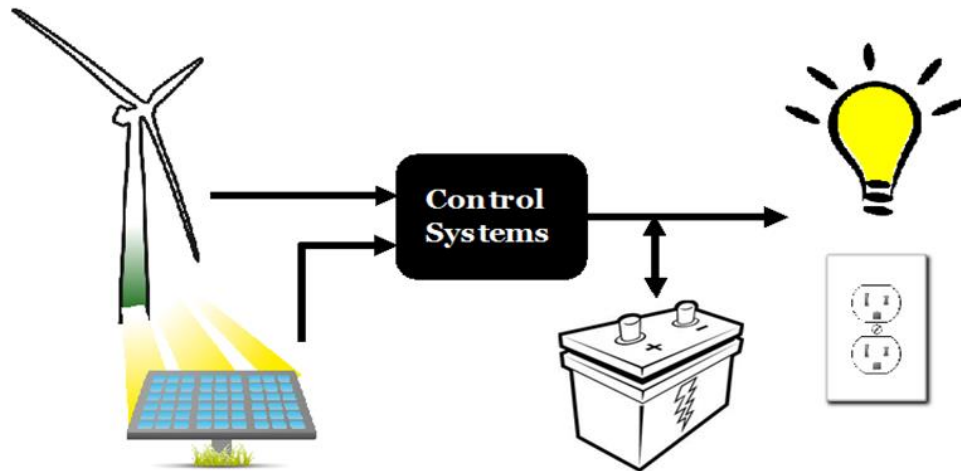# Hybrid Wind/Solar Generation System



*FINAL REPORT*

May1727
Iowa State University

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# 1. Project Design

## 1.1 PROJECT STATEMENT

The overall goal of this design project was the development of a hybrid wind and solar power generation system. We accomplished this by first building simulations of a wind energy system, as well as a solar PV array system in Simulink to gain a better understanding how each system worked. We then combined the simulations to run together as one system. Using the combined system, we tested scenarios with varying wind speed, irradiances and load to see how our system worked in all cases.  Along with the simulations, we were able to build and test the solar PV part of our simulation in hardware and confirmed that the system was working as designed.

An underlying goal of this project is to benefit the electrical engineering power department by creating lab documents, as well as the hardware that goes along with it upon project completion. We accomplished this by creating a bank of lab documents that help students test and learn from our simulations and take actual measurements from the solar pv hardware. Each lab explores a different topic and can be used to supplement the EE 452 class curriculum. On the last week of labs we were able to have the students of EE 452 go through one of our labs and learn about the pv hardware system.

## 1.2 RESEARCH LITERATURE

Our group was provided a great deal of literature pertaining to both Solar and Wind energy by our project TA Ankit Singhal, project faculty advisor Dr. Ajjarapu, and Nick David the technical advisor of WESO. The literature provided papers by Bhuvaneswari/Annamalai [1], and Mishra/Kar [2], and DenHerder [3] which were used for the development of our MATLAB simulation system. Other literature that was used to further aid in our understanding of the PV system modeling were written by Hansen/Sorensen/Hansen/Bindner [3]. To better understand the functionality of the MPPT, papers by Yu/Lin [4] were instrumental to making our system more efficient. For the wind aspect of the project, we used papers by Youssef/Abdel-Rahim/Shaltout [5] to gain a better understanding for indirect elements that need to be considered into our design, such as turbine blade length and wind fluctuation.

## 1.3 PROJECT HARDWARE COMPONENTS

### 1.3.1 Solar Hardware

**Kyocera KD125GX-LPU Solar Panels**

We are using two solar panels in series that take two inputs, irradiance and temperature, to produce power. The ratings of these panels are as follows:

- 36 modules per panel
- 135W max power per panel

- 8.37A short-circuit current
- 22.1V open-circuit voltage

**Sunsaver SS-MPPT-15L**

MPPT stands for maximum power point tracking. Its functionality is a DC to DC converter that optimizes the match between the solar panels and battery of the PV array. The MPPT converts higher DC output voltage from solar panels to lower voltage output needed to charge batteries. The maximum power point tracking comes from the MPPT reading the output of the solar panels to compare it to the battery voltage. From these readings, it figures out what the optimum power the panels can output to charge the battery.

**Samplex Power DC-AC Inverter: 600 W**

The inverter converts from a 24 V DC input to 120 V single phase AC voltage at 60 Hz to emulate a standard wall outlet.

