# SOLAR LIGHTING SYSTEM

Lyric Haylow

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# FINAL REPORT

REVISION – 3

30 April 2024

# FINAL REPORT

# FOR

# Solar Lighting System

TEAM 60

APPROVED BY:

Project Leader Date

Prof. Pranav Date

T/A Rhett Guthrie Date

# Table of Contents

# SOLAR LIGHTING SYSTEM

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# CONCEPT OF OPERATIONS

REVISION – 3

30 April 2024

# Change Record

| Rev. | Date | Originator | Approvals | Description |
|---|---|---|---|---|
| **1** | 08/29/2023 | Team 60 | JM, JG, LH | Draft Release |
| **2** | 09/28/2023 | Team 60 | JM, JG, LH | Draft Revision |
| **3** | 04/30/2024 | Team 60 | JM, JG, LH | Final Submission |

# List of Tables

# List of Figures

# 1. Executive Summary

The purpose of this project is to offer a simple and reproducible solution to address growing environmental concerns by utilizing renewable energy and sensors to reduce power consumption. The problem being addressed with this scope of work is the need for distributed off-grid power solutions to lessen burden on the current grid demand. Our aim is to develop a solar lighting system for two places in a house: the foyer (indoor) and the porch (outdoor). The panel gets energy from the sun and stores it in a battery for the lights. Sensors are used to determine when to turn on lights in both places. Outdoor lights can use motion sensors along with location data to turn on only at night. Indoor lights can use motion sensors to avoid unnecessary triggers by pets. For remote operation, a mobile application is provided for displaying system status and input from the users for their preferences.

# 2. Introduction

This document is an introduction to a Solar Lighting System (SLS), a system which makes use of renewable energy and sensors to provide a light source to several areas of the house with a sustainable source of energy. The outdoor light will turn on when motion activated and only during the night, illuminating people or small animals moving around in a dedicated space. The indoor lighting system will be motion activated as well, operating throughout all hours of the day. The entire system will be environmentally clean, limiting excess damage to our atmosphere from the usage of nonrenewable sources. An app will be implemented with the system, supplying the user with preferential control over the lights. Additionally, implementation of solar energy will provide homeowners with potential tax credits.

## *2.1. Background*

The world relies primarily on nonrenewable sources of energy such as coal, oil, and natural gas to run countless systems. It is no secret that these sources can have harmful effects on our environment. In 2010, coal alone contributed to 35% of the United States' emissions of carbon dioxide into the atmosphere. In addition to this, burning petroleum releases an abundance of harmful emissions and chemicals into the air and contaminates nearby ecosystems. The need for clean, renewable sources of energy is more apparent than ever, and yet many hesitate to make the change due to concerns about potential declines in efficiency or the difficulty in implementing such a system.

The Solar Lighting System (SLS) intends to provide environmentally clean, economically efficient, and easy-to-use indoor and outdoor lighting systems to potential homeowners. This system aims to replace active systems relying on city or state-wide power grids with a much more localized, environmentally friendly option. Although the positive environmental benefits of solar energy are well known, some consumers may be concerned about the budgetary risks or long-term performance of these panels. Solar panels typically last between 25 to 30 years before degrading in efficiency; in that time, homeowners may expect savings of up to $1,500 a year after switching from their existing power provider. Additionally, the Federal Tax Credit (2022) offers a 26% rebate on the installation of solar panels.

## 2.2. Overview

The SLS will integrate solar panels and a battery to provide light to a variety of areas in a house. The panels will absorb light from the sun during the day and provide energy to the battery in an efficient manner.

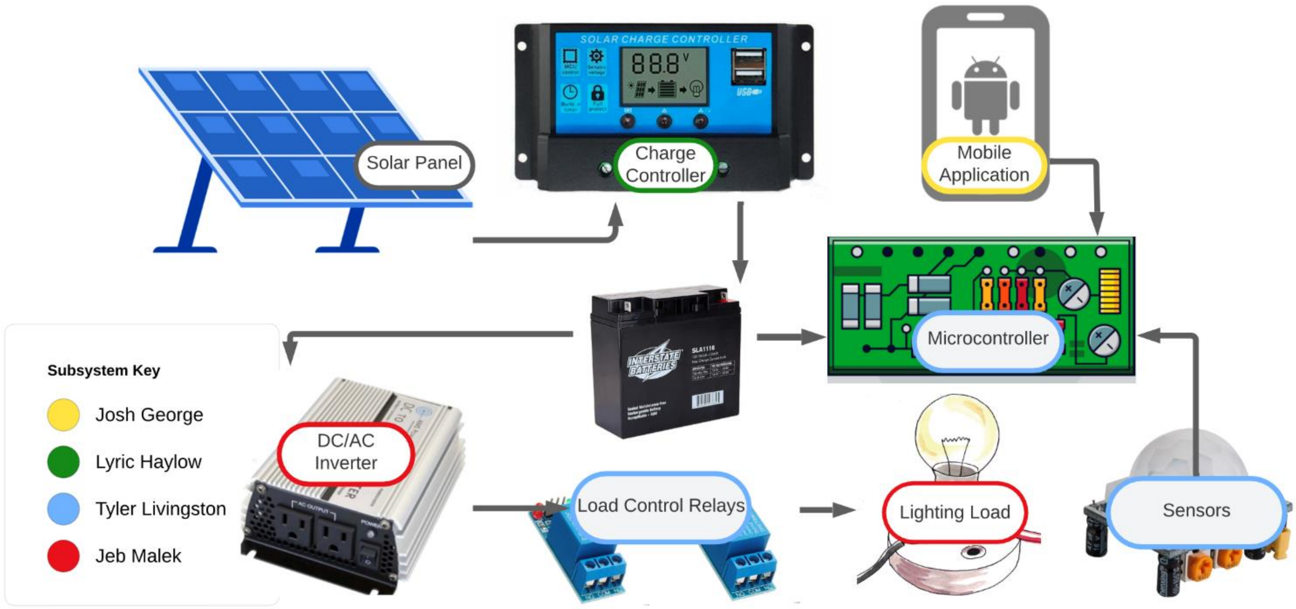



**Figure 1. Subsystem Diagram**

## 2.3. Referenced Documents and Standards

"IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems - Redline," in IEEE Std 937-2019 (Revision of IEEE Std 937-2007) - Redline , vol., no., pp.1-45, 28 Feb. 2020.

"IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces," in *IEEE Std 1547-2018 (Revision of IEEE Std1547-2003) , pp.1-138, 6 April 2018, doi: 10.1109/IEEESTD.2018.8332112.*

"IEEE Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems," in *IEEE Std 1562-2007* , pp.1-32, 12 May 2008, doi: 10.1109/IEEESTD.2008.4518937.

# 3. Operating Concept

## *3.1. Scope*

The Solar Lighting System (SLS) is intended to allow commercial consumers of electricity to easily use renewable energy to power a lighting system in their homes. Two sets of lighting fixtures, along with corresponding sensors for those lights, will be installed in the patio and the foyer of a home. For ease of use, sensors are provided so that the system is powered at opportune times, without the need for manual interaction. They'll primarily be motion sensors, with programs designed to recognize people rather than animals, or moving objects. The sensors will be connected to an app through Bluetooth for the purpose of manual and remote control of light switches. All systems within the house will be in turn powered by a solar panel that is set to charge the battery as needed when solar power is available. The system is intended primarily for commercial use in houses; however, it could be upscaled to industrial use.

## *3.2. Operational Description and Constraints*

This solar lighting system is intended to be used by the average homeowner in an area with ample sunlight. Solar panels will be installed on a high, unobscured surface outdoors. Motion sensors will be installed indoors and outdoors to activate lights. An app will control light preferences and provide data for battery and lights.

The following constraints are needed for this system:

- Direct sunlight will be needed in the installation spot for the solar panel.
- A direct line of sight will be needed for the motion sensors. Indoor motion sensors will need to be established to avoid accidental triggering by pets.
- A separate device will be necessary for app implementation. This device will need to be near the system to connect.

## *3.3. System Description*

- **Solar Panel:** This subsystem will send power to the battery charge controller, and power the whole system. The solar panel will charge the battery during the day until it reaches a full charge. A singular solar panel will be used, and placed preferably in a location that will get a large amount of sunlight, such as on a roof.
- **Battery Network:** The battery network system is comprised of a battery charge controller and the battery itself. The battery charge controller will ensure that the battery will not get overcharged or fed too quickly, and the battery will power the entire system during operational hours.
- **Microcontroller:** The microcontroller subsystem will interface with each individual component within the system other than the solar panel and battery. It will manage the sensor inputs and mobile app instructions, and in turn control the Load Control switches for the lights.
- **Sensors:** While the system is in automatic mode, it will be triggered by motion sensors, both in the foyer and the patio. The motion sensors will be programmed to recognize only movements made by people, rather than pets or a random moving object. Both the foyer and the patio will be using the same sensors and programmed to behave the same.

- **Lights:** The lights used will differ based on the location they are in and for what purpose they are being used. In the foyer, 3 LED lights will be set up to be activated by the motion sensors in that area and have a manual switch in the foyer. An outdoor light will be set up in the patio, though this one will only be activated by a manual switch and by the motion sensors for a limited time. An additional smaller LED light will be set up above the door of the patio, to be kept on whenever the app receives a signal that it has become appropriately dark.
- **Mobile Application:** The mobile app will be designed on Android Studio and will be able to connect to the SLS using Bluetooth. Data regarding panel irradiation and battery levels will be provided to the user through the app. The user will also be able to set their lighting preferences and modes with the app. The app will track sunlight and weather data in the user's location to determine when the lights and certain sensors should be active.

## *3.4. Modes of Operations*

The Solar Lighting System will have two modes of operation that it functions from: 'Automatic' and 'Manual'. The mode of operation can be controlled by a manual switch attached to the MCU, as well as by the app.

- **Automatic:** The SLS will function without need for constant interaction and will work until fault. Both the inside foyer lights as well as the outside patio lights will be triggered by any motion picked up from their respective motion sensors.
- **Manual:** The SLS can also be operated manually, triggering lights and sensors with a switch. The inside and outside lights can be operated either with a physical switch or a switch within the app.

## *3.5. Users*

This Solar Lighting System is intended for the everyday homeowner wishing to reduce their impact on the environment regarding carbon footprints, as well as diminish the cost of their utility bills. It will be designed such that the average person should have no issues with installation or use.

## *3.6. Support*

Support for the Solar Lighting System will be provided through a user manual and online support through the developed app. The user manuals will come with easy-to-understand installation instructions, with additional documentation for each subsystem to help with troubleshooting. Online support through the app will come with frequently asked questions and their answers, and another copy of the user manual in PDF format.

# 4. Scenarios

## *4.1. Porch*

Whenever the light sensor detects that it is dark, a small light will illuminate the entrance from the porch to the house. If some unidentified object triggers the motion sensor, a light will turn on illuminating the porch. The user will be able to customize when these lights turn on using the app.

## *4.2. Foyer*

Whenever the user enters or exits the foyer, the motion sensor will turn on or turn off the light. The app can also be used to control this light according to the users' preferences.

## *4.3. Rooftop*

Solar panel should be mounted on the southern facing side of a user’s installation site. This will ensure the most efficient operation of the cell for the desired power rating.

# 5. Analysis

## *5.1. Summary of Proposed Improvements*

The Solar Lighting System promises a variety of benefits, including:

- The system will be solar powered, providing environmentally clean and self-sustaining energy.
- The outdoor lights will only be active at night, limiting resource consumption during the day.
- Motion sensors will be implemented for indoor and outdoor lighting systems, limiting resource consumption when there is no one around. The outdoor motion sensor will be implemented with an outdoor light, illuminating moving objects when it is dark.
- Homeowners will save money over time from smaller energy bills and tax credits.
- The solar panels will last 25 to 30 years before degrading in efficiency.
- The app will provide an easy-to-use interface for consumers to interact with the system. The interface will display light and battery data and will also allow users to set preferences and modes.

## *5.2. Disadvantages and Limitations*

The Solar Lighting System has a few limitations, including:

- The sunlight received by the solar panel can vary based on location and weather patterns. This causes the energy source to be intermittent.
- The initial cost of the system will be substantial.
- Once the old panels degrade, new ones will have to be installed.
- The app will require a device with Bluetooth capabilities.

## *5.3. Alternatives*

Some alternatives to the Solar Lighting System are:

- Staying with the existing system provided by a power grid. This requires no extra installation costs or difficulties but will not save money over time and will not necessarily be clean.
- Switching to another form of renewable energy to power the lights. Solar power is currently the most commercially available form of renewable energy. Any other installations will be difficult to engineer and incredibly expensive.

## *5.4. Impact*

Three key impacts of this system are reduced greenhouse gas emissions, renewable energy sourcing, and economic relief. There are few environmental or ethical concerns about solar panels, only concerns regarding their efficiency and cost. The global impact of the SLS increases as the number of consumers increases.

# SOLAR LIGHTING SYSTEM

Lyric Haylow

Jeb Malek

Josh George

# FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – 3

3 December 2023

# FUNCTIONAL SYSTEM REQUIREMENTS

FOR

# Solar Lighting System

PREPARED BY:

_______________________________

Team 60 Date

APPROVED BY:

_______________________________

John Lusher, P.E. Date

_______________________________

T/A Zhewen Date

# Change Record

| Rev. | Date | Originator | Approvals | Description |
|---|---|---|---|---|
| - | 09/28/2023 | Team 60 | | Draft Release |

# Table of Contents

# List of Tables

## List of Figures

# 1. Introduction

## *1.1. Purpose and Scope*

Providing power for the everyday activities that an average household consumer does can cost a significant amount of money. To lower electricity costs, as well as help make our power sources cleaner, we offer the Solar Lighting System (SLS). This project is intended to use solar energy to power a lighting system that can be used throughout both night and day. The solar panel will actively charge a 12V 18Ah battery, and through a microprocessor controlling multiple sensors, lights appropriate for the time of day will turn on. We'll be lighting both the inside foyer and the outside patio. Motion sensors will be in both locations to turn on the lights as needed based on detected movement, and appropriate software will be applied to ensure only people are registered as valid moving objects. An additional light will be installed in the patio area, to be controlled by the motion sensors, and a standalone light will be on constantly at night. Our system will limit the need for directly turning on lights that are used in high traffic areas and help with the utility bill of the consumer.

**Figure 1. Solar Lighting System Conceptual Image**

The following definitions differentiate between requirements and other statements.

| | |
|---|---|
| Shall: | This is the only verb used for the binding requirements. |
| Should/May: | These verbs are used for stating non-mandatory goals. |
| Will: | This verb is used for stating facts or declaration of purpose. |

## *1.2. Responsibility and Change Authority*

Josh George, our team leader, will be responsible for the confirmation of requirements being met. The requirements will only be changed with approval from the team leader and Wonhyeok Jang.

| Subsystem | Responsibility |
|---|---|
| Battery Charger | Lyric Haylow |
| Power Delivery | Jeb Malek |
| Microcontroller | Jeb Malek |
| Mobile App | Josh George |

**Table 1. System Responsibility**

# 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 |
|---|---|---|
| ANSI C119.6-2011 | May 5, 2011 | American National Standard for Electric Connectors |
| 46 CFR Part 111 Subpart 111.15 | June 4, 1996 | Storage Batteries and Battery Chargers: Construction and Installation |
| IEEE 937 | February 28, 2020 | Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for<br>Photovoltaic (PV) Systems |
| IEEE 1547 | April 6, 2018 | Standard for Interconnection and Interoperability of Distributed Energy Resources with<br>Associated Electric Power |
| IEEE 1562 | May 12, 2008 | Guide for Array and Battery Sizing in Stand-Alone |

**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 |
|---|---|---|
| AN10216-01 | March 24, 2003 | I2C Manual |

**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

This section defines the minimum requirements that the development item(s) must meet. The requirements and constraints that apply to performance, design, interoperability, reliability, etc., of the system, are covered.

## *3.1. System Definition*

The Solar Lighting System is an ecologically clean and fiscally efficient option for lighting various locations of a home environment. It provides electricity to a set of lights indoors and outdoors powered solely by solar energy. The SLS has four primary subsystems: Battery Charger, Power Inverter, Microcontroller, and Mobile Application.

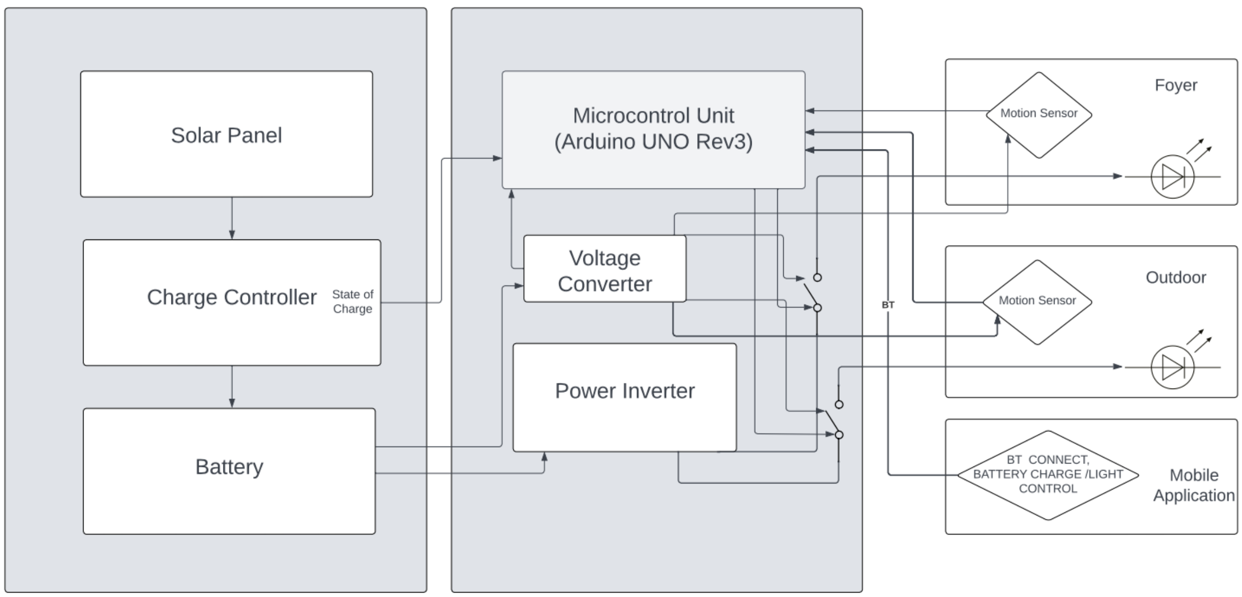



**Figure 2. Block Diagram of Solar Lighting System**

Described in the diagram above are the functional interconnections of the SLS. The figures outlined on the left represent the battery charging subsystem with the battery storage and charge controller grouped with the photovoltaic panel.

## *3.2. Characteristics*

### 3.2.1. Functional / Performance Requirements

#### **3.2.1.1.** Solar Panel Efficiency

The minimum solar power efficiency, the effectiveness at which the panel converts sunlight to electricity, shall be greater than 15%.

> *Rationale: Most commercial panels have efficiencies of at least 15%. Decent solar panel efficiency is required in order to obtain the maximum possible sunlight to electricity conversion. The battery will be charged more with higher efficiency.*

#### **3.2.1.2.** Power Inverter Efficiency

The minimum Power Inverter efficiency shall be 75%.

> *Rationale: It is important to have a relatively high efficiency to avoid wasting energy as the Solar Lighting System is powered finitely via battery.*

#### **3.2.1.3.** Battery Operating Time

The Solar Lighting System shall be able to function for 12-hour period from full battery life.

> *Rationale: Assuming a night cycle of 12 hours, the Solar Lighting System will at a minimum need to function this one-night cycle on one battery charge.*

#### **3.2.1.4.** Indoor Sensor Miss Rate

The Solar Lighting System's indoor sensor shall not exceed a threshold miss rate of 5%.

> *Rationale: This tolerance accounts for the edge cases such as possible misses from an object passing through the edges of the effective range. It also accounts for cases in which users may be carrying objects that block their heat signature from the sensor.*

#### **3.2.1.5.** Outdoor Sensor Miss Rate

The Solar Lighting System's outdoor sensor shall not exceed a threshold miss rate of 10%.

> *Rationale: This increased threshold percentage is to consider the various environmental factors that may affect the sensor's detection. Also, it also considers the edge cases mentioned in Indoor Sensor Miss Rate.*

#### **3.2.1.6.** Response Time

The Solar Lighting System shall have a maximum response time, from sensor detection to light activation, of 2 seconds.

> *Rationale: This limit of a maximum response time is needed to ensure the user's quality of life.*

### 3.2.2. Physical Characteristics

#### 3.2.2.1. Indoor Sensor Placement

The Solar Lighting System's indoor sensor requires installation mounted between 4ft and at most 15ft above the desired detection area on a 90-degree vertical surface, facing the foyer, and out of reach of indoor pets. The user may physically block certain parts of the sensor to modify the FOV and thus modify the height needed.

*Rationale: The sensor will capture little to no movement if installed incorrectly. To ensure proper system functionality, the sensors must be mounted as specified. Additionally, the sensor should be mounted at four or more feet off the ground so that pets are outside the sensor's detection area.*

#### 3.2.2.2. Outdoor Sensor Placement

The Solar Lighting System's outdoor sensor requires installation mounted at least 6ft above desired detection area on a 90-degree surface, facing the desired outdoor area.

*Rationale: The sensor will capture little to no movement if installed incorrectly. To ensure proper system functionality, the sensors must be mounted as specified.*

#### 3.2.2.3. Volume Envelope

The volume envelope of a single light without the solar panel, battery, or sensors shall not exceed 8 cubic inches. The volume envelope of the motion sensors shall not individually exceed 6 cubic inches. The volume envelope of the main control unit, with battery included, shall not exceed one cubic foot.

*Rationale: The light and sensor nodes should be small enough to easily mount on house walls, while also being large enough to not be inconspicuous. The main unit will consist of a solar charge controller, a battery, and a microcontroller to facilitate all activities.*

#### 3.2.2.4. Mounting Location

The Battery Unit falls under the small size battery installations and shall not be located in poorly ventilated spaces, such as closets, or in living spaces, such as staterooms. The lining for lead-acid batteries storage lockers, the lining shall be at least 1.6 mm (1⁄16 inch) thick lead or other material that is corrosion-resistant to the electrolyte of the battery. The main unit including microcontroller and power inverter shall be best located indoors away from contamination.

*Rationale: This mounting information ensures the safe keeping of the battery and components of the Solar Lighting System.*

### 3.2.3. Electrical Characteristics

#### 3.2.3.1. Inputs

a. The presence or absence of any combination of the input signals in accordance with ICD specifications applied in any sequence shall not damage the Search and Rescue

System, reduce its life expectancy, or cause any malfunction, either when the unit is powered or when it is not.

b. No sequence of command shall damage the Solar Lighting 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*

a. The maximum peak power of the system shall not exceed 200 watts.

