Small Scale Stand Alone Hybrid Solar PV Energy Generation

Project Plan

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Ω: Ohm

List of Definitions

AC: Alternating Current
DC: Direct Current
GFX: Graphics Effect
IEEE: Institute of Electrical and Electronics Engineers
LCD: Liquid Crystal Display
MPPT: Maximum Power Point Tracking
PV: Photovoltaic
TFT: Thin Film Transistor
ETG: Engineering Technology Group

1. Introduction

1.1 Acknowledgment

Our team acknowledges the two previous senior design teams who have worked on this project before us. Their documentation of the status of the project along with their references in the final documentation made it easy for our team to learn about the stand alone hybrid solar PV system. Further acknowledgement goes to Dr. Ajjarapu, who will help our team with funding, equipment, and lab space for the system. Finally, we acknowledge Pranav Sharma, a graduate student who also serves as Dr. Ajjarapu's assistant, who will be providing our team with technical guidance and suggestions in regards to the technology involved in the project.

1.2 Problem Statement

The problem that our team is working to resolve is the completion of the EE 452 Solar Power Lab. The previous senior design groups that worked with Dr. Ajjarapu put most components in place; our first job is to review the work that they have already done and facilitate lab operation.

Another issue the team will have to address is the wasted wattage that the PV system is producing. Our team will need to make use of this excess wattage by implementing a useful load. The previous team added a train to the system, but this only used 5 Watts out of the 270 Watt potential of the solar panel.

The second problem the team will be addressing is safety and stability while planning for future additions.

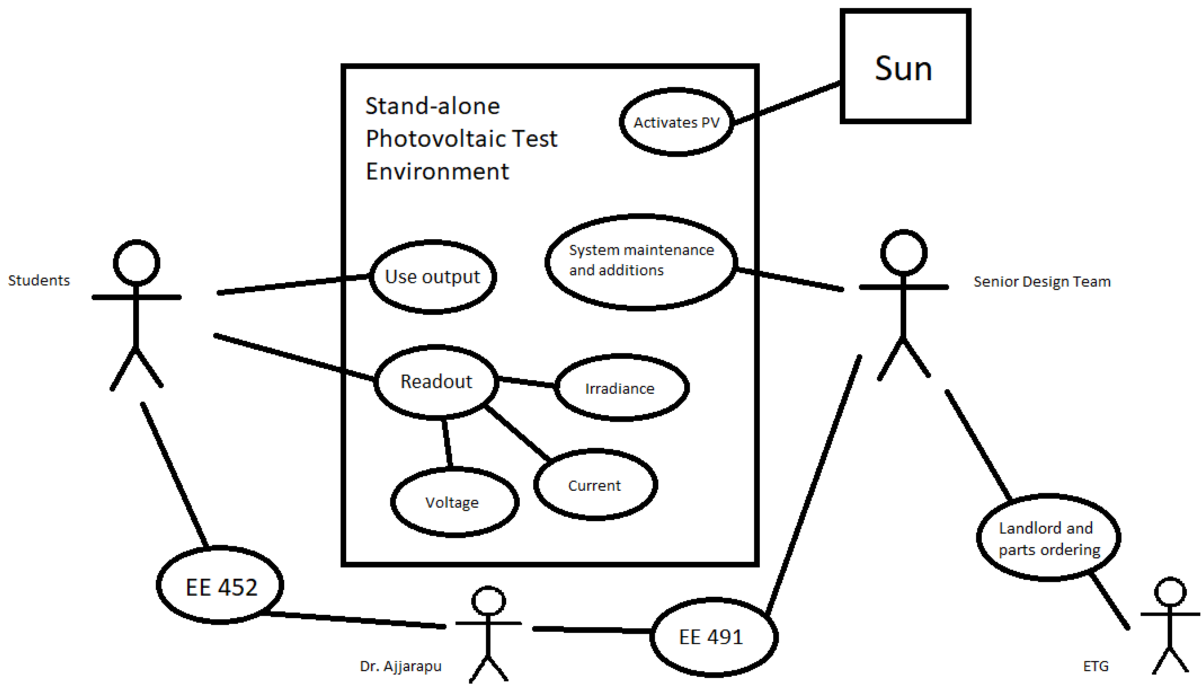

Figure 1: Use case diagram showing interactions between stakeholders

1.3 Operating environment

The entire project will take place in Coover 1102, the power electronic drives lab. This lab contains electrical measurements tools, electrical kits, and computer terminals. It is used mainly by students taking EE 452. There are spare components that are available near the system that our team will be able to utilize if necessary. The PV panel is located in the courtyard of Coover, with a connection running into the building. The rest of the components of the system are on metal shelves in the corner of the lab. This is where our team will be doing most of our work. A challenge posed by this is that the operating environment gives our team limited space to maneuver.

Safety is the highest priority of all members, since the solar panel in the system is capable of providing 270 Watts and could potentially be deadly. Our team intends to work on the project in pairs at all times. This will give our team enough space to operate while providing oversight, and thus be safe.

