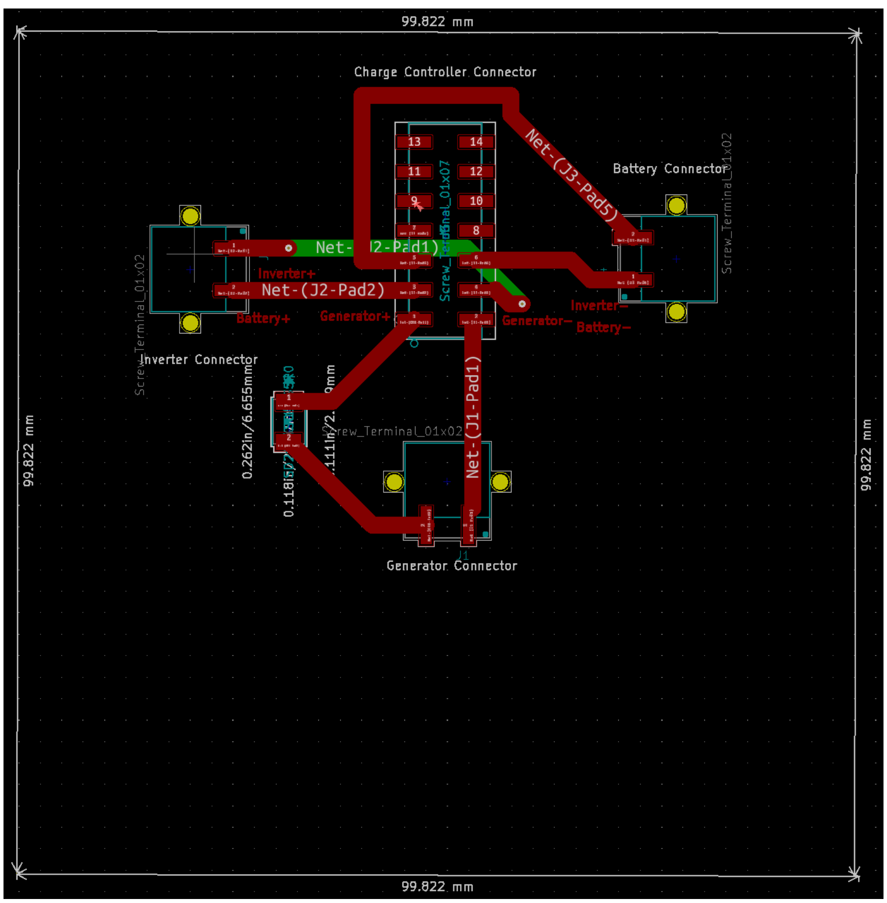


Figure 5: Final PCB design with reverse diode

3 Requirements and Verifications

Requirements	Verifications
Rotor Blades 1) The blades are aerodynamically shaped to turn easily against the average wind speed 2) They are placed circularly so they do not oppose each other's movement	**Rotor Blades** 1) Blow a fan or leaf blower at low, high, and medium to check rotation of blades. 2) We can use the data sheet of the leaf blower to know specific wind speed
Hub 1) Wide enough to interconnect steering columns, rotor blades, and brackets. 2) Sturdy enough to withstand the changing wind speed	**Hub** 1) Blow a fan/leaf blower to see how well the hub rotates with its attachments
Shaft 1) The steering column representing the shaft should be long enough to centrally connect all components of the turbine 2) It should be resistant to spin and requires greasing often to prevent this fiction.	**Shaft** 1) Visual inspection: by looking closely we can see if the shaft is well connected to components 2) Using a leaf blower we can check the shaft's strength in rotating with its components
Plastic Rotor	**Plastic Rotor**

