Hybrid Water Pump

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Abstract

This project seeks to use multiple sources to power a water pump. We will design a system which will combine inputs from solar and wind energy production to ensure the pump will have enough power to run. This will create a system powered by clean energy and will be self-sustained once completed. This will theoretically create a more sustainable source of power for the pump than only one of the sources. Because the power sources don't require outside inputs (aside from sun and wind), the pump can be placed in a remote area. This could be very helpful in developing communities, where residents may not have a reliable power supply. This system will allow these types of communities to pump water from wells to bring back to their homes. This will also reduce dependence on non-renewable sources of energy.

The system will consist of a solar panel, wind turbine, control system to integrate the sources, and the water pump. The system will be made to require minimal user input to run. Inside the control system, two DC-DC buck converters are used to regulate input voltages. Two diodes are used to joint 2 input sources and prevent backflow of energy. This method is selected instead of MISO (Multiple Inputs Single Output) converter due to its simplicity. An Arduino Uno microcontroller powered by AtMega328p microprocessor is used for displaying power reading from the two sources and the load. The microcontroller also control the relay for protection purposes. An adjustable speed drive and motors combination is studied and used for simulating the wind turbine generation. Relays and circuit breakers are also studied for circuit protection in renewable power systems.

This project showcase the possibility of having a hybrid renewable system for common electrical appliances as well as pointing out some difficulties in such system.

Chapter 1. Introduction

Motivation

For the past 2 centuries, fossil fuel has dominated the power generation market because of its high efficiency and low cost. With increased focus on sustainability and environmental issues, alternative energy generating methods have been explored and developed [1]. Many of these methods have proven to be sustainable, but not economical due to low efficiencies and high material costs. Recently, photovoltaic panels have become increasingly popular both in residential settings and commercial settings. Government subsidies for installations attracted consumers, which in turn promoted industry around photovoltaics. As more industries incorporate solar development, competition further decreases the cost of manufacturing and installing photovoltaics. Figure 1-1 shows the installation cost trend in the recent year in dollar per watt [2]. Figure 1-2 shows the trend in the past 30 years for solar module price in dollar per watt [2], exemplifying the lowering costs of solar. With increased attention, energy distribution also becomes an interest. If photovoltaic power generation replaces fossil-fuel-burning power generation, traditional long distance radial AC power distribution creates unnecessary power losses and becomes ineffective. Keeping the energy production local will be more efficient.

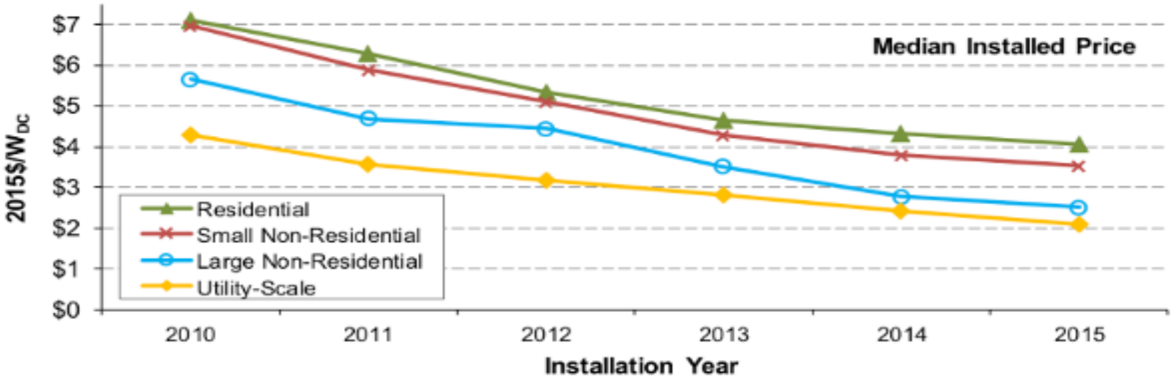
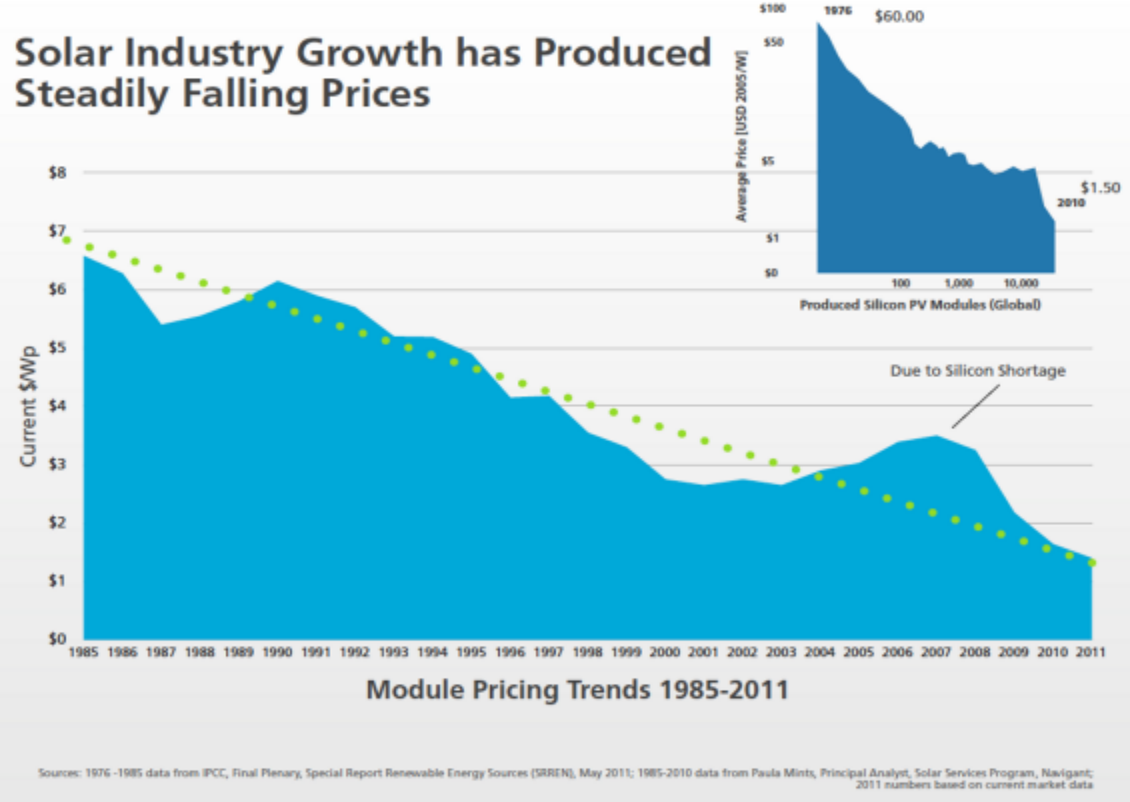


Figure 1-1. Dollar per watt trend 2010-2015 [2].



Sources: 1976 -1985 data from IPCC, Final Plenary, Special Report Renewable Energy Sources (SRREN), May 2011; 1985-2010 data from Paula Mints, Principal Analyst, Solar Services Program, Navigant; 2011 numbers based on current market data

Figure 1-2. Solar module price trend 1985-2011 [2]

DC-DC Converters

DC (Direct Current) energy has become a key in promoting the use of solar energy worldwide and reducing energy consumption. Most small electronics used in a common household consume DC energy. This is because most digital circuits are designed to constant polarity. The use of renewable energy especially for off-grid application requires storage. The most common way to store electrical energy is through batteries which store energy through DC. Currently, most renewable energy goes through inverters and rectifiers before reaching any electronic devices. This is accomplished to match the AC energy of electric grids. However, inverters and rectifiers have loses; therefore, if harvested DC energy could be directly used, and consequently some energy can be saved in the process. DC-DC converters therefore play a big part of making energy usage more efficient. DC-DC converters may operate to step up or down the input voltages to supply the loads. A step-down converter is called a Buck converter and a step-up converter is called a Boost converter. Despite its efficient operation, DC-DC converters still introduce power losses. There are many ways to make a DC-DC converter more efficient such as eliminating their switch loses. As their operating frequency is being pushed to a higher value, switching loss can be significant. Hence a resonant circuits is introduced so that switching happens when either the current or the voltage reaches zero; thus, limiting the switching power losses [3].

Water Pumps

Access to a reliable source of water defines the survivability of a community. Often, a community will be built near a water source for easy access. Some communities will instead pull water from the ground. This process has evolved from lowering a bucket down a well to fully automated pumps bringing water from deep in the earth. In remote communities, many different methods to pump water have been tested. NGO's and development organizations have installed bike-powered and hand pumps. Small wind turbines have been used to directly pump water. Some communities use livestock to drive a pump, allowing them to pump water with very little additional operating costs, see Figure 1-3 [4]. More recently, electric water pumps have been used to more quickly and effectively pump water. In remote communities, it is common to use gas generators in order to use these types of pumps. However, gas must be resupplied, incurring operating costs for the user. To mitigate this cost, it is logical to turn to renewable energy sources, such as wind turbines or solar panels. These sources generate power without additional input to the system. However, these sources are not always reliable because of variability in sunlight and wind. A solution to this is to supplement the power with a gas generator. This provides more reliable access to power, but still generates some cost for the user. If the user wants to be entirely free from fuel costs, renewable sources can be combined to provide more reliable access to electricity with less variability than only using one source.

Figure 1-3. Example animal driven water pump with gear box and bullocks [4]

Chapter 2. Background

Every community needs to have reliable access to water. For those in developed areas, a reliable water supply is common and seen as part of normal life. In rural communities, the infrastructure for water distribution is too difficult to construct or the community does not have the funds to construct it. In these cases, local sources of groundwater can serve as a reliable water source. Therefore, a reliable method of pumping water from the ground is a vital investment. Some communities also do not have reliable access to electricity, so they must rely on manual or generator-powered pumps. Especially in remote areas where grid extension is not feasible and transporting fossil fuels is very costly, communities put a high value on having a reliable limited energy supply. An increased awareness of the effect of fossil fuels on the environment as well as their limited nature are creating higher demand and lower prices for renewable energy technologies.