**Universal Battery UB12900 12 V and SigmasTk SP 12-100**

Two 12V batteries are connected in series to make a 24V battery bank that is connected in parallel with the inverter and the MPPT. This allows us to charge our batteries, as well as feed the load when needed. The MPPT will act as the switching device that determines whether to charge the batteries or provide power to the load.

**100 W Filament Based Light Bulbs**

We are using a variable load that consists of four 100 W, 144 Ohm, light bulbs connected in parallel with one another. They are each fed from the inverter, which is capable of powering both resistive, and non-resistive loads from the 120V AC output. Three switches allow the user to adjust the load from one lightbulb to four, pending on power generation.

**LI-COR Pyranometer PY 73079**

Measures the irradiance instantaneously and converts that to a millivolts output with 75 microamps of sensitivity. The irradiance is measured within 82° of the sensors photodiode to accurately compare with the solar panels.

**National Instruments Sensor Interface with NI software suite, 2010**

Allows real-time tracking of irradiance measurements from the Pyranometer and displays data on Windows XP Desktop Computer.

### 1.3.2 Wind Hardware

**Permanent Magnet Generator 1750 W**

The permanent magnet synchronous generator for our turbine is approximately rated at 1750 W and is manufactured by Hydrogen Appliances. It outputs 24 V AC with variable frequency.

**Blades & Tower**

The turbine has three metal rotor blades each 3 feet in length. Wind rotates the blades, connected to the rotor shaft, and the permanent magnet generator that mechanical power into electrical power. There is no adjustable pitch angle on the system. The turbine tower is 10 feet high and is stabilized by guy-wires and metal stakes.

**Anemometer**

The anemometer measures wind speed and wind direction. The anemometer is also on a 10 feet high tower and will give us an accurate representation of the wind influencing the turbine

**Tachometer**

Mounted on the generator is a tachometer that measures turbine rotor speed. Magnetic tape is on the rotor shaft so the tachometer can recognize when the rotor makes one revolution.

## 1.4 PROJECT SOFTWARE COMPONENTS

### 1.4.1 Solar Simulation

**Solar Panels**

In Simulink the solar panel block is modelled according to the ideal diode equation. This uses other Simulink components to model said equation then inputs that data to a modelled diode block.

**MPPT**

Using the perturb and observe algorithm the simulated MPPT follows along a curve of voltage versus power and then regulates the duty cycle of the buck converter to stay at that maximum point. This algorithm progress through a logic series of if/or statements in order to constantly verify the maximum power point.

**Buck Converter**

Input to the buck converter is the solar electrical outputs and the duty cycle and a constant 24 VDC is output from the buck converter. This is a pre-defined block that

computes the average input power and then simulates the output voltage using an ideal voltage source.

**Batteries**

Next the batteries are modelled via an ideal voltage source and an internal resistance. There is also a port that outputs all the charge parameters of the batteries.

**Inverter**

The inverter uses the buck electrical outputs and a reference sinusoid to model the inverter we have in hardware. The average model uses the inputs to create a perfect sinusoidal output.

**Load**

Using a resistor as the load, the resistance is able to be changed to reflect that of the 100 W lightbulbs. More resistors can be added in parallel to show the various load simulations we have in hardware.

### 1.4.2 Wind Simulation

**Wind Turbine**

In Simulink the wind turbine block takes wind speed, speed of rotation, and the turbine ratings to calculate and output power.

**Three Phase Synchronous Generator**

The synchronous machine that we are modeling in simulink is a four pole, three phase constant voltage machine. Constant voltage means that based on the rotation speed of the generator the turbine will output a specific voltage. I.e. 50 v per 1000 rotations per minute.

**Rectifier**

We are modeling a passive three phase bridge rectifier. The rectifier takes the three phase AC voltage and turns it into a DC signal. It is considered passive because it is made with diodes and is uncontrolled. We can use an uncontrolled rectifier because we are currently only serving a resistive load.

**Buck Converter**

Our buck converter takes in the varying output voltage from the three phase rectifier and, using controlled switching, outputs a constant twenty four volts with varying current.

**Batteries**

We have two standard car batteries that are in series with themselves and in parallel to the system. Our setup allows for the twenty four volts from the buck converter to match with the twenty four volts across the two batteries.

**Inverter**

Our pulse width modulated inverter takes the twenty four volts from the buck converter and batteries and outputs an AC signal at sixty HZ.

