Solar Powered Energy Storage: Preliminary Design Report

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Version 1.00
12/09/22

History of Document

- **Version 1.00** (12/09/22) – Initial document created

Executive Summary

The purpose of this project is to simulate, construct, and demonstrate a proof-of-concept design to show how a solar-powered energy storage system can be used to facilitate the repurposing of a growing number of used electric vehicle batteries, while also providing a solution to power generation companies during times of peak energy consumption. Our design will feature a solar panel as the main source of energy along with a battery which will be used together to provide AC power. The main requirements for this project include a 48 V Lithium-Ion battery for energy storage, a system that can produce 110 V Single-Phase AC output voltage and deliver 500 W of output power to a load, a visual display showing the state-of-health (SOC) of the battery over time, and a 195 W solar panel for battery charging with the ability to supply power directly to the load. In this report, we hope to provide a clear, detailed overview of our plan to meet these goals while also explaining in more detail the various components that will be used to create this solar-powered energy storage system.

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Problem Statement and Background

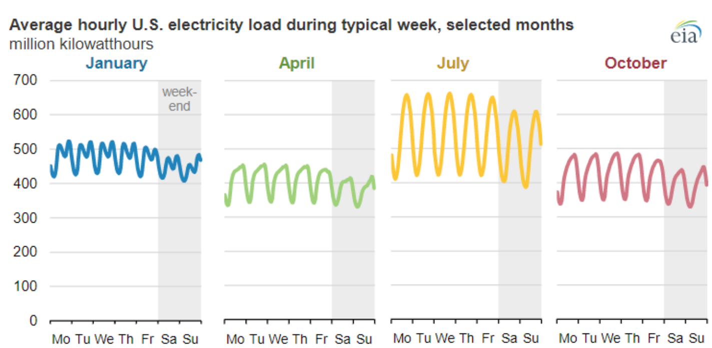
Electric vehicles (EVs) are becoming increasingly popular in the US and sales have grown drastically in the past decade. The federal government has set a goal that 50% of new vehicle sales be EVs by 2030 [1]. If this happens, there will be around 48 million EVs on the road by 2030 [1]. While EVs have many benefits over gas vehicles, such as decreased carbon emissions and lower lifetime operating and maintenance costs, they present some challenges as well.

First, EV batteries are often replaced when they reach about 80% of their original charge capacity. This is because unlike hybrid models, pure EVs run totally off of power from the battery. Thus, the range of the vehicle is limited by the charging capacity of the battery. When these batteries are replaced at 80% charge capacity, it will produce a stockpile of spare batteries that still have a useful life left and need to be repurposed or recycled.

The second challenge presented by the growing number of EVs is that the existing electric grid infrastructure in the US is not currently equipped to handle a jump to 48 million active EVs by 2030. Studies have shown that the energy produced by the electric grid would need to increase from 11 billion kWh to 230 billion kWh to meet the demand [1].

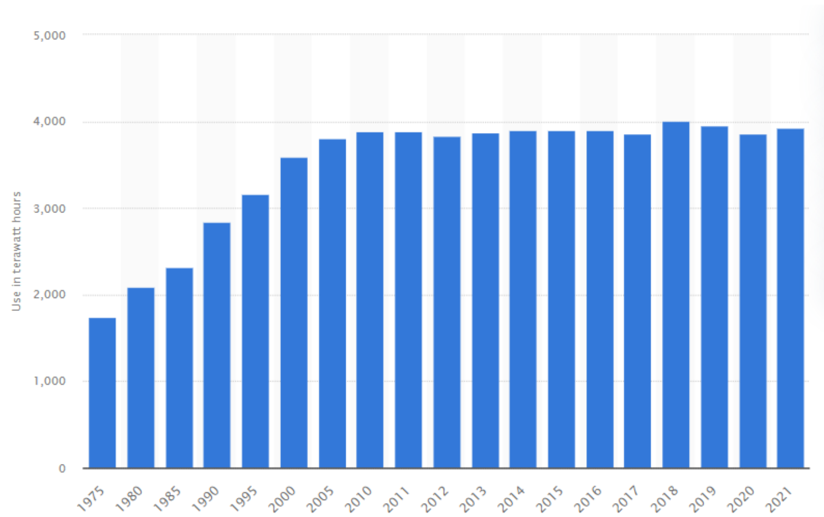
The design of our project will address both of these concerns by repurposing used EV batteries and using them in conjunction with solar energy to create an energy storage device that can be used to power the grid. Our target market for this project includes EV manufacturers and power generation companies. EV manufacturers could benefit from our design by having a useful product that could be created from repurposed EV batteries, and power generation companies could increase the efficiency of their operations by using this energy storage method in times of peak load or as a backup during outages.

With the increased demand for electricity in the United States, peak power consumption has become a problem. Peak power demand refers to the highest amount of energy used within a given time period. Peak hours vary across the United States depending on the region of the country, the season, and time of day. Generally, fall and spring months require less power due to comfortable temperatures, but summer and winter are the most strenuous on the grid as we fight the extreme temperature with air conditioning. Time of day is also a contributing factor to peak demand hours. Highest demand is usually around 6:00am -7:00am and 5:00pm -7:00pm, relating to the typical work schedule. Peak hour demand can be seen in Figure 1 below.



[2]

Figure 1: Average Hourly Electricity Load During a Typical Week in the US



[3]

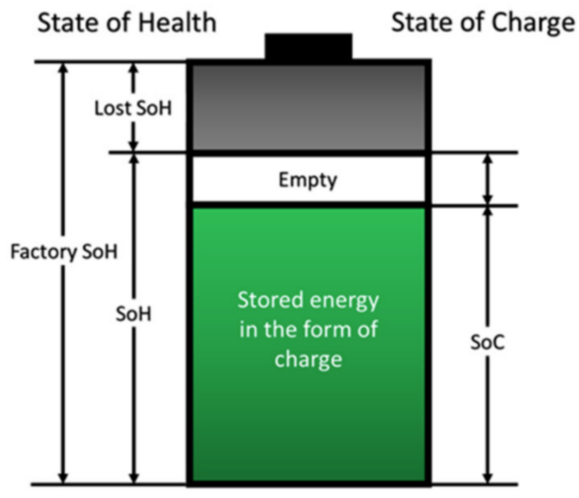
Figure 2: Annual Power Use in the US

Annually in the United States, we use just below 4,000 TWh a year as seen in Figure 2 above, and in Tennessee, Tennessee Valley Authority (TVA) generates roughly 22,000 MWh a year [4]. With this increase in demand on the grid, we need to become more efficient and more conservative with our power. One way this can be done is by using battery energy storage systems (B.E.S.S). By using B.E.S.S., energy can be supplied in emergency situations and the grid can be relieved at peak hours for short periods of time. One example of this type of system is TVA's Vonore B.E.S.S. station, which is currently in its early stages of development. This battery storage system will be able to store up to 40 MWh, and has the capability to power 10,600 homes for 3 hours [5].


[5]

Figure 3: TVA's Vonore B.E.S.S. Project Located in Vonore, Tennessee

We can accomplish something similar to this with recycled and repurposed EV batteries. Lithium-Ion batteries are popular for electric vehicle and hybrid use. There are many things to consider for these refurbished and repurposed batteries, especially their state of health (SOH), and their state of charge (SOC). SOH refers to a battery's ability to retain charge compared to its original factory rating. A battery's SOC refers to how much charge is left in a battery at a given time, or its capacity [6]. Accurately measuring the health and charge of the batteries is key to maintaining a constant power supply while using many batteries in various states of health and capacity.



[7]

Figure 4: Battery SOH and SOC

Requirement Specifications

The primary objective is to deliver a system for supplying AC power to a load using electrical generation from a solar panel and energy storage with a lithium-ion battery. These requirements were developed with Dr. Bai's oversight, and they represent the basic needs we are aiming to meet for this project. We are looking to provide a system where recycled EV batteries can be repurposed to store solar energy and in turn be supplied to the grid. The requirements of our project represent a proof of concept that could then be outfitted to repurpose EV batteries and scaled up for grid storage. The scale and magnitude of this project is small enough to be achievable within the time frame, but still large enough where it can be increased significantly to provide the desired amount of energy storage.

