Wind Turbine Phone Charger

ECE 445 - Spring 2018
Design Document

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Introduction

Objective

The need for an energy supply in the modern world has become a necessity for all humans. As fossil fuels continue to diminish, the need for renewable energy has been growing in demand. Although many large companies have invested in large scale harvesting of energy through hydro and wind power, the need for portable and home-accessible renewable energy still exists considering most of the turbines that provide this power are massive, towering over 212 feet tall. For countless people around the world whom do not have access to home-supplied power such as in India or Africa, an affordable renewable energy source is needed. As the use of cellphones and electricity continues to grow, so does the need for independently harvested energy.

A portable, yet affordable wind turbine generator would not only remove the need for a power outlet to be present, it would further the mainstream use of renewable energy. Cell Phone and portable batteries today have developed widespread use partly due to their portability and convenience. Hence, it is important that our wind turbine is portable enough that a user could stick it into a bag or preferably a pocket. The convenience, affordability, portability and durability of a miniature wind turbine will favor the needs of the end user. It will solve a much needed problem while providing a very clean and environmentally conscious solution.

Background

Historically, harnessing the power of the wind as an energy source has liberated man from manual labor for centuries. Windmills were first used to mill grain by turning stones, and then later as an efficient means of pumping water into storage for later use on demand. Efforts have been made to harness wind energy large scale like General Electric, Tata, Nordex, through hovering 212ft turbines that can generate more than 6 million KWh in a year, which is enough to supply 1,500 households. As of today, wind power provides 1.9 percent of all the energy consumed in the United States. Commercial wind energy generation has been relatively non-existent. The managing and extraction of fossil fuels and natural resources and the effective use of revenues is a challenge for many countries, especially in the developing world and for high value resources such as hydrocarbons. Partly due to this, studies have show at least half of the population in India does not have access to modern commercial energy.

For recreational purposes, other portable renewable energy devices have been marketed and used such as hand cranks and solar panels, but one requires energy expended from yourself and another one can only harvest energy during daylight. Successfully making a portable and powerful wind generator would not only advance the mainstream use of renewable energy, but would open up the uses of wind energy harvesting in all types of areas including sailing, hiking, camping, perhaps even in motorsports. The need for the adaptation of renewable resources in the modern home grows ever more import every second as the polar ice caps melt and Earth's supply of fossil fuels depletes.

High-Level Requirements list

- The turbine must be able to generate at least 2.5 Watt-hours of charge over 1 hour which can be stored in the internal battery and supplied to USB devices.
- The turbine must be able to work upto wind speeds of 12 m/s.
- The turbine must be portable and easy to mount.

Design

The wind turbine charger will consist of three sections for successful operation: a turbine/generator unit, a power electronics unit, and a microcontroller unit as shown in Figure 1. The power electronics unit ensures that the generated power is supplied at a healthy voltage value to the internal battery. The turbine unit will house the generator and is necessary for the conversion of wind to electrical energy. The microcontroller unit will contain a rotary encoder, an LED display, and a microcontroller to handle the collected data. The two auxiliary units consist of the battery system and the phone.

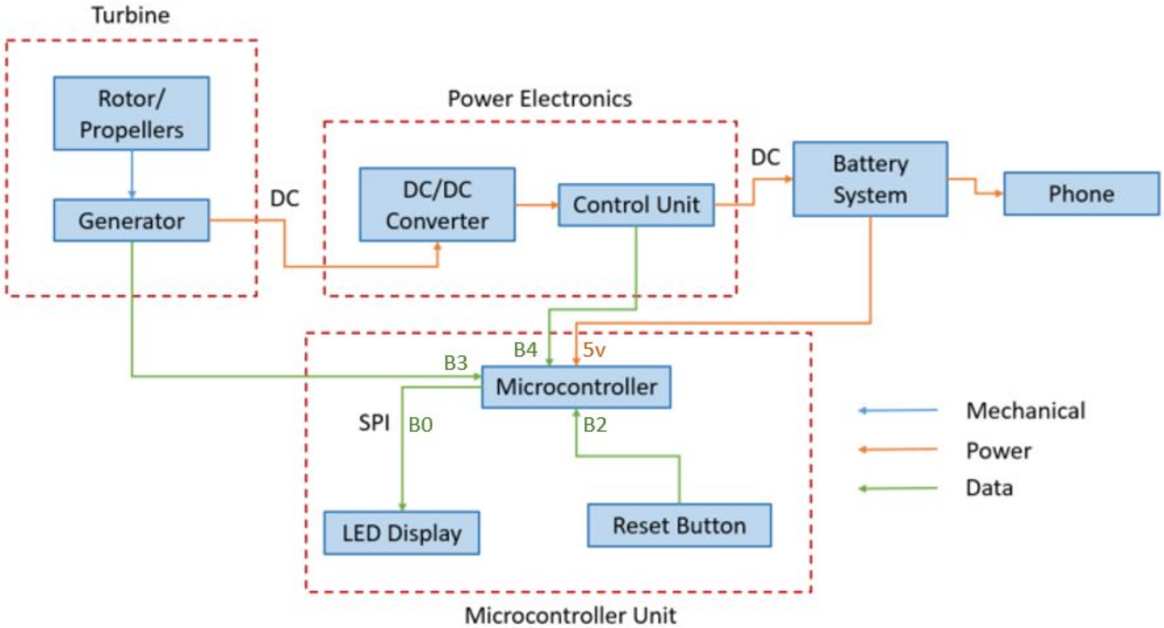

Figure 1: Block Diagram

Physical Design

The physical design will be constructed of three main units. The base, the lower rotor blades, and the top rotor blades. Encased inside the base will hold the generator, the PCB. The LED screen will be visible on the surface of the wind turbine. The battery pack may have an external housing for ease of access.