**Transformer**

The transformer takes the output AC signal from the inverter and make the amplitude one hundred and twenty volts root mean squared.

**Load**

Our load is modeled purely as a resistive load. Using the specified voltage from the inverter we can change the power drawn on the system by changing the resistance.

### 1.4.3 Combined Simulation

This system is made up of the same components that are explain above in sections 1.4.1 and 1.4.2

**Random Environment Simulator**

The random environment simulator is used to simulate varying wind speed, irradiance, and temperature similar to how these variables change in real life with respect to time.

# 2. Implementation Details

## 2.1 HARDWARE IMPLEMENTATION

### 2.1.1 Solar Hardware Implementation

Design execution was achieved by procurement of existing hardware supplied by the Department and WESO. The PV array hardware can be seen below:



Figure 1

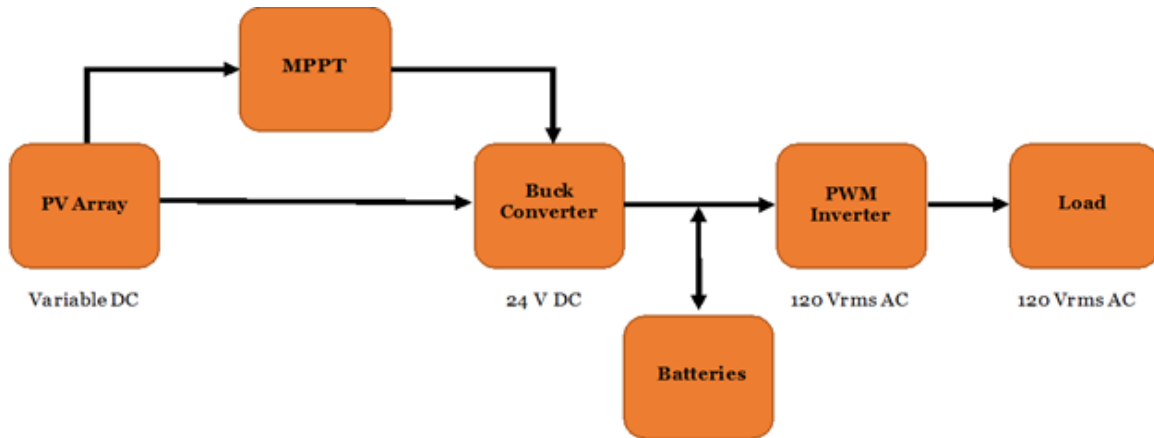Two solar panels feed into the MPPT and buck converter, which is in parallel with our battery bank and PWM inverter. Using the MPPT, we can power the load with a combination of battery and PV power, strictly PV power, or strictly battery power. A more detailed block diagram layout can be seen below, showing the isolation switches from both the inverter and the batteries, which allow the power flexibility.
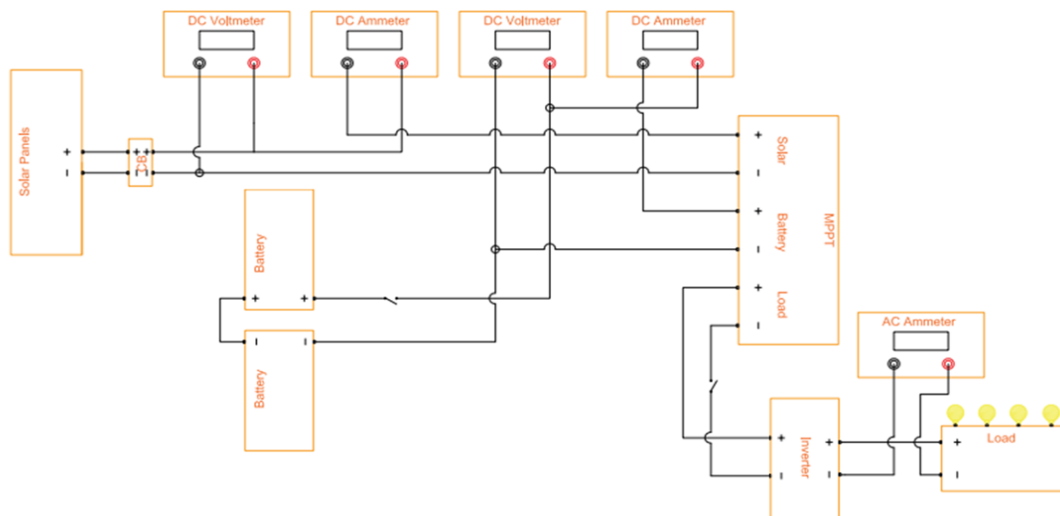


Figure 2

These switches also serve as a safety precaution to de-energize intermediate parts of the system. The MPPT of the actual hardware also has a built-in buck converter, which uses the duty cycle input from the MPPT.  The inverter takes an input from both the buck converter and the batteries to convert from 24V DC to 120V AC, which powers the load.