Renewable energy sources, especially solar panels and wind turbines, have a highly variable production rate and are both dependent on local conditions. In order to create a more reliable energy flow, these sources can be combined. This way, each source can compensate for the weaknesses of the other.

Combining energy sources with different outputs can cause some irregularities in power flow. Due to the differing production between each power source, diode OR circuit must be used to prevent backflow. More efficiently, a multiple-input-single-output (MISO) converter can be used to safely and efficiently merge the two sources.

Hybrid systems are an effective way to generate power in an off-grid application. As presented in the International Conference for power electronics in 2012, a hybrid system composed of PV panels and wind turbines was a great solution to power a desalination plant in a remote area in India. Here, a hybrid system worked to mediate the variable nature of each generator. Wind is generally stronger when there is no sun, and vice versa. The combination of wind and solar creates a more reliable renewable source of energy [5].

Commercially, hybrid systems are gaining popularity. While still a large investment, rising fossil fuel prices and dropping solar and wind technology prices have increased interest in these systems [7]. One of the biggest innovations in this sector is HOMER. This software creates an easy method of analyzing relevant site data to determine the feasibility of a hybrid energy system [6]. Small startups have started rising specifically to design hybrid systems. TEROC, a Sweden-based startup, specializes specifically in hybrid systems, mostly wind-diesel powered. They design small systems to power island communities and have their own software for design. The industry is still small, but growing.

Many completed projects aim to provide power for a community. This project entails the design and development of renewable energy DC powered water pump, potentially making it more realizable than larger scale projects for low-income communities. The DC electricity is being used for this project to improve overall system efficiency since the renewable energy sources used will be small scale and will output DC. Hence, there is no need to utilize the intermediate rectifier-inverter converter configuration. Furthermore and as previously mentioned, the design will make use of multiple renewable energy sources to mitigate the weaknesses in each type of renewable energy production. Lastly, some type of a method to enable a multiple-input-single-output (MISO) DC-DC converter will be investigated and implemented in this project to seamlessly combine the multiple energy received by the various renewable energy sources.

Chapter 3. Design Requirements

Level 0 Block Diagram

The module that will be constructed in this project will source power from a solar panel and DC wind turbine. The panel will source 30W, and the wind turbine contribution will be determined upon testing. The water pump will only draw 13W. This allows the module to run at 12V while keeping current through the system low, minimizing electrical complexity within the module. The power at the sources and the load will be read and shown on the display. Figure 3-1 depicts this level 0 block diagram.

Figure 3-1. Level 0 Block Diagram

Level 1 Block Diagram

The level 0 block diagram is decomposed into its components as illustrated in Figure 3-2. Each input is passed through a DC-DC converter to regulate the voltage to 12 V. The signals then pass through current sensors, which then passes the reading to the microcontroller to calculate the incoming power from each source. Each signal then passes through a diode before connecting to the same bus to prevent problems in power differences between the sources. These sources feed a charge controller which will further regulate the combined signals to charge a 12V battery. This battery will store power from the sources and then send power to the pump when demanded. The signal at the pump is also run through a current sensor and sent to the microcontroller for the user to see how much power is being drawn. A relay and breaker are also connected at the water pump. This will help to prevent power being drawn if there is not enough available, possibly due to periods of low sun and wind. The breaker will help prevent overcurrent damaging the pump if a short occurs in the system. The microcontroller is powered directly from the battery.

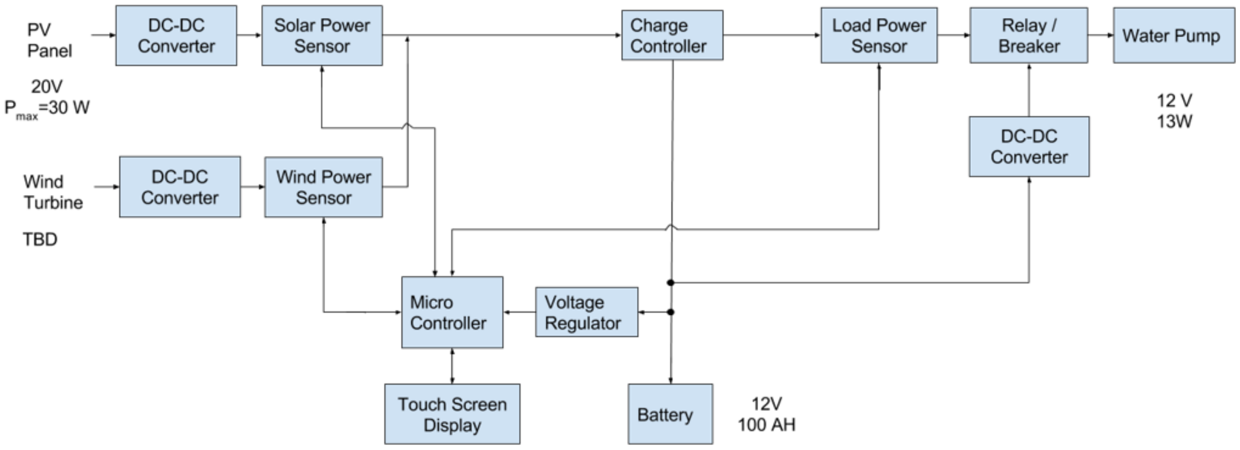


Figure 3-2. Level 1 Block Diagram

The following details the technical design requirements for this senior project along with their justifications:

1. The pump will be powered entirely by renewable sources
   This is system is created to be entirely off-grid. Therefore, the renewable sources must be able to provide all necessary power to run the water pump and internal controls. With the use of a battery to provide the start-up current the pump will demand, the system will not require any other power.
2. The module will sense the power at the sources and load and displayed to the user
   The user will be able to see the incoming power from the sources and power demanded by the load. This will help the user to gauge system performance and troubleshoot if there are problems.
3. All components will have necessary protection
   With three different generators (wind turbine, solar panel, and battery), every component will need to be protected from electrical faults, else components may be damaged. To protect the load (water pump) a combination of a circuit breaker and a relay will be implemented at the load, along with fuses to protect the lines.
4. Module Specifications
   The module will run when needed. Because of the small size of the motor, the battery will be able to source power to it for a considerable amount of time. The total input to the system could be up to 60W, which will be adjusted depending on the contribution from the wind turbine. There are no moving parts within the power management module, so it is unlikely to suffer from mechanical degradation, except for heat from the components. The module will output up to 13W as demanded by the motor.

Table 3-1 through 3-13 summarize the components that will be used for the project.

Table 3-1. Solar Panel

Rated Power Production	28 W
Open Circuit Voltage V_{OC}	21.7 V
Short Circuit Current I_{SC}	1.25 A
Physical Dimensions	Small

Table 3-2. Wind Turbine (using adjustable speed drive powered induction motor to simulate wind turbine production)

Maximum Power Production	< 100 W
Maximum Voltage	< 90 V
Maximum Current	< 3 A
Physical Dimensions	Using an Adjustable speed drive-motors combination to simulate a normal wind turbine production.

Table 3-3. Table Battery

Voltage	12 V
Current Rating	100 AH

Table 3-4. Water Pump

Maximum Power Consumption	20 W
Rated Voltage	12 V
Steady State Current	1 A
Surge Current	1.6 A
Physical Dimensions	small

Table 3-5. 24V/12V DC-DC Converter (Solar Panel)

Input Voltage(s)	10V-22V
Output Voltage(s)	12V
Physical Dimensions	2.756 x 2.047 x 1.969

Table 3-6. DC-DC Converter (Wind Turbine)

Input Voltage	4.5V-32V
Output Voltage	12V
Physical Dimensions	2.756 x 1.335 x 1.279

Table 3-7. DC-DC Converter (Relay)

Input Voltage	5V
Output Voltage	8V
Physical Dimensions	2.756 x 2.047 x 1.969

Table 3-8. Relay/Breaker

Relay Trip Voltage	7.6V on 1.8V off
Maximum Relay Current	30mA
Breaker Power Rating	160W
Maximum Circuit Breaker Current	5A

Table 3-9. Charge Controller

Rated Power	300W
Maximum Current	20A
Voltage Regulation	12V/24V
Physical Dimensions	1.89 x 4.17 x 4.88 inches

Table 3-10. Voltage Regulator

Part Number	LM7805
Maximum Allowable Current	2.2 A
Voltage Regulation	12V to 5V
Physical Dimensions	0.42 x 0.185 x 0.642 in

Table 3-11. Microcontroller

Module	Arduino Uno
Maximum Current Consumption	Active: Typical - 4mA Max - 12mA Sleep: Typical - 4 uA Max - 15uA
Source Voltage	5V
Physical Dimensions	2.7 x 2.1 in

Table 3-12. Current Sensor

Part Number	CS30
Voltage Range	2.8 to 30 V
Source Voltage	5 V
Maximum Current Consumption	300 uA
Physical Dimensions	0.118 x 0.118 x 0.057 in

Table 3-13. Display

Part Description	Smraza Serial LCD Display Module
Part Number	ADP01s
Screen Type	4 lines, 20 characters each
Source Voltage	5 V
Maximum Current Draw	200 mA
Physical Dimensions	4.3 x 3.1 x 1.5 in

Chapter 4. Design and Simulation

Wind Turbine

In lieu of a working DC wind turbine, we are using an adjustable speed drive. As shown in Figure 4-1, the adjustable speed drive is sourced by an AC voltage source and drives a DC motor. This is connected to a second DC motor which acts as a DC generator, which then outputs DC power to our control system. Effectively, this set-up acts as a DC wind turbine.