*Rationale: This is a requirement specified due to constraints of their system in which the Battery Charging System is integrating.*

#### *3.2.3.1.2 Input Voltage Level*

The input voltage level for the Battery Charging System shall be +22 VDC to +29 VDC from the PV Cell.

*Rationale: Inverters, Converters, Controllers, and Interconnection Systems for Use with Distributed Energy Resources UL 1741*

#### *3.2.3.1.3 Input Noise and Ripple*

The input noise and ripple for the Power Inverter shall operate while in the presence of a 1.5 Volt RMS ripple superimposed on the steady-state voltage over the frequency range of 0 Hz to 60 Hz AC.

*Rationale: Inverters, Converters, Controllers and Interconnection Systems for Use with Distributed Energy Resources UL 1741.*

#### 3.2.3.2. Outputs

##### *3.2.3.2.1 Data Output*

The Mobile App shall include an interface displaying general system data.

> *Rationale: Using the mobile app, the user should have convenient and easy access to data such as power consumption, battery life, etc.*

##### *3.2.3.2.2 Sensor Output*

The outputs from the motion sensors and ambient light sensors shall be designed to connect to the microcontroller via wire.

> *Rationale: Wired connection is a standard and relatively easy way to transmit data from sensors to microcontroller.*

#### 3.2.3.3. Connectors

The Solar Lighting System shall be designed following the standard: ANSI C119.6-2011 National Standard for Electrical Connectors

> *Rationale: Conform to connector standards.*

#### 3.2.3.4. Wiring

The Solar Lighting System shall conform to the guidelines in the National Electric Code regarding electrical wiring.

> *Rationale: Conform to wiring standards in the NEC.*

### 3.2.4. Environmental Requirements

The Solar Lighting System shall be designed to withstand and operate in the environments and laboratory tests specified in the following sections.

#### 3.2.4.1. Pressure (Altitude)

The Solar Lighting System shall be designed to operate in altitudes from 0ft (sea level) to 5000ft.

> *Rationale: The Solar Lighting System is being designed and developed with the average city altitude of 2000ft in consideration.*

#### 3.2.4.2. Thermal

The Solar Lighting System shall be designed to operate from -4°F to 122°F. A wide variety of temperatures is necessary considering that the solar panel, as well as the sensors, are located outside and subject to climate changes.

> *Rationale: This is based on temperature specifications of the battery, sensor, and microcontroller.*

#### 3.2.4.3. External Contamination

The Solar Lighting System shall be designed with normal contamination such as dust, pollen, etc. The effectiveness of the system outside of normal contamination will not be guaranteed.

*Rationale: The Solar Lighting System is being designed with the average homeowner's use-case in mind; it should withstand household contamination.*

#### 3.2.4.4. Rain

The Solar Lighting System's solar panel connections shall be designed to withstand rain. The main unit including the battery, inverter, and microcontroller will need to be stored indoors or in an enclosure protected from the rain.

*Rationale: The microcontroller and battery as stated would be best kept indoors away from the elements. The solar panel and its connectors will need to withstand rain as it is outdoors.*

#### 3.2.4.5. Humidity

The Solar Lighting System shall be designed to operate in a humidity range of 0% to 95%.

*Rationale: This humidity range includes the expected humidities of most cities or where households would reside.*

### 3.2.5. Failure Propagation

#### 3.2.5.1. Failure Detection

The microcontroller should be able to detect a critical failure in the Solar Lighting. The microcontroller may identify the user using the mobile app.

*Rationale: The Solar Lighting System is being designed with the average homeowner's use-case in mind; it should withstand household failures.*

# 4. Support Requirements

The user will require a mobile device with Bluetooth connectivity to utilize the Solar Lighting System to its full potential. The user must install the Solar Lighting System including its components.

# Appendix A: Acronyms and Abbreviations

| | |
|---|---|
| EMC | Electromagnetic Compatibility |
| EMI | Electromagnetic Interference |
| EO/IR | Electro-optical Infrared |
| FOR | Field of Regard |
| FOV | Field of View |
| GPS | Global Positioning System |
| GUI | Graphical User Interface |
| Hz | Hertz |
| ICD | Interface Control Document |
| kHz | Kilohertz (1,000 Hz) |
| LED | Light-emitting Diode |
| mA | Milliamp |
| MHz | Megahertz (1,000,000 Hz) |
| MPP | Maximum Power Point |
| MPPT | Maximum Power Point Tracking |
| MTBF | Mean Time Between Failure |
| MTTR | Mean Time To Repair |
| W | Watt |
| mW | Milliwatt |
| PCB | Printed Circuit Board |
| RMS | Root Mean Square |
| SLS | Solar Lighting System |
| TBD | To Be Determined |
| USB | Universal Serial Bus |
| SLS | Solar Lighting System |

# Solar Lighting System

Josh George

Lyric Haylow

Jeb Malek

# INTERFACE CONTROL DOCUMENT

REVISION – Draft

28 September 2023

# INTERFACE CONTROL DOCUMENT

FOR

# Solar Lighting System

PREPARED BY:

Team 60 Date

APPROVED BY:

Team 60 Date

John Lusher II, P.E. Date

T/A Zhewen Date

## Change Record

| Rev. | Date | Originator | Approvals | Description |
|---|---|---|---|---|
| **-** | 9/28/2023 | Team 60 | | Draft Release |

**Table of Contents**

# List of Tables

# List of Figures

# 1. Overview

This document provides a brief overview of how the solar panel cell, solar charge controller, lead-acid battery, power inverter, control unit, and lighting load will interconnect in the Solar Lighting System functionality. First, an explanation of how the panel will link up with the charge controller will be given, along with how that controller will charge the battery. Then, the charge inputs to the microcontroller and the power inverter will be described. The relay from the inverter to the lights will be explained. Finally, the connection of the mobile application to the microcontroller unit will be detailed as well.

# 2. References and Definitions

## *2.1. References*

Refer to section 2.2 of the Functional System Requirements document.

## *2.2. Definitions*

| | |
|---|---|
| A | Ampere |
| MHz | Megahertz (1,000,000 Hz) |
| m | Meter |
| mm | Millimeter |
| N/A | Not Applicable |
| TBD | To Be Determined |
| U/N | Unknown |
| uA | Micro Ampere |
| W | Watt |

# 3. Physical Interface

## *3.1. Weight*

### 3.1.1. Solar Panel and Charge Controller

| Component | Weight (lb/g) | Number of Items | Total Weight(lb/g) |
|---|---|---|---|
| Solar Panel | 16 lb | 1 | 16 lb |
| Battery | 11 lb | 1 | 11 lb |
| Charge Controller | 30 g | 1 | 30 g |

**Table 1 Solar Panel Charging Weight**

### 3.1.2. Power Delivery

| Component | Weight (g) | Number of Items | Total Weight (g) |
|---|---|---|---|
| Converter PCB | 15 | 1 | 15 |
| Inverter | 1179.34 | 1 | 1179.34 |

**Table 2 Power Delivery Weight**

### 3.1.3. Microcontroller Unit

| Component | Weight (g) | Number of Items | Total Weight |
|---|---|---|---|
| Arduino Uno R3 | 25 | 1 | 25 |

**Table 3 Microcontroller and Sensor Weights**



**Table 4. Solar Panel Charging Dimensions**

### 3.1.4. Dimensions of Solar Panel Charging

| Component | Length | Width | Height |
|---|---|---|---|
| Solar Panel | 43in | 17in | 4.5in |
| Charge Controller | TBD | TBD | TBD |
| Battery | 7.13in | 3in | 6.6in |

**Table 4 Power Delivery Weight**

### 3.1.5. Dimensions of Power Subsystem

| Component | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|
| Converter PCB | 50 | 50 | 2 |
| Inverter | 228.6 | 95.25 | 54.102 |

**Table 5. Power Delivery Dimensions [mm]**

### 3.1.6. Dimensions of Microcontroller

| Component | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|
| Ardunio Uno Rev3 | 68.6 | 53.3 | 8 |

**Table 6. Microcontroller and Sensor Dimensions**

## *3.2. Mounting Locations*

Mounting installations include the solar panel, an outdoor motion detector, and an indoor motion detector. Additional items include a battery, a charge control circuit, and a power inverter circuit.

### 3.2.1. Mounting Location of Solar Panel

Mounting the solar panel in a region with low year-round or day-to-day sunlight will yield poor charging capabilities and result in below optimal home lighting. The solar panel must be mounted outdoors on a part of the house high in elevation, preferably on a roof or terrace. The panel must not be obstructed from direct sunlight and securely fastened in an area that is not likely to be overcast by shade. The panel should not be placed too far from the charge controller and battery setup, as increasing the distance between the two will consume more resources.

### 3.2.2. Mounting Indoor Sensor

The indoor motion sensor should be wall mounted in the foyer at least 5 feet from the ground to avoid accidental triggers by household pets. The sensor must be securely fastened to a 90-degree vertical wall and should be mounted near the door in order to activate upon entering or exiting the foyer.

#### 3.2.3. Mounting Outdoor Sensor

The outdoor motion sensor should be mounted in the desired outdoor area, such as a side yard or a backyard. The sensor must be securely fastened to a 90-degree vertical wall and mounted at the desired level to activate outdoor lights.

# 4. Thermal Interface

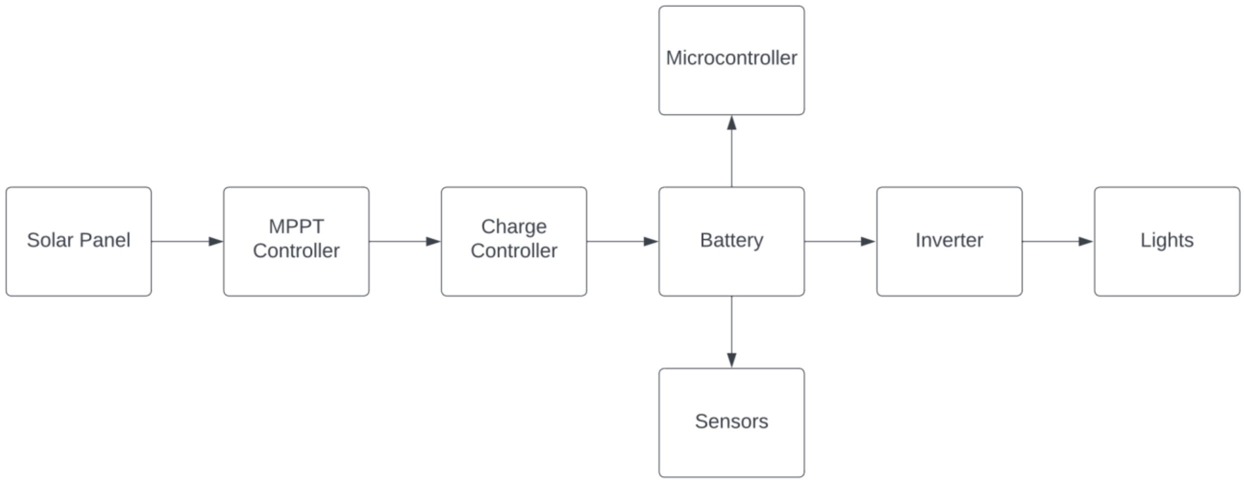
## *4.1. Inverter Cooling*

The Power Inverter will need the use of a DC operated fan for correct ventilation of heat dissipated from switching circuitry.

## *4.2. Battery Cooling*

Sealed Lead Acid batteries come with instructions to keep cells in ambient room temperature with adequate ventilation, which will be validated with waterproof storage design.

# 5. Electrical Interface




- 

**Figure 2. Electrical Interface Diagram**

## *5.1. Primary Input Power*

### 5.1.1. Lights

The lights will primarily be powered by a 12V 18Ah battery that will be relayed to the lights through a power inverter. At full battery capacity, the lights will be able to run for two full days.

### 5.1.2. Microcontroller Unit and Sensors

The battery will provide power to the microcontroller unit and to the sensors. The input voltages of all of these are 3.3V.

## *5.2. Signal Interfaces*

### 5.2.1. Sensors

Below are the following sensors that will be used including the type of sensor and the interface protocol of the output.

| Sensors | Sensor Type | Interface Protocol | Range [m] |
|---|---|---|---|
| EKMB1393111K | PIR (Motion) | Digital | 2.2 |

***Table 6. Sensor Signal Sensitivities***

## 5.3. Voltage and Current Levels

### 5.3.1. Maximum Values

| Component | Voltage [V] | Current [A] | Power [W] |
|---|---|---|---|
| Power Inverter | 12 V | 20 | 200 |
| Microcontroller | 3.6 V | 240 mA | 0.250 |
| Sensors | 4 V | 85 uA | - |
| Lights | 120 V AC | 2 | 80 |

***Table 7. Stand-By Voltage and Current***

The values listed in the table above are placed as referenced for nominal power consumption. Manufacturer data sheets provide interconnection characteristics for safe use of the intended circuit. Power consumption from sensors and microcontroller are negligible compared to rated support from the Power Inverter and Battery Capacity.

### 5.3.2. Converter Values

**Transformer Part: 0200MD-1-003**

| Component | Power [VA] | Current [A] | No Load [V] | Lead Wire[AWG] |
|---|---|---|---|---|
| Power Transformer | 12 V | 20 | 2x129.1 | AWG #20 |
| | | | | |
| | | | | |
| | | | | |

***Table 7. Transformer Values***

## 5.4. User Control Interface

The user control interface will be the mobile application that connects to the microcontroller via Bluetooth. The user's input and preference will be used to adjust modes of lighting motion activations, and settings.

# 6. Communications / Device Interface Protocols

## *6.1. Bluetooth*

The microcontroller utilizes an HC-05 Bluetooth module in order to connect to the app. These protocols will be utilized to connect and transmit data with the mobile application.

## *6.2. Device Peripheral Interface*

The PIR motion sensors will interface digitally directly with the microcontroller. The motion sensor will interface with the microcontroller.

# SOLAR LIGHT SYSTEM

Lyric Haylow

Jeb Malek

Josh George

# SUBSYSTEM REPORTS

REVISION – Final

3 December 2023

# Change Record

| Rev. | Date | Originator | Approvals | Description |
|---|---|---|---|---|
| **1** | 12/3/2023 | Team 60 | | Original Release |

# Table of Contents

# List of Tables

# List of Figures

# SOLAR LIGHT SYSTEM

Lyric Haylow

Jeb Malek

Josh George

# APPLICATION SUBSYSTEM REPORTS

REVISION – Final

3 December 2023

# 1. Application Introduction

The Solar Lighting System (SLS) includes an integrated mobile application designed specifically for Android devices. Developed using the Kotlin programming language on the Android Studios platform, this application serves as the central user interface for the entire SLS. Users will experience seamless interaction with the system. The application acts as a comprehensive gateway, facilitating two-way communication between users and the Solar Lighting System. Users can not only control and manipulate the system through the app but also receive real-time data and updates from the SLS. The user interface is thoughtfully designed to enhance accessibility, providing an array of options for users to customize their experience. From adjusting lighting schedules to monitoring energy consumption, the application delivers a holistic platform for users to engage with the Solar Lighting System effortlessly.

# 2. Application Details

The app comes with a main Home page as well as five individual fragments or sub screens. A flowchart depicting the navigation map of the application is shown below:

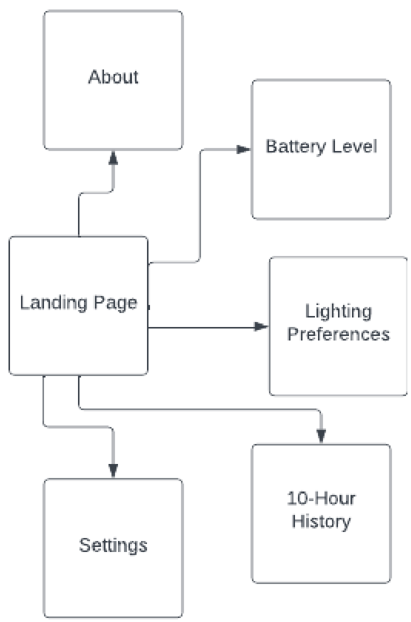



*Figure 1: A navigation map of the mobile application is shown above.*

Upon opening the application for the first time, the user will be met with the Landing/Home screen of the interface, showing the project name in a custom designed logo. A screenshot of the home page is shown below:

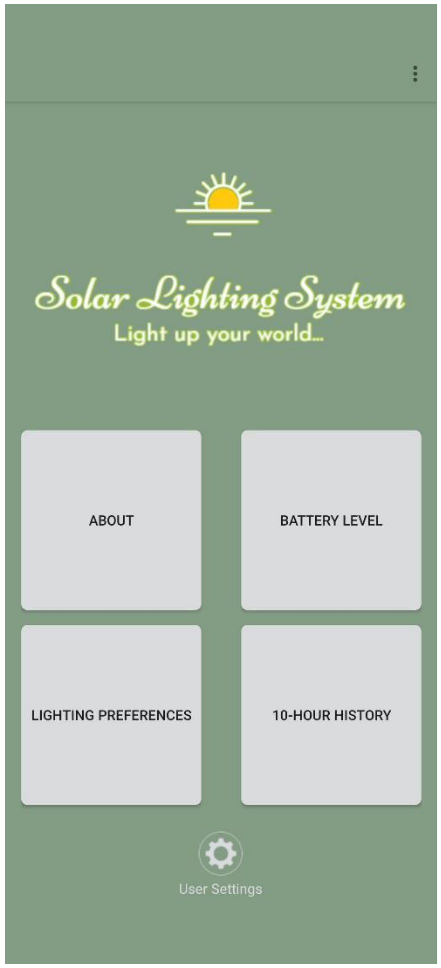



*Figure 2: The opening page of the Solar Lighting System mobile application.*

The landing page displays five silver buttons on a green background with white text throughout. Green and silver theming was primarily chosen to align with the eco-friendly and environmentally safe aspects of our project.

Each button on the home screen leads to a different page within the app. The first button navigates to the “About” screen, which provides a brief description of the project along with a small graphic depicting a solar panel:

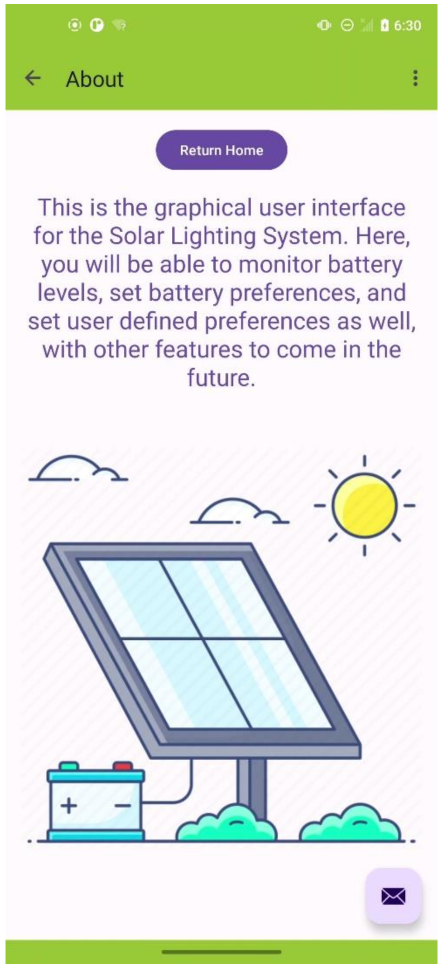



*Figure 3: The about page of the Solar Lighting System mobile application.*

Here a “Return Home” button is visible at the top of the screen along with a back arrow. Both buttons will take the user back to the Home page. These options are available throughout all subpages.

The next page is the “Battery Level” page, in which the user will be able to closely monitor the available charge on the battery of the Solar Lighting System:

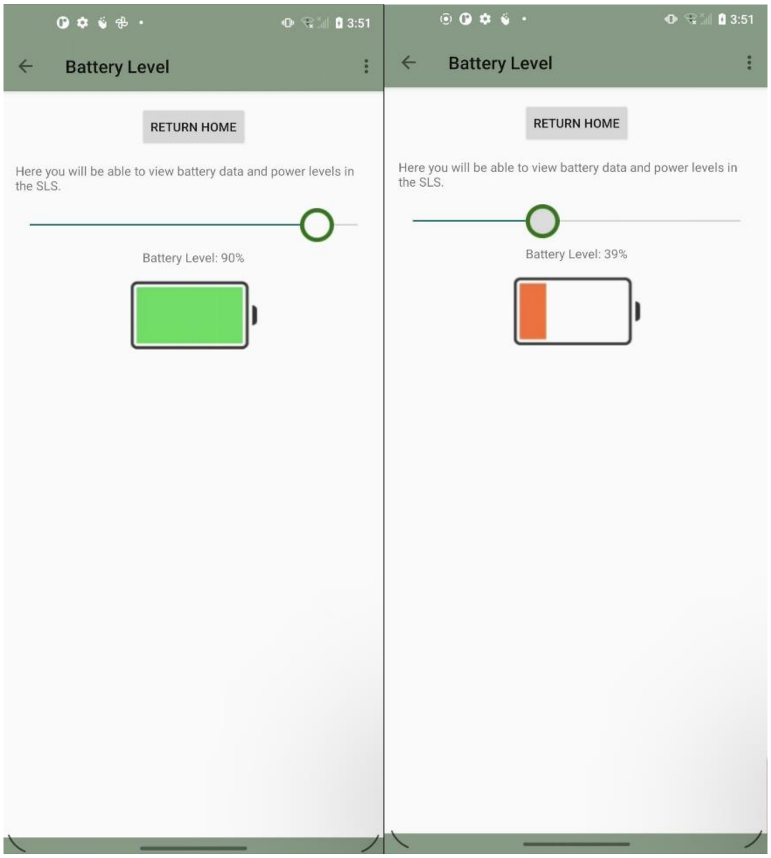



*Figure 4: Two side by side images of the "Battery Level" screen.*

Along with the text providing battery percentages of the system, a graphic is also provided to indicate how full or how empty the battery is with charge. The image updates live depending on the battery level given to the app from the microcontroller.

The third screen of the application involves the "Lighting Preferences" screen:


*Figure 5: The "Lighting Preferences" screen of the mobile application.*

This screen displays four sliders, each with their own preferences. Once there is stable connection to the microcontroller, this will give direct input into the system.