The material used for the floor bases as well as the rotor blades will be made from PVC. Each PVC pipe with a radius of $r = {\sim}15$ cm will be cut in half and then combined as shown in Figure 2. The power computations are made using the radius R. Note that $S>0$, $R>2r$, however, the calculations have been made assuming that R is approximately 2r.

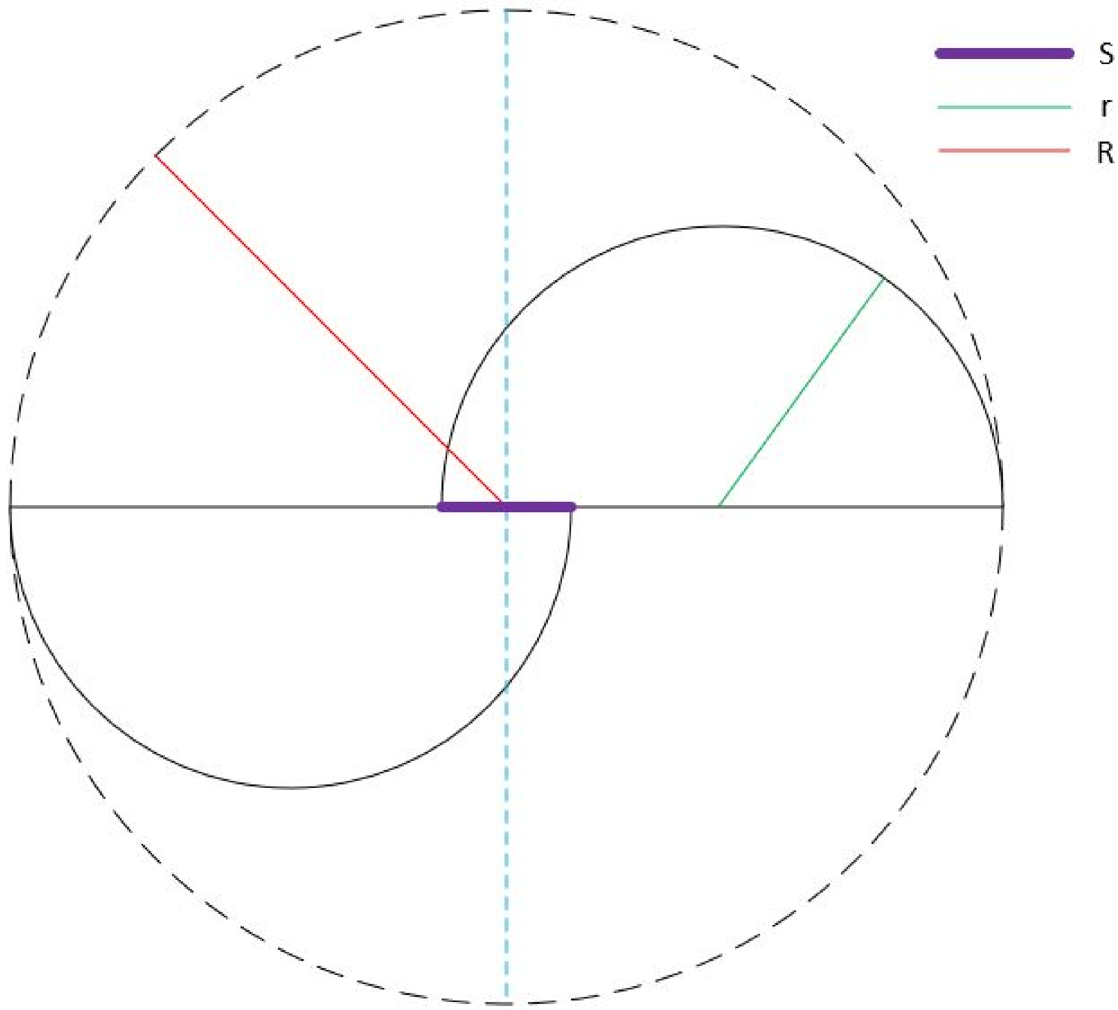

Figure 2: Two-bucket Savonius Design - Bird's-eye view

Figure 3: 3D model of wind turbine

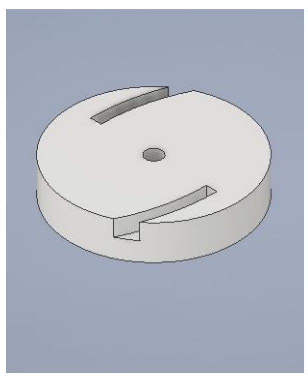

Figure 4: Bottom floor of rotors

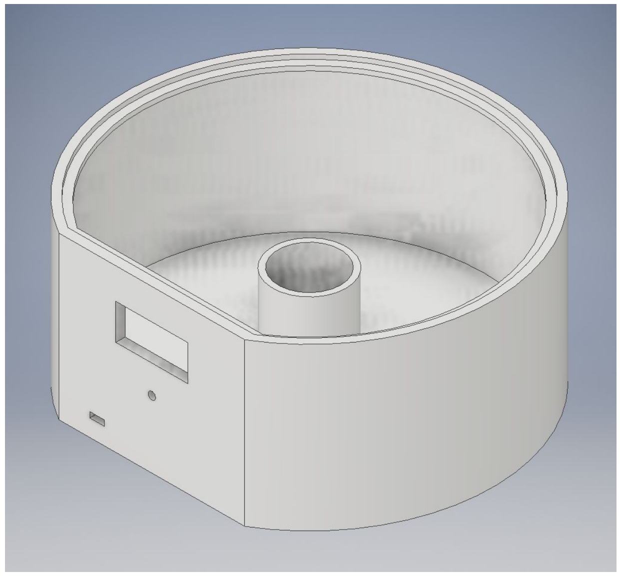

Figure 5: More detailed look inside the base. Dimensions for the PCB and a holding tube for the generator.

