

# Design and Implementation of a Small Scale Standalone Hybrid Solar PV and Wind Energy System

Project plan

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N/A

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MPPT: Maximum Power Point Tracking

# 1 Introductory Material

## 1.1 ACKNOWLEDGEMENT

We must acknowledge the previous senior design team who worked on the same lab before us. They left us their final deliverables fully outlining the initial design of the lab. Professor Ajarapu has also helped us a great deal by providing us with equipment and funding for the lab design. Pranav Sharma, an assistant to Professor Ajarapu has helped us by providing technical guidance and suggestions regarding the technologies involved in the lab.

## 1.2 PROBLEM STATEMENT

The problem that needs to be solved by our group revolves around the EE 452 Solar Power Lab. The lab currently in place is of insufficient quality to properly demonstrate the qualities of solar panels and the MPPT software that is used in conjunction with the panels.

Our solution is multi-faceted to address several issues in the lab. Primarily, the current DC load is too small to test the solar panel, and MPPT, characteristics. Solar panels are non-linear devices that output different amounts of power as the load resistance varies. We will implement a variable resistive load ( $0.5\Omega - 200\Omega$ ) that can handle at least 9 Amperes of current. Another issue is that the lab does not generate enough solar power. This is because the panels are located in the courtyard of Coover Hall, and thus are in the shade by approximately 2:00 P.M. every day, which is not sufficient for afternoon labs. Due to cost and security restraints, our solution is to add another pair of solar panels to the system. These solar panels will be placed in a different section of the courtyard that receives sunlight later in the day.

The other major issue with the lab has to do with safety and stability. The current setup has many instances of exposed leads that can have up to 300 Watts going through them at a given time. The stability issues include uninsulated wire in the courtyard, and a large group of wires that may harm the Arduino hardware over time. Our solution to both of these issues is to design a protective circuit that will isolate all dangerous terminals and protect the hardware from longtime damage.

## 1.3 OPERATING ENVIRONMENT

The solar panels, as well as the irradiance and temperature sensors are permanently located outside, accordingly, they will be exposed to all types of weather conditions. The rest of the lab will be located inside the lab room, but only used once each year. Because of the large amount of time sitting idle, it will need to withstand dusty conditions and not require constant maintenance.

#### 1.4 INTENDED USERS AND INTENDED USES

The final product's main use will be in the EE 452 Lab. This lab is closed off to outside students and all who have access will be familiar with power electronics. It will be used by EE 452 students learning about power electronics, specifically PV (Photovoltaic) cells. Due to the technological advances in wind and solar energy, renewable energy has been more common throughout the world. Thanks to this, there is an increase in demand for renewable energy thus Electrical Engineers need to understand concepts, processes, and challenges in renewable energy.

#### 1.5 ASSUMPTIONS AND LIMITATIONS

Assumptions: The project will only be used in the school laboratory; It will be used under supervision by qualified students.

Limitations: Sunlight is required for successful use of this lab; It cannot be used for many consecutive hours, as the lab is dependent on charge in the batteries.

#### 1.6 EXPECTED END PRODUCT AND OTHER DELIVERABLES

There are 2 main deliverables for our project. The first is a new DC load to be used in the lab. The preliminary design is simply a resistor bank with the ability to wire the circuit however is needed. The load will consist of 8 different resistors, with the ability to create a variety of equivalent resistances forming a range between  $0.5\Omega$  and  $200\Omega$ . The focus will be on functionality at first, but once the resistor bank is fully functioning we plan to add inductive and capacitive elements to model a house.

The second deliverable of this project is the final lab document. The whole project is centered around the Power Electronics Lab, so naturally we must produce a lab document capable of describing the experiment to the students. Last year's group also provided a lab document as a final deliverable, so our final product will merely be modifying the document to include our new load and safety features.

## 2 Proposed Approach and Statement of Work

### 2.1 OBJECTIVE OF THE TASK

The goal is to improve, revise, and expand the standalone PV system. The lab, as it was after last year's group, is simply not usable. It is not safe enough for students to use without heavy supervision and it does not properly display the characteristics of PV arrays and the MPPT. Thus, our objective is to add design components to fix the lab and make it intuitive, fun, and educational for its users.