The final page of the application is the "User Settings" module:

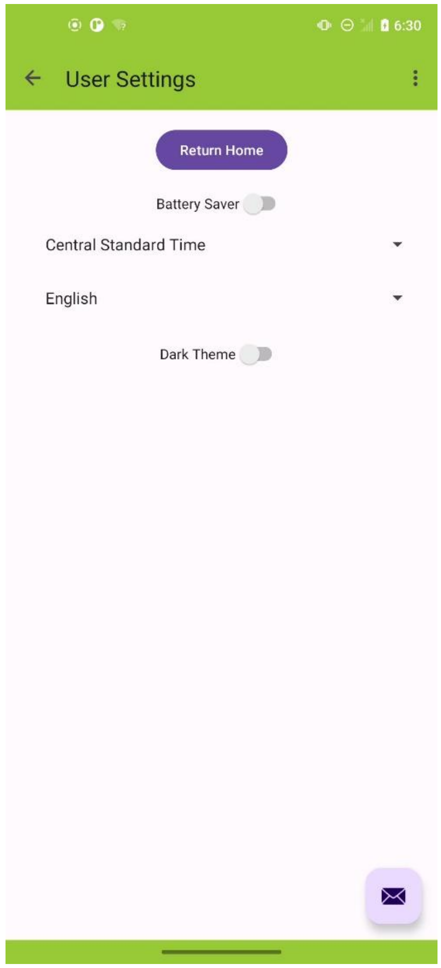



*Figure 6: The "User Settings" screen of the mobile application.*

Here the user can implement a battery saver mode into the system, input the date/time settings with a spinner, input language settings with another spinner, and activate dark mode if desired. Dark mode persists throughout the application, and is displayed below:

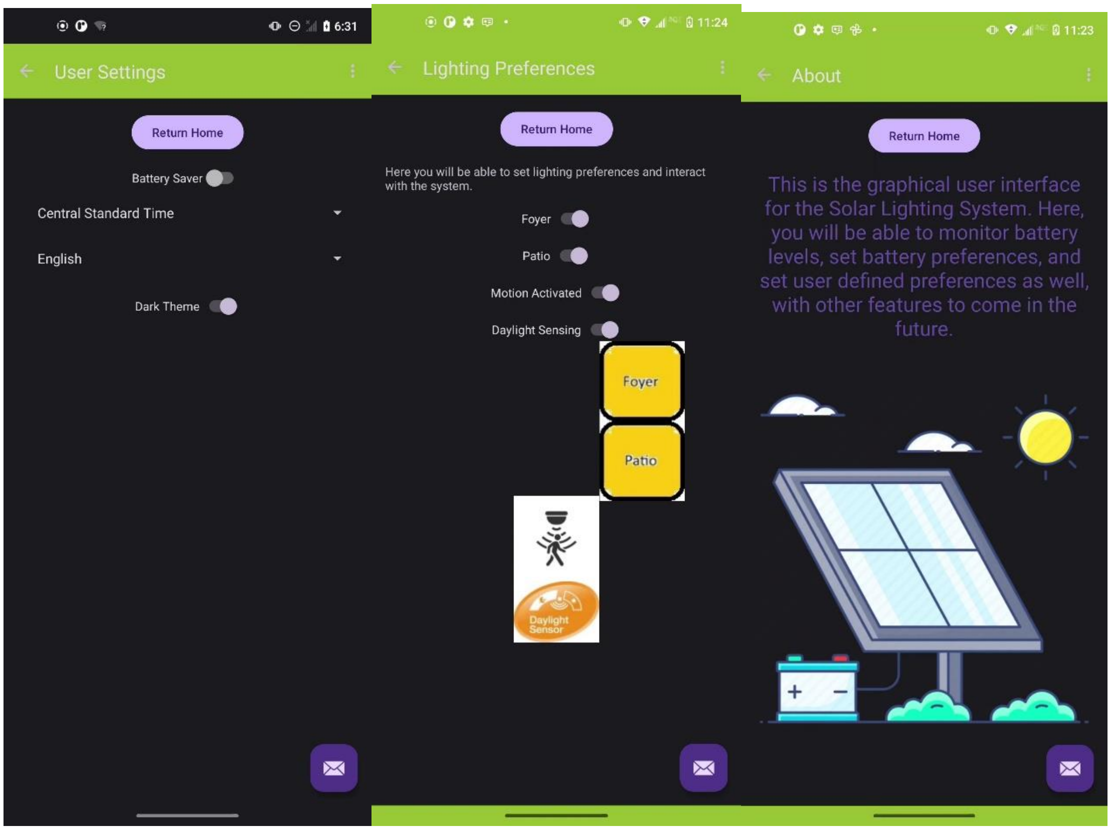



*Figure 7: Three side by side images, activated and persisting throughout the app.*

# 3. Application Validation

All of the previously described features are optimized and perform well. Testing indicated no significant bugs despite small UI improvements, and there were no crashes to report as well. A few things to be implemented include the Date/Time spinner the application.

BLE connection to an R3 Uno Arduino board was attempted through the use of the HC-05 Bluetooth module and succeeded.

# 4. Application Conclusion

In conclusion, the Solar Lighting System (SLS) stands as an advanced solution with its tailored mobile application, specifically crafted for Android devices. Developed using Kotlin on the Android Studios platform, this application serves as the central hub for user interaction within the SLS framework. The seamless integration fosters a user-friendly experience, allowing individuals not only to control and manipulate the system but also to receive real-time updates and data from the SLS.

# SOLAR LIGHT SYSTEM

Lyric Haylow

# BATTERY CHARGE CONTROLLER SUBSYSTEM REPORTS

REVISION – Final

# 1. Battery Charge Controller Introduction

## *1.1. Subsystem Introduction*

The Solar Lighting System will be powered exclusively by two solar panel cells, fed to a 12V 18Ah battery that will feed the rest of the system the power necessary. Since the system is expected to be powered solely by solar energy, an appropriate solar panel and battery were chosen to ensure there would be enough power for the system at any point in time. To ensure that the battery is charged efficiently and that it doesn't get overcharged, a charge controller for the solar panel is necessary.

## *1.2. Subsystem Details*

To ensure power is safely supplied to the battery, I chose a solar charge controller that would accommodate our chosen solar panel supply voltage, as well as our battery charge current limit. A block diagram of the subsystem is shown below.

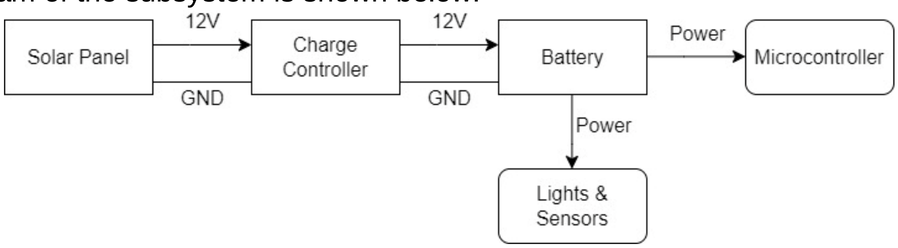



*Figure 8: Block Diagram of Solar Panel subsystem*

For this purpose, I'm using TI's BQ24650 Typical Application design for a Stand-Alone Synchronous Buck Battery Charge Controller. This chosen design with the BQ24650 meets the requirements for this subsystem, though it was necessary to change some component values to match the specifications of the solar panels and battery used. The solar panels we're using are Sunforce Model 58032 Solar Battery Chargers. Since we will likely be having a draw of power during the night to keep the small patio light on at all times during the night, we decided to use 2 solar panels to ensure that the battery is charged fully over the day. The Sunforce Model solar panels are 12V, with a 1.2A supply. The BQ24650 can have an input voltage of up to 28V, however since we want to charge a battery as efficiently as possible, we're going to wire the 2 solar panels we have in parallel to increase the supply current. That input voltage and current will then be supplied to the Charge Controller Schematic as shown below

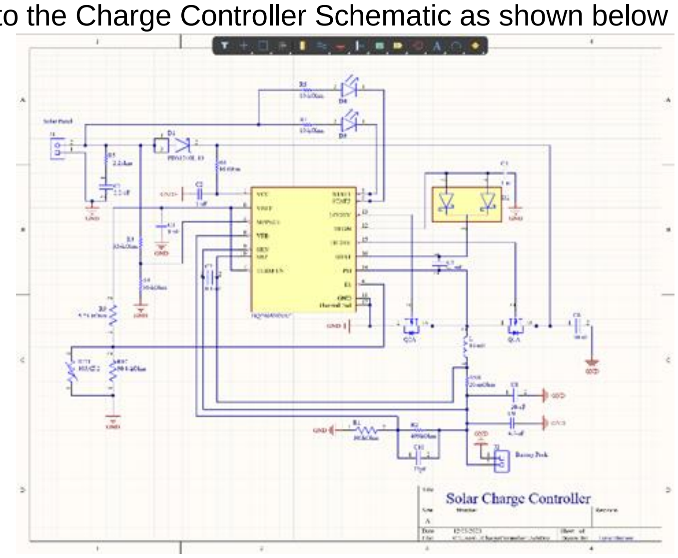


*Figure 9: Solar Charge Controller Schematic*

For the changes made to accommodate the solar panels, the regulation voltage that goes into the MPPSET pin is set by the following equation, with the MPPSET pin regulated to 1.2V.

$$V_{MPPSET} = 1.2V * [1 + \frac{R3}{R4}]$$

To match the supply voltage of 12V, R3 was changed from 499kOhm to 324kOhm. The second value that will be subject to change would be the charging current to the battery from the IC. The full-scale differential voltage set between pins SRP and SRN is fixed at 40mV, so as shown in the equation below, the charging current can be set by choosing an appropriate resistor.

$$I_{Charge} = \frac{40\,mV}{R_{SR}}$$

The default application provided by the TI documentation set the charging current to 2A with a 20mOhm resistor, however the battery obtained has a maximum charging current of 5.1A. Considering this, once the board has proven that it can work as designed with a singular 20mOhm resistor for a charging current of 2A, another resistor will be applied in parallel to jump the charging current to 4A. Charging current is the most important factor for quickly charging a battery, so should we be able to maintain a 4A output current, then that would be our best point of action.

To know whether the board is charging or not, there are two LEDs in the design which are set to light up on certain conditions. Pin 3 is connected to STAT1 and will light up to indicate that charging is in progress. Pin 5 is connected to STAT2 and will light up to indicate that charging is complete. Testing on the board will mainly comprise of ensuring that the LEDs light up, as well as checking validations.

## *1.3. Subsystem Problems & Solutions*

As the subsystem currently is, it is unsure whether it works. When testing the board before demo, the PCB board designed was attached to the battery, and the resulting current draw demanded from the battery overheated several traces on the board and caused them to burn out. Since no real results could be derived from the PCB board since then, this part of the subsystem report will cover more of what problems were noticed, how to fix them, and proposed solutions with plans going forward.

The Printed Circuit Board designed is shown in the Figure below. Several parts from the original design it was inspired from were changed and omitted as necessary. For instance, the Q3 component is not included in this design, as it was deemed unnecessary.

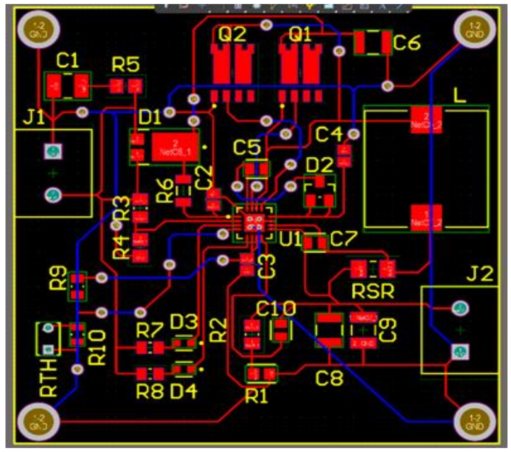



*Figure 10: Charge Controller PCB Design*

#### 1.3.1. *Problems Identified & Solutions*

The primary issue with the design that resulted in traces being burned out was simply that the traces on the PCB were too small. I had designed the PCB with only layout in consideration, and not paying appropriate attention to the trace widths. To remedy this issue, I had decreased charging current going to the battery to ~0.5A by using a 0.09Ohm resistor as my RSR component. The 5mil trace set for the input current could handle a low current supply, and the plan was to test the board with a small input and small output, to see whether the LED set to indicate charging would light up. Attaching the battery first, without a supply voltage ready to feed into the battery, resulted in a draw current that exceeded what 5 mil traces were capable of carrying. To account for this problem, a new PCB design will be made with appropriate trace sizes for relevant sections. Several other fixes will also be implemented to help ensure the new Charge Controller PCB works better than desired.

- Since the input current from the solar panels will be ~2.4V, the trace size for the Net attached to Vin will be set to 30 mils. That would provide accommodate 2.4V, as well as provide some leeway.
- Charge current to the battery would be best set to 4A, so 45 mil traces to accommodate this current would be set to the net corresponding to all traces attached to Vout. A complete redesign of component placement will likely be necessary to implement this change. Figure __ shown below is the result of not having sufficient traces, and the highlighted spots specifically show the problem areas.

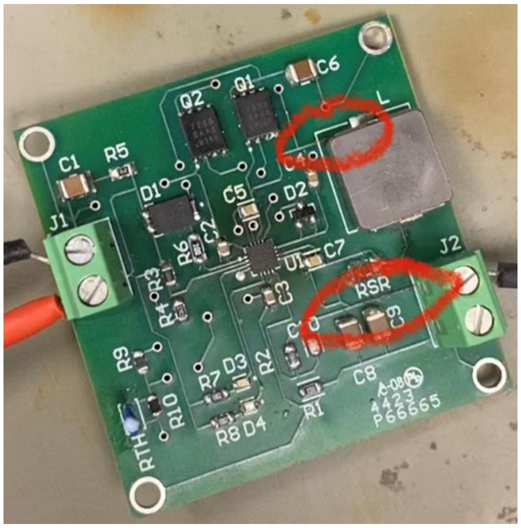


*Figure 11: Physical Malfunctioning Board*

- Though everything fit on a 2 inches^2 board, it made it very difficult to work any hotfixes necessary to be made. Once a number of components were placed, it also made soldering more difficult as well. The cost of the board also wasn't decreased sufficiently enough to warrant decreasing the size of the board, so the new PCB design will likely greatly increase in size to make both soldering and spot testing easier. Traces that hold large amounts of current will likely still be kept small though, as the increase in resistance and voltage drop would be greatly detrimental there.
- Though a simple issue, none of the inputs or outputs in my board were labeled. That made it hard to identify where input and output wires were supposed to go, as well as spot check issues within the board. This is not necessarily a harsh problem, but adding silk screen text boxes would greatly improve clarity and prevent mistakes.
- Having traces overlap from different layers was also a potential issue I can across. Since it wouldn't make sense to never overlap traces on different layers, as that would defeat their purpose, I will likely just reconsider the placement of traces that could result in heating issues. With the large amount of current traveling through my board, ensuring that there are no unnecessary hot spots located on the PCB would help alleviate potential future issues.

### *1.3.2. Plans Going Forward*

Going forward, the plan is namely two actions that should ensure that I have a working board around when 404 starts. I'll be spending most of my time this winter in CSTAT, so I'll have plenty of time to use the relevant equipment needed.

1. First action would be to use a perfboard with a 16pin footprint to test the design of the charge controller. One of my concerns regarding my design is that I was unable to test whether it would've worked properly for its intended purpose. As far as I'm aware, the board may have further complications that could inhibit it from working properly. To alleviate those concerns, I plan to buy a few sets of components that are through pin and several perfboards, to then test the validity of my design over the winter. So long as I keep the output current appropriate for the traces on the perfboard, this idea should work well to either identify further issues or prove that my design works and how I can further validate it works as intended.

2. My second action, that will in part be in progress while I work on the perfboard, would be to design a new PCB board with my planned improvements. I'll design this board at the same time perfboard testing is underway, that way if I decide components, footprints, or placements need to change, I can freely do so before I order the new PCB. Once I've validated my design using the perfboard and decided I'm happy with the new PCB design, I'll order it with the appropriate components. I hope to order the new PCB from new years to the first week of January, to then be put together once it arrives.

For potential budget concerns, I'm not too worried since the majority of our budget expenses have been covered by already having relevant products for our project. Both solar panels and batteries were obtained from prior projects, so our total budget should be able to withstand some extra expenses for the sake of validity.

### *1.3.3. Validation*

The included validation plan has been updated according to the changes I've made with the PCB board. As the subsystem is still in progress, nothing has yet been validated. The relevant validation procedures are provided below.

| | Test Name | Success Criteria | Methodology |
|---|---|---|---|
| 3.2.1.1 | Solar Panel Mount | Stays in space mounted for several days time | Verifying Hardware is properly mounted |
| 3.2.1.2 | MPPT Functionality | MPPT is working as expected within the IC | Set higher voltage than MPPT, check whether IC brings voltage down to set MPPT voltage level. |
| 3.2.1.3 | Charge Controller Verification | Voltage levels are modulated along with Current Levels | Steadily increasing current will be applied to charge controller, to point of max expected |
| 3.2.1.4 | Overvoltage Solar Panel Protection | Supply voltage levels do not exceed IC limits | Sending a increasingly higher voltage through the charge controller, eventually checking it functions as predicted |
| 3.2.1.5 | Overcurrent Battery Protection | Charging current levels do not exceed expected input values | When charging battery, consistently measuring charging current upon increasing supply voltage using DC power supply |
| 3.2.1.6 | PWM EMI Interference | Interference does not significantly alter design guidelines | Use a Broadband RF meter if one available, if not then the Oscilloscope to identify interference points. |
| 3.2.1.7 | Battery Charging to Capacity | Battery stops being charged once it has a full charge | Feeback voltage will be applied back to IC as shown in documentation |
| 3.2.1.8 | State of Charge (SOC) | Measurement for current State of Charge coincides with expected values | Measure the voltage with a multimeter and convert measured voltage to approximate power percentage expected |
| 3.2.1.9 | Depth of Discharge (DOD) | Measurement for current State of Charge coincides with expected values after discharge | Measure the voltage with a multimeter and convert measured voltage to approximate power percentage expected |

*Table 1: Validation Tests for Solar Charge Controller*

## 1.4. Subsystem Conclusion

Currently, the subsystem is still in progress towards completion. A minor setback resulting in a malfunctioning board has set this subsystem back, however plans to test just the design on a perfboard, as well as to make a new PCB to accommodate all the changes learned from the first board are in place as well as motion. Ensuring that a consistent and reliable amount of power is supplied to the other subsystems is crucial to this project, and by this upcoming January a working subsystem will be made.

# SOLAR LIGHT SYSTEM

Jeb Malek

# POWER INVERTER SUBSYSTEM REPORT

REVISION – Final

3 December 2023

# 1. Inverter Introduction

## 1.1. Scope

This subsystem entails the hardware and software design, PCB manufacturing, and assembly for the power inverter of the solar light system.

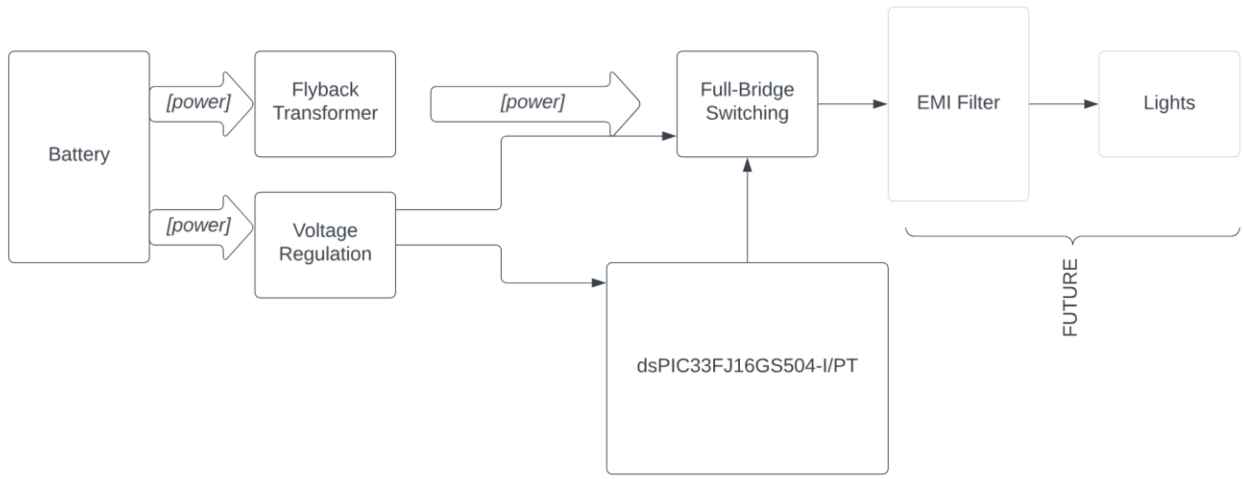



*Figure 12 Power Inverter System Diagram*

## 1.2. PWM Controlled Pure Sine Wave Inverter

### 1.2.1. Carrier & Modulation Signal

In order to create a utility grade output power supply from a DC battery resource a DC to AC sine wave inverter is needed to raise voltage levels, convert current waveforms, and ensure steady smooth voltage outputs with constant periodicity, or stable frequency.

A 24V input is designed for and will be sourced from a DC battery bank. In order to complete conversion of current waveforms from direct to alternating a sinusoidal reference is used to compare a signal with a characteristic triangular wave known as a modulation signal to create a sinusoidal pulse width modulation signal for switch control and current polarity inversion. \

Calculations can be done to monitor efficient output and verify tolerances set by power electronic professionals. From the fundamental power equation below harmonic analysis will be performed.

$$P_{out} = V_{out} \cos \omega t \cdot I_{out} \sin \omega t$$

# 2. Inverter Details

## *2.1. Battery Source*

Supplying a DC voltage source will be done with a 2 12 V Lead Acid Battery Pack will provide lower primary to secondary current draw as less amperage is needed to convert to the 120 V nominal value needed for switching and output stages. Sealed battery packs offer robust use and ease of long-term storage. Durability and cost are the main design factors contributing to selection of the *Interstate 12 V Sealed Lead Acid* part. Steady voltage sources are crucial for switching smoothly for an efficient output. Without voltage feedback systems, overvoltage detection, AC current sensing for short circuit shutoff and amperage limitation.