1) Plastic Plate cut in a circular shape to fit the diameter of the belt 2) Ensure Large gear is attachable to plate 3) It must appropriate holes along the periphery to screw lug nuts 4) Has hole in the center with the same diameter as the shaft	1) Take old brake rotor to machine shop to use as reference for precise cutting of plastic plate 2) Insert the shaft through the rotor hole to ensure appropriate diameter 3) Screw in lug nuts to make sure the brake rotor appropriately accommodates nuts they fit in well and tightly
Gear Ratio + Fan Belt 1) Using Wb = Ra/Rb * Wa, we need to accurately calculate the gear ratio using the ratio of radius of Gear A to to radius of Gear B 2) Find those gears online 3) This allows us to convert low wind speeds to DC Motor power generation	**Gear Ratio + Fan Belt** 1) Attach the belt to Larger Gear A with adhesive tape 2) Attach the belt to smaller Gear B with adhesive tape 3) With machine shop help, ensure accurate distance between gears 4) With machine shop help, ensure Gear A rotation causes Gear B rotation and hence DC Motor Power generation via multimeter measurement 5) Fan Belt is stretchable to accommodate gear sizes 6) Visual inspection of gear ratio
Generator 1) 1 DC motors (24V, 100A) 2) Operate long enough reliably to keep the battery charging 3) Mechanism for shaft to spin DC motor 4) Goal is to see how much time is needed to extract 2400W from the 24V, 100A DC Motor	**Generator:** 1) Using a dynamometer or similar device, we can run the generator with a sensor and braking motor to record a Voltage vs Power Curve 2) Using machine shop help, test equipment can be set up

Charge Controller 1) Bought online: PicaSoleil 12V/24V, 400-600W, with IP 67 rating	**Charge Controller** 1) Can be tested in the circuit to see if it charges battery properly and steps down voltage to the inverter 2) Verify power output regulation using multimeter 3) Fits on PCB
Inverter: 1) Tolerate wide AC input: wind speeds range from 9-13 miles per hour, meaning generated voltage can vary very quickly 2) Heat and weather resistant: El Durazno is experiencing a hurricane. 3) Converter's goal is to step down 48V from DC motors to 12V for battery input while transferring 4800 W power reliably	**Inverter:** 1) 12V - 110V inverter bought online 2) Can be tested to verify if AC output is being produced 3) Fits on PCB
Battery: 1) Affordable and readily available for plug and play use. No extra configuration needed. 2) Should not add drastically to the cost of energy production. 3) We can measure current and voltage across a load (bulb) the battery is charging. This measures the impedance of battery when charging and discharging	**Battery:** 1) Shopping, find out similar batteries we can buy here 2) Test batteries to hold 3.7V 600mAh rechargeable battery 3) Fits on PCB

4 Tolerance Analysis

Our greatest challenge would be producing power from the generator machine. We not only have to plot the Voltage vs Power Curve by testing the DC motor in our ECE lab, but also we need to harness the motor on the plastic belted circular sheet to run the machine.

According to WorldWeatherOnline.com, El Durazno gets a maximum wind speed of 46 RPM (14kmph) during the months of June to August and receives a minimum wind speed of 18.5 RPM during the months of October to November.

Our goal is to be able to construct a gear ratio, such that we can extract power from the DC motor in this wind speed range.

We need to calculate what are the appropriate limits to our gear ratios, in order to accurately convert the low wind speed into energy produced by the DC motor.

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Figure 6: El Durazno’s Wind speed Curve WorldWeatherOnline.com

Our DC motor can take the following graphs shape upon testing. We will be able to figure out more upon testing.

Furthermore, our goal is to measure how changes in the DC motor speed affects the AC frequency output of the motor, inverter design and charge controller design. Both the inverter and charge controller need to accommodate the full fluctuation caused by the variable DC motor speed.

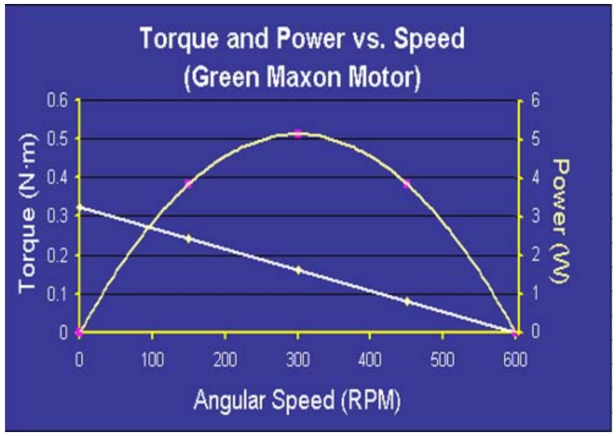

Figure 7: Torque and Power Vs Speed curve from Lancet.mit.edu

Originally, we had decided to use a DC Motor (24V, 100W) that was originally going to be used by the ABE project engineers. However, on testing, we realised that the output power that was being generated was not enough to power a pump of 373 W. The motor was not able to even produce power close to the rated power values at peak load. The power peaked at around 59 W. This made us rethink our design and with the help of Kevin in the lab, we were able to test alternatives and reach a decision to use the Minertia P Motor. The rest of the design was kept the same with minor modifications, such as adding a diode to the PCB to prevent current from going to the charge controller from the battery.