This will all culminate in a lab report that is easy to read and instructions that are easy to follow. The report will be paired with a lab station that is organized, concise, and most importantly safe and reliable.

## 2.2 FUNCTIONAL REQUIREMENTS

The functional requirements of this lab include being able to model all the components used in the lab in Simulink. Using those models, we are going to need to be able to test the system in a safe environment. This is to protect the students and the equipment. The lab needs a load which can fully model the functionality of the solar panels and MPPT. To make these measurements, we also need to provide an interactive interface that allows the students to see what is happening within the system, while using different loads. This includes providing displays that show voltage, current, and power at different points in the system. Our areas of focus are solar input, battery input, MPPT input, MPPT output, DC output, and AC output.

## 2.3 CONSTRAINTS CONSIDERATIONS

The non-technical constraints of our project all revolve around the fact that this is a lab to be used in a university setting. Below is a list of all requirements of the lab

- Must be robust enough for students with little to no experience with solar power to use effectively
- Must fit inside designated lab station of 2 by 2 by 3 feet
- Must withstand dust accumulation when not in use (365 days of the year)
- Must be feasible to complete in under 3 hours
- Solar panels and sensors must withstand weather conditions for the entire year

IEEE standard 1562-2007 provides regulations for properly sizing the batteries that are used in conjunction with solar panels in standalone systems. Naturally, it was necessary to verify that our batteries had a large enough capacity to support the solar panels currently in place. IEEE standard C37.10.1-2000 provides direction for necessary parameters to be included in high-voltage breakers. Each breaker we implement into our design must conform to these standards and be sufficiently tough to handle the high power used in the lab.

## 2.4 PREVIOUS WORK AND LITERATURE

There are other standalone PV systems for sale on the market, but designing and implementing one from scratch is far more cost effective. This has already been done for us by groups in the past, who included many useful things in their design, yet fell short in several key areas. Because of their work, there are several things that we do not have to worry about. Some examples of these include the wiring between solar panels, battery, and MPPT, the irradiance and temperature display, the AC load display, and connecting the DC-AC inverter. However, they failed to make the system safe and reliable, to

implement a DC load capable of showing the MPPT's usefulness, and to display accurate voltage and current readings from the solar panels and to the DC load. Nonetheless we are building upon their work and are grateful for the effort they put in before us. Their team website is cited in the References section.

We also have benefited from several research documents regarding the function of solar panels, the MPPT, and their respective Simulink models. To properly design an addition to this lab, we first needed a solid understanding of the science and software behind each component involved in the lab. These reference documents are the main way we gained an understanding of the solar IV characteristics, and the MPPT's tracking algorithm. Each document is cited in the References section.

## 2.5 PROPOSED DESIGN

Our design has 2 main components, the new DC load and the safety implementation. Functionally, the resistor bank will have 8 wire-round, power resistors capable of withstanding over 300 Watts of power at room temperature. Each resistor will have banana pins connected to both terminals, so the students can connect them however they choose (series or parallel). This flexibility serves the purpose of having the load resistance value vary from a minimum of  $0.5\Omega$  to a maximum of over  $200\Omega$ . This range is large enough to plot the IV characteristics of our solar panels at any possible irradiance and temperature value. The eight resistors will be completely enclosed in a plexiglass or plastic case so that the only access the students will have is through their banana pins.

If time allows, we will stretch our load design into a model of a house. We will add power inductors and capacitors to accurately model the larger loads of a home. This will both incorporate the inverter and AC power into the lab, and show students a common, practical use of solar power. In addition to the load elements themselves, the house will have 8 LED's (one connected to each resistor) to demonstrate which areas of the house are receiving power. This visual representation of the load will both increase interest in the lab, and benefit visual learners who can now watch as the load resistance value now changes via the lights.

On the safety side of things, our idea is to simply make any live terminal impossible to reach. This includes putting insulation around the leads to the battery, multimeter, and breakers. It also includes adding an auxiliary circuit which will encompass much of the exposed wiring unstable connections. The outputs of that circuit will be compact, robust, and most importantly safe to use. As much of the system as possible will be contained in this inaccessible circuit to ensure that no one touches a dangerous connection.

Our final safety considerations deal with circuit breakers. At the moment, there is one switch that turns off the solar power and battery supply. The single-phase and three-phase inverters are both supplied by an external power source, and thus need their own circuit breaker that is easily accessible from the outside of the lab station.