*Figure 12V Battery Image*

### 2.1.1. Voltage Regulator

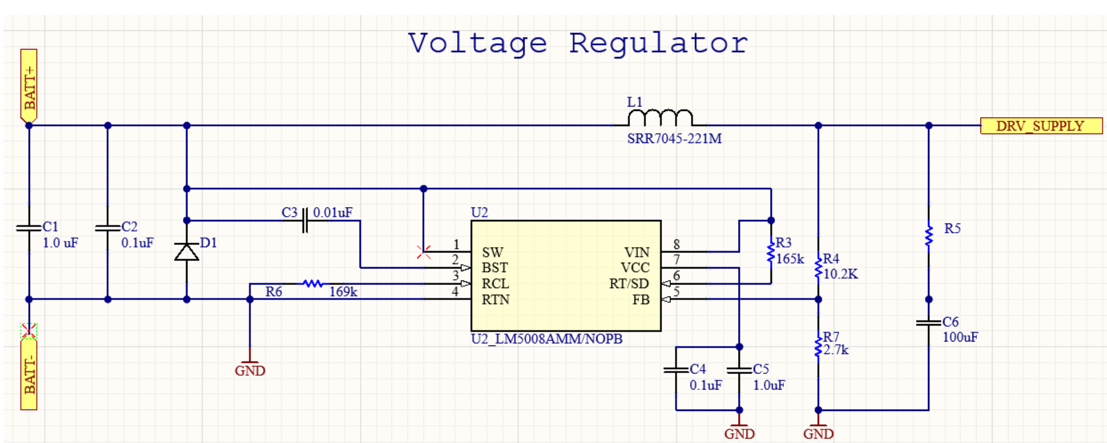



*Figure 13 Voltage Regulator, Continuous Output*

Battery input regulation is initially stepped down with a switching regulator from *Texas Instruments* , providing a

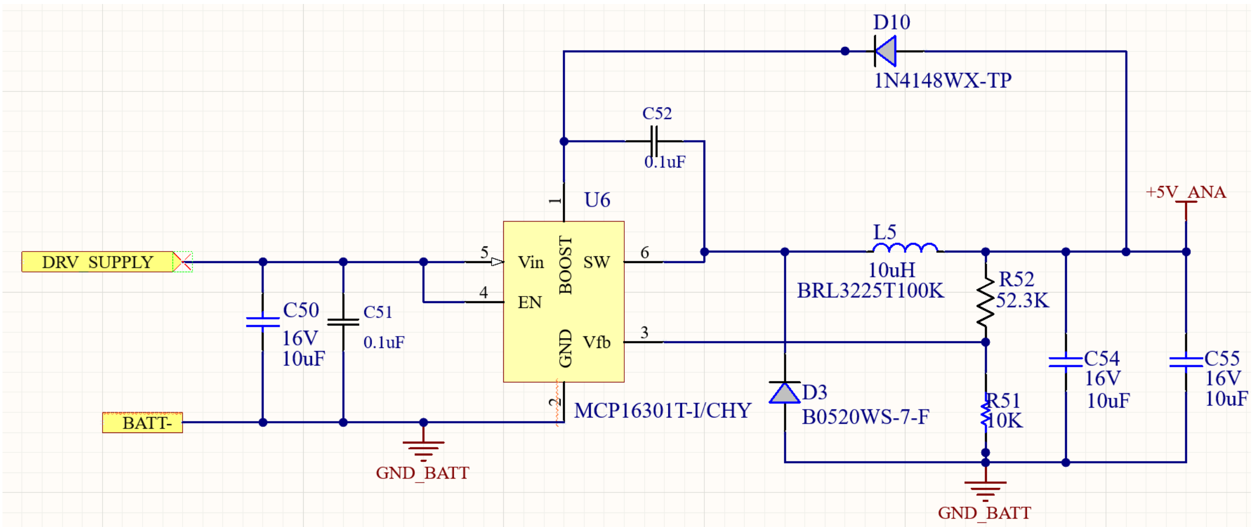



*Figure14 5V Power Supply Regulation*

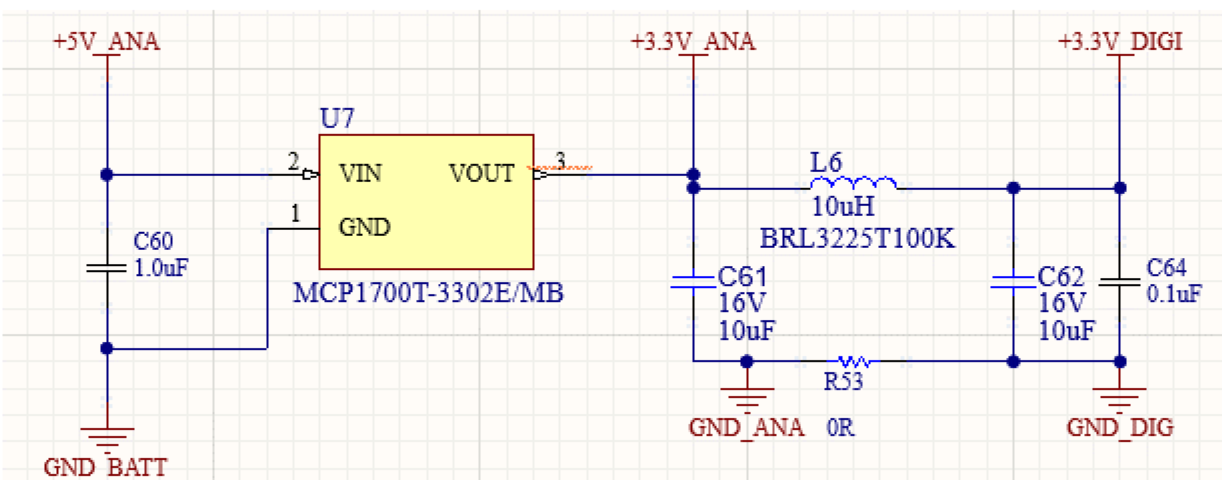



*Figure 15 Buck Switching Regulator*

To properly power integrated circuits on this inverter board the Low-Dropout Voltage Regulator is used for low current DC/DC conversion. Decoupling capacitors are placed on each output with the effort to ensure smooth DC voltage supply to circuits in this design.

A switching regulator is not necessary in this application as the efficiency of low voltage circuit powering is not as great of a concern in the scope of this project.

## 2.2. Switching

### 2.2.1. Duty Cycle Modulation of PWM Gate Driving

In initial research a decision of controlling MOSFET power switches with unipolar square wave pulse generation versus bipolar switching control for an efficient solution for a cost and component conservative design.

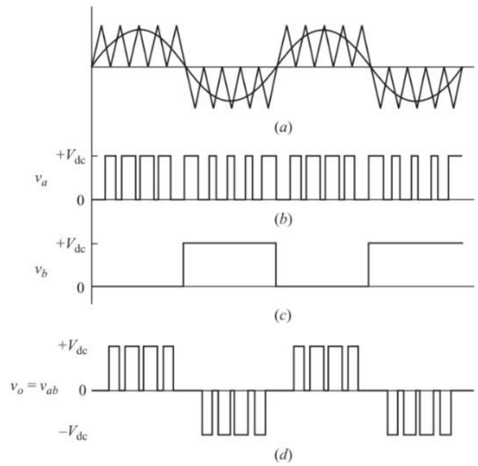



Figure 16 Theoretical SPWM

A MATLAB Simscape Control Topology can be seen below with results showing triangle wave carrier wave generation for comparison with the modulation signal.

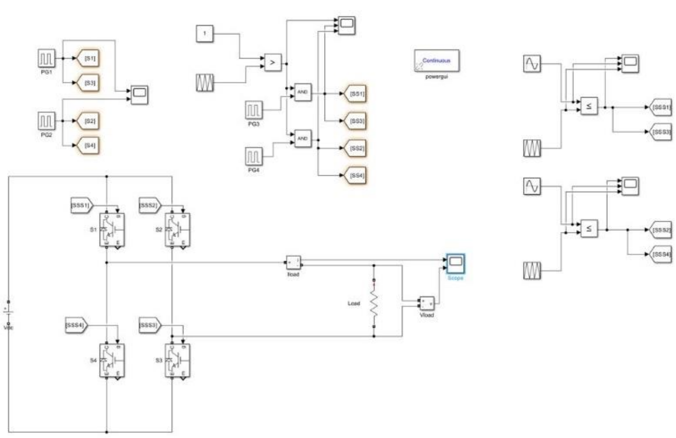


*Figure 17 MATLAB Full Bridge SPWM Simulation*

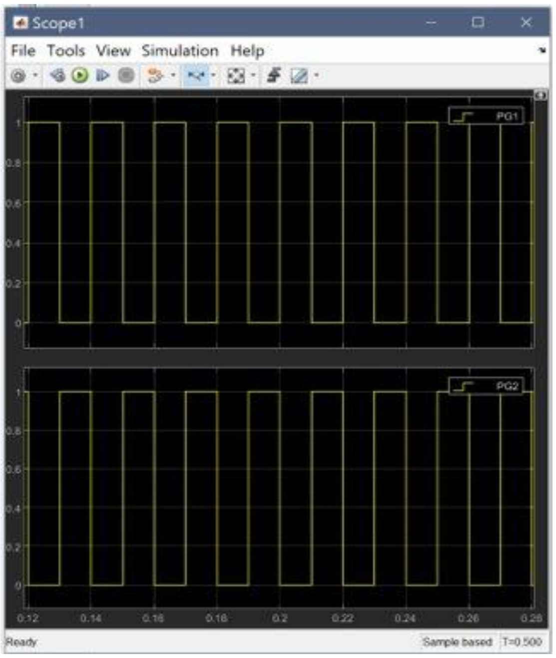



Figure 18 Dual Channel PWM / Full Bridge Control

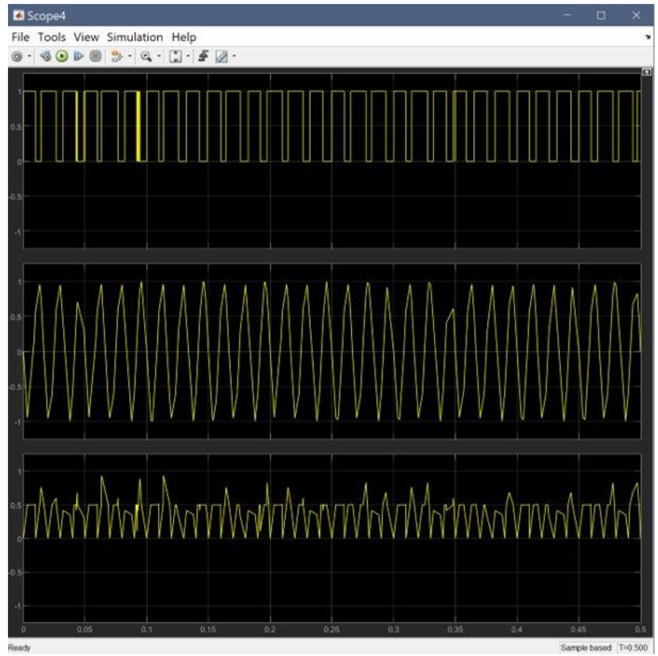



Figure 19 Output Simulation of Ohmic Load

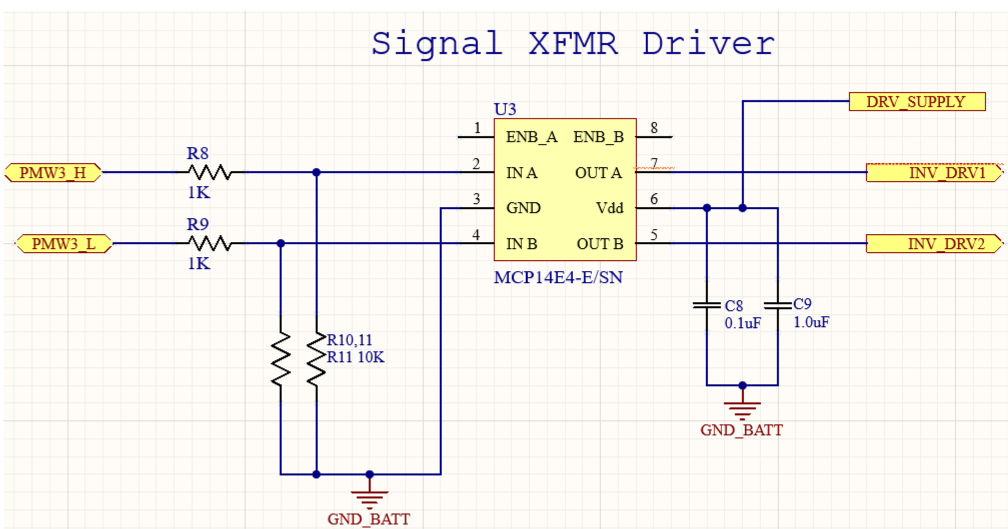



Figure 20 Signal Transformer Circuit for Full Bridge Driving

A *MCP14E4-E/SN* is used to provide a stable switching frequency for the signal transformer to operate in the intended purpose.

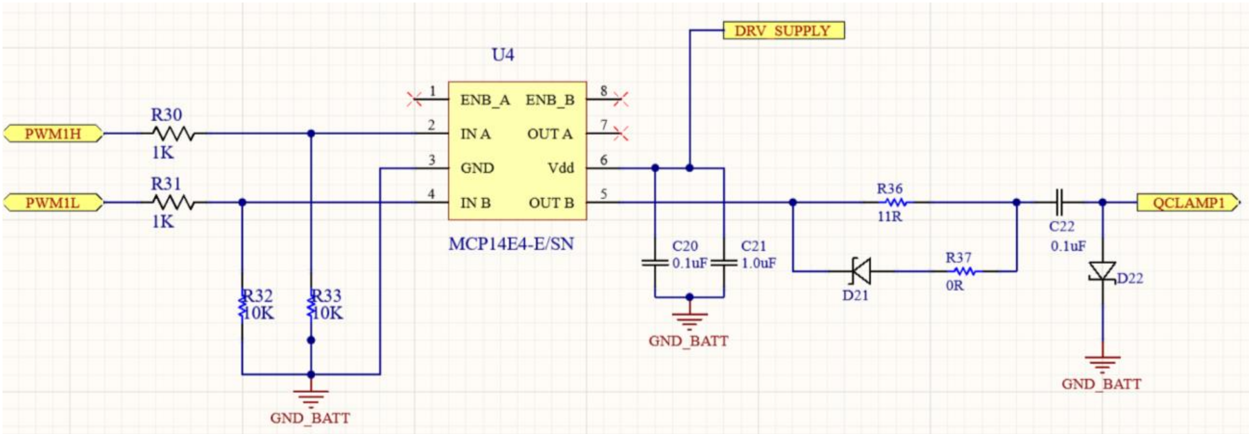



Figure 21 Flyback Driver Schematic

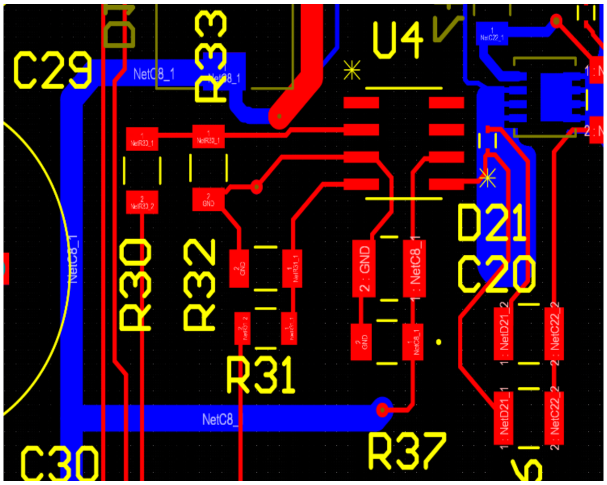



Figure 22 Flyback Driver 1

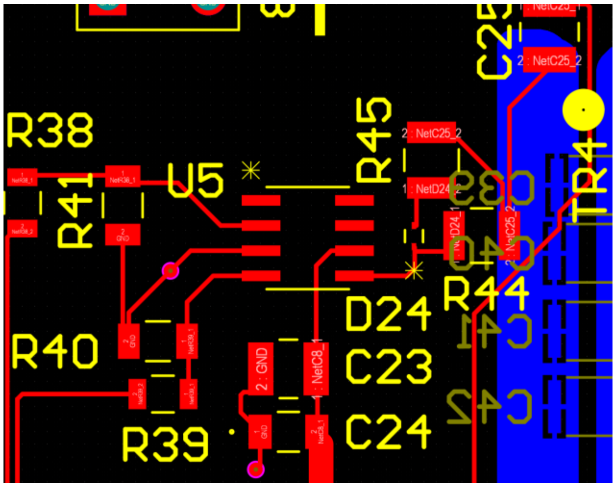



Figure 23 Flyback Driver 2

Each flyback driver is used to enable the proper functionality of the interleaved switching nature of the flyback converter.

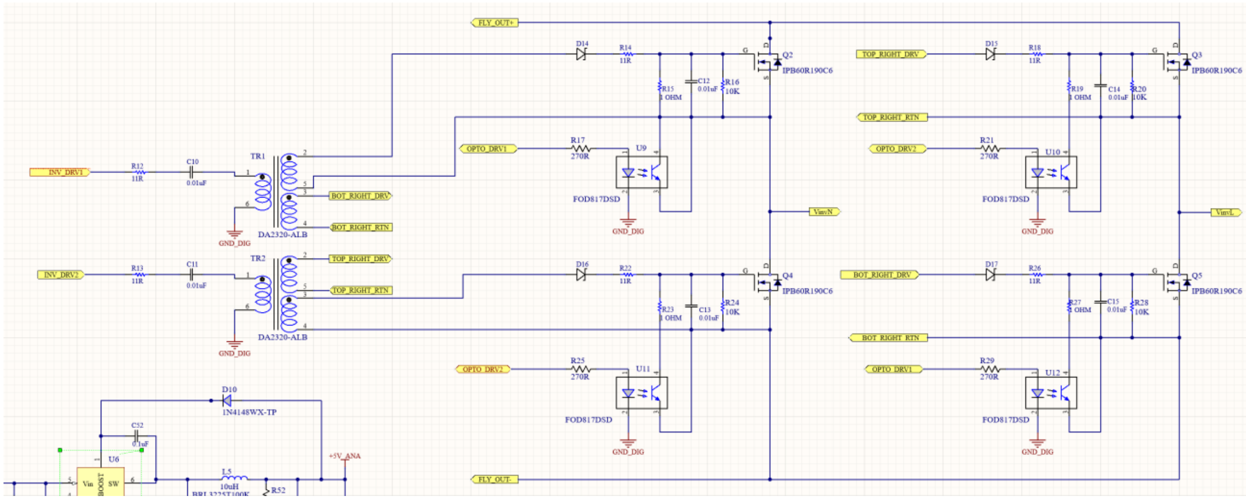


*Figure 24 Full Bridge Switching Schematic*

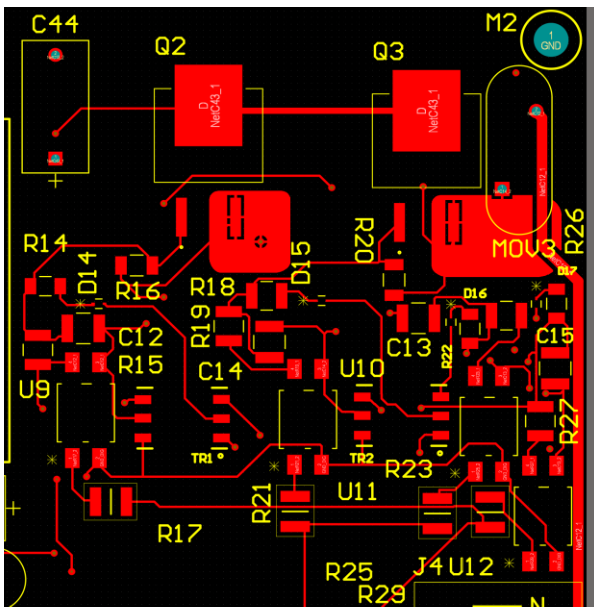


*Figure 25 Half Bridge Q2-Q3*

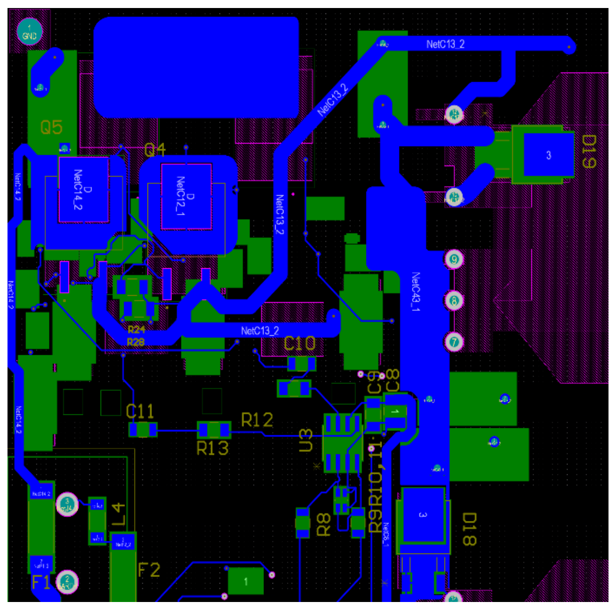


*Figure 26 Half Bridge Q4 Q5*

The Full-Bridge schematic and PCB lay above highlight the use of signal transformers *TR1* and *TR2* to create driving signals to two separate bridges of MOSFET power switches, By efficiently switching polarity during positive and negative half cycles a load can see both positive voltage from the source and negative voltage. In the Unipolar Sinusoidal Pulse Width Modulation signaling that is being driven into respective MOSFET gates the intended half bridge will commutate correct current flow for positive and negative half cycles.

## 2.3. Digital Signal Processor

Shown below are schematic symbols for the components used to facilitate gate driving logic.

