BATTERY BOX PROJECT

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Abstract

Our group was tasked with developing a battery box that can harness energy generated from a small wind turbine meant for home use. The system takes the energy generated from the turbine, stores it in a battery, which can then be used to power electronics or charge devices. All of these actions are governed by an Arduino Uno microcontroller. This was an ambitious project for our group and proved to be quite difficult, but we had many successes along the way which we will outline herein.

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1. Introduction

This project was contracted to us by the WIDE Impact Development Engineering RSO, which is focused on developing technologies for underdeveloped countries. While they design and build the small scale wind turbine, they tasked us with creating a way to harness the wind energy, store it, and make it available for powering small devices. This requires several different steps, as shown in our high level block diagram. The input 3-phase AC power is rectified into single phase DC power, which is then stepped down to a level required to charge a 12V Lead Acid battery. To step down the voltage in a proper manner, a microcontroller is used to govern the input and output voltages and a specific charging circuit is used to safely charge the battery. On the output side of the battery, an inverter is used to turn DC back into AC which is then stepped up by a transformer. A USB module and battery gauge are implemented as well to charge small devices and display the charge level respectively. We were able to accomplish many of these tasks, but struggled with some as well as will be detailed further on in this report.

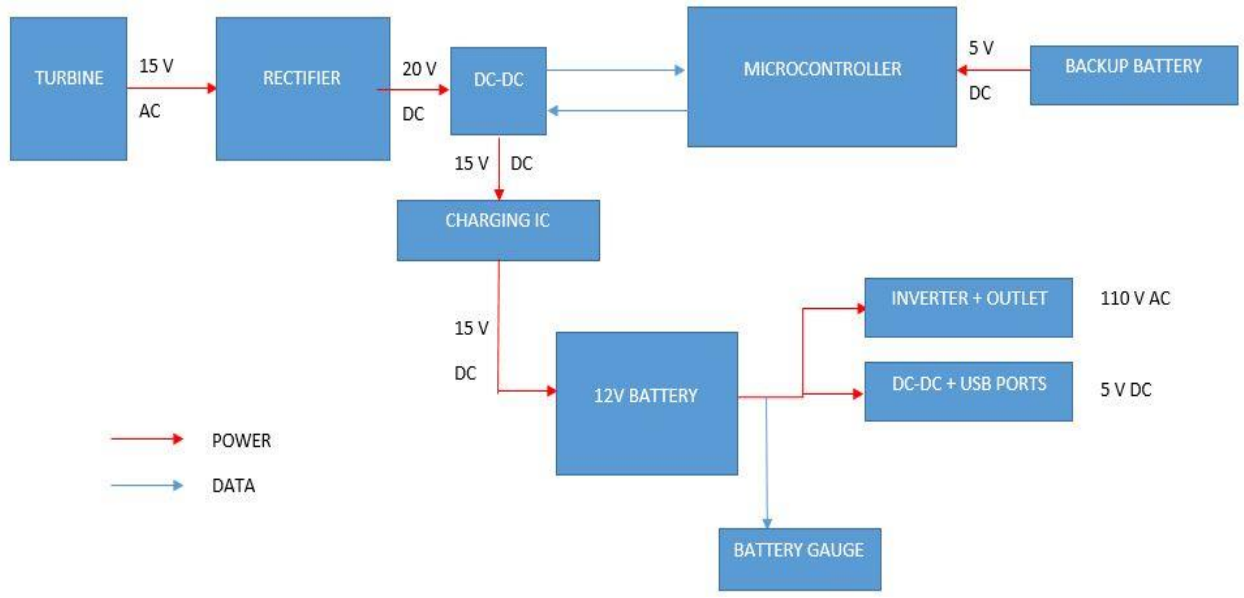

Figure 1: Top Level Block Diagram

1.1 Initial Challenges

We found out fairly early on in the semester that this would not be an easy project for us and that there would be several key challenges we would need to face. Dealing with high power at both the input and at the output is something that is considered generally unsafe and hard to deal with. Dealing with 3-phase input power and high voltage at the output of the inverter is difficult, especially because the only place to simulate 3-phase power is in the Power Lab, which non-registered students have very limited access to. Charging a 12V battery safely is challenging as well because there is such risk of danger when it comes to batteries and charging them. Any mistakes in battery charging will lead to battery failure and possibly more volatile reactions. We also want the cost to be kept down; being that this is mainly meant for underdeveloped countries without access to a reliable grid, the overall cost needs to be something people can afford/can be donated. Finally, because the end user is likely a person without much technical

background, this needs to be as easy to use as possible, meaning it needs to be modular and designed in a way that is portable and user friendly.

2 Design

2.1 Rectifier Design

The rectifier is a crucial part of our overall design because it is the first interface of the entire circuit. The power from the turbine first comes to the rectifier. We decided to use a standard bridge configuration found in several Power Electronics textbooks seen in the figure below. The six Schottky diodes work complementarily to rectify the signal, the resistor acts as the load, and the combination of the inductor and capacitor filter the output to minimize ripple.

