UniverSOL Charge Station

The Smart Solar Powered Cell Phone Charging Station

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1.0 Executive Summary

Cherished memories are important to every human on the planet. People are always looking for the best ways to remember the good days they had and the people they shared them with. Today's advances in technology have made this so much easier than ever before. Smartphones are now equipped with cameras with megapixels comparable to leading digital cameras on the market. They have internet that can surf the web at speeds just as fast as they can surf on their home computer. However, as more features are developed for smart phones, much more energy is needed to power them. In an app driven society, it is almost impossible to freely use all of the features of your phone without monitoring your battery levels. People are constantly surfing the web, updating their status on their social media, watching videos, and taking tons of pictures to digitally capture every moment of their lives. Since about one out of every five people on this planet own a smartphone, there is a ubiquitous demand for energy across the globe.

Many people can testify that there isn't anything worse than being in a special place surrounded by your best friends or family, and wanting to take a picture but your phone is dead. Our project is designed to help people avoid this situation and help them continue to have those memories recorded and shared with their friends. We have invented a secure, solar powered charging station that can be placed within almost any establishment. Therefore, people can have the convenience of leaving their phones to be recharged and picked up later with a full battery.

Due to the advancements in technology, we are now aware of the devastating effects that burning fossil fuels to produce energy has on our precious planet. So not only is there an incredibly high demand for energy, but there is also a demand for cleaner, alternative, and sustainable energy. Our design utilizes solar power to help meet these demands with zero carbon emissions. However, one of the biggest challenges for harnessing solar power is converting it into electrical energy efficiently. Due to a combination of natural conditions, a great amount of energy is lost within the system during its energy transfer. As a result, we've designed our solar powered charging station with advanced technology that can harness the sun's energy and charge cell phones at optimal efficiency. Plus, it's free to all of its users. The convenience of having a free charging station will bring in many customers for many businesses, and companies can easily gain revenue on this product by selling advertising slots.

The ultimate goal of our product was to not only supply an alternative and sustainable way to charge cell phones with renewable energy, but to build awareness of healthy environment practices. Phones will be automatically locked and unable to be retrieved by anyone other than the one who puts their phone in the charging compartment. Parents can leave their phones charging in the charging box and then be able to go on a ride with their kids and get their fully charged phone back after the ride to take pictures and share their day with all of their friends on their favorite social network website.

This device doesn't only give someone more alternative choices in energy to charge their phones, but it also serves as a promotional booth that attracts heavy traffic for businesses. With more battery level there is more of an option for people to share their pictures on their social media. It is cost effective and it utilizes renewable energy efficiently, as well as serving as a greener energy alternative by emitting zero carbon emissions. Therefore, this invention is a win economically, socially, and environmentally.

Several established standards are applicable to the the design and development of the UniverSOL Charge Station. Related standards that are relative to the design of this project are listed in Fig. 1.0 – 1.

Standards	Description
IEEE SA 1526-2003	Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems
IEEE SA 1013-2000	Recommended Practice for Sizing Lead-Acid Batteries for Photovoltaic Systems
IEC 61724	Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis
IEC 62093	Balance-of-System Components for photovoltaic systems – Design qualification natural environments
IEEE 1374-1998	Guide for Terrestrial Photovoltaic Power System Safety
IEC 60194	Printed board design, manufacture and assembly

IEEE 1562-2007	Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems
IEEE Std 1361-2003	Guide for Selection, Charging, Test, and Evaluation of Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems

2.0 Project Description

In this section, the team will detail our motivation and goals for the senior design project. Objectives and goals will be discussed, as well as the project's specifications and function requirements.

2.1 Project Motivation and Goals

During our first meeting as a team, each of us was looking about the room for outlets to plug in our tablets, laptops, and cell phones. One team member was waiting on a phone call and had high priority of changing the cell phone battery. We began to discuss how dependent we have become on cell phones since their humble beginnings in Manhattan in April of 1973 when the first cell phone call was made.

An entire industry has built up around the cell phones, making them more than a phone. They are portable hand-held rechargeable computers that can do practically everything a home computer can do, and more: take pictures, GPS, and phones calls, of course.

Each year more of society is demanding more from their cell phones. As cell phones do more, and more people are taking them more places, people need public areas where they can safely and quickly recharge their cell phone. People have emergency battery backup power supplies and car chargers to provide some quick, short-term power to their phones.

The team agreed people would like a solution to provide a fast, full-battery charge when they do not have access to their charging cables and plugs. Providing this service in a public place, where the cell phone can safely, securely, and quickly charge would be a good project. If we can use a clean, renewable energy, such as solar power, and have it be at no cost to the user, it would be a great project. The team decided upon the name, "UniverSOL," because it will be a UNIVERsal charger station for all cell phones, powered by SOLar energy, and can be used anywhere where solar power can be harvested and converted into chargeable energy for cell phone batteries, such as fairs, picnics, family reunions, concerts, festivals, football and baseball games, or a meeting room for college students discussing the senior design project. Therefore, the team agreed upon the name of the project as UniverSOL.

The team's main goals of the project are:

- Create a cell phone charging station
- That is fast
- Available to all current cell phones in use
- Using Solar Power as the energy source
- At no-cost to the users

- Providing data and information on the amount of solar energy used
- Amount electricity that would have been used
- Inform users of how using solar power in everyday applications cleans up the environment and saves the user money
- Provide practical examples users can do at home

2.2 Objectives

For the team to determine if we are successful with the goals we agreed upon, we came up with specific objectives that must be met. The UniverSOL entails the following objectives:

Efficient Solar Power Collection: The solar panel used will collect enough solar energy to power the UniverSOL for three 10-hour days without a recharge.
Seamless Energy Conversion: The solar power battery cell must be able to provide the needed amperage required to power the touch screen without dimming the amperage needed to quickly charge the users' cell phone batteries.
Touch Screen Programs: User-friendly touch screen leading the user through the charging process, as providing data on the solar energy usage using the "Green Chart" program.
Cell Phone Recognition: Recognize the cell phone battery requirements, with the goal to charge each cell phone according to the OEM specs.
OEM Battery Charging Goals: Have the UniverSOLs charging capacity reach the OEM maximum efficiency for charging each cell phone battery.
Solar Power Awareness: Using the UniverSOL as a learning opportunity for the users to know about ways to incorporate clean solar energy into their daily energy needs.

The team hopes that building the solar powered UniverSOL within Florida, the Sunshine State, will bring awareness of the ease and availability to use solar power and protect the environment.

2.3 Project Specifications and Requirements

After discussing the goals and objectives for the UniverSOL senior design project, the team turned to the specifications and requirements in order to build a robust solar-powered cell phone charging station. Below are listed the requirements and the table of design specifications that we will use to while designing the UniverSOL.

UniverSOL Build Requirements

- The solar panel generatd energy and recharges the SLA 12V battery when connected in line to the MPPT charge controller.
- The 12V SLA battery delivers power to the loads
- The switching regulator steps down the voltage and delivers power to smaller electrical components such as th eAtmega328p, Current Sensors, Shift Register and Touch Screen
- Atmeg328p communicates with touchscreen and current sensors and activates 12V solenoid locks and Green and Red LEDs.
- The system runs under 24-hr of Autonomy

1 – Metal/Aluminum Locker (72"H x 12W" x 15D")

6 – Chambers (12”H x 12”W x 15”D)

1 – 4.3” LCD Color Touch Screen

- 1 – Printed Circuit Board (PCB)
-
- 1 – 12V Rechargeable 89Ah Sealed Lead Acid Battery
- 1 – 235W 12V Monocrystalline Solar Panel
- 1 – 12v to 5v Switching Voltage Regulator

- 4 – 12v 650ma Solenoid locks
- 4 – Charge Doctor In-line Current and Voltage Sensors
- 3 – Green and Red LEDs
- 4 – ACS 712 Hall-Effect Based Linear Current Sensors

- 1 – MPPT Charge Controller
- 1 – High Powered 5V USB Charging Hub
- 4 – USB Cables

2.4. Functionality

The UniverSOL is a user-friendly, convenient cell phone charging station. The user touches the green “Start” button on the touch screen, and is notified of an available charging locker. The user inputs a PIN on the touch screen, re-enters the PIN, and that unlocks the available charging locker. The login starts the ATMega328P and runs through a validation code creating a secure user account. The user connects the cell phone to the correct cell phone plug. The connection completes the circuit, and the microcontroller notifies the LED identifying sequence of the change, turning the LED to red for charging. When the charge is complete, the LED activation sequence turns to green, indicating to the user the cell phone is completely charged. During the entire charging time, the charging locker is locked for security. The locker is unlocked when the user properly enters in the correct charging locker number and PIN.