1.4 Intended user(s) and intended use(s)

The project's members as well as future students enrolling in the EE 452 course will be asked to use this system in order to better understand how a PV system works. Professors and teaching assistants will also be users of this system and may need to make adjustments to the lab in order to include specific ideas taught in class. This system could also be used by anyone who is interested in adding renewable energy to their business or home.

1.5 Assumptions and limitations

One assumption we are making is that the solar panel will provide enough power for the load that we choose. We are also assuming that the batteries will provide power in the evening when the solar panel is unable to generate power. Lastly we are assuming that the purchased inverter with function properly. The most prominent limitation is that the end product must fit on the shelves provided in the EE 452 lab. This includes three shelves as well as a larger table surface.

1.6 Deliverables

1.6.1 Workstation

The workstation will be placed on a bench that is only used for the lab. This will include the enclosure for the circuitry created by previous groups and modified by our own. This enclosure includes: LCD screens used to tell the operator the irradiance, voltage, current, and temperature experienced by the solar panels. The enclosure is a redesign of the previous workstation first completed by the original senior design group and then revised by the second group. The enclosure will be revised/added to by our team and again be set up to allow for future expansion.

1.6.2 Schematic of Circuitry

Schematics have been created by previous groups and more will be added showing all the new components and wiring installed by our group. This is to ensure that there is no confusion in students seeking to improve and expand upon the system. This will also allow students and operators to clearly and intuitively understand how the system functions, and how each component relates.

1.6.3 Lab Manuals

A revised lab manual of experiments will include step-by-step instructions of how to use components of the workstation, the purpose of the lab, and the underlying theories learned in class that allow students to place their knowledge in an experimental environment. It will be noted that experiments will vary due to the exposure of sunlight during the experiment. Exposure of sunlight will be dependent on the current weather conditions and times of the day. Due to labs being at different times during the day, it needs to be noted that operators will have varying results due to these unpredictable conditions. Lastly, there will be operating system guidelines included with the lab so that operators are able to understand how each component works, and to avoid damaging the equipment and hurting themselves.

1.6.4 Resistor Box

The existing resistor box contains 8 resistors with nominal resistances of 1, 2, 5, 16, 25, 100, 150 and 200 ohms. Each resistor is labeled for ease of operation. This ensures that operators have enough varying resistance values to fully graph the maximum power point curve and find the resistance value associated with the maximum power point for the current weather conditions. The resistor box is intended to help reduce the amount of wires needed to get certain resistor values and allows for more intuitive understanding of what resistors are being connected in series or in parallel.

1.6.5 Expected End Product

The expected end product of the system will have additional solar panel(s) and an additional battery. Our team also intends to create/use a different load instead of the current resistor box, since the power consumed by the box is not productive besides getting readings for a lab experiment. Lastly, our team will research possibilities for adding wind generation to the system for future teams to develop.

2. Proposed Approach and Statement of Work

2.1 Objective of the Task

The final objective of the project is to create a stand-alone photovoltaic and wind energy system for use in the EE 452 course lab. This is an ongoing project; our team has the task of troubleshooting issues with the existing equipment with a focus on safety and usability. As shown in the figure below, there are multiple objective paths that can take place simultaneously. The red lines denote what was done by previous teams, while the blue lines show our teams planned tasks.

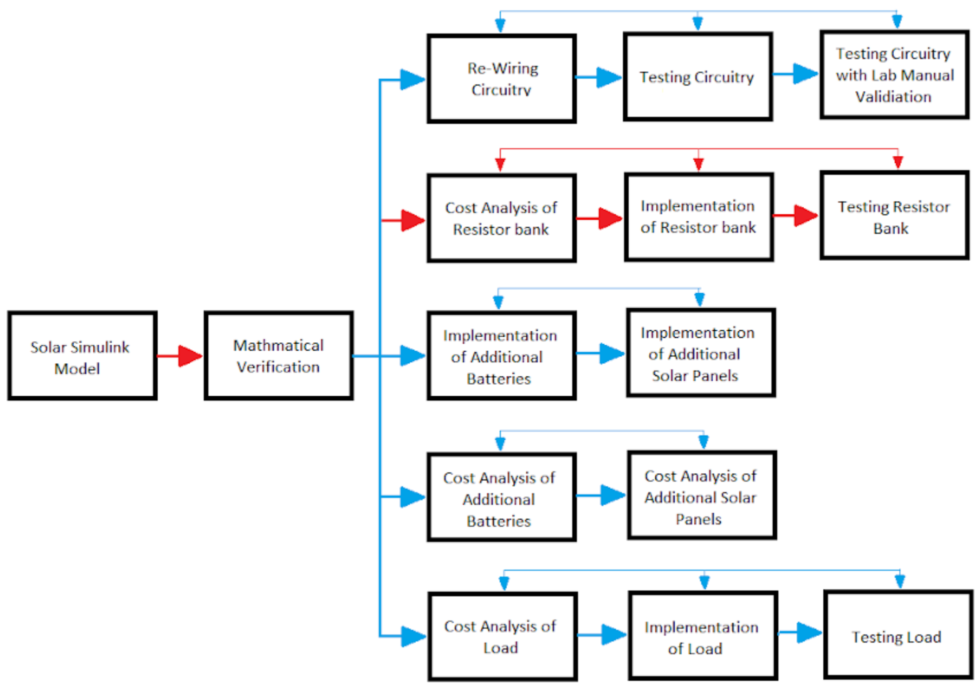

Figure 2: Objective flowchart showing completed tasks (red) and current tasks (blue)

2.2 Functional Requirements

The functional requirements of this project include connecting the existing system along with the additions made by our group in a manner that is safe for operators to use for lab experiments. Using what the previous groups completed and our own additions, the system will need to be tested in a safe environment. This is to protect both our group and the equipment.