## 2.6 TECHNOLOGY CONSIDERATIONS

Arduinos have been implemented into the current setup and will need to be improved to display necessary conditions. The Arduino, like any technology, has limits in processing speed, so the speed tradeoff vs the amount of information it displays will need to be considered. Arduinos are very easy to code compared to regular microprocessors, and as a result, are not as in depth with as many options as the alternatives.

The solar panels we currently use are the Kyocera KD135GX-LPU which is an 8-year-old model. Modern solar panels are capable of producing double the amount of power for the same sized panel. One of our designs for this year is to order some new solar panels that can increase the capacity of the lab, designing a device to support the panels, and incorporate them into the current circuit.

## 2.7 SAFETY CONSIDERATIONS

Safety considerations are a large part of our project. A standalone solar PV and battery system naturally has potential risks as there can be up to 300 Watts of power flowing through the devices and into the load. With up to 9 Amperes of current, touching an open terminal can seriously harm the individual, and it could possibly be fatal. Because last year's group failed to make their design secure and safe, we need to put a lot of emphasis on covering any open terminals, and making sure the students do not have access to dangerously large amounts of electrical power.

## 2.8 TASK APPROACH

Since the current project is to improve the previous group's work, the following are steps needed to analyze the current system, find possible errors, and problems. To fully understand the lab and its setup, first approach is to understand how each component is laid out in the circuit. How each component effects another component, and how they function with one another. Each component needs to be listed with its inputs and outputs, where it's getting certain variables from and what it is outputting. When a full understanding of the circuitry is developed, functionality of the system became the next step.

The usage of MATLAB Simulink was used to produce a model for the system to safety test and record values and compare them to the experimental values from the lab. This allows for checking of minimum and maximum sources of power for the system. This includes, maximum current, voltage, and power that can be created by the system. The information allows to gauge if the system is responding correctly and producing current data.

The creation of flowcharts and block diagrams will be implemented to outline the circuitry of our design. This will allow us and future students to understand what is occurring in the circuit, its components layout, and allow improvements to be easily added. Additionally, a similar layout will be added to the system for possible ease of usage and safety for the lab.

## 2.9 POSSIBLE RISKS AND RISK MANAGEMENT

Currently the system does not run as it should. Wire management is a huge concern since the wires coming from the solar panels are not color coordinated throughout the system. This is a risk because the way the circuit is setup makes it hard for the user to figure out where each wire is being inputted to and what component is getting its output. When examining the circuitry, the wires from the solar panels that are placed outside do not have any protection coding on it. The wires are left bare and have become brittle and will inevitably break. The sensor for the solar panel that records the irradiance was left placed on top of the solar panel, not mounted, therefore any strong wind would force the sensor off. So accurate reading of the sunlight hitting the solar panel would not be accurate.

The circuitry itself needs to be revamped and revised. Currently the wires are not color coded correctly, noted above. Wires connecting the Arduino to the LCD display can rip the pins off the Arduino, damaging the Arduino. Arcing can be seen when turning on the system on the inverter, this is a concerning system issue. Some components are connected into wires by nuts or bolts, when the system is turned on, these nuts or bolts will live, therefore causing safety concerns.

Currently all risks concerning safety and function of the system need to be revised and revamped. Wires need to be stripped and color coded, wires connected to the solar panels need to have protected coding. The system itself needs to be self-contained, so no student can get into the circuitry. Safety is of utmost importance, so fixing live bolts, shorts, and arcing to remove the risk of students getting hurt. Which in turn, will allow the system to function accordingly without deteriorating due to these problems.

## 2.10 PROJECT PROPOSED MILESTONES AND EVALUATION CRITERIA

Key milestones for this project include the following:

- Lab Setup Functions Correctly and Within Reason for Completion of Lab
- Checking Components for Functionality
- Re-soldering wires if needed (due to shorts within circuitry)
- Adding Additional Components, additional solar panels and batteries, to Improve Stability of System and Adding Longevity to Lab allowing night time students to complete lab at the same conditions as Day time students
- Overall Making sure the lab is intuitive for Students

Test used to ensure functionality of the lab will be conducted in Simulink. A simulated model of the system will be used in Simulink to give us values that the system should produce. The values used in the simulation will be given to us from the system and thus comparing the simulated results to the results from the lab will determine if the system functions correctly. A marginal error of between 0 to 10 percent difference will be acceptable. Since all components used in the lab can be simulated in Simulink, comparing simulated values and experimental values can easily be obtained.