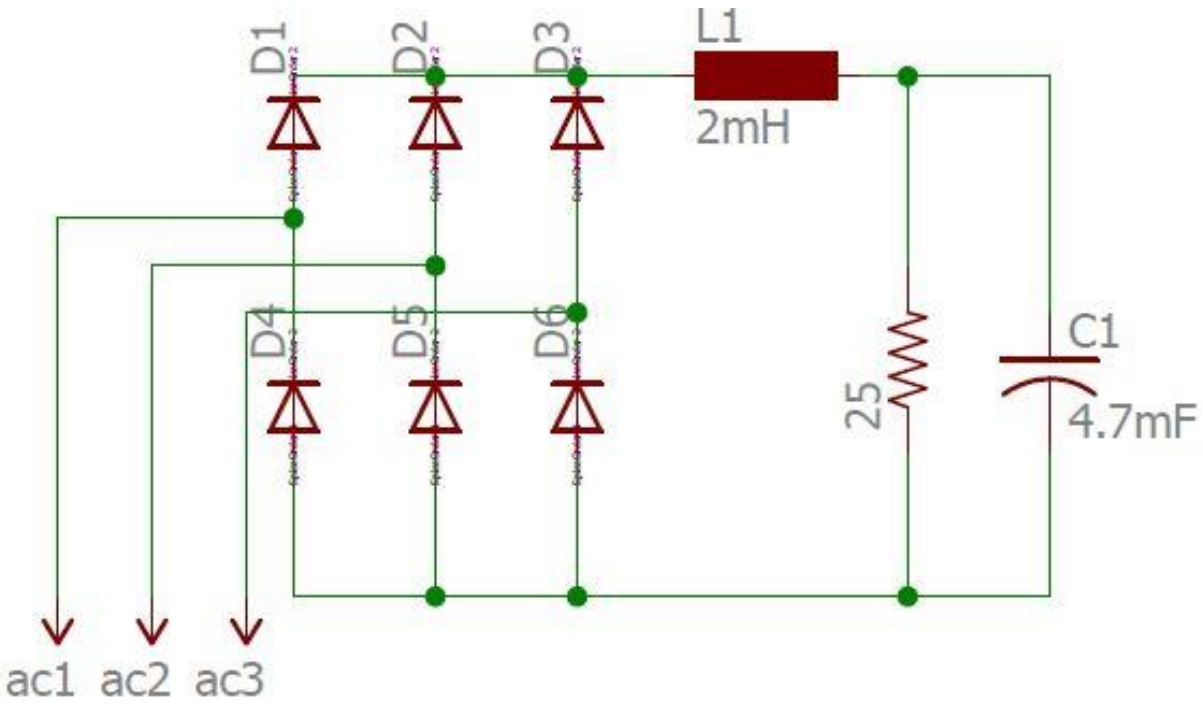

Figure 2: Rectifier Schematic

With the input of the rectifier (from the wind turbine) expected to be 9V Phase-to-Ground, we can calculate the output using the following expression:

$$V_o = V_{in} * \sqrt{3} * \sqrt{2} * 0.955 \quad (1)$$

Where $\sqrt{3}$ accounts for converting Phase-to-Ground to Phase-to-Phase, $\sqrt{2}$ takes just the amplitude of the signal, and 0.955 is a correction factor, because the ripple is not perfect as seen in the figures below. When using 9V as the input, we expect an output of 21.053 V. This output will enter the DC-DC converter.

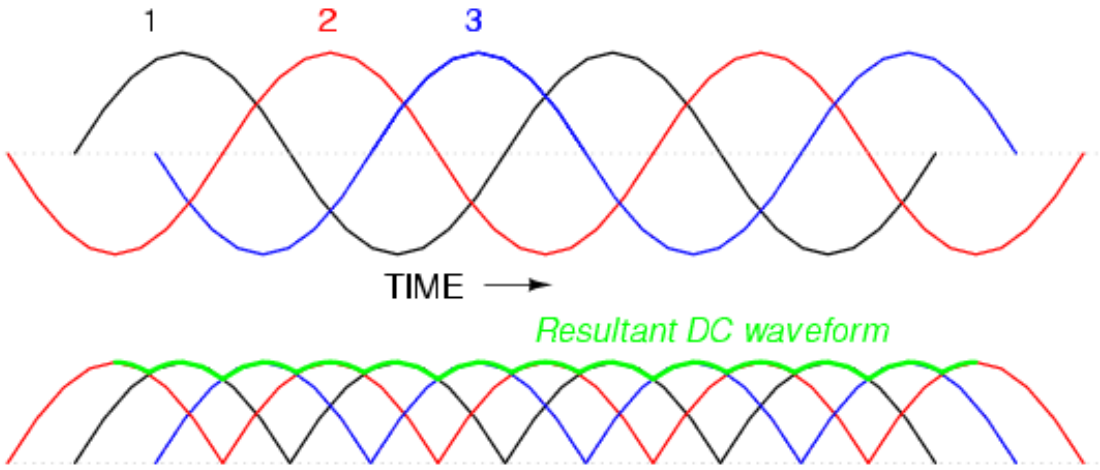

Figure 3: 3-phase AC signal and Resultant Rectified Waveform

2.2 DC-DC Converter Design

2.2.1 Buck Converter

The voltage from the rectifier requires reduction in order to be suitable for battery charging. From 21V, we must achieve 15V and thus a buck converter must be implemented. The schematic of our converter is shown in Figure 4. A typical buck converter consists of a N-MOSFET driven by a MOSFET driver chip. The driver is operated with a 12V input and the drain of the MOSFET is supplied with the 20V input from the rectifier (this should be 21V but in design and testing we used 20V as a more rounded value). The source of the MOSFET is the output which leads to filter inductors and capacitors. We chose to use five capacitors in parallel instead of one large one to reduce the ESR resistance which minimizes losses and increases efficiency. There is also a voltage divider at the output which is used to supply a reference for the Arduino Uno's control scheme.