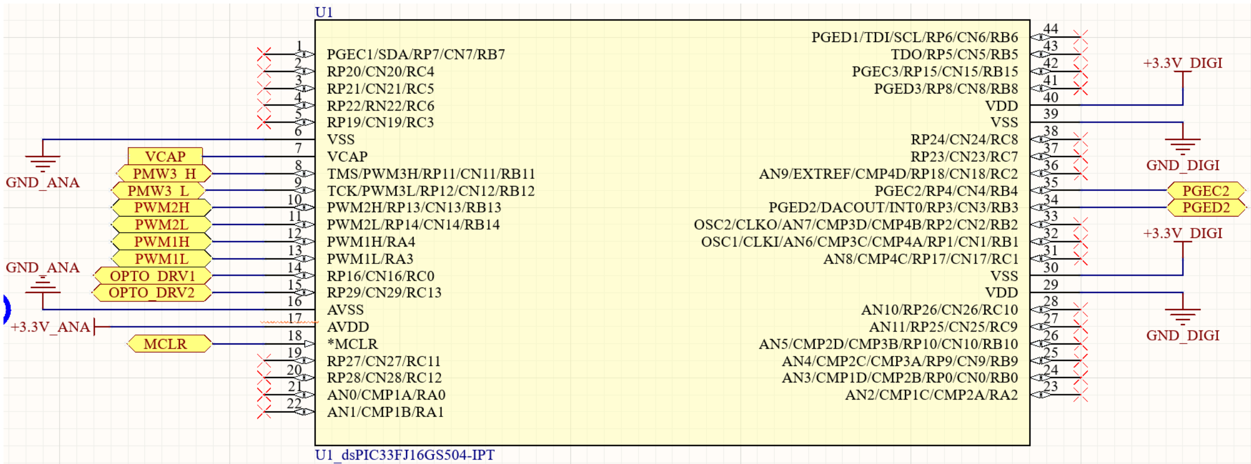



*Figure 27 Digital Signal Microprocessor : dsPIC33FJ16GS504-I/PT*

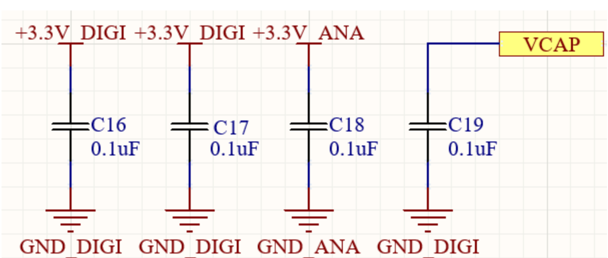



*Figure 28 Decoupling Capacitors for Voltage Inputs*

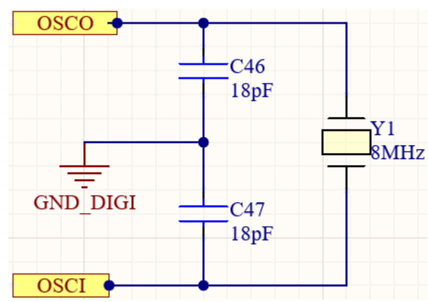



*Figure 29 External Crystal Oscillator for Carrier & Modulation Signal*

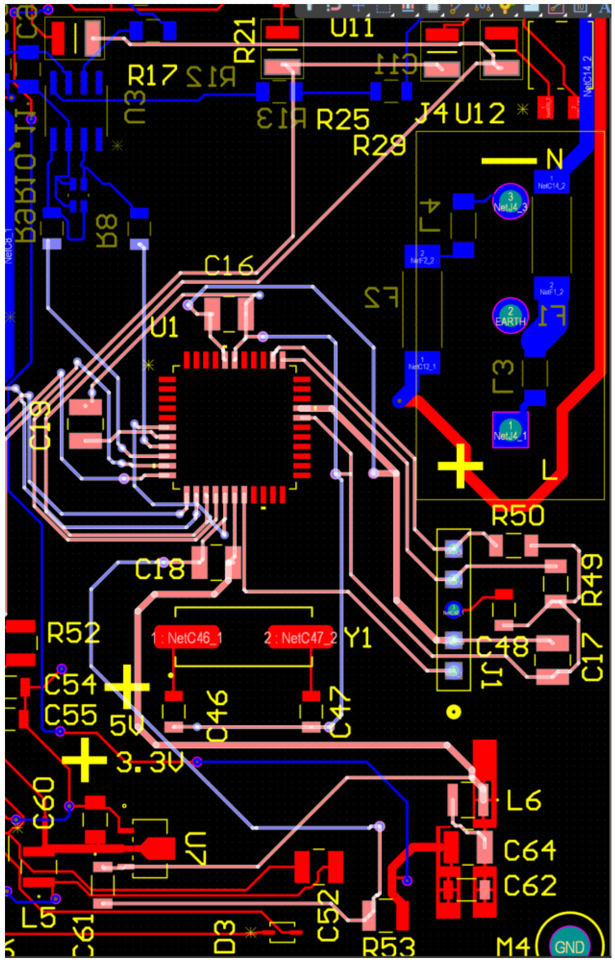



*Figure 30 PIC DSP 44 Bit TQFP Layout & Tracing*

The above graphic shows placement of the 44 pin package integrated circuit in a central location to receive necessary analog power from regulator circuits as a power source. Shown also are the various signaling traces used to control gate triggering of the power MOSFETs used in voltage conversion. The precise pulse width modulated signals from Microchips dsPIC series allows for programmable control of output characteristics waveforms.

## 2.4. Transformer

### 2.4.1. DC/DC Conversion Topology

Positive half cycle and the repetitive polarity inversion for negative half cycles are handled by the converter circuit shown below.

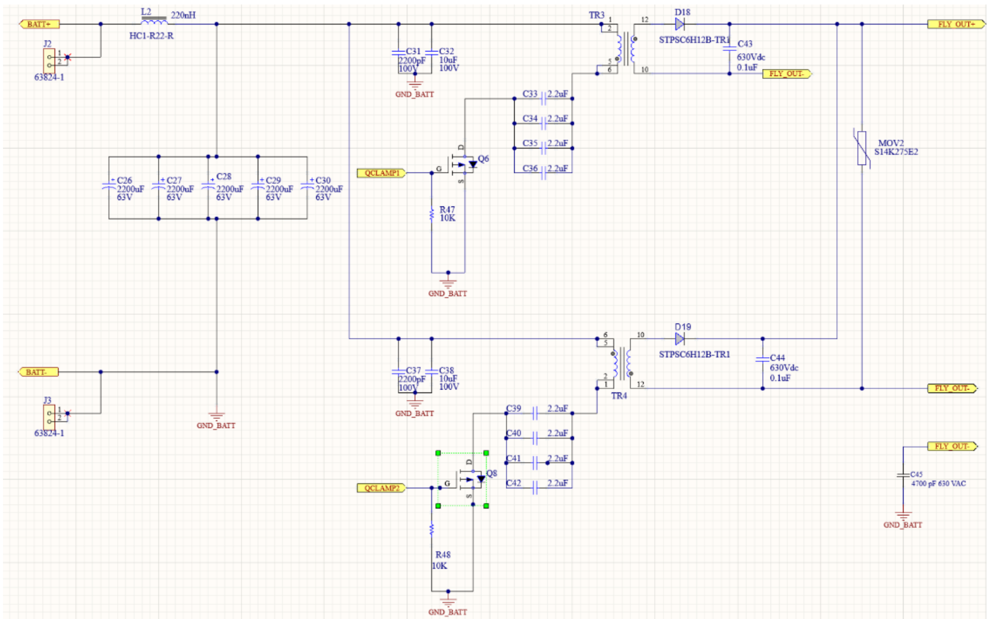


Figure:31 Interleaved Flyback Transformer Schematic

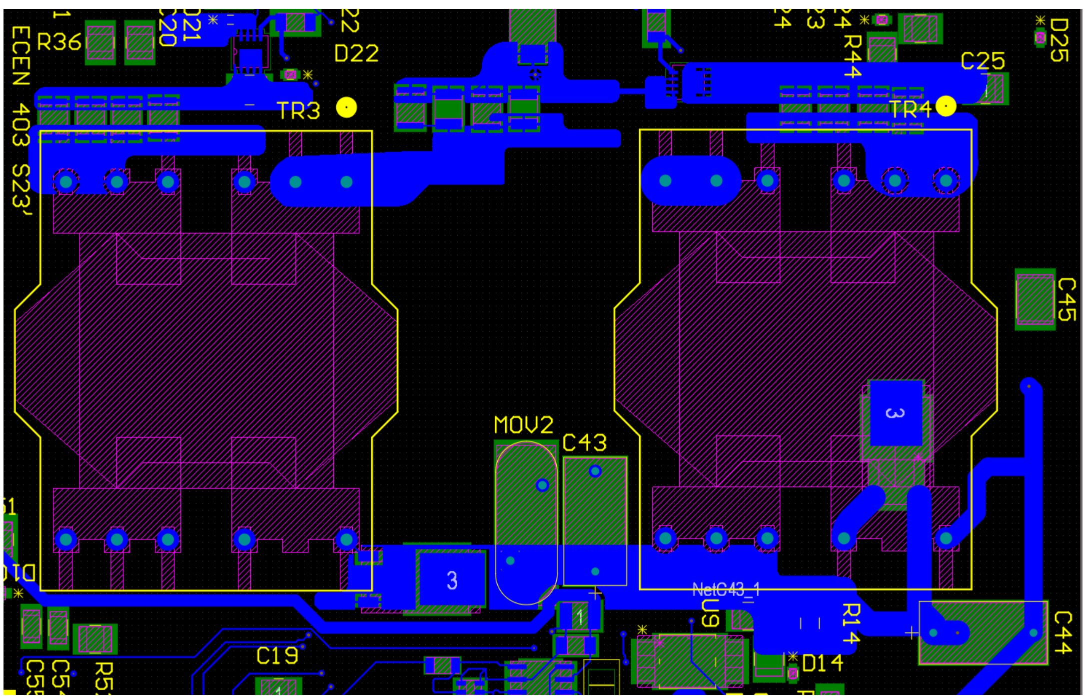



Figure 32 Flyback Converter Layout

# 3. Inverter Validation

## 3.1. *Microcontroller Programming*

### 3.1.1. ICSP (Inter Circuit Serial Programming)

To program the digital signal processor package with the correct modulation signals and external oscillation functionality the PICKit3 will be used to validate correct binary encoding for MCU processing of carrier/modulation signaling.

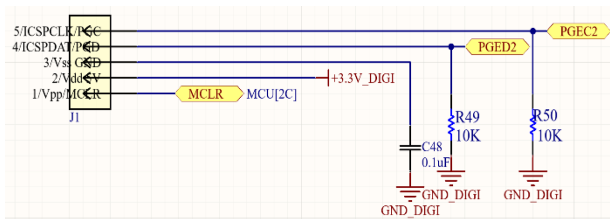



*Figure 23 3 ICSP Schematic*

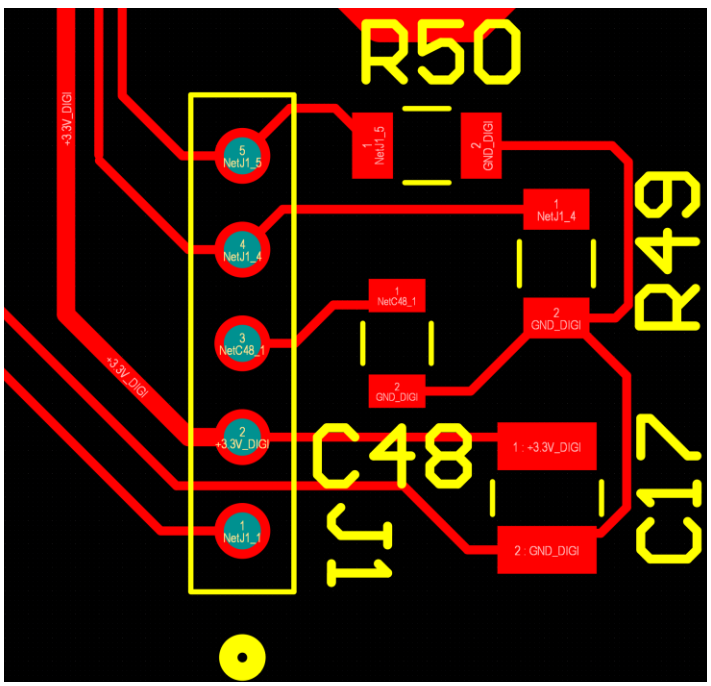



*Figure 33 PICKit ICSP Header Layout*

## 3.2. Full-Bridge Switch Control

### 3.2.1. Gate Drive Signal, Half-Bridge Operation

To generate a unipolar sinusoidal pulse width modulated signal SPWM

Oscilloscope measurements will be taken to verify gate driving signal timing is compliant with sinusoidal PWM logic. The presence of a Dead Time will validate safe switching practices for the

## 3.3. Sinusoidal Waveform from Oscilloscope

### 3.3.1. Output Voltage Waveform

Without an EMI output filtering feedback system the waveform supplying the load should have a ripple component at the frequency of the modulation signal. Verification of peak to peak timing of ripple component will prove modulation at this frequency.

## 3.4. Load Support

### 3.4.1. AC Voltage Output Range

### 3.4.2. Total Harmonic Distortion

Following the IEEE 1547

Harmonic distortion is totaled with the RMS value of the harmonic components detected during measurement with respect to the fundamental component. The equation below is used to calculate a total value to compare with specification.

$$THD = \frac{\sqrt{H_2^2 + H_3^2 + \cdots + H_N^2}}{H_{1,Fundamental}}$$

A spectrum analyzer procedure will be implemented to verify efficiency limits to comply with electrical class constraints.

# 4. Inverter Conclusion

Rated for 200VA , this inverter will be able to supply a large portion of a typical residential housing load, as there can will be a normal operating load around 45W with the minimum of 3 15 W LED Lights installed during the integration of subsystems.
In looking forward to the next 6 weeks of the execution plan a prototype board shipment will arrive , with three boards to perform testing on. Soldering procedures of small package components progressing to larger sizes will ease the assembly process and a cascaded validation plan will be implemented to verify each stage of this power inversion process. In reflection of this project's initial stage of validation important decisions to fit a board size constraint of 30 square inches required unanticipated delay in board ordering schedule. Along with verification of design rule checks without any errors contributed to further delay in schedule. Progress towards prototype completion and consideration of thermal and efficiency improvements will be of focus upon subsystem validation.