Because our project is tied to CURENT and they are providing most of our larger resources, our constraints are based on their equipment ratings, such as the solar panel and the DC/AC inverter board. Our design variables are the converters, gate drivers for MOSFET switches, and the system control using a microcontroller. For our converters, since we are using one DC/DC converter supplied by CURENT and also building one ourselves, the variation in this could play a factor in altering our output. We will use the microcontroller we purchased, an Arduino board, to supply waveforms to our circuits, while also facilitating our voltage and current measurements from the circuit. The amplitude and switching frequencies of these wave outputs will be an important design variable that we will need to consider when testing our design. Considering these variables, we have determined, with our sponsor, what our final product should be able to achieve. Table 1 shows the quantitative requirements that our project will meet. All of the engineering characteristics listed are design constraints for our project.

Table 1: Design Requirements

Item	Engineering Characteristics
Energy Storage	48 V Lithium Ion
Output Voltage	110 V Single Phase AC
Output Power	Up to 500 W delivered to the load
SOC Status Tracking	Visual Display of SOC over time
Power Generation	~100 V Solar Panel for battery charging with ability to supply power to load directly

The 48 V battery was required by our sponsor, since this is a smaller, yet proportional voltage to general EV batteries. Similar to the battery's voltage, the output voltage is also a design constraint at 110 V AC, which is the standard AC voltage in the US. Since our initial project proposal report, we had to adjust the output power of our system to 500 W to comply with the limitations of the solar panel CURENT is providing us. We will measure this using five 100 W light bulbs in series for a visual display of output power that will be able to demonstrate the amount of output power based on the intensity of light emitted. The SOC display will allow us to see the quality of the battery and track when it is charging or dissipating power. The final design requirement is that we are able to generate power through a solar panel and transfer this power to both a storage battery and the grid itself through our designed system of converters and inverters. Through these requirements, we plan to design and construct a proof of concept model that will be transferable to repurposing EV batteries for storage purposes.

Technical Approach

As mentioned briefly in the sections above, our full system design will use a solar panel in conjunction with a battery to create an AC power source capable of power outputs up to 500W. The system can be run in 4 configurations. Case 1 would occur when the battery is charged and the solar panel is actively providing a voltage output. In this case, both the solar and the battery would work together to power the AC load. In Case 2, AC power generation would be needed, but the battery does not have enough charge to provide power. Thus, the solar panel would have to power the load by itself. Case 3 would occur when the battery is charged but the solar panel could not provide an output voltage. This could happen on cloudy days or at night when there is not enough sunlight to provide adequate power to the solar panel. In this case, the battery would be the only power source to the system. Lastly, in Case 4, AC power generation is not needed and the battery voltage is low. In this case, the solar panel will be used to recharge the battery for future use. The block diagram in Figure 5 provides an illustration of the general layout of our design.

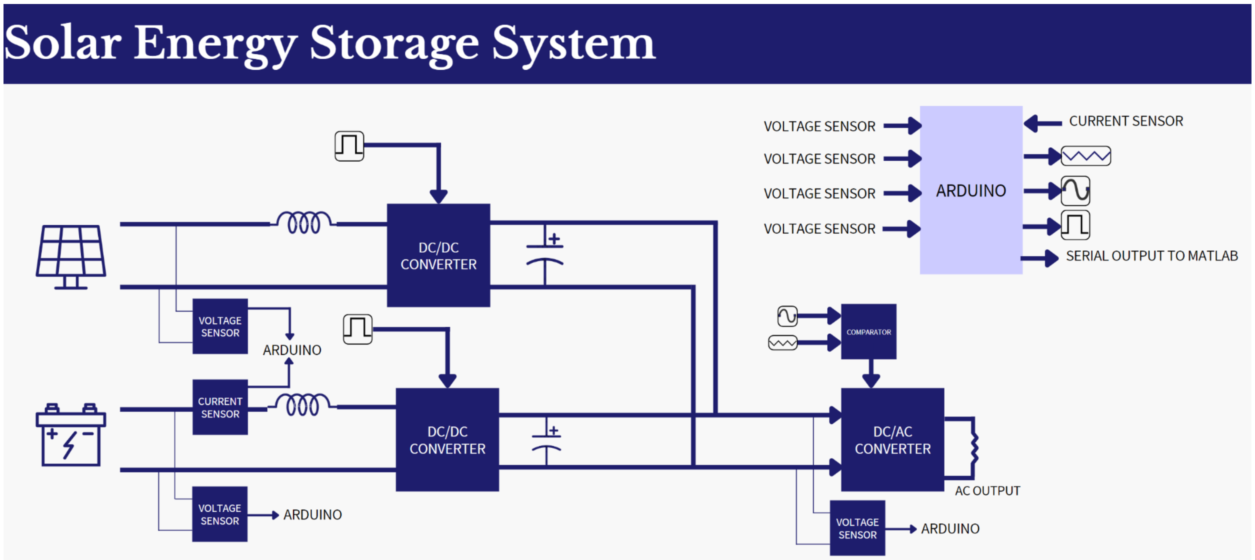


Figure 5: Block Diagram Representation for Solar Powered Energy Storage Project

As can be seen from the block diagram, two DC/DC converters will be used to provide a constant voltage to the DC bus, which is the circuit node directly to the left of the DC/AC inverter. These converters will be needed for two reasons. First, the solar panel and the battery provide unequal voltages to the system. The solar panel will provide around 55V, while the battery can only supply 48V. Second, the DC voltage needs to be boosted to around 110V to meet the requirement specifications. Thus, these two DC/DC converters will be used to equalize the voltage at the DC bus as well as to boost the DC voltage to meet project specifications.

At the right of Figure 5 is the DC/AC converter. This will be used to convert the DC voltage at the DC bus to an AC voltage which will be seen across the output load of the system. This AC output will be connected to a load during the demonstration of our system.

Another important part of our design are the voltage and current sensors. The voltage sensor at the solar panel and the battery will be used to monitor the voltage inputs to make sure they do not exceed the rated specifications for both the solar panel and the battery. These sensors will be a very important safety feature of our design, especially when the battery is charging. Overcharging a battery could cause a fire or explosion so it will be important to monitor this voltage carefully. The current sensor connected to the battery will also be a part of the safety system because it will allow us to calculate the SOC of the battery and monitor it at all times. The voltage sensor connected to the DC bus allows for the monitoring of output AC power due to the fact that the DC/AC converter has unity gain. This means that the DC voltage magnitude of the DC bus is equal to the AC voltage measured across the load.

The last part of our design is the microcontroller seen in the top right corner of the block diagram. This microcontroller will be used to monitor the inputs from the voltage and current sensors, provide waveform inputs to the switches controlling the converters, and to output data regarding SOC.

Design Decision Identification

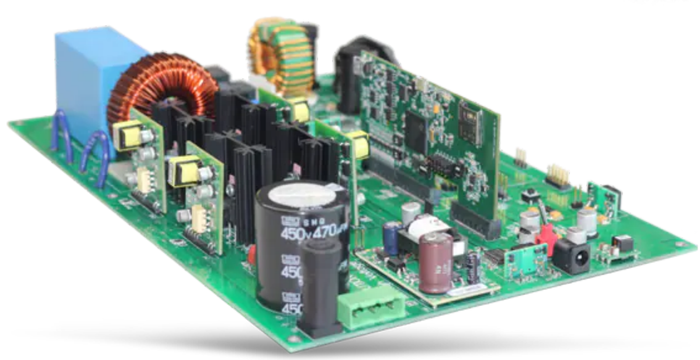
In order to begin the design process for our project, we have identified 3 major design decisions. First, 2 DC/DC converters and 1 DC/AC converter will be needed. The DC/DC converters must be able to handle 48V-60V input and 100V output, while the DC/AC must handle 100V input and output. It should also be noted that since the battery will be both charging and discharging during normal operation, the DC/DC converter at the battery must be designed such that current can flow in or out of the battery.

Second, we need to decide what to use as a load for the AC output. This load will need to be rated up to 500W and must be designed such that the magnitude of the provided output power can be illustrated. This will be very important to the success of our project when we present our final design next semester.

Finally, we need to design the data output display for the system. For example, one of the deliverables for our project is to provide a realtime SOC estimation display for the battery. To fulfill this deliverable, we will be using a microcontroller to take inputs from the voltage and current sensors and make the complex calculations needed to generate the SOC estimation data, which will then be exported from the microcontroller to the external display. This display should be designed to be user friendly and easy to read.

