Building an Efficient Maximum Power Point Tracking (MPPT) Solar Charge Controller

ECE 499: Design Project II

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Group Information

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Executive Summary

The increasing demand for sustainable energy solutions and the need for efficient off grid living systems have highlighted the importance of maximizing the efficiency of solar panels. This project focuses on developing an MPPT (Maximum Power Point Tracking) solar charge controller, the most effective type for optimizing solar energy conversion. Our objective was to design and build an MPPT controller that enhances the efficiency of solar panels by 30-40% over any other charge controller method (which is typical for MPPT), providing an efficient battery charging solution under varying sunlight conditions.

The project involved understanding various solar charge methods, explicitly focusing on MPPT due to its superior performance. We analyzed MPPT theory in relation to a solar panel's I-V and P-V curves. We explored the basic design of an MPPT controller, including key subsystems like the synchronous buck converter, current sensor, ADC, and microcontroller. We reviewed several open-source MPPT designs and selected the "1kW Arduino MPPT Solar Charge Controller" by ASCAS as our base due to its comprehensive resources and open-source firmware, which we modified for our needs.

We constructed a prototype, installed the open-source firmware, and set up a test environment with a solar panel and battery. Another important outcome of the project was building a comprehensive understanding of a how a high-efficiency MPPT controller works, which could demonstrate significant improvements in solar energy extraction and battery charging efficiency if they became more common, thereby contributing to more reliable and sustainable off-grid energy solutions.

I Introduction

Solar power is crucial in reducing fossil fuel dependency and carbon emissions. Despite its potential, maximizing solar energy efficiency remains challenging, especially in off-grid applications requiring consistent power supply. This project focuses on developing a Maximum Power Point Tracking (MPPT) solar charge controller, which optimizes energy extraction from solar panels to ensure they operate at peak efficiency in varying conditions. By enhancing solar power conversion efficiency, the project aims to improve the reliability of off-grid solar systems, supporting sustainable living and contributing to environmental conservation. The report details the problem definition, scope, design specifications, and methodologies of the MPPT controller, highlighting its potential social impact and significance in advancing renewable energy technologies.

Problem Definition

Solar energy systems are crucial for sustainable energy solutions and off-grid living. Operating solar panels at their Maximum Power Point (MPP) is essential to maximize efficiency. The MPP varies with sunlight conditions [1]. Maximum Power Point Tracking (MPPT) solar charge controller designs are by far the most efficient type and significantly improve solar energy conversion efficiency by 30-40% over other designs, providing a solution for efficient battery charging under varying sunlight conditions [2]. This project aims to contribute to sustainable energy technologies with practical applications for off-grid living, such as a cabin with low power needs.

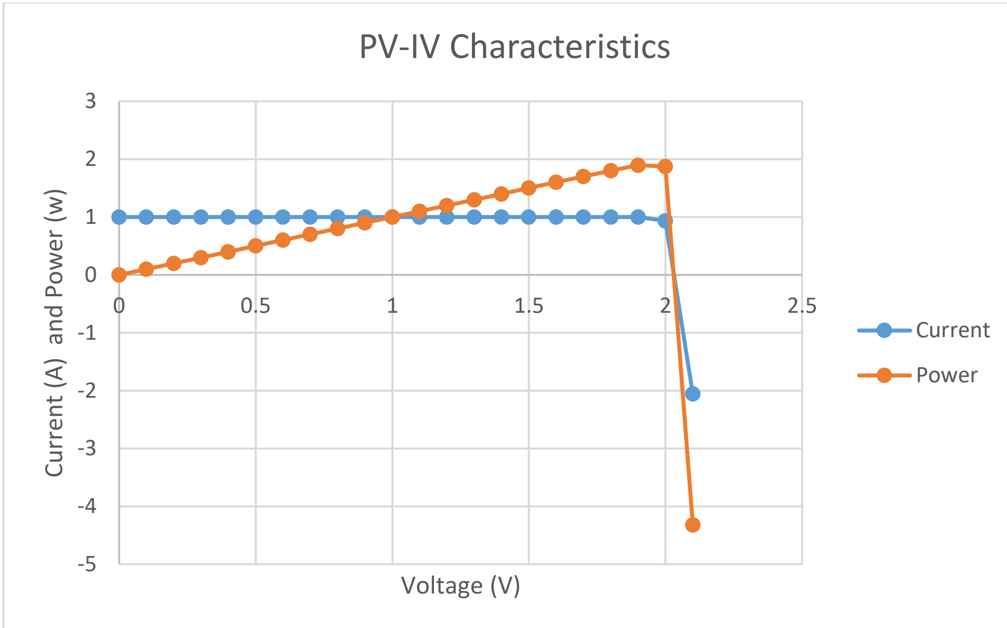


Figure 1: I-V and P-V curves of a photovoltaic (PV) panel.

By continuously tracking the solar panels' MPP and adjusting the synchronous buck converter's Pulse Width Modulation (PWM) duty cycle, the MPPT controller ensures that the panels operate at their optimal voltage, regardless of varying sunlight conditions. This leads to maximum energy extraction from the panels and efficient battery charging.

Scope of Work

This project aims to build an MPPT solar charge controller that works with a solar panel or array of panels to charge a battery or array of batteries. All MPPT controllers rely on a microcontroller to run the MPPT algorithm and continually adjust the PWM duty cycle of the buck converter (which uses MOSFETs and a MOSFET driver) at high-speed using feedback from a current sensor and input and output voltages measured by a fast sample-rate ADC to estimate the instantaneous power extracted while sweeping and keeping track across a range to find the current maximum power point. This process must be speedy to be effective. Some firmware development is necessary, even using the open-source firmware as a base, to tune the parameters to our test environment and enable the desired features. We also call on some knowledge of power electronics and an understanding of photovoltaic (PV) cell behaviour. A typical car battery voltage is 12VDC, as almost all cars (referring to starting batteries and electrical systems for typical gas/diesel autos, not EV main batteries, which are usually lithium and arrayed into much higher voltage configurations) and many off-grid setups use 12VDC electrical systems, using lead or lithium-ion. We wish to use a simple 12VDC car battery for our test setup, as this is easily attainable and represents a very basic off-grid setup. Solar panel output voltage varies between models. A single 100W panel has a maximum output voltage of 17-18V. Solar panels (often installed in series) have a voltage greater than the battery voltage. Many charge controllers use a buck converter to step this down to the desired battery charging voltage or inverter operating voltage. We do the same here, as it is the obvious choice for such a device. When controlled using an MPPT algorithm, this buck converter also allows us to independently control the battery charging voltage separately from the panel voltage (ideally kept as close to the maximum power point as possible).

Typical MPPT designs are very flexible and support a range of input voltages up to 100VDC and multiple battery chemistries from 12V lead-acid to 48V or more lithium cell arrays. Also, during low-light conditions like dawn/dusk, the panel voltage is often below the battery charging voltage. MPPT designs also allow the controller to work in boost mode (stepping up voltage vs. buck mode stepping down), extracting energy even in marginal conditions. We are targeting a 12V nominal (up to ~14V actual) charging voltage for a single lead-acid battery and 1-2 100W panels, as this is a widespread entry-level setup and is already owned by a group member. MPPT controllers, being all about efficiency and extracting maximum energy, typically rely on a synchronous buck converter rather than the much more common asynchronous type. This is because a synchronous buck converter has a much higher efficiency of ~98% than a comparable asynchronous version of ~80%.

Synchronous designs achieve this by replacing the blocking diode with another MOSFET. Simple in concept but difficult to implement. If both MOSFETs are accidentally switched on simultaneously, a short circuit occurs, and proper synchronous operation must be maintained with no interruption. For the MPPT controller to work correctly, the microcontroller must keep up with all tasks without stalling, freezing, or getting bogged down. The difficulties with implementing an MPPT charge controller (getting the synchronous buck design working and developing the firmware, and much more) have been solved by the instructables.com project creator ASCAS throughout his project "1KW

ARDUINO MPPT Solar Charge Controller (esp32 + WIFI)" [2]. We have chosen to build our design based on this project, as it is a phenomenal learning resource and helps us greatly in reducing the scope of what we need to do. The project creator wrote and released an open-source MPPT firmware for the ESP32 microcontroller (FUGU Open-Source MPPT Firmware), which we can use to run our controller, significantly reducing the amount of time needed to get up and running [2]. He also provides board schematics and component lists. The project article provides a complete overview of MPPT theory, operational understanding, and typical design, with a step-by-step guide that walks the reader through each design difficulty encountered, a discussion on each component (what it does and why it was selected), and rationale behind almost every nuance you could think of in building one of these devices.

Ethical Considerations

Several guidelines in the Engineers and Geoscientists BC (EGBC) Code of Ethics are relevant to this project. **The first principle** emphasizes holding paramount the public's safety, health, and welfare. Our project aims to create a solar charge controller that is dependable and safe, supports renewable energy sources, and advances public welfare. **Principle 2** involves undertaking and accepting responsibility for professional assignments only when qualified by training or experience. Our team comprises individuals with the necessary expertise in hardware design, software development, and power electronics, ensuring we are qualified to undertake this project. **Principle 3** states that one should provide an opinion on a professional subject only when it is founded upon adequate knowledge and honest conviction. We will base our design and implementation decisions on thorough research and testing, ensuring they are well-founded and reliable. **Principle 7** advocates conducting oneself with fairness, courtesy, and good faith toward clients, colleagues, and others. Our team will collaborate, maintain open communication, and share responsibilities fairly. All relevant principles from the Engineers and Geoscientists BC (EGBC) Code of Ethics that can be applied to this project, emphasizing the social values and impact on the public, are detailed in the Appendix.

Social Impact and Potential User Base

The drive to choose this project was to advance sustainable energy solutions and support off-grid living. By improving the efficiency of solar charge controllers, we contribute to reducing reliance on non-renewable energy sources and promoting environmental sustainability. The potential user base for our MPPT solar charge controller includes individuals and communities seeking reliable off-grid energy solutions, such as remote cabins, tiny homes, and disaster relief setups. By providing an efficient and dependable solar charge controller, we aim to enhance the quality of life for those relying on off-grid energy systems and contribute positively to environmental conservation efforts.

II Objectives

(i) Gain a thorough understanding of solar charge methods, including the various types (“direct-to-battery", “simple PWM” and “MPPT”), their basic designs and subsystems, and be able to explain why the ideal type of Solar Charge Controller uses a Maximum Power Point Tracking algorithm, or “MPPT” due to the nature of solar panel behaviour.

(ii) Analyze MPPT theory concerning a solar panel's I-V and P-V curves.

(iii) Explain and explore the basic design of an MPPT controller, including various subsystems (synchronous buck converter, current sensor, microcontroller, etc.).

(iv) Give a brief overview of the range of open-source MPPT designs currently available and explain various advantages/disadvantages of each and why we chose to build this design (with reference to “1kW Arduino MPPT Solar Charge Controller” by ASCAS on instructables.com).

(v) Explain the algorithm of the open-source firmware with analysis of firmware code section (with reference to FUGU MPPT open-source firmware and any modifications).

(vi) Explain and explore the basic design of an MPPT controller, including various subsystems (synchronous buck converter, current sensor, microcontroller, etc.).

(vii) Build a working prototype to try installing the open-source firmware and get a test setup working with a panel and battery before July ends.

(viii) Design a custom PCB for the MPPT controller.

(ix) Design an enclosure for the MPPT controller.

III Design Specifications

The design of the Maximum Power Point Tracking (MPPT) solar charge controller involves multiple subsystems, each with specific technical ratings and boundary conditions. These specifications are crucial to ensure the controller operates efficiently and reliably within the expected conditions of solar energy systems, particularly for off-grid applications.

Block Diagram of MPPT Design

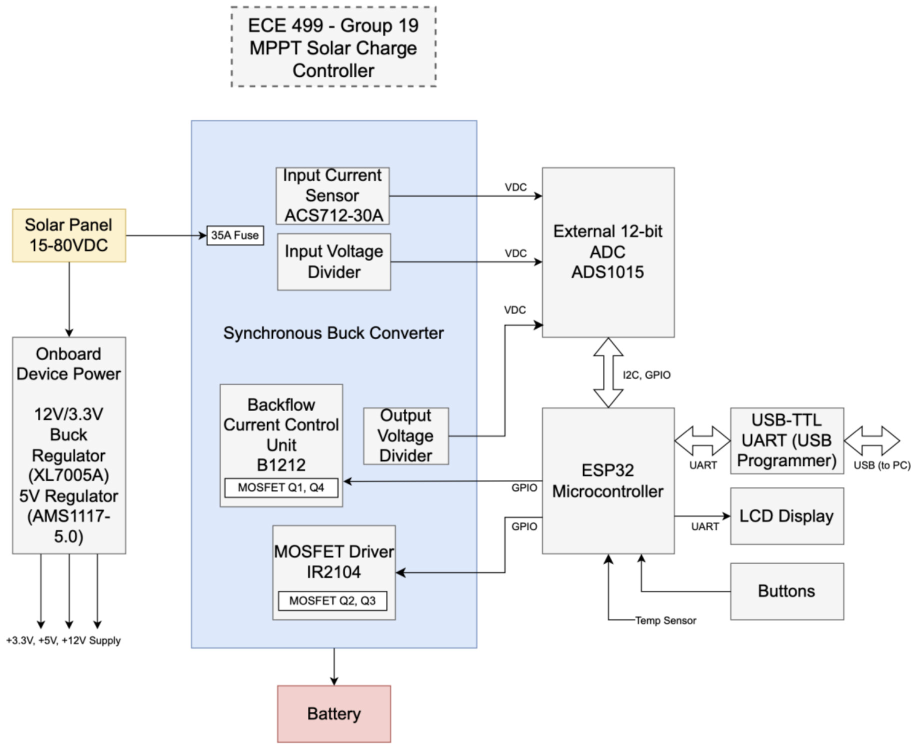


Figure 2: Block diagram of charge controller showing power, control and I/O sections with main components.

Input and Output Specifications

Input Voltage Range: The MPPT solar charge controller should handle an input voltage range of 15-100VDC, suitable for connecting to various solar panel configurations. A single 100W panel typically has a maximum output voltage of 17-18V. The chosen range accommodates single- and series-connected panels for higher-voltage systems, ensuring flexibility for different solar array setups.

Output Voltage Range: The controller is suitable for charging 12V lead-acid batteries, commonly used in off-grid solar systems. The buck converter efficiently steps down the input voltage to maintain the charging voltage, typically around 13.8V (greater than the fully charged voltage of 12.6V for a lead-acid battery).

Output Current Rating: The system can handle a maximum output current of up to 30A (designed for 30A, including the inductor, but ended up using 20A fuses for the prototype), which is suitable for charging standard off-grid battery banks and also achieve the 1kW power rating of the charge controller down to ~30-40V input (minimum of two ~18V panels in series to achieve roughly 1kW at 30A). This rating ensures sufficient charging capacity for typical solar energy storage systems, providing adequate power for continuous usage, and a typical rating for a smaller home solar setup.

Synchronous Buck Converter Specifications

Efficiency: The synchronous buck converter should achieve an efficiency of approximately 98%. This high efficiency is essential to minimize energy losses during the voltage conversion process and maximize the energy stored in the batteries.

Switching Frequency: The buck converter operates at a switching frequency of 100 kHz. This frequency must balance efficiency and the size of the inductive and capacitive components, ensuring compactness without compromising performance.