3.0 Research Related to Project Definition

3.1 Existing Charging Stations

To understand fully the scope in designing a solar-powered cell phone battery charging station, we began with the current cell phone charging station technology, along with the current solar power technology, as well as current cell phone charging requirements. In the process of investigation, the team looked at where future technology is headed, so we could determine if this would be feasible and applicable in the UniverSOL design, and a demand and need of the users of the UniverSOL in the near future.

3.1.1 Solar Powered Cell Phone Charging Stations

In all of our investigation, the team found two instances of a solar powered cell charging stations. Both are completely different.

3.1.1.1 goCharge, the Eagle

The company is goCharge, and the model is called the Eagle. It can be solar or not. However, the design is on the biggest we have seen, with 48 charging lockers. The canopy also supports the solar panels, and the Eagle is equipped with 32” HD display for advertising. The solar panels would sustain the multiple charging plus the display. The Eagle also weights 600lbs. So once it is set up, it is mostly likely not moving.

3.1.1.2 Occupy Wall Street, Zuccotti Park

The second was created during the 2012 Occupy Wall Street protest. A Florida Institute of Technology graduate student designed a solar power cell phone charging station. The battery was large enough to last 7 days between charges, which is important in areas of low sunlight, like New York City. The design resembled the charging pole stations in airports, with numerous plugs to charge various devices, including phones. It also had the same problems as the charging poles: if the port you needed was taken, you had to wait, and no security of your device. The charging station had a large white metal box on the ground housing the battery, with two 8 foot long pieces of conduit sticking up the back, supporting the charging ports and the solar panel. The design, though not pretty, worked well enough to make a story in the New York Times

3.1.2 Customary Charging Stations

There are many companies who provide cell phone charging, but most are not free. The ones that are free seem to be very basic in design, with only a Plexiglas door protecting the electronic device, or ports sitting on poles or tables in the open air. The companies that do charge a fee for service have locking doors, some with windows, LED lighting, and fast charging times. Three we investigated are in the table below, and listed are the facets of each that we considered for the design.

Existing Company	Pros	Cons	Takeaways
GoCharge www.gocharge.com	- Various styles, but we looked specifically at "Hawker" - Locker door window - 6 universally compatible compartments - Easy to use - Portable	- Charges users - No keyed locks - Charge card locks and unlocks - No LED in each locker, - Unable to tell Status of Charge	**- Vertical lockers** **- Universal compatibility** **- Locker, window door** **- Not Solar** **- No LED** **- Charges money**
ChargeBox www.chargebox.com	- Large screen for advertising - Keyed lock - Free to the user - Easy to use - Location app to find nearest box	- Each cell supports a single brand of cell phone - Only 30 mins of charge - No windows	**- Vertical lockers** **- Free to user** **- Locations app** **- NOT Solar** **- NO Door Window** **-30 min limit** **- NOT Universal**
ChargeCube www.chargecube.us	- Free to use - 98% of current technology - 17inch for ads - Locked door window - Keyed lock	- Not solar - No LED light in each cell - Unable to tell SOC	*** Vertical lockers** ***Free to use** *** Almost universal compatibility** *** Window doors** ***NO LED**

Table 3.1.2-1 Current Cell Phone Charging Technology Companies

3.2 Alternative, Sustainable, and Renewable Energy

As the renewable energy industry continues to grow annually, the possibilities of preserving a healthier planet through alternative energy is becoming more of a reality. Harnessing energy from the earth's natural resources such as sunlight, wind, and water is a smarter and significantly healthier method of providing energy as opposed to fossil fuels. Solar, wind farms, and hydropower plants are becoming ubiquitous throughout many regions of the world as renewable energy becomes more of a mainstream topic. As a result of these renewable energy systems, power has successfully been provided to a large number of homes and businesses. Implementing a cleaner approach to providing energy is critical to our planets health as well as individual health. Therefore, one of the driving factors of our design was to power our system solely from renewable and sustainable energy. Fortunately, this eliminates many of the hazardous effects that the combustion of fossil fuels would have on the environment, such as carbon emissions. Although the earth's atmosphere has seen a gradual decrease in Carbon dioxide (CO_2) emissions when using renewable energy systems rather than fossil fuels, it only accounts for a minor difference. It is difficult to control CO_2 emissions simply because there are so many important industries that rely on the combustion of fossil fuels. Generating electricity, transportation and industry practices all rely on the combustion of fossil fuels. Figure 3.2-1 is a bar graph which shows a breakdown of the main sources which contribute the most CO_2 emissions in the U.S.

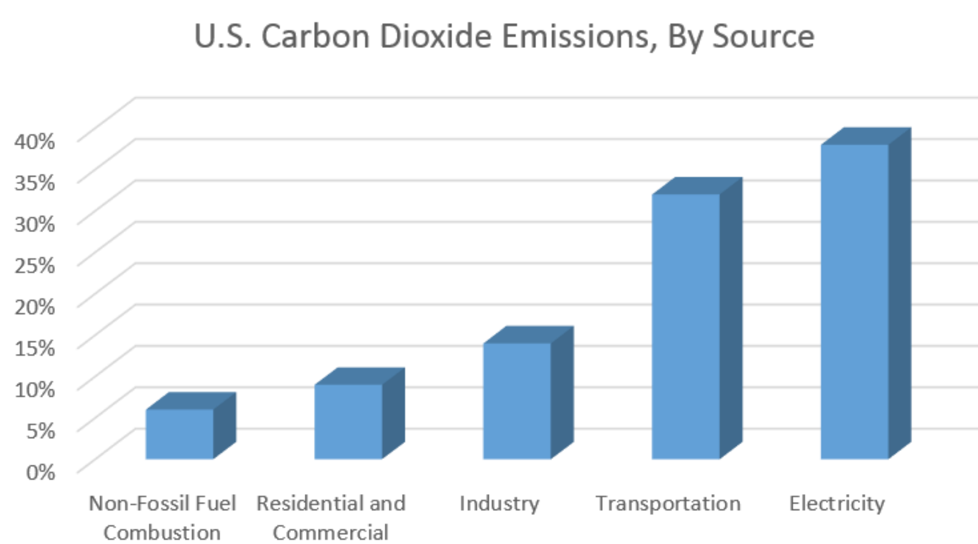


Figure 3.2-1

A breakdown of the greenhouse gas emissions in the U.S. for Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O) is shown in figure 3.2-2. These gases are the main constituents of climate change on Earth. Unfortunately, the chart clearly indicates that carbon dioxide is the most harmful gas which contributes to over four times the emissions than that of all of the other greenhouse gases combined.

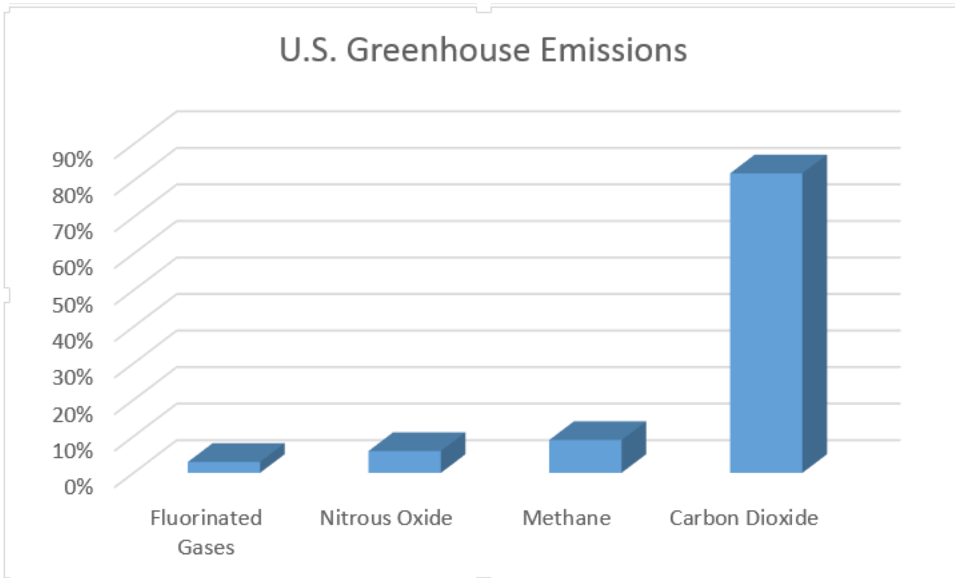


Figure 3.2.-2

With electricity being the biggest contributor to CO_2 emissions, The UniverSOL charging station is helping to meet some of the energy demands by providing power to charge four cell phones simultaneously through a sustainable photovoltaic system. While eliminating carbon emissions to our atmosphere, it will also help to bring awareness of the positive effects that renewable energy systems has on the environment.