Design Concepts

With the major design decisions identified, we began to brainstorm and research possible design concepts that would meet the requirements and specifications of our project. First, research was conducted on the types of converters that could be used. Uni-directional converters allow current to flow in one direction, while bi-directional converters allow current to flow in or out of the system. During this research, we consulted with Dr. Bai to get his suggestions on the most effective converter type to use in the circuit. He also suggested that we consider using a converter designed by CURENT, which could be configured to provide the AC/DC converter and one of the DC/DC converters.



[8]

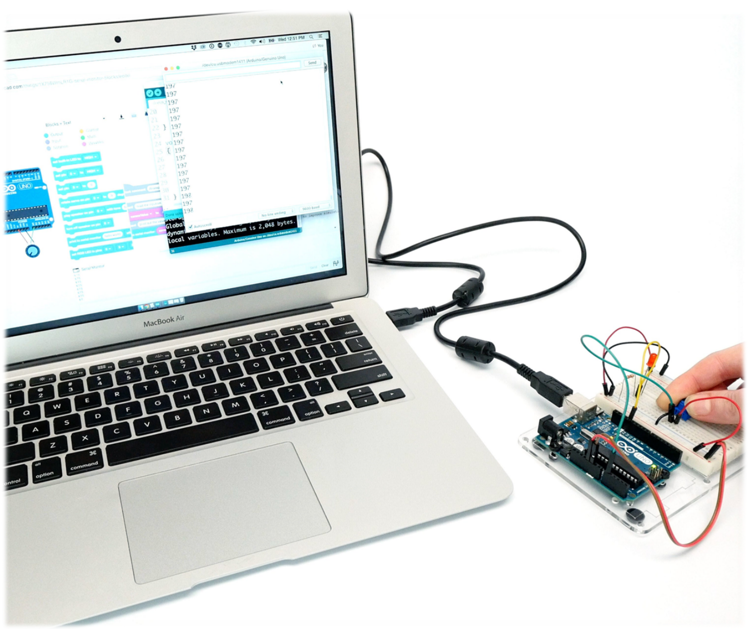
Figure 6: Example of DC/AC Inverter

For the output load design, two options were considered. First, our group considered devising a way to connect our design directly to the grid. This would steer the direction of our project towards being a demonstration of how our energy storage system could provide power to the grid during times of peak load. Second, we discussed a smaller, proof-of-concept version of our design that would use 100W light bulbs as the output load.. These light bulbs could then be connected in series with one another to demonstrate the range of power output.

[9]

Figure 7: Power Grid Distribution Systems

Lastly, we found that the best options for data output would be either a LCD display or using existing MatLab software. The LCD screen would be directly connected to the microcontroller, while MatLab software would be installed on a laptop, and then the laptop would be connected to the microcontroller.



[10]

Figure 8: Arduino Serial Monitor Applications

Concept Evaluation

For each of the design concepts discussed above, we came up with pros and cons of each so we could evaluate the possible benefits/drawbacks of each. Our last step was to create a decision matrix in the concept selection section of this report for each design decision and the corresponding possible design concepts.

Starting with the converters, we looked at each option individually to weigh their pros and cons. The unidirectional converters benefit from being simple to design, but their drawback is it would require two unidirectional converters to create the full DC/DC converter for the battery. This would increase system complexity, number of components, cost, and control needs. On the other hand, the bidirectional converters reduce the total number of converters needed for the system. The DC/DC converter for the battery could be implemented with a single bidirectional converter. The downside is this increases the complexity since bidirectional converters are more complicated compared to unidirectional ones. The last converter to be considered is the board supplied by CURENT. The board contains three pairs of switches, two of which could be used for the DC/AC inverter. The third pair of switches would be used for the battery DC/DC converter. Using this option, we would only need to construct one solar DC/DC converter instead of three. Other benefits include the free cost and the assurance of prior work that the board will function properly.

For the output load, we considered connecting our system directly to the grid or powering a light bulb. The pro of the grid connection is it formally demonstrates the purpose of the project to the full extent. However, a grid connection poses a much larger safety risk. It would be more difficult and time consuming to ensure safe operation since we are handling high voltages and high currents. The light bulb pros include simpler operation and construction, a visual indicator for showcasing output power, and ease of acquisition. The con is it limits our project's scope.

The last design concept to consider is the SOC estimation. Using an LCD display provides a visual representation of SOC estimation, but it has additional issues. We would have to program the display and plotting software. Beyond that we would also need to consider how to mount and integrate the screen within our system. On the other hand, using MATLAB on a laptop would enable us to have a high quality SOC estimation display backed by quality software. The laptop would not increase our costs since it can be provided by CURENT. MATLAB has the infrastructure we would need for plotting data as compared to programming an LCD display. The downside is that it is not a compact, independent system design.

Concept Selection

In order to select the most advantageous design options, we created three decision matrices to consider the pros and cons discussed in detail above in the design evaluation section. Figure 9 below shows the decision matrix created for the converter selection, which was our first design concept decision.

	(A) Decision to evaluate:	Types of Converters		
	Score (auto-calculated):	2	3	4
	(D) Options:	Uni-directional Converters	Bi-directional Converters	DC/AC Inverter supplied by CURENT
(B) Factors of this decision	(C) Rank of Factors (0-2)	(E) Meets need? (0 - 2)	(E) Meets need? (0 - 2)	(E) Meets need? (0 - 2)
overall design simplicity	0	0	1	2
# of converters needed	2	0	1	2
converter complexity	1	2	1	0

Provided by Zapier.com, adapted from a tool by Idea Sandbox (idea-sandbox.com) [11]

Figure 9: Decision Matrix for Converter Concept Selection

For this design concept, we needed to decide between three converter options. After considering the benefits and downsides of each one, we determined that the most important factors in this decision would be the overall design simplicity, the number of converters needed, and the converter complexity. Based on our circuit design, we determined that the number of converters needed for the project is the most important factor, followed by the converter complexity and the overall design simplicity. The first option, the unidirectional converter, definitely does not meet the need of overall design simplicity or reduce the number of converters needed. However, it does improve the converter complexity more than the other two options. Choosing bi-directional converters, the second design option, equally meets all three criteria because it would require less total converters than the unidirectional converter option, thus making the overall design more simple. However, it would be a more complex converter design to accommodate the necessary bi-directional functions. Finally, our analysis of the third option, the DC/AC inverter supplied by CURENT, found that both the overall design simplicity and number of converters needed factors would be satisfied better than the unidirectional or bidirectional converter options. However, the converter complexity factor would not be met because of the time and effort required to understand the components, operation, and limitations of the DC/AC inverter. But in the end, based on the decision matrix scoring shown in Figure 9 above, the DC/AC inverter provided by CURENT was determined to be the best choice since it met the most important criteria in more ways than the other two options. By choosing this option, we will be able to use this DC/AC inverter for (2) of the converters needed for this project and build (1) additional DC/DC solar converter.

The second design concept involves determining the type of output load we will use for our project demonstration. The two options are to connect directly to the grid or simply power a light bulb as the load. Figure 10 below is the decision matrix we used to assist in making this concept selection.

(B) Factors of this decision	(C) Rank of Factors (0-2)	(E) Meets need? (0 - 2)	(E) Meets need? (0 - 2)
	(A) Decision to evaluate:	Output Load	
	Score (auto-calculated):	2	9
	(D) Options:	Connect directly to grid	Power a light bulb as the load
scope of project	1	2	1
project timeline	2	0	2
safety	2	0	2

Provided by Zapier.com, adapted from a tool by Idea Sandbox (idea-sandbox.com) [11]

Figure 10: Decision Matrix for Output Load Concept Selection

The most important factors in this decision are the scope of the project, the project timeline, and the overall safety. In ranking these factors, we determined that safety and the timeline of the project are both very important, while the scope of the project is the least important of the three criteria. The option of connecting directly to the grid definitely has the potential to be much less safe and would also extend the timeline of this project beyond our completion deadline. However, it does meet the scope of project criteria as it would provide a larger-scale demonstration rather than only a proof of concept. In contrast, powering a light bulb as the output load of our system would definitely satisfy the safety factor as well as the project timeline requirements. While it would reduce the scope of our project and limit our demonstration to only a proof of concept, since the other two factors are more heavily weighted we decided to move forward with using a light bulb as the output load. This option will include using multiple light bulbs connected in series for a total power output of 500 W.