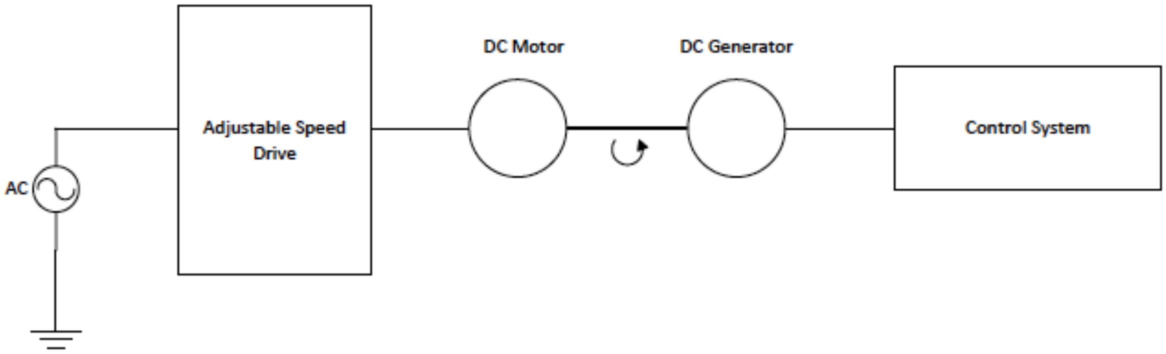


Figure 4-1. Block Diagram of Adjustable Speed Drive Set-up

In order to make it as accurate as possible, we first attempted to characterize the rotation according to typical wind speeds, which averages around 7 MPH, with gusts up to 40 MPH, as taken from a station in San Simeon, monitored by the National Oceanic and Atmospheric Administration. When converted to RPM, this speed only translates to maximum 40 RPM, which is too low. When we characterized the adjustable speed drive, the lowest it could operate the motor was 25 RPM, and at most around 3000 RPM as shown in Table 4-1.

Table 4-1. Adjustable Speed Drive Characterization

Power from Source (W)	**Voltage (V)**	**Speed (RPM)**	**Setting (% Power)**
3.8	1.1	25	10
8.8	10.1	422	20
13.5	20.8	868	30
17	30.1	1205	40
23.3	40.7	1671	50
28.4	50.6	2051	60
32.4	58	2368	70
36.7	67.4	2725	80
41.3	76.5	3112	90
44.7	82.7	3347	100

Instead of focusing on speed, we decided to focus on produced power. Assuming there are minimal losses between the motor and generator, the power applied to the control system will be similar to that produced by the source. We decided to label the maximum power at 32.4 W, or 70% power on the adjustable speed drive. This will provide more than enough power for the 13W motor. Since the converter attached to this has an input range of 8-60V, we will use a minimum of 20% power on the adjustable speed drive, which will push 10.1 V to the converter.

MISO Control

Due to the unavailability of a full Multiple-Input-Single-Output (MISO) system, we will be using two diodes (rated at 3A) to combine the two DC signals from the power sources. The OR diodes will force the two sources to take turn in delivering their power to the load based on which source has a slightly larger output. This simple system is also an inexpensive solution for this type of problem, which could be a deciding factor for this project in some environments, namely in low-income communities.

Connection to Peripherals

Since this apparatus is for academic purposes, all external peripherals (i.e. solar panel, adjustable speed drive, pump, and battery, will be connected to the control system through spade lugs.

Sensor Circuit

In order for the user to monitor the power coming from the sources and being supplied to the pump, there will be CS30 current sensors at each of these points, as shown in Figure 4-2. The readings from these will be fed into an Arduino and then displayed on an LCD screen. At most, each CS30 will consume 0.3mA. Since they are each supplied by 5V from the Arduino, they will draw 1.5mW each at most. The LCD will consume at most 5mA. Since this device is also tied to the 5 V output of the Arduino, it will consume 25mW at most. When active, the Arduino will consume around 10 mA for its own power, plus the required power for the peripherals attached to it. This means at maximum consumption, this circuit will require 15.9 mA. We use the LM7805 voltage regulator, to convert 12 V from the battery to 5 V to power the Arduino. After testing the circuit, we realized the Arduino actually requires a higher voltage for supply, so we added two resistors to boost the output voltage from the regulator to 6.8 V. This means that at peak use, the regulator will draw 80mW from the battery. This is minimal compared to the size of the battery and shouldn't interfere with the rest of the system.

Relay

An electrical relay operates using electromagnet to mechanically turn on and off a switch. In this design, a 12V relay is used to protect the load from under voltage. The relay is connected to the charge controller. The charge controller supplies no voltage to the relay in case of low voltage from the batteries and sources which will open the relay. The water pump is thus disconnected. The values stated is from lab testing since a usable datasheet cannot be found.

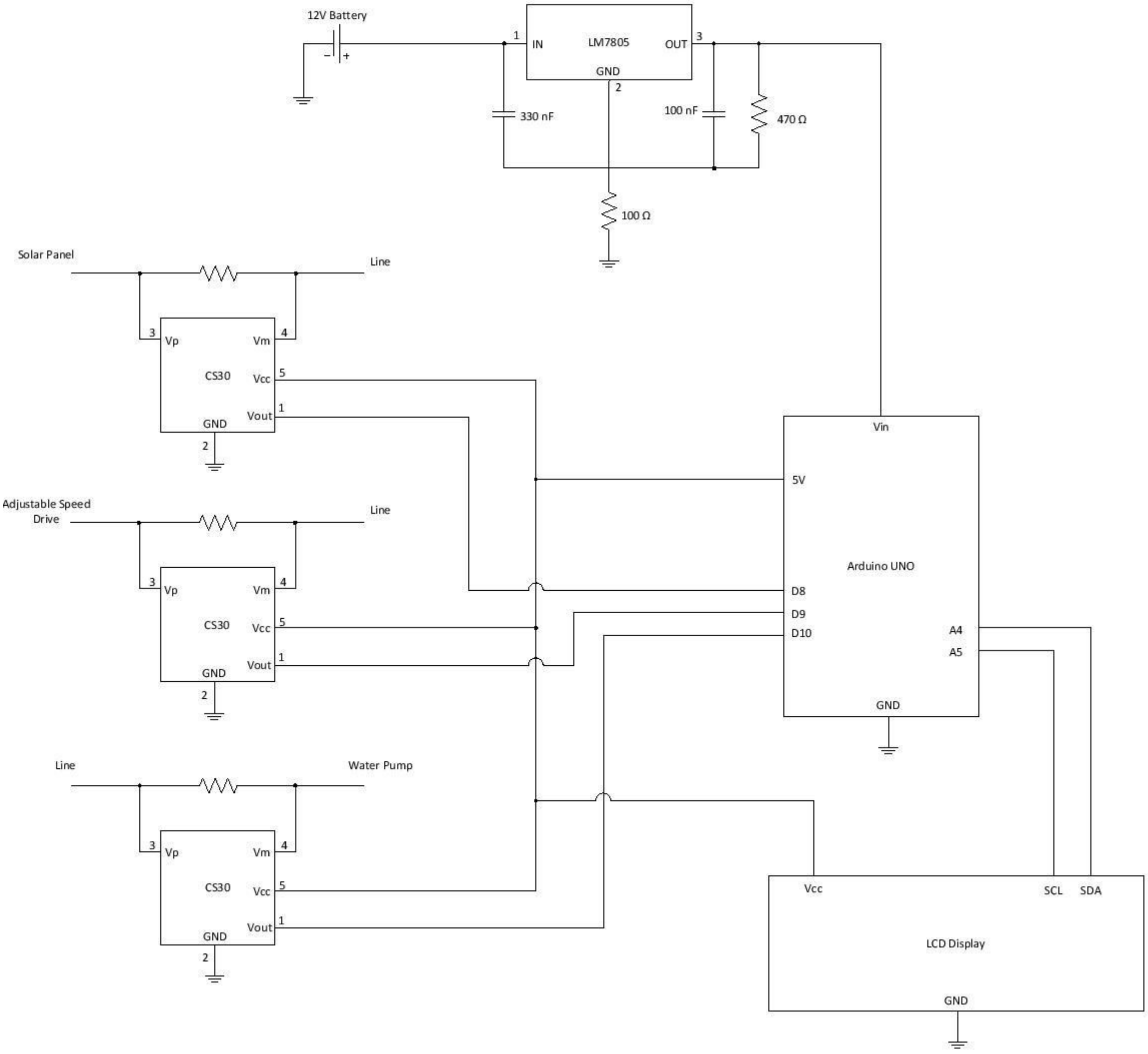


Figure 4-2. Sensing Circuit Schematic

Table 4-2. Relay characterization

Cut off Voltage (V)	Turn on Voltage (V)
1.8	7.5

Chapter 5. Hardware Test and Results

Build Procedure

The sensors, voltage regulator, and diodes were soldered to a protoboard. The diodes are the major limiting factor in the project since they can pass a maximum of 3W through them. They each drop 0.7 V, so the maximum current that can pass through each of them is 4.3A. However, based on the low power characteristics of our sources, this is more than enough. A jumper wire bank was also added so that the Arduino could be attached and detached easily, making testing easier. Each sensor then had to be calibrated. Due to inaccuracies within the sensors, their algorithms had to be adjusted slightly so that the actual current flowing through them matched the output. To do this, we ran a series of currents through them using an electronic load to regulate the current, and found the relationship between the actual current and output. The setup for this test is shown in figure 5-1. Results for one of the sensors is given in figure 5-2.