### 2.1.2 Wind Hardware Implementation

See Appendix II.

## 2.2 SOFTWARE IMPLEMENTATION

### 2.2.1 Solar Software Implementation

Software development was covered in the first semester of design and served as the foundation from which the hardware was created. The final design of the software program is given below and includes the same components as the hardware. The solar simulation did not change from the previous semester and the design still follows that scheme. The solar panels output variable voltage and current is based on the irradiance and temperature. This is input into an buck converter that is controlled by the MPPT to turn on and off the buck converter to create a constant 24 VDC. This voltage is used to charge the batteries as well as power the inverter. The inverter supplies a constant 120 VAC that is fed to the purely resistive, light bulb load.
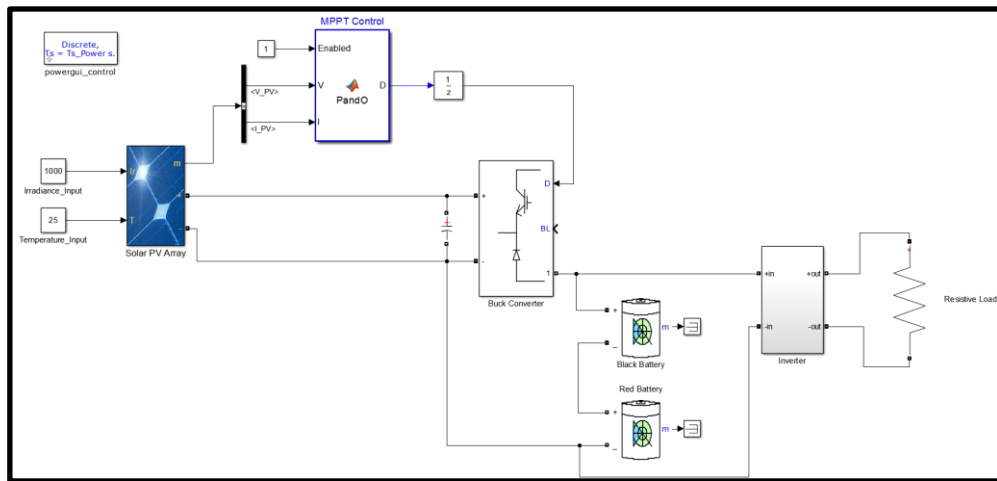


Figure 3

## 2.2.2 Wind Software Implementation

The wind system is comprise of a turbine, generator, three phase rectifier, buck converter, inverter, transformer and load. The connection diagram is shown below with the arrows indicating the flow of power in the system. Our simulation can be used to test different scenarios that represent real life situations and will be used for teaching Iowa State power electronics students about renewable energies.
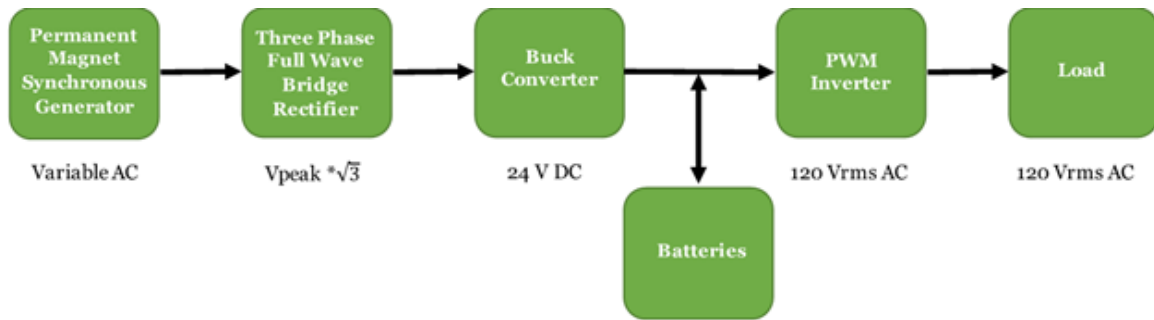


Figure 4

## 2.2.3 Combined Software Implementation

The combined software system takes both the solar and wind components and puts them together for a common battery bank and load. Combining both systems represents how a real life system would work to keep generation constant over the whole day as wind speeds are generally higher at night and solar only works in the day time. Our simulation has a random environment simulator helps us to implement a real life system by varying the wind speeds and irradiance of the simulation over time.



