Off Grid Optimized Solar Charging with Several Output Voltage Potentials

ECE 445: Project Proposal

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1. Introduction

1.1 Problem:

Due to the effects of climate change, the risk of natural disasters threatens several of the world's most populated areas. In the event of electricity going out for several days during a natural disaster, people are left with no way to charge their phones, flashlight batteries, or any other tools they may desperately need. This creates a need for some off-grid charging solution that can supply power to several different voltage requirements. There is also a need for such a device for consumers who want to utilize renewable energy to reduce their carbon footprint, but cannot control how their local electricity is generated or cannot install solar panels due to the cost. These two problems that arise from climate change both require a need for an off grid energy source, that can be used freely by the user, and is versatile by having several different charging outputs.

1.2 Solution:

Our team proposes a solar panel integrated with a cascaded DC-DC Converter, that can provide power to USB and rechargeable batteries in the event of emergencies. This device would utilize off-grid renewable energy and provide charging capabilities to multiple output potentials with different power ratings, for example, AA batteries and USB protocol for smartphones. The input power will be sourced from a Maximum Power Point Extraction (MPPT) algorithm, and the product will be able to measure and store the total energy accrued from the solar panel. This device can be used year-round to provide renewable energy to homes or be stored to be used in case of an emergency. This device must provide reliable, safe, and reproducible circuitry to allow maximum power to be extracted from the input solar panel, while strictly regulating the power ratings of several output terminals.

The overall product will display the cumulative power received from the solar panel, such that the environmental impact of the device can be measured. Typical applications for this would include setting this device up to run in remote locations that are isolated from the grid, such as hiking, camping, or in the event of a blackout. The device's success is based on the amount of energy received from the solar panels, and the necessary regulation of the output potentials.

1.3 Visual Aid

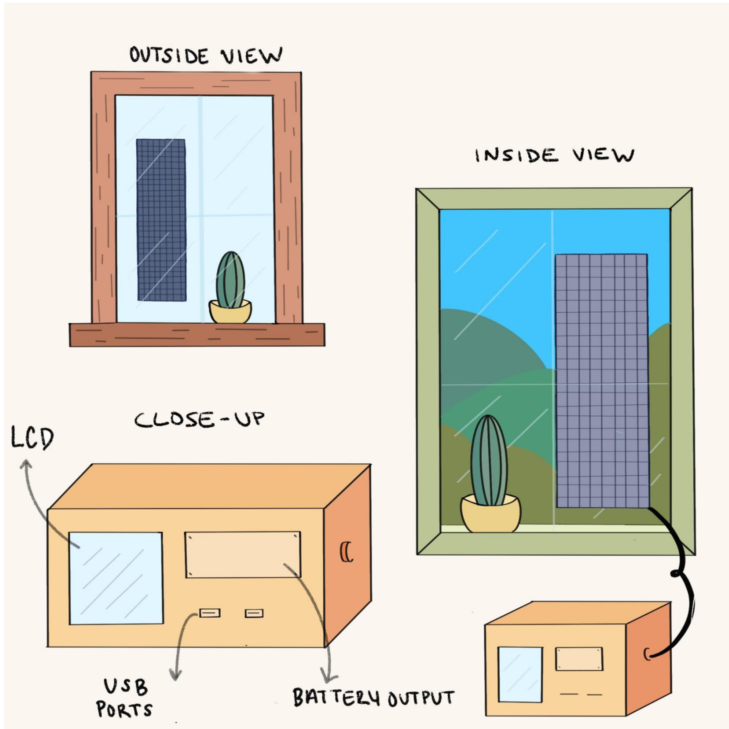

Figure 1: Consumer Design

1.4 High-level Requirements List

1.4.1: Solar Panel Input with Maximum Power Extraction: Displaying the energy saved