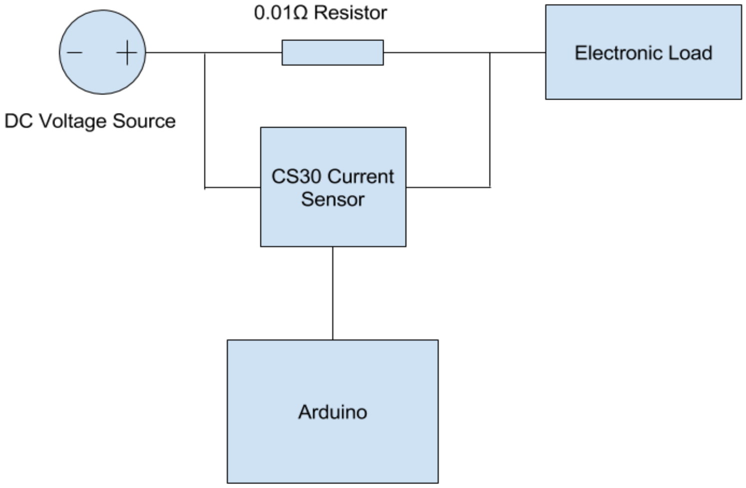


Figure 5-1. Test setup for sensor calibration

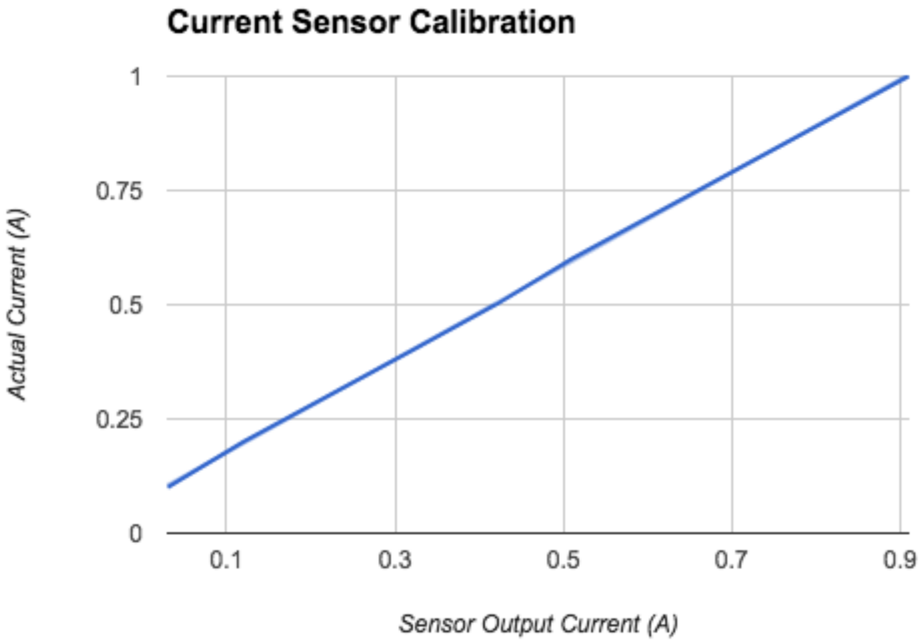


Figure 5-2. Current Sensor Calibration

Next, the converters were calibrated to convert the input to the correct voltage. In order for the system to work, we adjusted the converters to output 14 V to account for voltage drops across the diodes and the voltage required by the charge controller. The converters were then tested to characterize efficiency, ripple, and line and load regulation. The test setup is shown in Figure 5-3.

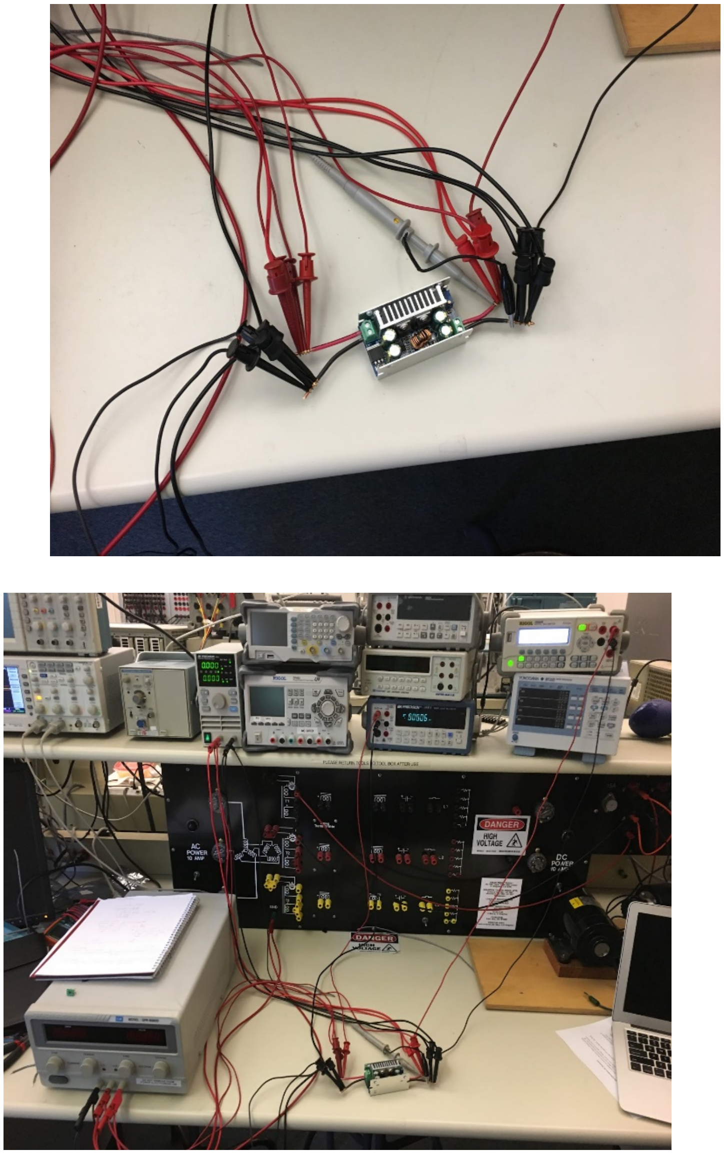


Figure 5-3. Test Setup for Converters

The converter for the solar panel (referred to as Converter 1) has a rated power of 150 W. To keep test equipment at a reasonable range, we tested up to about 100W. The input voltage range is rated between 4.5 and 32 V. Upon testing, the converter appeared able to handle higher voltages, but we did not push its limits. The converter for the wind turbine (referred to as Converter 2) has a rated power of 200W. Upon testing, the converter had trouble reaching 100W, and maxed out at 120W. The input voltage range is rated between 8 and 60V, which is why we chose it for the wind turbine. The turbine outputs voltages up to 60 V. Each turbine was tested with a rated input voltage of 20 V and rated output voltage of 14 V. The equations used to characterize the converters are shown below. The output voltage is measured at the output terminal of the converters which is set at 14V. The output current is measured from how much electronic load is taking in. The input voltage is measured at the output terminal of the power supply which is set at 20V. The input current is measured from the how much current the power supply is providing. Each converter was tested from 10% of the max load to 100% of the max load (as determined above). The characteristics for both turbines are summarized in Table 5-1. Efficiency curves for each converter are shown in Figures 5-4 and 5-5. The output wave for the ripple is shown in Figure 5-6 and 5-7.

% Efficiency

$$\frac{V_{out} * I_{out}}{V_{in} * I_{in}} * 100\%$$

% Line Regulation

$$\frac{V_{out}@V_{in-max} - V_{out}@V_{in-min}}{V_{out}@V_{in-nom}} * 100\% \text{ [at full load]}$$

% Load Regulation

$$\frac{V_{out}@10\% \text{ load} - V_{out}@100\% \text{ load}}{V_{out}@100\% \text{ load}} * 100\%$$

% Ripple

$$\frac{V_{out-p-p}}{V_{out-nom}} * 100\%$$

Table 5-1. DC/DC Converter Characteristics

	Converter 1	**Converter 2**
Rated Power	150 W	200 W
Rated Input Voltage Range	4.5-32 V	8-60 V
% Peak to Peak Ripple	5.6%	0.6%
% Line Regulation	4%	14%
% Load Regulation	2.6%	0.9%