Our team will attempt to procure a new load which can fully model the functionality of the solar panels and MPPT while providing some sort of use to prevent waste and improve lab application. We will also test and evaluate the interactive interface that allows operators to see what is happening within the system while using different loads. Adjustments will be made where needed. The interface includes the displays showing voltage, current, and power at different points in the system. The areas of focus are solar input, battery input, MPPT input, MPPT output, DC output, and AC output. An implementation of a new load will allow operators to test the maximum power point found in the lab.

When these requirements are met our team will research wind generation in a stand alone system. We will attempt to provide useful information for future groups to add a wind generator to the system.

2.3 Constraints Consideration

Our team must consider the unique constraints on the project. Perhaps the most noticeable constraint is sunlight. The PV array will not produce significant amperage without sunlight. The project will not function on cloudy days, mornings, and nights with voltage from the array. Second, our team is not the first to work on the project, and we are required to work using the final product of the previous team. This product has usability and safety issues that our team will correct. Another key constraint is parts. Any addition we design will need to be ordered through the Engineering Technology Group in Coover Hall and need to be approved by Dr. Ajjarapu. Finally, we must adhere to IEEE standards as this is an engineering project and must be undertaken in a professional manner. Of the general standards, the wellbeing of our users and respect for client property are most relevant.

2.4 IEEE Standards

There are a variety of standards that apply to this project. Since solar energy is a rapidly growing concept and is making noticeable improvements to renewable energy sources in the industry, standards are always being refined and developed. There are several IEEE guides and recommended practices that pertain to this project:

1. IEEE Recommended Practice for Testing Insulation Resistance of Electricity outlines the process of testing the insulation resistance of polarized machine windings. It goes into definitions, reasoning for importance, testing conditions and procedures, and expected outcome of different systems.
2. IEEE Guide for Insulation maintenance of Electric Machines is an overview of the standard procedure that goes into testing and maintaining different electric machines. It is focused around how one can prevent problems or how to solve issues as they arise.
3. IEEE Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems is focused on providing a structure for determining the battery capacity needed to have an independent PV system. It also covers a lot of definitions, and information on what it will take to have a PV as your only power source with batteries as your storage.
4. IEEE Guide for Selecting, Charging, Testing, and Evaluating Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV Systems) mainly discusses lead-acid battery charging requirements in relation to operational parameters of the PV system and battery performance. It

provides a guideline to select and test the battery. It also gives very thorough descriptions of hazards that can occur when handling batteries, how to prevent these problems, and how to deal with situations when a problem does occur.

If the project were to cease to be stand-alone and connect to the grid, then the standards of importing solar energy to the grid by the City of Ames would apply. Existing local, state, and federal code makes it unlikely that the standards above will apply exactly outside of a classroom setting; it is important that students learn about IEEE standards and follow them to ensure safety and ethics in the classroom as well as in the field. Safety of operators comes first, and it is our responsibility to ensure that safety throughout use of the project.