Microcontroller and Firmware Specifications

Microcontroller: The ESP32 microcontroller has excellent computational capabilities and low power consumption. It features integrated Wi-Fi for remote monitoring, allowing users to track system performance via mobile apps or web interfaces. It has a relatively fast 32-bit, 240MHz processor with two processor cores in the ESP32-WROOM-32D version that we chose, which is important, since we want the MPPT algorithm and synchronous buck converter control to have a dedicated core, as it is mission-critical that synchronous operation of the MOSFETs does not stop/stall/slow down for any reason (since this could cause a short or current flowing the wrong direction through the main power section), while the secondary core handles all user interfaces and telemetry data.

MPPT Algorithm: The Perturb and Observe (P&O) algorithm is implemented in the firmware to optimize energy extraction from solar panels. This algorithm dynamically adjusts the PWM duty cycle to maintain the panels at their maximum power point under varying sunlight conditions.

Sensor and Measurement Specifications

Current Sensors: The system employs Hall-effect sensing (ACS712-30A) for non-intrusive bidirectional current measurement, outputting over a range of 0-5V, with 2.5V representing the zero crossing (no current), and is connected to the external ADS1015 ADC. We configure this sensor in an alternative fashion to enable the use of the full range of the sensor in a single direction, with 0.5V representing 0A.

Voltage Sensors: The system uses voltage dividers connected to the ADS1015 ADC to measure voltage readings at the input and output stages of the charge controller.

These sensors provide real-time feedback to the microcontroller, enabling precise power calculations and MPPT adjustments.

Why not use the ESP32 GPIO ports and internal ADC?

The ESP32 has an internal ADC, but it is known to be non-linear, and since we require maximum stability and linearity to perform MPPT calculations and proper PWM duty-cycle adjustment accurately, we use an external ADC instead, the four-input 12-bit/3.3-kSPS ADS1015 from Texas Instruments. Since an accurate +5V supply to this device is critical to predictable current measurement (it provides a reference to the sensor, and the sensor output scales with the IC input voltage), we use a linear regulator here to provide power to it.

Safety and Compliance

Surge Protection: Diodes and fuses protect the system against voltage spikes and transients, ensuring safety and reliability. This design consideration aligns with the Engineers and Geoscientists BC (EGBC) Code of Ethics, emphasizing public safety and the integrity of engineering solutions [4].

Thermal Management: Adequate heat dissipation mechanisms, such as heat sinks and thermal pads, are incorporated to prevent the power electronics from overheating and ensure stable operation under full load conditions.

Justification and Standards

The specified technical ratings and boundary conditions are determined based on the typical requirements of off-grid solar energy systems. The chosen input and output voltage ranges, and the current rating provides flexibility and adaptability to different system configurations. The buck converter's efficiency targets and switching frequency mean to optimize performance while minimizing energy losses.

By the EGBC Code of Ethics, all design choices prioritize safety, efficiency, and sustainability, contributing to a reliable and environmentally friendly energy solution. Standards and regulations for electrical and electronic design are adhered to, ensuring the project aligns with industry best practices and ethical considerations [4]. These specifications and design choices are supported by thorough research and analysis, considering the latest advancements in solar energy technology and the specific needs of off-grid applications.

IV Literature Survey

The need for efficient solar charge controllers is paramount in enhancing the viability of solar energy systems, especially for off-grid applications. Various types of solar charge controllers, such as Direct Connection, PWM Charge Controllers, PWM with Buck Converter, and MPPT Charge Controllers, have been developed to address the challenges of maximizing solar power extraction and efficient battery charging.

Types of Solar Charge Controllers

The simplest way to charge a battery with a solar panel is to connect it directly to a battery. The battery will charge uncontrolled to its full voltage and needs to be disconnected manually once charged. Next, there are PWM charge controllers. These can control the charging current using pulse-width modulation. A limitation of a simple PWM charge controller is that the battery charging voltage is always the same as the operating panel voltage.

A further enhancement of this concept is to use a buck converter to step down the panel voltage to whatever battery voltage is needed, allowing for higher-voltage panel arrays. There is a deficit here: the panel voltage will change with light intensity and cannot be optimized independently to the panel's maximum power point. If one could constantly optimize that buck converter's PWM frequency while tracking the power output, one could do better by 30-40%. An MPPT solar charge controller makes these adjustments.

Table 1: Decision Matrix-Style Comparison of Solar Charge Controller Types

Criterion	**Direct Connection**	**PWM Charge Controllers**	**PWM with Buck Converter**	**MPPT Charge Controller**
Overview	Simplest method, direct connection of solar panel to battery.	Uses pulse-width modulation to control charging current.	Enhances PWM by stepping down panel voltage to match battery voltage.	Optimizes charging by continuously tracking the maximum power point of solar panels.
Capability	Basic	Prevents overcharging, better control over charging.	Allows higher-voltage panels, better voltage regulation.	Maximizes power extraction, accommodates wide range of configurations, adapts to light conditions.
Efficiency	Risk of overcharging and battery damage.	Moderate, tied to panel voltage.	Improved over basic PWM, still not fully optimal.	30-40% improvement over PWM
Cost	Very low	Moderate, affordable.	Higher initial cost.	Higher initial cost.
Ease of Use	Simple, requires manual monitoring.	Easy to install and use with basic knowledge.	More complex but manageable	More complex, often comes with user-friendly interfaces.
Suitability	Not suitable for long-term use or efficiency.	Good balance for cost vs. performance.	Better than basic PWM, but still not optimal.	Best choice for efficiency and performance despite higher cost.

After reviewing the different types of solar charge controllers, it is evident that MPPT charge controllers offer the best solution for maximizing the efficiency and longevity of solar power systems. While they are more expensive and complex than PWM controllers, their ability to continuously optimize the power output from solar panels provides substantial efficiency gains. MPPT controllers are preferred for residential and commercial solar power installations, aiming for high performance and reliability.

Justification for MPPT Charge Controller

<u>Efficiency and Performance:</u> The primary justification for choosing an MPPT charge controller over other types is its superior efficiency and performance. MPPT controllers dynamically adjust the panel voltage to its maximum power point, ensuring optimal energy extraction from the panels. This capability is crucial in varying sunlight conditions, where MPPT controllers can maintain high efficiency and continuous power output. The

increased efficiency translates to more energy being stored in the batteries, extending their lifespan and reducing the need for frequent maintenance.

Cost vs. Benefit: While MPPT controllers have higher initial costs than PWM controllers, the significant efficiency gains and long-term energy savings justify the investment. For off-grid applications, where maximizing energy harvest is critical, the increased reliability and performance offset the additional cost. Over the lifespan of the solar power system, the improved efficiency of MPPT controllers can lead to substantial cost savings, making them a cost-effective choice in the long run.

Ease of Use and Flexibility: Modern MPPT charge controllers often come with user-friendly interfaces and advanced features such as remote monitoring and control, making them accessible to novice and experienced users. The flexibility of MPPT controllers to work with a wide range of panel configurations and battery chemistries further enhances their applicability. These controllers are designed to be easy to install and configure, with detailed instructions and support available from manufacturers.

Adherence to Standards and Regulations: Relevant standards and regulations are crucial in designing and implementing an MPPT charge controller. The Engineers and Geoscientists BC (EGBC) Code of Ethics emphasizes the importance of public safety, professional competence, and integrity. Following established guidelines and ensuring robust design practices, we aim to develop a reliable and safe product that contributes positively to renewable energy adoption.

Social Impact: The development of efficient solar charge controllers aligns with broader societal goals of reducing carbon emissions and promoting sustainable energy solutions. By improving the efficiency and reliability of solar power systems, MPPT controllers support the transition to renewable energy sources, benefiting both the environment and public welfare.

A Simple Explanation of How an MPPT Solar Charge Controller Works

Imagine adjusting a knob that controls the PWM (Pulse Width Modulation) duty cycle of a buck converter connected between a solar panel and a battery. A wattmeter measures the power flowing into the battery. As sunlight intensity varies, the knob is turned to sweep the duty cycle from 0-100%. The goal is to find the PWM frequency at which the wattmeter shows maximum power output. When sunlight changes, the sweep is repeated to locate the new PWM frequency for maximum power. This process is the essence of an MPPT (Maximum Power Point Tracking) charge controller. Instead of manual adjustments, a microcontroller automates this process by running an MPPT algorithm. It continuously adjusts the PWM duty cycle and uses feedback from a current sensor to calculate and maintain the maximum power point.

The MPPT controller will use a microcontroller to manage the pulse width modulation (PWM) required for optimal performance. By decoupling the panel voltage from the battery voltage, the controller can adjust the duty cycle of the PWM signal to maintain the panels at their maximum power point while regulating the charging voltage and current to the battery.

Discussion on Maximum Power Point Tracking Algorithm

"Steady Output and Fast Tracking MPPT (SOFT-MPPT) for P&O and InC Algorithms" [1] discusses three algorithms. The P&O algorithm calculates PV output power and adjusts the voltage periodically. If power increases, the adjustment direction is maintained; otherwise, the direction is reversed.

$$P = VI$$

$$\Delta P = P(n) - P(n-1)$$

$$\Delta V = V(n) - V(n-1)$$

$$\text{If } \Delta P > 0 \text{ then } V(n+1) = V(n) + \Delta V$$

$$\text{Else } V(n+1) = V(n) - \Delta V$$

The InC algorithm finds the maximum power point (MPP) when the incremental conductance is equal to the negative of the instantaneous conductance.

$$\frac{dI}{dV} + \frac{I}{V} = 0 \qquad \text{at MPP}$$

$$\text{If } \frac{dI}{dV} > -\frac{I}{V} \qquad \text{then increase V}$$

$$\text{If } \frac{dI}{dV} < -\frac{I}{V} \qquad \text{then decrease V}$$

The SOFT-MPPT algorithm dynamically adjusts the voltage and current. This algorithm introduces a modulating factor (M) related to the current that changes the perturbation size (D). It also adds steady-state detection that stops artificial perturbation to minimize unnecessary oscillations in power when it is close enough to the MPP.

$$\Delta D(k) = \Delta D_{min} + M\frac{dP}{dV}$$

$$M(k) = \frac{1 - 2.5\%}{I(k)}$$

V Team Duties & Project Planning

Our team consists of three members: Angel, Ben, and Jenna. Each person will have specific roles and deliverables that contribute to the success of our project.

- Angel's responsibilities include creating a thorough project plan, managing the spending plan, and ensuring that the team members communicate and work together efficiently. Following recommendations, she will also oversee the procurement of the test PCB and beginning parts. Angel needs to get input from Ben and Jenna to understand their needs, hold regular meetings to track progress and ensure that all necessary components are ordered to be delivered on time. In addition, Angel is going to design and produce a 3D-printed case for the charge controller. Without a well-defined project plan and timely material acquisition, the project may experience mismanagement and delays.
- Ben will focus on assembling and testing boards using the ordered components. He will check the electrical system to ensure it is operating correctly. If the prototype functions as intended, Ben will work with each

team member to design a special PCB and make the final component selections. The electrical system must be designed and tested for the charge controller to function correctly, and any issues or delays in this area will directly impact the project.

- Jenna is working on installing and testing open-source firmware on a prototype, making necessary modifications, and collaborating with Ben to test and integrate hardware and software. She will help Ben solder the surface mount components for the prototype. Success requires ensuring hardware-software compatibility and relies on Ben's detailed input on system design. Angel requires frequent updates to stay on track. The firmware and enclosure design are crucial to the charge controller's operation and user interface. Any delays in these areas could impact the project's timeline.

The deadline for this project is the end of July. It is crucial to identify potential setbacks that could delay the project. For example, the late arrival of components due to shipping or supply chain issues could postpone the arrival of necessary parts. In contrast, malfunctioning components could disrupt the assembly and functioning of the MPPT solar charge controller. Additionally, team members may need more time due to other academic or professional commitments, impacting their availability for the project.

We will break the project into smaller parts to mitigate these risks, allowing us to progress even if certain parts are delayed or require rework. Each section can be developed, tested, and completed independently. We will also provide cross-training for team members to ensure that everyone understands each other's roles. This understanding will allow us to cover for one another if someone is unavailable or an area encounters issues. Additionally, we will maintain backup suppliers by identifying multiple sources for critical components used in the project. This precaution will help us avoid delays due to supply chain issues, as we can quickly turn to an alternative source if there are any complications with a supplier. These measures will help ensure the project remains on track and is complete before the August deadline despite potential setbacks.

VI Design Methodology & Analysis

The design methodology for the Maximum Power Point Tracking (MPPT) solar charge controller involved developing a reliable and efficient system capable of maximizing energy extraction from solar panels. This section outlines the design process, analysis methods, and decision-making criteria for achieving the project objectives.

Requirement Gathering and Specification

The design methodology began with a comprehensive requirement gathering and specification phase. The primary objectives are maximizing solar energy conversion efficiency, ensuring reliable battery charging, and specifying the input and output voltage ranges, current capacity, and efficiency targets, which are defined based on typical off-grid solar applications. The design specifications were the basis for forming future design decisions.

Conceptual Design Phase

The conceptual design phase included a research and literature review. This phase provided a deep understanding of existing solar charge controller technologies, explicitly focusing on MPPT algorithms, converter topologies, and their advantages over other types. Regarding converter topologies, an asynchronous buck converter was initially considered but rejected due to its lower efficiency than the synchronous design.

Component Selection

In the component selection stage, the ESP32 microcontroller was chosen for its computational capabilities, low power consumption, and integrated Wi-Fi for remote monitoring. The power electronics components, such as Hall effect sensors and voltage dividers, were made with a focus on reliability and efficiency.

Algorithm Development

The algorithm development phase focused on selecting and implementing the Perturb and Observe (P&O) MPPT algorithm, known for its simplicity and effectiveness in tracking the maximum power point. We considered the Incremental Conductance method due to its improved accuracy under rapidly changing conditions. However, it would be more complex to implement and could introduce more points of failure. Firmware was developed for the ESP32 based on the Instructables firmware, emphasising real-time adjustments of the PWM duty cycle based on sensor feedback.

Mathematical Analysis

Mathematical analysis consists of efficiency calculations using:

$$\eta = \frac{V_{out} I_{out}}{V_{in} I_{in}} \times 100\%$$

Where η is the efficiency, V_{out} and I_{out} are the output voltage and current, and V_{in} and I_{in} are the input voltage and current respectively [8]. This calculation assesses the charge controller's performance in converting solar energy to usable energy.

Prototype Development and Validation

We measured resistances, voltages, and currents during the prototype development, ensuring they were within expected ranges. This thorough validation process was crucial for identifying any discrepancies, potential areas of concern, and areas for improvement in the system design.

VII Design & Prototype

This section details the design process and prototype development of the MPPT solar charge controller. The system aimed to maximize energy extraction from solar panels while providing efficient battery charging under varying sunlight conditions. The prototype development focused on integrating design components into a functional system capable of real-world applications.

