Mobile Charging Using Solar Power

Edrick Joe
April 24, 2023

Abstract

With the rise of the number of electronic devices that people carry with them daily, portable chargers have become very popular. These portable devices have the issue of needing to be periodically recharged by the power grid or a generator. This means that they are likely fossil fuel dependent, and are not useful in more remote areas. This solar powered battery pack aims to solve this problem by allowing users to recharge their portable devices wherever there is sunlight.

Introduction

Nearly everybody now carries a portable electronic device. Whether it be smartphones, smart watches, wireless earbuds, or something else, the average person in the US will carry a portable electronic device with them throughout their day. With all these devices, portable chargers have become very popular. These chargers are useful if a person is on the move or is in an area where outlets are unavailable. Portable chargers have their downsides, however, pertaining to how they are recharged. Conventional portable chargers need to be recharged with energy from the grid or whatever generator the user has access to. This raises environmental and portability concerns. It is very likely that these devices will be powered with electricity made with fossil fuels, which is not the ideal source of energy during the climate crisis. This also means that whenever a user needs to recharge their power bank, they must be in a location that has access to electricity. In areas with little to no electric infrastructure, such as rural and remote areas, it is difficult to find any power source for one's portable electronics. The solution to these problems is to design a portable battery pack that can use solar energy to recharge itself, which is what this project aimed to do. By incorporating a solar panel into the system, users will be able to charge their devices with no emissions anywhere that the sun shines.

This project also incorporates an algorithm designed to extract the maximum amount of power from the solar panel. This algorithm, called Maximum Power Point Tracking (MPPT), identifies the point in the solar panel's operation that results in the most energy being delivered to the battery, and then adjusts as necessary to keep it at that point. This algorithm, combined with the proper solar panel sizing, allows for the battery to charge faster than a device can discharge from it. What that means is that with enough sunlight the charger can continuously provide power to a device.

Project Objectives

The main objectives for this project were to create a mobile charger that was able to both power itself sustainably, and have the performance to be able to generate more power than a device may draw from it. The first objective was rather simple to solve. No sustainable power source matches the portability, availability, and economics of solar power for this application. As long as the panel can receive sunlight, there will be sufficient power to charge the power bank. The next objective was a bit more challenging to solve. The project needs a solar panel that can input more energy than the system outputs. However, to get more power, one must usually either increase the size of the panel to absorb more sunlight. This solution was not good for this project, as mobility was a key goal, so a focus on extracting the maximum amount of power from a solar panel was needed. Thus, the MPPT algorithm was chosen. When compared to a standard Pulse Width Modulation (PWM) controller that outputs a constant voltage, a MPPT controller will find the maximum power that the panel can generate at that time and keep it at that point. This is because the relationship between a solar panel's power and voltage is not constant, nor linear. As the voltage increases, the power increases until a certain point when power drops off quickly. An example can be seen in Figure 1 below.

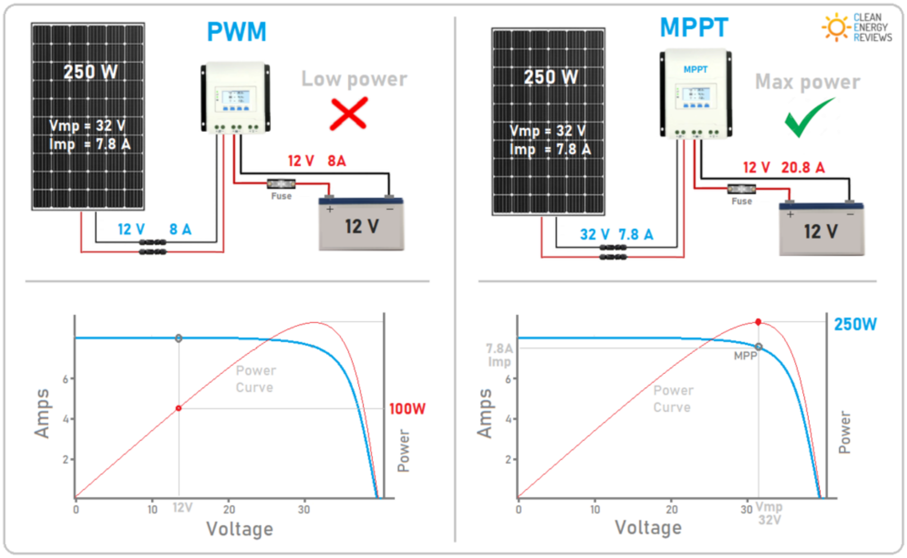

Figure 1: Performance differences between a PWM and MPPT controller.