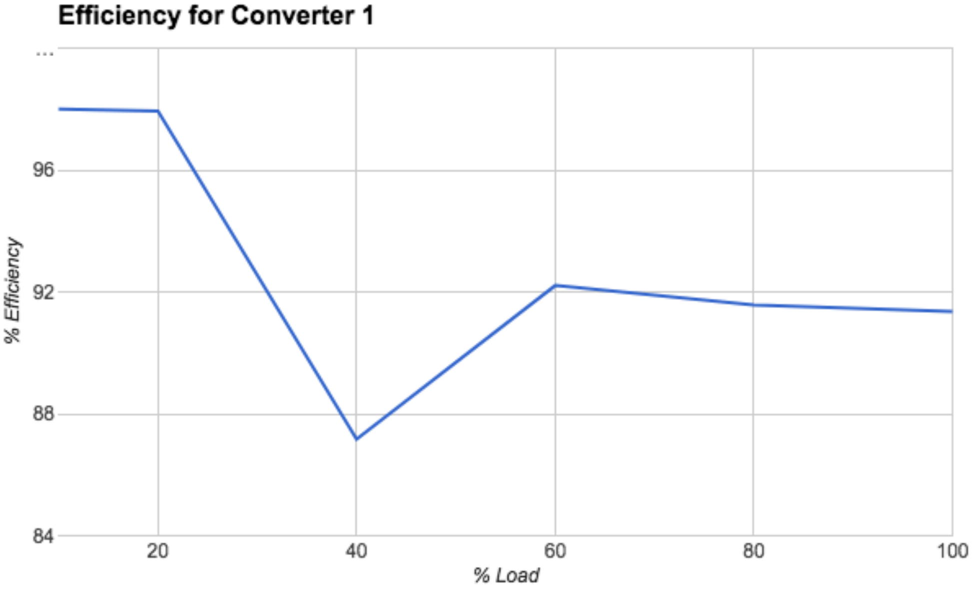


Figure 5-4. Efficiency curve for Converter 1

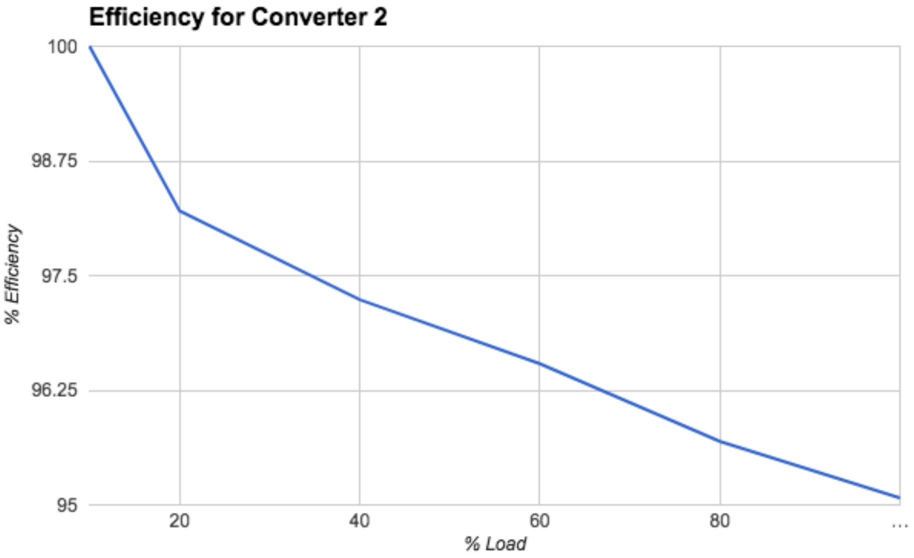


Figure 5-5. Efficiency Curve for Converter 2

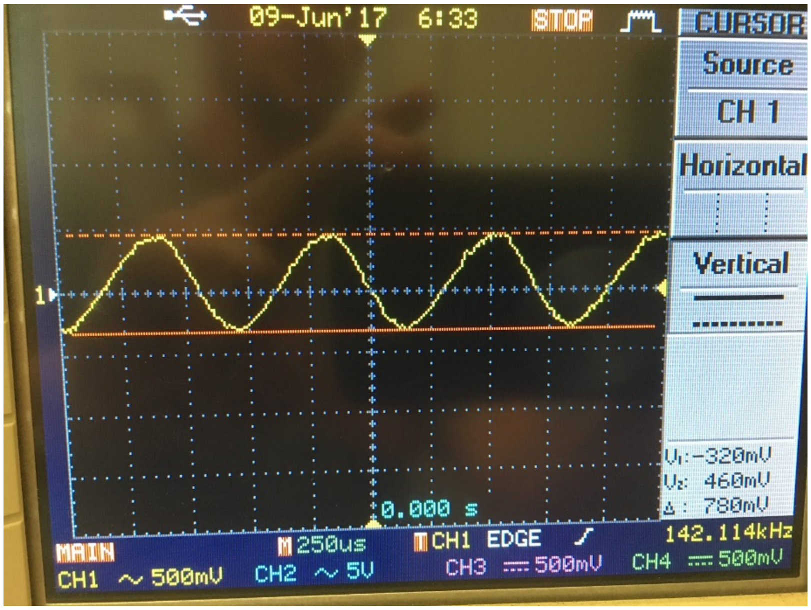


Figure 5-6: Ripple Wave for Converter 1

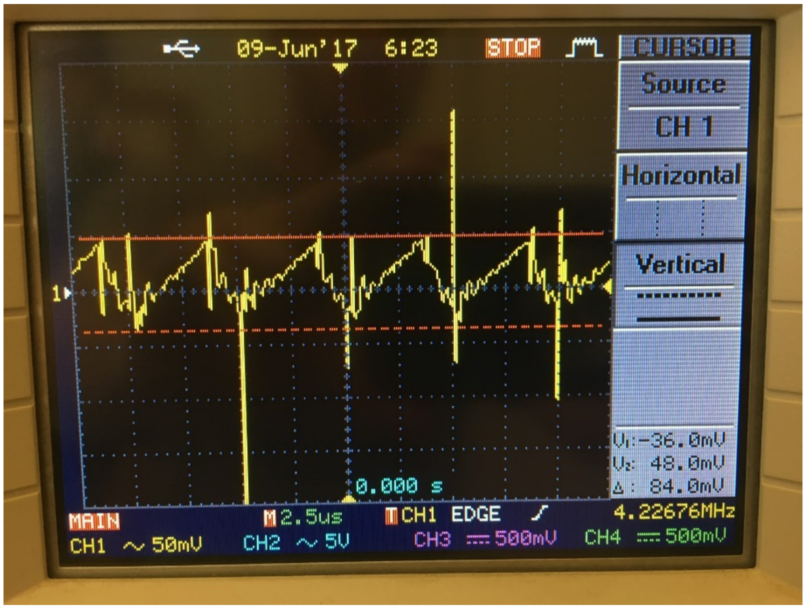


Figure 5-7. Ripple Wave for Converter 2

Next we tested the charge controller and battery. We found that when a source and load were connected to the charge controller, the charge controller would directly power the load from the source. When a load is not present then all of the current from the source would charge the battery. This shows the charge controller is prioritizing the load when battery has enough charge. During our testing, the solar panel was providing 1.3 A at around 14.45V. This test was conducted around 3pm with direct exposure to the Sun. We can safely assume that the panel can produce around 1.5A at noon and is within the current limit of the charge controller. In later tests, minimal current were directed to the battery. This seems to be because the battery was well-charged. With all the above tests, we can conclude that the charge controller is performing as expected. The test setup is shown in Figure 5-8.

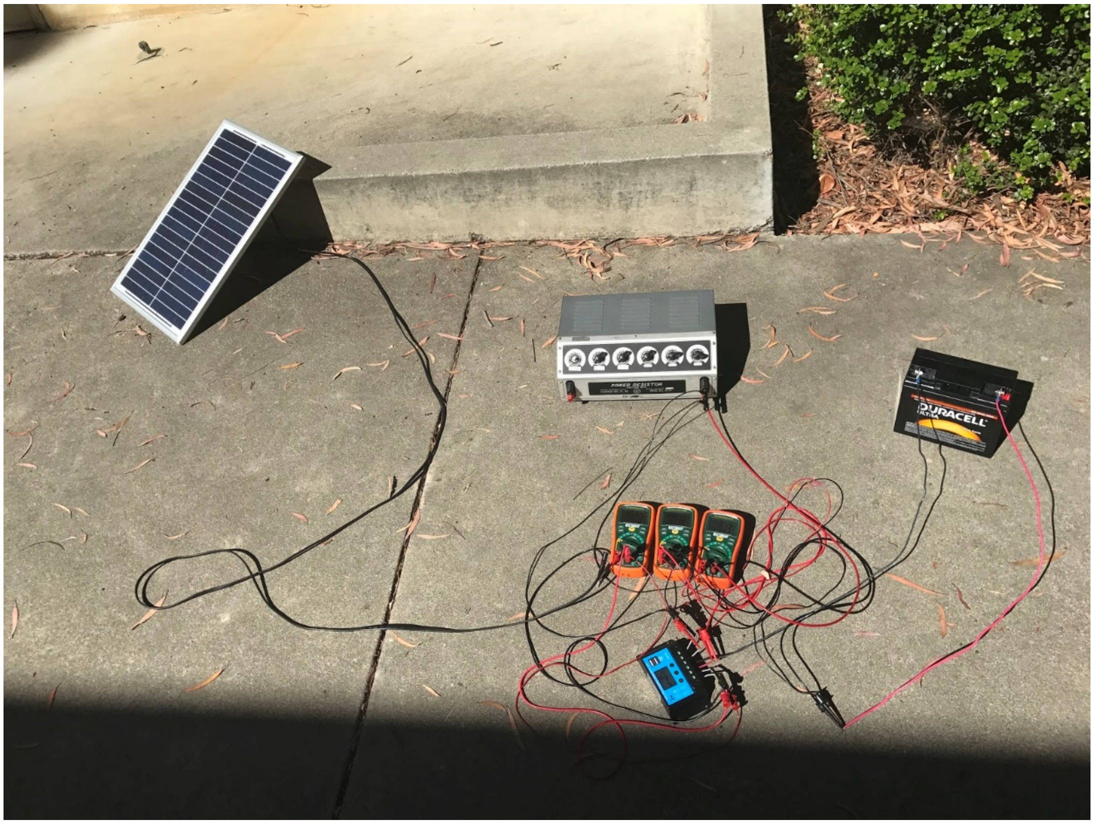


Figure 5-8. Test Setup for Charge Controller and Battery

System Testing

To test the system, we first connected a voltage source to the inputs of the first two sensors and connected an electronic load to the output of the diodes, shown in Figure 5-9. Note that any floating wires seen are not energized. This allowed us to make sure the diodes were functioning correctly and there were no odd connections on the protoboard. Then we connected the charge controller and battery to make sure the system could charge the battery, shown in Figure 5-10. Next, we connected the Arduino to make sure the sensors were still working correctly and the Arduino could be powered by the battery.