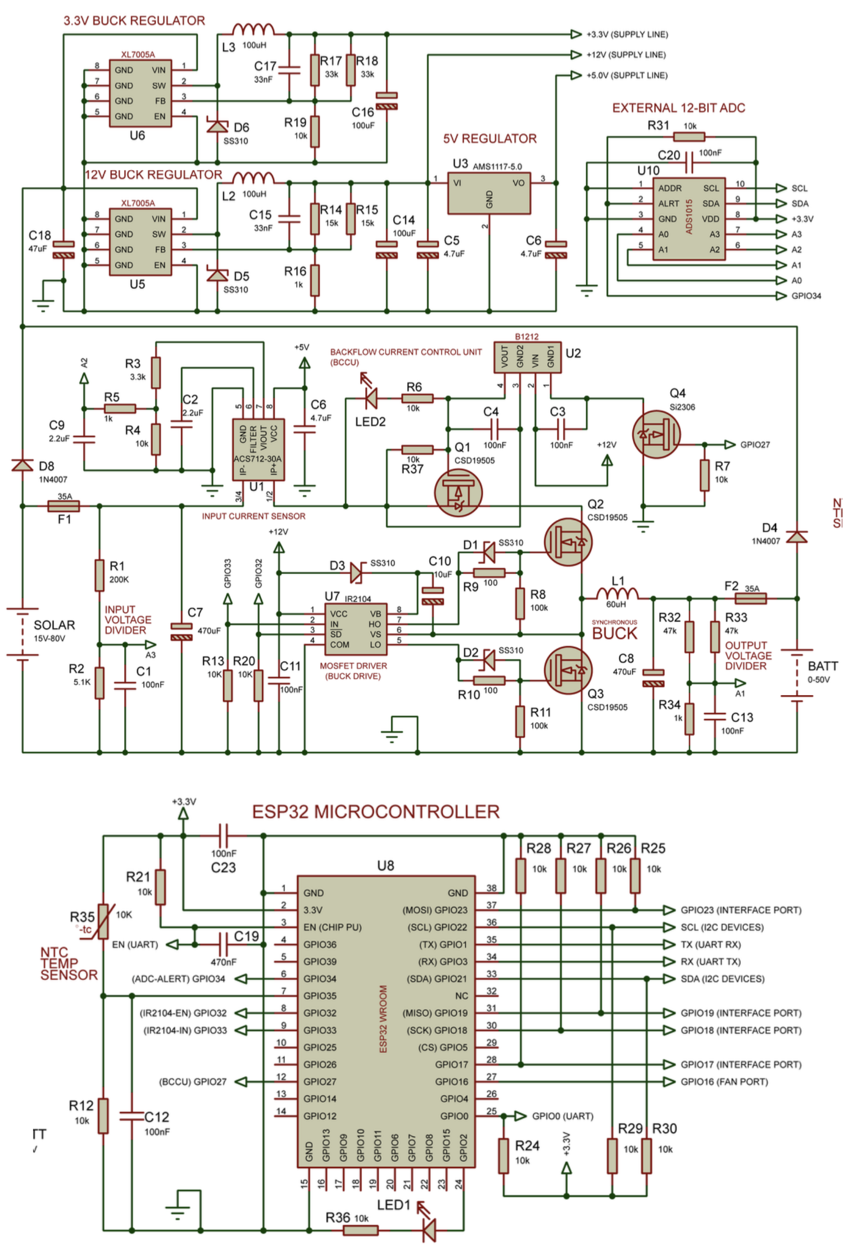


Figure 3: Reference MPPT controller schematic used during construction of prototype from ASCAS tutorial [2].

PART#	TYPE	VALUE	SPECS	PACKAGE	Brand
Q1	N-Channel MOSFET	CSD19505	80V, 208A, 2.6mΩ	TO220	Texas Instruments
Q2	N-Channel MOSFET	CSD19505	80V, 208A, 2.6mΩ	TO220	Texas Instruments
Q3	N-Channel MOSFET	CSD19505	80V, 208A, 2.6mΩ	TO220	Texas Instruments
Q4	N-Channel MOSFET	Si2306DS (A6SHB)	30V, 2.8A, 94mΩ	SOT23	Vishay
Q5	NPN Transistor	MMBT3904 (AM1)	40V, 200mA	SOT23	ON Semi
Q6	NPN Transistor	MMBT3904 (AM1)	40V, 200mA	SOT23	ON Semi
D1	Schottky Diode	SS310	100V, 3A	DO214	TSC
D2	Schottky Diode	SS310	100V, 3A	DO214	TSC
D3	Schottky Diode	SS310	100V, 3A	DO214	TSC
D4	Rectifier Diode	M7 (1N4007)	1000V, 1A	DO214	TSC
D5	Schottky Diode	SS310	100V, 3A	DO214	TSC
D6	Schottky Diode	SS310	100V, 3A	DO214	TSC
D7	Schottky Diode	SS310	100V, 3A	DO214	TSC
D8	Rectifier Diode	M7 (1N4007)	1000V, 1A	DO214	TSC
U1	Current Sensor	ACS712-30A	30A Isolated Bidirectional	SO8	Allegro
U2	DC-DC Isolator	SPU01M-12	12V to 12V Isolator	Special	MEAN WELL
U3	Linear Regulator (LDO)	AMS1117-5.0	5V, 1A	SOT223	A.M.S.
U4	Linear Regulator (LDO)	AMS1117-3.3	3.3V, 1A	SOT223	A.M.S.
U5	Buck Converter	XL7005A	80V, 0.4A Buck	SO8P	XL Semi
U6	Buck Converter	XL7005A	80V, 0.4A Buck	SO8P	XL Semi
U7	MOSFET Driver	IR2104	520ns Deadtime	SO8	Infineon
U8	MCU	ESP32	32-bit, 240MHz, Dual Core	Special	Espressif/ WROOM
U9	USB To Serial UART	CH340G/ CH340C	USB 2.0, 2MBPS	SO8	WCH
U10	ADC	ADS1115	16-Bit I2C ADC	SOP10	Texas Instruments
X1	Crystal Resonator	12MHz	12MHz Resonator	SMD	Generic
F1	Automotive DC Fuse	35A	Mini Size	THT	Generic
F2	Automotive DC Fuse	35A	Mini Size	THT	Generic
L1	Inductor	64uH	36A (DIY)	THT	Generic
L2	Inductor	100uH	0.5A	SMD	Generic
L3	Inductor	100uH	0.5A	SMD	Generic
LED1	LED Indicator	-	-	_0805	Generic
LED2	LED Indicator	-	-	_0805	Generic
C1	Ceramic Capacitor	100nF	8 total (10)	_0805	Generic
C2	Ceramic Capacitor	2.2uF	1total (2)	1206	Generic
C3	Ceramic Capacitor	100nF		_0805	Generic
C4	Ceramic Capacitor	100nF		_0805	Generic
C5	Ceramic Capacitor	4.7uF	5 total (10)	1206	Generic
C6	Ceramic Capacitor	4.7uF		1206	Generic
C7	Electrolytic Capacitor	470uF / 100V	2 total	THT	Generic
C8	Electrolytic Capacitor	470uF / 100V		THT	Generic
C9	Ceramic Capacitor	2.2uF	1 total (2)	_0805	Generic
C10	Ceramic Capacitor	4.7uF		1206	Generic
C11	Ceramic Capacitor	100nF		_0805	Generic
C12	Ceramic Capacitor	100nF		_0805	Generic
C13	Ceramic Capacitor	100nF		_0805	Generic
C14	Electrolytic Capacitor	100uF/16V	2 total (10)	THT	Generic
C15	Ceramic Capacitor	33nF	2 total (3)	_0805	Generic
C16	Electrolytic Capacitor	100uF/16V		THT	Generic
C17	Ceramic Capacitor	33nF		_0805	Generic
C18	Electrolytic Capacitor	47uF/ 100V	1 total (2)	THT	Generic
C19	Ceramic Capacitor	470nF	1 total (2)	_0805	Generic
C20	Ceramic Capacitor	100nF		_0805	Generic
C21	Ceramic Capacitor	4.7uF		1206	Generic
C22	Ceramic Capacitor	4.7uF		1206	Generic
C23	Ceramic Capacitor	100nF		_0805	Generic

Figure 4: BOM (Part 1) of electronic components referenced in schematic and used for placing Digikey order

R1	Resistor	200k	1 total (10)	_0805	Generic
R2	Resistor	5.1k	1 total (10)	_0805	Generic
R3	Resistor	3.3k	1 total (10)	_0805	Generic
R4	Resistor	10k	20 total (50)	_0805	Generic
R5	Resistor	1k	3 total (10)	_0805	Generic
R6	Resistor	10k		_0805	Generic
R7	Resistor	10k		_0805	Generic
R8	Resistor	100k	2 total (10)	_0805	Generic
R9	Resistor	100 ohms	2 total (10)	_0805	Generic
R10	Resistor	100 ohms		_0805	Generic
R11	Resistor	100k		_0805	Generic
R12	Resistor	10k		_0805	Generic
R13	Resistor	10k		_0805	Generic
R14	Resistor	15k	2 total (10)	_0805	Generic
R15	Resistor	15k		_0805	Generic
R16	Resistor	1k		_0805	Generic
R17	Resistor	33k	2 total (10)	_0805	Generic
R18	Resistor	33k		_0805	Generic
R19	Resistor	10k		_0805	Generic
R20	Resistor	10k		_0805	Generic
R21	Resistor	10k		_0805	Generic
R22	Resistor	10k		_0805	Generic
R23	Resistor	10k		_0805	Generic
R24	Resistor	10k		_0805	Generic
R25	Resistor	10k		_0805	Generic
R26	Resistor	10k		_0805	Generic
R27	Resistor	10k		_0805	Generic
R28	Resistor	10k		_0805	Generic
R29	Resistor	10k		_0805	Generic
R30	Resistor	10k		_0805	Generic
R31	Resistor	10k		_0805	Generic
R32	Resistor	47k	2 total (10)	_0805	Generic
R33	Resistor	47k		_0805	Generic
R34	Resistor	1k		_0805	Generic
R35	NTC Thermistor	10k		THT	Generic
R36	Resistor	10k		_0805	Generic
R37	Resistor	10k		_0805	Generic
USB1	MINI USB Port	Generic		SMD	Generic
MISC.	Toroidal Core	0077071A7 (TRC02)		-	Magnetics Inc.
MISC.	AWG 16 Wire	Generic		-	Generic

Figure 5: BOM (Part 2) of electronic components referenced in schematic and used for placing Digikey order.

The MPPT solar charge controller contains several key components and subsystems. The team selected the ESP32 microcontroller for its processing power, built-in Wi-Fi, and low power consumption. It runs the MPPT algorithm to optimize power extraction. The Perturb and Observe (P&O) algorithm continuously adjusts the PWM duty cycle, ensuring the solar panel operates at its maximum power point. The synchronous buck converter efficiently steps down the higher solar panel voltage to the lower battery charging voltage for voltage conversion. This system utilizes MOSFETs for high-speed switching, theoretically achieving efficiencies of around 98%. Current and voltage sensors are crucial in measuring input and output currents and voltages, providing feedback to the microcontroller for power calculation and MPPT adjustments. Hall effect sensors are used for non-intrusive current measurement, ensuring accurate real-time data collection. Diodes provide surge protection to guard against voltage spikes and transients.

The system includes a small LCD that provides real-time information on system status, power output, and battery charging. The device's Wi-Fi capabilities enable remote monitoring via a Blynk website and mobile app.

The components for the MPPT solar charge controller were carefully selected based on the Instructables parts list and schematic. Some parts of the list were unavailable, and accommodations had to be made when implementing them on the board. To ensure quality and reliability, we sourced the components from DigiKey, a reputable company. Surface mount and through-hole components were added to the PCB using hand-soldering and hot air.

With more iterations, a future MPPT solar charge controller design could meet most of the project's objectives, providing a robust, efficient solution for off-grid solar applications. While there were some challenges, the iterative design and troubleshooting process ensured that the final prototype would adhere to industry standards and ethical guidelines, aligning with the Engineers and Geoscientists British Columbia (EGBC) code of ethics.

During the ordering of components, it was necessary to substitute the two XLSemi XL7005A 80V buck regulators (providing +12/5/3.3V power to the components on board) with regionally available components that could arrive promptly. This posed a serious problem and was likely one of the reasons our prototype had severe issues since the replacement, the AD5033 from Analog Devices, despite satisfying the specifications (76V was very close) and having the same SOP-8 package, had a different pin configuration.

This discrepancy necessitated an improvised solution using the already manufactured PCBs. Figure 6 illustrates the workaround implemented to accommodate this difference.

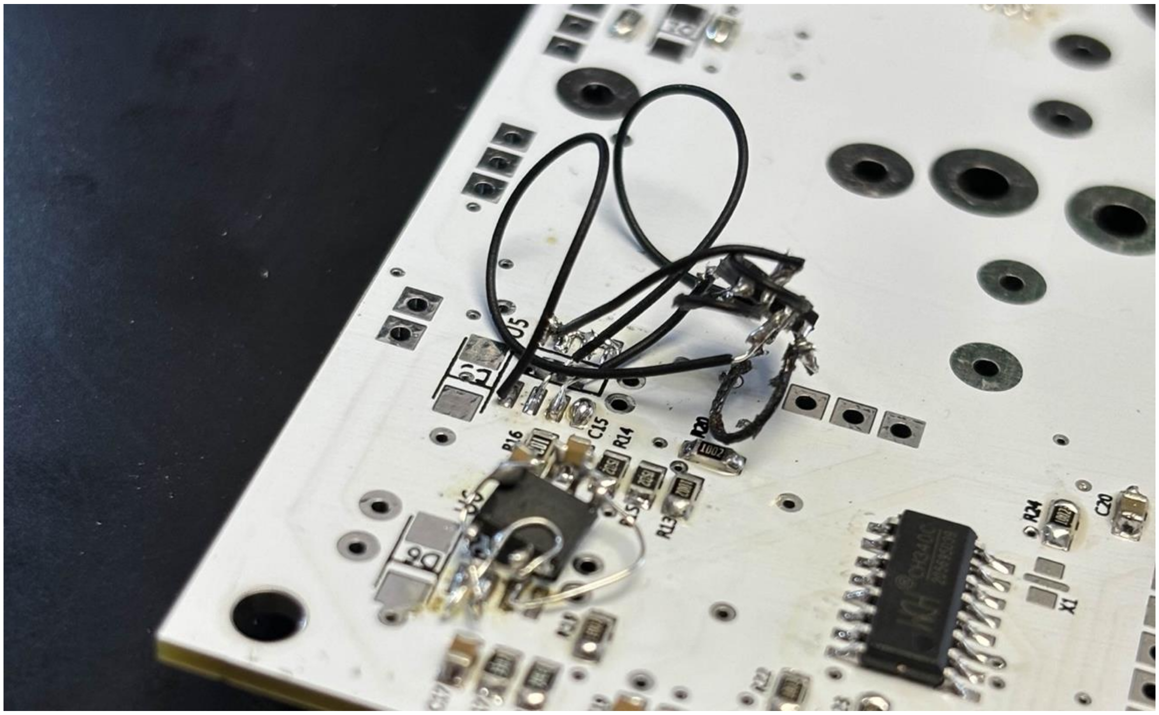


Figure 6: AD5033 in place of an XL7005A.

For the inductor, we chose to build our own using a Sendust inductor and 16AWG enamelled wire (superior magnetic flux saturation, core material used in high-performance inductors) to achieve the desired 30A current rating and ~64uH inductance. It would have been nice to use a lab-grade LCR tester to verify the inductor performance, and an inquiry was made to see if one was available at the school, but unfortunately, it was not. The inductor calculator tool from “coil32.net” was used to calculate the number of turns for the desired inductance values with the properties of the inductor core entered, shown below in figure 7.