a. Original DC Motor

We did not know the exact resistance of our components or our PCB so we had to test this device on no load and peak load values. With the help of Kevin, I was able to calculate peak load by attaching resistors in parallel with the circuit and see at what resistance I was getting the highest power at the same speed. I was able to calculate that the peak load was around 0.91 Ω. This was achieved by reading the ohmmeter on the fluke meter machine in the lab. The calculation for the peak load value is: (1 || (8||8||8))= 0.727 Ω. The following table shows the readings collected.

No load	RPM	Voltage (V)
	100	0.696
	500	3.442
	998	6.878
	1498	10.315
	1998	13.754
	2099	14.425

Table 1: Original DC Motor at No Load

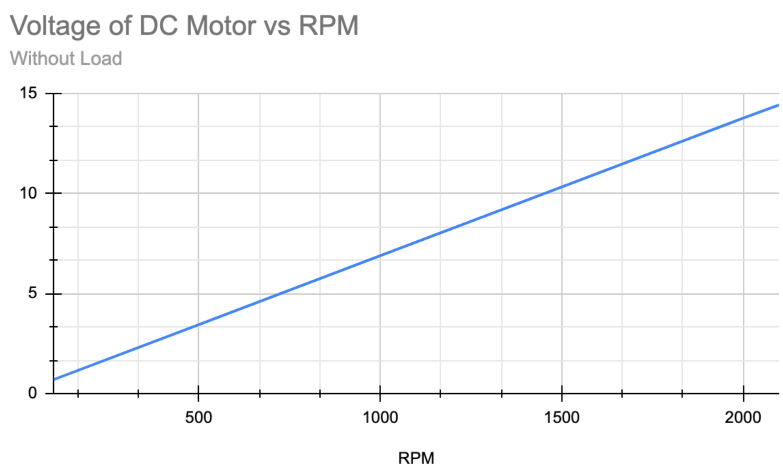

Figure 8: Graph of Original DC Motor at No Load

Load = 0.91 Ω	RPM	Voltage (V)	Current (A)	Power (W)
	100	0.307	0.34594	0.1062
	500	1.561	1.7939	2.820
	998	3.170	3.6300	11.585
	1498	4.715	5.3816	25.250
	1998	6.126	7.041	42.88
	2099	6.340	7.287	45.96
	2198	6.564	7.542	49.18
	2298	6.756	7.723	51.93
	2398	7.003	7.858	54.83
	2498	7.2003	8.085	58.82
	2598	7.096	8.113	57.43