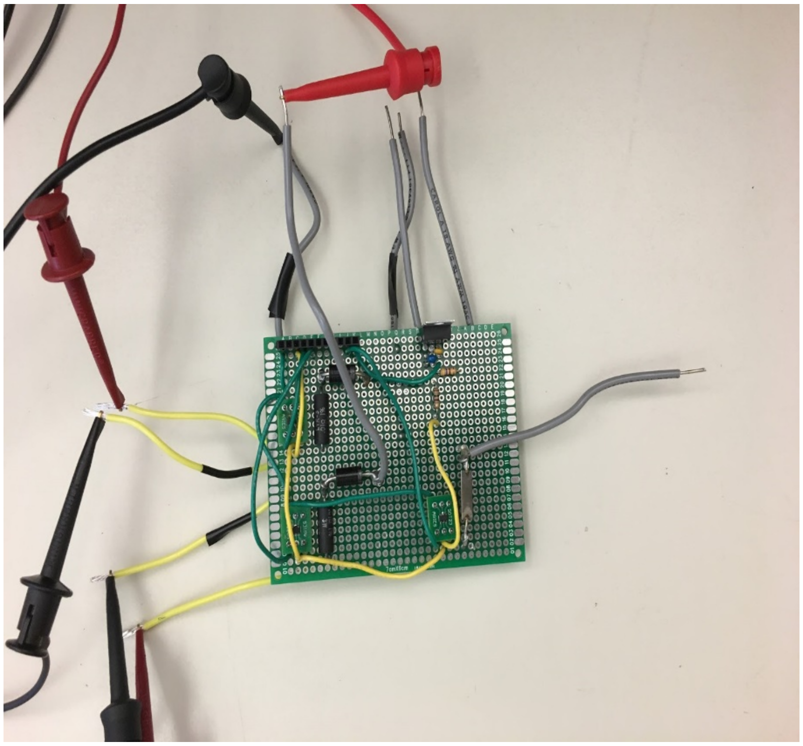


Figure 5-9. Diode Test

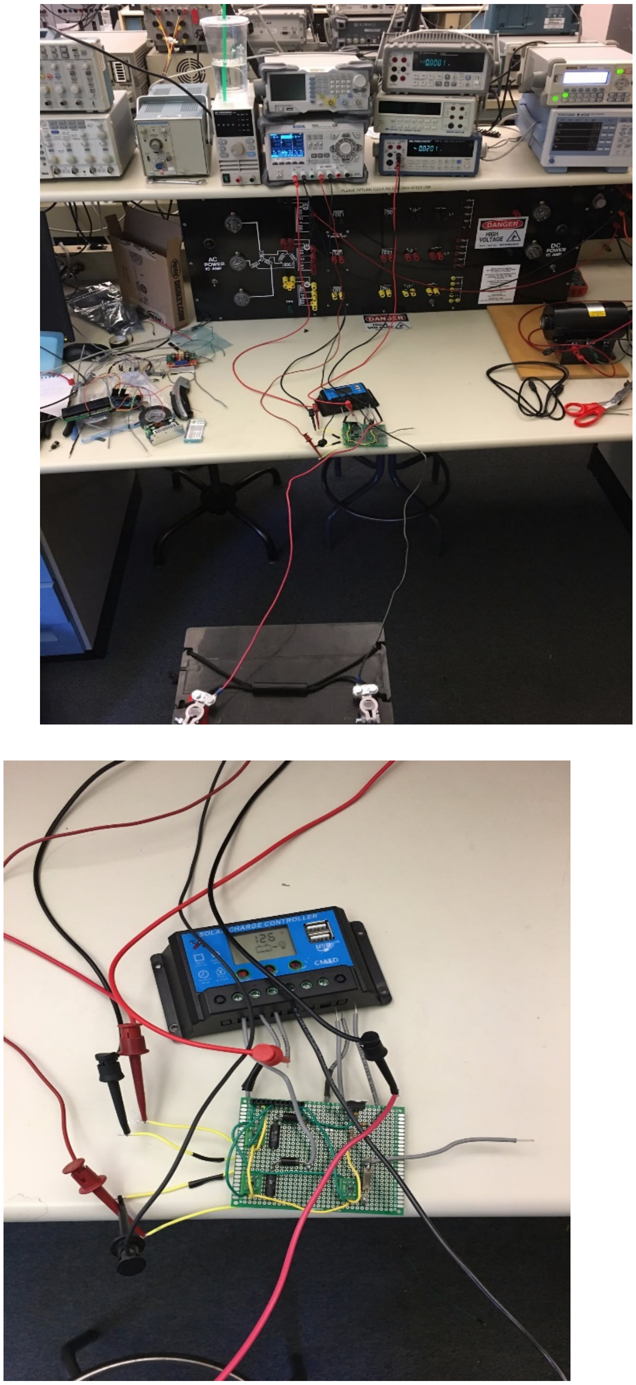


Figure 5-10. Battery and Charge Controller Connection

After this connection was tested, the converters were connected to the two sensors at the inputs of the diodes. At this stage, it was realized the charging current of the battery was higher than expected. In order to test it, multiple sources were connected and driven through one converter. We determined that the charging current was higher than our system could handle, and changed to a 20 Ah battery, which had a max charging current of 1.3 A. However, as we tested, the charging current decreased due to the battery being well-charged. The full connection is shown in figure 5-11.

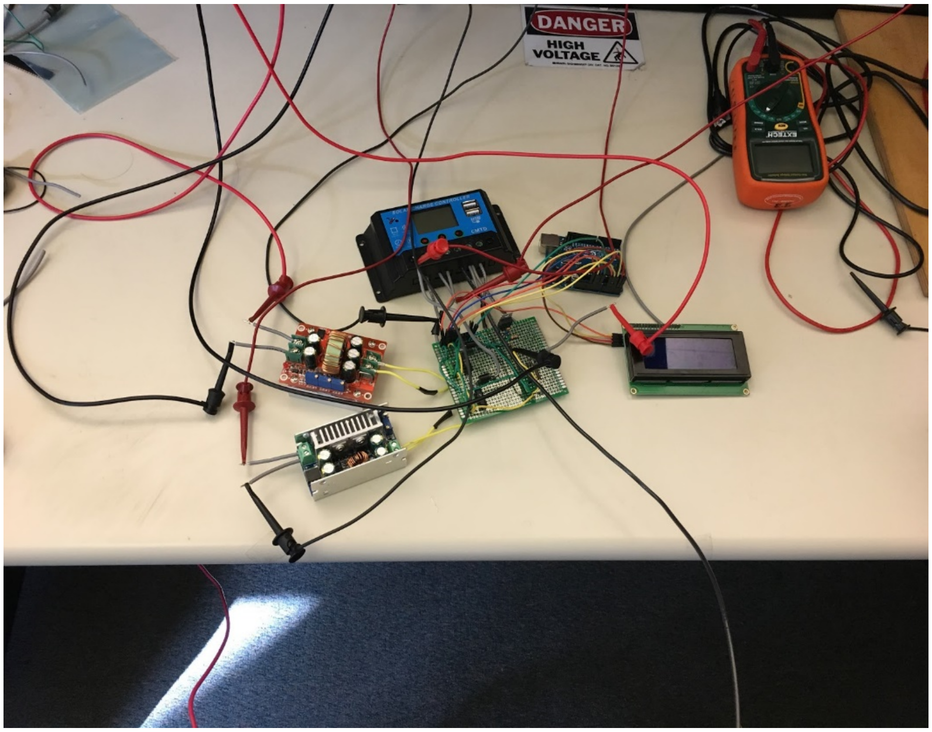


Figure 5-11. Full Connection Test of System

Once the full system operated as expected, fuses were added and the full system was tested. The adjustable speed drive and power supply to model a solar panel as shown in Figure 5-12, were connected at the inputs. The entire system setup is shown in Figure 5-13.

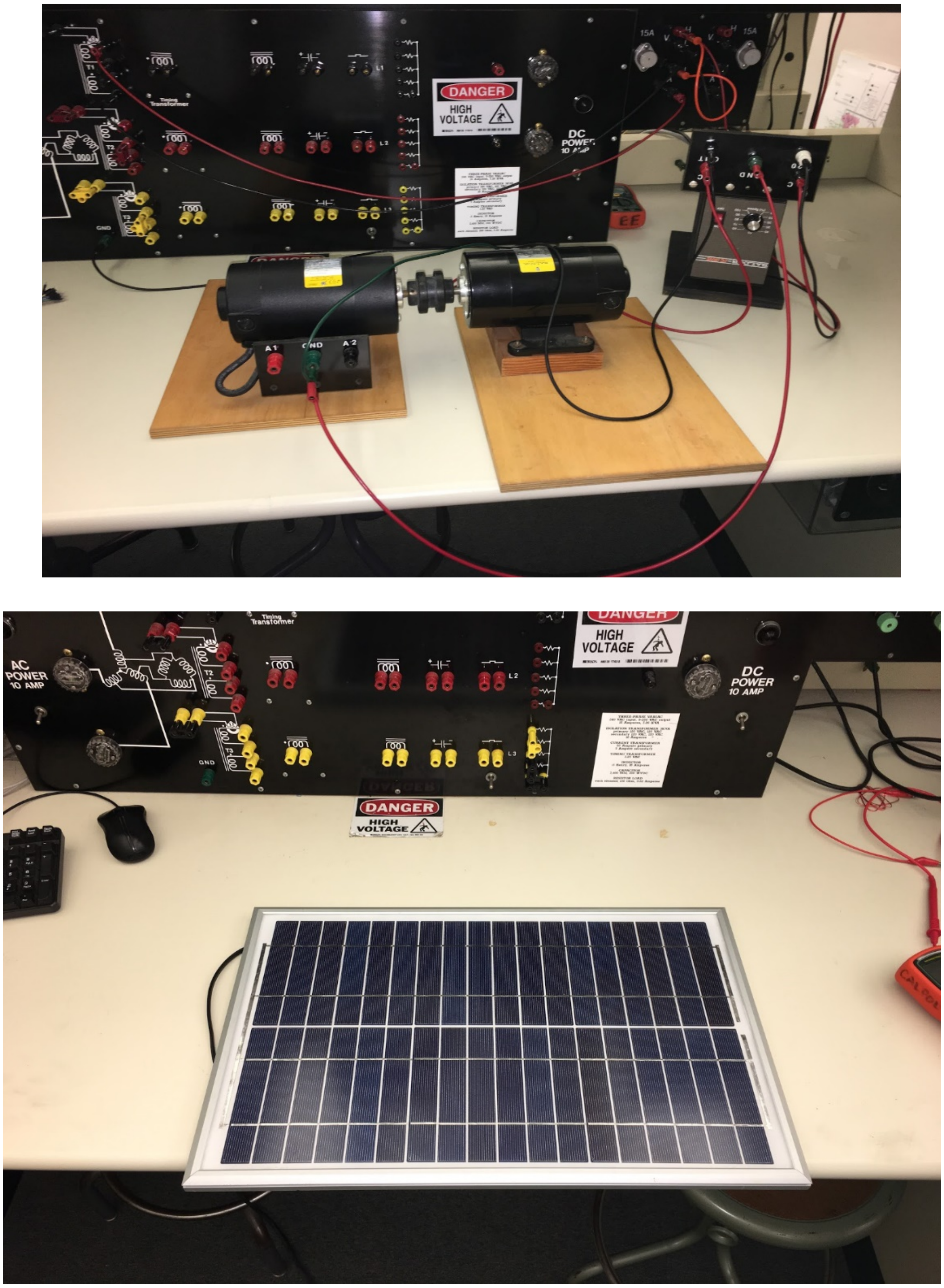


Figure 5-12. Renewable Sources. Adjustable Speed Drive (top) and Solar Panel (bottom)

