Creating STEM Contents: Solar Power with a Tracking System

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MIDTERM REPORT

REVISION –
3 October 2022

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CONCEPT OF OPERATIONS

REVISION – 1
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Concept of Operations
for
Creating STEM Contents: Solar Power with a Tracking System

Team <49>

Approved by:

Project Leader Date

Prof. Kalafatis Date

T/A Date

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1. Executive Summary

As the electrification and digitization boom further grows, there is a need for more sustainable power generation methodologies as non-renewable sources prove ineffective for long term power generation solutions. For this reason, renewable energy solutions have been proposed and explored over the years. One promising alternative is solar power. Solar power is more complex in the way it generates electricity however it is simpler in its system design and maintenance. As the demand for engineering solutions increases in society, it is imperative that future generations of engineers are inspired as young students to excite them about the pursuit of engineering (or STEM more broadly) as a career path. Due to the miniaturization of solar panels and the simpler nature of their system integration than a power plant, a portable solar solution can be designed with the ability to self-track the efficiency of the system. This solution can show the methodology of solar-based power generation in a way that is digestible for K-12 students while being interesting enough to draw students to the STEM field to help produce new talent for the future of engineering solutions.

2. Introduction

The Concept of Operations is an introductory description of the solar power generation system with a tracking scheme. The system itself as well as subsystem operation, system integration, and scenarios of usability will all be discussed. The system will be primarily designed to act as an educational tool for K-12 students to generate interest in STEM as a career path but to also demonstrate the basic operational premise of the solar power generation system while also being able to track its efficiency.

2.1. Background

Engineering is becoming a more expansive field as new solutions are required for problems that did not used to exist prior to the electrification and digitization of society. As such, it is imperative that the engineers of today inspire future generations that will provide solutions once we are gone. STEM has become a very lucrative field yet it is gatekept due to its technical difficulty and dedication that it requires resulting in lower than necessary matriculation rates into engineering programs. As STEM program graduates slowly stagnate [Fig. 1], the demand for solutions continues to grow.

One solution is to increase the number of students that pursue engineering by exposing K-12 students to STEM related concepts early in their education in hopes that it generates interest through their creativity. STEM requires creativity to design innovative solutions to emerging problems and it is imperative that creative students are encouraged to pursue STEM early on to capitalize on their unique viewpoints. The design of a portable and physical device such as the solar power generation system that can present relevant data about itself in a technically digestible manner for young students while also being complex enough to inspire these students in an effective way to address this problem.

In commercial solar power generation, systems that can generate enough energy to power a home or on a larger scale such as a power grid require bulky and heavy panels that are not only expensive but not portable. The solar energy required to power a house would require a large surface area of the roof to be covered by panels while energizing a grid would require a farm of panels to power the load. In order for this system to be portable, a palm-sized panel will be required as well as a similarly sized battery which also meets the panel power specification. The rest of the system has to be designed as small as possible to meet the portability requirement.

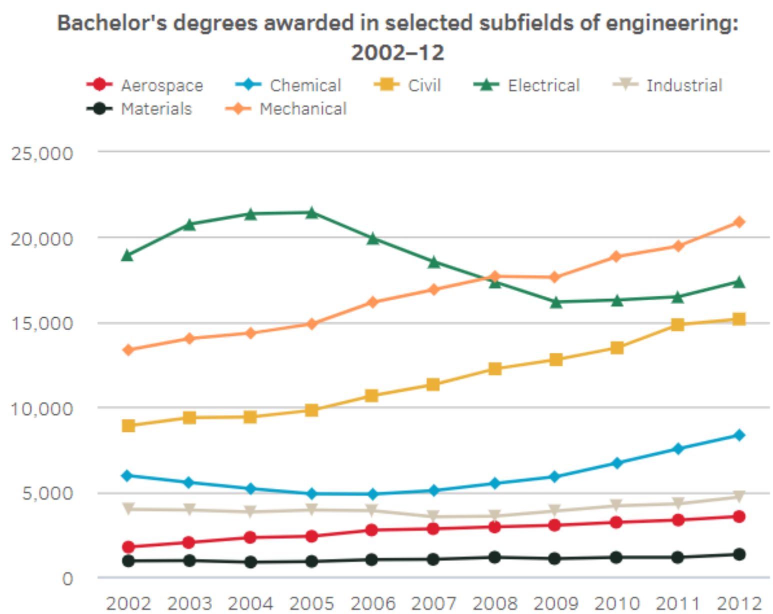

Figure 1: Trend of Engineering B.S. Graduates over Time (Section 2.3 Ref. 1)

2.2. Overview

As discussed, the system will be powered by a palm-sized solar panel. Since the power generation of the panel can be sporadic and not consistent, it isn't sufficient to drive a load directly. A battery will need to be charged so that it can discharge according to a polynomial curve so that relevant power data can be more easily measured. Since the panel will charge the battery over several hours, implementing a battery and load will make it easier to track system performance over longer periods of time as linear operation of the circuits are easily predictable. A microcontroller unit (MCU) will be used to take measurements, process the information, send control signals to the power generation subsystem, and interface with a database and graphical user interface (GUI). The GUI will read information from a database that is written to from the MCU and will display the relevant data as graphical and tabular information onto an interactable display to switch between two operating modes. The figures displayed will be designed to be easily understandable by a young and scientifically amateur audience to effectively demonstrate and explain the process of solar power generation.

2.3. Referenced Documents, Standards, and Citations

1. 'How many degrees are earned in engineering, and what subfields are the most popular?', National Science Board.
https://www.nsf.gov/nsb/sei/edTool/data/engineering-01.html
2. Electrical Rechargeable Battery Standards:
https://www.epectec.com/batteries/battery-standards.html
3. Solar Power Standards: https://webstore.ansi.org/industry/solar-energy

3. Operating Concept

3.1. Scope

Solar Power with a Tracking System will be a miniaturized system that can generate power from solar energy through the use of solar panels that charge batteries and discharge that energy into a load. Using a MCU, measurements will be taken about the system's voltage, current, and power while storing that information in a database. Then, a GUI will take the data and display the relevant figures that detail the system performance and efficiency. Since the project is intended to be used as a demonstration tool for K-12 students, the system will be designed to be portable and comprehensible for a more technically amateur audience to convey the basics of power generation, system design, electrical energy, and software.