While Figure 1 uses different battery and solar panel specifications than my project, it is clear that the MPPT controller was able to extract the maximum power from the solar panel. With this algorithm, a smaller solar panel can be chosen while still maintaining performance.

Component Selection

With the power source and controller topology selected, design of the system and component selection could begin. First, the system outputs were chosen. The output was chosen from what would be required to charge a smartphone, as this is one of the most popular portable electronics people use. The output port was selected to be USB-A, as that is the standard for most portable electronics. 5 watts was chosen as the power output, as that is the nominal power output of an iPhone charger. The USB standard voltage is 5V, so at a 5W output 1A must be delivered.

With the output specifications selected, I moved onto battery selection. I wanted a system that had the capacity of the average portable charger, which is usually around 6000 mAh. I also wanted a battery without a built in charge control system, as this would interfere with the MPPT operation. The battery must also be compact and lightweight for good mobility. With these criteria, a 3.7V 6600 mAh Lithium Ion battery was chosen.

To bring the power from the battery from 3.7V to the 5V needed by the USB output, a boost DC DC converter was needed. This DC DC converter needed to bring a wide range of voltages up to a stable 5V output, as well as be able to output 5W. The Adafruit MiniBoost 5V @ 1A - TPS61023 was a perfect choice for this application, as it was designed for applications similar to mine.

The solar panel was chosen with consideration to size, cost, and power output. The power rating needed to be at least 6W, determined by the 5W system output, and 1W as a conservative estimate for losses in the system. I wanted to keep the panel size no bigger than the size of a binder, and to keep the cost under $60. With these constraints, the Voltaic Systems P108 was chosen. The P108 outputs a maximum of 9W, is 274x223 mm, and was $49 at the time of purchase.

Finally, the hardware for the MPPT controller needed to be chosen. Specifics about the MPPT can be found later, but at a high level, the MPPT needs a half bridge, a low pass filter, a current sensor, and a microcontroller. The ESP32 was chosen to be the microcontroller because of my prior experience with it, its low cost, small size, and ability to produce PWM signals. The half bridge needed to be rated for the 18VOC and 10W received from the solar panel. It also needed to be PWM controlled and operable by the ESP32. The Qunqi L298N Motor Drive Controller Board fits all of the requirements. The low pass filter was designed to have a peak resonant frequency of 1000x lower than the PWM switching frequency. This ensures that the current to the battery is as close to DC as possible, which prolongs the life of the battery. The current sensor needed to be a hall effect sensor, as they provide great insulation and high accuracy. It needed to also be able to sense the relatively low currents sent through the system. The SEN-13679 fit this requirement. These components together, along with the software, make up the MPPT converter. The entire system can be seen in Figure 2 below. The circuit schematic can be seen in Figure 3.