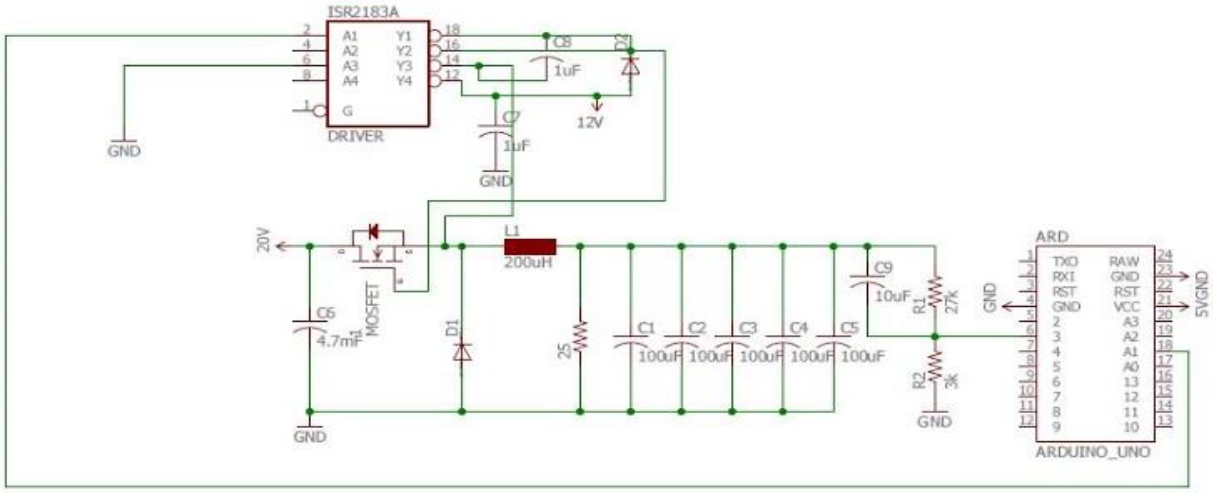

Figure 4: DC-DC Converter Schematic

2.2.2 Microcontroller

The DC-DC converter, specifically the MOSFET driver needs a PWM input to control the MOSFET. Based on the input voltage from the rectifier, a specific duty cycle must be generated for the PWM signal to properly administer the 15V output required. This is why a microcontroller is needed, and the Arduino Uno is perfect for this purpose. In the ideal scenario (20V input, 15V output), a 75% duty cycle is required for the PWM signal as given by this equation:

$$D = \frac{V_{in}}{V_{out}} \tag{2}$$

The input voltage is not constantly 20V because it depends on the input from the turbine. At full tilt, the turbine will supply the 20V into the DC-DC converter, but this could be lower if there is not full wind speed. The DC-DC converter still needs to produce 15V at the output regardless of the input, granted that the input is at least 15V. The microcontroller solves this problem as shown in the flow chart in Figure 5. The voltage divider at the output of the DC-DC converter sets that voltage to 1V, which the Arduino can use to compare to its own internal reference. If the voltage at that point is higher than the internal reference voltage, the duty cycle is reduced by 1. If it is lower than the internal reference voltage, the duty cycle is increased by 1. This happens iteratively until the proper output voltage is reached.

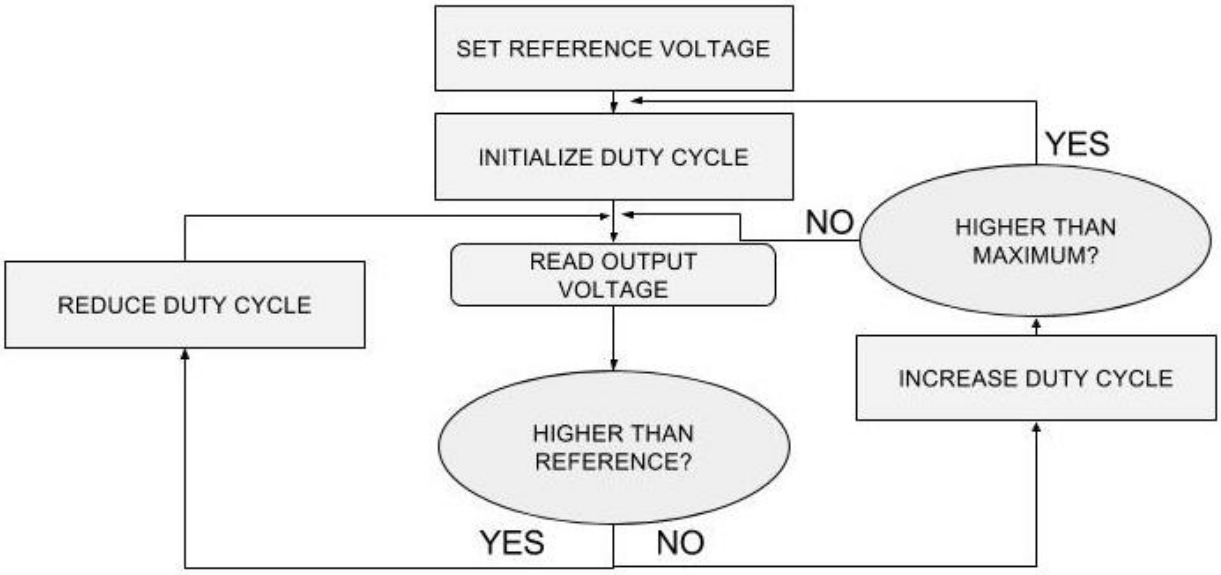

Figure 5: Flow Chart Describing Microcontroller Code

2.3 Charging IC

As described earlier, 12V lead acid batteries have a specific method required to charge them properly and safely. This method is known as Constant Current/Constant Voltage charging and is illustrated in Figure 6. In stage one of charging the battery, the current stays constant while the voltage slowly rises to a constant value. In stage two, the current exponentially decreases as the voltage stays constant to top off the charge. Finally, in stage three, the voltage decreases slightly to a constant amount and the current stays at a constant low value to maintain counteract any battery leakage.