3.2. Operational Description and Constraints

In order for the system to be used optimally, there are several details that must be discussed and elaborated on to ensure that the system can be used effectively for multiple demonstrations. The solar panels will charge batteries that can be disconnected once the batteries are charged. The batteries are then connected to a buck converter to step the voltage down for safe powering of a load. The battery will also have a disconnect between itself and the load since it doesn't discharge the system while storing energy from the panel. The MCU will take measurements from the system to be stored in a database and then displayed in a GUI. For the system to operate properly:

- The solar panels must be given several hours of sunlight to properly store the battery.
- The system must have a wired connection to an interface that can allow user input to control the circuits at the power generation side.
- The GUI and database must be designed for a computer or laptop since the connection will be wired and wireless connectivity will not be supported.
- Due to the portability constraint, the solar panel, battery, and circuit board must be small and light enough that the system is easily transportable.
- The battery and MCU must be sufficiently small to be mounted onto a printed circuit board (PCB).
- To satisfy budget constraints, the mechanical arm that holds the panel and hinge for axial rotation will be 3D-printed and must have sufficient range of motion.

3.3. System Description

There are three subsystems to this design including the solar power generation, the electrical I/O, and the database with GUI. One student each will design and manage their subsystem.

Solar Power Generation: The solar panel will be placed into a 3D-printed mechanism that can hold the panel so that the surface faces the sun. There is a hinge with a motor that will serve to rotate 180 degrees to follow the sun as it travels from the eastern to western horizon. The generated power from the panel will be fed directly to a battery storage network. Between the two will be a disconnect circuit that can switch so the battery can be disconnected from the panel when it is fully charged so the battery does not lose structural or chemical integrity. The battery will also connect to another disconnect circuit that will drive a buck converter to step the voltage down. This is so it can more safely drive a resistive load. There will be two measurement points at the battery and load side so that analog voltage measurements can be taken and tracked by the MCU for processing. The network will have a custom PCB designed for it so that it can be cleanly and safely connected for the purpose of visual ease of explanation of system operation.

Electrical I/O: The I/O will be controlled by an MCU which will take measurements, control the system, and interface between the circuit network and the custom display software and database. The MCU will take the analog voltage and current measurements, perform analog-to-digital conversion, and temporarily store the data. It will then compute the current and power based on known loads and transmit the data to the database for permanent storage. Since the GUI will take user input on operation modes (discussed in Section 3.4 and 4.1), it will need to be able to communicate with the GUI to control the operation of the circuit network and motor to control the charging or discharging of the battery and rotate the motor, respectively.

Database and GUI: From the MCU, the database will collect information about voltage, current, and power from the measurement ports in the circuit network in unit time intervals. The GUI will then draw the data from the database and provide graphs, tables, and/or figures to visualize information that track and demonstrate the system performance and operation. The GUI will also serve to take user input on operation mode control and network disconnect control to manage the system in a simple way to avoid additional external control schemes.

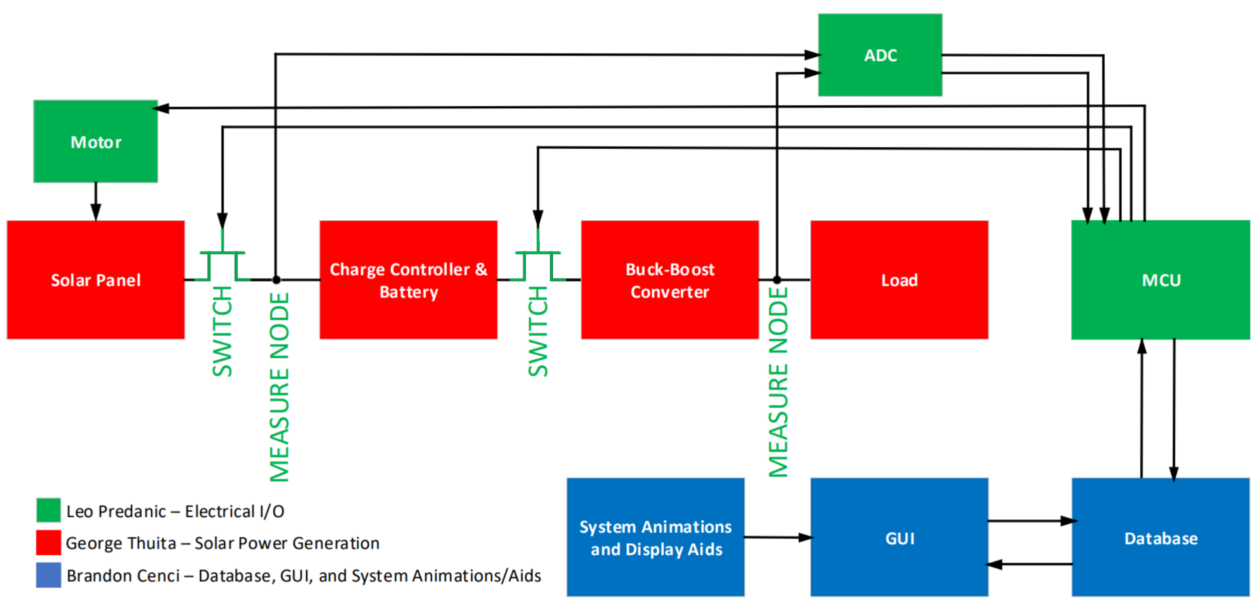

Figure 2: Top Level System Flow Diagram

3.4. *Modes of Operations*

There will be two primary modes of operation based on the rotation of the solar panel's axis. The first is 'fixed axis' as the motor will be set to 90 degrees from horizontal and the panel will remain stationary throughout its power generation process. The GUI will reflect that the system is in fixed axis mode. The second mode is 'single axis' where the panel will be able to rotate 180 degrees to follow the sun across the duration of the day. The GUI will also reflect that the system is in single axis mode and will display key metrics on system performance across the two modes for comparison as well as be able to select which mode the system will operate in.

3.5. Users

Since the target audience for this system are K-12 students, the display figures will be catered to the technical knowledge of these students. Due to the mechanics of the system where hardware and software are integrated, students in AP Physics 1 & 2, AP Physics C, and AP Computer Science will also be targeted with more specific details and information due to their background in the subject material and additional technical aids can be used to further elaborate on system design and operation. Because the system will be used as an educational tool, the user interface will be simple so that interaction with the system does not require extensive knowledge of the system. This means that the interface will have only several options for system interaction to avoid malfunction due to user error.