2.5 Hardware/software Platforms

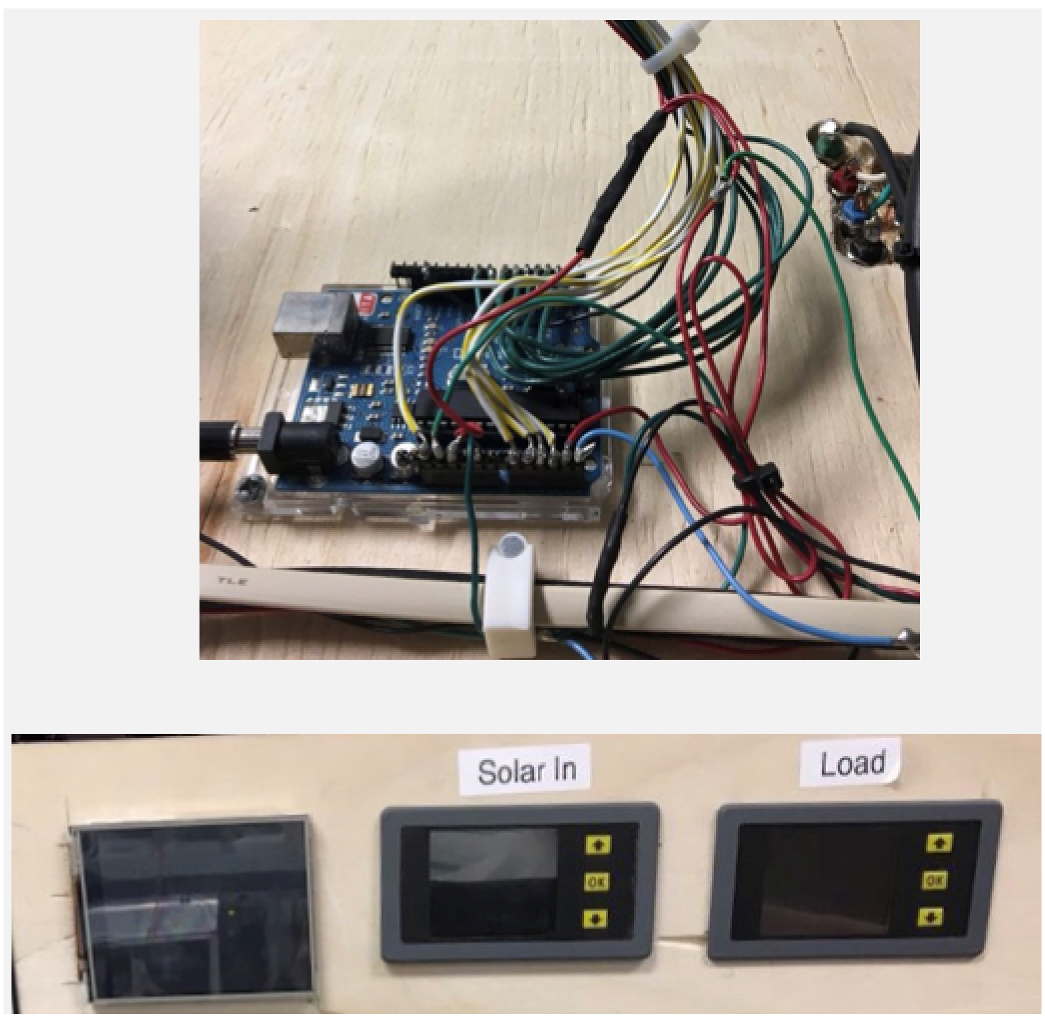

Figure 3: Arduino wiring (above). Irradiance and temperature, solar in, and load displays (below).

- Current setup includes an Arduino connected to a thermometer and pyranometer.
- Data is stored and displayed using 2 libraries (GFX and TFT LCD).
- A TFT LCD screen displays the irradiance and temperature.
- 2 other displays receive and display data from the multimeters.
- Solar Panel characteristics and load characteristics for an AC load are also displayed

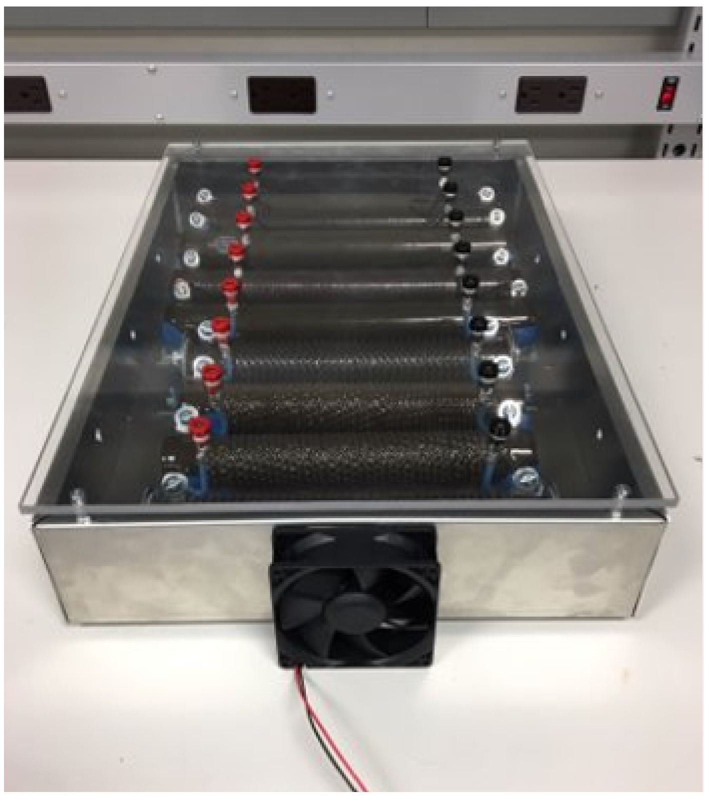

Figure 4: Resistor bank used as load

Resistors Load specifications:

- Aluminum Enclosure 17" x 2"
- Resistors: 8" x 2" and 10" x 2"
- Resistance Needed: 0.5Ω - 200Ω
- Current Power Rating: 300 W
- Resistor Values: 1, 2, 5, 16, 25, 100, 150, 200 Ω
- Provides Max Resistance: 499 Ω
- Provides Min Resistance: 0.54 Ω

Figure 5: An overhead view of the enclosure

Circuit Safety Design

- Fully Enclosed Circuit Container
- Locking Access Panel
- Wire Management, and High Voltage Isolation
- Circuit Breaker to Disconnect Solar Panels
- Wire Insulation
- Grounding the Ground Rail

The software portion of the system uses modelations in simulink. The previous team has modeled the system and its specifications. Below are the provided modules:

- Booster_Inverter_Combo
- Complet System
- PV_cell
- PV_cell_array
- MPPT _Battery_ Controller
- MPPT_Manual
- Resistive_Load_Only