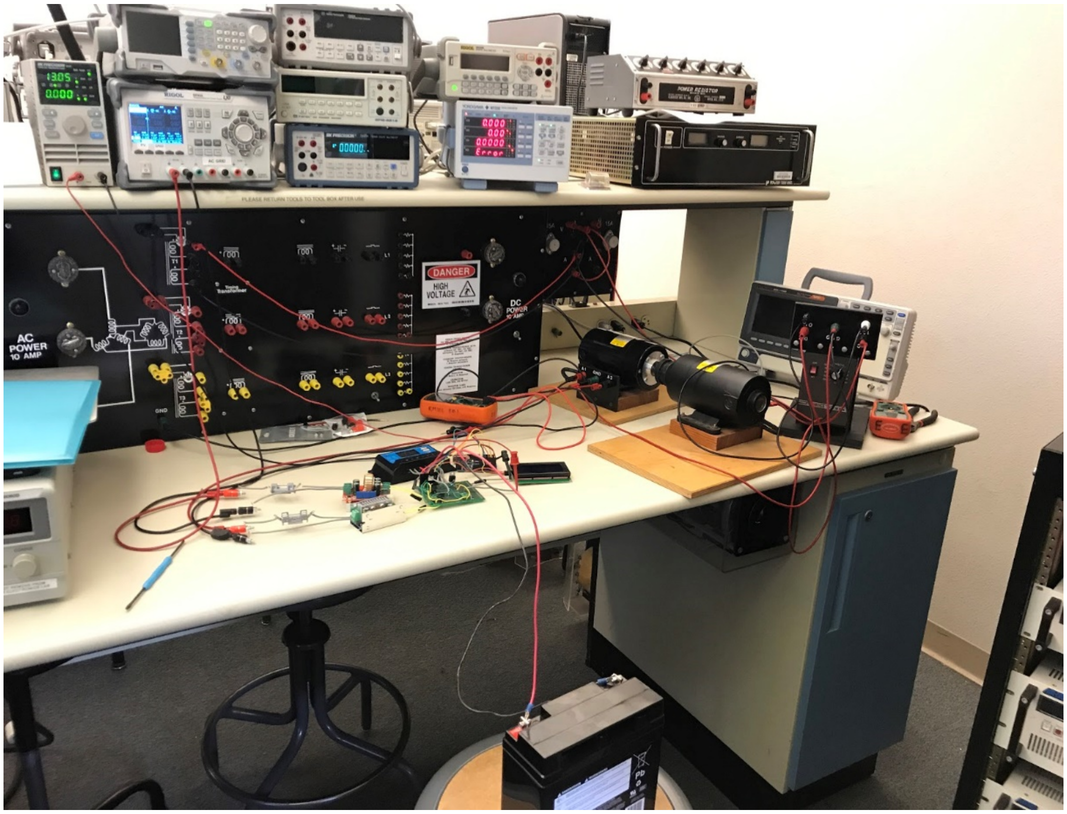


Figure 5-13. Full system setup.

Chapter 6. Conclusion

In this project, we attempt to determine the feasibility of a hybrid powered system. The major concept we deal with is the difficulties associated with trying to combine two sources of power. In our case, we used two diodes. This worked for our purposes, but scaling this up would present significant difficulties. If the system is high power, much would be dropped across the diodes. Using diodes to bind two sources together also becomes problematic when the output voltages of the converters are different, even slightly. Having different converter output voltages causes the diodes to have different anode voltages. This will cause the diode with lower anode voltage to turn off. Fine tuning the voltages to be equal can solve this problem but can be challenging. Converters also have peak to peak voltage ripples due to having switches for voltage conversion. Synchronizing the output voltage ripples of both converters therefore is essential to turn on both diodes. In our project, one of the converters was switching at very low frequency and luckily matched the higher frequency of the other converter. All the above reasons suggest that using diodes is not the best approach for building a multiple-input single-output system. Although diodes work in our case, there are too many complications during the setup process for us to confidently suggest this method. A MISO converter would be an easier and smarter choice for a MISO system.

We attempted to make the system more scalable by increasing the voltage through the system, which would decrease current, but the electronics needed to convert the signal to charge the battery proved out of our price range. We settled on keeping the voltage low, which meant current was more of a concern, due to the inverse voltage-current relationship. Therefore, we used low power sources and loads to keep current low. To improve this design, better power electronics should be used for Multiple-Input-Single-Output and the system should be designed at a higher voltage to keep current low.

In this project, we learned the complexities of combining renewable sources and learned how to characterize and build a renewable energy system. It is difficult having two sources that aren't always reliable. The battery help to increase reliability, but there is no base source of production, as in a system that is tied to a grid or uses a diesel generator. We hope that by doing this project, we have a better knowledge of how these types of systems can be efficiently designed.

Appendix A: References

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Appendix B: Arduino Source Code

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

LiquidCrystal_I2C lcd(0x3F,20,4);
// set the LCD address to 0x3F for a 20 chars and 4 line display
int spin1 = 1; //the analog pin the sensor outputs are connected to
int spin2 = 2;
int spin3 = 3;

void setup()
{
  Serial.begin(9600);          //Start the serial connection with the computer
  lcd.init();                  //Initialize the lcd
  lcd.backlight();
  lcd.setCursor(0,0);
}

void loop()
{
 float read1 = 0;
 float read2 = 0;
 float read3 = 0;

//getting the voltage reading from the temperature sensor and averaging over
//100 readings

 for(int x=0; x<100; x++){
  read1 += analogRead(spin1);
  read2 += analogRead(spin2);
  read3 += analogRead(spin3);
 }
 read1 /= 100;
 read2 /= 100;
 read3 /= 100;

//Converting the digital signal to a voltage.
//Since the internal gain of the sensor is 100 V/V and the
//sense resistor is 0.01ohms, the current is equal to the output
//voltage. The sensors are also adjusted for inaccuracies

 float i1 = (read1*5/1024*1.041)+.104;
 float i2 = (read2*5/1024*1.044)+.074;
 float i3 = (read3*5/1024*1.036)+0.139;

 //Calculate power by i*V (nominal)
 float p1 = i1*14;
 float p2 = i2*14;
 float p3 = i3*13;

 // print out the power

 if(i1<0.2){
 lcd.print("Solar: 0.00 watts");
 lcd.setCursor(0,1);
}
 else{
```

```
 lcd.print("Solar: ");
 lcd.print(p1);
 lcd.print(" watts");
 lcd.setCursor(0,1);
}

  if(i2<0.2){
 lcd.print("Wind: 0.00 watts");
 lcd.setCursor(0,2);
}
 else{
 lcd.print("Wind: ");
 lcd.print(p2);
 lcd.print(" watts");
 lcd.setCursor(0,2);
}

   if(i3<0.2){
 lcd.print("Pump: 0.00 watts");
 lcd.setCursor(0,0);
 //lcd.print("0.00 amps");
 //lcd.setCursor(0,0);
 }
 else{
  if(p3>20){
    lcd.print("Pump: 0.00 watts");
    lcd.setCursor(0,0);
  }
  else{
  lcd.print("Pump: ");
  lcd.print(p3);
  lcd.print(" watts");
  lcd.setCursor(0,0);
 }