Figure 5

**Random Environment Simulator**

The random environment simulator is used to simulate the system using real life variables that change with respect to time. This enables us to view a changing system as if the inputs were taken directly from a source outside.

# 3. Testing Process and Results

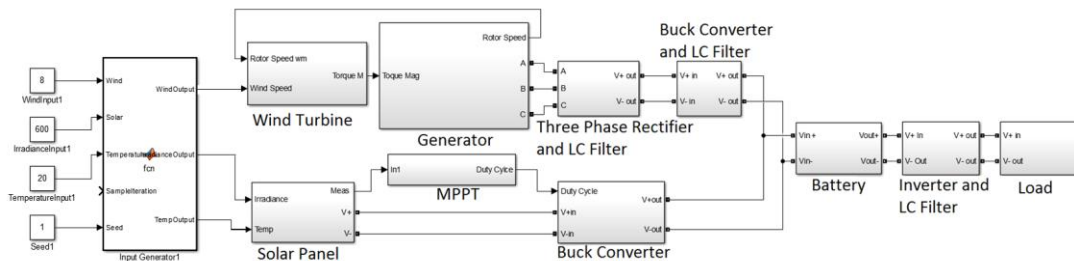Testing for both the hardware and software systems are somewhat dependent on each other, as well as the literature and data that we had collected throughout the project process. All testing was done to verify that the systems are functioning on a level that is deemed necessary to perform laboratory testing and experiments. To do this, it means that each system must be working in perfect order, and all system components, outputs, and losses need to be explained and verified.

## 3.1 HARDWARE TESTING

### 3.1.1 Solar Hardware Testing

Over the course of spring semester, our team tested the PV hardware by taking power measurements of both the generation and load in the system. The first set of data that was collected for multiple test cases was taken on February 15, 2017 during partially cloudy conditions. The data points that were taken were at the battery terminals, the solar input, and the inverter terminals of the system. Both voltage and current were recorded to calculate power. Power generated from the solar panels and battery were added together for total power generation, and power loss was calculated by subtracting the load power from total generation power. Two test cases were performed, including one light bulb with battery and solar generation, as well as 2 light bulbs with battery and solar power generation. The results are shown below:

| 2/15/2017 | | | |
|---|---|---|---|
| **1 Lightbulb Battery and solar** | | | |
| | Voltage (V) | Current (A) | Power |
| Battery | 24.7 | 1 | 24.7 |
| Solar | 26.4 | 3.6 | 95.04 |
| Inverter | 122 | 0.82 | 100.04 |
| | | | |
| Power Gen (W) | 119.74 | | |
| Power Loss (W) | 19.7 | | |
| **2 Lightbulbs Battery and Solar** | | | |
| | Voltage (V) | Current (A) | Power |
| Battery | 23.85 | 7 | 166.95 |
| Solar | 26.16 | 3.241 | 84.785 |
| Inverter | 122.08 | 1.69 | 206.32 |
| | | | |
| Power Gen (W) | 251.73456 | | |
| Power Loss (W) | 45.41936 | | |

Table 1

As seen for the one lightbulb case, the total battery power was calculated to be 24.7W, while solar produced 95.04W, totaling 119.74W, while the load power totaled 100.04W.

This accounted for a 19.7W loss in the system. Similarly, a loss of 45.41W can be seen in the two lightbulb test case.