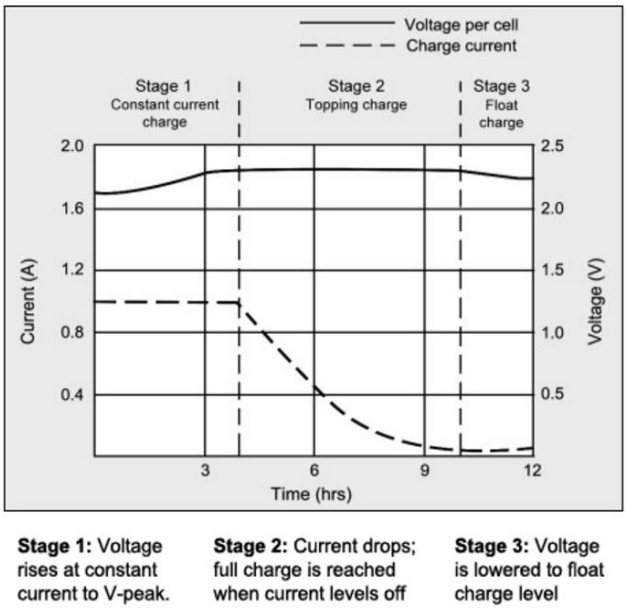

Figure 6: Constant Current/Constant Voltage Charging Method (Source: BatteryUniversity.com)

We decided to use the LT1513 Charging Chip for its presumed simplicity and effectiveness. By using the recommended application of the chip shown in Figure 7, we expect an output of 15V and 1.25A to charge the battery safely. The chip would adjust the voltage and current depending on the level of charge in the battery.

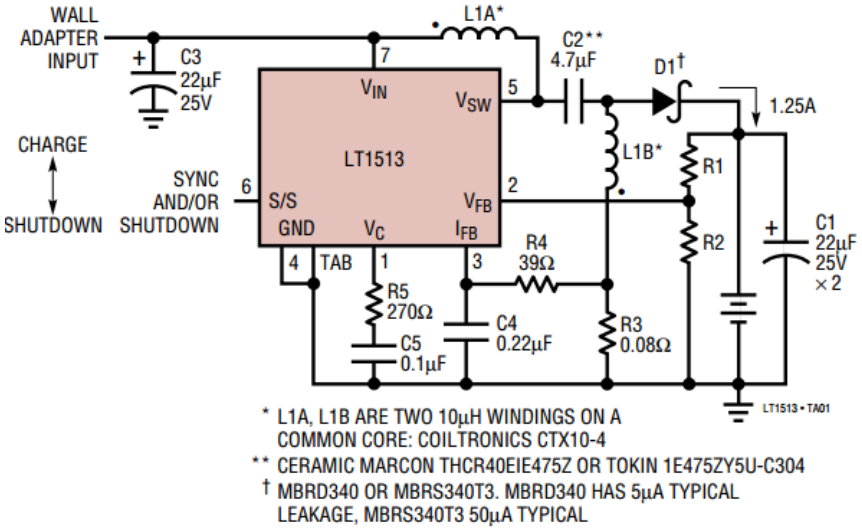

Figure 7: LT1513 Recommended Schematic (Source: LT1513 Data Sheet)

2.4 Inverter

At the output end of the battery, we want to be able to use energy stored to power electronics and charge devices. In order to power electronics such as lamps, the 12V DC that comes from the battery must be converted to 110-120V AC. This requires an inverter circuit and a 1:10 step up transformer. In our design process, we went through several different implementations of an inverter circuit, and most were not successful. Implementations included using 555 Timer chips along with Bipolar Junction Transistors to oscillate the signal, but coupling this with a transformer did not lead to an ideal as you will see in Section 3 and Section 5. This made us pressed for time to choose a configuration and the one we decided to use in the end is shown in Figure 8. An H-Bridge using four N-MOSFETS (and four MOSFET drivers) oscillate the input voltage to turn it into alternating current. Two opposite PWM signals (from the microcontroller into a NOT gate) keep MOSFETs 1 and 3 on while turning 2 and 4 off and vice-versa. This creates an 12V square wave alternating current signal. This would then feed into the step up transformer to create a final output of 120V AC which can be used to power different electronics.

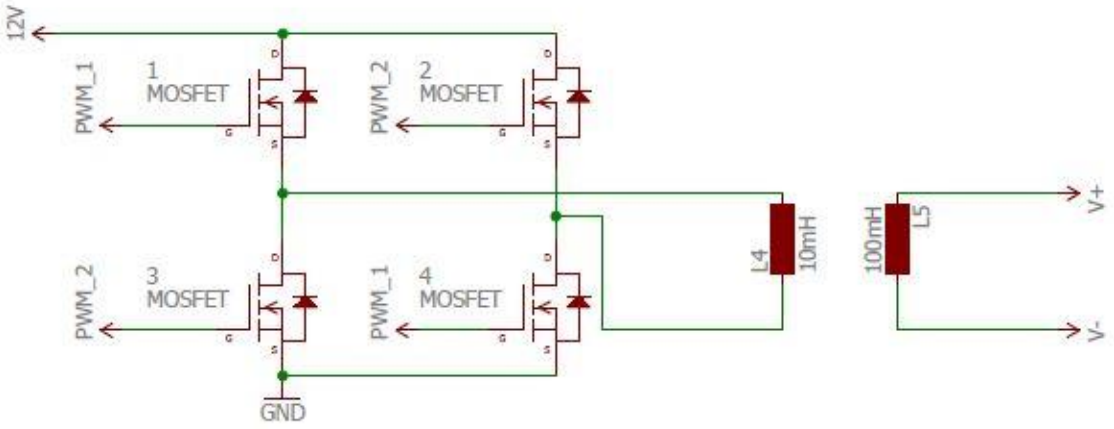

Figure 8: Inverter Schematic

2.5 USB Ports and Battery Gauge

These are two off the shelf items that we expect to work. They both run off of power from the 12V battery. The USB device has two ports that can supply up to 2.1A depending on the load and depending on how much current any load at the end of the inverter circuit draws. The device has a built in DC-DC converter that steps the voltage down from 12V to 5V that USB devices need. The battery gauge is essentially a digital voltmeter with a low 20 mA draw. It is expected to show an accurate measurement of the level of charge in the battery to one decimal place.