Our third and final concept selection is related to the SOC estimation display. The two options under consideration are the LCD display and using MATLAB on a laptop. Figure 11 is a visual representation of the decision-making process we used to make this selection.

	(A) Decision to evaluate:	SOC Estimation Display	
	Score (auto-calculated):	3	7
	(D) Options:	LCD display	MATLAB on a laptop
(B) Factors of this decision	(C) Rank of Factors (0-2)	(E) Meets need? (0 - 2)	(E) Meets need? (0 - 2)
visual representation	2	1	2
ease of implementation	1	0	1
cost of implementation	1	1	2

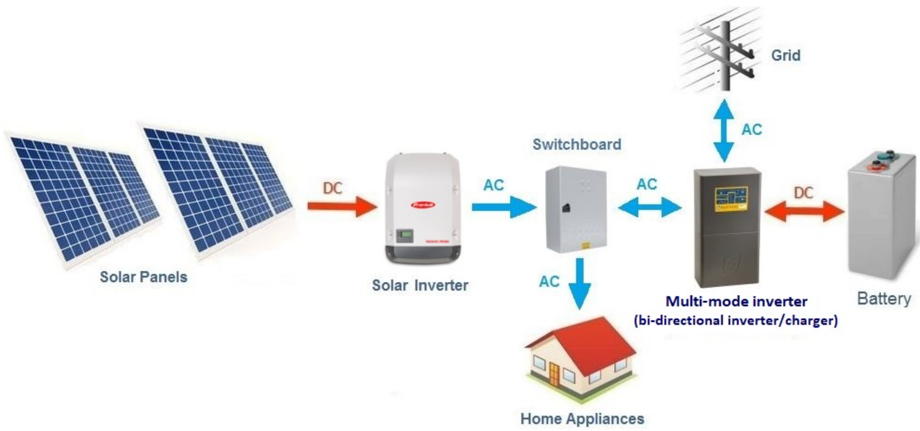
Provided by Zapier.com, adapted from a tool by Idea Sandbox (idea-sandbox.com) [11]

Figure 11: Decision Matrix for SOC Estimation Display Concept Selection

For the SOC estimation display design decision, we determined that the most notable factors were the visual representation of each option, the ease of implementation, and the cost of implementation. Of these three criteria, we concluded that the visual representation is the most significant. The other two factors are equally important, but not as notable as the visual representation. The first option under consideration, the LCD display, meets the need of visual representation and cost, but will not be easy to implement. Using MATLAB on a laptop, on the other hand, is more visually appealing, easier to implement, and cheaper since it will not need to be purchased for this project. If the later stages of our project turn out to be ahead of schedule and we have the available funds, we would consider using the LCD display since it would allow the system to operate independently. However, we are currently planning to stick with using MATLAB on a laptop to display the SOC estimation for this project based on the decision matrix scoring shown in Figure 11 above.

Deliverables

After several group meetings with our project sponsor, Dr. Kevin Bai, we have determined several main components that will be delivered to our customer at the end of this project. The deliverables specified below will be fine-tuned over the course of the next several months to ensure that the consumers receive the best possible version of the final product.



[12]

Figure 12: Visual Representation of Project Deliverables

The first main component that will be delivered to the customer is the circuit design simulation. This will consist of a working simulation to demonstrate the solar-powered energy storage system in action. Also included will be a block diagram built in MATLAB Simulink design software showing the various DC and AC components of the product. The second main deliverable is the solar panel converter. This component will be a DC/DC boost converter to facilitate the energy transfer from the solar panel to the DC bus.

The third requirement of the product will be a battery converter, which is also a DC/DC boost converter to transfer energy from the battery to the DC bus. This battery converter will also be bi-directional, which will allow the DC power from the solar panel to recharge the battery when necessary. The fourth component is a DC/AC inverter to facilitate the conversion of DC voltage to AC voltage, which is the form of energy needed to power the load. This component will be provided by CURENT. Finally, the fifth deliverable of this project is the SOC estimation display. This screen will represent a visual demonstration of the state-of-charge of the battery in order to prevent overcharging and depletion.

By presenting these deliverables to our customer, we hope to show that a solar-powered energy storage system can be used to not only help stabilize the power grid, but also provide a beneficial means of recycling EV batteries. Once the SOH of EV batteries reach 80%, they are no longer suitable for use in electric vehicles. However, they can be used in our applications for energy storage to help stabilize the power grid in times of peak demand. By creating a small-scale model, we hope to demonstrate that a solar-powered energy storage system is feasible in large-scale applications. Because of this forward-minded approach to our project, we believe that the end consumer of our product will not only be our project sponsor, Dr. Kevin Bai, but it will also extend to large-scale automobile companies and power generation companies who will be able to build upon our small-scale model.

Project Management

The table below is the tentative timeline that Team 1 will be using to maintain the progress of the project deadlines that were given to us by our project sponsor and advising professors. The main deadlines for the Fall 2022 semester are making sure the research, the handwritten calculations, the simulation/circuit design/block diagram are done by mid-November. This will allow us to make sure the purchase orders are submitted by December 7th. With this much lead time on purchase orders, our team should have enough time to get the necessary parts delivered, and also have enough time to make any corrections for incorrect items that might have been delivered by accident. The parts should not be delivered any later than early February. Making sure the parts show up by early February will set the pace for the spring semester deadlines.

The first main deadline for the Spring 2023 semester is getting parts on time and starting to build prototypes by mid-February. There will be roughly a month and half to work toward a final prototype design. Completing the final circuit assembly by 4/1/23 is another major deadline. The goal for this step of the project is to have a working model and design by the beginning of April so we will have enough time to run real world benchmark tests and make any small adjustments, if necessary. With the benchmark tests completed, the next big deadline is the Final Design Checklist on 4/10/23. This deadline was set up to be the last day we want to be working on the final design. The reason for this is because the Final Design Checklist will go through all the design requirements and make sure that our project sponsor and advising professors are satisfied with the final product. With the deadline being 4/10/23, our team will have enough time to make small improvements before the next deadline.

The next major deadline for Spring 2023 is creating a draft for Team 1's patent application and submitting a final patent application by 3/31/23. The last big deadline for spring 2023 is gathering all data, research notes, test results, and final design of our product and presenting our findings to the public. This deadline is set for late April on 4/24/23. The last deadline is the Detailed Design Report that will be due on 5/12/23. The last few deadlines will be close to each other, and we will need to be diligent in the closing weeks to meet these deadlines on time. Another key part of the project management aspect is that Team 1 is meeting with our project sponsor on a bi-weekly basis to get feedback and to make any improvements based on his advice. This constant and consistent feedback will decrease design errors and boost the productivity of our team.

Furthermore, as part of the project management, we are keeping continuous communication between group members so we can produce the most efficient and effective results. Note that these deadlines for Fall 2022 and Spring 2023 are tentative and are subject to change, but we will need to be conscious of these changes in the deadlines as they arise. Table 2 summarizes the role of each team member, and Table 3 shows the anticipated schedule of our project. Note that Table 3 follows our Gantt Chart, which has been split into 5 screenshots and included in the Appendix section of this report.