As stated above, if components such as additional solar panels are added or more batteries are added to the current setup, Simulink can simulate what projected values these additional components add to our setup. If additional components add extra load to the overall system, components can be ordered with permission from client.

Lab manual will be revised when additional components are added. A new DC load will be implemented in the current system, introducing more variability to the system load. Additional information will be added to the lab manual, such as photos of how the new load will operate. Additionally, a solution manual will be added, for students to have comparable data. When comparing simulated data to experimental data, a 0 to 10 percent difference is acceptable.

### 2.11 PROJECT TRACKING PROCEDURES

Weekly reports will be used to keep track of everyone's accomplishments and contribution to the project. This will continue into the next system. A report will be made weekly to our client, to keep them informed of the progress of the project and if problems occur. Weekly meetings with client will continue from this semester and throughout the next semester. We were provided with a TA by the client to overlook our progression, he will also be informed with the progression of the project. The timeline used in the following section will be used to track the completion of each task, and if need be, the projected time to complete the task can be lengthen or shorten.

### 2.12 EXPECTED RESULTS AND VALIDATION

The desired outcome for the project is having a working lab station that is intuitive for students to learn about concepts about MPPT, and the P-V, I-V characteristics of solar panels. The workstation needs to be clean up, a LCD displayed is needed to be mounted that displays the DC output voltage coming from the solar panel before it is converted into the MPPT. The buck chopper that is currently controlling the DC voltage needs to be mounted onto the workstation with pins to manage the amount of wires needed for the lab. Currently, the display measures the load and solar energy coming from the solar panels. From the measuring using ammeters and voltmeters, we determined that the displayed values were off. Therefore, an overhaul of the system needs to be made to read correct values. Wires leading from the solar panel into the circuitry needs to be colored coded accordingly, wire colors should not change from the solar panel to the MPPT and the battery. This will allow future groups to make changes to the circuitry without having to fumble around figuring out where the wire is inputted and to what device is it outputting to.

Overall, the workstation needs to be revamped for easily usage by the students. The circuitry needs to be placed in a standalone containment so no students can tamper with the components without having to removing a panel. All values simulated from the lab in Simulink will need to be able to be simulated experimentally within the lab station, with values no less than 0 to 10 % error.

Validation of the workstation working fully will be from simulating the workstation using Simulink with real life values obtained from the station. These values will be compared to the simulated values to verify if the overall workstation values produced are the same as the values projected by the simulation. These experiments will be run throughout the day to get different values for solar contact with the solar panels. This will allow us to validate if the experimented results match the simulated results. Since labs are going to be throughout the day with different varying amounts of sunlight hitting the solar panel, experiments with varying weather, and sunlight contact will help determine if the workstation is running correctly. The workstation will be easily accessible so that future students can make improvements upon the system.