3.6. Support

Support for Solar Power with a Tracking System will be provided as an instruction manual that describes proper system maintenance and usage. To reduce the amount of system components, the manual will be given electronically as a ‘Read Me’ during program boot-up as an option to read prior to any interaction with the system

4. Scenarios

4.1. Fixed Axis Operation Mode

In Fixed Axis Operation Mode, the system will not rotate about its axis and collect its energy at 90 degrees from horizontal. This mode will be selected in the GUI where it will notify the MCU that the system is to operate in a stationary mode. The battery will charge while it is disconnected from the buck converter to ensure that no power is driving the load while charging. As the battery charges, the voltage and current will be measured and the power data will be calculated and sent to the database where the GUI will retrieve it and display the relevant information. When the battery is fully charged, the panel will be disconnected and the battery will then be switched to the buck converter which will step down the voltage to drive the load. Measurements will be taken the same way at the load and the information will be displayed in the GUI.

4.2. Single Axis Operation Mode

In Single Axis Operation Mode, the system will operate similarly to Fixed Axis Operation Mode but the MCU will control the rotation of the solar panel via a motor. The measurement data will be collected identically as Fixed Axis Operation Mode and the disconnect will operate the same as well. The GUI will display the collected data and will show the differences in efficiency of the two modes to illustrate how different system operation can affect performance.

4.3. System Charging Operation Mode

In System Charging Mode, the system will be in a state where the panel is charging the battery. The switch between the panel and charge controller will be connected and the switch between the battery and converter will be disconnected. The MCU will sample voltage and current data from the generator side and communicate with the GUI. The panel will either rotate or not depending on whether the system is in Fixed Axis or Single Axis Operation Mode.

4.4. System Discharging Operation Mode

In System Discharging Mode, the system will operate similarly to System Charging Mode but the switch connections will now be reversed. The battery will be driving the load and the solar panel will be disconnected.

5. Analysis

5.1. Summary of Proposed Improvements

This system will provide several improvements as an education tool than previous designs. Since the system is interactable, it will help teaching as the system provides instant feedback. The new graphical displays will be designed in a way that is understandable for young students while containing the necessary information to explain the concepts of solar power generation. Since the system is designed at block level, it will be easier to explain the operation without getting too in-depth into the physics and computer science of the system. Its light, portable, and organized design will be beneficial to clearly articulate where system blocks are, connections, and operation. Its dual operation modes are an efficient way of demonstrating different design philosophy and how that contributes to the performance of a system versus its alternatives.

5.2. Disadvantages and Limitations

Due to the miniaturized design, the solar panel output power will not be comparable to commercial systems and therefore will be limited in its ability to do useful work outside of being educational. Another issue of being solar powered is the long charging time. Data collection for power generation will take several hours and might not be demonstrable in real time due to time limitations. Sunny weather is necessary for proper system operation so inclement weather conditions might limit the ability of the system to be demonstrated in a classroom environment. Since cheap batteries are used due to budget constraints, the batteries might self-discharge and not be able to hold enough charge for long periods of time requiring frequent system charging and reducing its frequent demonstration potential.

5.3. Alternatives

As demonstration tools for K-12 students, different systems could be either purely software or purely hardware based. Projects that are software based can be used to encourage interest in computer science related fields whereas purely hardware based systems can feature mechanical systems that are controlled electronically such as robotics which are able to take user input and respond accordingly. For this particular system, instead of using DC-DC conversion, DC-AC conversion could be used to demonstrate the concept of AC power will is more prevalent in power distribution systems due to its less lossy propagation opposed to DC power.

5.4. Impact

Since this system is used for educational purposes, the impact of this system is to demonstrate to students the concept of renewable energy via solar radiation and how it can be used as a power source as the world transitions to cleaner energy. Additionally, it will hopefully capitalize on the creativity of young students and encourage them to pursue careers in STEM, providing innovative solutions to the ever growing list of problems that society faces in the age of electrification and digitization. Some ethical concerns of the system is that it can also be used as a way to discourage students in the pursuit of STEM. If the system's complexity is too deeply elaborated on, it can drive away student interest as their lack of understanding might create fear and distrust in their abilities to learn STEM concepts and might provide the opposite of the intended effect.

Creating STEM Contents: Solar Power with a Tracking System

Leo Predanic
George Thuita
Brandon Cenci

FUNCTIONAL SYSTEM REQUIREMENTS

REVISION –
3 October 2022

Functional System Requirements

for

Creating STEM Contents: Solar Power with a Tracking System

Prepared by:

Author	Date

Approved by:

Project Leader	Date

John Lusher, P.E.	Date

T/A	Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	10/3/2022	Leo Predanic, George Thuita, Brandon Cenci		Draft Release

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1. Introduction

1.1. Purpose and Scope

As the demand for engineering solutions increases exponentially, it is imperative to inspire future generations of STEM students by creating captivating demonstration tools to drive their interest and creativity. The goal of this system is to foster this latent interest by being a simple and portable apparatus that is interactable and tracks the system's performance by displaying the information in a digestible format for K-12 students. The Creating STEM Contents (CSC) system will contain a solar power generation solution to drive a physical load that generates visual, tactile, or aural excitations. The system will have an MCU to take various analog measurements and process it to provide relevant data about the system's performance. The MCU will store information into a database where a GUI can read in the data and display figures and animations about system operation. The GUI will also feature interactive controls to set operation modes and control the circuitry. This allows through explanation of the concepts of solar power, electronics, and computer science to the target audience.