Figure 9: USB Ports and Battery Gauge

3. Design Verification

3.1 Rectifier

3.1.1 Testing Procedure

For the initial test, the rectifier, formed by six Schottky diodes, was connected to a three-phase source along with a Variac to step down the voltage and adjust it to the desired 9 V phase-to-ground that was measured by an external power meter. A bench simulated the alternator of the wind turbine which is estimated to produce that voltage at 240 rpm. At the output of the rectifier an 8-ohm resistor was allocated so that the current drawn from the source measured 2.63 Amps.

After succeeding with the first test, a second-order low-pass filter composed of a 2mH inductor in series and a 4.7mF capacitor in parallel was added to the initial 8-ohm load to improve the output ripple that will be significant for the implementation of the subsequent DC-DC converter.

3.1.2 Results

From the first test, the results were close to the initial estimates. The output voltage was measured to be an average of 20.67 V with a ripple of 5 V – excessive due to its implications on the overall circuit. This is why it was necessary to implement the low-pass filter. The results obtained from the definitive testing including the rectifier and the filter are shown in Figure 10. The negative value of the signal can be explained from a misplacing of the oscilloscope terminals in the measurement process, but the average of the waveform is shown as 21 V and a highly improved ripple of 2 V. Equation 3 also represents the calculated efficiency for the rectifier from testing results.

$$\eta = \frac{P_out}{P_{in} * 3\ phases}$$

$$\eta = \frac{45.048}{16.498 * 3} = \mathbf{91.017}\% \tag{3}$$

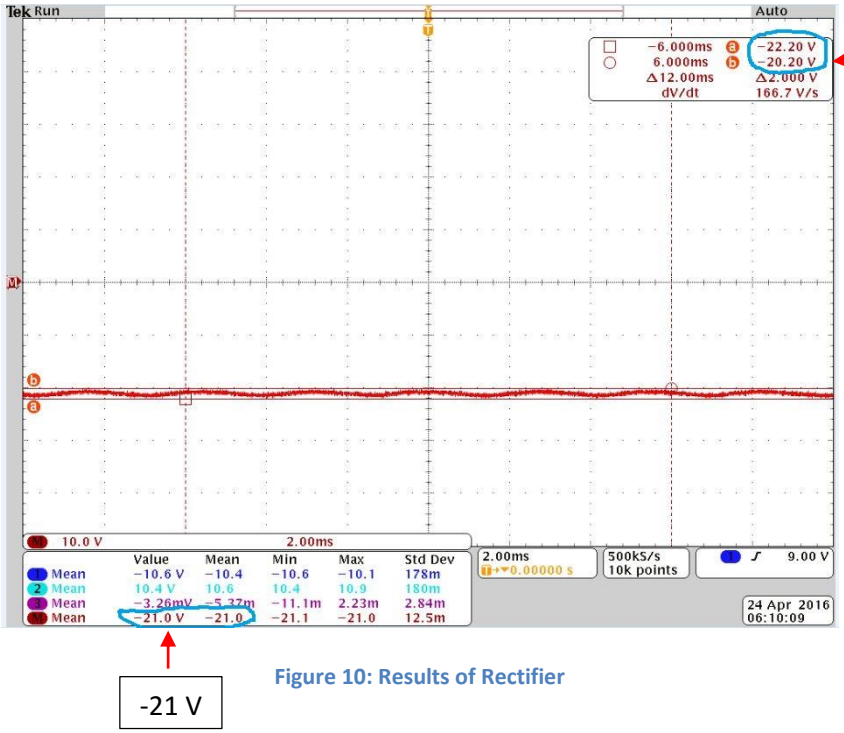

Figure 10: Results of Rectifier

3.2 DC-DC Converter

3.2.1 Testing procedure

Two different circuits were tested in order to make the definitive design operational. The inaugural schematic was formed by a 5 V source, a MOSFET, a MOSFET driver to activate the switching, and a load connected at the output to examine the proper functioning of this part of the converter. The second configuration added the rest of the elements of the buck converter including an output resistor of 30 Ohms. Supply voltage for the driver was 12 V, input voltage of the converter was 20 V and the duty cycle for the PWM signal was configured at 62kHz and a duty cycle of 75%.

3.2.2 Results

Current drawn from the source was fixed at 0.264 Amps and the output voltage is shown in Figure 11 below. The expected output was governed by Equation 4 and its theoretical value is 15V. However, the voltage drops across the diode and the MOSFET turn this value into 12.75 volts. This value hinders the battery charging process. Therefore, the inclusion of a microcontroller (shown in Section 3.5) providing feedback for the variation of the duty cycle is highly recommended in order to remain the 15 V constant output. From testing results, efficiency of the buck converter is calculated in Equation 5

$$V_o = V_{in} * D = 20 * 0.75 = 15V \quad (4)$$

$$\eta = \frac{U_{out}^2 / R_{out}}{U_{in} * I_{in}}$$

$$\eta = \frac{12.745^2/37}{20.0\ x\ 0.247} = \mathbf{88.9\%} \quad (5)$$

Figure 11: Buck Converter Results

3.3 Charging IC

3.3.1 Testing procedure

The utilized circuit to charge the battery was recommended by *Linear Technology*© so that the same components were purchased and attached to the PCB. The initial performance consisted in carefully studying the continuity of all the soldered components. Thereafter, continuous 12 V were connected to the input of the open charging circuit to measure the voltage across the terminals that will be connected to the battery in the last test.