Table 2: Summary of Team Member Roles

Name	Team Role
Matthew Allison	Team Leader
Justin Cash	Project Manager
Austin Allison	Researcher and Designer
Kelli Determan	Designer and Treasurer
Jazmin Wallace	Researcher
Colin Wikle	Programmer

Table 3: Updated Fall 2022 and Spring 2023 Project Deadlines

Deadline Date	Deadline Details	Deadline Date	Deadline Details
10/21/2022	Project Proposal Report	1/11/2023	Complete PCB Design
11/14/2022	Background Research Completed	2/1/2023	Receive Parts***
11/15/2022	Gantt Chart Completed	2/6/2023	Begin SoC Arduino Software Programming
11/18/2022	Matlab Simulations/Circuit Design	2/8/2023	Start Circuit Component Assembly
11/18/2022	Meeting to discuss Preliminary Design Presentation	3/6/2023	Finish SoC Arduino Software Programming
11/23/2022	Block Diagram	3/27/2023	Draft Patent Application Started
11/28/2022	Preliminary Design Presentation	3/29/2023	Final Circuit Assembly
12/2/2022	DC/DC Converter and SoC Research Completed	3/31/2023	Draft Patent Application Finished
12/2/2022	DC/AC Converter Research Completed	4/3/2023	Draft Patent Application Presentation
12/2/2022	Handwritten Calculations for Converters	4/10/2023	Final Design Checklist***
12/5/2022	Start PCB Design	4/24/2023	Detailed Design Presentation Completed
12/7/2022	Purchase Orders***	5/12/2023	Detailed Design Report Submission***
12/15/2022	Preliminary Design Report***		

Budget

The majority of our costs will go to PCB fabrication and purchasing a lithium-ion battery to act as our energy storage device. This battery will, in theory, be able to supply power to the grid and will collect power that is generated by an attached solar panel. The solar panel will be donated to our senior design group from CURENT, and will be approximately 100 Watts. We have purchased an Arduino microcontroller to control a visual display to show the state of charge of our battery, along with some other voltage and current measurements. To demonstrate that our battery is able to dissipate energy, we will purchase 2 100W LED bulbs arranged in series to have a visual of the power output our battery will produce. To be able to store the solar energy and move power to the grid purchased various parts to build converters and inverters in hardware. We also have a PCB donated from CURENT, which we will use to help simplify our design.

Team 1 had a budget increase from the initial estimate of $390 to $716.13. This is due to our group decision to have our PCB fabricated to ensure high efficiency and smooth operation. While this adds a $300 cost to the budget, our intention is to produce a higher quality product [13, 14]. The remaining budget increase is due to vendor price increases on several components. For example, the microcontroller was initially $30, but increased to $48.40 before ordering. The purchase of a small soldering tip was also required to build the converters and inverters, which further adjusted the budget. Table 4 below shows the current planned budget for the project. The items with a check mark have been ordered and received.

Table 4: Updated Project Budget

Item	Amount	Cost/item	Total Cost	Link	Check when Received	Notes
Lithium Ion Battery	1	$249.99	$249.99	48v Battery	☐	Power Supply
Microcontroller	1	$48.40	$48.40	A000067 Arduino | DigiKey	☑	Controls the modes
LED Bulbs (100W)	2	$11.99	$23.98	SYLVANIA ECO LED Light Bulb, A19, 100W Equivalent, Efficie	☐	10 bulbs for load
CURENT Board	1	Donated	$0	Provided by CURENT	☑	
PCB Fabrication	1	$300	$300	https://blog.svtronics.com/	☐	**This is an estimation**
Wiring (6 Gauge) per foot	1	$35.99	$35.99	Amazon.com: 6 Gauge Wire	☐	Worse Case Scenario
Soldering Tip (6pc)	1	$12.99	$12.99	Amazon.com:	☐	Used for PCB Board
Soldering Kit	1	$0.00	$0.00	Provided by CURENT	☑	Used for PCB Board
Voltage Sensors Parts	1	Donated	$0	Designing and Building Provided by CURENT	☐	**This is an estimation**
Laptop (Display)	1	Donated	$0	Provided by CURENT	☑	Used for Output Data
Circuit Parts for Fabrication:						
MOSFET: (100V, 10A)	1	$1.35	$1.35	FQD18N20V2TM onsemi	☑	DC/DC Converter
Diodes: (100V, 10A)	1	$1.41	$1.41	MURSB1520-TP Micro Commercial Co	☑	DC/DC Converter
Inductors: (1mH, 55V, 10A)	1	$13.14	$13.14	PE-96190NL Pulse Electronics | Filters | DigiKey	☑	DC/DC Converter
Capacitors: (1mF, 100V, 5A)	1	$4.88	$4.88	160USG1000MEFCSN22X40 Rubycon | Capacitors | DigiKey	☑	DC/DC Converter
Gate Driver (Op Amp)	2	$12.00	$24.00	https://www.mouser.com/	☐	**This is an estimation**
Solar Panel	1	Donated	$0	Provided by CURENT	☑	
					☐	
			$716.13		☐	

References

[1] P. Kampshoff, A. Kumar, S. Peloquin, and S. Sahdev, "Building the electric-vehicle charging infrastructure america needs," McKinsey & Company, 31-Aug-2022. [Online]. Available: https://www.mckinsey.com/industries/public-and-social-sector/our-insights/building-the-electric-vehicle-charging-infrastructure-america-needs. [Accessed: 12-Oct-2022].

[2] "Hourly electricity consumption varies throughout the day and across seasons - Today in Energy - U.S. Energy Information Administration (EIA)," www.eia.gov, Feb. 21, 2020. https://www.eia.gov/todayinenergy/detail.php?id=42915

[3] "TVA at a glance." [Online]. Available: https://www.tva.com/About-TVA/TVA-at-a-Glance. [Accessed: 21-Oct-2022].

[4] B. Alves, "U.S. electricity consumption 2021," Statista, 18-Oct-2022. [Online]. Available: https://www.statista.com/statisticYang, and B. Guo, "Estimation of State-of-Charge and State-of-Health for Lithium-Ion Degraded Battery Considering Side Reactions," Journal of The Electrochemical Society, vol. 165, no. 16, pp. A4018–A4026, 2018, doi: 10.1149/2.0981816jess/201794/us-electricity-consumption-since-1975/. [Accessed: 21-Oct-2022].

[5] "First TVA-owned battery storage to Shape Energy Future." [Online]. Available: https://www.tva.com/newsroom/press-releases/first-tva-owned-battery-storage-to-shape-energy-future. [Accessed: 21-Oct-2022].

[6] Y. Gao, X. Zhang, J. Yang, and B. Guo, "Estimation of State-of-Charge and State-of-Health for Lithium-Ion Degraded Battery Considering Side Reactions," Journal of The Electrochemical Society, vol. 165, no. 16, pp. A4018–A4026, 2018, doi: 10.1149/2.0981816jes.

[7] "BU-105: Battery Definitions and what they mean," Battery University, Sep. 05, 2010. https://batteryuniversity.com/article/bu-105-battery-definitions-and-what-they-mean. [Accessed: 20-Oct-2022].

[8] "TIEVM-HV-1PH-DCAC Inverter Reference Design - TI | Mouser," [Online]. Available: https://www.mouser.com/new/texas-instruments/ti-tievm-hv-1ph-dcac-reference-design/. [Accessed: 16-Dec-2022].

[9] D. Patrascu, "UK Power-Grid: Bring on the Hybrids and EVs," 04-May-2009. [Online]. Available: https://www.autoevolution.com/news/uk-power-grid-bring-on-the-hybrids-and-evs-6316.html. [Accessed: 15-Dec-2022].

[10] Circuits and Instructables, “Arduino serial monitor in Tinkercad,” 19-Sep-2022. [Online]. Available: https://www.instructables.com/Arduino-Serial-Monitor-in-Tinkercad/. [Accessed: 15-Dec-2022].