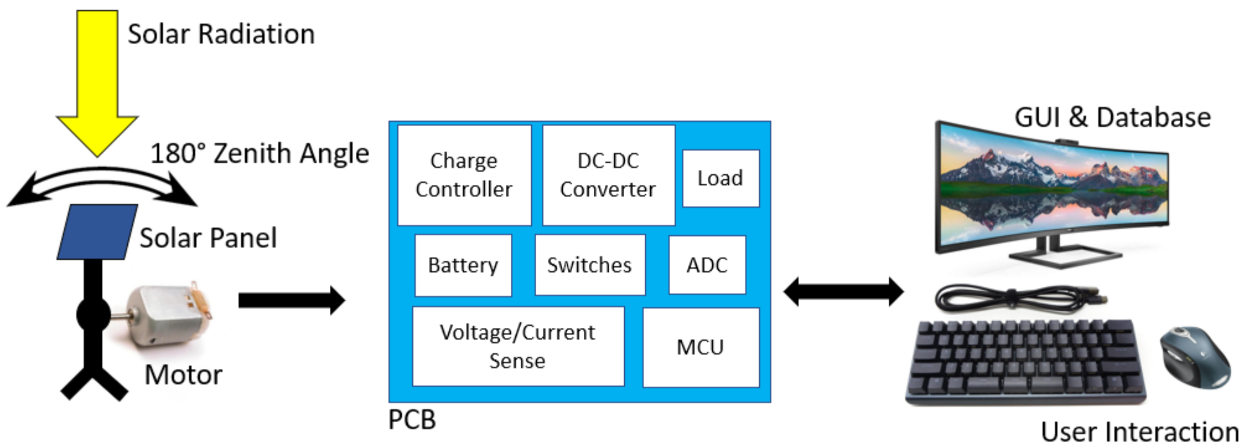

Figure 1: Project Conceptual Image

1.2. Responsibility and Change Authority

The team leader, Leo Predanic, will be responsible for verifying the requirements of the project have been satisfied and will track progress. The requirements can only be changed with the approval of the team leader and Doctor Wonhyeok Jang.

Subsystem	Manager
Solar Power Generation	George Thuita
Electrical I/O	Leo Predanic
GUI and Database	Brandon Cenci

Table 1: Subsystem Partition

2. Applicable and Reference Documents

2.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
NEMA 1	2001	Enclosure, Box, & Cabinet - Rating and Definition
NEC 210.52(E)(1)-(3)	2009	Outdoor Outlets.

Table 2: Applicable Documents

2.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
IEC 60086-4	5/1/2020	Primary Batteries. Safety Standard for Lithium Batteries.
UL 1642	9/29/2020	Safety of Lithium-Ion Batteries - Testing.
ASTM E927-19	2/25/2019	Standard Classification For Solar Simulators For Electrical Performance Testing Of Photovoltaic Devices.

Table 3: Reference Documents

2.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

3. Requirements

3.1. System Definition

The CSC system is a low power, portable solar power system that is used as a demonstration tool for K-12 students to stimulate their latent interest in STEM careers. It has a GUI interface that can interact with a user to control the system as well as track the system’s performance and display that information in a digestible format. Since the system is used as a teaching tool, it will also contain animations that describe the physics and computer science of how the system operates, explaining the engineering concepts that are involved in the operation of the system. The CSC system had three subsystems: Solar Power Generation, Electrical I/O, and the Database, GUI, and System Animations/Aids.

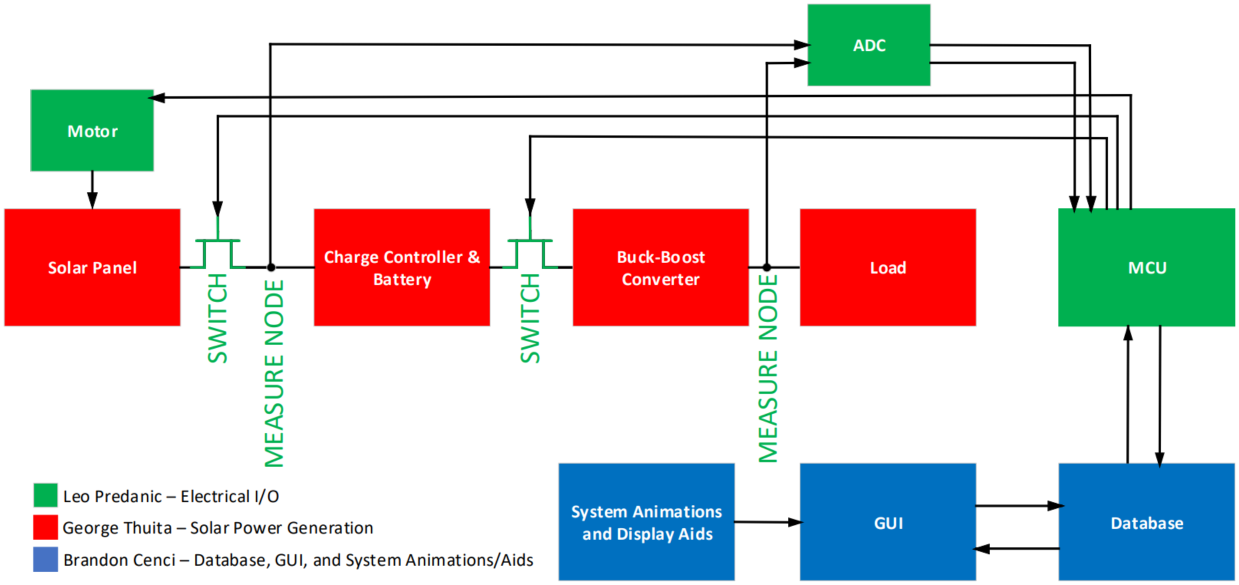

Figure 2: Block Diagram of System

There will be a solar panel that will generate electricity from solar energy. Since the system can't use the power directly from the panel, it will have to charge a battery. To protect the battery, an MPPT charge controller will be used to control the flow of electricity. Between the panel and the controller will be a FET switch to disconnect the two once the battery has completed charging to avoid damaging the system. A motor will also be connected to the stand which the panel is mounted on to control 180 degree rotation across the zenith angle. The battery will then power a buck boost converter which will drive a load that has a visual, tactile, or aural response to demonstrate the flow of power to the K-12 students. Another FET switch will be between the battery and the converter to avoid involuntary discharge of the battery during charging which could have the potential to damage it. An ADC will take voltage readings at the generator and load side. At this node there will also be a current sense resistor. A current sense amplifier will take the differential voltage across it to measure the current flow. The MCU will take both the voltage and current to compute the power. The MCU will then feed this data into a database stored locally on the MCU. A GUI application will read this data in and display it in a digestible format so that K-12 students can understand what is being measured and how it plays into system performance. To further explain system operation, animations will be designed to explain how the system operates. This allows the system to teach and demonstrate all by itself without the need for a STEM instructor. As long as an individual is trained to maintain the system, it will be an independent teaching tool.