 }

 delay(1000);     //wait a second
}
```

Appendix C: Bill of Materials

Product	Price	Amount	Total Cost	Source
Prototyping board (pack of 5)	$7.00	1	$7.00	Amazon
Circuit Breaker	$5.96	1	$5.96	Ebay
Relay (bag of 5)	$1.75	1	$1.75	Ebay
5A Fast-blow Fuses (bag of 5)	$5.00	1	$5.00	Radio Shack
1.5A Slow Blow Fuses (bag of 5)	$5.00	1	$5.00	Radio Shack
3W Diodes (pack of 5)	$5.94	1	$5.94	Amazon
20 Ah Battery	$40.00	1	$40.00	Batteries Plus
20A Charge Controller	$20.00	1	$20.00	Amazon
13W Brushless DC Water Pump	$28.00	1	$28.00	Ebay
150W DC/DC Converter	$9.00	1	$9.00	Ebay
200W DC/DC Converter	$8.14	1	$8.14	Ebay
Arduino Microcontroller	$18.00	1	$18.00	Amazon
4-Line LCD Screen	$15.00	1	$15.00	Amazon
CS30 Current Sensor	$1.10	3	$3.30	Digi-Key
LM7805 Voltage Regulator	$0.62	1	$0.62	Digi-Key
Misc. (Wires, Capacitors, Resistors, Fuse Holders, etc)	$20.00	1	$20.00	Ace Hardware, Radio Shack, Amazon
		Total:	$192.71	

Appendix D: Senior Project Analysis Form

Project Title: Hybrid Water pump

Student's Name: Wei Chen Yeh Student's Signature: ____________

Dylan W. Grant Student's Signature: ____________

Advisor's Name: Dr. Taufik Advisor's Initials: ______ Date: ____/____/2017

1. Functional Requirements Summary

Hybrid Water Pump inputs multiple renewable sources and manages sufficient input energy to either drive the load or charge the system battery. This system uses photovoltaic panels and wind turbine as the primary inputs, and water pump as the primary load. However, this project also could have other potential applications. This system has two stages. The system's first stage converts input energy into the required load energy type. The second stage manages the input energy to satisfy detected load requirement using a microcontroller. This system also has all necessary power protections.

2. Primary Constraints

Inexperience makes up some significant challenges this project encounters. Although having some designing experience from club activities, my partner and I have little knowledge about following electrical devices designing codes and guideline. We also have limited manufacturing experience which provides significant challenges when we construct our designs. More extended research into National electric code, IEEE code of ethics, and ISO standards helps us identifies requirements we might know and prevents preventable failures. Finding correct component presents another significant challenge. Our limited component purchasing experience prevents efficient constructions. We spent extra time in testing and finding working component. Insufficient microcontroller coding also proves challenging. Reviewing materials learned in previous microcontroller related course helps us overcome encountered troubles when designing the microcontroller system. Quick internet search also help us identify our microcontroller logic as well as answering additional questions which course materials did not address. Other limiting factors include not knowing the typical wind turbine performance, not knowing DC motor characteristics.

3. Economic

This project's economic impact involves human capital. Human capital means what people do. Human capitals used in this project mainly involve creating jobs. Jobs include physical labor during manufacturing processes and intellectual properties needed during designing. Human capitals also involves managing skills requires to allocating resources around. This means hiring necessary labors. The hiring process creates an impact on the labor market. Today, money remains the most used trade mediums. This project's financial capital mainly involves paper currency. Exchange of paper currency occurs during hiring labors and purchasing the devices. This exchange of paper currency creates money flows and a fixed amount of the monetary assets means our products impact the existing economy' financial flow direction. This product involves a couple components that required mature manufacturing skills. We do not process these skills therefore purchasing existing products make more sense financially. Purchasing parts involves real capital already made. Our product impacts the economy because we acquire other companies' product. This creates other markets involving other industries. Because this project involves water pump, water represents the number one natural capital. Also solar power and wind power represent the main inputs, this product also involve natural capitals of solar energy and wind energy.

The costs and benefits accrue all throughout the projects. Costs accumulate during designing process. This happens since we tried different parts for determining the best design. Although we anticipated a high designing cost, however the cost will probably exceed the estimated costs. Time related cost accumulates when we need more than 4 designs, the iteration amount we planned. We need more experimental time which affects our costs. Other cost includes footprints. Our products and its subsequence components take spaces and create footprint. This creates an environmental cost. The benefits accumulate after our product's environmental benefit exceeds all our costs. Benefit includes a more sustainable energy solution and zero negative byproducts.

Inputs this experiment requires include solar powers, wind powers and any user picked additional power sources. The project's design specifications determined these inputs. Achieving these inputs has a few costs. Monetary cost includes the solar panel manufacturing cost. Our customers pay this cost because we designed our products with solar panels representing the primary input. Monetary cost includes Wind turbine costs. Our customers again pay this cost because wind turbine also represents our products' primary input. The environmental cost includes photovoltaic panels manufacturing created pollution and photovoltaic panels' ecological footprints. The environment pays this cost. The environmental cost also includes wind turbine's land use and manufacturing pollution. Land use negatively affects the ecosystems surrounds the wind turbine. The environment again pays this cost. Our device itself uses components including metal, semiconductor, and electronics manufacturing related chemicals. All these components have monetary cost and environmental cost. We the producers pay the monetary costs while Earth pays the environmental cost.

4. If manufactured on a commercial basis

If this device manufactured on a commercial basis, we estimate selling 20,000 units a year. After finding out water pumps sales for a few companies, we feel confident that we can sell 20,000 units a year. Design requirements such as versatilities and flexibilities give our product a broad market. A potentially big market gives us confidence that we could meet the 20,000 units a year goal. Each device should cost around $300. We determine this price after roughly estimated each components' costs. Microcontroller cost the most in manufacturing. If this device manufactured on a commercial basis, the microcontroller cost could drop if we start purchasing microcontroller in large quantity. Other manufacturing costs include labor costs, electrical component costs, and PCB manufacturing costs. Considering Californian minimum wage, $300 seems like a reasonable manufacturing cost. If manufacturing costs around $300, it seems reasonable if we retail our device around $400-$500. If our products can sell for $400-$500, we could have net revenue around $100-$200. With such net revenue per unit and 20,000 units a year, we could have an estimated profit at around $200,000-$400,000. Other than the initial purchase cost and occasional maintenance cost, our customers do not have any cost operating our device during its lifetime. Our device can work for an estimated 5 years-10 years if we design it well. We set this 5-10 years based on how fast computer chips updates.

5. Environmental

Directly induced environmental impacts include PCB manufacturing related pollutions, electrical components manufacturing related pollutions, and metal manufacturing related pollutions. Our device uses metal alloy casing, copper wires, semiconductors such as MOSFETs, integrated circuits and PCB boards. Manufacturing these components creates pollution. In most cases, water pollution represents the biggest environmental impact silicon related components manufacturing has. This pollution occurs since silicon related technology requires a large amount of water during manufacturing. For example, creating an integrated circuit on a 300 mm wafer requires approximately 2200 gallons of water. Since solar panel represents this device's primary input, photovoltaic panels manufacturing related pollution counts as this device's environmental impact. Photovoltaic panels still mainly uses silicon thus the same pollution mentioned above applies. Since solar panels and wind turbine represents this device's primary input and water pump represents this device's primary output, this project uses water, Sun irradiance, wind directly. Excludes the initial pollution, this project can benefit the environment greatly. Since this device uses clean and renewable energy, it can help reduce carbon emission created by traditional power generation. Land use represents the biggest negative effects solar panels create. Wind turbines also leave a large footprint and it has negative effects for its surrounding ecosystems. For example, wind turbine provides a huge threat to the bird populations surrounding it.

6. Manufacturability

Marketing our devices represents our biggest challenges. Our device cost $300. With such price tag, customer might not find our device necessary. If customers do not buy our product, we cannot manufacture it. We need incentives for the customers so we could sell our product and get the budgets. Other manufacturability challenges include how to obtain commercial right to use other companies' product and how well can we fit other companies' products in our device. Since we do not have the manufacturability of every single component in our design, working with other companies can determine this device’s manufacturability. Other issues include assembly issues, component supply lines issues, and distribution issues. Assembly issues could arouse when we have compromising parts which no longer fit our design. When that happen, we need enough devices in the storage to meet the demands. Distribution issues could happen when shipping companies lose or damage our shipment.

7. Sustainability

Maintaining our completed device has a few challenges. These challenges include our device waterproofing and weatherproofing ability. Successful water and dust shielding can greatly improve our device’s longevity. Other challenges associated include how we can make our device shockproof and crush proof. This device helps with the sustainability of our natural resources by encouraging uses of clean and renewable energy. One upgrade we already have in mind is adding energy storages. This led to more complicated microcontroller logics and additional parts to an already complex system.

8. Ethical

Describe ethical implications relating to the design, manufacture, use, or misuse of the project. Analyze using one or more ethical frameworks and the IEEE Code of Ethics.

This device is conceived from one fundamental ethical frameworks, Ethical Egoism. With increasingly raising awareness regarding how careless consumption of natural resource would become fatal to the human, preservation of our environment and sustainability becomes increasingly important to countries all around the world. Ethical Egoism says humans ought to act in self-interest. Finding alternative, sustainable energy and become independent from fossil fuel usage proves essential to human survival. If our device encourages the use of clean sustainable energy which helps us to act in our best interest. This device provides a risk to Ethical Egoism at the same time. This product’s completion means spent time, spent money, and occupied spaces. Such resources allocation might not represents our best interest since we could use them elsewhere for more immediate benefits. Our project closely follows the IEEE code of ethics. We design our device with public’s safety, health, and welfare in mind. We haven’t discovery any way our products could endanger the public's but we take the responsibility of disclosing dangerous factor as soon as we discovered them. We also avoid any potential conflicts of interest between us and our customers by eliminate any possible ambiguities. We only state claims about our devices based on actual test data and reviewed experiments data. We reject any bribery for alternating our device to fit someone’s interest. We cannot prevent bribery once the device leaves our hands but we try our best. This device can help improve the comprehension of existing power electronics technologies, all their appropriate applications, and potential consequences. Our device also helps maintain IEEE’s technical competence by using the latest technology available. We also work closely with our advisor to see how we can improve IEEE’s technical competence further. We welcome whatever criticism we have once others examined and tested our device. We credit the critics and correct our design immediately. Creating equal access to our device allowed largely prevents discrimination against people of any race, religion, gender affiliation, disability, age, or nationality. Our product design prevents customer from using it as a weapon. We also discourage any malicious intent with our product. This device sets a good example for following the IEEE's Code of Ethics.

9. Health and Safety

Potential health and safety issues include those common in electrical system. Issues such as potential short circuits of our system led to electrocution. Other non-electrical-related issues include those common with large devices. Issues such as accidental dropping our devices onto customers and inflict physical harm. We try our best to prevent any potential health and safety issues that we can prevent. These preventions include using fire retardant materials and limiting sharp edges. This project can help overall health and safety because it encourages cleaner energy which reduces air pollution. Reduced air pollution helps reducing lung related diseases.

10. Social and Political

Social and political issues related to our device could include government opposition to renewable energy due to the profitability of traditional energy generation, foreign government raising tariff to protect local business, or political leaders using fear to opposite science awareness for his/her own political agenda. The stakeholder for this project includes the entire humanity because this project encourages smarter allocation of our available resources which prolong our specie's survival. To narrow it down, direct stakeholders include customers, engineers, and government. Customer needs our device to work to complete their tasks. Engineers can use our device as an opportunity to apply their knowledge. They also needs our device to work so they can study it. This project benefits the stakeholders unequally since some of them can benefit financially from this projects thus create inequities.

11. Development

Continued power electronics research helps us greatly during this project's designing phase. Power electronics advancement gives us multiple options to deal with protections and efficiency problems encountered. Below we attached a literature research and justifications for all the sources.