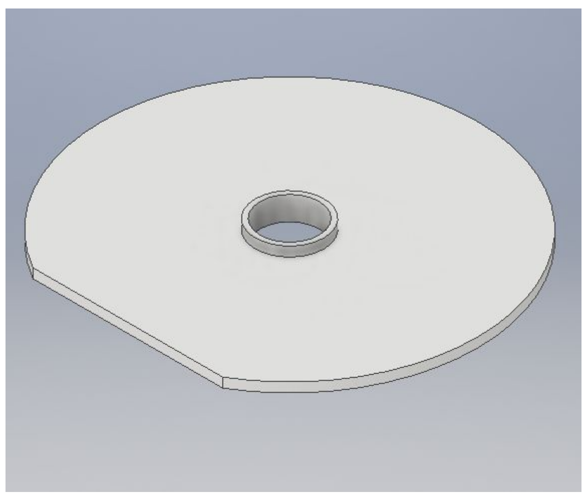

Figure 6: A second unit for the base. Will hold the ball bearing in the center for the generator's power generation.

Block Design

1) Turbine: As illustrated in the block diagram, the turbine has several subcomponents. The turbine is responsible for producing power from the wind. The motion of the rotor will cause the generator to turn, which in turn will produce electrical power. The swept area determined by the height, radius and wind speed will determine the raw power produced.

(a) Savonius Rotor: This is the main exterior component that will provide the torque necessary to power our generator. They will be thin PVC piping .

Requirement	Verification
1.Rotor should be begin spinning at a minimum 5 m/s since this is about the speed needed for 2.5W power 2. Rotor should be able to spin at speeds up to 11 m/s since this should be the speed that makes the generator operate at rated power	1. Using a digital anemometer and a fan set the speed of the fan to produce wind at speed of 5 m/s. Observe if the rotor spins. 2. Set the wind speed to 11 m/s with a variable speed leaf blower and see if our structure is stable

Vertical Axis Wind Turbines, or VAWTs, in larger designs allow for ease of access to the generator and other mechanical and electrical components in comparison to the the Horizontal Axis Wind Turbines, or HAWTs. Additionally, VAWTs are not limited by the directionality of the wind, and can maximize the sudden changes in direction that low altitude winds generally have. Finally, VAWTs provide many more portable friendly designs for our specific focus.[2]

The Savonius design doesn't face the centrifugal issues that a Darrieus design would, and the compact form allows it to be convenient and portable.Having a 2-barrel, two story design allows the turbine to be self starting which is very beneficial for the market user as it minimizes user input when setting up the turbine.

Betz's Equation provides the power possible from an ideal wind turbine,

$$P = (16/27) * (\rho/2) * A * v^3 \quad [W]$$

However, since real world applications aren't perfect, this can be written as the following, assuming the air density to be $\rho = 1.2$ kg/m^3

$$P = 0.18 * (\rho/2) * A * v^3 \ [W]$$
$$A = h * R$$

Where h = 0.5 m and R = 0.3 m. The following plot shows the power output by the generator under various wind speeds.

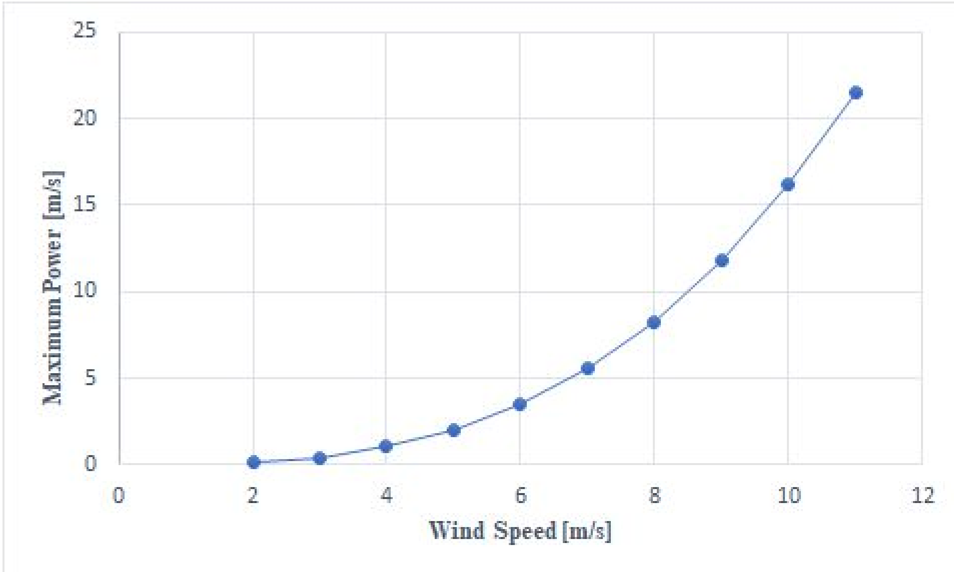

Figure 5: Wind Speed vs Maximum Power

The Betz coefficient 0.18 is achievable for a Savonius design, and is confirmed by previous tests.[1]

The gear ratio can be calculated by comparing the frequency of the turbine to that of the generator.

$$v = w * R$$

$$f = w/2\pi \quad [\mathrm{Hz}]$$

$$1 \text{ rpm} = 1/60 \text{ Hz}$$

Gear Ratio = Generator Rated rpm / f

The following calculations are made assuming a generator rated at 2500 rpm.

V [m/s]	R [m]	f [rpm]	Gear Ratio
5	0.3	159	15.7
6	0.3	191	13.1
7	0.3	223	11.2
10	0.3	318	7.9
15	0.3	477	5.2

Table 1: Turbine performance variation with wind speed

(b) Generator:

Taking its input from the propeller, the generator will provide the
conversion of the mechanical motion of the blades to electrical power. The current generator is a 36W DC permanent magnet motor that can be run as a DC generator. Using an appropriate gearing scheme the low speed of the rotor will translate to high speed rotation the motor can use. After consulting with Professor Haran, he suggested a permanent magnet motor could be easily run as a generator. Based on the relative availability, size, and cost this motor was chosen. The generator is rated for 36 W which makes our high-level requirement of 2.5W reachable.