2.6 Safety Considerations

Safety is a large part of our project. A standalone solar PV system has potential risks as there can be up to 270 Watts of power flowing through the devices and into the load. With up to 15 Amperes of current, touching an open terminal can seriously harm a person and even possibly be fatal. Last year's group was able to make their design relatively secure and safe. Even so, emphasis will be put on covering any open terminals and making sure the operators do not have access to dangerously large amounts of electrical power. One important safety issue is the batteries location, 2 batteries with a total of approximately 25 V are setting on the same table with other components and can cause a huge spark if their terminals get shorted. We will need to place the batteries underneath the table or on a shelf away from the area where students will be directly working. Another issue is the wiring. We will need to work with the ETG to rewire the input cable so that the irradiance wires are brought directly into the box to improve safety.

2.7 Previous work, Market Survey, and Literature

A large focus of this project is to design and implement a hybrid solar and wind stand-alone PV system. Dr. Ajjarapu has stated that the focus is to mainly be on the solar energy system aspect of the design. However, wind energy design remains a possibility for the second part of the senior design course (Fall 2019). In light of this our focus is on the implementation of solar energy, cleaning up the circuitry, implementing a new workspace, finding a beneficial use of the power generated and using a resistor box that allows students to graph the maximum power point curve accurately through experimentation.

The PV power project has been used in many fields. Homeowners and businesses are implementing PV power residentially and commercially. Our team's job is to not only build/improve the PV system but also to track the maximum power generated. This is what makes the project different from the market products.

There were two previous groups working on this project in past semesters. Our team has taken up the project starting spring 2019. These transitions of the work have impacts on the current group. The positive impact is the completion of the soft/hard ware, as a great percentage of the installation work is already done. Most of the components needed are installed in the lab and only require connections. The simulink diagram is ready to simulate and run once the project's components are connected.

On the other hand, transferring ideas and files back and forth from group to group may have caused dilution in information. Our team will attempt to implement and follow the work of two previous groups, which relies heavily on the quality of existing documentation.

2.8 Possible Risk and Risk Management

The risks affecting the solar project appear throughout the entire project lifetime, but vary greatly in character. Here are some examples:

- Construction risk: Risk of PV installation or liability stemming from errors during the building of PV arrays, however, those panels have been installed in Coover hall since 2010.
- Future risk: Risk affecting the viability of the project developer, for example, risks related to key personnel, financial solidity and technical ability to expand the system in the future.
- Environmental risk: Risk of environmental damage that could cause any physical or functional damage to the PV arrays.
- Market risk: Risk of a cost increases for key input factors such as lack of resources, equipment damages or component failures.
- Technology risk: Risk of components generating less electricity over time than expected.
- Political and regulatory risk: Risk of a change in policy that may affect the profitability of the project. Solar projects are under a huge debate at the moment.
- Climate and weather risk: Risk of changes in electricity generation due to lack of sunshine or snow covering solar panels for long periods of time.

The risks above have been generated and inspired by the Renewable Energy World Organization.

Risks that directly involve students include:

- Workstation needs to be clean, organized, labeled correctly, safe, dependable, and allow for future expansions.
- Lab manual needs to be concise, intuitive, organized, and follow information learned from course lectures. Lab needs to be able to be completed in the 3-hour time frame. Students need to fully understand underlying safety hazards. Topics of the lab are to pertain to solar power energy systems, theory of maximum power point tracking, PV cells, buck/boost converters, and the effects of solar irradiance and temperature experienced by the solar panel.

- Control panel and resistor box need to be fully labeled with corresponding resistor values and be secured in a location with ease of access in the workstation.
- All simulations in Simulink should be organized and reflect the physical hardware.

2.9 Proposed Design

This project, as previously mentioned, is a continuation of previous groups' work. Our first task is to debug and fix the previous groups work on the project and get the overall system functioning for the EE 452 lab. First we must test and measure the voltages across several components to determine if the connections were properly installed. From a conversation with a previous group member we are aware of some potential problems with the system already - one being a dead 12V battery and another being a potentially failed breaker. Our team must work to ensure the connections are safe and functional in order for students to use the system for lab experiments at the end of April 2019. There are several lab experiments that we will be finalizing and editing as well as creating a answer key for the lab instructor. Our goal will be to make the lab instructions as organized, clear, and concise so that students can maximize their time learning about how the system works. This will also help this lab to run smoothly in future years.

The second half of this project will be finalizing the current set up, improving safety of the system, as well as designing and implementing a more useful way to use the wattage from the system when a lab is not in session. The following is a list containing more details for the second portion of this project:

1. Testing and updating the workstation to insure safety for students who will be using it for future labs.
2. Adding inverter to the system in order to add three phase power to the lab setup.
3. Rewiring the input power to the lab for EE452 to allow the solar panels to be moved. Currently the solar panels are located in the courtyard of Coover and are placed in a position that is completely shaded by four pm. Longer cables outside will allow for the solar panels to be moved to a location with a longer period of sunlight.
4. Making a schematic of the overall system circuitry so that future students can understand what each component does and how it work.
5. Designing and implementing a practical way to use the wattage produced by the system when lab is not in session.