The MPPT will allow us to extract the maximum amount of power, over a wide range of ambient weather conditions. This is required for consumer use, who want to maximize their energy savings. We propose to design our MCU around the MPPT algorithm, with the necessary control feedback to regulate current from the solar panels. The MCU would control the duty cycle of a synchronous buck boost converter, which affects the relationship between the input and output current. By doing this, the duty cycle can be altered to achieve maximum power extraction, where the Buck circuit can be modeled as a variable resistor with minimal losses. This is the fundamental mechanism behind our efficient MPPT algorithm, where the output voltage of the Buck circuit dictates the amount of power being extracted. We can then attach a current sensor directly to the Buck terminals to measure the total power extracted. The microcontroller can store this information in memory, and display it on an external LCD display, allowing the user to accurately measure their energy savings. This part of the project is vital to its success because we want to maximize the efficiency of our renewable energy source and provide users with highly accurate and efficient energy savings.

1.4.2. Ability to Work off Grid

A critical part of our design is the ability to operate completely isolated from the grid. This requires the system to rely on the solar panel for its auxiliary power. There cannot be any external connections to power sources, which requires the system to interface the MPPT algorithm with voltage regulators required to power internal ICs and the microcontroller. The MPPT cannot cause volatile behavior for the currents and voltages inside the device, thus the device must be powered from an internal source that is separate from the output voltage controlled in MPPT. This is the first step in the device being able to work isolated from the grid, but it also must be able to generate the control, duty cycle, and data signals for all of the internal components as well. Thus, to be isolated from the grid, the device has to be complex enough to interface several circuit blocks, while managing and consuming the energy extracted from the solar panel.

1.4.3 Quality of the Output Voltage and Current

The quality of the output voltage and current is an area that we want to constrain the accuracy of. Typically for a mobile phone, we would expect the USB charging to be rated at 5V/2A. We want these to be as accurate as possible and so we limit our ringing and our switching tolerances to 2% both on the voltage and current sides. This type of issue can be sourced to the fact that there is ringing in our synchronous converter system [1]. We want to minimize this as much as possible to allow our average voltage and current to even out and stay within those bounds as aforementioned. That being said, we also want to make sure that those peak voltages and currents are accounted for especially when selecting our switches, FETs, and wire gauge sizes to prevent malfunction and breakdowns. This will help increase the durability of our design.