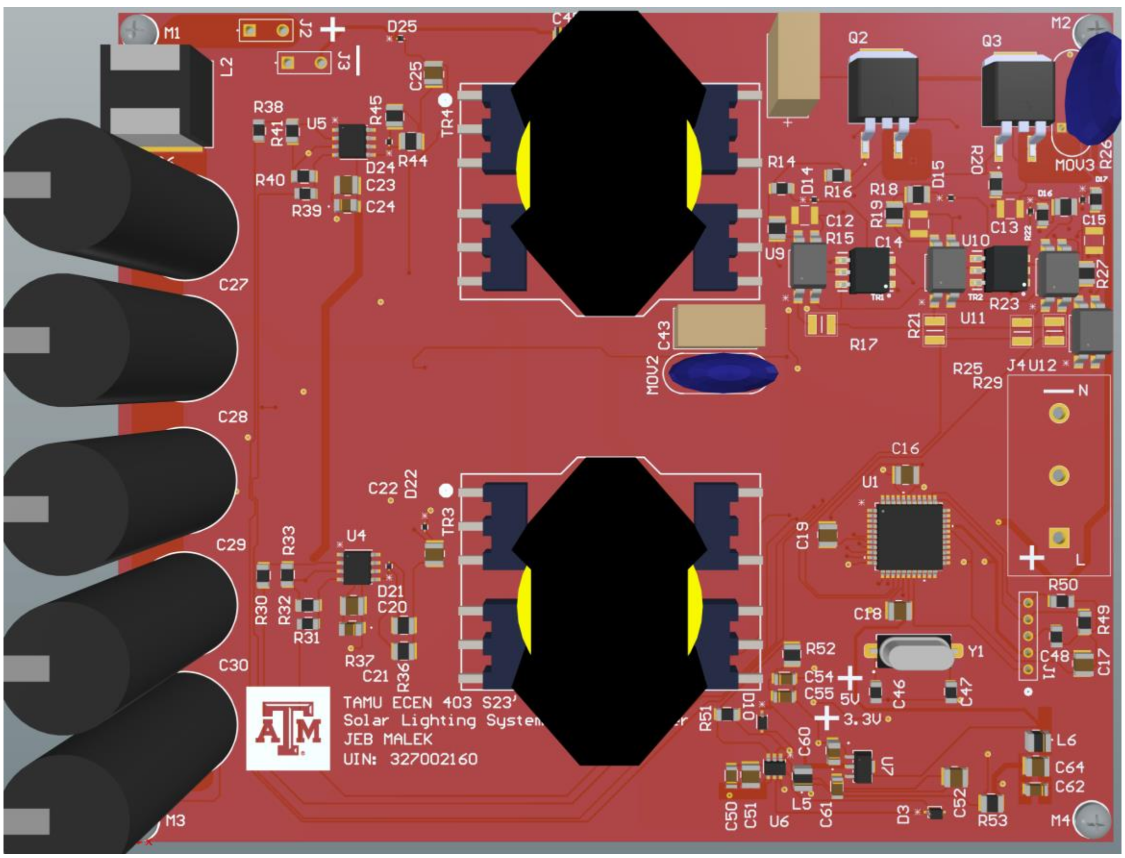



*Figure 34 Power Inverter Initial Prototype Design*

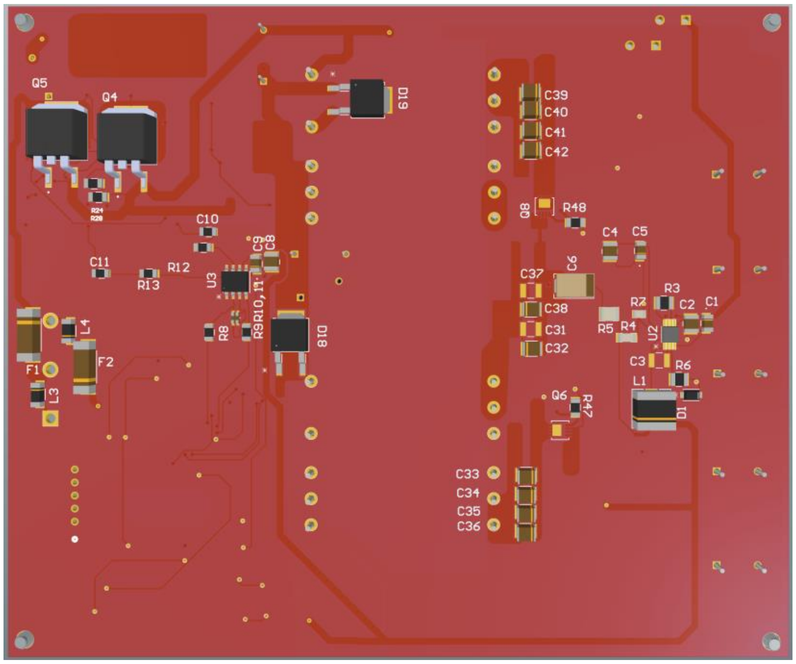



*Figure 35 Power Inverter Initial Prototype Design Bottom View*

| Designator | Item Name | Part Number | Location to Buy From | Item Description | Cost per Part | Quantity | Total Cost | Order Date |
|---|---|---|---|---|---|---|---|---|
| C1 | 1.0 uF Capacitor | HMK316B7105KL-T | HMK316B7105KL-T Taiyo Yuden \| Capa | 1 µF ±10% 100V Ceramic Capacitor X7R 1206 (3216 Metric) | $ 0.231 | 10 | $2.31 | 11/1/2023 |
| C2 | 0.1 uF Capacitor | C1210C104K1RACAUTO | C1210C104K1RACAUTO KEMET \| Capa | 0.1 µF ±10% 100V Ceramic Capacitor X7R 1210 (3225 Metric) | $ 0.234 | 10 | $2.34 | 11/1/2023 |
| C3,C12, C13, C14,C16, | 0.01 uF Capacitor | CC1210KKX7R9BB103 | CC1210KKX7R9BB103 YAGEO \| Capac | 0.01 uF 10000 pF ±10% 50V Ceramic Capacitor X7R 1210 (3225 Metric) | | | $0.00 | 11/6/2023 |
| C4,C7,C8, C44,51,64 | 0.1 uF Capacitor | CC1206KRX7R9BB104 | CC1206KRX7R9BB104 YAGEO \| Capac | 0.1 µF ±10% 50V Ceramic Capacitor X7R 1206 (3216 Metric) | $ 0.135 | 10 | $1.35 | 11/1/2023 |
| C5, C20, C25, C29, C39,C60 | 1.0 uF 16V Capacitor | CC1210KKX7R7BB105 | CC1210KKX7R7BB105 YAGEO \| Capac | 1 µF ±10% 16V Ceramic Capacitor X7R 1210 (3225 Metric) | $ 0.298 | 10 | $2.98 | 11/1/2023 |
| C6 | 100 uF 16V Capacitor | TAJD107K016RNJ | TAJD107K016RNJ KYOCERA AVX \| Ca | 100 µF ±20% 16\V Ceramic Capacitor X5R 1210 (3225 Metric) | $ 0.630 | 2 | $1.26 | 11/1/2023 |
| C25, C26, C27,C28, C29 | 2200uF 63V Capacitor | UPW1J222MHD | UPW1J222MHD Nichicon \| Capacitors \| | 2200 µF 63 V Aluminum Electrolytic Capacitors Radial, Can 8000 Hrs @ 105°C | $ 2.360 | 10 | $23.60 | 11/6/2023 |
| C31 | 10uF 100V | CC1206KRX7R9BB822 | GRM32EC72A106KE05K Murata Electro | 10 µF ±10% 100V Ceramic Capacitor X7S 1210 (3225 Metric) | $ 0.890 | 3 | $2.67 | 11/6/2023 |
| C43, C44 | 0.1uF 630VDC | BFC233920104 | BFC233920104 Vishay Beyschlag/Dralo | 0.1 µF Film Capacitor 310V 630V Polypropylene (PP), Metallized Radial | $ 1.760 | 4 | $7.04 | 11/6/2023 |
| C45 | 4700pF 250VAC | GA343DR7GD472KW01L | GA343DR7GD472KW01L Murata Electro | 4700 pF ±10% 250VAC Ceramic Capacitor X7R 1812 (4532 Metric) | $ 1.430 | 3 | $4.29 | 11/1/2023 |
| C46,C47,C50, C54,C55,C61,C62 | 10uF 16V Capacitor | CL31A106KOHNNNE | CL31A106KOHNNNE Samsung Electro-M | 10 µF ±10% 16V Ceramic Capacitor X5R 1206 (3216 Metric) | $ 0.129 | 10 | $1.29 | 11/6/2023 |
| D1 | Schottky Diode | DSS16U | DSS16U SMC Diode Solutions \| Discrete | Diode 60 V 1A Surface Mount SOD-123FL | $ 0.210 | 5 | $1.05 | 11/6/2023 |
| D2 | Schottky Diode | NSR05T40P2T5G | NSR05T40P2T5G onsemi \| Discrete Sem | DIODE SCHOTTKY 40V 500MA SOD923 | $ 0.299 | 10 | $2.99 | 11/6/2023 |
| D3 | Schottky Diode | B0520WS-7-F | B0520WS-7-F Diodes Incorporated \| Dis | Diode 20 V 500mA Surface Mount SOD-323 | $ 0.350 | 4 | $1.40 | 11/6/2023 |
| D10 | Swtich Diode | 1N4148WX-TP | 1N4148WX-TP Micro Commercial Co \| D | Diode 75 V 150mA Surface Mount SOD-323 | $ 0.100 | 2 | $0.20 | 11/6/2023 |
| J1 | 5PIN Connector Female Header | PPTC051LFBN-RC | PPTC051LFBN-RC Sullins Connector So | Vertical 0.100" (2.54mm) Through Hole Tin | $ 0.480 | 1 | $0.48 | 11/9/2023 |
| J4 | 3 Position Termincal | 387206303 | 0387206303 Molex \| Connectors, Interco | 3 Circuit 0.375" (9.53mm) Barrier Block Connector Screws | $ 3.650 | | | 11/6/2023 |
| L1 | 220uH | SRR7045-221M | SRR7045-221M Bourns Inc. \| Inductors, | 220 µH Shielded Drum Core, Wirewound Inductor 640 mA 700mOhm Max Nonst | $ 0.780 | 2 | $1.56 | 11/6/2023 |
| L2 | 220 nH Inductor | HC1-R22-R | HC1-R22-R Eaton - Electronics Division | 220 nH Unshielded Drum Core, Wirewound Inductor 51.42 A 0.36mOhm Max No | $ 5.060 | 2 | $10.12 | 11/6/2023 |
| L3,L4 | 60 Ohm Ferrite Beads | BLM41PG600SN1L | BLM41PG600SN1L Murata Electronics \| | 60 Ohms @ 100 MHz 1 Power Line Ferrite Bead 1806 (4516 Metric) 6A 9mOhm | $ 0.340 | 3 | $1.02 | |
| L5,L6 | 10 uH | BRL3225T100K | BRL3225T100K Taiyo Yuden \| Inductors, | 10 µH Unshielded Drum Core, Wirewound Inductor 700 mA 420mOhm Max 121C | $ 0.220 | 2 | $0.44 | 11/6/2023 |
| MH1, MH2, MH3, MH4 | Screw Stainless Steel | PMSSS 440 0025 PH | PMSSS 440 0025 PH B&F Fastener Sup | #4-40 Pan Head Machine Screw Phillips Drive Stainless Steel | $ 0.083 | 100 | $8.25 | 11/17/2023 |
| MOV2 | VARISTOR | B72214P2271K101 | B72214P2271K101 EPCOS - TDK Electr | VARISTOR 430V 6KA DISC 14MM | $ 0.630 | 4 | $2.52 | 11/14/2023 |
| Q2, Q3, Q4, Q5 | Switching Nchannel MOSFET | IPB60R190C6ATMA1 | IPB60R190C6ATMA1 Infineon Technolo | N-Channel 600 V 20.2A (Tc) 151W (Tc) Surface Mount PG-TO263-3 | $ 2.872 | 10 | $28.72 | 11/1/2023 |
| Q6, Q8 | P-CH MOSFET 150V 8.9A | SI7115DN-T1-GE3 | SI7115DN-T1-GE3 Vishay Siliconix \| Dis | MOSFET P-CH 150V 8.9A D2PAK1212-8 | $ 2.000 | 5 | $10.00 | 11/1/2023 |
| R1,R16,R20, R24,R28, R51 | 10kOhm 1/10W 1% 1210 SMD | ERJ-14YJ332UU | RMCF1206FT10K0 Stackpole Electronics | 10 kOhms ±1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Automotive AEC-Q200 Thick Film RES SMD 10KOHM 0.01% 0.6W J LEAD | $ 0.122 | 10 | $1.22 | 11/1/2023 |
| R2 | 3.3k Ohm 1/10W 1% 1210 SMD | RK73B2ETTD332J | ERJ-14YJ332U Panasonic Electronic Cc | 3.3 kOhms ±5% 0.5W, 1/2W Chip Resistor 1210 (3225 Metric) Automotive AEC- | $ 0.120 | 12 | $1.44 | 11/4/2023 |
| R3 | 165kOhm 1/10W 1% 1210 SMD | ERJ-14NF1653U | ERJ-14NF1653U Panasonic Electronic C | 165 kOhms ±1% 0.5W, 1/2W Chip Resistor 1210 (3225 Metric) Automotive AEC | $ 0.360 | 5 | $1.80 | 11/1/2023 |
| R4 | 10.2kOhm 1/10W 1% 1210 SMD | ERA-8ARW1022V | ERA-8ARW1022V Panasonic Electronic | 10.2 kOhms ±0.05% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Automotive AEC-Q200 Thin Film | $ 1.490 | 2 | $2.98 | 11/1/2023 |
| R5 | 1.5 Ohm 1/10W 1% 1210 SMD | ERJ-14BQF1R5U | ERJ-14BQF1R5U Panasonic Electronic ( | 1.5 Ohms ±1% 0.5W, 1/2W Chip Resistor 1210 (3225 Metric) Automotive AEC- | $ 0.343 | 10 | $3.43 | 11/1/2023 |
| R6 | 169kOhm 1/10W 1% 1210 SMD | ERJ-14NF1693U | ERJ-14NF1693U Panasonic Electronic C | 169 kOhms ±1% 0.5W, 1/2W Chip Resistor 1210 (3225 Metric) Automotive AEC | $ 0.360 | 5 | $1.80 | 11/6/2023 |
| R7 | 2.70K OHM 1/10W 1% 1210 SMD | CRCW12062K70FKEAHP | CRCW12062K70FKEAHP Vishay Dale \| | 2.7 kOhms ±1% 0.75W, 3/4W Chip Resistor 1206 (3216 Metric) Automotive AEC | $ 0.250 | 2 | $0.50 | 11/5/2023 |
| R8, R9, R30 R31 | 1K 1/10W 1% 1210 SMD | RC1206FR-071KL | RC1206FR-071KL YAGEO \| Resistors \| [ | 1 kOhms ±1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistan | $ 0.036 | 10 | $0.36 | 11/5/2023 |
| R10,11 | 2 PK 10kOhm 1/10W 1% 1210 SMD | RM2012A-103/103-PBVW10 | RM2012A-103/103-PBVW10 Susumu \| F | 10k Ohm ±0.1% 50mW Power Per Element Voltage Divider 2 Resistor Network/Array ±25ppm/°C 0805 (2012 Metric), Long Side Terminals | $ 1.480 | 2 | $2.96 | 11/1/2023 |
| R12,R13, R14, R18, R22, R26 | 11.0 1/10W 1% 1210 SMD | RC1206FR-0711RL | RC1206FR-0711RL YAGEO \| Resistors \| | 11 Ohms ±1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistar | $ 0.036 | 10 | $0.36 | 11/5/2023 |
| R15,R19, R23,R27 | 1.0 1/10W 5% 1210 SMD | ERJ-P14J1R0U | Panasonic Electronic Components \| Res | W, 1/2W Chip Resistor 1210 (3225 Metric) Automotive AEC-Q200, Pulse Withsta | $ 0.220 | 4 | $0.88 | 11/5/2023 |
| R17, R21, R25, R29 | 270 1/10W 1% 1210 SMD | CRGP1210F270R | CRGP1210F270R TE Connectivity Passi | 270 Ohms ±1% 0.75W, 3/4W Chip Resistor 1210 (3225 Metric) Pulse Withstand | $ 0.146 | 10 | $1.46 | 11/5/2023 |
| R34,R37 | 0 Ohms 1210 | ERJ-S140R00U | ERJ-S140R00U Panasonic Electronic Cc | 0 Ohms Jumper Chip Resistor 1210 (3225 Metric) Anti-Sulfur, Automotive AEC-( | $ 0.210 | 25 | $5.25 | 11/5/2023 |
| R52 | 52.3K 1/10W 1% 1210 SMD | ERJ-14NF5232U | ERJ-14NF5232U Panasonic Electronic C | 52.3 kOhms ±1% 0.5W, 1/2W Chip Resistor 1210 (3225 Metric) Automotive AEC | $ 0.360 | 2 | $0.72 | 11/5/2023 |
| TR1 TR2 | Gate Drive Transformer | DA2320-ALB | DA2320-AL \| Gate Drive \| Coilcraft | Gate Drive Transformer | $ 2.020 | 4 | | 11/1/2023 |
| TR3, TR4 | Power Transformer | NA5919-AL | NA5919-AL \| Power Converter Transforr | Inductance is for the primary, measured at 150 kHz, 0.1 Vrms, 0 Adc,( | $ 9.790 | 4 | $39.16 | 11/1/2023 |
| U1 | Digital Signal Microcontroller | DSPIC33FJ16GS504-I/PT | DSPIC33FJ16GS504-I/PT Microchip Tec | dsPIC33F Microcontroller IC 16-Bit 40 MIPs 16KB (16K x 8) FLASH | $ 6.360 | 2 | $12.72 | 11/1/2023 |
| U2 | Buck Converter | LM5008AMM/NOPB | LM5008AMM/NOPB Texas Instruments \| | Buck Switching Regulator IC Positive Adjustable 2.5V 1 Output 350mA 8-TSSOP | $ 3.730 | 3 | $11.19 | 11/1/2023 |
| U3, U4, U5 | Optoisolator | FOD817ASD | FOD817ASD onsemi \| Isolators \| DigiKey | OPTOISOLATOR 5KV TRANSISTOR 4SMD | $ 0.390 | 10 | $3.90 | 11/2/2023 |
| U6 | 5V Switching Regulator | MCP16301T-I/CHY | MCP16301T-I/CHY Microchip Technolog | Buck Switching Regulator IC Positive Adjustable 2V 1 Output 600mA SOT-23-6 | $ 1.360 | 2 | $2.72 | 11/9/2023 |
| U7 | 3.3 Linear Regulator | MCP1700T-3302E/MB | MCP1700T-3302E/MB Microchip Technc | Linear Voltage Regulator IC Positive Fixed 1 Output 250mA SOT-89-3 | $ 0.500 | 4 | $2.00 | 11/9/2023 |

*Table 1 Power Inverter Prototype Bill of Material*

# SOLAR LIGHT SYSTEM

Jeb Malek

# POWER CONVERTER SUBSYSTEM REPORT

REVISION – Final

3 December 2023

# 5. Converter Introduction

## 5.1. Scope

This subsystem entails the hardware and software design, PCB manufacturing, and assembly for the power converter of the solar light system.

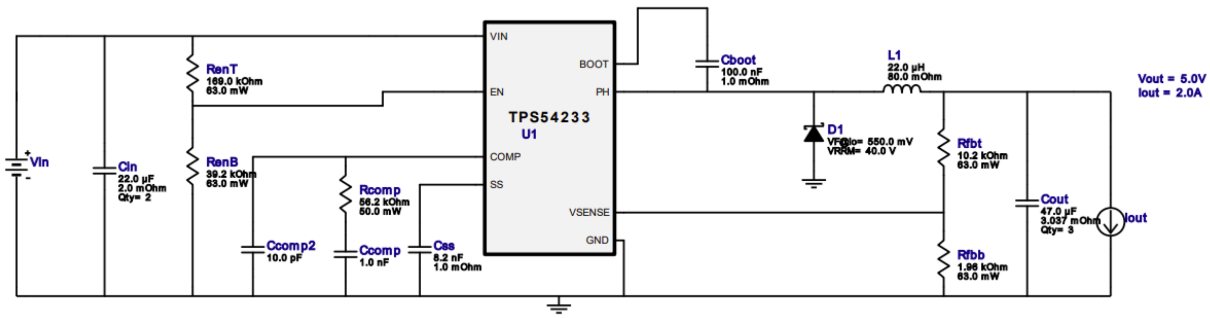


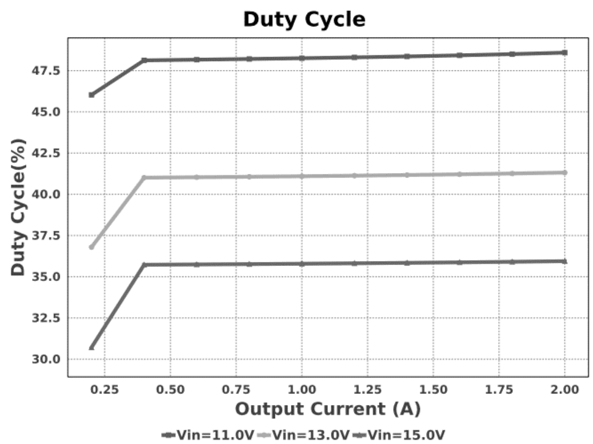

*Figure 12 Power Converter Circuit*

## 5.2. Buck Converter

### 5.2.1. PWM Duty Cycle Signal

In order to create a DC battery to DC load voltage converter from a higher 12 volt level to a smaller regulated steady state output with a constant value of close to 5V nominal.

A 12V input is designed for and will be sourced from a DC battery bank. In order to complete conversion of voltage a PWM Duty Cycle is required.



# 6. Converter Details

## *6.1. Battery Source*

Supplying a DC voltage source will be done with a 12 V Lead Acid Battery Pack will provide the necessary voltage to convert via a to the 5 V nominal values that were needed for load testing.

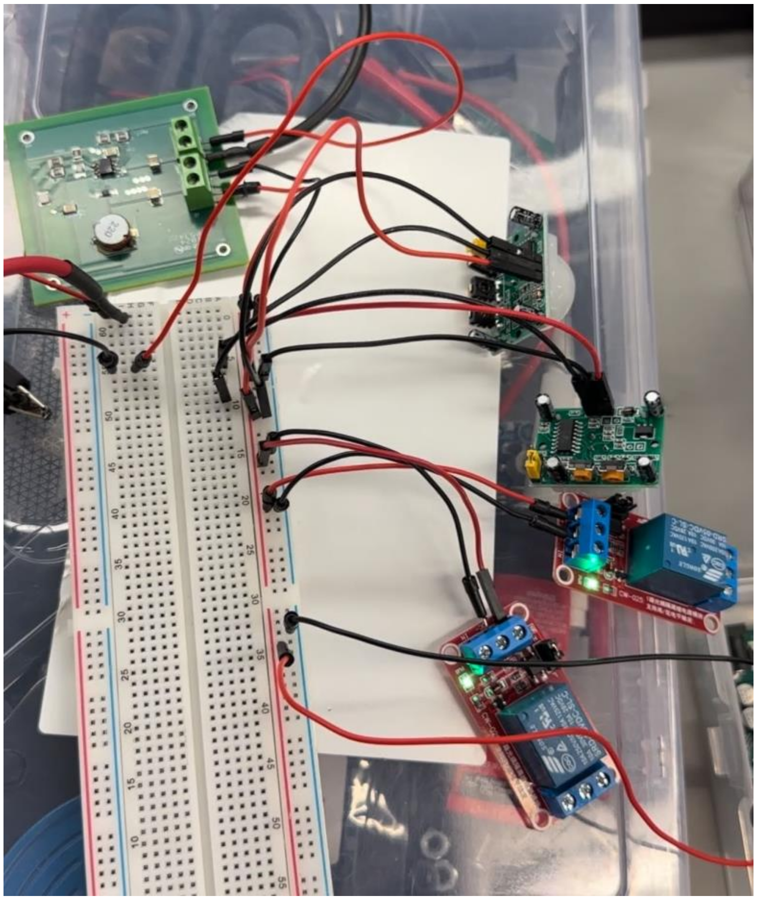


*Figure 14 5V Power Supply Regulation*

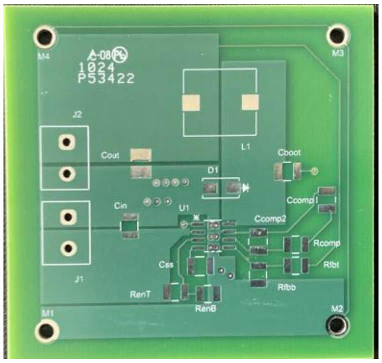


*Figure 15. Printed 5V Converter*

To properly power a buck voltage converter is used for low current DC/DC conversion.

# 7. Converter Validation

Converter validation was achieved with full system load testing.

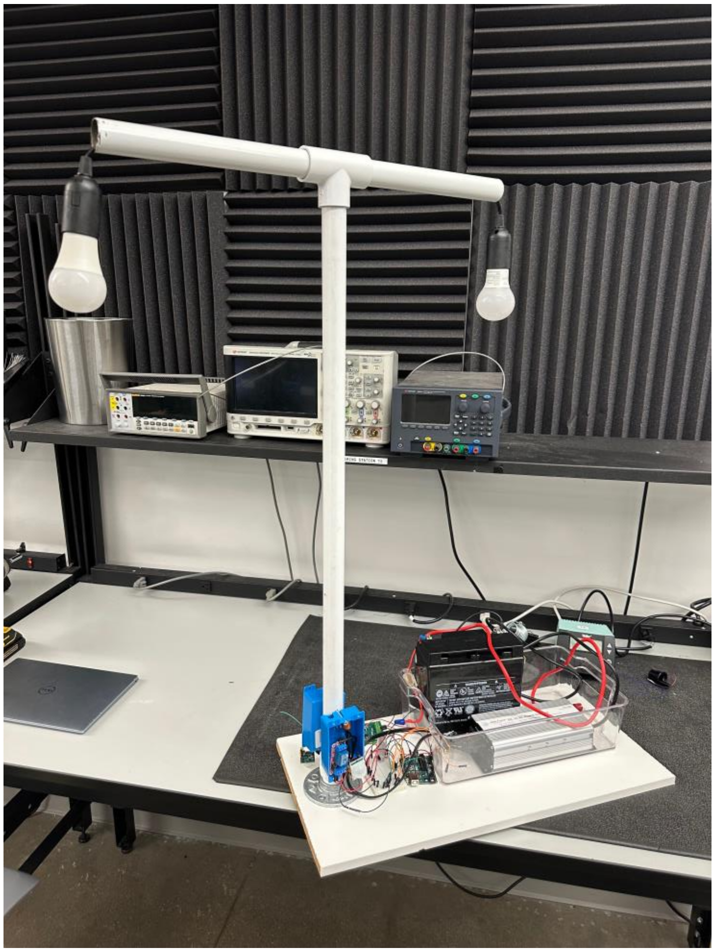


Figure 16. *Converter Validation*

# 8. Converter Conclusion

Rated for this converter will be able to supply a portion of system DC load for full integration of subsystems. Validation was seen with implemented full power to load at a regulated voltage. In reflection of this project's initial stage of inverter design and a need for change of scope an important decision was made with the aid of our sponsor to print a converter board and assemble, validate, integrate to support technical merit.

| | Power Converter | | | | |
|---|---|---|---|---|---|
| Cboot | CAP CER 0.1UF 50V X7R 1210 | https://www.digikey.com/en/products/detail/yageo/CC1210KKX7R9BB104/5884736 | | 3 | $ 1.29 |
| Ccomp | CAP CER 1000PF 100V X7R 1210 | https://www.digikey.com/en/products/detail/kyocera-avx/KGM32RR72A102KU/563710 | | 3 | $ 1.86 |
| Ccomp2 | CAP CER 10PF 50V C0G/NPO 0805 | https://www.digikey.com/en/products/detail/yageo/CC0805JRNPO9BN100/302833?s=N4IgTCBcDalMJwAwA5EFYBSA | | 3 | $ 0.30 |
| Cin | CAP CER 22UF 25V X5R 1210 | https://www.digikey.com/en/products/detail/samsung-electro-mechanics/CL32A226KAJNNNE/3886759 | | 3 | $ 1.32 |
| Cout | CAP CER 47UF 16V X6S 1210 | https://www.digikey.com/en/products/detail/murata-electronics/GRM32EC81C476KE15K/7363053 | | 3 | $ 1.56 |
| Css | CAP CER 8200PF 50V C0G/NP0 1210 | https://www.digikey.com/en/products/detail/vishay-vitramon/VJ1210A822JXAAT/8320960 | | 3 | $ 3.09 |
| D1 | DIODE SCHOTTKY 40V 0.5A SMA | https://www.digikey.com/en/products/detail/rohm-semiconductor/RB400VYM-50FHTR/8028520 | | 3 | $ 1.26 |
| Rcomp | RES SMD 56.2K OHM 1% 1/2W 1210 | https://www.digikey.com/en/mylists/list/SW46HQUBVC | | 3 | $ 1.11 |
| Rfbt | RES SMD 10.2K OHM 1% 1/2W 1210 | https://www.digikey.com/en/products/detail/panasonic-electronic-components/ERJ-14NF1022U/383823?s=N4IgjCBcpgt | | 3 | $ 1.11 |
| Rfbb | RES SMD 1.96K OHM 1% 1/2W 1210 | https://www.digikey.com/en/products/detail/panasonic-electronic-components/ERJ-14NF1961U/383938 | | 3 | $ 1.11 |
| RenB | RES SMD 39.2K OHM 1% 1/2W 1210 | https://www.digikey.com/en/products/detail/panasonic-electronic-components/ERJ-14NF3922U/384079 | | 3 | $ 1.11 |
| RenT | RES SMD 169K OHM 1% 1/2W 1210 | https://www.digikey.com/en/products/detail/panasonic-electronic-components/ERJ-14NF1693U/383911 | | 3 | $ 1.11 |
| J1, J2 | TERM BLK 2POS SIDE ENTRY 5MM PCB | https://www.digikey.com/en/products/detail/w%C3%BCrth-elektronik/691137710002/6644051 | | 6 | $ 2.46 |
| L1 | IND 22UH 3A 80 MOHM SMD | https://www.digikey.com/en/products/detail/bourns-inc/SDR1105-220ML/2561904 | | 3 | $ 2.94 |
| U1 | TPS54233DR Buck Switching Regulator IC Positive Adjustable 0.8V 1 Output 2A 8-SOIC | https://www.digikey.com/en/products/detail/texas-instruments/TPS54233DR/1967861 | | 3 | $ 5.10 |
| | | | Total Cost | | $ 26.73 |
| | | | | | $ 34.14 |

*Table 1 Power Converter Bill of Material*

# Solar Lighting System

Lyric Haylow

Jeb Malek

Josh George

# System Description and Final Report

Revision – 0

30 May 2024

# Table of Contents

# Table of Figures

# Table of Tables

# 1. Overview

The Solar Lighting System is a modular household-based application that uses renewable energy sources to cut down on utility expenses. The system uses a solar panel to power lights in both the patio and foyer and work autonomously with motion sensors controlling their activation. The system consists of several different subsystems: Charge Controller, Power System control, Microcontroller, and a Mobile Application. Proper integration of all subsystems was necessary to ensure a working product, as well as pass all deliverable requirements.

# 2. Development Plan and Execution

## 2.1 Design Plan

The design for the Solar Lighting System begins with the solar panel. A large panel absorbs sunlight and converts it to energy, powering a large battery through a solar charge controller. The 12V battery is charged up and connected to a power inverter, which inverts direct current into the alternating current necessary for the lights to be operated. Two LED lights are implemented into the system, one to represent an indoor foyer light and the other to represent an outdoor patio light. A microcontroller is also powered by the battery and connected to the sensors, enabling them, and disabling them on command. The battery is also connected to the microcontroller through a stepdown circuit, lowering the voltage to a value readable by the MCU. Finally, the microcontroller connects to a mobile application, allowing a user to turn lights on and off at will, switch the operational mode of the system from “Manual” to “Motion”, and read the battery percentage of the system.