Our design for using the wasted wattage produced by the system is a charging station that can be used to charge things like phones and calculators. The idea is that the station would display the current voltage, current, irradiance, and temperature from the system which would allow students to see a real time use of solar energy. An advantage of implementing this would be to show a more real life application for the system. Something that we will need to improve is the fact that if we do this there will still be using the full wattage produced by the panels.

2.10 Task Approach

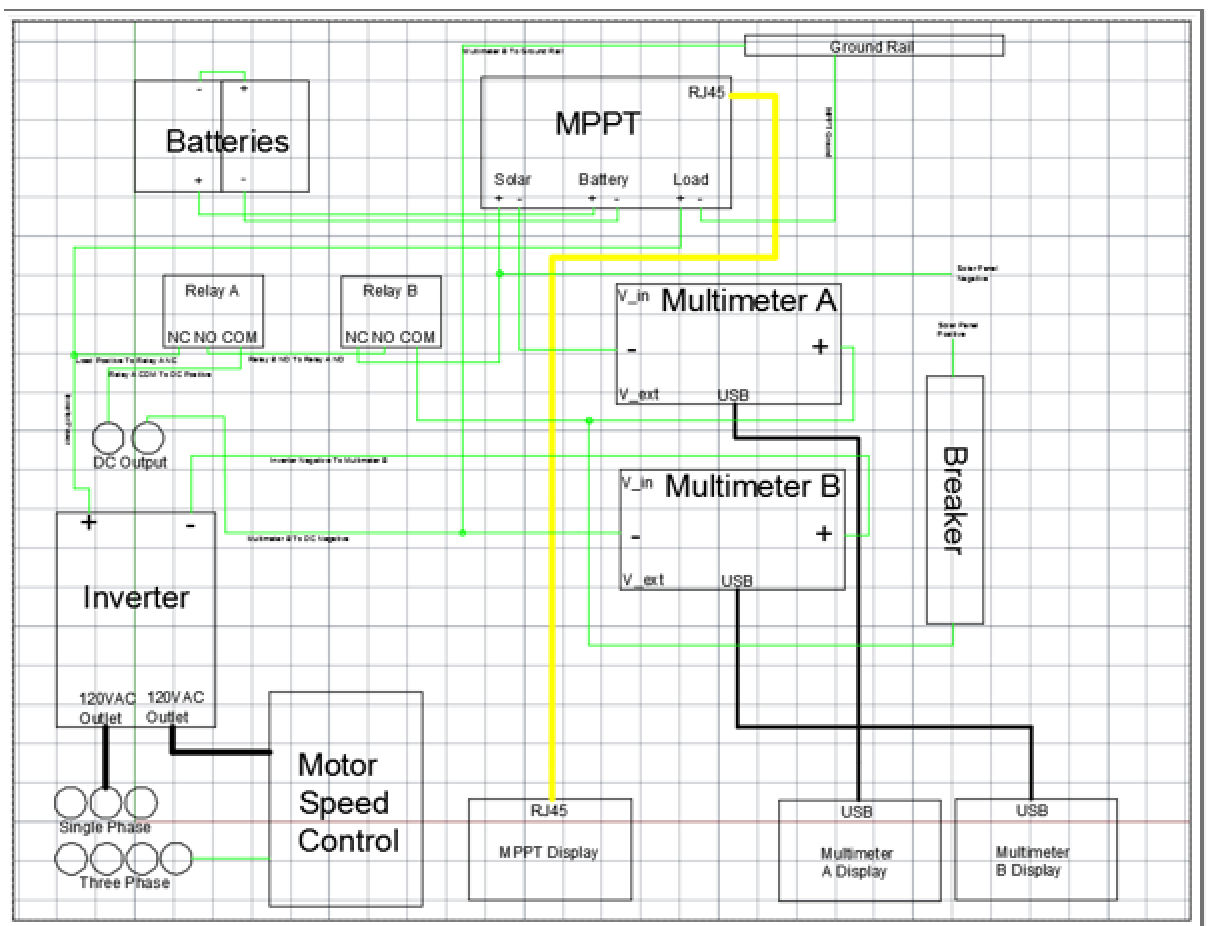

Figure 6: Enclosure circuitry design

2.11 Test Plan

Our project must produce DC voltage at terminals. This can be tested with a multimeter. Our project must be properly grounded, and have no accessible points with voltage other than terminals. This is difficult to test, and relies heavily on proper connections and safety considerations. A multimeter probe will also be used to test this. Must be easy to turn off in case of emergency. This will be tested with breaker additions and flipping of switches. Must be useable throughout the day. This can be tested by checking voltage at all points during the day. Must produce readouts that match with physics. This can be verified through our simulation and mathematical calculations. Must be able to run labs (safe, useable, accurate). This will be tested both on the members of our group, students taking the lab, and also unrelated parties pulled in for testing.