Table 2: Original DC Motor at 0.91Ω Load

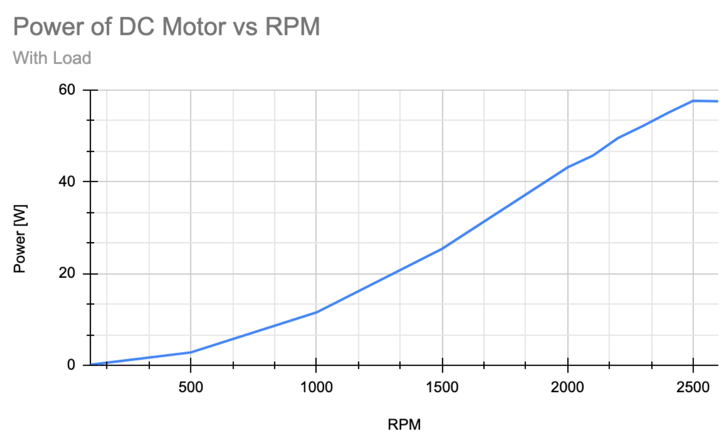

Figure 9: Graph of Original DC Motor at 0.91Ω Load

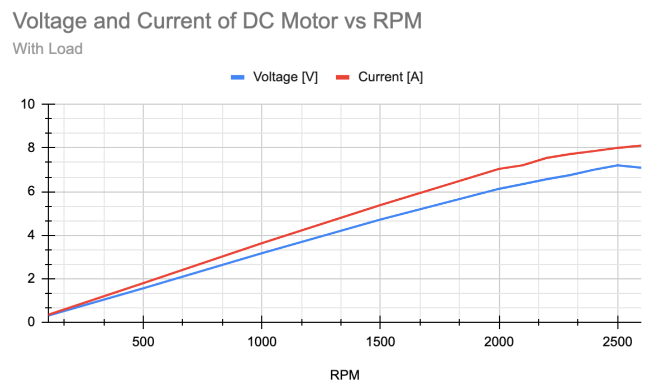

Figure 10: Graph of Voltage and Current of Original DC Motor at 0.91Ω Load

b. Minertia P Motor[7]

We had decided the parts and were able to calculate the approximate load of the PCB, with AJ's help. This came to around 6 Ω. We then connected the load in parallel to the circuit and then took readings to see the behaviour of this motor. The following table shows the readings recorded.

Load = 6 Ω	RPM	Voltage (V)	Current (A)	Power (W)
	200	2.6	0.49	1.3
	400	5.6	0.89	5.0
	600	8.6	1.37	11.8
	800	11.5	1.84	21.2
	1000	14.5	2.32	33.6
	1200	17.6	2.80	49.3
	1400	20.6	3.28	67.6
	1600	23.6	3.76	88.7
	1800	26.7	4.23	112.9
	2000	29.7	4.71	139.9
	2200	32.8	5.18	169.9
	2400	35.8	5.64	201.9
	2600	38.8	6.10	236.7
	2800	41.7	6.55	273.1

Table 3: Minertia P Motor at 6Ω Load

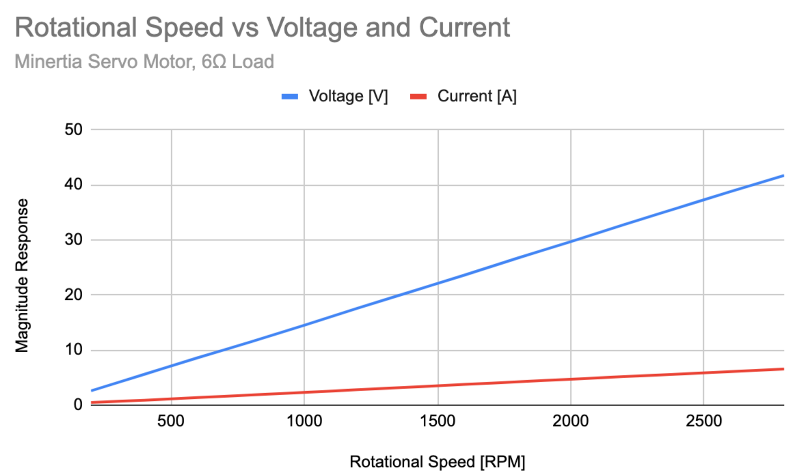

Figure 11: Graph of Voltage and Current of Minertia P Motor at 6Ω Load

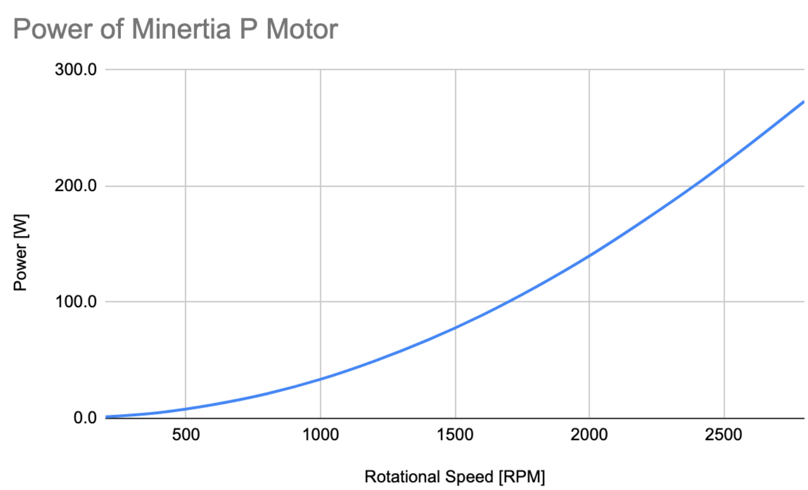

Figure 12: Graph of Power of Minertia P Motor at 6Ω Load

c. Alternator

The alternator did not work at any speeds. Instead it worked like a 65000 Ω resistor. Therefore, it was not feasible to use the alternator to generate any power.