Requirement	Verification
1. When rotated at an appropriate speed generator must output about 3W to account for inefficiencies in the converter circuit.	1. Test and measure output of the generator when it is connected to a similar sized motor that turns at a specified rate.

2) Power Electronics:

a) DC/DC Converter:

The generator will output unregulated DC, which must be regulated through the converter to a suitable output voltage for the battery bank. The DC will pass through an input filter first. Then, the converter will behave as a buck or a boost depending on if the input voltage is higher or lower than what the output should be. It must output very small ripple to be compatible with commercial devices. The topology will be a Cuk which can do both boost and buck. It has the added advantage of having a constant current output which other topologies such as SEPIC struggle with. It also has quick response to changes which will be necessary when dealing with gusts of wind.

Requirements	Validation
1. Accepting voltages as low as 1.8 to as high as 20V and convert it to 5V 2. Efficiency greater than 80% 3. Low ripple to avoid damaging the commercial parts that expect smooth outputs. Ripple ratio ~1%	1. Put a DC input of 1.8V-20V and measure the output voltage with a voltmeter and compare it to 5V 2. Measure input and output power either using a wattmeter or current and voltage meters and preform efficiency calculations 3. Connect the output to an oscilloscope and measure the peak to peak ripple of voltage and current.

Using a TPS25810 chip, we are able to achieve USB-C power delivery. The USB-C can output 15W.

b) Control Unit:

The main function of the control unit will be to certify that our voltage output will not exceed what the battery is rated for. It's a fundamental feature that will safeguard a sensitive component, the battery. Since we may have voltages lower or higher than the required output the control will change the duty ratio fed into the gate of the MOSFET which is our switch for the buck/boost converter. The control unit will be a Proportional-Integral control circuit. First, an error generator circuit is constructed using a TLE2082 op amp which is outputted to another opamp of the same model but wired to give PI control. Lastly, this is sent to a comparator op-amp and is compared with a triangular reference signal. The output of this comparator goes to the gate driver which in turn will send the appropriate signal to the MOSFET. The triangular reference signal is generated by a Schmitt trigger and an integrator circuit. The full circuit is pictured in Figure 8.

Requirements	Validation
1. Error generator produces appropriate error signal i.e reference =5V and input= 6V then error = 1V 2. When an error signal is passed through the PI controller it should output a voltage equal to or proportional to the correct duty ratio to achieve the reference voltage based on the input voltage i.e input =1.8V ref = 5V D=0.74V 3. The Schmitt Trigger and Integrator circuit should output a triangle waveform of amplitude 1V.	1. Have a voltmeter monitor reference, input, output of the error generator circuit and check for correct values. 2. Input an error signal into the PI controller and monitor the output. Should be equal to the duty ratio needed for the given input to produce the correct output through the converter. 3. With two op-amp circuits connected in series with a feedback loop the output of the circuit should be monitored through an oscilloscope to see if it is the required triangle wave.

3) Battery System:

This will be an off the shelf purchase. It is rated for 15W based on USB-C cable ratings. This will allow us to charge our device. It will be powered through the output of our DC/DC converter. This will power the phone and microcontroller. It must have 3 ports so that these functions may be performed correctly. That is, the battery pack should be able to have a USB-C input to charge the pack upto a maximum power of 15W, while having two other USB outputs(not required to be USB-C) that will power the microcontroller while charging the phone.

4) Anemometer:

As a requirement for the microcontroller, we will measure the voltage produced by the generator, correlate this to the rpm of the generator, and then correlate this with the wind speed. The data line from the generator to the microcontroller will be stepped down to a readable voltage that will not damage the microcontroller and we can then derive the wind speed from the given data.

Requirement	Verification
1. Accurately correlates produced voltage values with wind speed. The voltage will range from 0-5V and the wind speed will range from 0-11 m/s. 2. Does not damage the microcontroller with a voltage too large, that is the input voltage of the microcontroller does not exceed 5V.	1. A. After stepping down the voltage to below 5V and using whatever collected data to give a slope and correlate a wind speed, we will simultaneously be using an anemometer to test the wind speeds. 2. A. Step voltage down with proper voltage divider circuit, using an oscilloscope we can measure the voltage produced and the values it ranges.

5) Reset Button

We will use a simple button to use to reset the microcontroller software for easier debugging and if any software bugs occur. Just needs to be a generic button that trigger an interrupt to reset the software running on the microcontroller.

Requirement	Verification
1. Is able to read a simple binary value that can indicate that the software needs to be reset.	1. A. Power the button via the 5v source powering the microcontroller and have a signal leading to the input pin of the microcontroller. A simple program will print if the pin high or low voltage.

6) Microcontroller:

We will be using an ATmega32 microcontroller because its relatively high power and low power consumption. This 8-bit controller has up to 2 Kilobytes of SRAM, 32 general purpose I/O lines and 32x8 general purpose working registers. The I/O has a master/slave SPI serial interface and other functions that we will need for communicating with the LED display. The several input output lines serve us well since we will need to input data collected from the generator and the voltage regulator to monitor performance. On top of giving us the needed hardware for the project, the ATmega32 microprocessor can run at a clock speed of 1MHz with 3V and 1.1mA which is very low amount of power consumed by our generator. The ATmega32 processor is supported by a C compiler, Macro Assemblers and Evaluation kits.