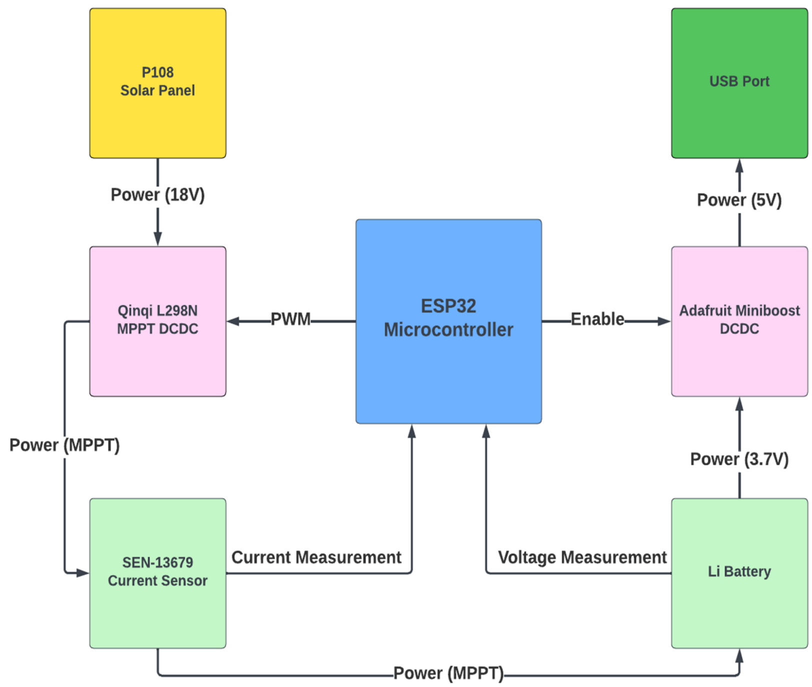

Figure 2: System Diagram

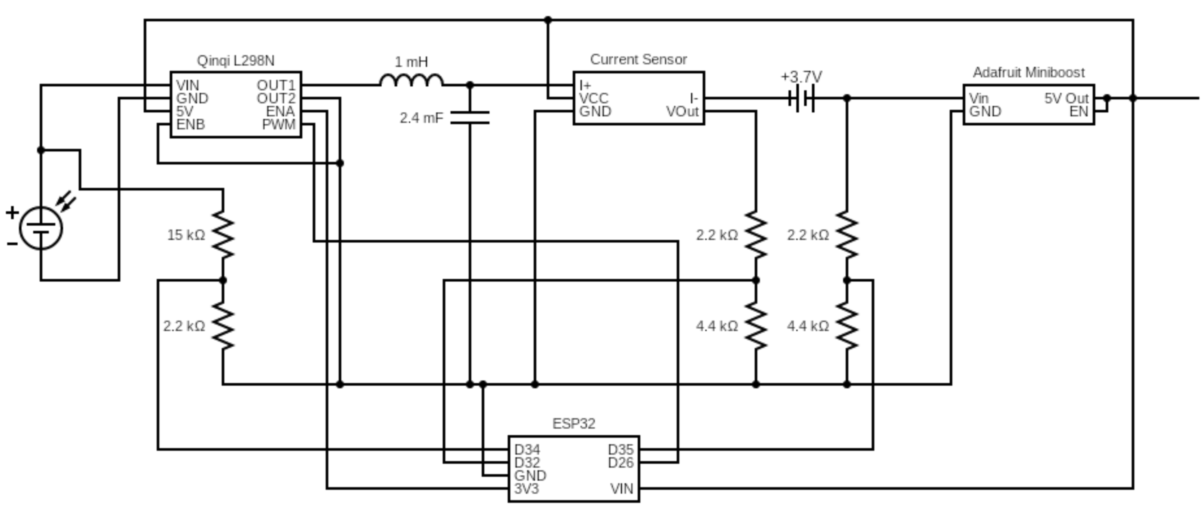

Figure 3: Circuit Schematic

MPPT Operation

The MPPT operates by calculating the current power produced by the solar panel, comparing that power to the previous power value, and then increasing or decreasing the duty cycle of the PWM signal sent to the half bridge. Power is calculated by using the equation $P = I * V$. By using the ESP32 to take a voltage measurement from the solar panel, and with the current measurement from the current sensor, the instantaneous power is calculated and then stored by the algorithm. The algorithm then calculates if the duty cycle needs to increase or decrease. It does this by calculating the derivative of the power with respect to the duty cycle. The duty cycle effectively controls the voltage of the solar panel. So by taking the derivative with respect to the duty cycle, we can find the maximum power point. The maximum power point for a solar panel power voltage graph can be found where the derivative is equal to zero. A visual of this can be found below in Figure 3.