3.3.2 Results

Despite the continuity was correct for all the elements of the designed circuit and they corresponded to the precise recommendations of the LT1513 datasheet, no coherent results were obtained from this test and the voltage across the output was nonexistent thus making it unable to properly charge the battery.

3.4 Inverter

3.4.1 Testing procedures

In this case, two different schematics were examined. In the first one, four MOSFETs were fed by two complementary PWM signals created from the function generator and a power resistor of 30 Ohms (4W) was connected at the output to analyze the inverting capacity of the MOSFETs separately.

In the second test, the PWM signals were inverted by means of a NOT Gate and supplied by the microcontroller as it will be in the definitive module. At the output a 12-110 V transformer was connected with no load on the high side and the measurement of the low side was conducted via the oscilloscope.

3.4.2 Results

Both designs successfully proved that MOSFETs inverted the 12-volt input from DC to AC. The output voltage on the low side of the transformer is shown in Figure 12.

Figure 12: Inverter Output Waveform

3.5 Microcontroller

3.5.1 Testing Procedures

The microcontroller was programmed for two functions. First, it will automatically adjust the duty cycle with an iterative control to set the output voltage at 15 V constantly. Second, it will send a PWM signal at 62 kHz to the Logic Gate to turn on and off the inverter MOSFETs. Once the buck converter was fully operational, a voltage divider was allocated to step down the voltage to a value lower than 5 V to make it readable by the microcontroller. The divider consisted of two resistors, 3k and 27k, and a 10uF capacitor in parallel. The output pin of the microcontroller was connected to the PWM input of the MOSFET driver and consequently the duty cycle was adjusted to provide a reference output voltage. On the other hand, in parallel, another PWM signal of 60 Hz was sent to the inverter to govern its driving circuits.

3.5.2 Results

Both functionalities succeeded in this testing. Firstly, regardless of the input voltage of the buck converter, the duty cycle of the PWM signal to the MOSFET driver was adjusted and the output voltage was fixed at 15 V as it is shown in Figure 13**.** The efficiency calculation for the buck converter is also shown in Equation 6**.** The only limitation for the control occurred when the input voltage was inferior to the referenced output voltage and the duty cycle is forced to be higher than 1 which is physically impossible and was also

empirically demonstrated. Secondly, the timers for the microcontroller were also appropriately modified to yield a 60 Hz PWM signal from one of the pins, which was inputted into the inverter circuit.