To complete our lab manual deliverables, we needed to figure out where the losses were occurring, and why they were occurring. More importantly, we needed to prove that the conservation of energy was not being violated. The last set of data was taken on April 6, 2017 in sunny conditions. Data collection points now included terminals of the MPPT, both before and after the isolation switches to account for possible losses. Data also accounted for the 35mA consumption by the MPPT, and the efficiency of the inverter, which was 85% peak performance as stated in the product manual (Samplex

| 4/6/2017 | | | |
|---|---|---|---|
| 1 Lightbulb With Solar and Battery | | | |
| | Voltage | Current | Power |
| Solar | 37.9 | 0.713 | 27.0227 |
| Battery | 24.4 | 4.4 | 107.36 |
| MPPT (PV) | 37.9 | 0.82 | 31.078 |
| MPPT (Battery) | 23.4 | 3.94 | 92.196 |
| MPPT (Load) | 23.4 | 5.1 | 119.34 |
| Inverter In | 23.1 | 5.31 | 122.661 |
| Load | 122.2 | 0.87 | 106.314 |
| | | | |
| Input Power | 134.3827 | | |
| Output Power | 106.314 | | |
| Power Loss | 28.0687 | | |
| Efficiency | 79.11286 | | |
| | | | |
| Loss Factors | | | |
| Battery Switch | 3.94 | | |
| Inverter Switch | 1.593 | | |
| MPPT Efficiency | 0.8496 | | |
| Inverter Efficiency | 108.8001 | | |
| Unaccounted Wattage | 2.486085 | | |

| 2 Lightbulbs With Solar and Battery | | | |
|---|---|---|---|
| | Voltage | Current | Power |
| Solar | 31.3 | 7.43 | 232.559 |
| Battery | 24.81 | 0.581 | 14.41461 |
| MPPT (PV) | 30.58 | 7.76 | 237.3008 |
| MPPT (Battery) | 24.4 | 0.78 | 19.032 |
| MPPT (Load) | 24.5 | 9.8 | 240.1 |
| Inverter in | 24 | 9.84 | 236.16 |
| Load | 122.2 | 1.66 | 202.852 |
| | | | |
| Input Power | 246.9736 | | |
| Output Power | 202.852 | | |
| Power Loss | 44.12161 | | |
| Efficiency | 82.13509 | | |
| | | | |
| Loss Factors | | | |
| Battery Switch | 0.3198 | | |
| Inverter Switch | 4.92 | | |
| MPPT Efficiency | 0.8496 | | |
| Inverter Efficiency | 204.7516 | | |
| Unaccounted Wattage | 1.899579 | | |

Power Owner's Manual). Results are shown below:

Table 2                                                Table 3

The latest data collection contrasts the beginning stages of data collection with the ending stages of the project, as deliverables were being completed. Included with the additional data collection points are the loss factors created across the switches, MPPT consumption, and inverter efficiency. With these factors, we were able to account for almost all power loss for both test cases and verify the conservation of energy.

Completion of data collection and the verification of conservation of energy allowed for us to move forward on writing our lab experiment bank for solar hardware. It also provided a learning experience that enabled us to take extremely accurate measurements with the addition of the pyranometer, which allowed for us to track irradiance on the LabView software. This lead to 3 major factors to account for when measuring  and explained where the remaining unaccounted wattage might occur:

1. Tracking irradiance allowed us to pick a range of values, during which we could take measurements and ensure that both PV and battery current were steady. Any adjustment seen in irradiance would either raise or lower the PV current, thus raising or lowering battery current to account for gains or losses to the load. This leads to the next factor.
2. MPPT adjustment in current to ensure maximum power output on the VI curve. The MPPT adjusts the current of the battery and solar panels on a minute to minute basis, making it difficult to accurately collect data.
3. Hardware efficiency and current consumption.

We also learned that most of the multimeters we were attempting to use to take measurements had a max amp rating of three amps, which we were almost doubling in most cases, especially from the battery current. Most measurements can be read from the analog devices that are included in the system circuit, but in some cases we maxed out readings on the scales that were provided. For both accuracy, and to account for maxed out circumstances, we used a combination of the multimeter voltage measurements and current clamps that would measure current in milliVolts. We would then use the conversion factor of 100mV/A to convert from volts to amps and record the current.

### 3.1.2 Wind Hardware Testing

See Appendix II.

### 3.2 SOFTWARE TESTING

### 3.2.1 Solar Software Testing

To verify the accuracy of the solar simulations numerous experiments were performed beginning on a component by component level. First the solar panels were placed by themselves to measure the open circuit voltage and short-circuited current. Next, the MPPT and buck converter were tested in conjunction with the solar panel to show that the maximum power from the PV arrays could be achieved and held steady. The batteries were added to be able to store charge or provide extra power. Lastly the inverter was placed to convert the DC power to AC power for the load. Once the entire simulation was in place, multimeters were added to measure the voltages and currents at every node in the system. Using this data the conservation of energy was verified and the efficiency of the system was calculated to be 99.96% for a two light bulb load scenario. Using simulation the efficiency was expected to be 100% and this loss in power is likely due to slight differences in the measurement times.