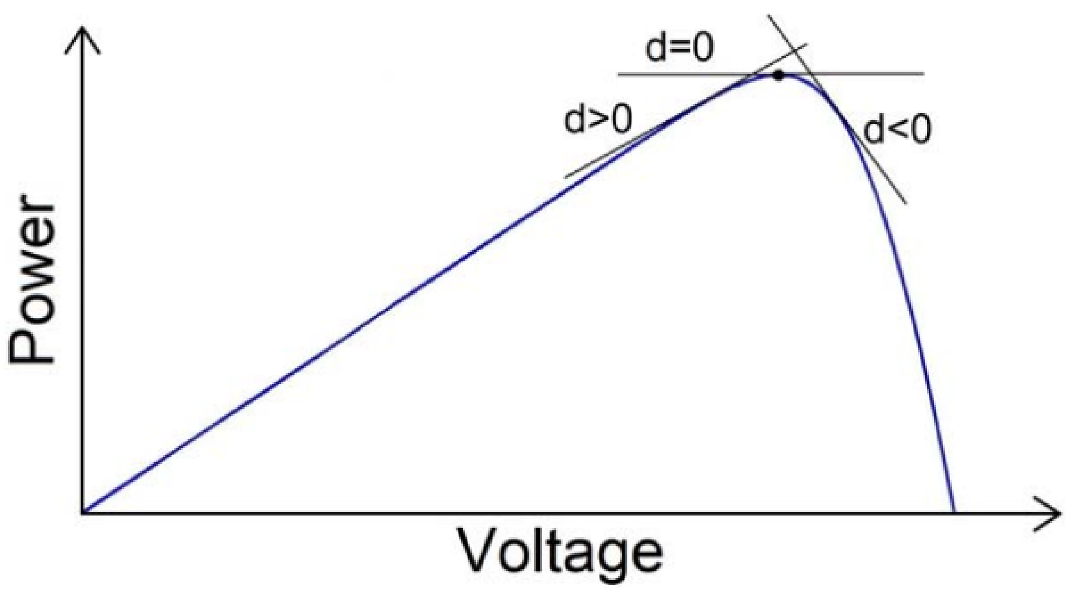

Figure 4: Power curve with its derivative

To reach this point, the algorithm analyzes if the derivative is positive or negative. If it is positive, the duty cycle is increased until the derivative reaches zero. If the derivative is negative, the duty cycle is decreased until the derivative reaches zero.

There are a few safety limits built into the algorithm. The amount of power made by the solar panel can not exceed the voltage or current limits for charging the battery. As such if these limitations are reached, the algorithm will keep the duty cycle at that point, and will no longer search for the maximum power point.

Results

I was able to deliver a working basic prototype of the system. The system was assembled using breadboards and jumper wires. A picture of the prototype found in Figure 4. The system was successfully able to charge a device, as I used it to charge my phone from 70% to 100%. The system was also able to charge itself with the solar panel, producing roughly 5.2 W in my initial testing.