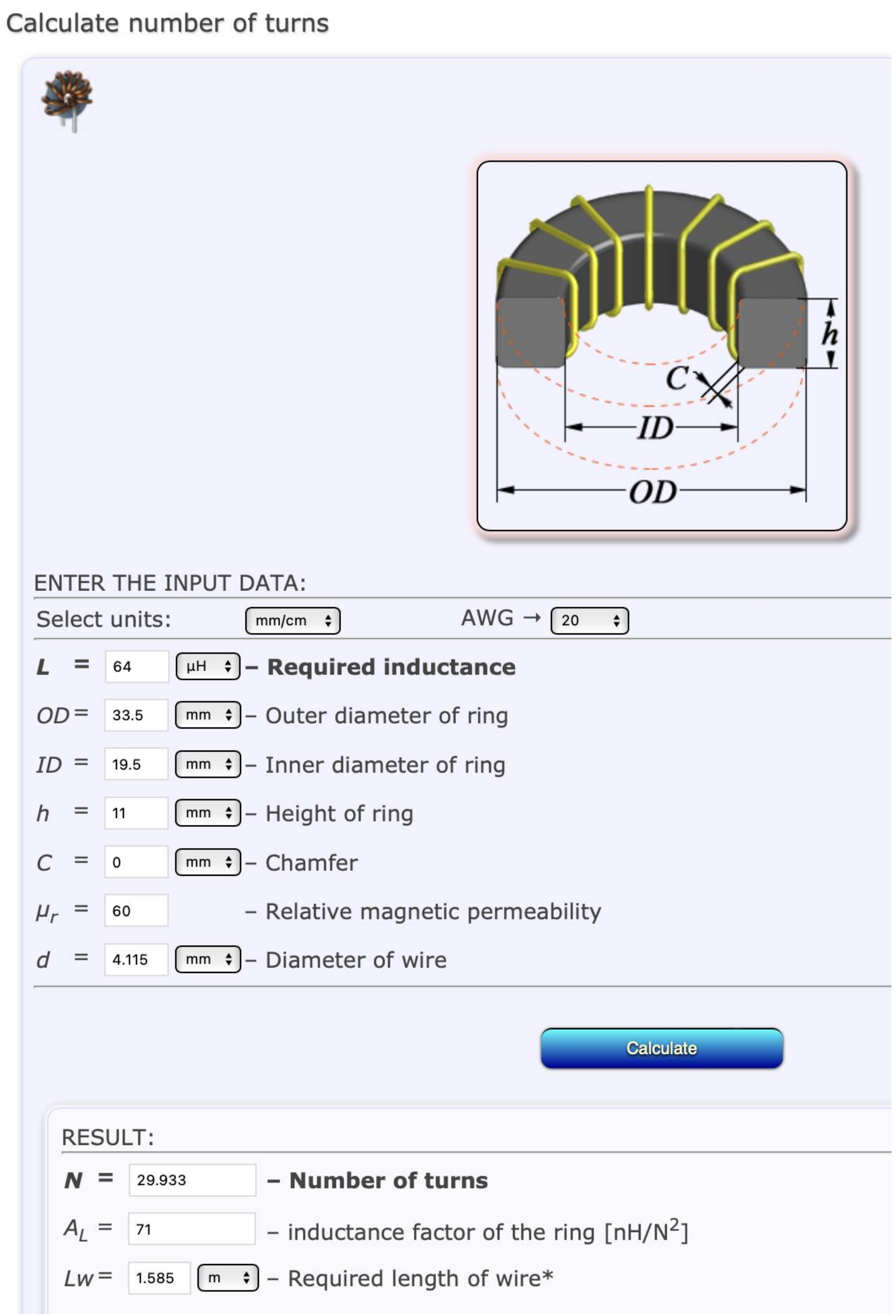


Figure 7: coil32.net inductor calculator showing 30 turns required with properties of 0077071A7 inductor core from Magnetics, Inc. with 16AWG wire.

Figure 8: 0077071A7 inductor core from Magnetics, Inc. wrapped with 30 turns of 16AWG magnetic wire for ~64uH inductance.

All SMD components were soldered first, followed by the through-hole components and then the wiring harnesses. The small 10-pin IC next to the ESP32 is the ADS1015 ADC.

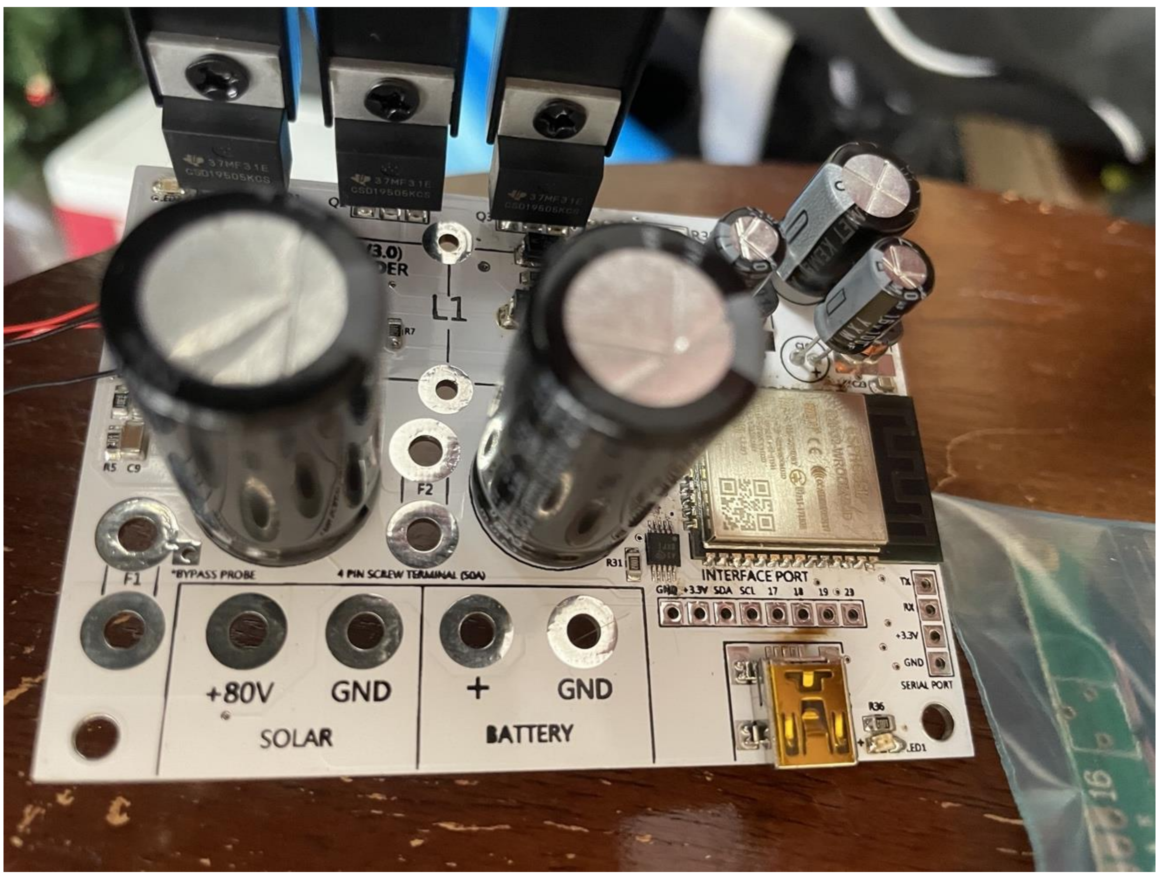


Figure 9: SMD components all soldered with partial soldering of through-hole components completed.

Another component substitution that had to be made was the Mean Well SPU01M-12 12V-12V isolator. The original specification (and PCB layout) was designed for a B1212S-1W from EVISUN, which was not available from Digikey.

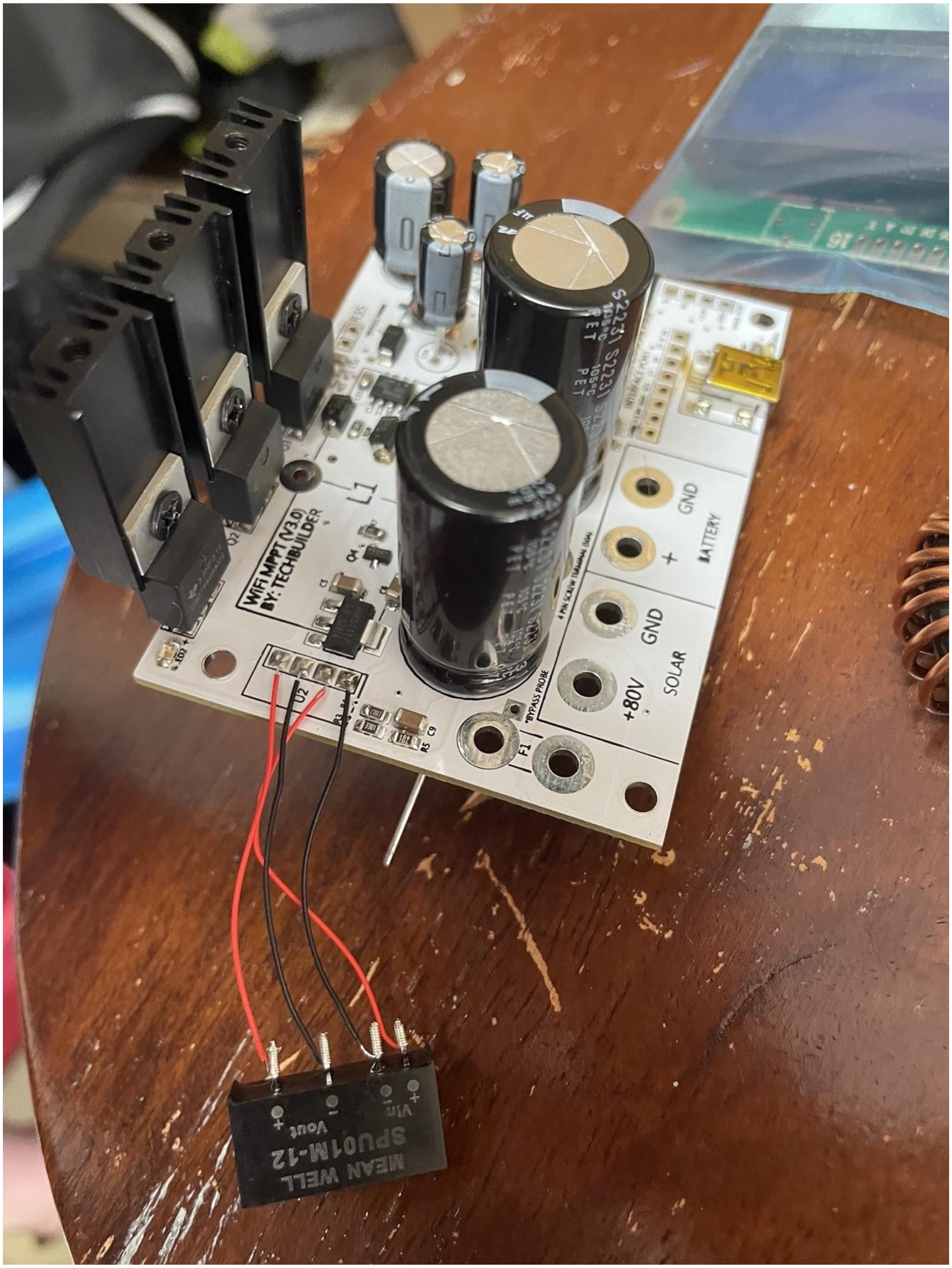


Figure 10: Heatsinks installed on MOSFETs Q1, Q2, Q3 and Mean Well 12V-12V DC isolator connected with wire wrapping technique.

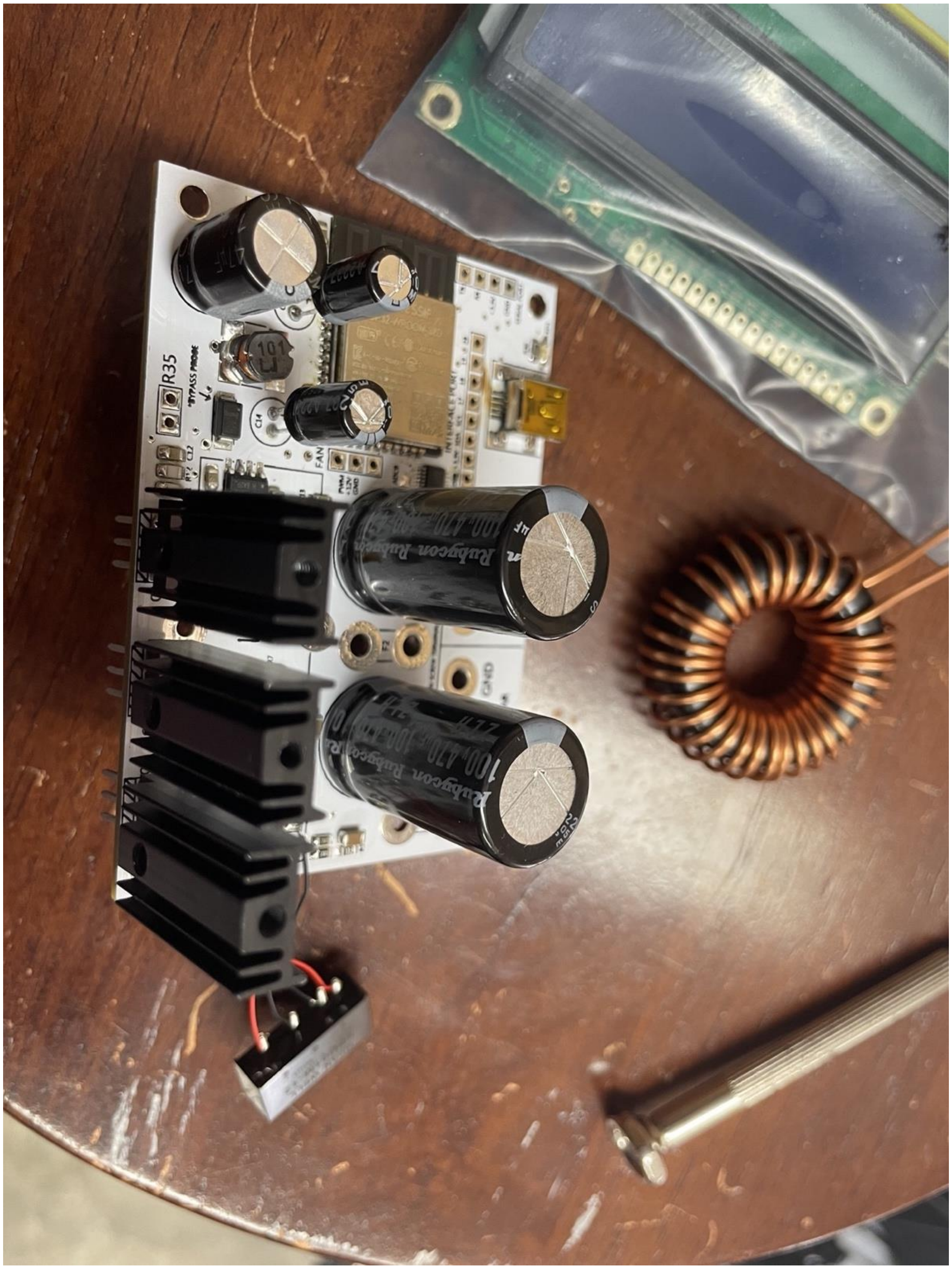


Figure 11: Alternate view of board with components installed.

The larger electrolytic capacitors are Rubycon ZLH with a 10000-hour longevity rating, as this device is designed to operate continuously in a wide range of temperatures and high loads.