$$\eta = \frac{U_{out}^2 / R_{out}}{U_{in} * I_{in}}$$

$$\eta = \frac{15.128^2/30}{20.01\ x\ 0.426} = \mathbf{89.5\%} \quad (6)$$

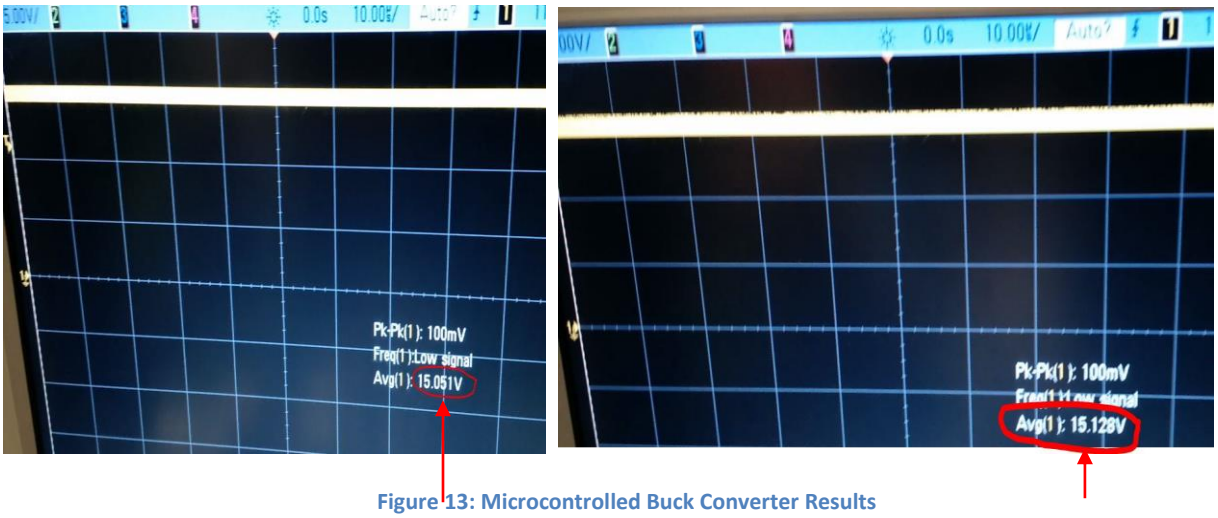

Figure 13: Microcontrolled Buck Converter Results

15.051 V

15.128 V

4. Costs

4.1 Parts

Module	Item	Part Number	Vendor	Unit cost $	Quantity	Total cost $
Rectifier	Schottky diode	SB360-E3/54	DIGIKEY	0.50	6	3.00
	Inductor	DENO-23-0001	DIGIKEY	3.38	1	3.38
	Capacitor	UVR1E472MHD	DIGIKEY	1.43	1	1.43
	Fuse	SSQ5	DIGIKEY	0.37	3	1.11
	Fuse Holder	BK/1A5600	DIGIKEY	0.64	3	1.92
Rectifier Total						**10.84**
Buck converter	Mosfet	IRF520PBF	DIGIKEY	0.95	1	0.95
	Mosfet driver	IRS2183STRPBF	DIGIKEY	1.16	1	1.16
	Driver diode	SB360-E3/54	DIGIKEY	0.50	1	0.50
	Driver capacitor	T350A105K035AT7301	DIGIKEY	0.24	2	0.48
	Buck diode	SB360-E3/54	DIGIKEY	0.50	1	0.50
	Inductor	70F204AI-RC	DIGIKEY	1.26	1	1.26
	Output capacitor	35ZLH100MEFC6.3X11	DIGIKEY	0.30	5	1.50
	Load Resistor	SQP500JB-30R	DIGIKEY	0.56	1	0.56
	Measure capacitor	TAP106M025CRW	DIGIKEY	0.38	1	0.38
	Measure resistor	RNMF14FTC3K00	DIGIKEY	0.10	1	0.10
	Measure resistor	CF14JT27K0	DIGIKEY	0.10	1	0.10
Buck converter Total						**7.49**
Inverter	Mosfet	IRF520PBF	DIGIKEY	0.95	4	3.80
	Mosfet Driver	IRS2183STRPBF	DIGIKEY	1.16	4	4.62
	Driver Diode	SB360-E3/54	DIGIKEY	0.50	4	2.00
	Driver Capacitor	T350A105K035AT7301	DIGIKEY	0.24	8	1.92
	Not Gate	SN74LS04N	DIGIKEY	0.69	1	0.69
	Transformer	F260-U	TRIAD MAGNETICS	42.00	1	42.00
Inverter Total						**55.03**
Microcontroller	Arduino Uno		ECE SHOP	23.00	1	23.00
Microcontroller Total						**23.00**
Battery charger	Capacitor input/output	50YXJ22MTA5X11	DIGIKEY	0.51	2	1.02
	Capacitor pin 3	UVR2AR22MDD	DIGIKEY	0.23	1	0.23
	Capacitor pin 5	400PX4R7MEFCTA8X11.5	DIGIKEY	0.46	1	0.46
	Resistor pin 1	CFM12JT270R	DIGIKEY	0.10	1	0.10
	Resistor pin 3	CFM12JT39R0	DIGIKEY	0.10	1	0.10
	Resistor pin 2	CW0054K000JE73	DIGIKEY	0.41	2	0.82
	Resistor 0.08 Ohms	MSR3-0R08F1	DIGIKEY	0.91	1	0.91
	Diode	SB360-E3/54	DIGIKEY	0.50	1	0.50
	Inductor	CTX10-3-R	MOUSER	6.54	1	6.54
	LT1513	LT1513IR#PBF	LINEAR TECHNOLOGY	0.00	1	0.00
Battery charger Total						**10.68**
Battery bank	Battery gauge	PRO36FRC	AMAZON	16.00	1.00	16.00
	USB ports	BT-081-0158	ADV.DESIGNS	10.00	1.00	10.00
	12 V Battery 35Ah	BSL1075	RAKUTEN	19.59	1.00	19.59
Battery bank Total						**45.59**
Grand Total						**152.63**

4.2 Labor

NAME	HOURLY RATE	HOURS INVESTED	TOTAL = RATE *2.5 *HOURS INVESTED
Prash Ramani	$30	150	$11,250
Marcos Rived	$30	150	$11,250
TOTAL	$60	300	$22,500

5. Conclusion

5.1 Accomplishments

Aside from gaining an invaluable amount of knowledge and insight in power generation and conversion, we accomplished several goals in our semester of working on this project. We successfully rectified a 3-phase AC source into a single phase DC signal with high efficiency, despite challenges in testing in the Power Lab. We were then able to step down an input DC voltage to 15V with a DC-DC converter we designed, built, and tested. We successfully implemented control for the DC-DC converter using an Arduino Microcontroller that allowed us to generate a feedback loop for the DC-DC converter, ensuring that a constant output voltage of 15V was achieved even with a varying input voltage. We built an inverter circuit after many trials and tribulations of finding the proper design. It effectively took in an input of 12V DC and outputted 12V AC with a perfectly square output waveform. The USB ports and gauge worked flawlessly as well, allowing us to charge our phones from the battery and display exactly how much charge was left in the battery.

5.2 Uncertainties

Given the many design reconsiderations, the time constraints, and issues with receiving our PCBs in a proper manner, we did have some difficulties and shortcomings as well. Implementing the LT1513 Charging chip proved to be more difficult than we first thought. We did not lay our PCB in an efficient and easy to use manner, causing functionality to suffer. Soldering issues specifically led to this part of our circuit not operating as expected. We theoretically would be able to charge the battery directly from the output of the DC-DC converter, but this is not safe and would not meet our original standards.

Our many trials and tribulations with the design of the inverter, along with the difficulties of using a transformer in general led to us not being able to provide 110V at the output of our overall circuit. By flip-flopping between using a bridge inverter or using a 555 Timer IC in conjunction with an oscillating circuit, we did not give ourselves enough time to perfect the design. Having to use a step down transformer in reverse as opposed to a step up transformer due to its unavailability to purchase was not an ideal scenario for us as step down transformers in reverse do not operate in the same fashion as step up transformers. We also initially decided to use an inverter configuration that required a center-tapped transformer to operate, but we changed our inverter to a more effective design that would not allow for the center tapped transformer to function as we needed it to.

Finally, having the whole circuit work together was a goal we had in the beginning of this project that we did not meet. The above shortcomings, along with not being able to have the rectifier and DC-DC converter work in tandem with control feedback created a broken design. However, these are fixable problems and we believe that with some more time we could fix these issues and have a fully functional system.

5.3 Ethical considerations

Our battery box is in the best interests of the people. We want to help provide a way for people that do not have reliable access to an energy grid to have a simple way to harness wind energy to use their devices.