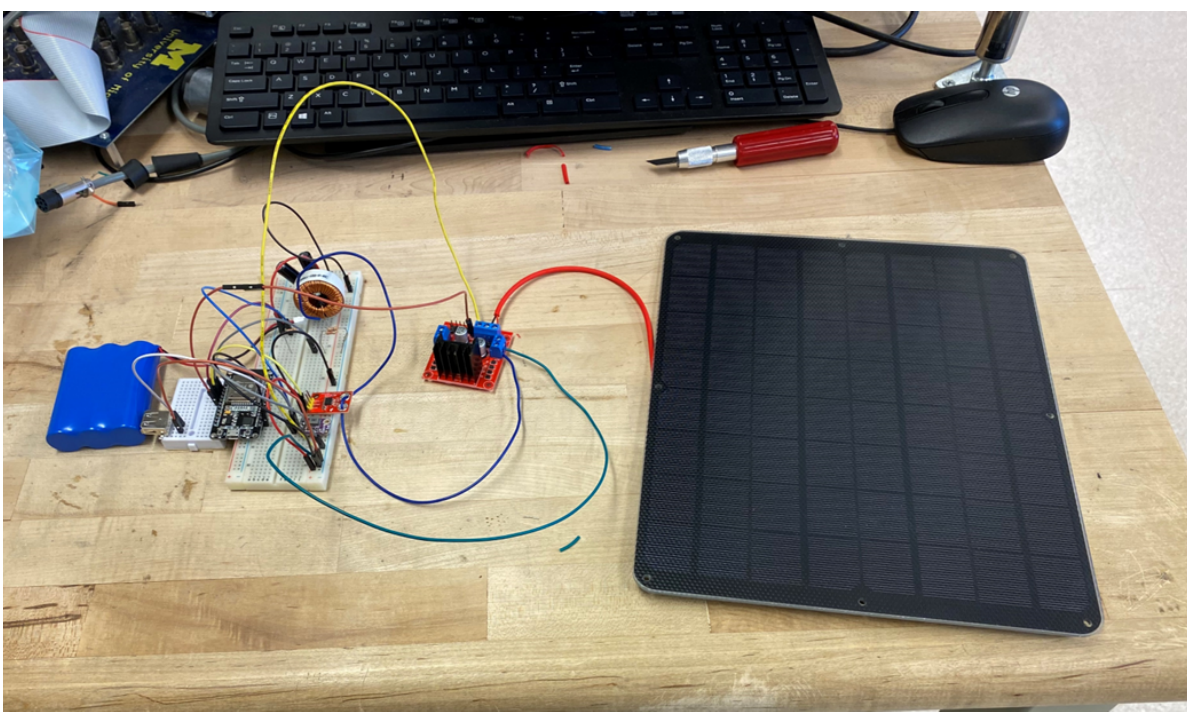

Figure 5: Prototype of the Solar Powered Mobile Charger

Future Improvements

There are a few areas in which this project could be improved. First, the system hardware can be optimized. Off the shelf components and breadboards were chosen due to the time restraint of this project: being designed, assembled, and tested over the course of 3 months as a full time college student. This allowed for known reliability, as well as ease of assembly and testing of the system. The downsides of this choice were that the components weren't optimized for the project needs. For example, the half bridge board had two half bridges, as well as some other circuitry that I never used. It was also rated for almost triple the power of the solar panel. Were I to design and optimize the hardware myself, a custom PCB with only the hardware the project needed, with specifications optimized for the project, would significantly reduce area. This would also improve the system efficiency, as the breadboard connections tend to be high impedance, resulting in a lot of losses due to heat. PCB connections have far less impedance, which would decrease the amount of system losses.

Another improvement would be designing packaging for the system. The prototype, while functional, could not be used in a real life scenario. None of the connections are secure, the electronics are unprotected, and the design takes up too much space. With the custom PCB mentioned above, creating a high durability package for the system would allow a user to use this system as intended anywhere.

Currently, there is no way to charge the power bank other than the solar panel. Adding a way for the system to charge conventionally would greatly increase the usability of the system.

The final improvement I would like to mention would be to integrate some physical controls for the user to increase the performance of the system. The prototype continually outputs power and takes in power through the solar panel, there is no way to shut it off without disconnecting the supply pin to the ESP32 microcontroller. Adding a switch to turn off the microcontroller when the user doesn't want it to be on, as well as adding a switch to the power output in case the user just wants to charge the power bank, would be great improvements in the usability in the system.

Conclusion

This project was a fantastic learning experience. I was able to learn about a variety of topics. From making the MPPT algorithm I learned about control systems. From the MPPT converter I learned about the design of DC DC converters. I learned about the operation of USB. I learned a great deal about system design through the entire project. This knowledge will be very useful as I start my career and work on personal projects.

Sources

Figure 1: *MPPT Solar Charge Controllers Explained — Clean Energy Reviews*. (2022, October 12). MPPT Solar Charge Controllers Explained &Mdash; Clean Energy Reviews. https://www.cleanenergyreviews.info/blog/mppt-solar-charge-controllers

Figure 4: H. S. Moreira, M. V. Gomes dos Reis, L. S. de Araujo, T. Perpetuo e Oliveira and M. G. Villalva, "An experimental comparative study of perturb and observe and incremental conductance MPPT techniques for two-stage photovoltaic inverter," 2017 Brazilian Power Electronics Conference (COBEP), Juiz de Fora, Brazil, 2017, pp. 1-6, doi: 10.1109/COBEP.2017.8257370.