There is an incredible demand for energy across the globe which has been increasing exponentially ever since the introduction of mobile devices. The daily consumption of energy for the average human being today is significantly higher than that of the average person's energy consumption thirty years ago. Today, it is obvious to see that an incredible amount of power is needed to drive an economy efficiently. From Automobiles and Airplanes to laptops and cell phones, every aspect our lives relies on energy. Therefore, it is imperative that an alternative approach to produce cleaner energy is used to replace fossil fuels so we can preserve what remains of our precious planet.

A realization of healthier energy choices that are cost effective has become common knowledge between the general public. Alternative approaches to supplying energy are no longer too expensive such that only commercial properties can afford them, but are now practical enough to be implemented in almost any family home. Some renewable energy systems are designed to specifically power individual components, furthermore, increasing the flexibility of the system. For instance, a wind turbine in the backyard of a home in Texas may be used to solely power a refrigerator, while solar panels on the roof of a Florida home may be used to supply the power to operate the pool only. Although expandable, these energy systems are specifically designed for a single application, and that is to supply a certain amount of power to a specific load. Minimal requirements allow for simplicity which helps to increase the overall efficiency of the system. The UniverSOL Charging Station was specifically designed to harness the sun's energy and efficiently supply power to a specific load of charging cell phones. Using cleaner power alternatives to power smaller devices, such as electronics, is critical to the success of a future moving away from fossil fuels. Implementing renewable energy systems on a smaller scale will help deviate from the reliability on fossil fuels and make the transition to a full alternative, renewable energy system less complex.

3.3 Solar Energy

The sun is an infinite energy source that is a powerful entity to sustaining life on our planet. However, it only accounts for roughly 4% of the world's electricity. The natural sunlight which lights up the day is converted into electrical energy to power the lives of thousands. This conversion can be done through either a solar thermal process or by using a photovoltaic system. Solar thermal power plants use the sun's energy as a heat source to create steam that drives turbines supplying energy to thousands of homes. Thermal insulated tanks are used to store energy when there is little light available, typically during the evening or when experiencing bad weather. Photovoltaic systems, on the other hand, use a much different method. These systems are generally made up of silicon which undergo the photovoltaic effect through semiconductor physics converting light into electricity. A battery is typically used in these systems as the energy storage device that makes up for intermittency during the evening or bad weather.

The amount of energy supplied by the sun in a day is sufficient enough to meet the global energy demands for one year. Capable of giving off 1000kWh/m^2, it is a viable solution to fossil fuels. Although it is an industry that is slowly growing, it is making a powerful impact and influencing many to harness free energy from the sun to power their own needs. Geographic and weather constraints are two major conditions which have to be considered before building any renewable energy system. There are particular regions that are desired for their high solar temperatures to maximize the amount of power that can be harnessed from the sun. Considering these conditions, it was obvious that Florida was an ideal location for harnessing energy from the sun. Figure 3.3-1 shows the United States' irradiance levels with the Southwest region leading in generating over 6.5kWh/m^2/Day Florida having great potential in generating 5 to 6kWh/m^2/Day.

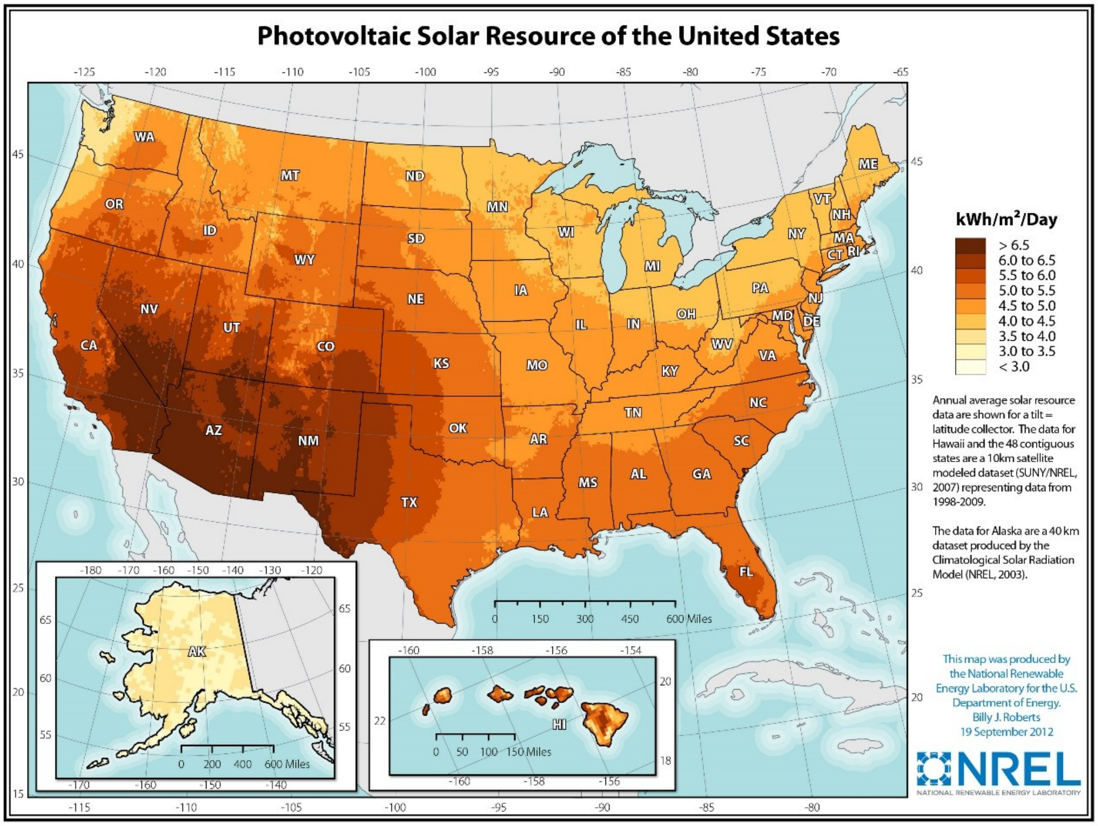


Figure 3.3-1 Photovoltaic Solar Resource of the United States Map

This solar map was created by the National Renewable Energy Laboratory for the U.S. Department of Energy

After evaluating geography and weather conditions, solar energy was clearly the best renewable energy resource for our project. There is an abundance of sunlight and clear skies in Florida that is ideal for any photovoltaic system. For the purposes of our design, the sun would be solely capable of providing the necessary power to operate the system. The system will utilize the sun's energy through a solar PV panel to convert into electrical current to charge a 12V lead-acid battery that will supply power to the necessary components of the system. Seasons come and go and clear and sunny skies don't stick around forever, therefore the battery will serve as an energy storage device that will supply power to the system when there is little or no sunlight available.

3.3.1 Photovoltaics

For the purposes of our design, a photovoltaic (PV) system will be used as opposed to a solar thermal system since we are operating under lower power requirements and maintaining a constant DC power to the loads. This requirement is ideal when functioning under a PV system's parameters as it can operate efficiently while having no moving parts. The UniverSOL Charging Station is a specific application which is designed off the basis of semiconductor device physics and the photovoltaic effect. Harnessing energy from sunlight and directly converting it into DC electricity is an excellent alternative to supplying renewable and sustainable energy as opposed to fossil fuels as it emits zero carbon emissions. Therefore, it was extremely important to understand these concepts completely in order to assure that a system in which can operate at optimal efficiency will be designed.

Silicon (Si) and Germanium (Ge), are two elements that share some of the properties of a conductor and an insulator which makes them ideal for solar cells. Although there are some applications in which Ge is a desired semiconductor element, Si is the most used because of its abundance and cost effectiveness. As the leading material of all solar cells, silicon solar panels were used for about 75% of all of the installations in 2011. Although silicon is the most abundant material, it is not the reason why it is the most used element for making solar cells. The reason it used more than other materials is because of our ability to make increasingly good silicon devices. However, in order to produce the photovoltaic effect, the Silicon must undergo an extreme purification process. As a result, such pure "semiconductor grade" silicon is very expensive to produce. It is also in high demand in the electronics industry because it is the base material for computer chips and other devices. Crystalline solar cells are about the thickness of a human fingernail. They use a relatively large amount of silicon. Almost perfect crystal lattices of silicon are grown through mass production today. This generally makes them easily obtainable as well as inexpensive, therefore, for the purposes of this project, we will use a solar panel with solar cells made from silicon.