Requirement	Verification
1. Can both receive and transmit over Serial Protocol Interface at speeds greater than 2Mbps 2. Can monitor and accurately read voltage produced by the generator and power supplied by the battery.	1. A. Connect the microcontroller SPI port to another microcontroller SPI port, such as a BeagleBone. Both connected with a terminal in Putty. B. (Start Timer) send a 0.2Mbit block of random data from the ATmega32 SPI output to the Beaglebone's SPI input. C. Echo the data back, this time from the Beaglebone's ARM processor. D. (Stop Timer) ensure that the data received matches the data sent, and the time does not elapse 100ms. 2. A. Have a regular power supply feed into a node on a breadboard B. Step down the voltage so it can be read at a voltage stickly below 5V so the microcontroller is not damaged. C. Correlate the value read digitally by the microcontroller to the voltage being supplied by the power source.

Circuit schematics

Microcontroller and LED Display

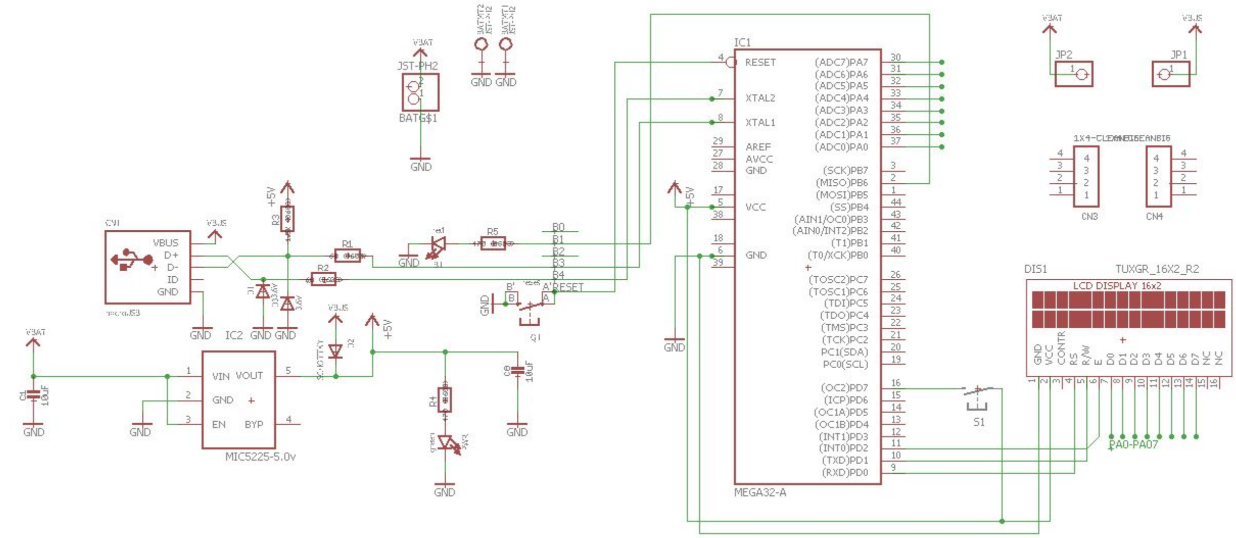

Figure 6: Circuit schematic for Microcontroller Unit with ATmega32 processor

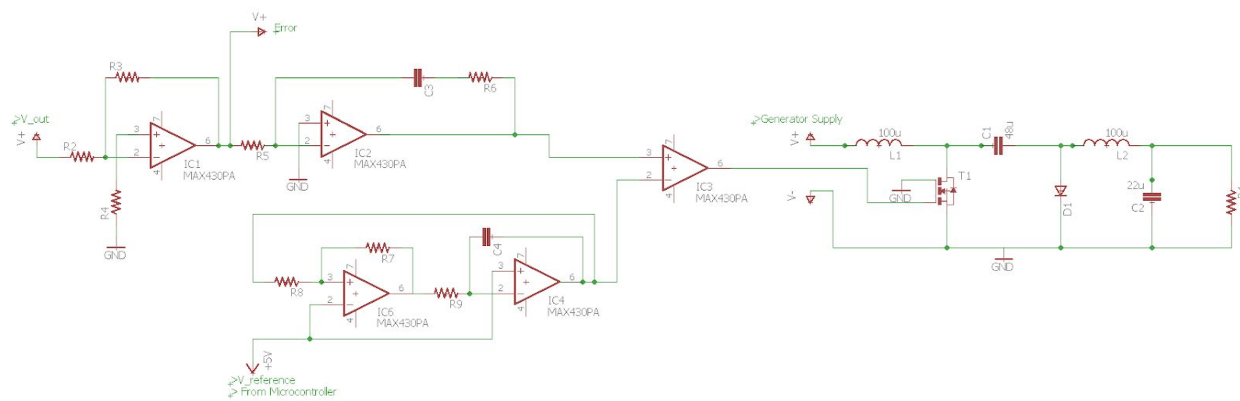

Figure 7: Circuit schematic for Power Electronics and voltage regulator

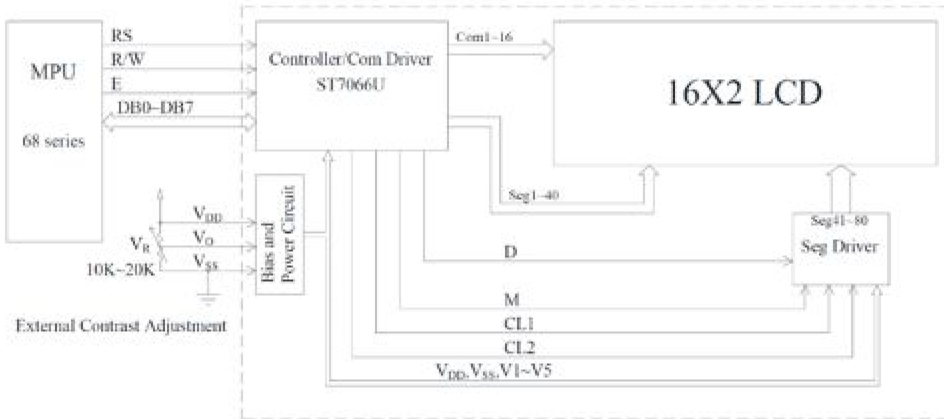

Figure 8: Circuit schematic for16x2 LCD display

Ćuk Converter

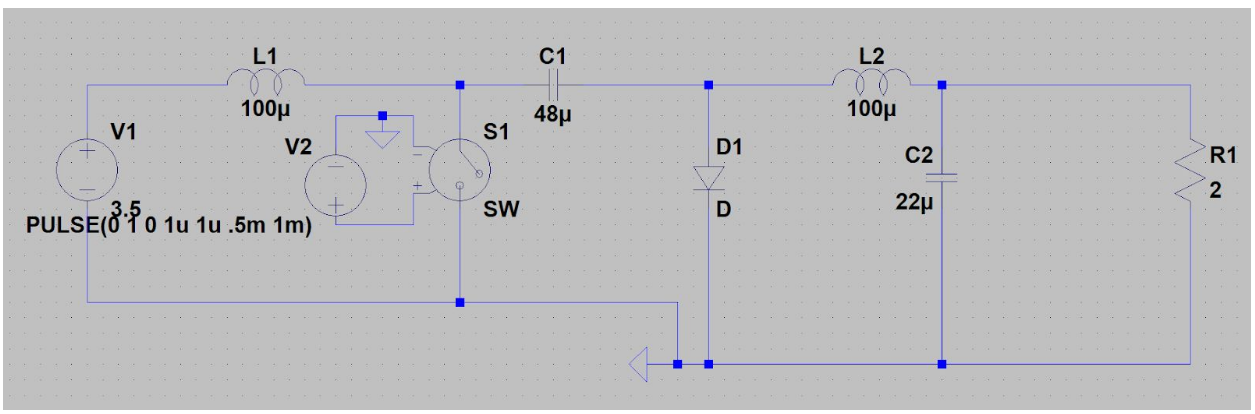

Figure 9: LTSpice Cuk Simulation Circuit

Control Circuit

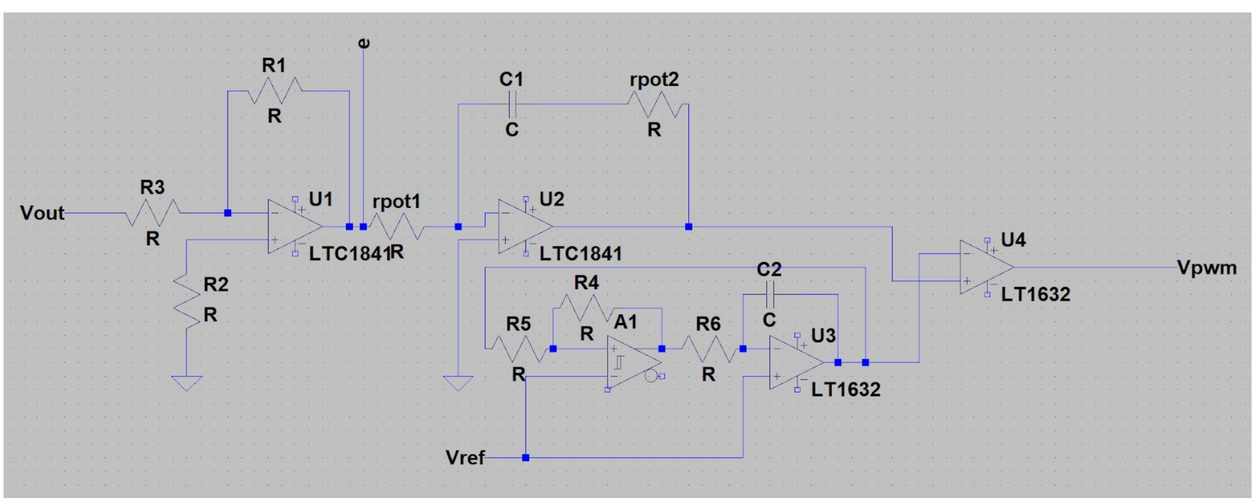

Figure 10: LTSpice Gate Driver and Control

Tolerance Analysis

The wind turbine is highly dependent on the availability of wind. It will be unable to provide the required power at low speeds, and at high speeds it may become unsafe to operate due to the electrical and mechanical constraints of the components that we use. The minimum generation must be 2.5 Watt-hour in order to operate a typical mobile phone.