3. Estimated Resources, Project Timeline, and Closure Materials

3.1 Financial Requirements

OVERALL COST ANALYSIS:
The overall cost of the implementation of the workstation and the resistor box is:

- 1-ohm Resistor: $21.83
- 2-ohm Resistor: $24.32
- 5-ohm Resistor: $24.32
- 16-ohm Resistor: $21.83
- 25-ohm Resistor: $42.10
- 100 ohm Resistor: $25.10
- 150-ohm Resistor: $35.59
- 200-ohm Resistor: $25.29
- Circuit Breaker: $19.19 and $20.19 x 2
- Arduino Uno Rev3: $22.00 x 2
- Banana Pins: $.65 x 24
- Fan: $5.87 x 3
- Digital Multimeter: $19.99
- Terminal Blocks: $5.60 x 4
- Resistor Clips: $.63 x 8, $1.36 x 6, and $9.10 x 2
- Resistor Enclosure: $38.96
- Circuitry Enclosure: $53.70
- Buck Boost: $44.99
- **Overall Cost: $568.6**

For future expansion of the current system, the cost of additional solar panels and batteries are as follows:

- Solar Panels: $350.00 x 2 (depending on brands and specifications)

Batteries $45.98 x 3 (One battery has been replaced)
Additional Load: TBD
Overall cost of additional parts: $837.94 + Additional Load

Note: With expansion of the system, existing hardware and limitations will need to be considered. For example, additional solar panels will increase the power provided by the system. However, all other components should be considered when the system expands.

3.2 Project Timeline

This project essentially has two different deadlines for two tasks. The first task that the team is currently working on has a deadline in the first semester. The goal is to fix the current PV system that has been left by the previous group. The second task, planned for the second semester, is to add more safety features and a useful load instead of several resistors to the working PV system. These new loads don't necessarily need to be used for experiments in the EE 452 lab, but instead used directly for utility.

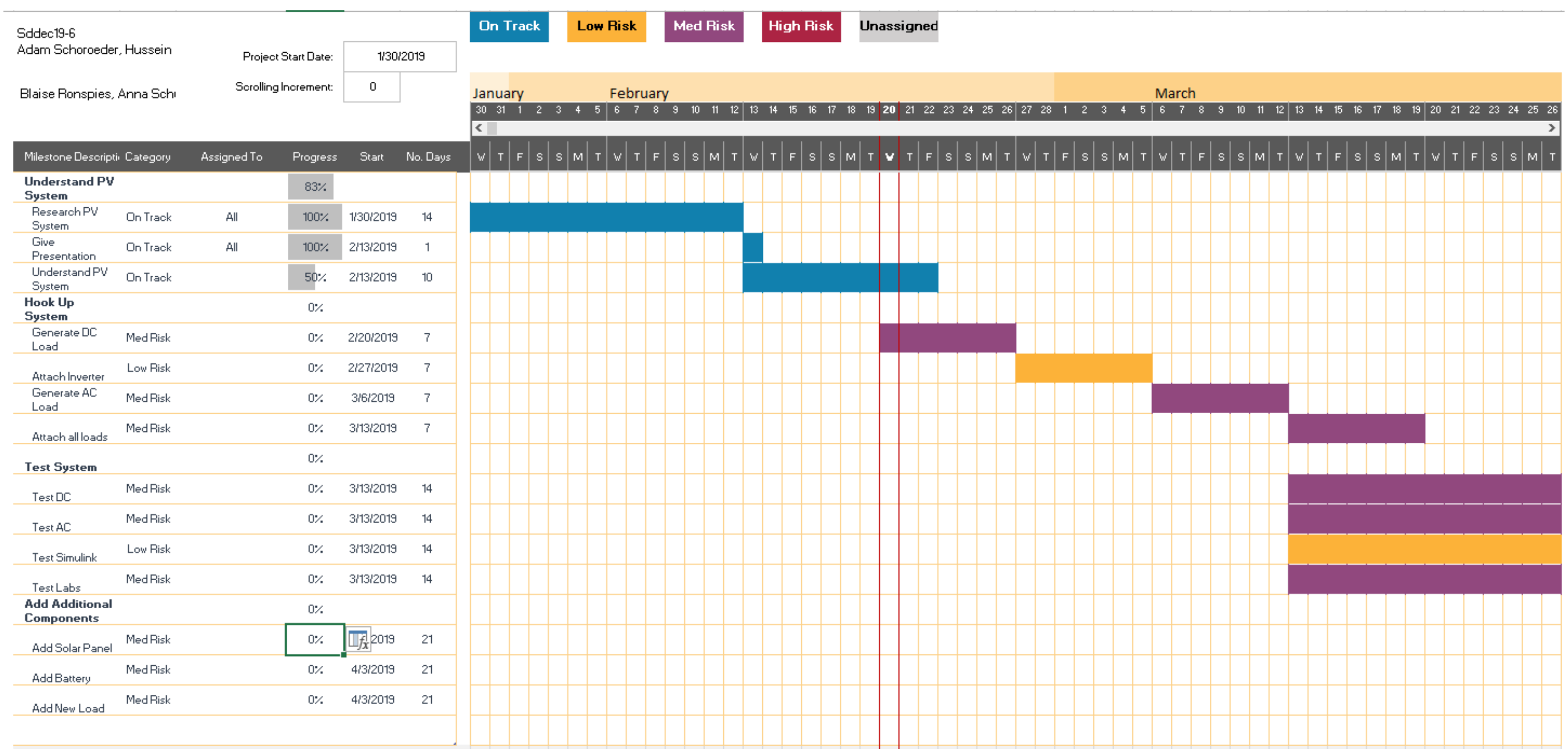

Figure 7: First semester timeline

The beginning of the timeline of the first task is taking the time to fully understand the PV system itself before beginning work. The rest of the semester is reserved for fixing current issues with the system and ensuring that the lab experiments created by the previous group can be run by current students in EE 452. This needs to be completed by the current semester since Iowa State only offers this class in the spring semester, and EE 452 is what this senior design project is for.