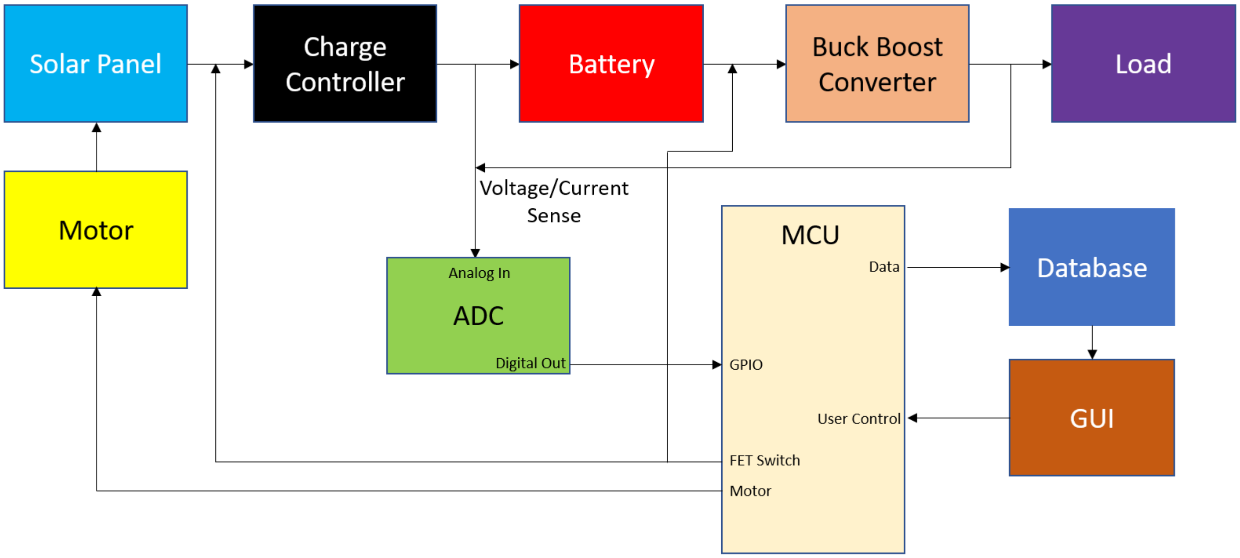

Figure 3: System Flow

3.2. Characteristics

3.2.1. Functional / Performance Requirements

3.2.1.1. System Battery Charge Time

The battery for the system shall take no longer than 12 hours to fully charge.

> *Rationale: The system should be charged fully within the day prior to demonstration otherwise it will not meet the portability and speed aspects of the system goals.*

3.2.1.2. System Battery Discharge Time

The battery for the system shall take no sooner than 2 hours to fully discharge.

> *Rationale: The system should be fully discharged within a demonstration period to be able to make sufficient use of the system charging mode.*

3.2.1.3. Analog Voltage/Current Generator Side Measurement Timing

The ADC will sample the generator side voltage and current for power tracking no less than 10 times per hour.

> *Rationale: Power generation takes a much longer time than power dissipation to prevent unnecessary oversampling and minimize clutter on any power generation figures or graphs that are presented on the GUI.*

3.2.1.4. Analog Voltage/Current Load Side Measurement Timing

The ADC will sample the load side voltage and current for power tracking no less than 50 times per hour.

> *Rationale: Power dissipation is expected to take only several hours. To track accurate power curves, the system must sample load side measurements much more frequently than the generator side.*

3.2.1.5. Motor Rotation Discrete Step Sizing

The motor shall have no less than 10 discrete steps across the 180 degrees of rotational freedom.

> *Rationale: To have sufficient solar coverage across the zenith angle, the step size should be small enough to follow the sun closely enough to maximize the flux across the surface. This allows the system to maximize the amount of solar radiation captured during Single Axis Operation Mode.*

3.2.1.6. Time for System Response

The time delay between GUI interaction and system response shall be no longer than a minute.

> *Rationale: To provide quick feedback to the user about the system performance and operation, the system should be able to communicate from end to end in a reasonable amount of time to be a useful demonstration tool.*

3.2.2. Physical Characteristics

3.2.2.1. System Mass

The mass of the CSC system shall be less than or equal to 10 kg.

> *Rationale: The premise of the CSC system is to be light and portable. 10 kg is a reasonable weight for most adults and older children to safely carry. The system can also be dragged on a wagon for easier movement and storage.*

3.2.2.2. System Area

The system should be able to fit on a table with a minimum size of 30 in by 15 in.

> *Rationale: To support the portability goal of the system, the system should fit on an averaged sized computer desk.*

3.2.2.3. Circuitry and Electronics Area

All used miniaturized electronics and circuitry will have sufficient size to sit on a single PCB.

> *Rationale: To satisfy portability, it is imperative to minimize the number of loose parts. Containing all of the circuits and electronics (excluding the monitor, keyboard, and mouse) shall sit on a PCB for easy transportability.*

3.2.2.4. System Bring-Up

All information for system maintenance and usage shall be provided in a tab within the GUI that can be opened when booting up the system. This is to minimize the amount of loose materials that the system is provided with.

> *Rationale: Having all information available in the GUI makes for simple and easy access to necessary information without need for paper documentation.*

3.2.2.5. Mounting

Mounting information for the solar panel stand shall also be provided in a tab with System Bring-Up. It will also contain details about proper construction and maintenance.

Rationale: See Section 3.2.2.4.

3.2.3. Electrical Characteristics

3.2.3.1. Inputs

The presence or absence of any combination of the input signals in accordance with ICD specifications applied in any sequence shall not damage the CSC system, reduce its life expectancy, or cause any malfunction, either when the unit is powered or when it is not. No sequence of command shall damage the CSC system, reduce its life expectancy, or cause any malfunction.

Rationale: By design, should limit the chance of damage or malfunction by user/technician error.

3.2.3.1.1 Power Consumption

The maximum peak power of the system shall not exceed 25 watts.

Rationale: To ensure the battery and converters maintain both thermal and physical integrity, the maximum power output of the system will not exceed a maximum of 25 W to prevent exceeding the rating limits of the system components.

3.2.3.1.2 MCU Input Voltage and Current Level

The input voltage and current level for Raspberry Pi MCU shall be 5V 3A DC. This will be generated through an adaptor from 100-240V 50-60Hz AC wall outlet power.

Rationale: Raspberry Pi 4 Model B Electrical Specification.

3.2.3.1.3 External Commands

The CSC system shall document all external commands in the appropriate ICD.

Rationale: The ICD will capture all interface details from the low level electrical to the high-level packet format.