5 Cost Analysis

1. Labor:

   Manpower: $30/hour * 2.5 * 6hrs/week * 3 students * 16 weeks = $21,600

   Motor testing: $50/hour * 2 hours * 2 people = $200

   ECE Machine Shop: 50$/hour * 2 people * 2 hours = $200

   Welding for Harness: $100/hour * 1 hour = $100

   Total Labor Cost: $21,600 + $200 + $200 + $100 = $22,100

2. Equipment:

Vendor/Company	Catalog #	Item Description	URL	Quantity/units	List Price
Amazon	B006LO9XHA	12V, 7AH rechargeable battery	https://www.amazon.com/CB-CHROMEBATTERY-Sealed-Battery-Piranha/dp/B006LO9XHA/ref=psdc_404722011_t1_B00B8U37RO	1	$21.95
Amazon	B08MT5ZF8L	12V - 110V AC, 300W inverter	https://www.amazon.com/dp/B08MT5ZF8L/ref=sspa_dk_detail_0?psc=1&pd_rd_i=B08MT5ZF8L&pd_rd_w=lLKTW&pf_rd_p=4269e1a0-a218-4fbd-9748-1cd337d2f2a5&pd_rd_wg=zR26N&pf_rd_r=F54793TV0JP21DJVF3ZJ&pd_rd_r=c124f6ce-1d6d-465c-ad23-2d7f4b8bbc43&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUExRFhSNk1KWDVQNEM5JmVuY3J5cHRlZElkPUEwODkyNTE1M0JBTjVVSjRZNlBNWSZlbmNyeXB0ZWRBZElkPUEwNzQwNzU2QlVMUThYRUMxSldEJndpZGdldE5hbWU9c3BfZGV0YWlsJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ==	1	$29.99

Amazon	14GA100-2RB	14 Gauge wire, red and black	https://www.amazon.com/Primary-Bundle-Selection-Product-Family/dp/B07C3MZPLS/ref=sr_1_3?dchild=1&keywords=14+gauge+wire&qid=1616967272&s=electronics&sr=1-3	1	$16.95
Amazon	B07VZ4D2J4	Wire terminals Crimper Kit	https://www.amazon.com/dp/B07VZ4D2J4?pd_rd_i=B07VZ4D2J4&pd_rd_w=NCPxl&pf_rd_p=51cf0d17-50cf-4c89-b1a7-606703cfac11&pd_rd_wg=0TLx8&pf_rd_r=195XZPQ0XRXHEWCKG4CR&pd_rd_r=ed3b7b83-60d4-4429-acd3-b51b7f23c164	1	$25.99
					$94.88

3. Total Cost: $22,100 + $135 = $22,235

6 Schedule

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March 5th: (Saanil, Alex, Ganpath)	Design Document Completed
March 8th: (Saanil, Alex, Ganpath)	Design Review with Prof. Schuh
March 9th-12th: (Saanil, Alex, Ganpath)	Changes to Design Doc
March 12th: (Ganpath)	Start PCB Design
March 13th-14th: (Ganpath)	Machine Shop Discussion
March 16th: (Ganpath)	PCB Design Completed, Audit Passed
March 19th-21st: (Saanil, Ganpath)	DC Motor Testing
March 22nd-26th: (Alex, Ganpath)	Minertia P Motor Testing
March 27th: (Alex)	Data Plot, Motor Characteristic Curves
March 27th-30th: (Alex Ganpath, Saanil)	Chose Minertia P Motor + Gave Machine shop
March 31st- April 2nd (Alex, Ganpath, Saanil)	Team Huddle
April 3-4th: (Ganpath)	Charge Controller Testing
April 6th: (Ganpath)	2nd PCB design complete, audit passed
April 7th-9th: (Saanil, Alex)	Battery Impedance, Bulb, Electrical Fitting
April 10th-12: (Ganpath, Saanil, Alex)	Wind Tunnel Testing

7 Ethics and Safety

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 [3]. 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 [3].

Additionally, we would also need to adhere to Guatemala national energy laws such as the General Electricity Act [4]. 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.

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