2. Design

2.1 Block Diagram

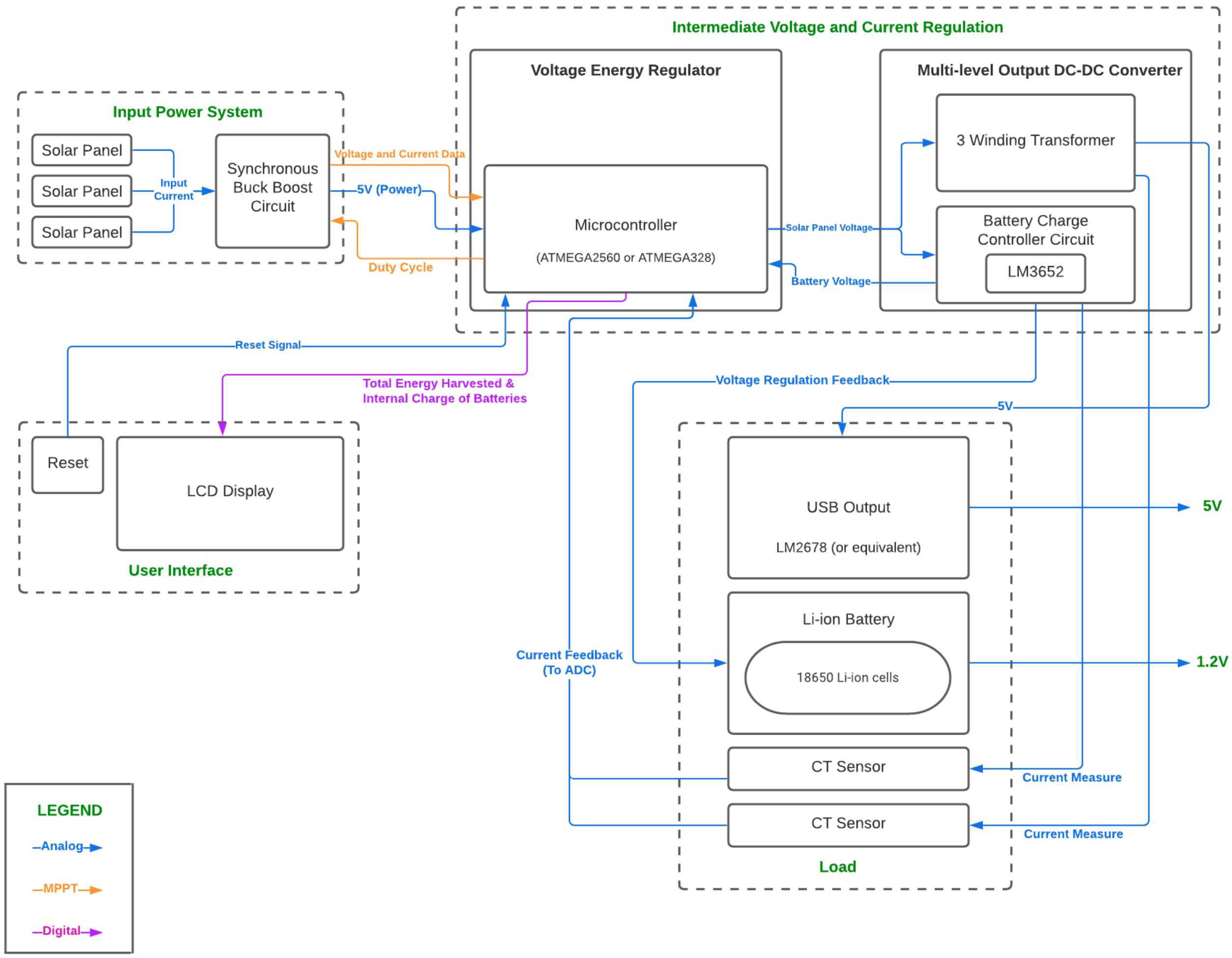

Figure 2: Block Diagram

2.2 Subsystem Overview

2.2.1 Input Power System

Component Requirements:

- **Solar Panels**
  - This will be our main source of input power. We expect that we will need at least 12-16 Watts of input power from the solar panel, to satisfy the conservation of power and charge two output batteries simultaneously. If a 16 W solar panel or array of lower output power solar cells is not available on the market, we can look into alternative solar panels that are provided in various labs throughout ECEB.

    We have begun discussing with the TA possibility of using solar panels owned by the university, to reduce our cost.

- **Synchronous Buck or Boost Converter**
    - For the synchronous buck-boost converter, we'd expect to utilize this particular topology to allow us to utilize varying inputs from the solar panel to output a constant 5 V/2 A DC. In addition to this topology, we also plan to use a buck or boost converter to model a variable resistor that's dependent upon the duty cycle that we feed into the buckboost converter. This variable resistor model is essentially created because we model R = V/I where V and I are the buck converter's output voltage and current respectively, and this variable resistance is vital to the MPPT hardware implementation.
- *Requirement 1*: Providing an output of 5V / 2A according to specifications decided by our charging devices 10 [W] with appropriate current and voltage ripple.
- *Requirement 2:* Implement a topology that allows for a varying input from the solar panel to be outputted as a constant DC. This can be done with a synchronous buck, boost, or buck boost converter, where we will simulate and select the most efficient topology.