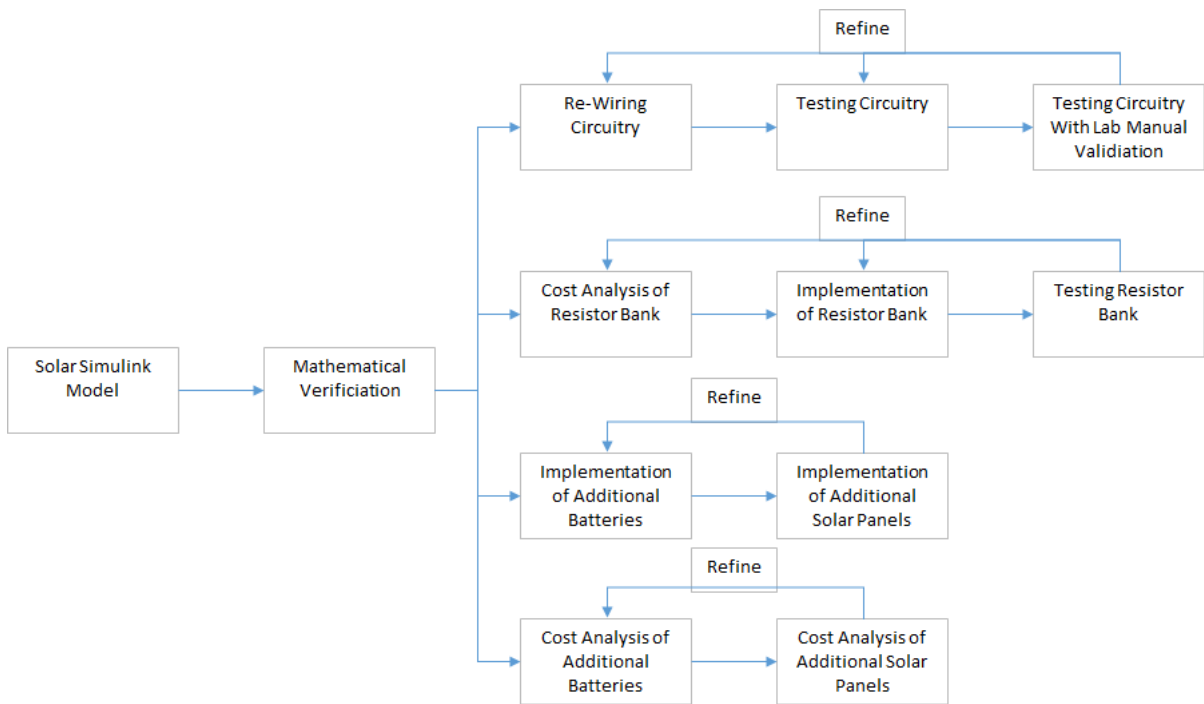
### 2.13 TEST PLAN

When the model is revised, such as making sure there are no more shorts in the circuit, no actual live bolts, wires are color coded correctly, and wires running from the solar panel to the inside of the building are protected, the following will be used for testing the model. For testing the model, the group will mathematically prove that the overall model was accurate. Equations were used for the PV system, conservation of energy, and more. Once the mathematical verification is finished, simulation of each component will be the next step.

Simulation of the battery, solar panel, MPPT, and dc output will be used in simulated in Simulink, and compared to values experimentally conducted. Simulation will allow us to see if the mathematical calculation is accurate and acceptable to our client. This ensures that there are two different tests that can validate our model.

A lab manual was provided to us from pervious group, an updated manual was developed by us and thus will be used to run through the experiment. Recorded values from different time periods with different amount of irradiance and temperature will be used to compare to simulated values to validate that the model works properly.

Below in figure 1 of the process we will be using for this project. This helps ensures that we deliver a product that meets or exceeds the requirements of our client. The improvement of the overall workstation and to help students effectively learn about solar power and different concepts learn through the EE 452 class.



(Figure 1: Block diagram for our design process)

## 3 Project Timeline, Estimated Resources, and Challenges

### 3.1 PROJECT TIMELINE

Task Name	Start Date	End Date	Duration (Days)	Days Complete	Days Remaining	Percent Complete
Talked to Client About Expectations	1/18/2018	1/23/2018	5	5.00	0.00	100%
Understanding Lab setup/ Prior Group's Work	1/22/2018	2/12/2018	21	21.00	0.00	100%
Simulate and Evaluate Prior Group's work	2/12/2018	2/26/2018	14	14.00	0.00	100%
Find Errors/ Re-Evaluation of WorkStation	2/26/2018	3/19/2018	21	16.80	4.20	80%
Possible Fixes to Errors/Additional Components	3/19/2018	4/18/2018	30	15.00	15.00	50%
Planning of Adding Components	4/18/2018	4/30/2018	12	6.00	6.00	50%
Fixing Components/Testing Functionality	8/20/2018	9/3/2018	14	0.00	14.00	0%
Implement Extra Battery/Solar Panels	8/20/2018	8/20/2018	0	0.00	0.00	0%
Fixing Circuitry/Wiring	8/20/2018	9/3/2018	14	0.00	14.00	0%
Positioning Solar Panels for more Sunlight	9/3/2018	9/4/2018	1	0.00	1.00	0%
Evaluation of Successful Implementation of Components	8/20/2018	8/26/2018	6	0.00	6.00	0%
Implement Screen for Buck Chopper	9/3/2018	9/10/2018	7	0.00	7.00	0%
Implement Screen for Battery	9/3/2018	9/10/2018	7	0.00	7.00	0%
Resistor Bank Implementation	9/10/2018	10/10/2018	30	0.00	30.00	0%
Resistor Bank Tested/Verified	9/10/2018	10/10/2018	30	0.00	30.00	0%
Successful Testing of Workstation/Lab	10/10/2018	11/9/2018	30	0.00	30.00	0%
Re-revision of Lab manual	11/9/2018	11/20/2018	11	0.00	11.00	0%