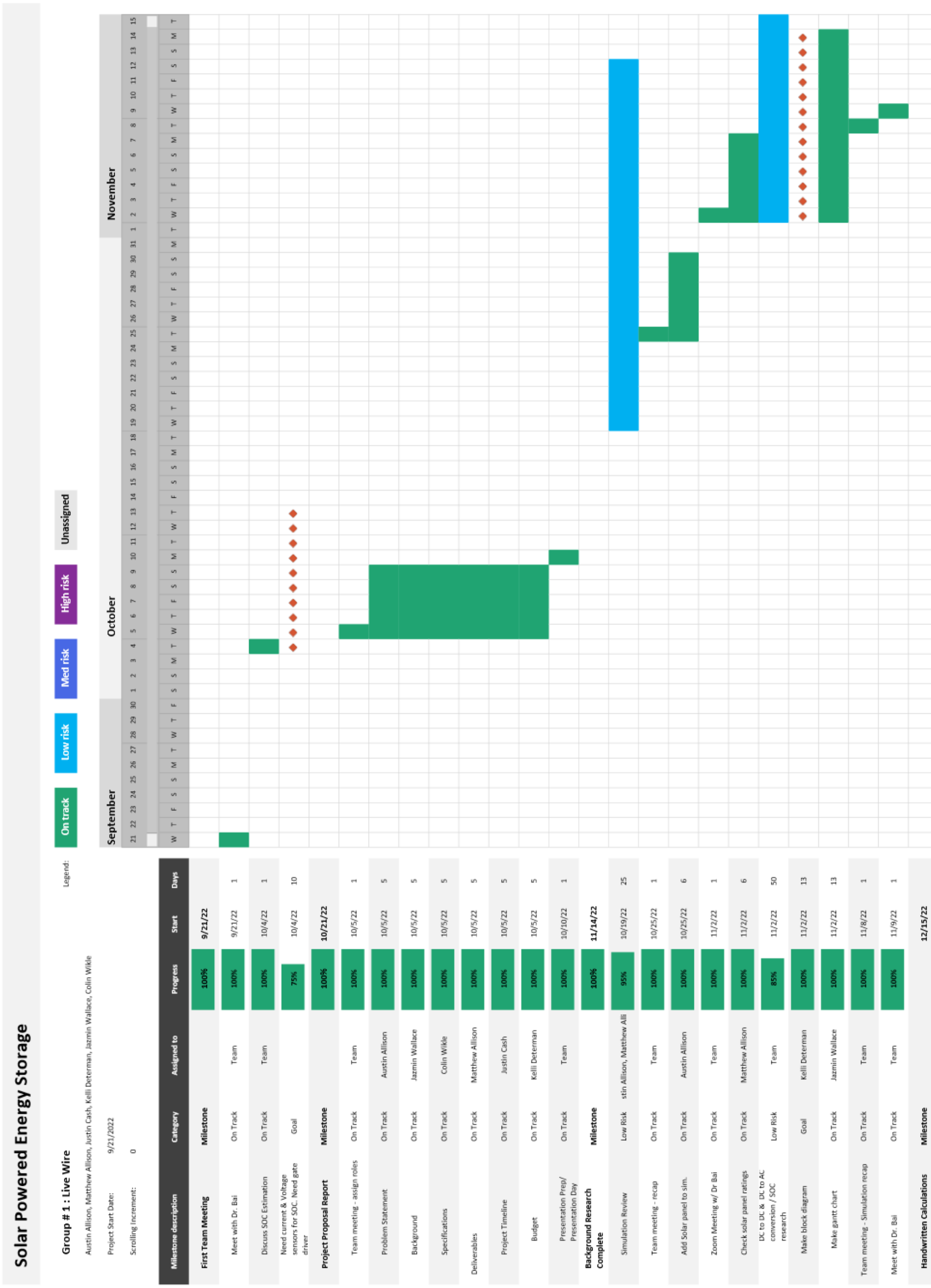
[11] M. Pinola, “The Decision Matrix: Make Better Decisions With This Spreadsheet Template,” *Zapier*, 18-Feb-2019. [Online]. Available: https://zapier.com/blog/decision-matrix-template/. [Accessed: 15-Dec-2022].

[12] J. Svarc, “Technical guide to sizing hybrid inverters and off-grid solar systems,” CLEAN ENERGY REVIEWS, 12-Feb-2022. [Online]. Available: https://www.cleanenergyreviews.info/blog/hybrid-solar-selection-guide. [Accessed: 21-Oct-2022].

[13] S. Editor, “How Much Does It Cost To Make PCB Board?,” *KINGFORD*, 11-Jan-2022. [Online]. Available: https://www.kingfordpcba.com/news/how-much-does-it-cost-to-make-pcb-board.html. [Accessed: 15-Dec-2022].

[14] S. Patel, “How Much Does PCB Assembly Cost?,” *Candor Industries*, 12-Apr-2022. [Online]. Available: https://www.candorind.com/how-much-does-pcb-assembly-cost/. [Accessed: 15-Dec-2022].

Appendix



Solar Powered Energy Storage

Group # 1 : Live Wire

Austin Allison, Matthew Allison, Justin Cash, Kelli Determan, Jazmin Wallace, Colin Wikle

Project Start Date: 9/21/2022

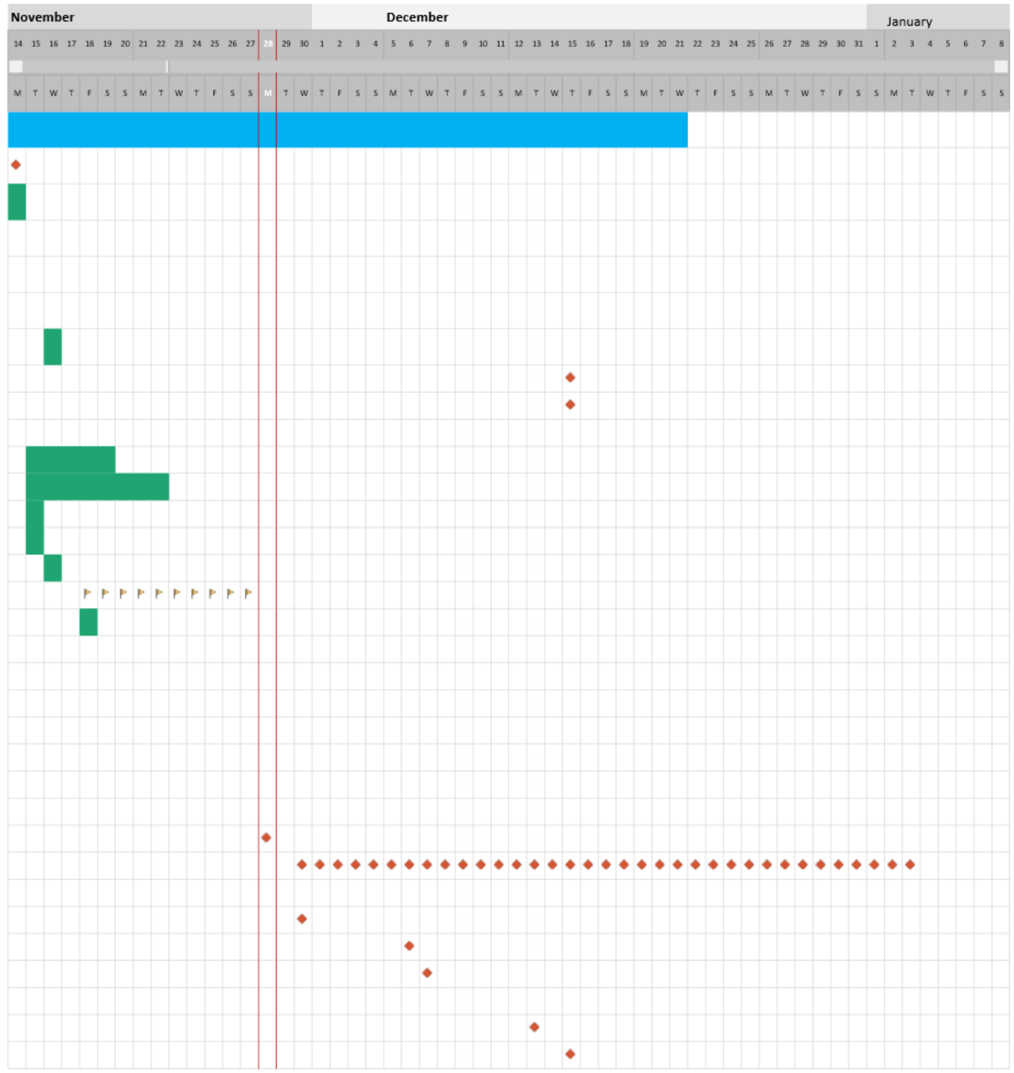
Scrolling Increment: 0

Milestone description	Category	Assigned to	Progress	Start	Days
First Team Meeting	**Milestone**		100%	**9/21/22**	
Meet with Dr. Bai	On Track	Team	100%	9/21/22	1
Discuss SOC Estimation	On Track	Team	100%	10/4/22	1
Need current & Voltage sensors for SOC. Need gate driver	Goal		75%	10/4/22	10
Project Proposal Report	**Milestone**		100%	**10/21/22**	
Team meeting - assign roles	On Track	Team	100%	10/5/22	1
Problem Statement	On Track	Austin Allison	100%	10/5/22	5
Background	On Track	Jazmin Wallace	100%	10/5/22	5
Specifications	On Track	Colin Wikle	100%	10/5/22	5
Deliverables	On Track	Matthew Allison	100%	10/5/22	5
Project Timeline	On Track	Justin Cash	100%	10/5/22	5
Budget	On Track	Kelli Determan	100%	10/5/22	5
Presentation Prep/ Presentation Day	On Track	Team	100%	10/10/22	1
Background Research Complete	**Milestone**		100%	**11/14/22**	
Simulation Review	Low Risk	stin Allison, Matthew Alli	95%	10/19/22	25
Team meeting - recap	On Track	Team	100%	10/25/22	1
Add Solar panel to sim.	On Track	Austin Allison	100%	10/25/22	6
Zoom Meeting w/ Dr Bai	On Track	Team	100%	11/2/22	1
Check solar panel ratings	On Track	Matthew Allison	100%	11/2/22	6
DC to DC & DC to AC conversion / SOC research	Low Risk	Team	85%	11/2/22	50
Make block diagram	Goal	Kelli Determan	100%	11/2/22	13
Make gantt chart	On Track	Jazmin Wallace	100%	11/2/22	13
Team meeting - Simulation recap	On Track	Team	100%	11/8/22	1
Meet with Dr. Bai	On Track	Team	100%	11/9/22	1
Handwritten Calculations	**Milestone**			**12/15/22**	