PV systems are normally made up of PV cells that can convert sunlight directly into electricity. PV cells are made up of layers, an n-type layer which is negatively charged and has excess electrons, and a p-type which is positively charged and has excess holes. When both layers are joined together they create a p-n junction which causes the charges to experience a force. This force causes the charges to move and creates a buildup of electrons on the p-type side and holes on the n-type side and induces an electric field at the junction. When photons emitted from the sun come into contact with the PV cell, electrons are excited and move from the valence band to the conduction band creating a current through a flow of electrons. This electric current occurs within the depletion region which is the region around the p-n junction where electrons have diffused over to the p-type side. The applied electric field than drives the current to the load.

3.3.2 Solar Cells and Panels

The option of designing a solar panel as opposed to purchasing one arises. The parts are obtainable, and there are also kits that are readily available. However, considering the cost, labor, and time constraints, it is wiser to purchase a solar panel. Although the solar panel is supplying the power to charge the battery in the system, designing them doesn't define the purpose of the project. Our objective is to evaluate the different types of technologies and styles of solar panels available on the market, compare specifications to our requirements, and determine which solar panel most efficiently meets the requirements of our design. A side by side comparison between different types as well as a design specification requirement check-off will be conducted before making a final decision.

Since PV cells are the heart of all solar panel systems, different factors must be considered before selecting the correct solar panel to supply the power for our project. For instance, while one side will focus on the technical aspect, such as the power specifications, and operating temperatures, the other side will examine the cost, dimensions, and weight to meet the requirements of our design. As a result of the sun only having a finite window of time to generate usable sunlight, the speed in which the battery charges is a significant factor that must considered. The ultimate goal of the group is to build an optimally efficient and self-sustainable system, therefore solar cell efficiency is of top priority and will be one of the leading factors in determining the proper solar panel for the project. The efficiency of a solar panel tells us how much of the sunlight is being converted into electrical energy. In the following equation:

$$\epsilon(efficiency)=\frac{Pm}{E*A}$$

The energy conversion efficiency equation is shown and can be used to calculate the efficiency of a solar panel. The efficiency of a solar panel is simply the ratio of the maximum power point output (Pm) to the product of the input light (E) and the surface area (A). For the purposes of our design, we will obtain solar panels with the efficiency ratings already calculated and specified.Figure

PV System efficiency has been increasing over time for all types of solar cell technologies. A line graph of the efficiencies of the three major solar cell technologies over time is shown in figure 3.3-2.

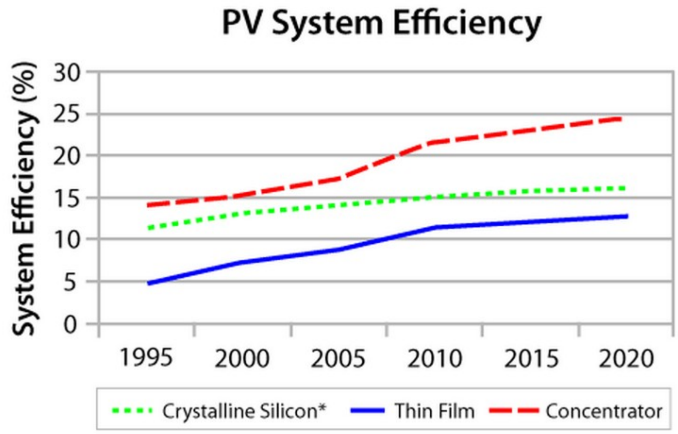


Figure 3.3-2 PV System Efficiency vs Time Graph from1995 – 2020 -Printed with Permission from the Office of Energy Efficiency & Renewable Energy

Considering Crystalline Silicon and Thin Film technology, it is clear to see that although Crystalline Silicon has been consistently dominating Thin Films over time, they are both approaching the same efficiency values in the near future. A comparison of the efficiencies was researched between three of the major materials used to make solar cells, Monocrystalline (also called single-crystal), Polycrystalline, and Thin-Film Technologies, and although monocrystalline was more expensive, it was clearly the most efficient at around 25%, as seen in Figure 3.3-3.

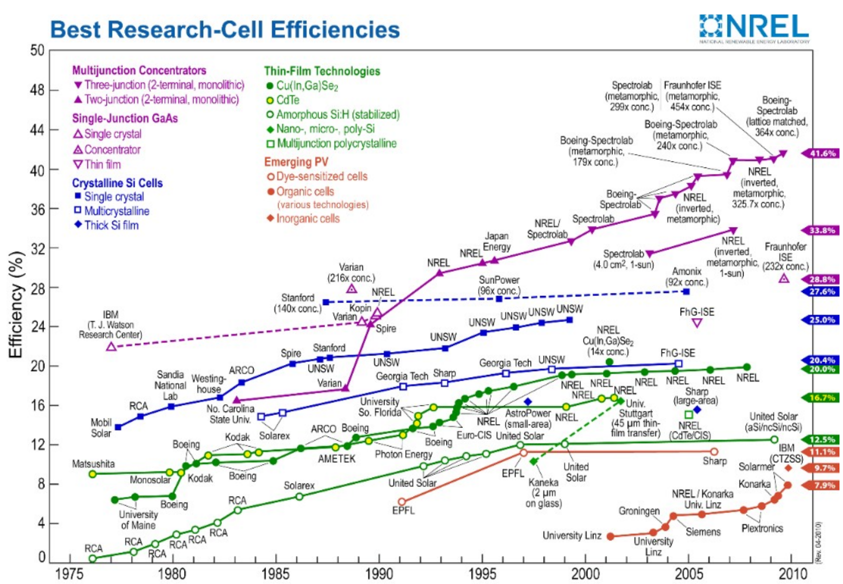


Figure 3.3-3 PV Cell Efficiency vs. Time plot

Printed with Permission form the National Renewable Energy Laboratory for the U.S. Department of Energy

A measurement of the quality of a solar cell can be obtained by using the Fill Factor (FF) approach. By finding the ratio of the maximum power (Pmax), which is simply the product of the voltage (Vmp) and current (Imp) at the maximum power point, to the theoretical output power (Pt), which is the product of the short circuit current (Isc) and the open circuit voltage (Voc), as seen in the following equation.

$$FF = \frac{Pmax}{Pt} = \frac{Imp * Vmp}{Isc * Voc}$$

The greater the fill factor then the better the quality of the cell.

Typically PV cells are rated at about a 0.5 DC Voltage and produce under 3 Watts of power, therefore to accommodate for higher power applications they have to be arranged in a either a series or parallel array to maximize the power delivered to the output. This is essentially the basis on how PV solar panels are designed to supply more power to the load. In addition, due to the typical small manufacturing sizes of PV cells, they have to be configured in arrays to produce more power. However, a tradeoff presents itself when switching topologies from a series to a parallel configuration. A series configuration of the cells would increase the output voltage, while a parallel connection would increase the current.

There are several types of solar panels available on the market made up of different materials, each with individual power and efficiency ratings. Crystalline Silicon cells are a main trend with Monocrystalline, and Polycrystalline as two of the major types found in PV cells, along with Thin-Films technology as being the third. Due to the longevity and successful history of silicon based solar cells, it has grown in reliability and popularity. Crystalline Silicon cells roughly make up 90% of the international solar cell market. Monocrystalline and Polycrystalline cells are made by slicing a block of silicon into wafers and doping the surface to create a p-n junction. A common material used in making mono-crystalline thin film panels is gallium arsenide (GaAs). Some materials used to create polycrystalline thin film panels are cadmium telluride (CdTe), amorphous silicon (A-Si), and copper indium gallium selenide (CIGS).

3.3.2.1 Monocrystalline Cells

Monocrystalline Cells are the oldest of all PV technology and still currently the most practical and efficient material used for solar cells. The single cell method is efficient due to having the entire cell aligned in only one direction. This maximizes the current generated when incident light is shining brightly in the correct angle. As a result, these are better conditions for generating electricity during low sun light conditions. This is extremely useful for the UniverSOL charging station because we will not be utilizing a solar tracking device in our system, therefore we will need to maximize the amount of wattage generated by each cell. Although monocrystalline cells are more difficult to manufacture, the cost balances out with the potential savings from producing power. With an average efficiency rating of roughly 17%, monocrystalline surpasses polycrystalline and thin-films which only have an average efficiency rating of roughly 11% - 14%. A higher efficiency rating translates to more power per square inch, as seen in equation [1] where the efficiency (ϵ) would increase as the Area (A) decreased. This means that with monocrystalline solar panels, we can get a high efficiency rating with a smaller panel than with polycrystalline solar panels. The physical dimensions of the solar panel play a significant role in the overall design of our project. A smaller size would help to bring symmetry to the design when centered above the unit and due to their long life and durability, manufacturers normally offer a 25 year warranty with each unit. Monocrystalline cells are also more attractive in many cases as they tend to have more of a uniform, sleek, black design to them as seen in Figure 3.3-4 where the three silicon based solar panels are being considered.