2.2.2 Intermediate Voltage and Current Regulation

- **MCU**
    - We will use a custom designed microcontroller board to perform (MPPT) for the solar panels and regulate the solar panel output current. Currently, our two options are ATMEGA 2560 for more I/O and peripheral expandability or ATMEGA 328 for compactness. In addition to the MPPT functionality, MCU will be used to calculate and process feedback data for the control of the various components (i.e. Multi-Potential DC-DC Converter components) and data to be displayed to the users on the LCD display. Hence, the MCU is critical to power extraction and regulating the output power ratings.

- **Battery Charge Controller Circuit**
    - To store access energy after the main energy is drawn from the USB port, lithium ion batteries will be used. For the safety and proper charging operation of these batteries, LT3652 PMIC will be used to regulate the charging current according to the total power being harvested by the solar panels (adjustable according to the irradiation level via the sensible difference in input voltage and battery voltage feedback loop) [2]. Also, this circuit will be responsible for controlling the charging current according to the battery's charge (even shut down after a certain voltage threshold). A Zener diode will be used on the load side for over-charge protection.

- **Multiple Output DC-DC Converter (Flyback or Forward Converter)**
  - We propose to implement a Flyback or Forward topology that makes use of a three-winding transformer to control the different output potentials. By successfully designing our transformer, we solve for the turn rations N1:N2:N3 such that the two loads can be connected. These implementations will require the design of output filters working in conjunction with battery charge controllers, such that the output voltage potentials and currents are confined. The transformer will also provide galvanic isolation (using a transformer) to ensure the durability of the system in case of faulty operation, but also introduces additional losses in the system.
- *Requirement 1:* Secondary Converter is able to regulate and limit to different load terminals.
    - Must select a duty cycle and turn ratio that allows us to achieve USB (5V at 2A) and battery power ratings (1.2V at 500mA).
    - Development of two different output filters to ensure the voltage and current ripple are within 1-2% of the expected value.
- *Requirement 2:* Safe control mechanisms that successfully charge the battery
    - Battery charging rate is automatically adjustable according to the solar irradiation level.
    - According to the battery charge levels, the speed of charging is adjustable or even can be stopped.

2.2.3 Load Regulation

- **USB Output**
  - To output 5V 2A output via USB connection, a DC-DC voltage regulator will be used to step down the voltage to 5V and regulate the output current to 2A. PMIC such as LM2678 has a wide range of input voltage (from 8V to 40V) [3]. Therefore, implementing LM2678 or similar ICs at the output of the 3 winding transformer will be an optimum modular solution (wide input range capacity) and reliably output the 5V, 2A configuration to the load [3]. For the over current protection, putting a fuse at the load will be a good practice on this subsystem [4].
- **Li-ion Battery**
  - Specific battery capacity is still tbh since depending on the solar panel implementation, the battery capacity may vary. If we can get access to ECEB's solar panel (can harvest up to 80W or more), battery capacity needs to increase. However, if smaller solar panels are implemented, battery capacity can be small. One possibility of Li-ion battery implementation is using 18650 lithium ion battery cells. The typical voltage rating for these cells is 3.7V and depending on the capacity requirements, "battery pack" voltage may also vary. Going back to LT3652, this IC is capable of supporting a battery rating of up to 15V, which is a

modular design choice since a wide range of battery configurations are possible depending on future design changes [2].

- **CT Sensors**
  - CT sensors will be used to measure the current being drawn by two outputs (output current drawn by USB output and the charging current of the battery). These data will be sent to MCU and will be used to calculate the energy being harvested and the battery charge level.
- *Requirement 1:* Overcharge protection via shutting the current off according to the battery charges so that the battery can last long.
- *Requirement 2:* Overcurrent protection at the load (or user interaction side) for the safety of the users.
- *Requirement 3:* Feedback data received on MCU for the controls and displaying the data.