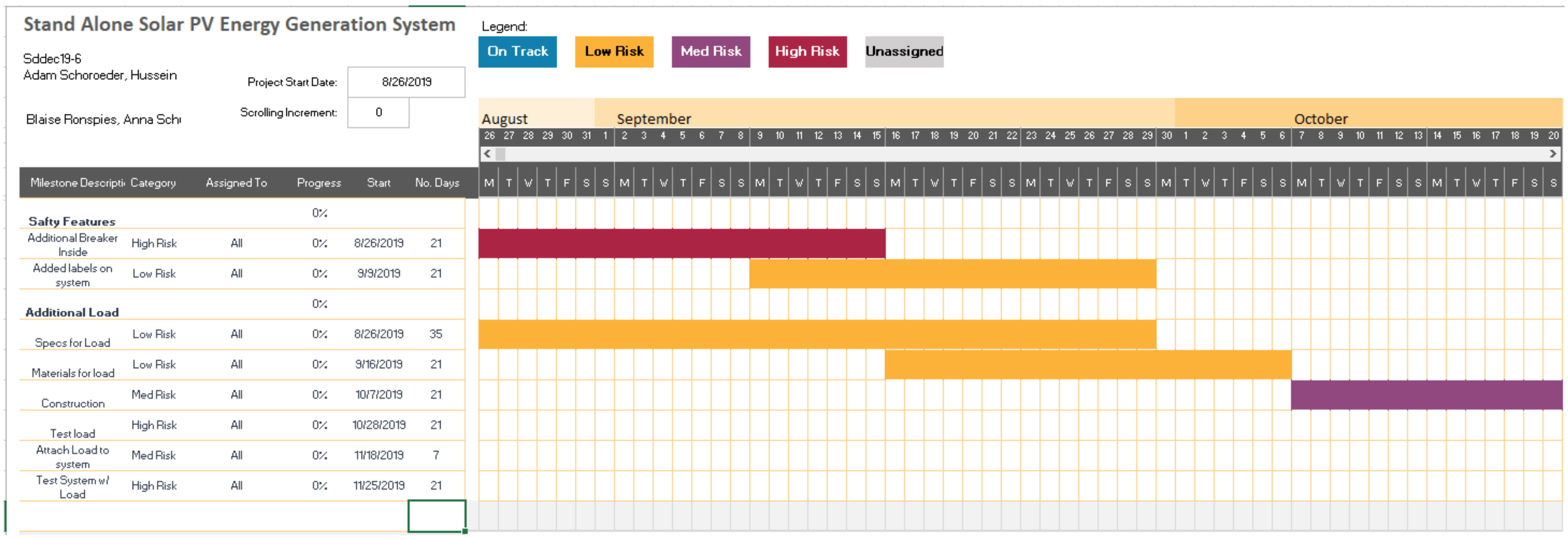

Figure 8: Timeline for second semester

The beginning of the timeline for the second semester is focused on what our team can add to the PV system to make it more safe, and useful for students. Starting with safety by adding an additional breaker for the batteries that are connected to the system and physical labeling for students to correctly identify the functions of switches. Later researching for specs for adding on an additional load and the construction and installation of said load.

3.3 Closing Statement

The project plan was to redesign the workstation to be simple, organized, and safe. The workstation also needed to facilitate expansion by future design groups. A schematic of the overall layout of each component in the circuitry needed to be drawn so that future design groups have a better understanding of the system. Another goal was to create an enclosure that was organized and safe for operators in order to prevent tampering with the circuitry. This also created a more organized workstation. Our project should allow future design groups to intuitively understand the system. Though PV technology use is growing rapidly throughout the world, this project explains the whole process step by step for an inexperienced user with only a limited knowledge of engineering in general.

3.4 References

Anca D. Hensen, Poul Sorensen, Lars H. Hansen, Henrik Binner, “Models for a Stand-Alone PV System”, *Riso National laboratory*, Roskilde, pp. 1-78, 2000.

Worren, Jon. “Assessing the Risks in Solar Project Development.” Renewable Energy World, 8 Feb. 2012 www.renewableenergyworld.com/articles/2012/02/assessing-the-risks-in-solar-project-d evelopment.html.

Wassenaar, Drew, et al. “Design and Implementation of a Small Scale Standalone Hybrid Solar PV and Wind Energy System.” file:///C:/Users/annalaree/Desktop/Senior%20Design/Senior%20Design%20Deliverables/Fall%202018%20Final%20Deliverables/Final%20Documentation.pdf