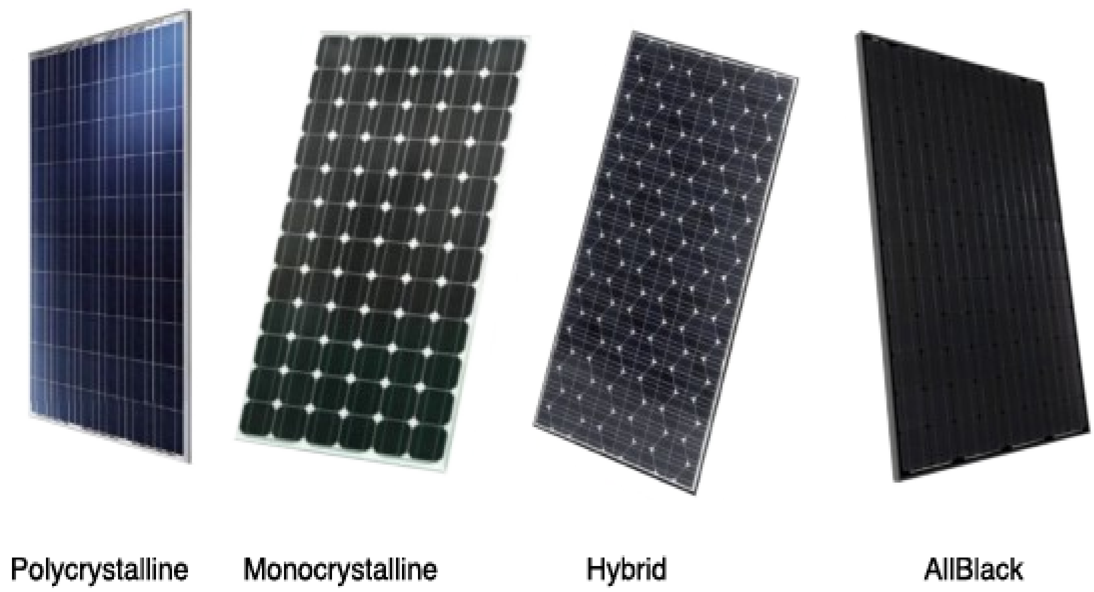


Figure 3.3-4 Solar panels currently available on the market

Printed with Permission from C-Changes

3.3.2.2 Polycrystalline Cells

Polycrystalline Cells made an entrance into the PV solar cell industry about 30 years after Monocrystalline and is also a silicon based cell. As the prefix of the name suggests, polycrystalline cells are made up of multiple crystals, by undergoing a process of melting and pouring silicon into a mold which gives the panel more of a dark bluish hue to its appearance, as seen in Image 3.3.2.e. However, there are some inconsistencies in the blue cells throughout the panel unlike monocrystalline panels which have a deep black consistency throughout their panel. This configuration, however causes there to be less wattage generated per square inch, hence the lower overall efficiency rating. Polycrystalline cells are less expensive to manufacture and are ideal for some cases, especially when used for projects covering a large amount of area. Due to having a lower heat tolerance, polycrystalline solar panels are not suitable for high temperatures. This proposes a problem because the project is being built and tested in Central Florida where, although there is an abundance of sunlight, the temperature is constantly over 90 degrees Fahrenheit. Generally desired for larger PV systems, polycrystalline systems are sometimes used more for residential and commercial purposes. It is difficult to get an accurate comparison between manufacturer's polycrystalline based solar panels because of the 11% - 14% range that the efficiency rating had. As shown in Figure 3.3-5, Monocrystalline panels seem to meet our project's requirements more than polycrystalline.

	Monocrystalline Solar Panel	**Polycrystalline Solar Panel**
Efficiency	About 17%	11% - 14%
Power generated per (ft^2)	More	Less
Aesthetics	Consistent Deep Black Design	Inconsistent Blue Cell Design
Temperature Tolerance	Higher	Lower
Cost	Higher	Lower

Figure 3.3-5 Monocrystalline and Polycrystalline Project Requirement Solar Panel Comparison Chart

3.3.2.3 Hybrid Photovoltaic Cells

Another type of technology being developed and tested today is the Hybrid photovoltaic cell. This cell uses two different types of PV technology. The Hybrid PV cell is a mixture of a mono-crystalline PV cell covered by an ultra-thin amorphous silicon PV layer. The advantages of these types of cells are that they perform well at high temperatures and maintain higher efficiencies roughly between 18% - 22%. However, these cells are much more expensive than others. Therefore, in order to remain within our budget, Hybrid PV solar panels will not be used for this project.

3.3.2.4 Thin Film Technologies

As a newer technology than its Silicon based counterparts, thin film technology is great for efficiently using raw materials to produce PV modules. A very small amount of semiconductor can be used to make each individual module, instead of a silicon wafer. This is achieved by depositing a thin layer of some PV material onto a substrate typically used when designing semiconductors like metal, glass, or plastic. Each material is associated with its individual specifications and efficiency ratings. Thin film technologies also have an efficient manufacturing process, low carbon footprint, fast energy payback time, better performance under high temperatures, and reduced sensitivity to overheating. Due to the thin film being sandwiched between two glass panels, it may be heavier than necessary for most applications. However, there is a laminate that can be applied to the solar panel in place of the glass that decreases the weight, adds flexibility, which makes it ideal to install under unleveled surfaces. One of the advantages that thin film technologies has over silicon based solar panels is that it will continue to operate with minor performance loss when a thin film is damaged. Unlike silicon solar panels which become inoperable once a cell is damaged. There are several technologies used for producing thin film solar cells like Copper Indium Gallium Selenide (CIGS), Cadmium Telluride (CdTe), and Gallium Arsenide (GaAs) which are three of the most popular. Unfortunately, thin films have a terribly low efficiency range at about 4% - 7%. Although it is an improving industry and the cost has declined more rapidly than crystalline silicon, as seen in Figure 3.3-6, its low efficiency causes it to come in behind silicon based solar panels.

3.3.3 Photovoltaics Efficiency and Cost Projections

Due to advances in manufacturing and technology, photovoltaic systems cost have gradually decreased with time, and is projected to continue to decrease slightly into the near future. Although trailing behind hydro and wind power in renewable energy supplier standings, solar PV is a growing industry that has been steadily improving and becoming more affordable. The PV System Capital Cost between 1995 and 2020 for three of the major PV system materials is steadily decreasing as time progresses as seen in figure 3.3-6.

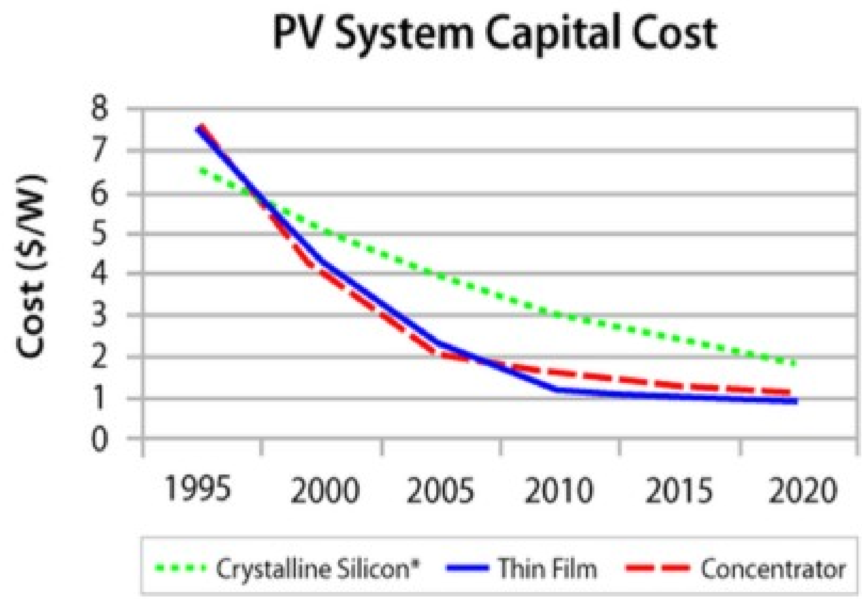


Figure 3.3-6 PV System Capital Cost Chart from 1995 – 2020 - Printed with Permission form the National Renewable Energy Laboratory for the U.S. Department of Energy

3.4 Maximizing Solar Power Efficiency

Solar panel rating efficiencies are categorically low to begin with. These rating efficiencies measure what percentage of sunlight actually hitting a panel gets converted into electricity. Based on research done by Dr. Steve Byrnes of Harvard University, the maximum achievable efficiency in affordable panels is approximately 20%. Therefore, these systems have already lost a substantial amount of efficiency known as irradiation loss. Irradiation loss can be a result of a number of factors including shading, reflection, and inaccuracies in power ratings and mainly occur prior to concentration of sunlight by the PV module.