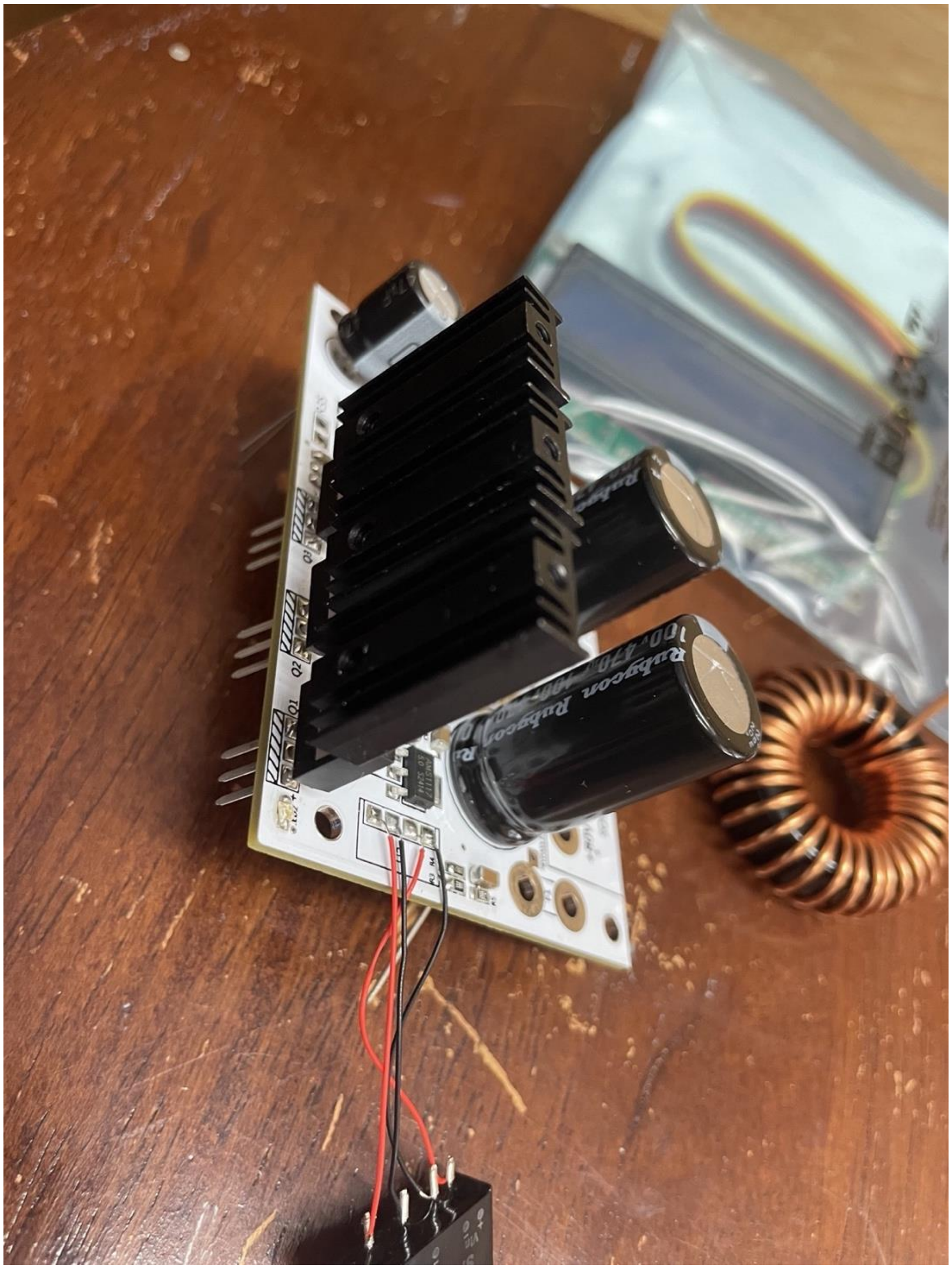


Figure 12: View of backside of heatsinks on main MOSFETs.

Main MOSFETs (Q1, Q2, Q3) are CSD19505KCS from Texas Instruments, rated for 80V, 150A, in TO220-3 package, and have very low $R_{DS(ON)}$ of 2.6mΩ. This characteristic is very important, because it is a relative measurement of how much the MOSFET will heat up with lot of current flowing through it, and because of this, we can use three MOSFETs in a (relatively high power and current) 30A controller instead of 6 or 9 if they had higher $R_{DS(ON)}$ values and we had to double or triple them up.

TEXAS INSTRUMENTS

CSD19505KCS
SLPS480C – JANUARY 2014 – REVISED APRIL 2024

CSD19505KCS 80V N-Channel NexFET™ Power MOSFET

1 Features

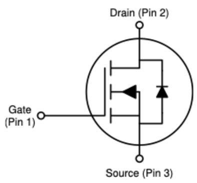
- Ultra-low Q_g and Q_{gd}
- Low thermal resistance
- Avalanche rated
- Pb-free terminal plating
- RoHS compliant
- Halogen Free
- TO-220 plastic package

2 Applications

- Secondary side synchronous rectifier
- Motor control

3 Description

This 80 V, 2.6 mΩ, TO-220 NexFET™ power MOSFET is designed to minimize losses in power conversion applications.



Product Summary

T_A = 25°C			TYPICAL VALUE	UNIT
V_{DS}	Drain-to-Source Voltage		80	V
Q_g	Gate Charge Total (10V)		76	nC
Q_{gd}	Gate Charge Gate to Drain		11	nC
$R_{DS(on)}$	Drain-to-Source On-Resistance	V_{GS} = 6V	2.9	mΩ
		V_{GS} = 10V	2.6	mΩ
$V_{GS(th)}$	Threshold Voltage		2.6	V

Ordering Information[(1)]

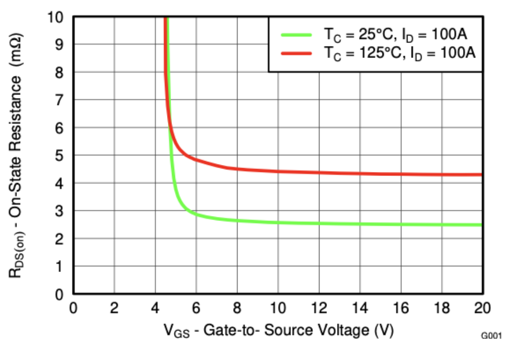
Device	Package	Media	Qty	Ship
CSD19505KCS	TO-220 Plastic Package	Tube	50	Tube

(1) For all available packages, see the orderable addendum at the end of the data sheet.

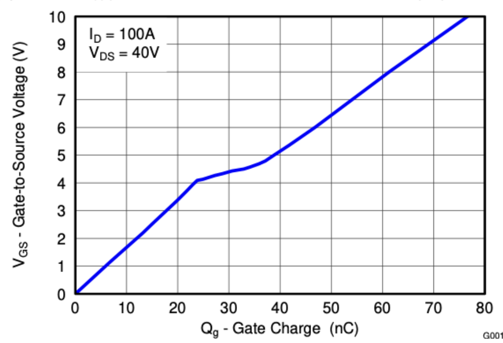
Absolute Maximum Ratings

T_A = 25°C		VALUE	UNIT
V_{DS}	Drain-to-Source Voltage	80	V
V_{GS}	Gate-to-Source Voltage	±20	V
I_D	Continuous Drain Current (Package limited)	150	A
	Continuous Drain Current (Silicon limited), T_C = 25°C	208	
	Continuous Drain Current (Silicon limited), T_C = 100°C	147	
I_{DM}	Pulsed Drain Current [(1)]	400	A
P_D	Power Dissipation	300	W
T_J, T_{stg}	Operating Junction and Storage Temperature Range	–55 to 175	°C
E_{AS}	Avalanche Energy, single pulse I_D = 101A, L = 0.1mH, R_G = 25Ω	510	mJ

(1) Max $R_{\theta JC}$ = 0.5°C/W, pulse duration ≤100μs, duty cycle ≤1%



$R_{DS(on)}$ vs V_{GS}



Gate Charge

Figure 13: CSD19505KCS datasheet showing very low $R_{DS(ON)}$ value of 2.6mΩ and otherwise that this MOSFET is a particularly good choice for this device.

Figure 14: View of components around ESP32 microcontroller.

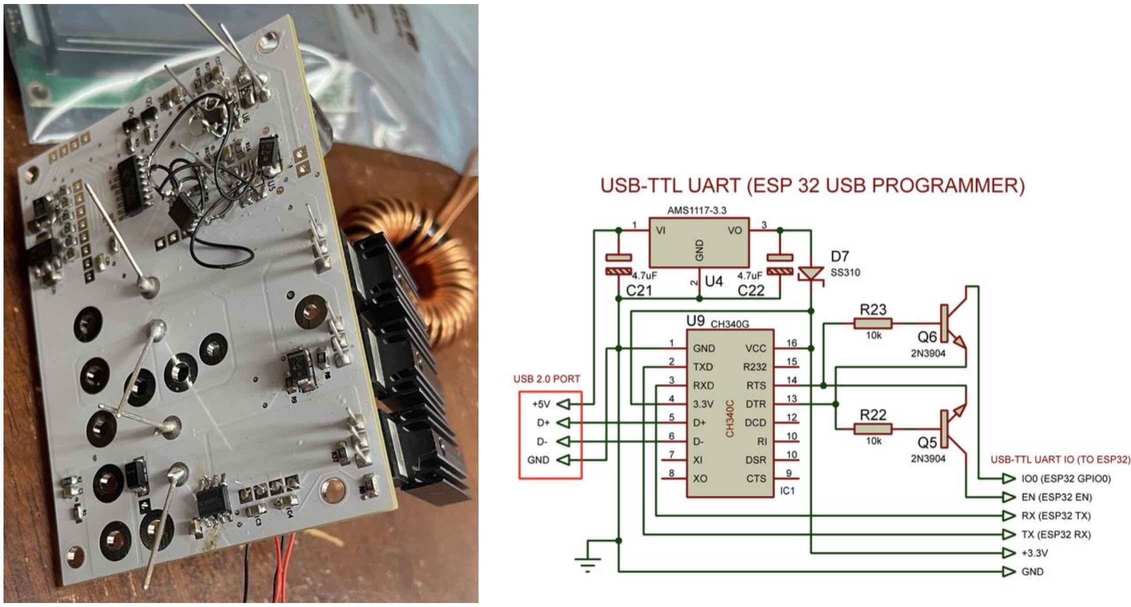


Figure 15: Underside of board before trimming legs of through-hole components, shown with CH340C schematic.

The 16-pin chip on the bottom is a CH340C USB-TTL UART programming interface and allows programming of the ESP32 via the miniUSB port. During testing, this chip got very hot and stopped connecting after being plugged in for several minutes.

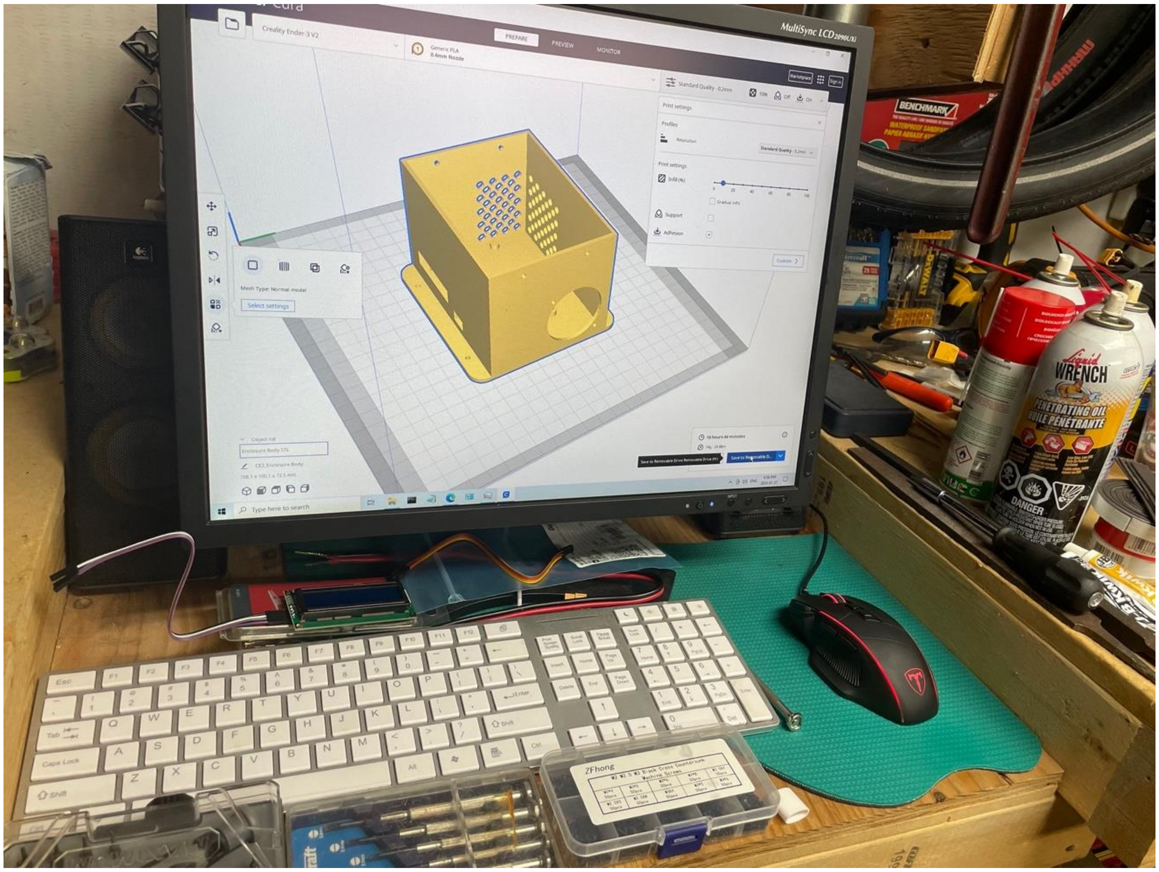


Figure 16: Converting enclosure .stl file into gcode for 3D printing using Cura slicer software.

The enclosure was printed from the .stl files from the ASCAS tutorial [2]. There are two main pieces, the enclosure body and the faceplate. Four buttons were also printed for the faceplate. The design features integrated standoffs, ventilation holes around the MOSFET heatsink area, a spot for a 40mm fan, and mounting holes.

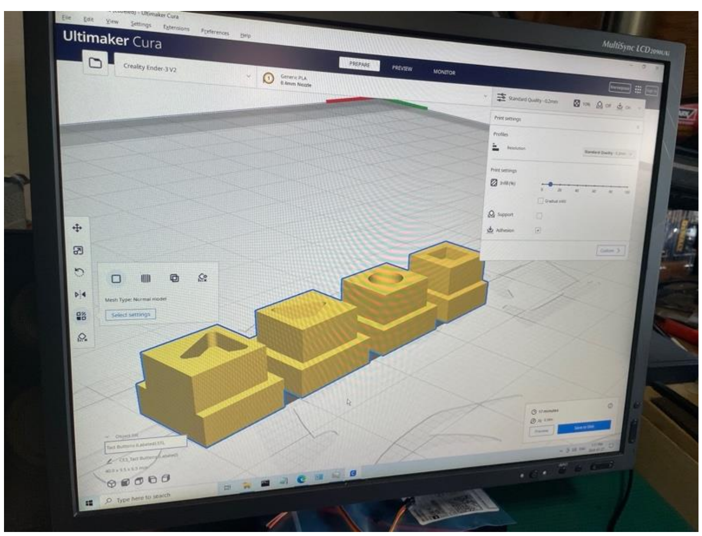


Figure 17: Converting button .stl file into gcode for 3D printing using Cura slicer software.