3.2.3.2. Outputs

3.2.3.2.1 Data Output

The CSC system has output voltage, current, and power data from the system generator and load sides to a CSV based database that is stored locally on the MCU.

Rationale: To keep all data on the MCU allows the for system to operate without the need for any internet connectivity. This also allows the user to operate the system without a laptop or desktop computer.

3.2.3.2.2 Diagnostic Output

The CSC System shall include a diagnostic interface for control and data logging.

Rationale: Provides the ability to control things for debugging manually and a way to view/download the node map with associated potential targets.

3.2.3.2.3 Raw Video Output

The CSC System central unit may include a raw video interface to support external recording.

> *Rationale: Since the system will have bring-up, usage, and maintenance information, any necessary videos to accompany these documents shall be stored on the MCU.*

3.2.3.3. Connectors

The CSC system shall use external connectors in accordance with the NEMA 1 Rating.

> *Rationale: This is a requirement of the MCU and monitor power specification. In order for safe operation, the connector should be used in scenarios that are safe in a NEMA 1 standard.*

3.2.3.4. Wiring

The CSC system shall only use outdoor receptacles during charging mode that are in accordance with NEC 210.52(E)(1)-(3).

> *Rationale: Similar rationale to Section 3.2.3.3. Additional standards here are for safe use receptacles in outdoor environments.*

3.2.4. Environmental Requirements

The CSC System shall be designed to withstand and operate in the environments and laboratory tests specified in the following section.

> *Rationale: The CSC system will need to be able to charge outdoors in conditions similar to Bryan-College Station, Texas.*

3.2.4.1. Pressure (Altitude)

The CSC system shall be able to function correctly at altitudes ranging from sea level to 500 ft above sea level.

> *Rationale: See Section 3.2.4.*

3.2.4.2. Thermal

The CSC system shall be able to function correctly at temperatures ranging from 0 degrees Fahrenheit to 110 degrees Fahrenheit.

> *Rationale: These are temperatures consistent with average temperatures during the summer and winter months of Bryan-College Station, Texas.*

3.2.4.3. Humidity

The CSC system shall be able to function correctly at humidity levels between 0 and 100% humidity.

> *Rationale: These humidity levels are consistent with levels found in Bryan-College Station, Texas.*

3.2.5. Failure Propagation

The CSC System shall not allow propagation of faults beyond the CSC system interface.

3.2.5.1. Failure Detection, Isolation, and Recovery (FDIR)

The CSC system may have failure detection as a failsafe during system bring-up to ensure safe and proper operation. When the system is booted up, the switches will be set in off mode to ensure that there is no unexpected discharge. The ADC will sample voltage and currents at the measure nodes to ensure that the system is not letting power flow. The motor will be shut off to ensure that there will be no harm caused by unexpected mechanical motions. The system charge will be assessed to determine if the battery is in a safe condition to operate. If any of these checks are unsuccessful, the GUI will display a message indicating that the system might not be in a safe state to operate and advise professional assistance to determine the issue.

3.2.5.1.1 Built In Test (BIT)

The CSC System shall have an internal subsystem that will generate test signals and evaluate the CSC system responses and determine if there is a failure.

3.2.5.1.1.1 BIT Critical Fault Detection

The BIT shall be able to detect a critical fault in the CSC system 90 percent of the time.

> *Rationale: This will allow the CSC system to access system operation quality and alert the user if a fault occurs and warn the user not to operate the system.*

3.2.5.1.1.2 BIT False Alarms

The BIT shall have a false alarm rate of less than 10 percent.

> *Rationale: Limiting the number of false alarms is important to ensure the system can operate when it is safe to operate.*

3.2.5.1.1.3 BIT Log

The BIT shall save the results of each test to a log that shall be stored in the CSC system for retrieval and clearing by maintenance personnel.

> *Rationale: This will be used as a diagnostic for the user to track system operation quality and health over time and determine if the system has components that should be replaced.*

3.2.5.1.2 Isolation and Recovery

The CSC system should provide for fault isolation and recovery by enabling subsystems to be reset or disabled based upon the result of the BIT.

> *Rationale: In order to protect the user if the integrity of any component is at risk of being compromised, the system will notify the user and shut down or reset depending on the issue.*

4. Support Requirements

The CSC system requires access to a monitor, keyboard, and mouse for the usage of the Raspberry Pi as well as access to a wall outlet to power it. Users should verify that the system is on a clear surface without any clutter to safely operate the system. A wall outlet should be in near proximity to power the monitor and RPI. The system is comprised of (1) single-board computer, (1) solar panel, (1) solar panel rotatable stand, (1) motor, (1) MPPT charge controller, (1) buck boost converter, (1) load network, (2) ADCs, (2) current sense amplifiers, (2) current sense resistors, (2) FET switches, (1) monitor, (1) keyboard, and (1) mouse.

Appendix A: Acronyms and Abbreviations

A	Amp (Ampere)
AC	Alternating Current
ADC	Analog-to-Digital Converter
BIT	Built-In Test
CCA	Circuit Card Assembly
CSC	Creating STEM Contents
CSV	Comma Separated Values
DC	Direct Current
FET	Field-Effect Transistor
ft	Foot (Feet)
GUI	Graphical User Interface
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
in	Inch
I/O	Input/Output
K-12	Kindergarten through 12th Grade
kg	Kilogram
LED	Light-emitting Diode
mA	Milliamp
mW	Milliwatt
MCU	Main Control Unit
MPPT	Maximum Power Point Tracking
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
mW	Milliwatt
PCB	Printed Circuit Board
PMOS	P-type Metal-Oxide Semiconductor
RPI	Raspberry Pi
SBC	Single-Board Computer
STEM	Science, Technology, Engineering, and Mathematics
TBD	To Be Determined
V	Volt
W	Watt

Appendix B: Definition of Terms

Appendix C: Interface Control Documents

Creating STEM Contents: Solar Power with a Tracking System

Leo Predanic
George Thuita
Brandon Cenci

Interface Control Document

REVISION –
3 October 2022

Interface Control Document

for

Creating STEM Contents: Solar Power with a Tracking System

Prepared by:

Author	Date

Approved by:

Project Leader	Date
John Lusher II, P.E.	Date
T/A	Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	10/3/2022	Leo Predanic, George Thuita, Brandon Cenci		Draft Release

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1. Overview

This document will serve to provide detail on how the solar power generation circuitry, ADC, switches, motor, MCU, monitor, keyboard, and mouse will interface. All relevant input, outputs, connections, and how each is controlled will be discussed. First, information on the physical aspects of the system will be provided. This will be followed up by a discussion of thermal and electrical interfaces. Here, in depth detail will be provided on the operation of the system at the block level. Finally, there will be discussion on the communication methodology between the system and the user.