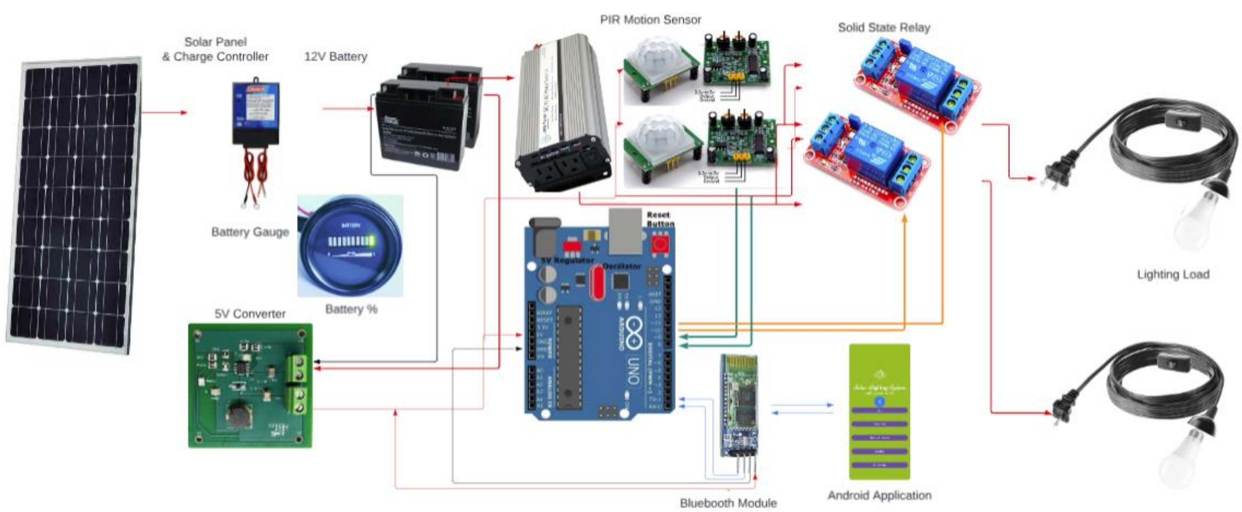



Figure 1. System Plan Diagram

## 2.2 Execution

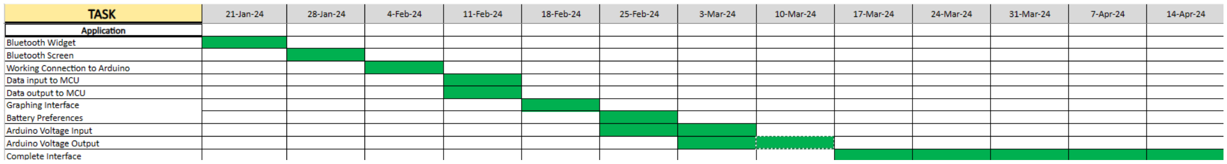



*Table 1: Mobile application validation plan.*

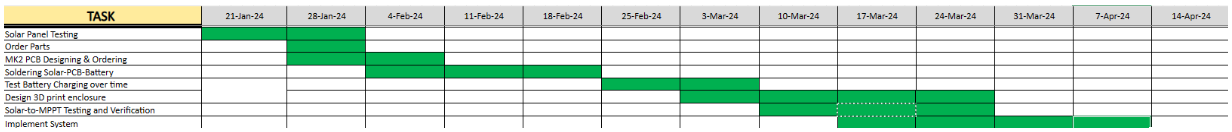



*Table 2: Solar charge controller validation plan.*

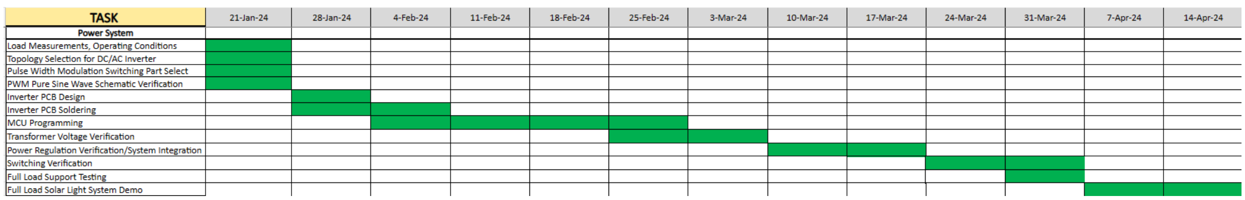



*Table 3: Power inverter validation plan.*

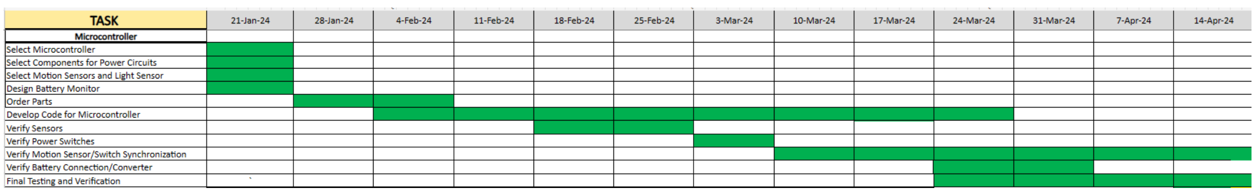



*Table 4: Microcontroller validation plan.*

## 2.3 Validation Plan

| Paragraph # | Test Name | Success Criteria | Methodology | Status | Responsible Engineer |
|---|---|---|---|---|---|
| | App Requirements | | | SUCCESS | Josh George |
| 3.2.5.1 | App Connection to phone Via USB | Android studio establishes a connection with Android phone when connected via micro USB | Beginner code in android studio | SUCCESS | Josh George |
| 3.2.5.2 | App Connection to phone Via APK File | Android studio establishes a connection with the Android phone when the app is downloaded on the phone via the APK file | Beginner code in android studio, uploaded through Bluetooth | SUCCESS | Josh George |
| 3.2.5.3 | Establish Bluetooth Connection with A | Able to connect to a bluetooth capable device and detect the serial number | Work with microcontroller Bluetooth package to connect to android studio | SUCCESS | Josh George |
| 3.2.5.4 | Bluetooth Communication via App | App displays screen with good connection. | Make sure code runs successfully on Android device | SUCCESS | Josh George |
| 3.2.5.5 | Main Screen | App is able to display a home screen | Code home screen in Android studio, make sure it runs, debug errors. | SUCCESS | Josh George |
| 3.2.5.6 | Data from Charge Controllor | App is able to connect to charge controller and accurately display readings. | Understand how charge controller connects to MCU, adapt code accordingly. | SUCCESS | Josh George |
| | | | Solar Panel Battery Charge | | |
| 3.2.1.1 | Solar Panel Mount | Stays in space mounted for several days time | Verifying Hardware is properly mounted | SUCCESS | Lyric Haylow |
| 3.2.1.2 | MPPT Functionality | MPPT is working as expected within the IC | Set higher voltage than MPPT, check whether IC brings voltage down to set MPPT voltage level. | SUCCESS | Lyric Haylow |
| 3.2.1.3 | Charge Controller Verification | Voltage levels are modulated along with Current Levels | Steadily increasing current will be applied to charge controller, to point of max expected | SUCCESS | Lyric Haylow |
| 3.2.1.4 | Overvoltage Solar Panel Protection | Supply voltage levels do not exceed IC limits | Sending a increasingly higher voltage through the charge controller, eventually checking it functions as predicted | SUCCESS | Lyric Haylow |
| 3.2.1.5 | Overcurrent Battery Protection | Charging current levels do not exceed expected input values | When charging battery, consistently measuring charging current upon increasing supply voltage using DC power supply | SUCCESS | Lyric Haylow |
| 3.2.1.6 | PWM EMI Interference | Interference does not significantly alter design guidelines | Use a Broadband RF meter if one available, if not then the to identify interference points. | SUCCESS | Lyric Haylow |
| 3.2.1.7 | Battery Charging to Capacity | Battery stops being charged once it has a full charge | Feeback voltage will be applied back to IC as shown in documentation | SUCCESS | Lyric Haylow |
| 3.2.1.8 | State of Charge (SOC) | Measurement for current State of Charge coincides with expected values | Measure the voltage with a multimeter and convert measured voltage to approximate power percentage expected | SUCCESS | Lyric Haylow |
| 3.2.1.9 | Depth of Discharge (DOD) | Measurement for current State of Charge coincides with expected values after discharge | Measure the voltage with a multimeter and convert measured voltage to approximate power percentage expected | SUCCESS | Lyric Haylow |
| 3.2.1.10 | Functional Charge Controller | Charge controller works as specified in project report. | Test and Validate entire subsystem. | FAILED | |
| | | | Power Inverter Characteristics | | |
| 3.2.2.1 | Output Voltage | Inverter will supply a steady 120 VAC RMS value | With an attached load a benchmark of current drawing configurations to satisify stable pure sine wave voltage of 120 VAC | SUCCESS | Jeb Malek |
| 3.2.2.2 | Output Frequency | Inverter will supply a steady output sinusoid at a frequency of 60 Hz | Proper inverted sine waves shall operate at normal operating constraint of 60 Hz | SUCCESS | Jeb Malek |
| 3.2.2.3 | DC/DC Conversion | Inverter will supply 5V / 1 A regulated output | Attaching E-Load to Inverter USB-C Receptacle provides 5 V load at varying currents | SUCCESS | Jeb Malek |
| 3.2.2.4 | Output Stability | Output Voltage is maintained at desired value | Measurement with load with charging and discharging states and verifying voltage flucuation | SUCCESS | Jeb Malek |
| 3.2.2.5 | Varying Loads | Inverter will supply light loads of varying configurations | Measurement with E-Load with benchmark loads attached while charging, discharging, in all modes of operation | SUCCESS | Jeb Malek |
| 3.2.2.6 | Switching Continuity | Inverter will supply loacd when varying switching configurations are accuated | Measurement with E-Load with benchmark loads attached while Solid State Relays perform circuit configurations | SUCCESS | Jeb Malek |
| 3.2.2.7 | Integrated Subsystems | Inverter will supply full load when sensors circuit is controlling solid state relays | Measurement with Multi-Meter to check voltage currents and line frequency under changing load conditions | SUCCESS | Jeb Malek |
| 3.2.2.8 | Integrated Subsystems | Inverter will maintain load voltage and current when supporting microcontroller and charge controlling circuits are attached. | Measurement with and Multi-Meter to check voltage currents and line frequency under changing load conditions | SUCCESS | Jeb Malek |
| | | | Microcontroller and Sensor Characteristics | | |
| 3.2.3.1 | Switch Voltage | The indoor sensor miss rate does not exceed 5% and outdoor sensor miss rate does not exceed 10% | Move an object within detection ranges over a 30 min duration. Monitor for detected objects using its output | SUCCESS | Jeb Malek |
| 3.2.3.2 | Switch Control | The control of AC relay with digital signal | Communication of digial output of switch pin and output from microcontroller to relays to control an AC Load | SUCCESS | Jeb Malek |
| 3.2.3.3 | Bluetooth Connectivity | Microcontroller is able to connect to a mobile device via Bluetooth | Use multiple devices and connect to the microcontroller via bluetooth module | SUCCESS | Jeb Malek & Josh George |
| 3.2.3.5 | Application Communication | Arduino receives communication from Bluetooth Module, and can communicate mobile application | Verifying digital pin setting for manual mode operate at appliaction button pushes actuate relays and set mode of operation to motion. | SUCCESS | Jeb Malek & Josh George |
| 3.2.3.4 | Motion Sensor Voltages | The input voltages of the microcontroller and peripherals shall be 5V nominal | Using a multimeter to validate the correct voltage levels and taking current readings | SUCCESS | Jeb Malek |
| 3.2.3.7 | Response Time | Arduino receives communication from motion sensors that can operate at a timing range that operates with switches | Verifying sensitivity setting for motion sensor can operate at its optimal distance triggering limits | SUCCESS | Jeb Malek |
| 3.2.3.8 | Sensitivity | Arduino receives communication from motion sensors that can operate at maximum distant range | Verifying sensitivity setting for motion sensor can operate at its optimal distance triggering limits | SUCCESS | Jeb Malek |

*Figure 2: The validation plan for the solar lighting system.*

# 3. Critical System Report

## 3.1 Mobile Application Report

The mobile application for the Solar Lighting System works as intended with five unique screens in addition to the Home Screen: About, Battery Level, Lighting Preferences, 10-Hour History, and User Settings. The following screenshots are taken directly from the app, which was loaded on a Motorola Moto G Stylus.

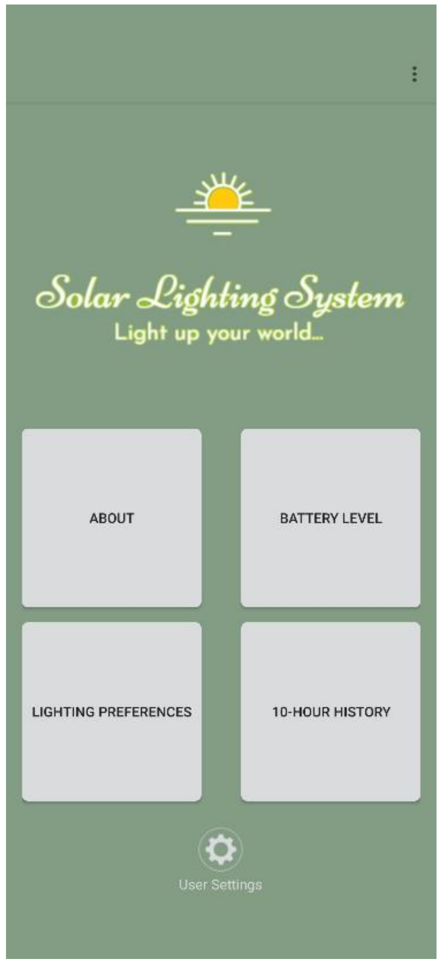



*Figure 3: The Home screen, displaying four different buttons and a settings option.*

The home screen was redesigned to better portray the system to a customer as well as give the UI a cleaner feel. Clicking on “About” will successfully display a page which provides the user with a paragraph explaining the purpose of the app. Clicking on “Battery Level” will lead to the following screen.:

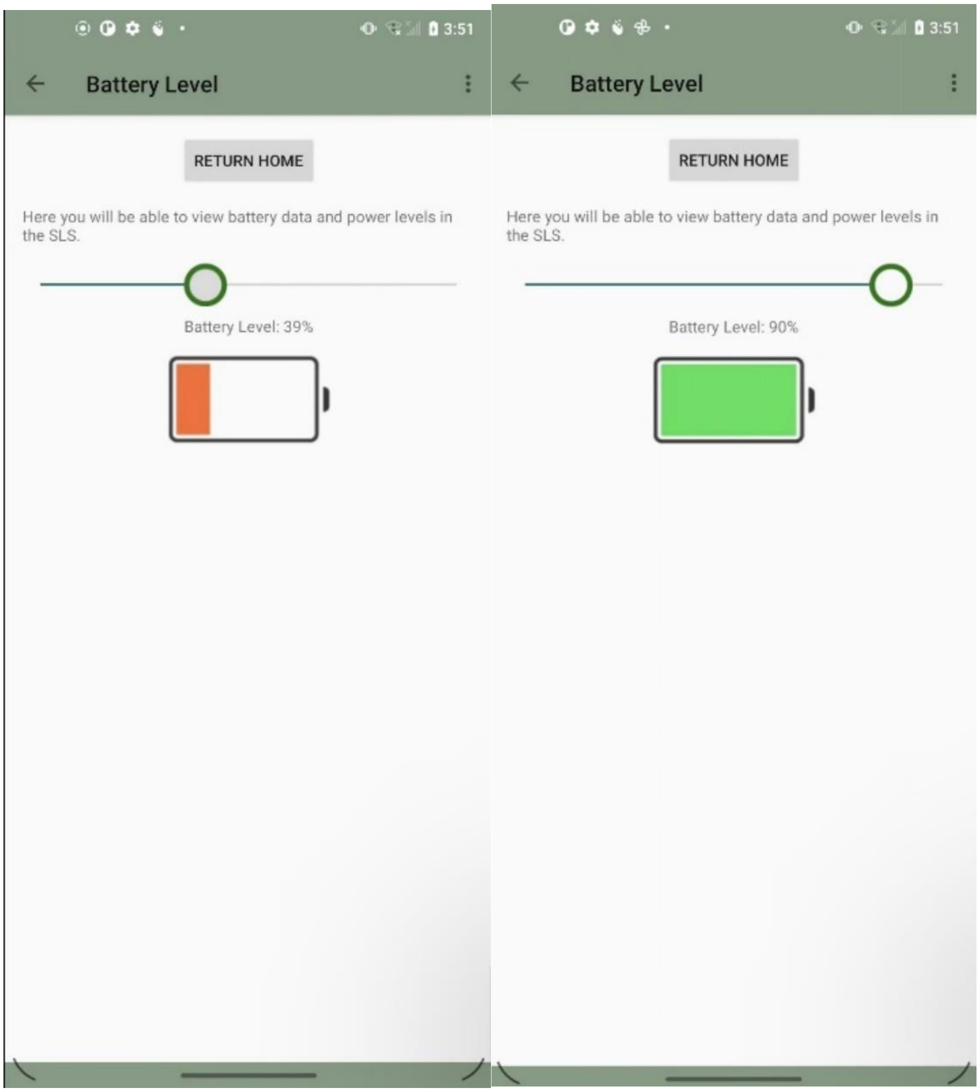



*Figure 4: The battery level screen when the system is low in charge (left) and the same screen when the system charge capacity is nearly full (right).*

The app is able to reliably indicate the battery percentage and updates live every time this screen is loaded. Both screenshots were taken on the same sunny day, in which the system was able to charge up from 40% to 90% within 2 hours.

From the home page, clicking on Lighting Preferences will lead to the following page:

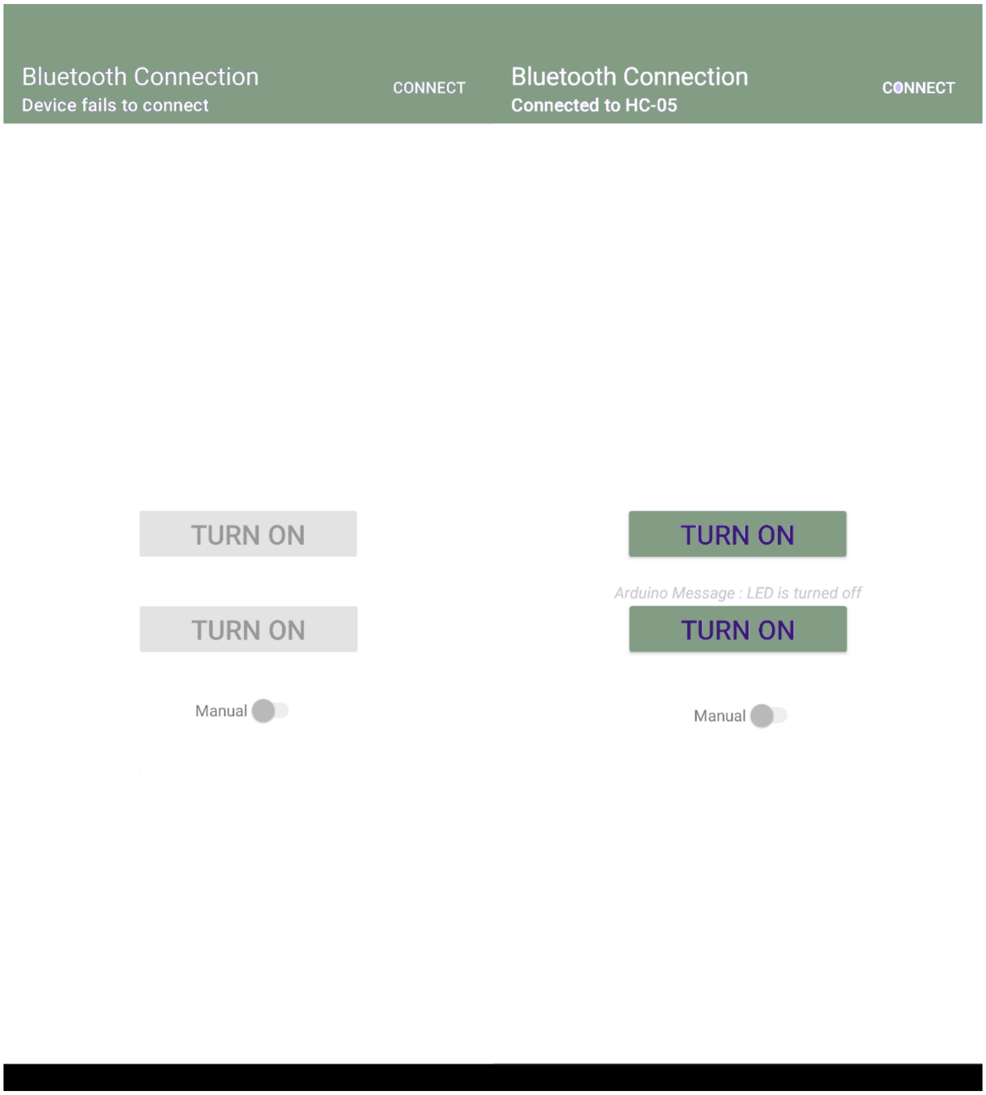



*Figure 5: The Lighting Preferences screen before and after connection.*

The buttons on this screen will only activate once Bluetooth connection has been established with the Arduino Rev3 Uno board through the HC-05 Bluetooth module. To connect, first pair the discoverable module with the phone through the phone settings. Next, open the app and navigate to this screen. Clicking on “Connect” in the top right corner will open the following screen:

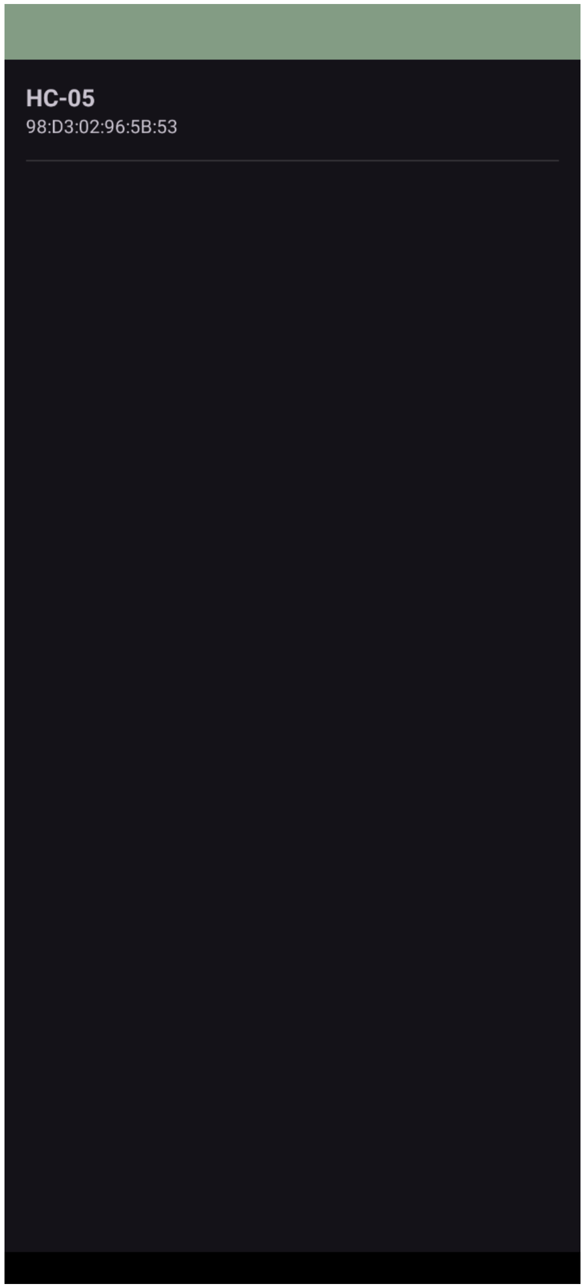



*Figure 6: The list of paired Bluetooth devices in the area. HC-05 module is shown as discoverable.*

Click on the shown Bluetooth module to connect to the system. Once the connection has been established, the user will be able to interact with the system in two operational modes, “Manual” and “Motion”. Using the switch can toggle between the systems. In “Manual” mode, the motion detectors are off and the lights can be manually turned on or off using the displayed buttons. Setting the switch to “Motion” disables the two buttons and activates the motion sensors through the microcontroller.