Shading loss can be caused by nearby obstructions to sunlight like trees or telephone poles or distant obstructions like buildings (known as horizon shading). Reflection loss is the lost energy that is not captured by the module based on an angle of incidence and equal and opposite reflection of a percentage of light off of the surface. Figure 3.4-1 demonstrates this below. Finally, the power ratings provided from factory condition settings do not always accurately depict what will actually occur in a real-time setting. In order to pursue a more accurate rating, it is suggested to request a "Photovoltaic USA Test Conditions Rating" (PTC) rating from the manufacturer rather than the provided "Factory Standard Test Conditions" (STC) rating. This real-time setting can have an effect on conversion efficiency within the module when an increase in temperature occurs. A typical factory setting regards "1,000 watts per square meters, 1.5 Air Mass and 77 degrees Fahrenheit cell temperature". The project temperature setting in Florida is known to exceed the temperature standards so it is expected to incur additional power rating loss. To further achieve the actual output of power from the panel, testing should occur and measurements should be taken to realize the actual power rating that is expected from the panel following purchase of the product.

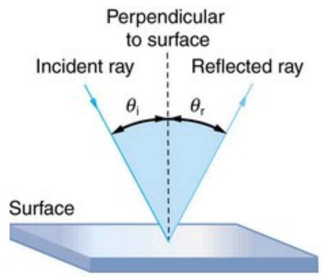


Figure 3.4-1 Angle of Incidence

Permission from Open Stax College

Beyond irradiation losses, losses will occur once the power is output to the system. There will be resistance loss in the cables and wires. If an inverter is required, the inverter efficiency rating and size will further deter the output power. Selection of quality products for these components can assist in maximizing solar efficiency.

While addressing the criteria listed above is essential in the design process to maximize solar power efficiency, the key is to acquire maximum power from the PV system itself. It is recognized that solar panels will not receive the same amount of power throughout the day due to the aforementioned losses, making it impossible for a continuous nominal supply of power. The power delivered from the solar panel will fluctuate throughout the day. For projects with rechargeable battery based systems, where PV systems cannot always deliver the power the battery demands, damage to the lifetime of the batteries is highly likely. A solution to this problem is to implement a charge controller within the system.

3.4.1 Charge Control

The main purpose of a charge controller is to protect the PV system by preventing reverse current flow and inhibiting overcharge to the battery. The solar panel may begin to draw a small amount of current when the voltage drops below the battery voltage. A slight discharge of the battery transpires. This especially happens during overnight periods when there is a lack of energy supplied to the module. Overcharge of the battery occurs when the battery is fully charged, yet the panel continues to supply energy. This normally happens at maximum energy times during the day. Consequently, too high of a voltage is provided for the battery to withstand. In a worst case scenario, the battery can overheat, boil over gasses, and possibly explode. In both cases, damage is done by adding stress to the battery and eventually resulting in stress to the electrical loads.

Most charge controllers block reverse current using one of two methods. The first method is with the implementation of a semiconductor device that only allows current to flow in one direction. The second method involves the use of an electromagnetic coil known as a relay that closes a switch to stop current from flowing back to the module.

Charge controllers regulate the voltage by reducing energy flow to the battery when the voltage reaches a maximum level and by increasing flow when the voltage level drops below the acceptable voltage point. This can especially be effective in the case of a panel with a higher voltage rating matched with a lower rated battery accepting from the solar panel. The controller allows for the voltage to return to a safe level for charging the battery.

The maximum and minimum voltage levels that determine when the controller must adjust the rate of charge are referred to as set points. Depending on the type of battery that is installed, specifications from the manufacturer decide those set points based customarily on 77° F/ 25° C temperature conditions. In addition, most controllers are supplied with a “temperature compensator” to allow for fluctuations in temperature setting. Since batteries require more voltage to charge in low temperatures and lose water in high temperatures, a full charge may not be achieved. This feature adjusts the set point accordingly to those conditions to guarantee as close to a full charge of the battery as possible. For this reason, many charge controllers also come equipped with a temperature sensor. Furthermore, the set points may be factory pre-set or adjustable depending on the product. For this project, adjustable settings are desired.

Another necessary consideration when purchasing a charge controller is the Low Voltage Disconnect (LVD) feature. The LVD feature will protect the battery from over discharge. For this project, the desirable percentage of discharge allowable is 50 percent (refer to Section 3.6.1). Under the circumstances that the battery reaches a point of critically low voltage, the controller will disconnect loads at that set point. When the battery regains the charge that reaches the LVD reset point, the loads will be reconnected. It is recommended that any system with DC loads (UniverSOL Charge Station) should incorporate a charge controller with this feature. In order to handle the DC Load, the controller specifications must meet or exceed the total load (Amps) in current rating. In addition, demands for optimal efficiency for voltage set points, temperature compensation, and LVD may be included in the battery specifications (refer to Section 3.6.1).

Because the controller acts as the intermediary between the PV panel and battery, the most important design parameters to adhere to is based on the product specifications to handle both the maximum current from the solar panel and the maximum voltage of the battery. Matching the specifications of the controller to be as close to the panel current rating (Amps) and battery voltage rating (Volts) will assist in achieving maximum efficiency.

The most basic charge controllers (commonly known as two-stage controllers) can be implemented for a PV system to only control overcharge and discharge. The term “two-stage” is representative of the exclusively on/off charging modes the controller performs. While these types are the least expensive on the market, they are not the most efficient. Over time, these devices have been known to cause batteries to fail earlier than their more progressive counterparts. As the number of charge cycles increase and the system ages, disconnects from the DC load occur more frequently.

However, advancements in charge controller technology provide more sophisticated techniques in power distribution control and monitoring that can further benefit the system for maximum solar power efficiency beyond simple charge control. These charge controllers are classified as three-stage and four-stage controllers and include Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) Controllers. Because optimal efficiency with respect to cost is desired, exploration into these more sophisticated options is necessary.

3.4.2 Pulse Width Modulation Controller

PWM Controllers are algorithm-based and send out short electrical pulses to the battery rather than sending a constant charge. By adjusting the duty cycle of the pulse, the amount of current being delivered to the battery can be managed and regulated providing more protection to the battery based on the demands of the battery in its present state.

When a battery is in a low voltage discharge state, the PWM reads the state of charge (SOC) and introduces a full current into the battery. This phase is referred to as the “bulk” state. As the battery nears full charge capacity, the PWM senses this, and gradually tapers the current down to hold the voltage at a constant rate for a greater duration of pulses. This period is known as the “absorption” stage. When full capacity charge of a battery is reached, the charge mode enters into the “float” stage. A minimal amount of current to maintain optimal charge is delivered to the battery to hold the voltage constant.

Many PWM controllers now come equipped with an optional fourth stage feature for “equalization”. This application is necessary for flooded lead acid batteries which will not be used for this system (refer to Section 3.6.2).