We want these people to live in a safe environment where they have the ability to use devices, rather than being completely off the grid. This is in accordance with the first code in the IEEE Code of Ethics:

"to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;"

Our box must be reliable and efficient. This includes showing the user proper readouts of how much energy is in the battery and making sure the components are assembled well enough to stay efficient for the life of the unit. We will make sure the readouts are accurate and the components used are of the highest grade such that they will not fail under pressure. This is in accordance with rule 3:

"*to be honest and realistic in stating claims or estimates based on available data;"*

This concept, along with the bigger concept of harnessing wind energy, is a field with much research and understanding in the large scale, but not so much in small scale applications such as ours. As we went deeper into this field, we continued to learn as much as we could about it, in order to benefit future generations of wind power engineers. This is in accordance with rule 5:

"to improve the understanding of technology; its appropriate application, and potential consequences;"

As we dove deeper into this field that we did not have much experience in, we made sure we challenged ourselves in making sure we are made the best possible decisions and design choices. This required taking criticism and advice from many sources of intelligence, including professors, researchers, people in the field, etc. We consulted with many in the field, including Power Researcher Kevin Colravy and power electronics expert Zitao. Only if our work is valued by those in the field will we know we have completed a successful and meaningful project. This is in accordance with rule 7:

"to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;"

This shall be a device for all those that need it. Therefore, we will not discriminate and/or segregate in any way. This device is meant to help people, regardless of what their background is. If there is a need for this device, they shall have every right to use it. This is in accordance with rule 8:

"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;"

5.4 Future work

Aside from fixing up all of the issues stated in section 5.2, there are several aspects we think would be great additions to implement in further work on this project. We currently have the Arduino powered by a backup battery, which would not be feasible for the actual final product on its own. But with a simple relay and voltage regulator circuit from the 12V battery to the backup battery, the microcontroller will always be powered and there is no need for backup battery replacement as it would continuously be charged by the 12V battery as energy is coming from the turbine. The form factor is something that could use improvement as well. With our PCB troubles, we were unable to create a truly portable and modular

design that would be ideal for the end user. But by using smaller components mounted on a better PCB with a better layout, a future worker could easily achieve this goal to make a portable and modular device. Finally, implementing PI control instead of iterative control for the microcontroller would greatly improve efficiency. As articulated in Section 2.2.2, the iterative control reads the output, compares it to a reference, and based on whether it is higher or lower than the reference voltage will adjust the duty cycle accordingly. While this is certainly operational and efficient enough, it can be more efficient with PI control. This method would calculate the error between the output and the input voltages, eliminate this error, and choose a duty cycle that exactly matches and accounts for this change in error. This would provide a much more constant output when the input varies with much greater efficiency.

5.5 Acknowledgements

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Appendix A Requirement and Verification Table

Table 3 Battery Box Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Rectifier a. Connections b. Output Voltage ~21V DC c. Output Current 3A DC d. Ripple (±1V) (±0.4A) e. Efficiency over 90%	1. Verification a. Connect the rectifier to the generator or a three-phase output from ECE Power Lab to obtain 9 V_{rms} phase voltage. b. Connect a resistor of 40 Ohms that draws 0.5 Amps DC at the output along with a filter of 30 mH to filter it out c. Measure output voltage across the load with a two-channel oscilloscope and check it is 21V DC with a ripple of ±1V and ±0.4A	Y
2. DC-DC Converter a. Connections b. Driver is switched correctly c. Applying an input of 20V DC the output is 1 V ±0.5V d. Efficiency >85%	2. Verification a. Connect to regulated DC power source in lab b. Set offset 20 Volts and sinusoidal wave of 0.3 V Amplitude c. The load will be a 100 Ohms 2W resistor to test it d. Measure the output current with a two-channel oscilloscope along with the output voltage across the load	Y
3. Battery Bank a. Voltage measurements are correct b. Gauge displays proper amount c. Time of charging <20 hours d. Temp <77°F	3. Verifications a. With a backup battery we supply 15V and 2 Amps and check that the gauge reflects the battery is charging b. Fully charged, connect a load of 5 Ohms at the output of the batteries and check that the gauge reflects now they are	Y (a. b. and d.) N (c.)

	discharging at 3 Amps constantly c. Measure the time with a cell phone chronometer it takes to charge a quarter of the battery and extrapolate for full-time charge to check whether is reasonable d. Routinely make sure area surrounding battery is not too hot	
4. USB Ports a. Connections b. USB ports supply 5V at 0.7A each	4. Verification a. Connect 12V power supply to USB ports b. Measure voltage across USB ports with two channel oscilloscope c. Plug in portable device (cell phone) to show charging capability	Y
5. Inverter a. Output of circuit is 12V AC b. Output at transformer is between 110V and 120V AC c. Transformer Ratio is correct	5. Verification a. Isolate transformer, supply 12V AC, measure output to confirm ratio b. Connect power supply to inverter to supply 12V DC c. Measure voltage across inverter output d. Measure voltage across transformer output	Y (a. and c.) N (b.)
6. Microcontroller a. No errors in Arduino code b. Output is 15V from input signal c. Output remains constant when changing input	6. Verification a. Isolate the buck converter for testing b. Supply the converter with a sinusoidal wave of amplitude 1 volt and an offset of 20 volts (similar to the output of the rectifier) c. Measure the output voltage after running the Arduino code and ensure that it still remains at 15 volts regardless of any disturbances	Y
7. Charging IC a. Output is 15V b. Battery Charges	7. Verification a. Use power supply to supply 15V DC	N

c. Time is less than 20 Hours for full charge	b. Measure output using oscilloscope to confirm 15V output at 1.3A c. Connect to battery to ensure proper charging and confirm with voltmeter	