Clicking on 10-Hour History from the home page will navigate the user to the following page:

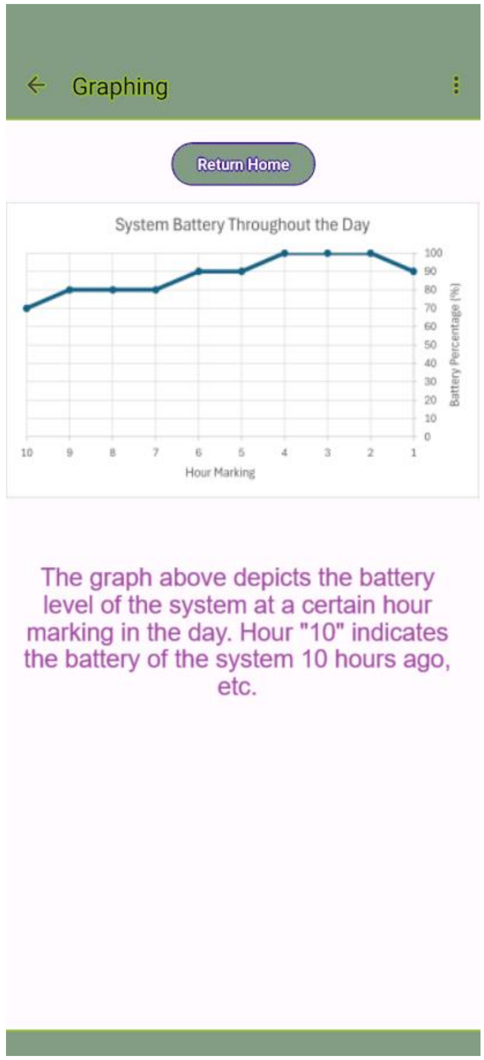



*Figure 7: The 10-Hour History fragment of the application.*

A graph is displayed on this fragment, along with some text explaining this screen. The graph displays battery percentage data of the system throughout the day, more specifically from the past 10 hours of the system operating. The system successfully records the battery percentage on the Y-axis and displays them with their respective hour marking on the X-axis. The percentage is read by the microcontroller, sent to the app, and then sent from the app to a database hosted by Firebase. The data in the database is then read by the app and graphed in a comprehensive manner. The above graph was taken from a moderately sunny day which got darker in the evening.

Clicking on the “User Settings” icon navigates the user to the final page of the app:

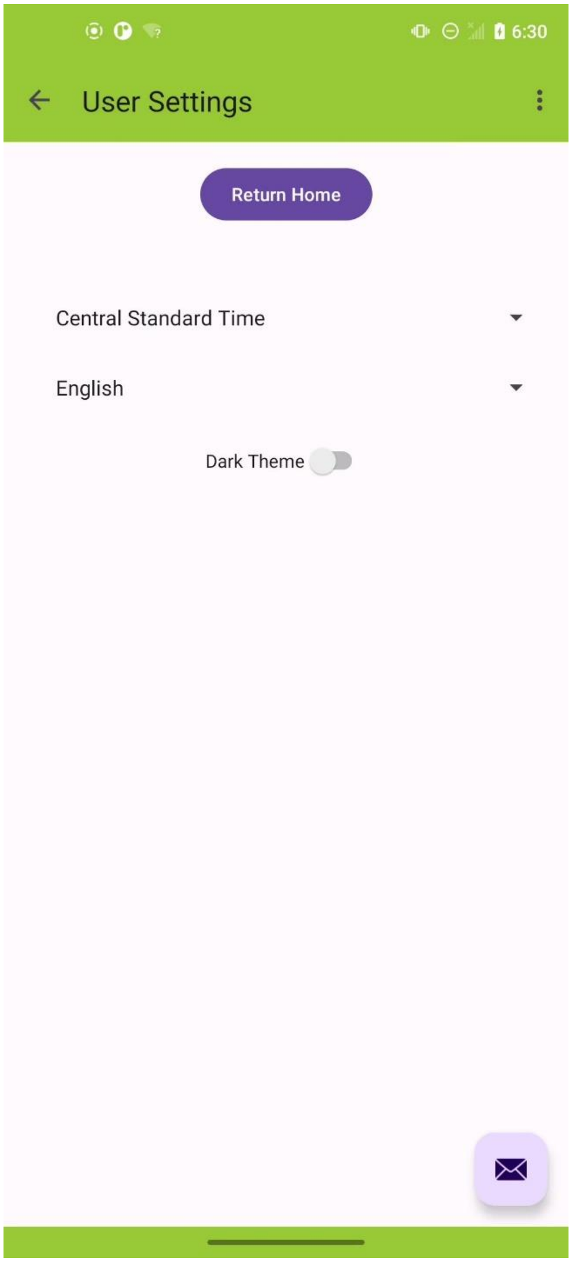



*Figure 8: The User Settings segment of the application.*

The settings for the app include a Time Zone setting, a Language setting, and a dark theme. The time zone is implemented in the graph, which provides different hour markings depending on which time zone was selected. The language dropdown box allows the user to choose between English, Spanish, French, and Japanese as viable options to operate the app within. Lastly, the dark theme offers a different UI scheme for those who desire it. It can be seen below, demonstrated with the "About" screen:

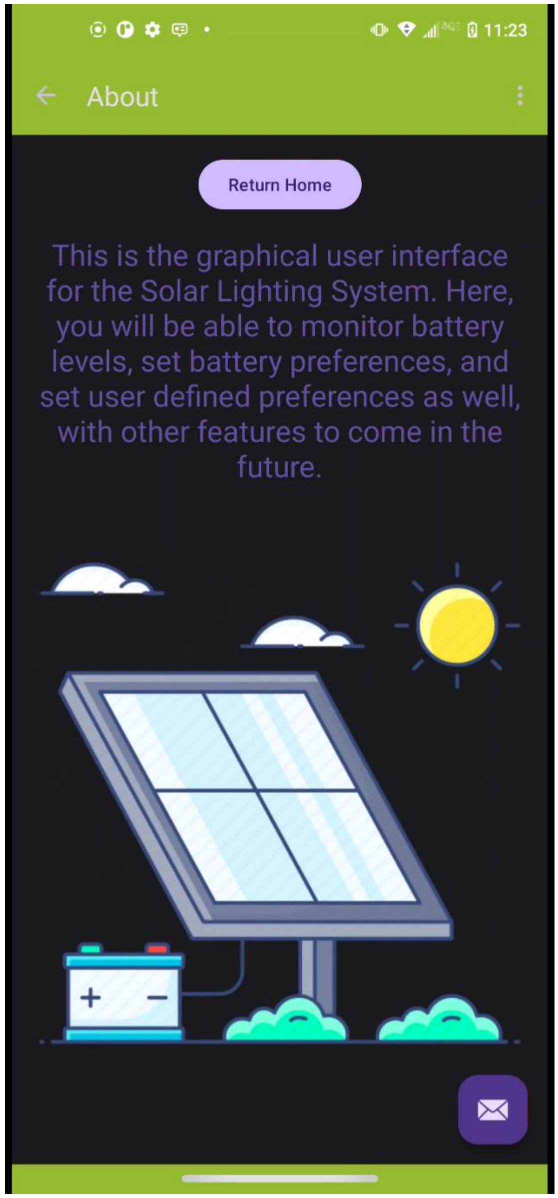
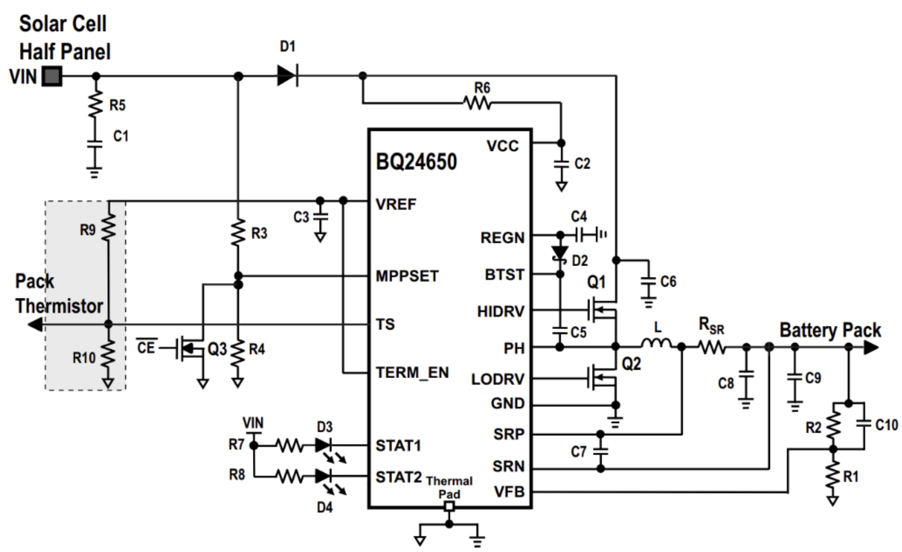



*Figure 9: About segment of the application, displayed when "Dark Theme" is switched on.*

In conclusion, the application successfully provides data to the system in the form of setting the operational and successfully processes data from the system in the form of the battery percentage and a graphical user interface. It accurately reads the battery percentage of the implemented 12V battery and is able to command the system in real time with the use of Bluetooth and the Arduino R3 Uno microcontroller. The app succeeded in its primary functionality; however, future adjustments to this subsystem would likely include more options for user customization. It would also be worthwhile to implement functionality for multiple Solar Lighting Systems, so that a user could control and obtain data from more than one system at once.

## 3.2 Charge Controller Report

The Solar Charge Controller, which was to regulate power coming from the solar panel to the battery, was chosen to be the BQ24650 design from TI. During 403 and 404 efforts were made to get the design to work, and the design shown in the datasheet is shown below.




Solar Panel 21 V, MPPT = 18 V, 2-cell, $I_{CHARGE}$ = 2 A, $I_{PRECHARGE}$ = $I_{TERM}$ = 0.2 A, TS = 0 – 45°C

**Figure 15. Typical System Schematic**

*Figure 10: BQ24650 Typical Application schematic*

Two separate boards were printed during this time, and several attempts to get them to draw current were inconclusive. After many attempts, much testing, and looking into their datasheet, the conclusion I've come to is that their typical application design is faulty. Listed below are verifications of what the second board was capable of, and worked, as well as tests done to try and correct functionality. All mentions to parts will be in reference to Figure 2.

- Connecting board to 21V 1A input from DC Power Supply resulted in Charging light turning on, and voltage carries across the board appropriately. Output voltage and Battery Pack high pin read at ~12V, so output also set correctly. When connected to 12V 18Ah Lead-Acid battery, charging light stays on, however charging current limited to around 4mA. The voltage at the VFB pin read around 2.1V, which is value expected for the board to be set to output.
- Connected fully charged battery to output with no input attached, and LED D4 turned on, showing it recognizes fully charged batteries. Confirmed for both Lead-Acid and Lithium-Ion batteries.
- After hooking up DC Power, attached the faulty battery, and all LEDs turned off, showing the board accurately reads faulty attachments.
- Attempted changing R2 and R1 voltage divider ratio, both for raising and lowering voltage division value. Raising it caused no real change, as still recognized battery

needed charge but didn't pull large current, and lowering it caused board to recognize battery as prematurely fully charged.

- Attempted to change R3 and R4 voltage divider ratio for proper reading from solar panel. No real change, but ultimately changed both values to match solar panel voltage input we chose.
- Resoldered both IC and Q1-Q2. No discernable change in voltage values.
- Attempted to remove Rth, thermistor. The board would not work without it, which is incorrect with what datasheet provides.
- Attempted using solely 12V 10Ah Lithium-Ion battery, rather than planned Lead-Acid batteries, since charger is built more for Lithium-Ion batteries. There was no discernable difference in voltage between the two, and the main functionalities worked the same. Returned to Lead-Acid battery since it had larger capacity.
- Soldered a second board completely, just in case first soldering had some issue with it. Same functionality as first board.

After much testing, I turned to the evaluation sheet for the BQ24650 and concluded that the typical application design in their main datasheet is faulty. Shown below is the evaluation board schematic, and all components circled in red are not represented in the typical design schematic that TI proposes works. There are additional components listed, but many of them are for the purposes of testing.

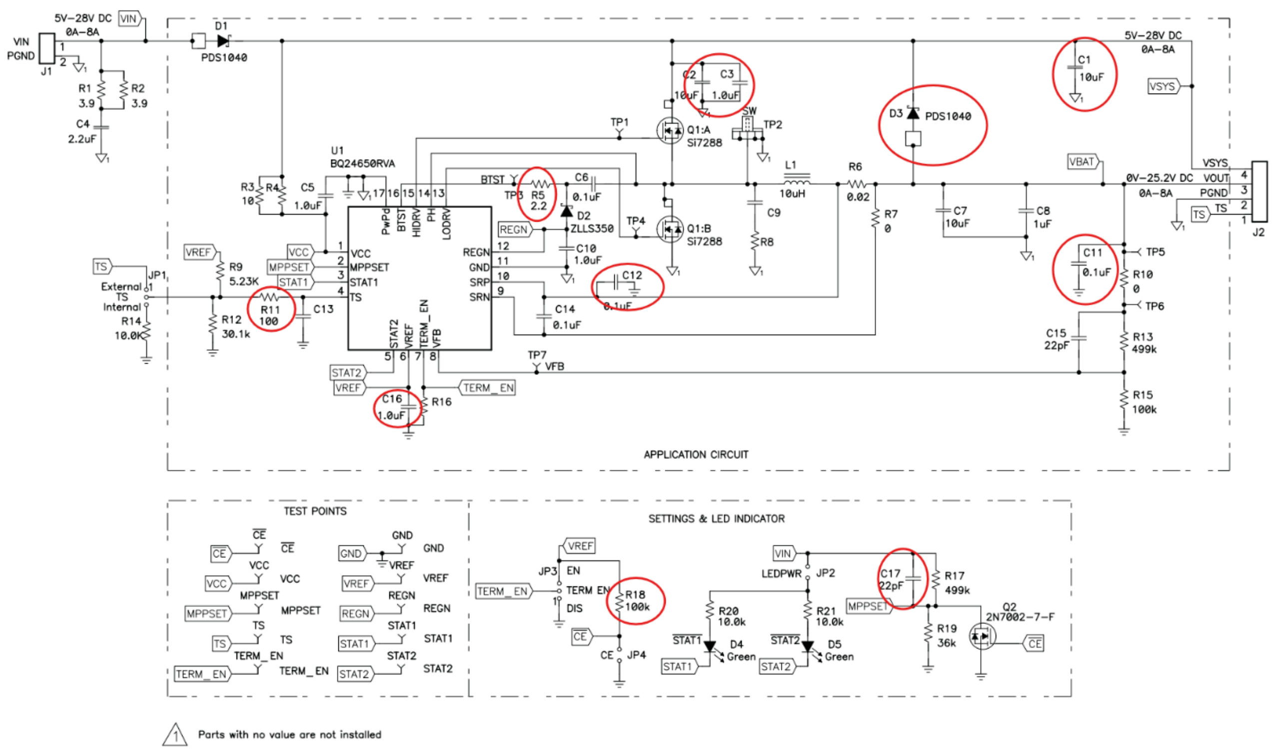



*Figure 11: BQ24650EVM schematic*

With these obvious differences between boards, as well as another associate who is using the same board and coming across the same issue, I strongly believe that the BQ24650 typical application design is faulty, or at the very least missing several components. Because of this, we opted for using the charge controller that came with the solar panel we had bought. Using this charge controller, I was able to meet integration requirements for my subsystem.

The other addition I had for the project was creating a quick connection between the battery and the Arduino, for the purpose of reading voltage from the battery and sending it to the app for reading the battery percentage. While estimating battery percentage using voltage isn't as accurate, we were going for functionality first, and if we then had time we planned to add a current sensor. In the end we opted for reading through voltage. This was accomplished by a high resistor value voltage divider, which stepped the voltage value down from 12V to around 2.0V, using a ratio of $\frac{100\Omega}{570\Omega} = 0.1754$. For testing, we applied the circuit and read the 12.6V from the battery as 2.23V on the Arduino programming. The slight change in value I've determined was likely due to a slight difference in resistance than expected.

## 3.2 Power System Report

The power system was able to provide stable voltage for required loads for demonstration purposes. The nominal 5 V Output was regulated and supplied Arduino, switch, motion sensor, and Bluetooth Module sufficient voltage and current supply to maintain operation.

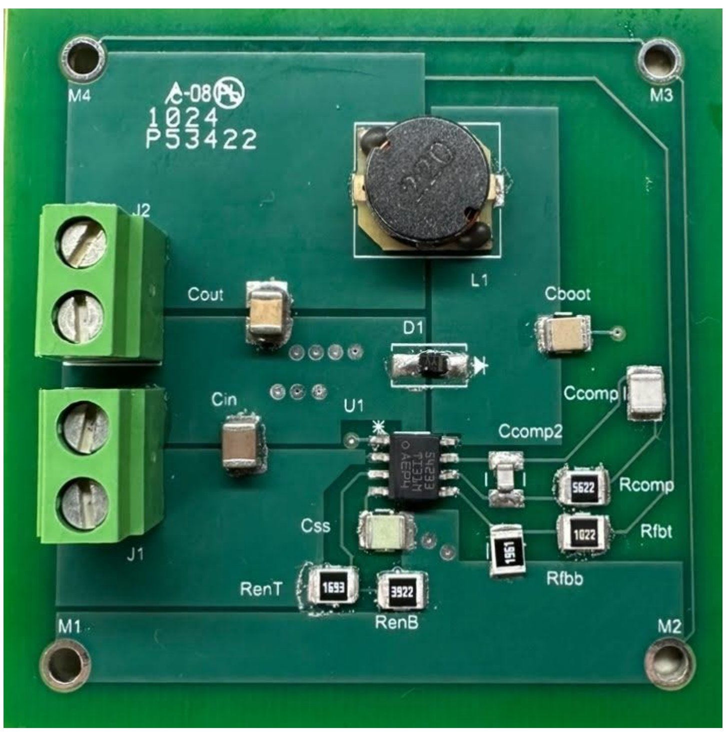



Figure 12. Converter PCB

The inverter subsystem required a factory-made solution for AC load support. After strenuous testing on the Microchip device which was unable to be targeted the most likely explanation is that through a design flaw with a grounding issue in the transformer. Converters needed for the microcontroller were not able to supply source voltage therefore the MCU was not powered up. After consideration to focus more on the converter subsystem the AC load was supported with the purchase of the AIMS Power DC To AC Power Inverter rated for 800W well over our intended demonstration load.


*Figure 13. Inverter*

The final system structure is shown below.

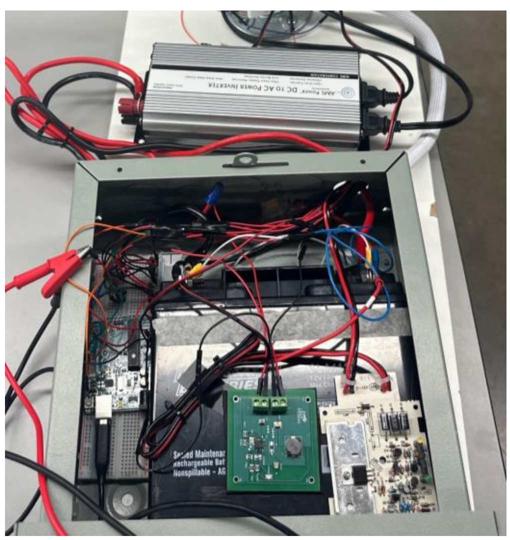


*Figure 14. System Power Structure*

### 3.3 Microcontroller Report

Using an Arduino Uno Rev 3 the motion sensor data, switch actuation, and mode of operation control were implemented in this subsystem of the project.

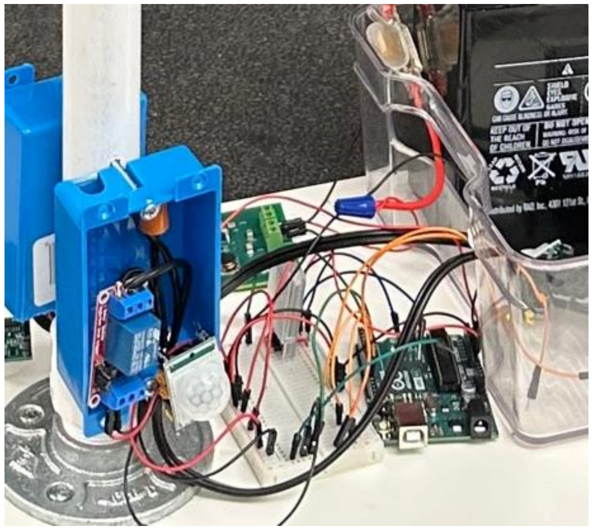


*Figure 15. Microcontroller Connection*

# 4. Conclusion

The Solar Lighting System demo we made functioned as needed, however numerous improvements could be made for better overall quality. Regardless, all subsystems worked as needed for integration purposes and led to a fully functional project.

*Figure 16. Final Demonstration*

## 4.1 Key Decisions

All decisions regarding what pieces were to be used for individual subsystems were made by those in charge of that part of the project, however frequent communication between each other, as well as our sponsor for this project, led to a few aspects of our original project being changed.

One of the initial key decisions made was how to implement an Arduino microcontroller. With the loss of a teammate early on, we gained permission to use a bought microcontroller, rather than solder one ourselves. The software portion was delegated to both Jeb and Josh, seeing as they are most closely affected by the microcontroller and are most aware of how these subsystems integrated.

The other major decision we made was to remove the flood light from our system design. Ultimately, our sponsor decided that the power requirements of a flood light would likely cut down on the product's lifetime by an amount too detrimental. Our expected lifetime of the lighting system would be around 9 hours; however, a flood light would have cut that value down to around 2 hours.

## 4.2 Learnings

Android application design. Arduino microcontroller coding. Printed power circuit board design, manufacturing, and assembly, and physical power electronic construction were key takeaways from this senior engineering design project. Problem solving and design choices lead to critical decision making and schedule forecasting considering costs. The final product demonstrated provided a functional representation of what our team's task required.