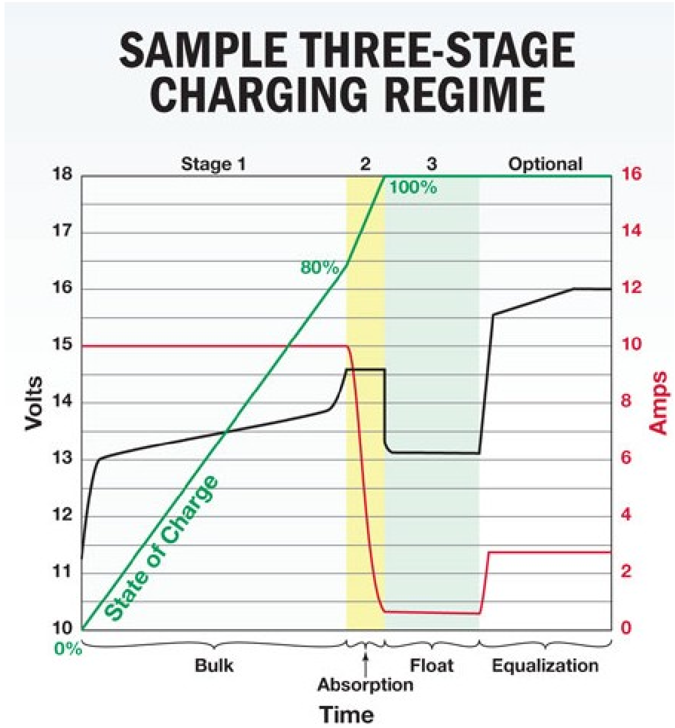


Figure 3.4-3 Sample Three-Stage Charging Regime

Investigation shows that the PWM Controller concentrates on the extension of battery life by protecting it. This type of control is especially beneficial to lead acid batteries because it prevents sulfation which can reduce battery lifetime.

Additional battery protection (verses an on/off charge controller model) of the battery leads to the following advantages:

- Reduction in the cost of the overall system over time because battery replacement and disposal is less frequent
- Increased dependability of the system and battery because of reduced load disconnects
- Possible reduction in the size of the battery and solar panel due to increasing the power delivered to the system at times of need and decreasing energy used during less essential periods
- More environmentally friendly because disposal of batteries are less frequent

3.4.3 Maximum Power Point Tracking Controller

Certain characteristics of solar panels affect the overall power output of the panel. In particular, a solar panel voltage output decreases as the current drawn from the panel increases. When the current drawn exceeds a threshold, the voltage will collapse and power drawn from the panel will drop significantly, becoming very low. When looking at the I-V curve relationships and using the formula P=VI, a point at which the panel outputs the greatest amount of voltage and current to produce the most power, the Maximum Power Point (MPP) can be established:

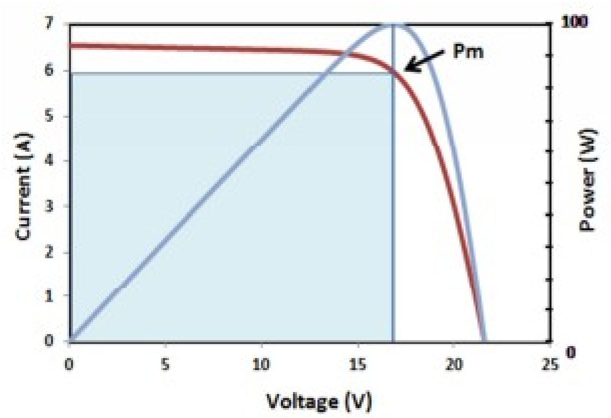


Figure 3.4-4 Maximum Power Point (Pm)

Permission from Victron Energy

In ideal conditions, the panel would produce the power output at MPP at all times. However, practical conditions (refer to Section 3.4.) do not allow for the panel to perform in this way consistently.

Furthermore, the panel produces a lower voltage when not under prime conditions. Therefore, there must be an allowable deviation for voltage so that it does not drop below the battery voltage requirements for optimal charge. For this reason, a panel voltage rating must be sized higher than the voltage rating of the battery. Moreover, manufacturers design the panels while paying respect to specific current and power output accordingly. As a result, a mismatched system is inherent and a loss of power follows.

Example A (similar to the projected project design):

A 130 W rated solar panel from Everbright Solar carries specifications of peak power voltage (Vmp) 17.2 V and peak power current (Imp) 7.56 A and supplies a 12 V battery using a regular charge controller. The output power of the panel, using the equation P=VI, is (17.2 V)(7.56 A) = 130 Watts. Because the panel can only furnish 7.56 A and the battery receives approximately 12 V (at low charge the battery can require 1V+ more), the total power output under peak battery conditions is approximately (12 V)(7.56 A) = 90.7 W. Therefore, only 70% of the power is actually being used verses what the panel is putting out.

Fortunately, current technology provides a solution to these problems. MPPT controllers are designed to collect maximum power from a solar panel at a higher voltage and convert to an equally nominal power adjusted for the lower voltage supply requirements of the battery. To follow with the P=VI equation, as power stays the same and voltage decreases, current supplied to the system will systematically increase.

Example B (allowing for MPP):

A 130 Watt rated Everbright Solar solar panel provides a 12 V battery with power using an MPPT controller to transform the power. As calculated above, the panel outputs maximum 130 W of power. The controller transforms the voltage to the lower voltage requirement of 12 volts and raises the current required to accommodate the power with minimal loss, (12 V)(10.8) = 129.6 W.

The rating of MPPT controllers is dictated by the specifications based on the selected solar panel and battery implemented into the design. First and foremost, an MPPT controller must be designed for the maximum watt output rating from the solar panel and the voltage rating of the battery. For instance, if a 130 W solar panel is chosen to work in conjunction with a 12V battery, the MPPT controller should be rated minimally for those parameters.

Additionally, amperage capacity is a vital consideration because it must be able to handle current through the system. It is important to realize that the input current from the solar panel is not the amperage to design for. The maximum output current value of the controller will be higher than the input current as the MPPT controller converts voltage and current to get maximum power as illustrated in Example B. For this calculation, the P= VI equation is applied:

$$\frac{Solar\ Panel\ Rating(Watts)}{Battery\ Voltage\ Rating(Volts)} = Amperage\ Capacity\ MPPT\ Charge\ Controller$$

To design for conditions in which the solar panel power supply exceeds the manufacturer rating under extreme conditions (occurs during very bright days and high array reflection circumstances), a 25% nominal safety increase of amperage capacity can be applied.

The final parameter that the charge controller should be designed for is the open circuit voltage rating (Voc) of the solar panel. The Voc value represents the solar panel array output voltage maximum under any conditions. The Voc rating is a crucial factor in MPPT charge control design. If the charge controller receives voltage exceeding the limit, the controller will burn out.

.3.4.3.1 Maximum Power Point Tracking Methods

The MPP has to be tracked because the position the MPP lies on in the I-V curve is not known ahead of time and this location is dynamic, subject to change based on irradiation and temperature. Several techniques have been implemented in MPPT control including power feedback based strategies and intelligence based strategies. These applications are the algorithms behind the controller that are used to monitor the system and track the MPP.

There are many algorithms available and decisions should be based on a number of criteria. The deeper that the level of complexity of an algorithm is, generally requires the use of more sensors. Be that as it may, the greater a level of accuracy of the MPPT will be obtained. In addition, the requirements of speed at which the system converges to the required voltage or current must be taken into account because the system must maintain the load at the MPP. High performing systems require more speed. Finally, cost must be taken into consideration. The hardware that supports the MPPT system can fluctuate dramatically in expense from the controller to the sensors required for the algorithm to function.

3.4.3.2 Perturb and Observe

Perturb and Observe (P&O) algorithms are commonly used for MPPT because they are simple in structure, cost-effective because they only require voltage sensing, and are easy to implement. By perturbing (incrementing or decrementing) along the voltage curve from the array and analyzing the output PV power against the preceding MPPT cycle, tracking is performed. The tracking advances on the same course along the voltage curve as long as the power continues to increase, searching for the MPP. When the power decreases, tracking along the voltage curve reverts back in the opposite direction along the curve.