A corollary to the fact above, the power electronics must be able to provide a constant output. Even though there may be a threshold through the use of an anemometer and a brake, it is extremely important that the power provided to the battery and microcontroller is stable and within the electrical limitations of the devices.

The mechanical design is not the main focus of the project so the tolerance for the mechanical components is wide. Our initial design assumes that we will have a height of 50 cm and a diameter of 30 cm. Variations in the piping, cutting and assembly of the turbine may cause higher or lower power outputs.

Additionally, the variation in wind as illustrated in Figure 5, imply that the design is prone to sudden spikes or unexpected behaviours caused by nature.

The converter has many components with tolerances that may affect the final output. This output is critical for the function of the system since it may damage the battery or microcontroller which are vital. The tolerance ranges for the capacitors and inductors are typically +/-20% found after searching Mouser and Digikey for similar parts used in the simulation. According to preliminary capacitor and inductor selections, the following simulations were performed: setting the capacitance and inductor values for the two extreme cases plus 100% was used in the even that heat and/or frequency would greatly impact the tolerance. The values used in the tolerance simulation were calculated using the following equations. (1) and (3) are for the capacitor and (2) and (4) are for the inductor.

$$20\%\ \text{tolerance} = (22*10^{-6})*(-.8) = 17.6*10^{-6}\,F \tag{1}$$

$$20\%\ \text{tolerance} = (100*10^{-6})*(-.8) = 80*10^{-6}\,H \tag{2}$$

$$+100\%\ \text{tolerance} = (22*10^{-6})*(2) = 44*10^{-6}\,F \tag{3}$$

$$+100\%\ \text{tolerance} = (100*10^{-6})*(2) = 200*10^{-6}\,H \tag{4}$$

The tolerance of these components would mainly affect the ripple seen on the output side.