2. References and Definitions

2.1. References

NEMA 1
Enclosure, Box, & Cabinet - Rating and Definition.
2001

NEC 210.52(E)(1) - (3)
Outdoor Outlets.
2009

IEC 60086-4
Primary Batteries. Safety Standard for Lithium Batteries.
5/1/2020

UL 1642
Safety of Lithium-Ion Batteries - Testing.
9/29/2020

ASTM E927-19
Standard Classification for Solar Simulators for Electrical Performance Testing of Photovoltaic Devices.
2/25/2020

2.2. Definitions

AC	Alternating Current
ADC	Analog-to-Digital Converter
CSC	Creating STEM Contents
DC	Direct Current
FET	Field-Effect Transistor
in	Inch
g	Gram
GUI	Graphical User Interface
mA	Milliamp
mm	Millimeter
mW	Milliwatt
PCB	Printed Circuit Board

TBD To Be Determined
V Volt
W Watt

3. Physical Interface

3.1. Weight

3.1.1. Weight of Solar Power Generation Circuitry

Component	Weight	Quantity	Total Weight
Solar Panel	17g	1	17g
Battery	TBD	1	TBD
Charge Controller	TBD	1	TBD
Buck Boost Converter	TBD	1	TBD
DC Load	TBD	1	TBD
PCB	TBD	1	TBD

Table 1: Weight of Solar Power Generation Circuitry

3.1.2. Weight of MCU and Electrical I/O Interface

Component	Weight	Quantity	Total Weight
Raspberry Pi 4 B (MCU)	TBD	1	TBD
DC 5V 3A Micro USB Power Adaptor	TBD	1	TBD
ADC	TBD	TBD	TBD
Motor	TBD	1	TBD
FET Switch	TBD	2	TBD

Table 2: Weight of MCU and Electrical I/O Interface

3.1.3. Weight of User Interface

Component	Weight	Quantity	Total Weight
Monitor	TBD	1	TBD
Keyboard	TBD	1	TBD

Mouse	TBD	1	TBD

Table 3: Weight of User Interface

3.2. Dimensions

3.2.1. Dimensions of Solar Power Generation Circuitry

Component	Length	Width	Height
Solar Panel	2.75 in	2.165 in	0.059 in
Battery	2.07 in	1.37 in	0.23 in
Charge Controller	63 mm	33 mm	TBD
Buck Boost Converter	3 mm	3 mm	0.75 mm
DC Load	TBD	TBD	TBD
PCB	TBD	TBD	TBD

Table 4: Dimensions of Solar Power Generation Circuitry

3.2.2. Dimensions of MCU and Electrical I/O Interface

Component	Length	Width	Height
Raspberry Pi 4 B (MCU)	3.4 in	2.2 in	0.4 in
DC 5V 3A Micro USB Power Adaptor	TBD	TBD	TBD
ADC	0.75 in	0.25 in	0.13 in
Motor	TBD	TBD	TBD
FET Switch	TBD	TBD	TBD

Table 5: Dimensions of MCU and Electrical I/O Interface

3.2.3. Dimensions of User Interface

Component	Length	Width	Height
Monitor	TBD	TBD	TBD
Keyboard	TBD	TBD	TBD
Mouse	TBD	TBD	TBD

Table 6: Dimensions of User Interface

3.3. Mounting Locations

The CSC system will need to be small enough to total fit on an average computer desk. The monitor, keyboard, and mouse will take up the largest space on the desk so the PCB and solar panel stand have to occupy minimal area to allow the entire system to operate on a desk. Additionally, to access power for the MCU and the monitor, the desk will need to be situated near a wall outlet for mains AC power.

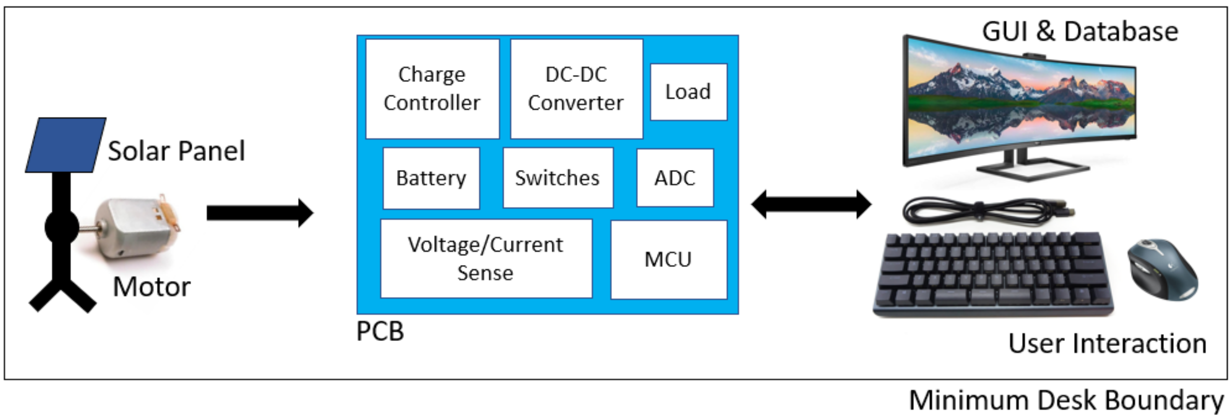

Figure 1: Suggested Mounting Scheme

4. Thermal Interface

The solar panel is the main thermal interface of this design. The Silicon based photovoltaic cell is most efficient in the temperature range of 54-95 degrees Fahrenheit. Temperatures above this range will result in decreased efficiency. No active or passive cooling method will be used for the solar panel. The Raspberry Pi will be exposed to the heat from the sun, and will also generate its own heat while processing I/O and storing data. The Raspberry Pi will be contained in a kit provided by the Canakit corporation. This kit contains a heatsink, a fan, and a case with the necessary dimensions and ports to maintain positive air pressure inside the kit for the most efficient cooling. The buck boost converter will only need a heatsink to dissipate the heat generated by operation. A heatsink may be installed on the buck boost converter to help it dissipate heat.