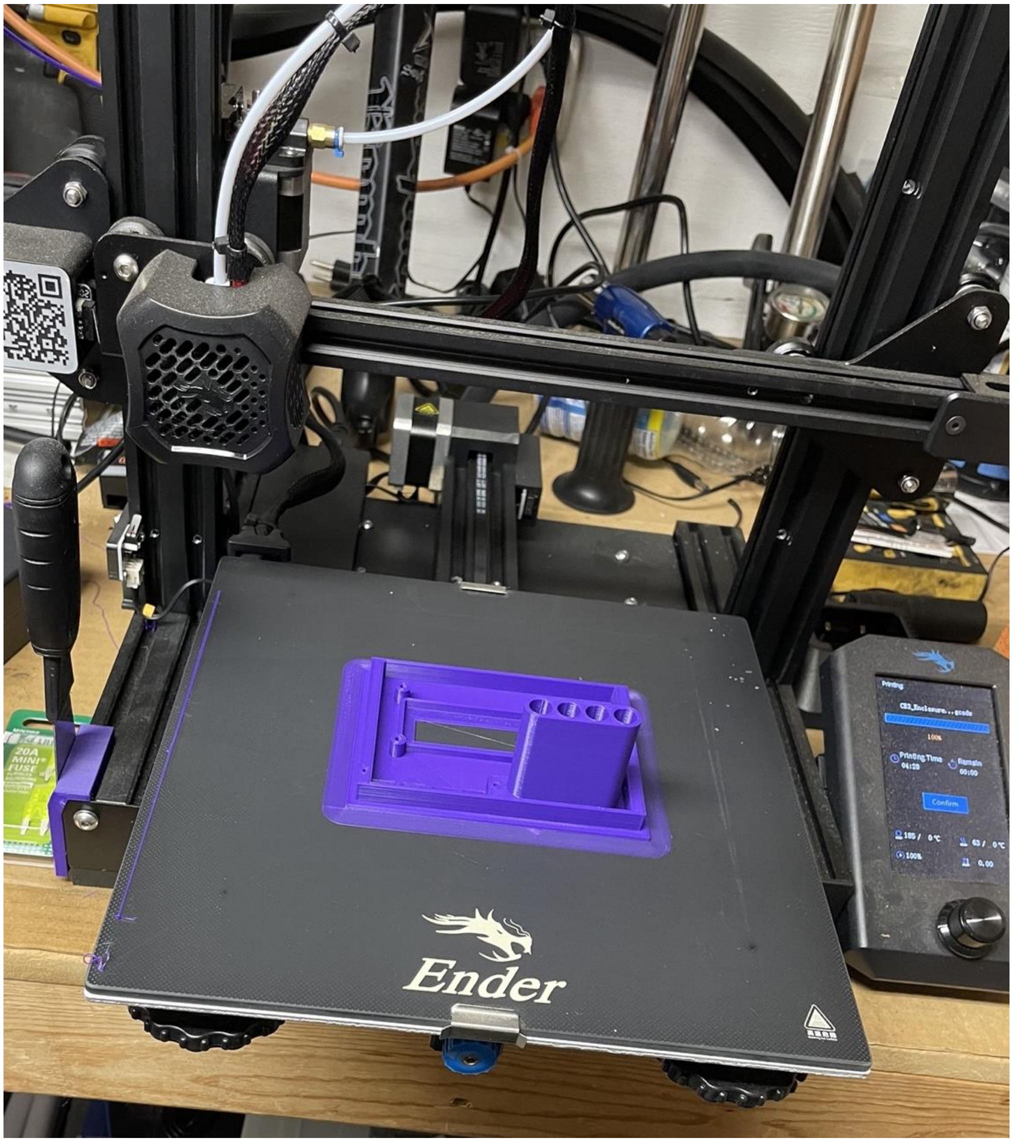


Figure 18: Enclosure faceplate printing complete.

The enclosure pieces were printed on an Ender 3 V2 in PLA filament, with normal quality settings, default speed, 10% infill, an adhesion raft, and no supports.

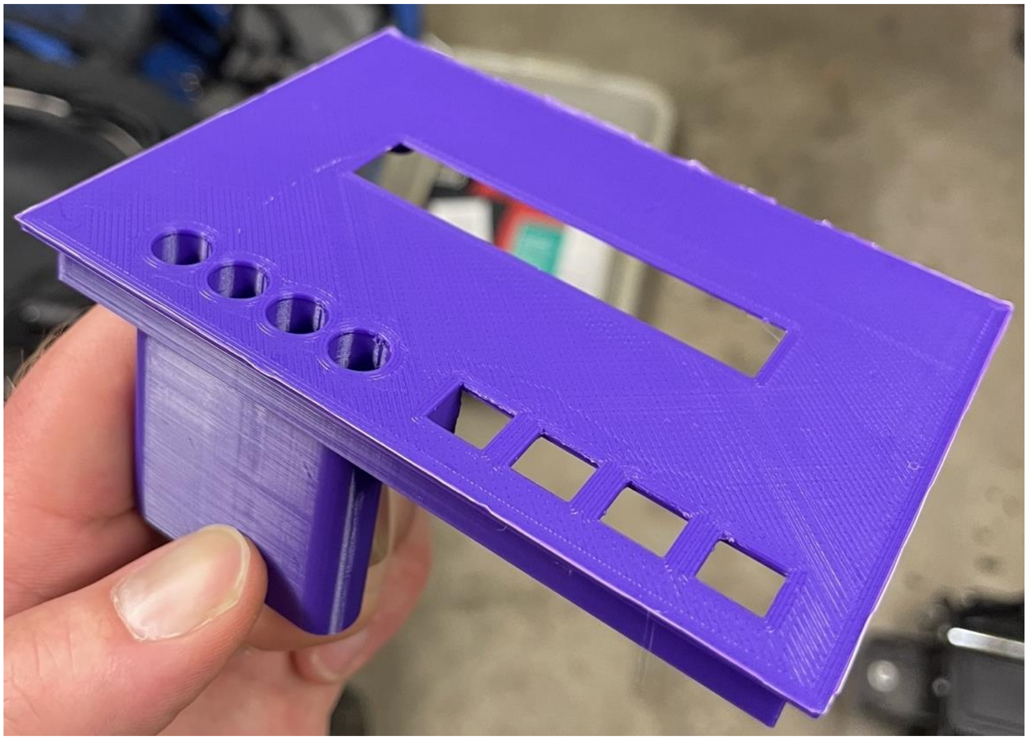


Figure 19: View of faceplate after 3D printing.

The faceplate and enclosure printed successfully. Often in 3D printing, the side of an object "to be displayed" like the front of the faceplate here, is printed upside down, so the uniformity of the print bed leaves a flat surface.

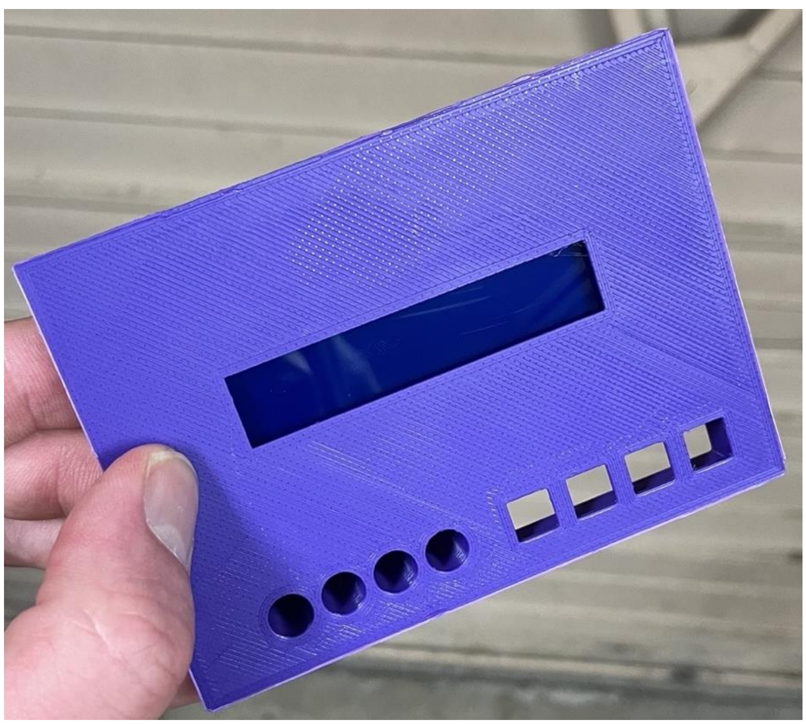


Figure 20: Faceplate with LCD installed (front).

Figure 21: Faceplate with LCD installed (back).

A simple 16-character, 2-line LCD display (a "1602") was chosen because it already is known to work with the open-source firmware. This variant has a built-in I2C controller so that we can connect it using I2C and not have to use half of the output pins on the ESP32 to drive the display directly.

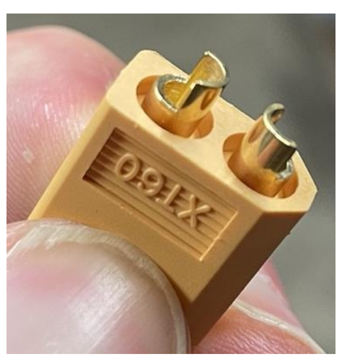


Figure 22: XT60 connector used in wiring harnesses, rated for 60A, and commonly used in RC/drone/hobby..

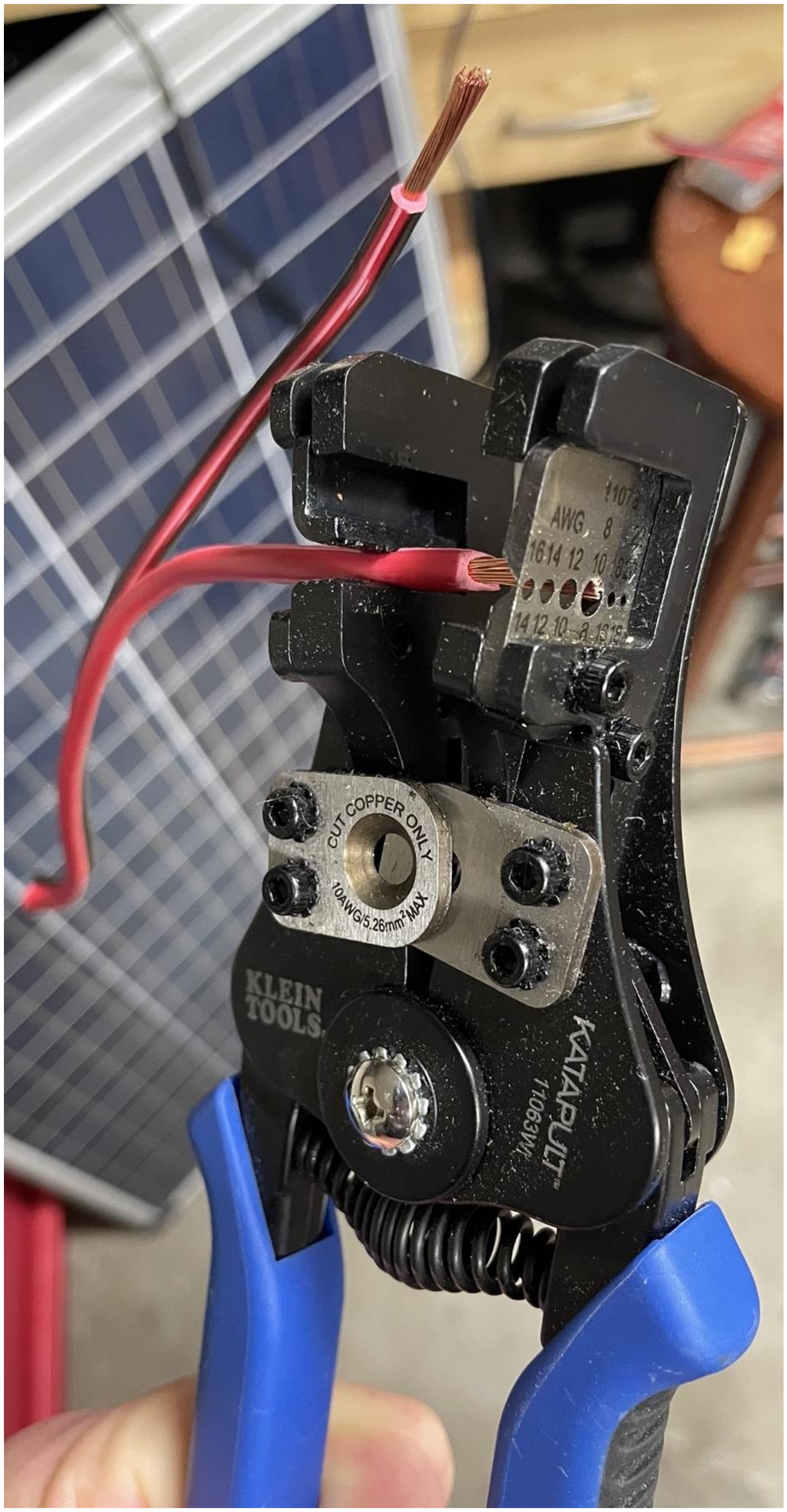


Figure 23: Stripping wire for panel connections. Wire for harnesses was simply a few feet of wire cut off one of the panels, since a connector had to be added to a panel anyway.

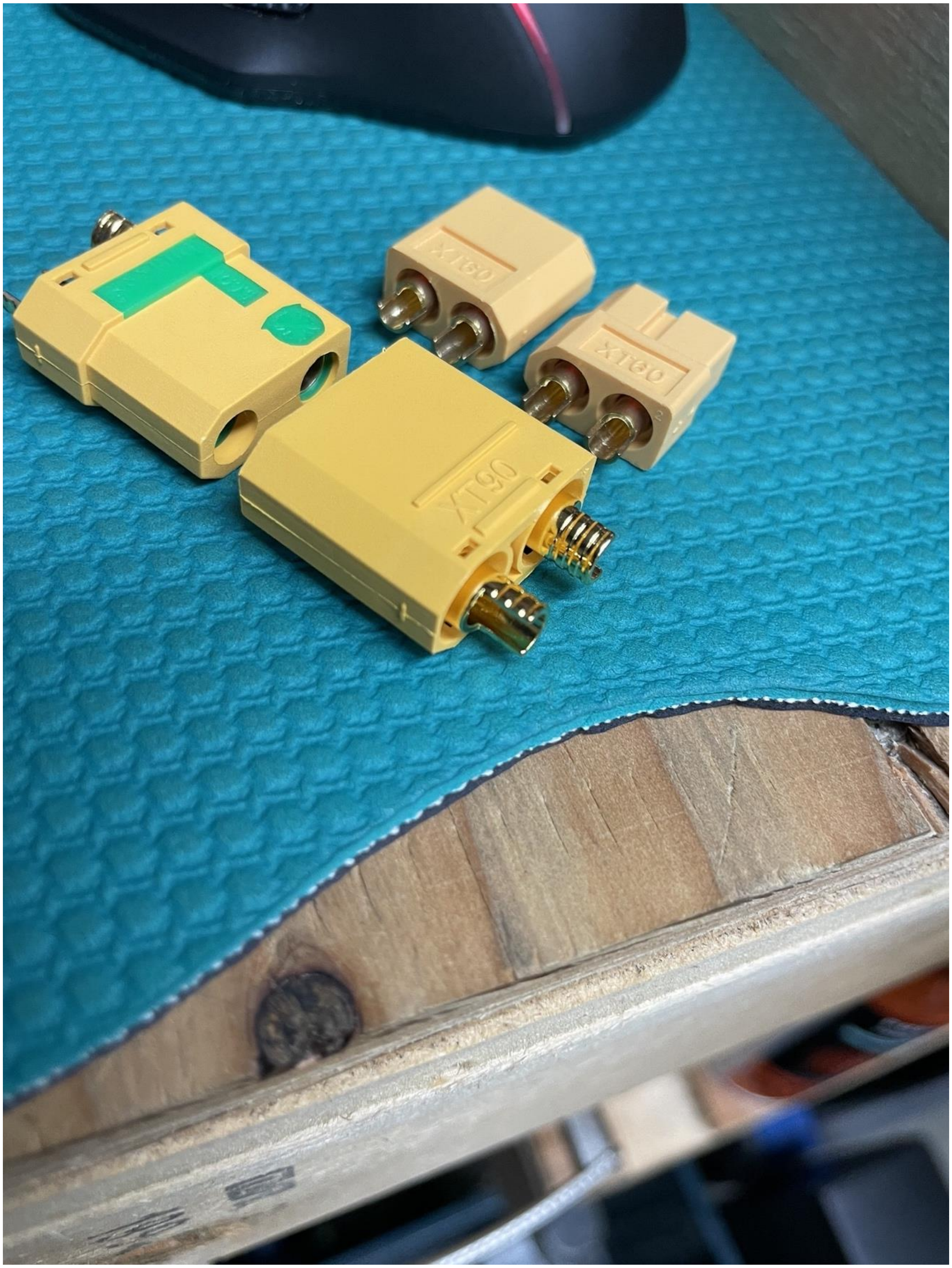


Figure 24: XT90S (spark arrestor version) connector used for main connection to solar panels.