(Table 1: Timeline of objectives and completion progress)

The following project timeline is dated from the start of 1/18/2018 and ending in the end of fall 2018 semester. The overall continuation of the project timeline will be created afterwards but details of adding components to current setup are included in the project timeline.

The tasks were chosen in this manner so that we can test and complete each additional component added to the lab and to verify the stability of the setup. Each component is a task so that it can be simulated both in Simulink and experimentation to verify that the results are the same. This will allow for checks on safety of the lab dealing with high voltages. Other than validating that the setup works and each component functions correctly, safety is at utmost importance when additional components are added.

The Gantt chart will be attached at the bottom of the document in the appendices with a link to course website with excel spreadsheet for better viewing.

### 3.2 FEASIBILITY ASSESSMENT

Revising and revamping the workstation setup can be achieved in the upcoming semester. Ensuring that the lab is safe and that the following are fixed:

- Color Coding wires, making sure all output wires are matching in color
- There are no live bolts or components in the circuitry
- System is contained, and cannot be easily entered by students
- Reading values from components, such as battery, MPPT, and solar panel are within a 0 to 10% error
- Soldering wires on Arduino to ensure that pins are working correctly

These can be done within a month of the upcoming semester. Since the EE452 course is conducted in the spring, we will be allowed to adjust without impacting other labs in the course.

Some foreseen challenges will be re-wiring and color coding the wires running from the solar panel to the circuitry. Due to most of the system's wires have been soldered into the workstation, we will need to rewire everything and solder all components into the displays, Arduino, etc. Currently, many of the team members do not have any experience with soldering so an outside help will be needed.

A concern would be replacing current components if they are not functioning correctly. With re-wiring the circuit, many parts could already be damaged from the current setup, therefore, financially, we will need to buy new components to supplement for the damaged ones.

### 3.3 PERSONNEL EFFORT REQUIREMENTS

The given table (table 2) below goes through each of the tasks throughout the timeline and gives a brief explanation of the task and the amount of effort (Low, Medium, or High)

Tasks	Explanation	Effort
Talked to client about expectations	Talked about the problems that the lab has and what needs to be done to improve the lab	Low
Understanding lab setup and prior group's work	Consider previous group's documentation about the system in the lab and look at the system ourselves	Low
Simulate and evaluate prior design	Test the prior team's Simulink simulation	Medium
Find errors and re-evaluation of setup	Look at the system to find possible issues with the current setup	Medium
Possible fixes to errors/additional components	After finding issues regarding the setup, come up with ideas to resolve these issues	Low
Implementation of Resistor Bank	Create/Implement Resistor Bank	High
Fixing up components/testing for functionality	Fix connection issues within the electrical system	High
Implement extra battery	Add an extra battery to the electrical system	Medium
Implement extra solar panels	Add an extra solar panel to the electrical system	Low
Positioning solar panels for more contact with sunlight	Move the solar panels in the court yard of Coover so that they have access to more sun throughout the day	Medium
Evaluating successfulness of implemented components	Review and test the additions we made and evaluate their effectiveness	Medium
Implement screen for chopper	Add a screen for the current buck chopper	Medium
Implement screen for battery	Add a display to monitor the batteries in the electrical system	Medium

(Table 2: List of tasks and personal effort required to complete each task)

### 3.4 OTHER RESOURCE REQUIREMENTS

Following are resources needed to conduct the experiment and to revise the lab setup:

- Additional wires, color coded
- LCD Screens for displaying voltage, charge, for Battery, DC output
- Protective covering for circuitry
- Pins for load and Buck Chopper
- Pile wood for creation of Resistor Bank
- Various Resistors
- Extra Arduino boards
- Possible New MPPT/Batteries/Additional Solar Panels

### 3.5 FINANCIAL REQUIREMENTS

The following are the estimated cost of each resistor, materials, batteries, solar panel and MPPT needed to create the resistor bank and improve the work station.