5. Electrical Interface

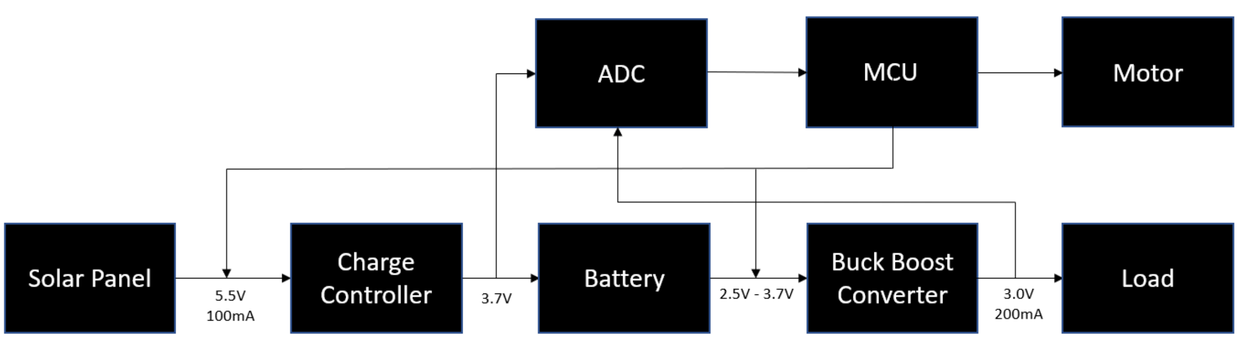

Figure 2: Electrical Interface Diagram

5.1. Primary Input Power

5.1.1. Solar Power Generation Subsystem Power Delivery

The entire solar power generation subsystem will be powered from the energy generated by the solar panel and stored in the battery.

5.1.2. MCU Power Requirement

The MCU will be powered from a 100-240 V receptacle located near the system. The MCU will be able to provide additional power to any modules on the PCB that are not powered by the battery such as the ADC, motor, and FET switches.

5.1.3. Monitor Power Requirement

The monitor will be powered from a 100-240 V receptacle. This means the CSC system will require a total of two wall outlets to power.

5.2. Voltage and Current Levels

5.2.1. Maximum Values

Component	Voltage	Current	Power
Solar Panel	5.5 V	100 mA	550 mW
Charge Controller	3.7 V	TBD	TBD
Battery	4.2 V	TBD	TBD
Buck Boost Converter	3 V	200 mA	600 mW
Raspberry Pi 4 B (MCU)	5 V	3 A	15 W

Table 7: Maximum Voltage and Current Levels of Power Providing Blocks

5.3. Signal Interfaces

5.3.1. Raspberry Pi GPIO Interface

The ADC, switches, and motor will be controlled via the GPIO pins available. Any additional required controls or power delivery to individual modules will be provided by the Raspberry Pi GPIO pins.

5.4. User Control Interface

The user control interface will be the GUI application that communicates with the database and the MCU. Additionally, it will feature controls to adjust the mode of operation and display data that the MCU measures to track the system performance.

6. Communications / Device Interface Protocol

6.1. Device Peripheral Interface

Connection to the keyboard, and mouse will be provided by a standard Universal Serial Bus (USB) port located on the MCU. Connection to the monitor will be provided by a High-Definition Multimedia Interface (HDMI) port also located on the MCU.

Creating STEM Contents: Solar Power with a Tracking System

Leo Predanic
George Thuita
Brandon Cenci

EXECUTION AND VALIDATION

REVISION –
3 October 2022

Execution and Validation

for

Creating STEM Contents: Solar Power with a Tracking System

Prepared by:

Author Date

Approved by:

Project Leader Date

John Lusher, P.E. Date

T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	10/3/2022	Leo Predanic, George Thuita, Brandon Cenci		Draft Release

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1. Execution Plan

Complete by Date	Solar Power Generation	Electrical I/O	GUI, Database, and Animations	Status
10/14/22	90% completion of buck boost converter and load simulations.	MCU is integrated with ADC. Can take sample voltage measurements.	70% Database setup.	Incomplete
10/21/22	Finalize simulations and select passive components.	Current sense resistor and amplifier are implemented. ADC can read sample current measurements.	100% Database setup. Can write and read sample data.	Incomplete
10/28/22	Order passive components and begin PCB design.	MCU can control switching functionality.	30% GUI complete.	Incomplete
11/4/22	25% PCB Design Complete.	MCU can process and output voltage, current, and power data.	90% GUI complete.	Incomplete
11/11/22	50% PCB Design Complete.	MCU can control motor functionality.	100% GUI complete. 30% system description animations complete.	Incomplete
11/18/22	90% PCB Complete.	Initial full subsystem integration testing.	90% system description animations complete.	Incomplete
11/22/22	100% PCB Completed and design review with team. Full subsystem Verification.	Subsystem Verification. PCB Design Review.	100% system description animations complete. Fully user interactable. Full subsystem verification.	Incomplete

12/2/22	Demo.	Demo.	Demo.	Incomplete

Table 1: Execution Plan

2. Validation Plan

Task	Specification	Result	Owner
Peak Solar Panel Output Voltage	5.5 V	Untested	George Thuita
Charge Controller Output Voltage	3.7 V	Untested	George Thuita
Minimum Full Battery Capacity Charge	900 mAh	Untested	George Thuita
Input Voltage Range - Buck Boost Converter	2.5 - 3.7 V	Untested	George Thuita
Output Buck Boost Converter Voltage	3 V	Untested	George Thuita
Maximum Battery Charge Time	12 hours	Untested	George Thuita
Minimum Battery Discharge Time	2 hours	Untested	George Thuita
Maximum Switch Response Time	15 seconds	Untested	Leo Predanic
Maximum ADC Measurement Time	15 seconds	Untested	Leo Predanic
Minimum Motor Response Time	15 seconds	Untested	Leo Predanic
Maximum Current Sense Amplifier Measurement Time	15 seconds	Untested	Leo Predanic
Minimum Motor Step Size	18 degrees	Untested	Leo Predanic
Sample Data Read/Write in	Yes/No	Untested	Brandon Cenci

Database			
GUI Data Read-In From Database	Yes/No	Untested	Brandon Cenci
Functional User Interaction System Response	Yes/No	Untested	Brandon Cenci

Table 2: Validation Plan