The use of a spark arrestor (a resistor is built into one side and connects first) is a nice feature to have since panel voltage could be up to ~80V range.

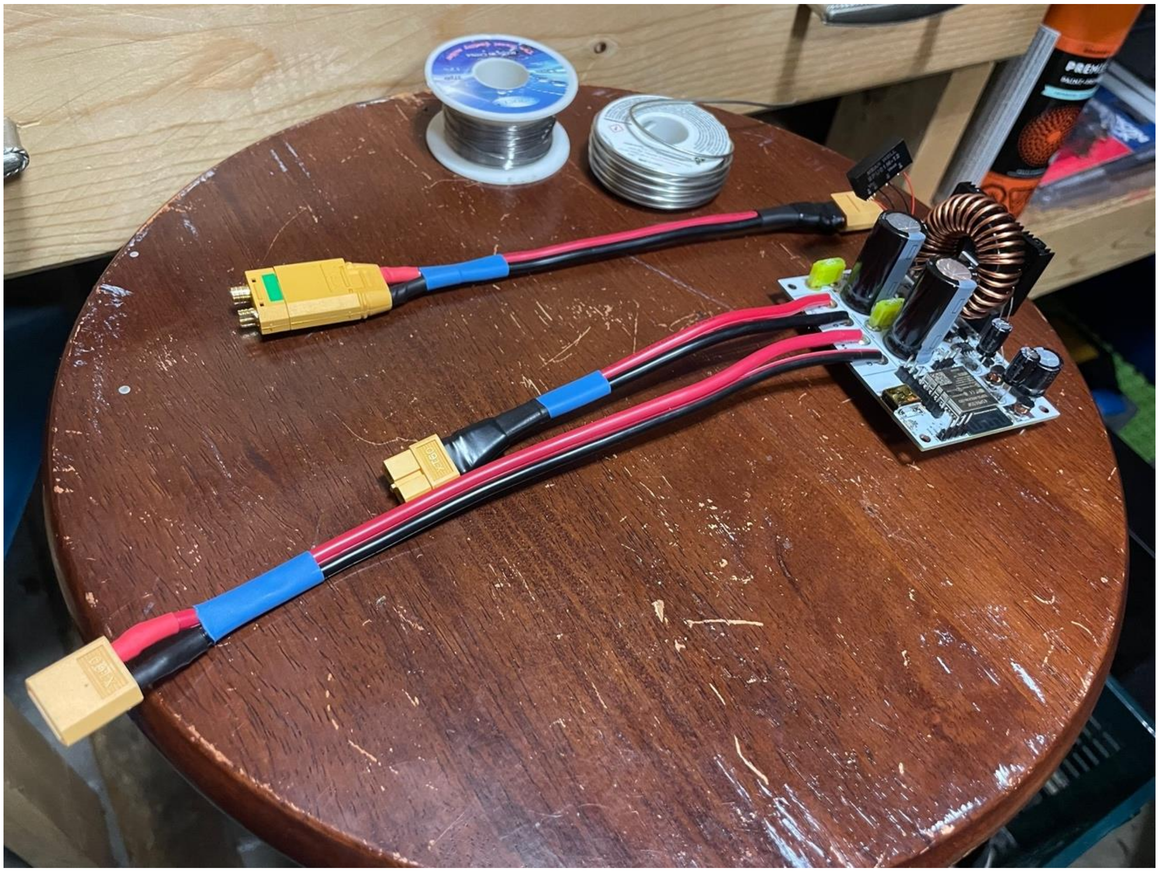


Figure 25: Final prototype board assembly shown with wiring harnesses soldered to board. Installation and removal in enclosure is possible by disconnecting panels and battery and feeding connectors through enclosure holes.

Figure 26: View of board installed into enclosure with faceplate and wiring harnesses.

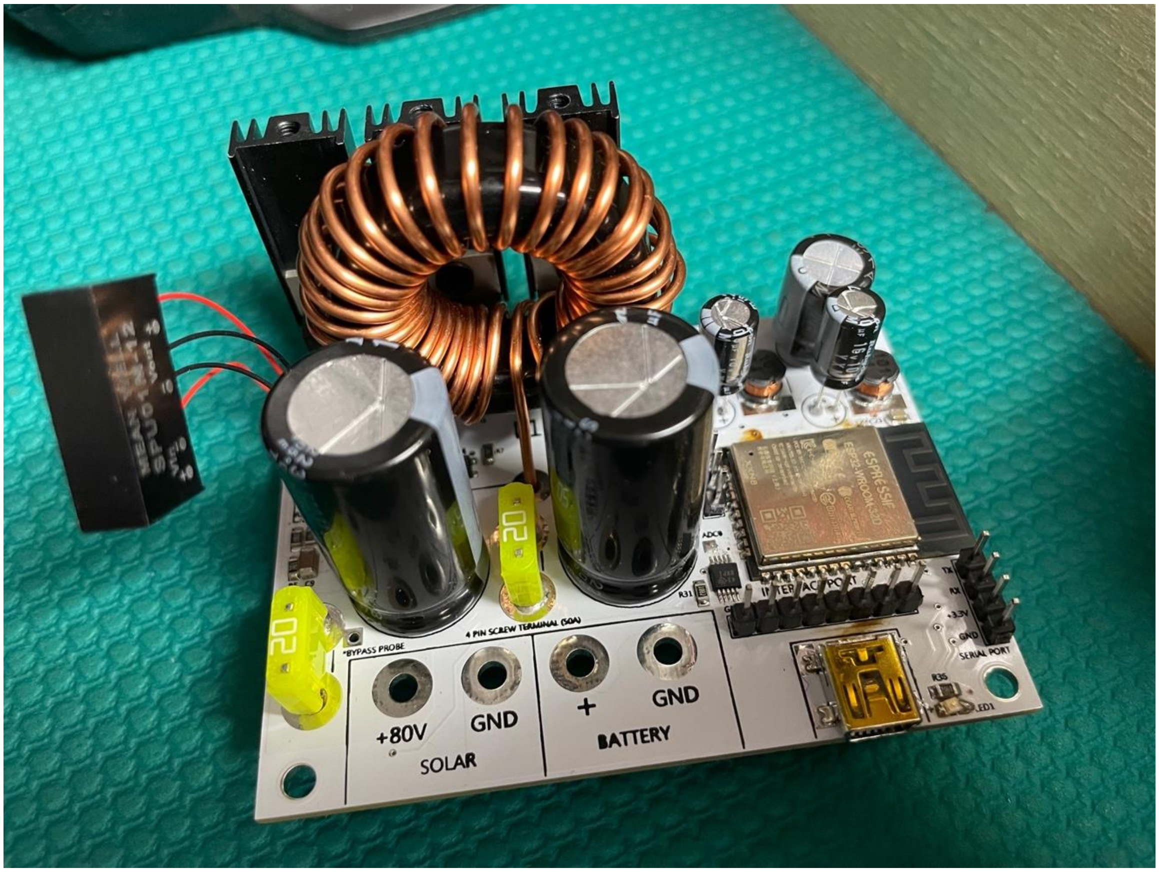


Figure 27: View of finished board without external connections installed.

VIII Testing & Validation

This section outlines the test plans for the prototype's critical subsystems, detailing the operating conditions, expected outcomes, and results. These plans are designed to ensure repeatability across different locations and maintain consistent operating conditions. The validation process is carried out by running several test sequences to confirm that the prototype meets the desired objectives. Where applicable, compliance with EGBC's code of ethics is highlighted.

Figure 28: 12V lead-acid car battery used for test/demo.

This is a picture of a battery originally hoped to be used as a viable test battery, but it had been sitting for far too long. It was unable to hold a charge, so instead, all testing was done (and demo) with the actual battery out of a group member's car.

Figure 29: 100W polysilicon PV solar panels used for test/demo setup.

Test Plans

The following are comprehensive test plans devised to evaluate the USB connectivity, synchronous buck converter, and MPPT algorithm within the system. Each test plan was designed to validate the device's specific objectives.

Testing USB Connectivity and Firmware Upload

Objective: Validate the USB connectivity and ensure successful firmware uploads to the ESP32 microcontroller.

Setup: Connect a computer to the prototype using a Mini-USB cable.

Procedure:

1. Connect the prototype to a computer using a mini-USB cable.
2. Upload the firmware code.

Expected Outcome: Computers should correctly recognize the ESP32, firmware uploads should be successful, and any issues with board shorts should be resolved to ensure stable operation.

Testing the Synchronous Buck Converter

Objective: Validate the buck converter's ability to step down the input voltage to the desired battery charging.

Setup: Connect the converter to a variable DC power supply simulating solar panel output and a resistive load representing the battery.

Procedure:

3. Vary the input voltage to simulate different solar panel conditions
4. Measure output voltage.
5. Record the efficiency of the converter under different conditions.

Expected Outcome: The output voltage should maintain the 12V battery voltage with a ripple of less than 1%. It should achieve an average efficiency of 98% over all test conditions.

Compliance: Ensure the converter operates efficiently and safely to comply with Principle 1 of the EGBC's emphasis on public safety.

Testing the MPPT Algorithm and Microcontroller

Objective: Ensure the microcontroller executes the Maximum Power Point Tracking (MPPT) algorithm accurately to maximize power extraction.

Setup: Connect the microcontroller to a solar panel simulator and the synchronous buck converter.

Procedure:

1. Implement the MPPT algorithm on the microcontroller.
2. Monitor the PWM duty cycle.
3. Use sensors to measure input and output power.

Expected Outcome: The microcontroller should track the maximum power point accurately, maintaining optimal power output under varying sunlight conditions.

Compliance: Promote efficient energy utilization to ensure optimal efficiency, aligning with Principle 1 of the EGBC guidelines for sustainability.

Prototype Troubleshooting

Computers did not recognize the original prototype when connected via a mini-USB cable. After conducting tests, we discovered a short in the USB serial chip. To overcome this issue, we modified a mini-USB cable, connecting the corresponding wires for VCC and GND to the header pins and soldering the wires to the GPIO and EN pins on the ESP32. Unfortunately, this did not resolve the issue.

Next, we used a development board to connect the TX, RX, and GPIO header pins and found that the ESP32 was still malfunctioning. There was a problem with the ESP32 on the PCB. We then uploaded the firmware to a new ESP32 using the development board, replaced the faulty ESP32 with this newly programmed one, and soldered it onto the board.

To further diagnose the issue, we removed the ESP32 and checked for shorts on the board and the ESP32 itself. The board's resistance readings fluctuated between kilo-ohms and mega-ohms, while the ESP32 consistently read in the mega-ohm range. We suspect there may be a problem with a capacitor somewhere on the board that burned our first ESP32.

Validation Process

The initial issues with USB connectivity and board shorts were identified and addressed. Using a development board for firmware uploads and resistance measurements helped isolate the problem of a faulty USB serial chip and potential issues with capacitors on the board. We aimed to test each primary subsystem, including the buck converter, MPPT algorithm, and microcontroller, under different operating conditions to verify that each subsystem met its design specifications. The overall system performance was to be evaluated by comparing the test outcomes with the expected results. Any deviations were to be analyzed and addressed to ensure the prototype's functionality.

IX Cost Analysis

The cost analysis for the MPPT solar charge controller project examines both direct and indirect costs associated with developing and implementing the prototype. Direct costs include expenses for purchasing components, while indirect costs encompass labour, overheads, and potential costs associated with delays or additional consultations. This section details these costs, presents funding considerations, and suggests strategies to optimize expenses.

Direct Costs

Table 2 outlines the direct cost of the prototype components. Other direct costs include gas for team meetings, totalling around $100.

Table 2: Direct Costs

Type	Quantity	Unit Price (CAD)	Total Cost (CAD)
N-Channel MOSFET	3	Varied	13.38
NPN Transistor	10	0.13	1.3
Schottky Diode	18	0.5	9
General Purpose Diode	10	0.1	0.95
Current Sensor	1	5.26	5.26
LDO Voltage Regulator	1	0.74	0.74
LDO Voltage Regulator	1	0.51	0.51
Gate Driver	1	2.5	2.5
Microcontroller	1	6.47	6.47
PCB	1	30	30
Various Capacitors	23	Varied	22.77
Various Resistors	36	Varied	10.28
Inductors	3	1.3	7.8
Heatsink	1	1.01	1.01
LED Indicators	2	0.28	0.56
USB Connector	1	0.94	0.94
Thermistor	1	0.61	0.61
Buttons	4	0.10	0.40
Ferrite Core	1	4.12	4.12
Total Cost of Components		$118.60	

The direct costs total $218.60.

Indirect Costs

Each team member worked approximately 100 hours on this project, which, at a rate of $30 per hour, totalled $9,000 in labour costs. Additional consultations included 10 hours with family members in the field and one hour with Dr. Miha Sima, priced at $150 per hour, resulting in consulting costs of approximately $1650.

Total Cost

The total cost, comprising both direct and indirect costs, is CAD 10768.60. With departmental funding of CAD 120, the final project cost is CAD 10648.60.

Pricing and Return on Investment Calculation

Setting a price of CAD 260 per unit and estimating a production cost of CAD 130 per unit, the sale of 100 units would yield a significant return on investment (ROI) of 122.08%.

$$ROI = \frac{100(260 - 130)}{10648.60} \times 100\% = 122.0818\%$$

By managing costs and optimizing production, the project would be profitable if properly marketed with little cost.

Cost Reduction

Some strategies we could implement to reduce the cost of the MPPT solar charge controller project include bulk purchasing of components that can significantly lower unit prices. This approach can also provide the advantage of securing inventory for future production runs, thereby stabilizing costs against market fluctuations. For a second option, we could update the design to minimize material waste and enhance production efficiency. This update would involve streamlining the design to eliminate unnecessary components and optimizing the layout for easier assembly. Third, collaborating with other projects or departments can facilitate resource sharing, such as tools and equipment, reducing overhead expenses associated with individual procurement. Additionally, seeking sponsorships or forming partnerships with industry leaders can provide financial support and access to expertise, potentially offsetting development costs. The project can maintain a competitive edge by adopting these strategies while delivering an even higher quality with a lower budget.

X Conclusion & Recommendations

Despite extensive efforts, the prototype did not fully achieve its intended objectives. While the USB connectivity and MPPT algorithm implementation showed potential, the system encountered significant challenges. Issues with the USB-TTL UART interface chip and other unresolved electrical difficulties with the first prototype highlighted the complexity of the design and the need for further refinement and electronics technique. These challenges provided valuable insights into areas that require improvement, showing the importance of thorough testing and debugging to obtain a reliable system.