### 3.2.2 Wind Software Testing

To test our wind simulation we built our system piece by piece and tested as we went. We started with testing the turbine and generator by inputting the max wind speed and compared the output to what we expected. With a wind speed of twelve meters per second our turbine and generator produce around one thousand watts which is what they are rated for. The rest of the system was then added piece by piece and the

voltage and power output was observed at each section. For the final system we were able to show how the voltages changed throughout process and how the power was being conserved throughout the system.

### 3.2.3 Combined Software Testing

Testing the combined simulation followed suit with the previous two, individual systems. Conservation of energy was again verified to assure the simulations were working as expected. This testing also proved the combined simulations were reliable and accurate as before.

# Appendix I: Operation Manual

The solar hardware system can be used in the following way:

1. Turn the hardware on.
    a. To turn the hardware on, the user must know the location and function of all four switches that belong to the solar panels, batteries, and inverter (inverter has two). The master switch for the solar panels is located in the panel box. The battery isolation switch can be found on the wire between the battery input terminal and the DC voltmeter input terminal. The inverter has a power switch physically on the front of the unit, as well as on the wire from the input terminal of the device and the MPPT load.
2. For measurement purposes, perform the following:
    a. For general measuring purposes, each piece of hardware is connected to either an analog voltmeter or an ammeter.
    b. For accurate measurement purposes, connect the multimeter on any terminal that needs measuring. A current clamp can be used with a bullet connector to connect to the multimeter. Using a conversion ratio of either 10 mV/amp, or 100 mV/amp (selected by the user on the clamp device), convert from voltage to current.
3. To vary the load (increase or decrease), flip the switches on the load box. One light will automatically light if either the solar panels or battery are on, and the inverter is on. Flipping the switches on the load box will turn the next bulb on or off in order down the line.

The wind, solar and combination systems can all be operation and tested in a similar fashion. The following provides details on how to run the simulations:

1. Open the provided simulink files.
2. Set the wind speed and solar irradiance to the value you want to use as test values. If you would like to use a random speed and irradiance, that varies with time, connect the Random Environment Simulator.
3. Once you have the inputs you would like to test with you simply run the simulation using the green "Play" button at the top of the screen.

4. All results can be seen at various scoped locations. At the bottom of the simulation you can see the average power after each component in the simulation to see where power is be generated, lost and transformed.
5. If desired the user can even have the load change while the simulation is running by using the switches within the Transformer and Load block. Changing the resistor signal to one allows the circuit to change and therefore change the resistance that is seen by the system.

## Appendix II: Alternative Designs

Originally, we planned to have wind hardware to use junction with the solar panels by the end of our project. For several months, we looked at small scale wind turbines that could be used. There were many considerations involved such as technical aspects, price, and safety. Initially we researched turbines rated around 300 W due to their relative low cost. After looking more into the 300 W turbines, we discovered that these turbines had a rated wind speeds around 11-12 m/s and startup speeds of around 2-3 m/s. In normal conditions, the 300 W turbines would be less than ideal because our average power output would be extremely low. We then started to look into turbines rated around 500 W. The problem with having higher rated turbines is that they are more expensive. Prices started to exceed $500 and we would have to acquire additional funds from our faculty advisor. Another obstacle was that the turbine would preferably be a vertical axis wind turbine because vertical axis turbines take wind from all directions so it wouldn't matter which direction the wind is blowing from. Vertical axis turbines are also generally safer than horizontal turbines based on the design structure. Our search became even more challenging because vertical axis wind turbines are far less common than horizontal axis wind turbines.

The design requirements changed numerous times throughout the year when we encountered roadblocks that turned our current strategy to be impossible. This was particularly the case when we were seeking permission to place a wind turbine next to the power lab that EE 452 takes place in. It was considered essential to place the wind turbine near the EE 452 lab so we could physically connect the wind turbine to the rest of our hardware. Initially, we explored the possibility of placing the wind turbine on top of Coover Hall's roof, but we quickly realized this would be next to impossible after discussing this idea with the Coover Hall Facility Planner, who informed us that just seeking a quote to install a wind turbine on Coover Hall's roof would cost well over $500. The quote would entail hiring someone to look into the zoning permits and to hire an Iowa State architect to survey Coover Hall to ensure the wind turbine meets Iowa State's aesthetics requirements. If the quote gave us good feedback, we would then have to hire a professional to install the turbine; all of this would most likely cost us well over a thousand dollars just for installation.