Project Start Date: 9/21/2022

Scrolling Increment: 54

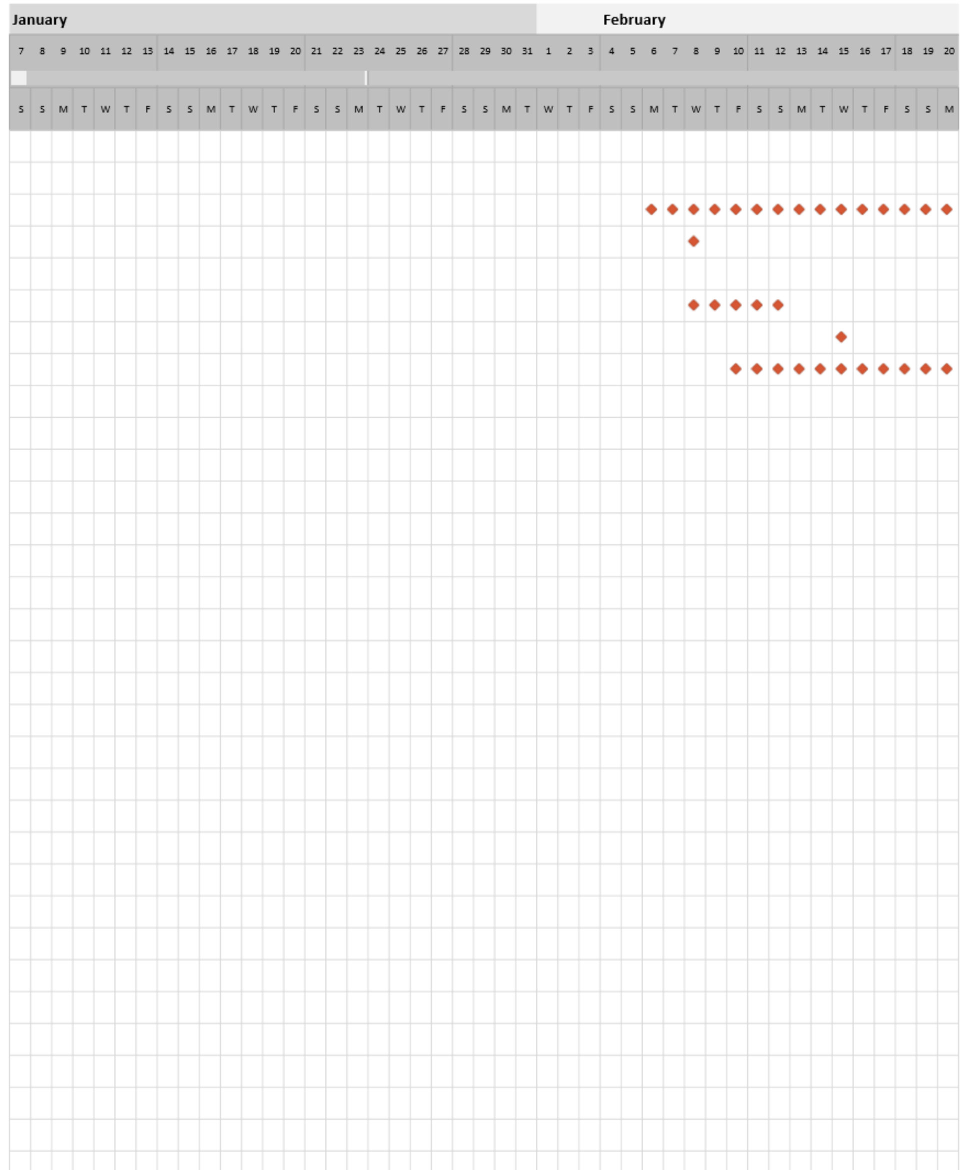
Milestone description	Category	Assigned to	Progress	Start	Days
DC to DC & DC to AC conversion / SOC research	Low Risk	Team	85%	11/2/22	50
Make block diagram	Goal	Kelli Determan	100%	11/2/22	13
Make gantt chart	On Track	Jazmin Wallace	100%	11/2/22	13
Team meeting - Simulation recap	On Track	Team	100%	11/8/22	1
Meet with Dr. Bai	On Track	Team	100%	11/9/22	1
Handwritten Calculations	**Milestone**			**12/15/22**	
Meet with Dr. Bai @ 4:45 pm- hand calculations	On Track	Team		11/16/22	1
Handwritten Calculations (Converters)	Goal	Team		12/15/22	1
Finalize Calculations w/ Dr. Bai	Goal	Team		12/15/22	1
Simulation/Circuit Design/ Block Diagram	**Milestone**			**11/18/22**	
Finalize Simulation/ Circuit design	On Track	Austin Allison		11/15/22	5
Finalize Block Diagram	On Track	Kelli Determan, Justin Cash		11/15/22	8
Finalize Gantt chart	On Track	Jazmin Wallace	100%	11/15/22	1
Team meeting @ 3:30 pm- notebooks, gantt chart, sim, & SOC	On Track	Team		11/15/22	1
Critical resign review meeting MK 337 @ 3:20 pm	On Track	Team		11/16/22	1
Preliminary Design Presentation	**Milestone**			**11/18/22**	**10**
Team Meeting - presentation roles	On Track	Team		11/18/22	1
Role 1					
Role 2					
Role 3					
Role 4					
Role 4					
Role 5					
Role 6					
Presentation Review/ Presentation Day	Goal	Team		11/28/22	1
Design layout PCB Build	Goal	Kelli Determan		11/30/22	35
Purchase Orders	**Milestone**			**12/7/22**	
Team Meeting - Finalize parts to order, verify with	Goal	Team		11/30/22	1
Meet with Dr Bai & finalize order	Goal	Team		12/6/22	1
Submit purchase Order	Goal	Kelli Determan		12/7/22	1
Preliminary Design Report	**Milestone**			**12/15/22**	
Team Meeting - discuss report	Goal	Team		12/13/22	1
Submit design report	Goal	Team		12/15/22	1