In the future, we recommend building breakout boards for each significant module to facilitate easier debugging of the integrated circuits. This approach would allow for more efficient identification and resolution of issues.

References

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Appendix 1 – EGBC Code of Ethics

The Code of Ethics required under the *Professional Governance Act*, S.B.C. 2018, c. 47 and created in the Bylaws of Engineers and Geoscientists BC provides a set of principles that all registrants are required to follow.

Code of Ethics

A registrant must adhere to the following Code of Ethics:

Registrants must always act with fairness, courtesy and good faith toward all persons with whom the registrant has professional dealings, and by the public interest. Registrants must uphold the values of truth, honesty, and trustworthiness and safeguard human life and welfare and the environment. In keeping with these basic tenets, registrants must:

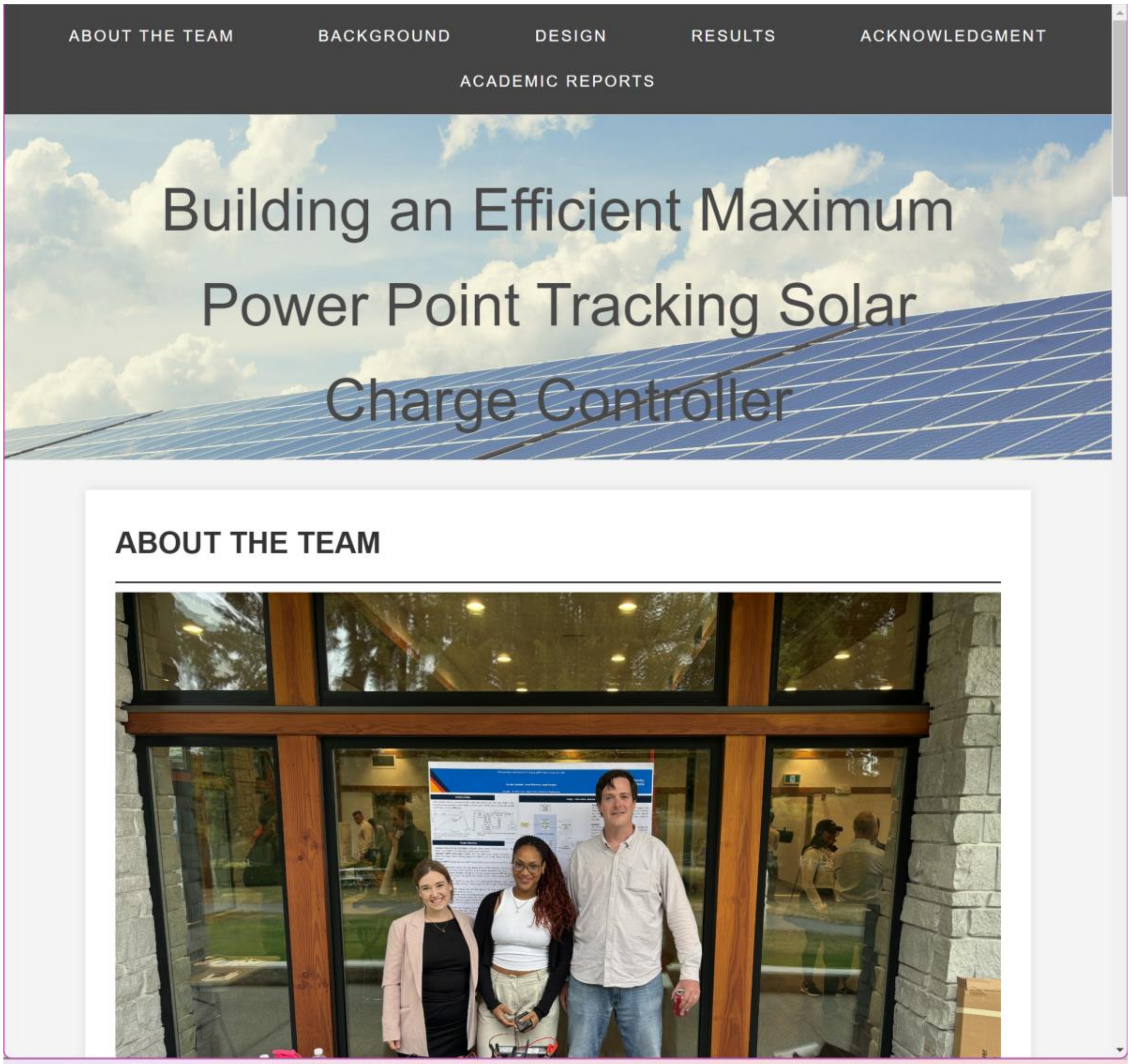
1. Hold paramount the safety, health, and welfare of the public, including the protection of the environment and the promotion of health and safety in the workplace.
2. Practice only in those fields where training and ability make the registrant professionally competent.
3. Have regard for the common law and any applicable enactments, federal enactments, or enactments of another province.
4. Have regard for applicable standards, policies, plans, and practices established by the government or Engineers and Geoscientists BC.
5. Maintain competence in relevant specializations, including advances in the regulated practice and relevant science.
6. Provide accurate information in respect of qualifications and experience.
7. Provide professional opinions that distinguish between facts, assumptions, and opinions;
8. Avoid situations and circumstances in which there is a real or perceived conflict of interest and ensure conflicts of interest, including perceived conflicts of interest, are properly disclosed and necessary measures are taken so a conflict of interest does not bias decisions or recommendations.
9. Report to Engineers and Geoscientists BC and, if applicable, any other appropriate authority, if the registrant, on reasonable and probable grounds, believes that:

   a. The continued practice of a regulated practice by another registrant or other person, including firms and employers, might pose a risk of significant harm to the environment or to the health or safety of the public or a group of people; or
   b. A registrant or another individual has made decisions or engaged in practices which may be illegal or unethical.
10. Present clearly to employers and clients the possible consequences if professional decisions or judgments are overruled or disregarded.
11. Identify each registrant who has contributed professional work, including recommendations, reports, statements, or opinions.
12. Undertake work and documentation with due diligence and in accordance with any guidance developed to standardize professional documentation for the applicable profession; and
13. Conduct themselves with fairness, courtesy, and good faith towards clients, colleagues, and others, give credit where it is due and accept, as well as give, honest and fair professional comment.

Appendix 2 – Project Website

Below is the website link and screenshot of the top of the page.

https://jennahilderman.github.io/ece499g19/



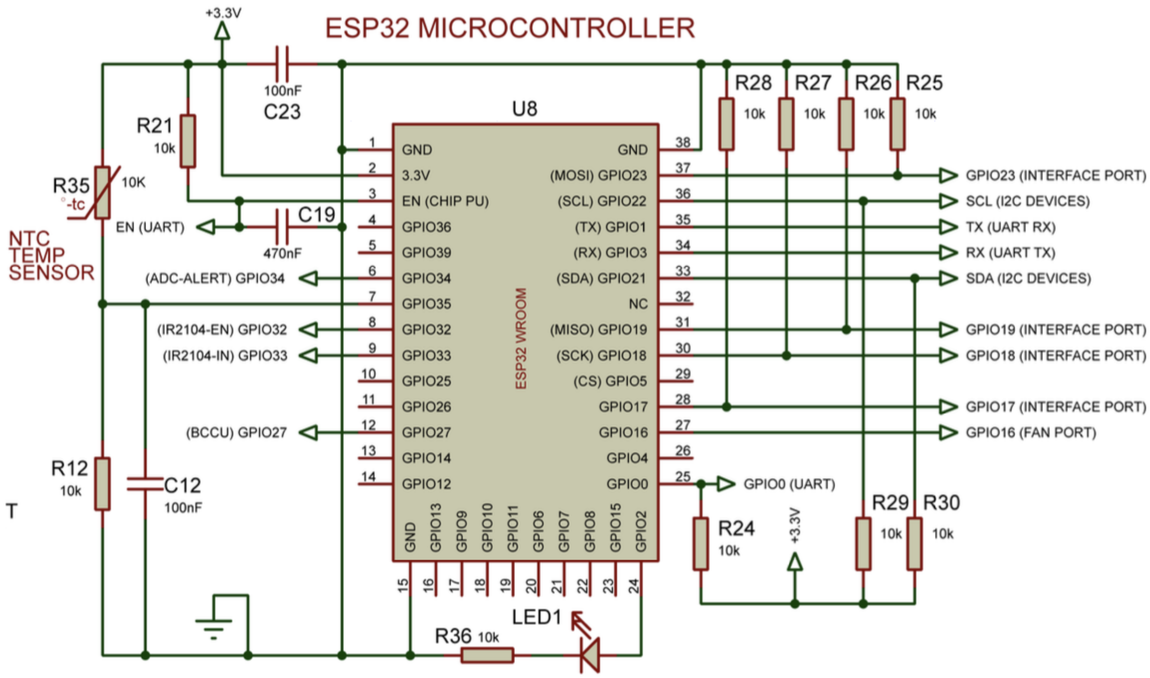
Appendix 3 – Project Code

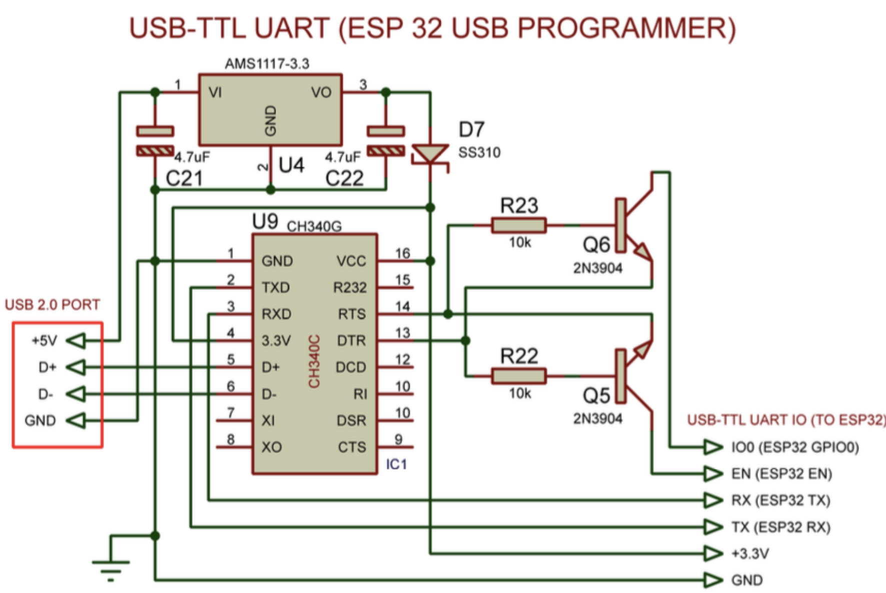
Below is the Google Drive link containing the modified code from the Instructables project.

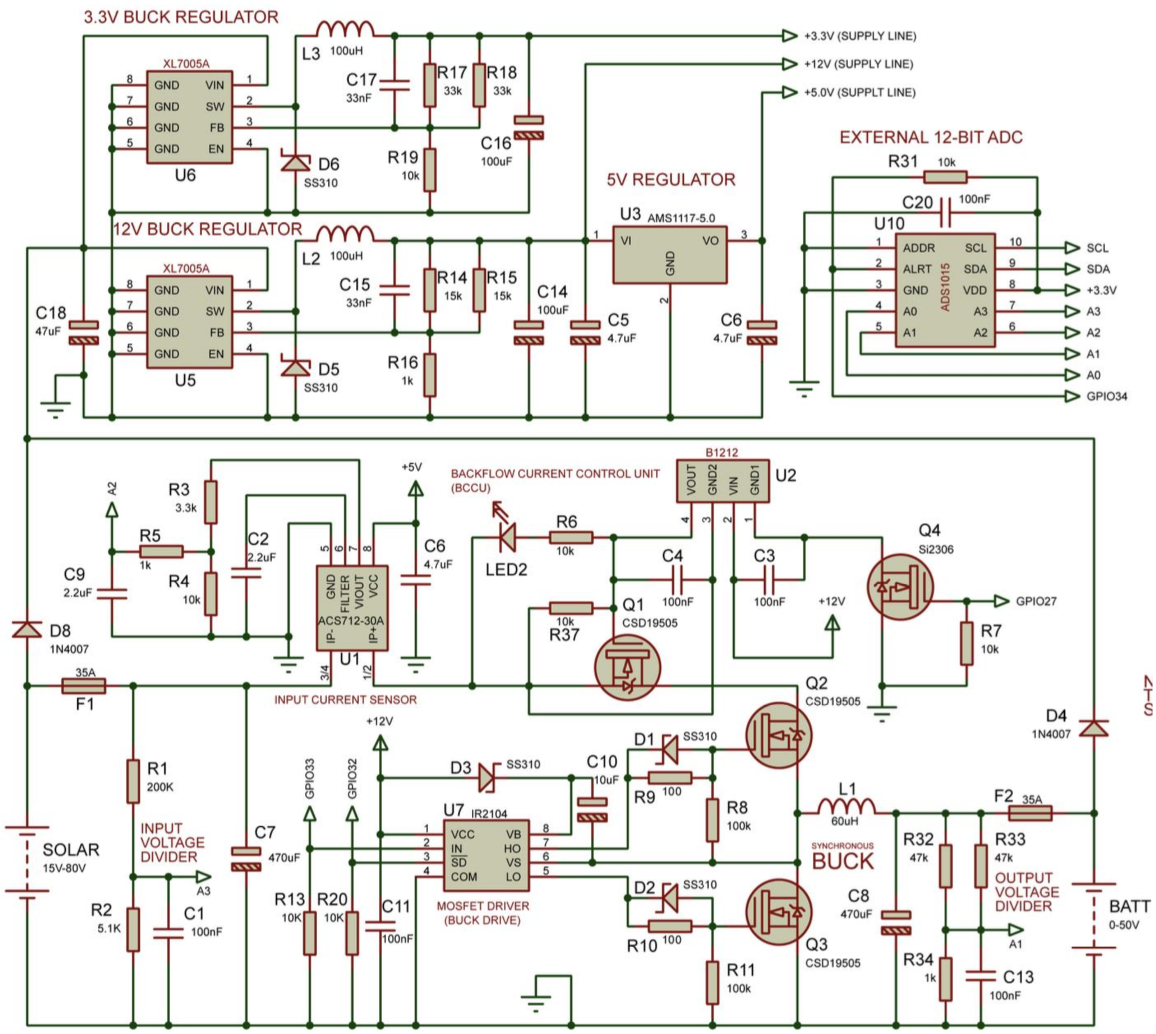
https://drive.google.com/file/d/1WJmno9lSVq6Btec18TycTya8SLFFeORL/view?usp=sharing

Appendix 4 – Schematics

The following schematics used here are from the referenced tutorial by ASCAS [2].






3.3V BUCK REGULATOR
12V BUCK REGULATOR
5V REGULATOR
EXTERNAL 12-BIT ADC
+3.3V (SUPPLY LINE)
+12V (SUPPLY LINE)
+5.0V (SUPPLT LINE)
BACKFLOW CURRENT CONTROL UNIT (BCCU)
INPUT CURRENT SENSOR
INPUT VOLTAGE DIVIDER
MOSFET DRIVER (BUCK DRIVE)
SYNCHRONOUS BUCK
OUTPUT VOLTAGE DIVIDER
SOLAR 15V-80V
BATT 0-50V
XL7005A
AMS1117-5.0
ADS1015
ACS712-30A
B1212
IR2104
CSD19505
Si2306
SS310
1N4007

Appendix 5 – Block Diagram