Our next option was to place the wind turbine in Coover Hall's atrium, but we soon encountered two problems: there was not enough wind to successfully employ a wind

turbine, and the foundation most likely couldn't handle a wind turbine because the ground is covered with rocks. Having a weak foundation would be problematic for our wind turbine because the wind turbine is stabilized by stakes in the ground. Our next decision was to place the wind turbine just northwest of Coover Hall and place it there only for a week. Temporary installation would mean we wouldn't have to seek aesthetic approval, and since the ground is grass and soil, we wouldn't have any foundation problems. We did however face safety issues in that bystanders could hurt themselves by touching the blades with their hands. This was possible since the wind turbine we acquired is ten feet off the ground and the blades are three feet in length meaning the blades reach a minimum height of seven feet. We tampered with the idea of increasing the wind turbine's height, but for safety reasons, all wind turbines need a radius around its base equal to its height in case it falls over. With this said, there are no places immediately around Coover Hall with such a large radius.

Our final solution is to place the wind turbine in a field a mile north of campus next to the applied sciences buildings. This location does not require abiding by strict safety and zoning standards like we faced on campus by Coover Hall. This solution does however mean that we cannot physically combine the wind turbine with the solar panels in the EE 452 lab; instead, the hardware in Coover Hall will either be moved out into the field or the data of the wind turbine outputs will be sent from the field to the lab wirelessly. Around the middle of March, the direction the wind hardware was taking became out of the scope of the overall project goals we were striving for, so we reassessed our priorities and decided to focus more on the simulations and solar hardware.

## Appendix III: Other Considerations

The greatest surprise the team encountered while working on this project was the realization that not all of the challenges that we were going to face were purely technical in nature. One of the most problematic challenges the team faced throughout the entire year was to obtain permission to place a wind turbine on Iowa State University's campus. We faced numerous barriers in regards to zoning laws and safety concerns both of which put a damper on our efforts which ultimately resulted in us being unable to place any wind turbine on campus. On a positive note, every time we faced a new roadblock, we approached the problem at hand with a little more creativity which helped us think of a potential solution to this project. The potential solution we thought of, albeit an imperfect solution at that, is to place the wind turbine off campus in an open field a mile north of campus and bus students out to the field to view the wind turbine and to calculate its parameters in question there. This solution would not have been considered unless we were left with no other options, and it may work in our favor because placing the wind turbine in an open field would alleviate most of the restrictions we would otherwise have had to abide by.

# Appendix IV: Code

MPPT perturb and observe algorithm provided by previous group:

```matlab
function D  = PandO(Param, Enabled, V, I)
% MPPT controller based on the Perturb & Observe algorithm.
% D output = Duty cycle of the boost converter (value between 0 and 1)
% V input = PV array terminal voltage (V)
% I input = PV array current (A)
Dinit = Param(1);   %Initial value for D output
Dmax = Param(2);    %Maximum value for D
Dmin = Param(3);    %Minimum value for D
deltaD = Param(4); %Increment value used to increase/decrease the duty cycle D
% ( increasing D = decreasing Vref )
persistent Vold Pold Dold;
dataType = 'double';

if isempty(Vold)
    Vold=0;
    Pold=0;
    Dold=Dinit;
end
P= V*I;
dV= V - Vold;
dP= P - Pold;
if dP ~= 0 & Enabled ~=0
    if dP < 0
        if dV < 0
            D = Dold - deltaD;
        else
            D = Dold + deltaD;
        end
    else
        if dV < 0
            D = Dold + deltaD;
        else
            D = Dold - deltaD;
        end
    end
else D=Dold;
end
if D >= Dmax | D<= Dmin
    D=Dold;
end
Dold=D;
Vold=V;
Pold=P;
```

# Appendix V: References

 [1] Bhuvaneswari, G., and R. Annamalai. "Development of a Solar Cell Model in MATLAB for PV Based Generation System." 2011 Annual IEEE India Conference (2011): 1-5. Web.

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