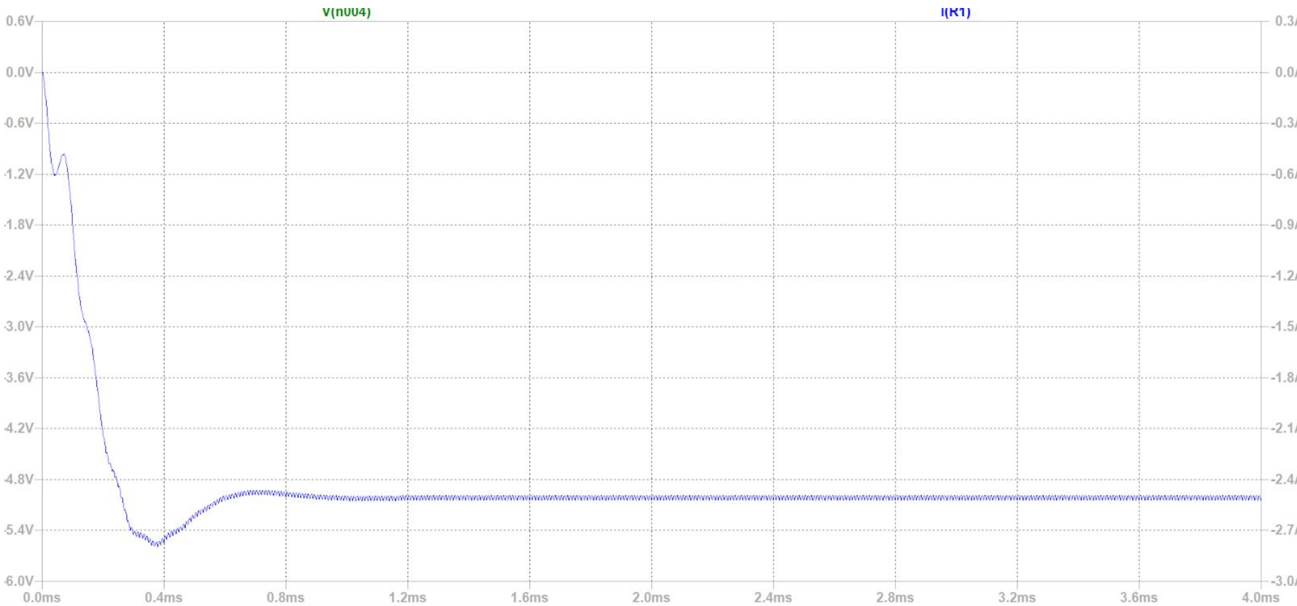

Figure 11: Tolerance test at -20%

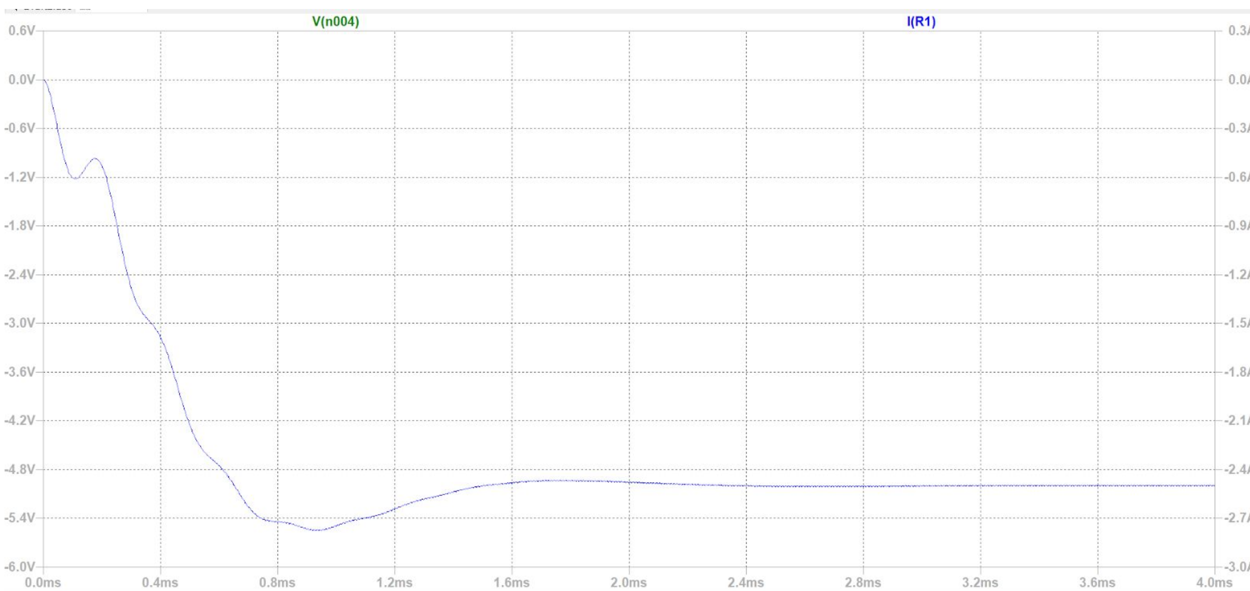

Figure 12: Tolerance Test for +100%

From the two figures it is clear that after initial startup there is virtually no effect on the circuit output from the tolerance ranges.

The seller of the generator did not provide tolerances for the output. However, since we are designing a wide range voltage regulator it should not be an issue if the output varies from what the seller claims.