Project Start Date: 9/21/2022

Scrolling Increment: 108

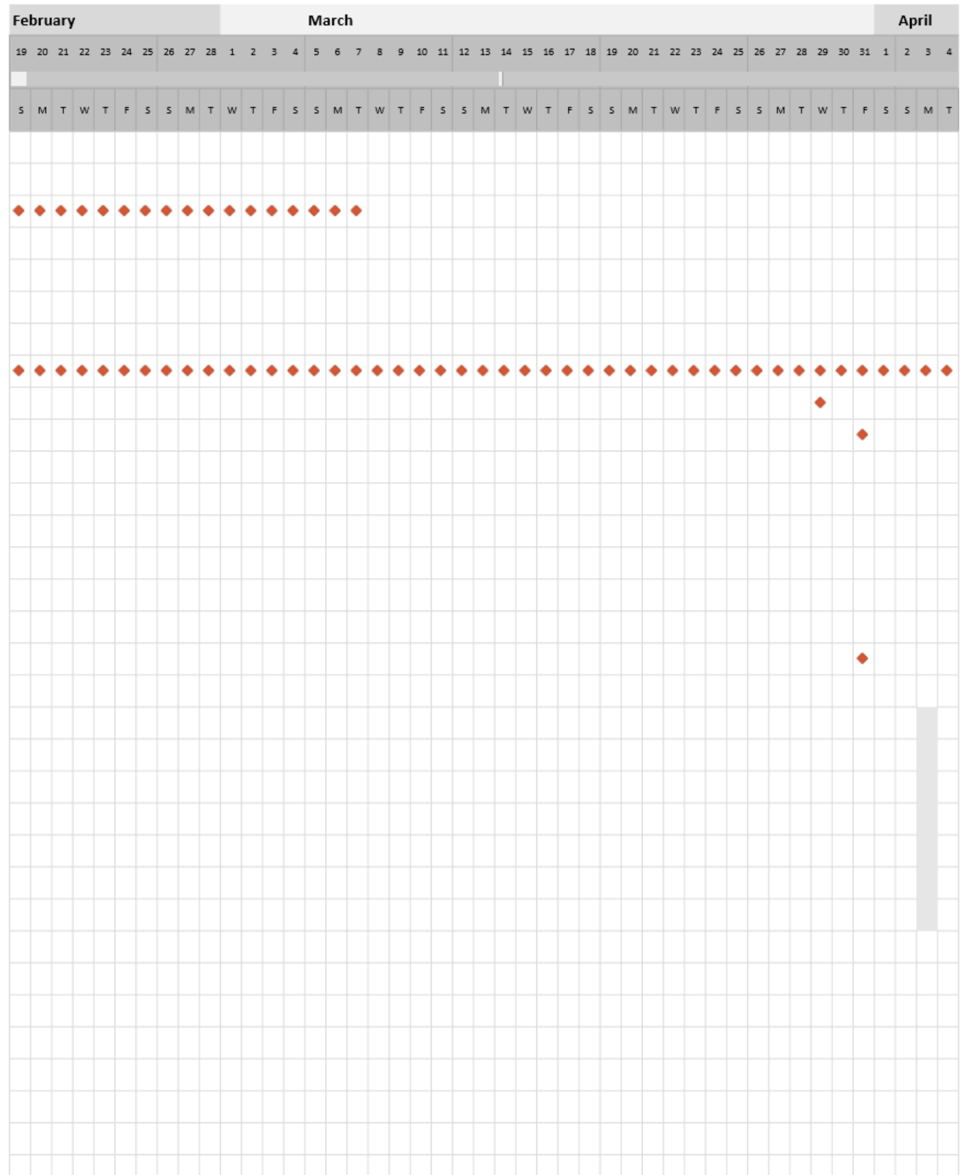
Milestone description	Category	Assigned to	Progress	Start	Days
Submit design report	Goal	Team		12/15/22	1
Receive Parts	**Milestone**			**2/1/23**	
Begin SOC arduino software	Goal	Colin Wikle		2/6/2023	30
Team meeting- discuss build	Goal	Team		2/8/23	1
Start Circuit Component Assembly	**Milestone**			**2/8/23**	
Start Building Design	Goal	Team		2/8/23	5
Meet with Dr Bai & review build	Goal	Team		2/15/23	1
Troubleshooting	Goal	Team		2/10/23	60
Team Meeting	Goal	Team		3/29/23	1
Meet w/ Dr. Bai	Goal	Team		3/31/23	1
Finalize circuit assembly	Goal	Team		3/29/23	
Team Meeting	Goal	Team		4/7/23	1
Meet w/ Dr. Bai	Goal	Team		4/12/23	1
Draft Patent Application	**Milestone**			**3/27/23**	
Team Meeting	Goal	Team		4/14/23	1
Meet w/ Dr. Bai				4/19/23	1
Submit Application	Goal	Kelli Determan		3/31/23	1
Draft Patent Application Presentation	**Milestone**			**4/3/23**	
Team Meeting - presentation roles				4/3/23	1
Role 1				4/3/23	1
Role 2				4/3/23	1
Role 3				4/3/23	1
Role 4				4/3/23	1
Role 5				4/3/23	1
Role 6				4/3/23	1
Final Design Checklist	Goal	Team		4/10/2023	
Detailed Design Presentation	**Milestone**			**4/24/23**	
Team Meeting - Review roles / test run	Goal			4/21/23	15
Meet w/ Dr. Bai - test runs	Goal			4/25/23	5
Presentation day	Goal	Team		4/30/23	
Detailed Design Report	**Milestone**			**5/12/23**	
Team Meeting - discuss report	Goal	Team		5/1/23	4
Submit Report	Goal	Team		5/12/23	1



Project Start Date: 9/21/2022

Scrolling Increment: 151

Milestone description	Category	Assigned to	Progress	Start	Days
Submit design report	Goal	Team		12/15/22	1
Receive Parts	**Milestone**			**2/1/23**	
Begin SOC arduino software	Goal	Colin Wikle		2/6/2023	30
Team meeting- discuss build	Goal	Team		2/8/23	1
Start Circuit Component Assembly	**Milestone**			**2/8/23**	
Start Building Design	Goal	Team		2/8/23	5
Meet with Dr Bai & review build	Goal	Team		2/15/23	1
Troubleshooting	Goal	Team		2/10/23	60
Team Meeting	Goal	Team		3/29/23	1
Meet w/ Dr. Bai	Goal	Team		3/31/23	1
Finalize circuit assembly	Goal	Team		3/29/23	
Team Meeting	Goal	Team		4/7/23	1
Meet w/ Dr. Bai	Goal	Team		4/12/23	1
Draft Patent Application	**Milestone**			**3/27/23**	
Team Meeting	Goal	Team		4/14/23	1
Meet w/ Dr. Bai				4/19/23	1
Submit Application	Goal	Kelli Determan		3/31/23	1
Draft Patent Application Presentation	**Milestone**			**4/3/23**	
Team Meeting - presentation roles				4/3/23	1
Role 1				4/3/23	1
Role 2				4/3/23	1
Role 3				4/3/23	1
Role 4				4/3/23	1
Role 5				4/3/23	1
Role 6				4/3/23	1
Final Design Checklist	Goal	Team		4/10/2023	
Detailed Design Presentation	**Milestone**			**4/24/23**	
Team Meeting - Review roles / test run	Goal			4/21/23	15
Meet w/ Dr. Bai - test runs	Goal			4/25/23	5
Presentation day	Goal	Team		4/30/23	
Detailed Design Report	**Milestone**			**5/12/23**	
Team Meeting - discuss report	Goal	Team		5/1/23	4
Submit Report	Goal	Team		5/12/23	1



Project Start Date: 9/21/2022

Scrolling Increment: 194

Milestone description	Category	Assigned to	Progress	Start	Days
Submit design report	Goal	Team		12/15/22	1
Receive Parts	**Milestone**			**2/1/23**	
Begin SOC arduino software	Goal	Colin Wikle		2/6/2023	30
Team meeting- discuss build	Goal	Team		2/8/23	1
Start Circuit Component Assembly	**Milestone**			**2/8/23**	
Start Building Design	Goal	Team		2/8/23	5
Meet with Dr Bai & review build	Goal	Team		2/15/23	1
Troubleshooting	Goal	Team		2/10/23	60
Team Meeting	Goal	Team		3/29/23	1
Meet w/ Dr. Bai	Goal	Team		3/31/23	1
Finalize circuit assembly	Goal	Team		3/29/23	
Team Meeting	Goal	Team		4/7/23	1
Meet w/ Dr. Bai	Goal	Team		4/12/23	1
Draft Patent Application	**Milestone**			**3/27/23**	
Team Meeting	Goal	Team		4/14/23	1
Meet w/ Dr. Bai				4/19/23	1
Submit Application	Goal	Kelli Determan		3/31/23	1
Draft Patent Application Presentation	**Milestone**			**4/3/23**	
Team Meeting - presentation roles				4/3/23	1
Role 1				4/3/23	1
Role 2				4/3/23	1
Role 3				4/3/23	1
Role 4				4/3/23	1
Role 5				4/3/23	1
Role 6				4/3/23	1
Final Design Checklist	Goal	Team		4/10/2023	
Detailed Design Presentation	**Milestone**			**4/24/23**	
Team Meeting - Review roles / test run	Goal			4/21/23	15
Meet w/ Dr. Bai - test runs	Goal			4/25/23	5
Presentation day	Goal	Team		4/30/23	
Detailed Design Report	**Milestone**			**5/12/23**	
Team Meeting - discuss report	Goal	Team		5/1/23	4
Submit Report	Goal	Team		5/12/23	1