1 Ohm resistor - \$21.83

2 Ohm resistor - \$42.81

5 Ohm resistor - \$41.21

15 Ohm resistor - \$21.27

25 Ohm resistor - \$25.29

100 Ohm resistor - \$25.29

150 Ohm resistor - \$25.29

200 Ohm resistor - \$25.29

Breaker: 1P Standard Plug in Circuit Breaker - \$9.86

2 Additional Batteries - \$45.98 each

2 Additional Solar Panels - \$350.00 each

Pile Wood - \$19.73

Plexiglass - \$23.74

MPPT - \$ 243.00

Overall estimated cost of all resources is \$1317.29

## 4 Closure Materials

### 4.1 CONCLUSION

This project is to improve the EE452 photovoltaic system in the lab for future students by improving stability of the electrical system with additional solar panels and/or batteries and internal connections within the system as well as additional displays and finally additional documentation within the lab document. This project will in turn help future EE452 students with how a photovoltaic system works with the additional displays as well as the added documentation in the lab document. The project will also help prevent electrical shock as well as any harm that may come to the students with using the photovoltaic system.



## 4.2 REFERENCES

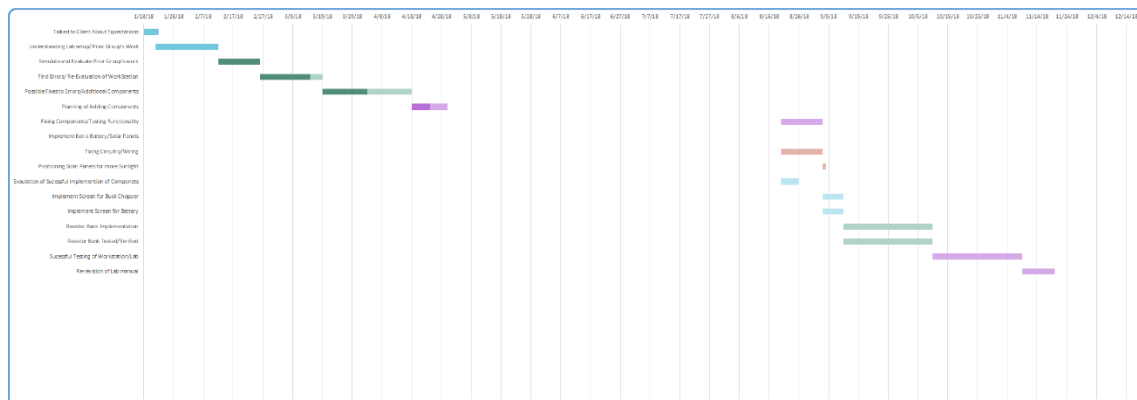
References include prior senior design groups work, senior design group DEC1706 and DEC1621. These includes all Arduino code, lab manual, and documentations.

Literature files used and will be used in future work include:

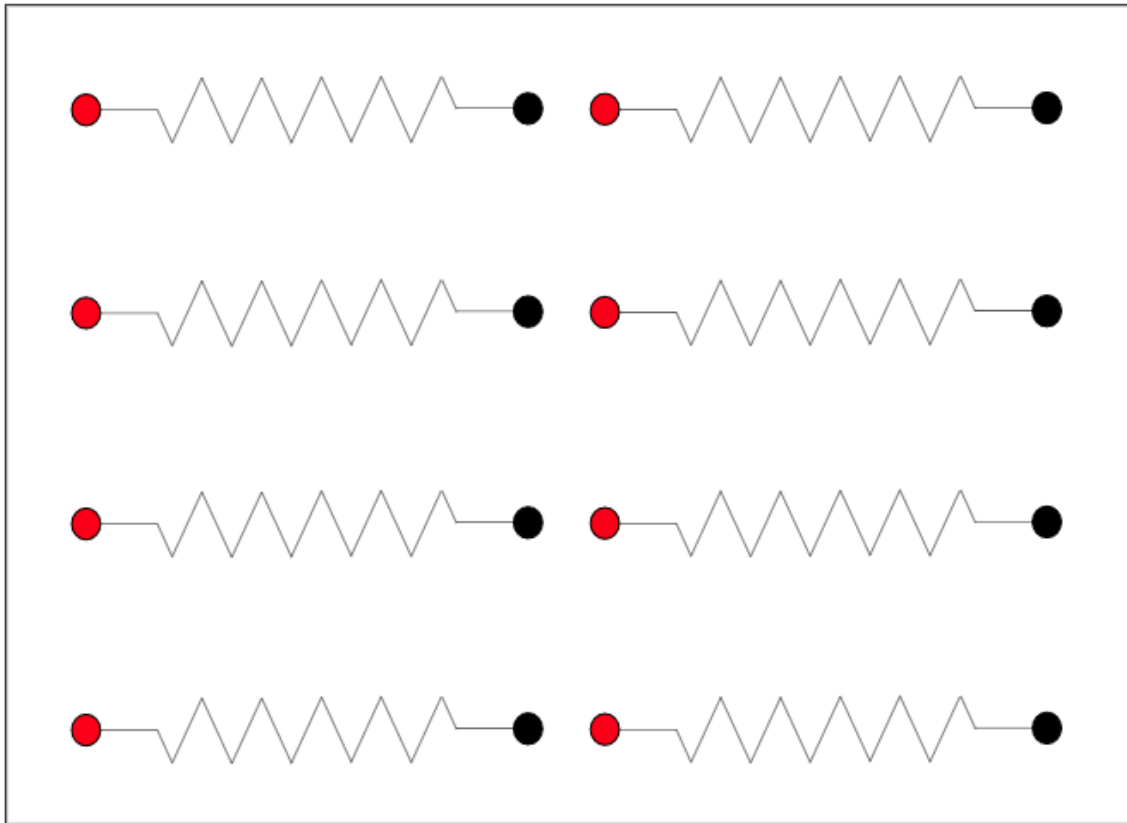
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## 4.3 APPENDICES

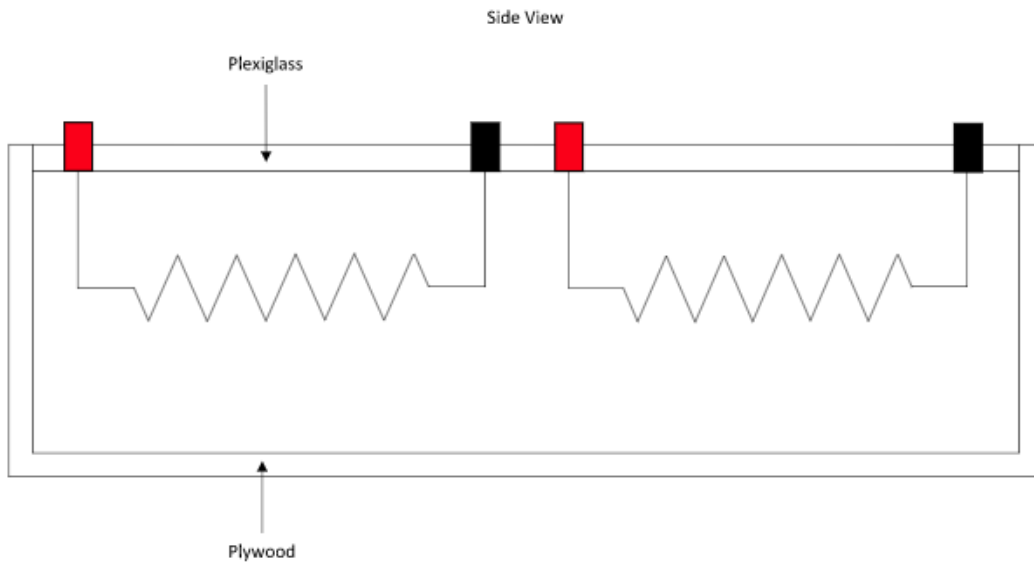
The following is the Gantt chart for project timeline. For better viewing use the following link to access the excel file from Team website. <https://sddec18-19.sd.ece.iastate.edu/docs.html>



Below is the model for the resistor bank from the top view and side view



(Figure 3: Diagram of Resistor Bank Top down view)



(Figure 4: Diagram of Resistor Bank Side view)