2.2.4 User Interface

- **LCD Display**
  - A simple display will be mounted on the system to show human comprehensible data. Some of the data we will try to focus on displaying include total energy harvested and battery charge level. Battery level is an important measure because the user needs to know how much power he or she can pull from the storage in emergencies. Since we intended this device to be able to operate off-grid, we have to ensure that it can operate reliably during the low solar irradiation weather as well. Displaying the battery level is crucial for this purpose since the users will be able to keep track of the stored energy and use it accordingly. Total energy harvested will be an important indicator of how much energy users can save by using this device.
- *Requirement 1:* Human comprehensible data output display of the total energy harvested in units of [Watts].
- *Requirement 2:* Human comprehensible data output display of the battery charge status in units of [mAh].

2.3 Tolerance Analysis

One area of conflict that we must be prepared for, is how we implement the USB protocol and limit the current being sent to the output device. Standard USB protocols do not limit the current being sent to the host device, but instead, follow a communication protocol to incrementally increase the load current [5]. This places a constraint on the output USB current, which is directly tied to the input current obtained through MPPT. Thus we may have to limit the efficiency of the MPPT algorithm, such that the input current does not exceed the maximum power rating and does not disrupt the communication protocol between the host and port connection. This operation must also control the no load condition of our output terminals, but no USB host actively turns off the power from the port**.** The USB host expects that 5 [V] and 2 [A] will always be available, which we may need complex circuitry to reroute this power to the charging bank for no load conditions, while being able to source power from the storage element and the solar panel itself. This all ties back to section 2.2.3 for the load regulation requirements, where the output power terminals are safe for battery charging.

This problem can be solved by modifying the MPPT algorithm to supply the maximum allowed power, by setting an upper bound on the output solar panel current. This upper bound restricts the current on the primary winding of our transformer, which is mathematically represented as $I_1N_1 + I_2N_2 + I_3N_3 = 0$. Thus, if we can place an upper bound in I_1 by programming the microcontroller, then there will also be an upper bound on the sum of the output currents $I_2 + I_3$, and the total output current does not exceed any ratings. Furthermore, in the no load conditions when $I_2 = 0$ and $I_3 = 0$, we can focus on providing a path for the current I_1 to the charge storage unit. This is the strength of using a three winding transformer in our design, but we must also be prepared to account for additional losses, such as the magnetizing inductance of the system.

3. Ethics and Safety

The IEEE Code of Ethics states that members are hereby committed to "uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities" [6]. With this in mind, we have compiled a few risks associated with following through with these projects. These are important especially since we are utilizing batteries as a power source while also reporting our current power outputs.

In terms of ethics, we want to make sure that we understand the safety and the risks associated with utilizing external batteries. This involves each member of our team conducting the battery safety training that has been provided to us by the course staff here at ECE 445. Precautionary measures that we can take are to make sure that we protect our system from overheating, loss of voltage and other surges that could occur while the device is operating. Furthermore, it is best if we can isolate the power signals and the data signals in our design, such that the PCB manufactured is not at risk of accidental short circuits destroying the device or battery.

In addition to this, we will be tracking overall power input into our system and so it is our responsibility as the engineers to make sure that these values are accurate as they may be used to supplement other use cases and as such may be reported as official statistics. Providing accurate and factually correct information is important to consumers and is also advised under IEEE code of ethics under section 7.8 section 1.5 whereby it is stated that individuals must "be honest and realistic in stating claims or estimates based on available data" [6]. This will be apparent in future reports and revisions to our project, where the device provides reliable and accurate data to the user.

4. Conclusion

Our proposed device can be applied to a variety of different economic and environmental concerns. The significance lies in the ability of our project to work completely isolated from the grid, harness energy efficiently, and the ability to have several output voltage potentials from a single renewable source. By further tracking the amount of energy accrued over the solar panels' lifetime, there is immediate feedback on the return of investments from purchasing this device. A consumer can utilize our design for numerous circumstances, such as hurricane relief, emergency power during a blackout, or reducing their carbon footprint by reducing their energy bill. These aspects of our design indicate the project will not only solve the aforementioned problems but also can be expanded upon in the future to provide more output potentials with different power ratings as the global energy demand continues to increase.

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