Cost and Schedule

Cost Analysis

Our fixed development costs are estimated to be \$33.75/hour assuming the average annual salary is \$65,000 per year, 8 hours/week for three people.

$$3 \cdot \$33.75/hr \cdot 8\ hour/week \cdot 10\ weeks/0.6 \cdot 2.5 = \$33{,}750$$

Parts

Description	Quantity	Per Unit Price	Total Parts Cost
Rotary encoder (PEC11-4215F-S24)	1	$1.63	$1.63
36W Permanent Magnet DC motor/generator	1	$34.99 ($22.99 from international suppliers)	$34.99
LED Display (CFAH1602S-YYH-ET)	1	$7.10	$7.10
ATmega32 Microprocessor, Resistors, USB port	1	$6.10	$6.10
PCBs (PCBWay)	1	$3.10	$3.10
20000mAh Battery AUKEY PB-Y14-US*	1	$39.99	$29.99
TPS25810**	1	$0	$0
TE Connectivity ALCOSWITCH Switches MSPS103C0	2	$4.66	$4.66

Total	-	$92.91	$92.91

Table 2: Cost of Parts

Labor	$33,750
Parts	$92.91 * 2 = $185.82
Grand Total	$33,935.82

Table 3: Grand Total Costs

Considering we build 2 wind turbine generators, this will yield a total development cost of $33,935.82.

*This is an auxiliary component similar to the phone, so it is important to note that this component may be subsidized if the user owns a similar product. The battery pack should have 3 ports, as well as USB-C support to be compatible with the wind turbine. Excluding the battery pack decreases the per unit cost of the parts by 43%.

**The specific prototype will use a Texas Instruments free sample, however, the unit price for per build is $1.40 assuming the quantity to be 1-9, a bulk order such as 750-999 lowers the per unit cost to $0.71.

Schedule

Week	Kemal	Charlie	Sachin
02/25	**Ordering generator** DC/DC circuit Building and Debugging	**Ordering battery** DC/DC circuit Building and Debugging	**Order rotary encoder** **Order LED screen** Mechanical design (housing)
03/04	DC/DC circuit	DC/DC circuit	**Order Trinket 5V**

	Building and Debugging	Building and Debugging	Mechanical design (housing)
03/11	Testing generator Testing battery	Testing generator Testing battery	Version 2: Control Unit
03/18	**Ordering part for assembly** Powering the microcontroller	**Ordering PVC Pipes** Powering the microcontroller	**Ordering PCB parts** Programming microcontroller (LED screen, anemometer, battery percentage)
03/25	Testing and debugging circuit	**Ordering extra parts** Testing and debugging circuit	Programming microcontroller (LED screen, anemometer, battery percentage)
4/4	Version 2: Power electronics	**Ordering extra parts** Version 2: Power electronics	Version 3: Control Unit? Building base and propeller Assembly and testing
4/11	Building base and propeller	Building base and propeller	Debugging and testing
4/18	Assembly and testing	Assembly and testing	Anemometer Programming and testing
4/25	Environmental tests Power output tests	Environmental tests Power output tests	Program bug fixes
5/1	Prepare for final presentation Begin final report	Prepare for final presentation Begin final report	Prepare for final presentation Begin final report

Table 4: Overall Schedule

Ethics and Safety

The user of our Wind Turbine will be directly involved with the operation of the device; thus, it is important that we ensure a safe and reliable product. There must be safeguards in place to protect both the product and the user.

There are several components in our product that may be potential safety hazards for the user if mishandled or incorrectly designed. The main components to consider is the battery, the rotor blades, the gears and the electrical circuitry.

Batteries always pose a risk since they can leak or explode. Proper handling will minimize the risks associated from damaging the battery due to impact. In order to prevent an explosion, it’s important to monitor the temperature of the device, as well as the power input into the battery. Since the input of the battery is through the output of the power electronics, there is always an underlying risk of unstable power being fed. The monitor of the output through the phone app, as well as a meticulous power electronics design will lessen the risks related to the battery.

Another component to consider are the blades that will be spinning when the wind turbine is in motion. The responsibility is on the user side mostly, users should always approach these machines with the knowledge that they will have moving parts which should be handled with care. The blades will be made from a plastic-like material which at high speeds may be dangerous if direct contact is made. As the designer, there is a responsibility to make these blades safe to operate and through the use of tools such as brakes have the required automated oversight.

Gears in wind turbines are a hot topic of discussion since resolving the issues associated with them may help extend their longevity. The mechanical fatigue and wear of these components can cause fires in the long term, if not properly maintained. Future applications of these designs can avoid the use of gears by using much higher pole generators that would decrease the RPM to match the turbine.

The wind turbine is expected to portable and may be chosen to be brought along on hiking trips or other strenuous outdoor activities. Such activities may lead to occasional impacts, however, it is not the normal mode of operation and therefore it should ideally be handled with care. There are many electrical elements within the structure, and a strong exterior will provide the necessary protection for the fragile interior. Different weather conditions in which the turbine will operate must also be considered when designing the exterior and choosing the materials.
In addition to the portability and the conditions in which the turbine will be carried through, we must also consider the operating conditions. At high speeds there may be vibration and temperature variations that

we have to account for. Ideally, the material and structure of our turbine should withstand these effects. The consideration of a secure mount also holds paramount importance in this aspect, as it may help to minimize these factors.

Most products assume that the user will behave such that they do not put themselves or others at risk. This wind turbine is no exception and it assumes that the user will act responsibly. We as the designers must ensure that all the necessary steps are taken in order to mitigate the risks.

In compliance with the IEEE Code of Ethics[3], we must consider that our product will be available to everyone, and that "to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression", thus adhering to #8 of the IEEE Code of Ethics. Additionally, we must follow the guidelines underlined in #1, "to hold paramount the safety, health, and welfare of the public…" and in #3, "to be honest and realistic in stating claims…" We must make sure that our wind turbine operates in a way that is safe for the environment and surroundings. The output data that we provide in our phone application must reflect what is measured in our devices.

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