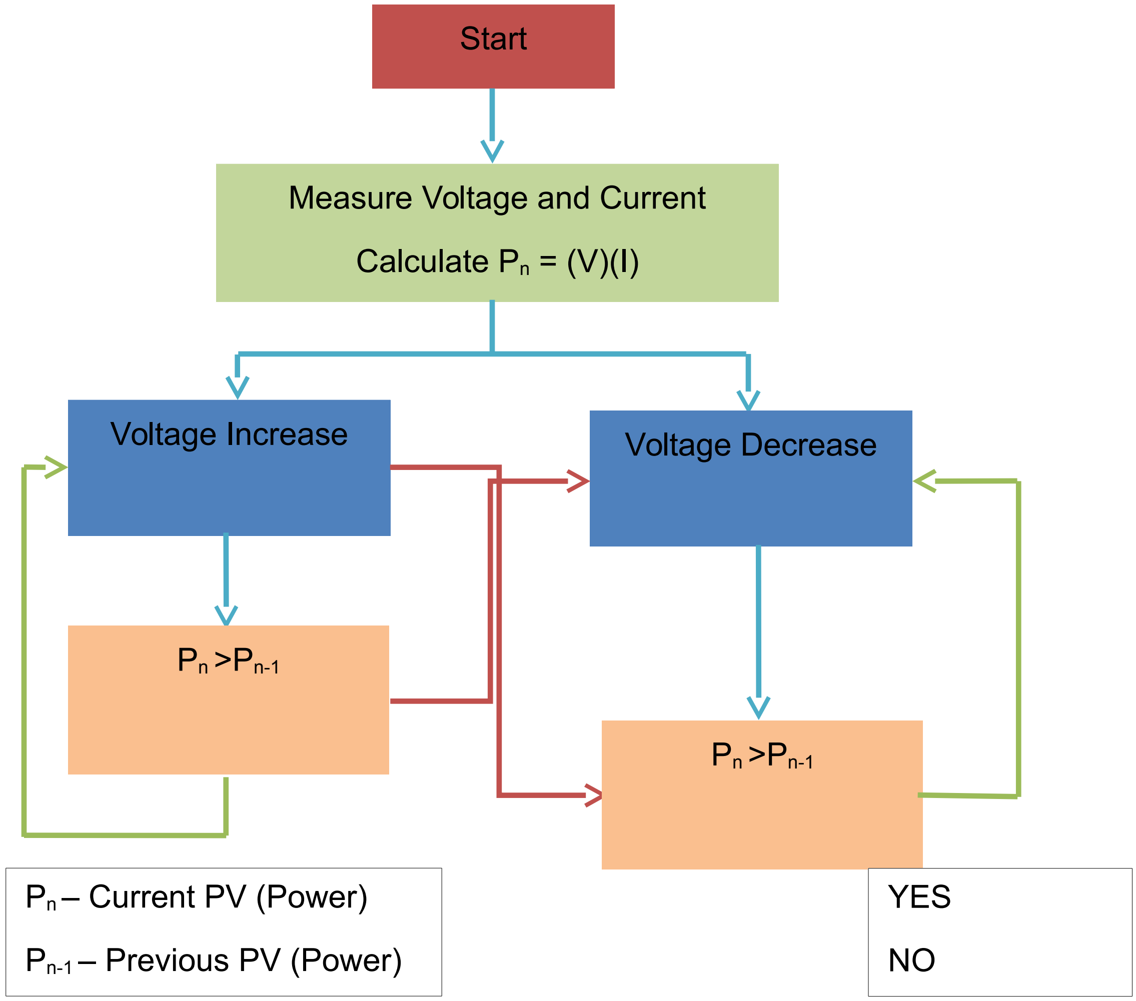


Figure 3.4-5 Perturb and Observe Algorithm

P&O algorithms have disadvantages, though. When the P&O algorithm arrives at the MPPT, oscillation occurs at steady state operation. This results in a loss of power under low varying irradiance conditions. In rapidly changing conditions, the algorithm may get confused and track in the wrong direction.

3.4.3.3 Incremental Conductance

Incremental Conductance applies a method using the slope of the line of the power voltage curve:

$$\frac{dP}{dV}=\frac{d(IV)}{dV}=I+V\frac{dI}{dV}=I+V\frac{\Delta I}{\Delta V}$$

At MPP, the slope of the PV curve is zero:

$$\frac{dP}{dV} = I + \frac{\Delta I}{\Delta V} = 0$$

Thus, we can calculate the points on the curve below:

$$\frac{\Delta I}{\Delta V} = \frac{-I}{V} \, at \, MPP$$

$$\frac{\Delta I}{\Delta V} > \frac{-I}{V} ¿ \frac{MPP \wedge \Delta I}{\Delta V} < \frac{-I}{V} ¿ \, of \, MPP$$

Using these conclusions, the algorithm is written to compare the instantaneous conductance, I/V to the incremental conductance, ΔI/ΔV. When the MPP is found using this comparison, the system continues to supply power based on this MPP until atmospheric conditions change. The algorithm will understand these changes through a change in voltage or current.

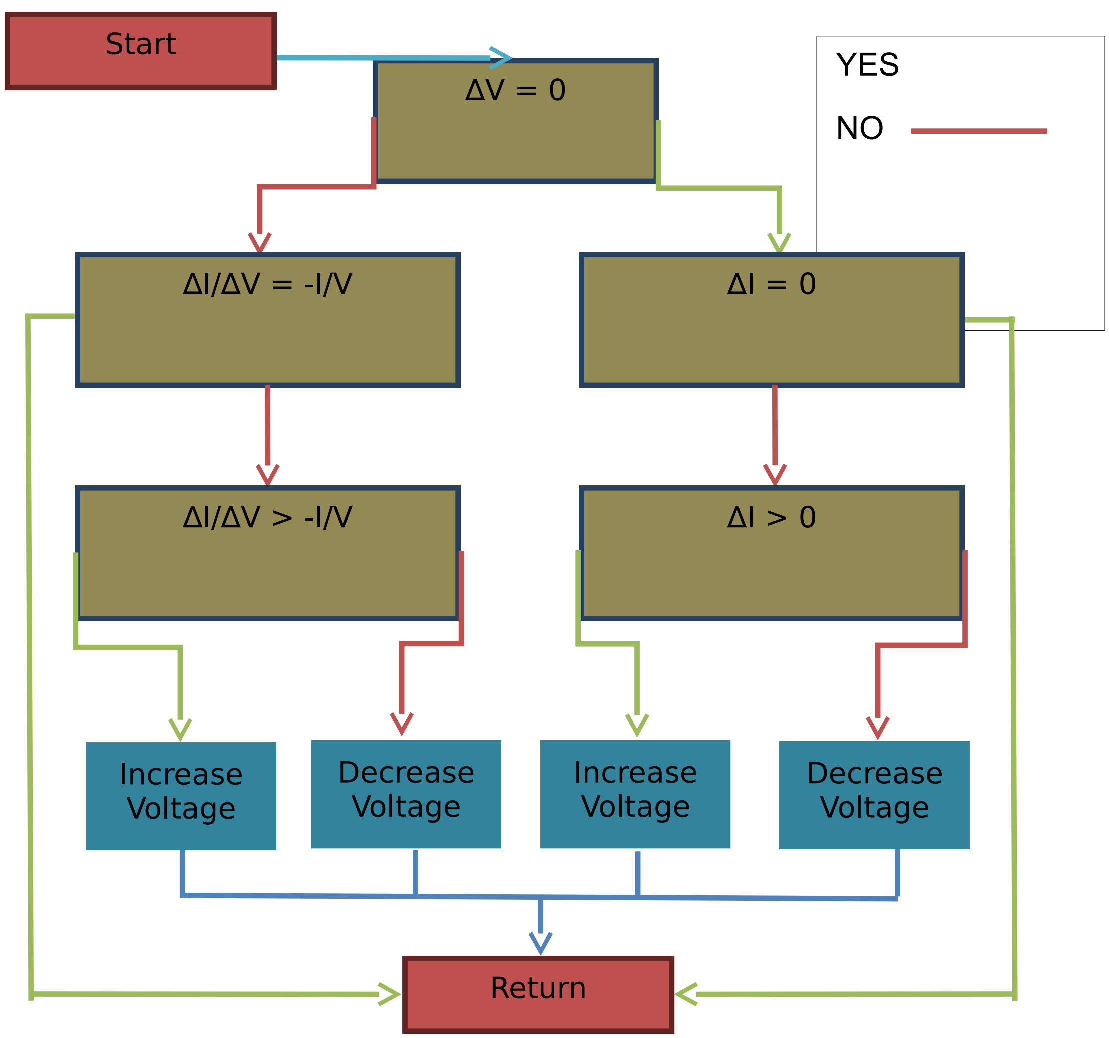


Figure 3.4-6 Incremental Conductance Algorithm

There are some improvements that have been made with Incremental Conductance in regards to P&O. Incremental Conductance eliminates the problem with oscillation around the MPP. Accuracy in tracking the MPP during times of rapid changes in irradiation and atmospheric conditions is enhanced. Additionally, passing the MPP is better recognized resulting in fewer instances of tracking in the wrong direction. At the same time, there are some limitations. The task of determining the MPP consumes more time than P&O due to the more extensive calculation process of this algorithm. Moreover, this causes the sampling frequency of voltage and current to occur less frequently.

3.4.3.4 Fuzzy Logic Control

The main advantage of using Fuzzy Logic Control (FLC) is the increased speed of the tracking process verses both Incremental Conductance and P&O. It is a simply designed and powerful logic controller that eliminates an extra P-I control loop, enhancing the performance. The algorithm is based on four steps illustrated in Figure 3.4-7. The computations rely upon information provided from the PV solar panel inputs and include the change in power and current. The output from the system is the change in “boost converter current reference” which manages the source current from the PV array.

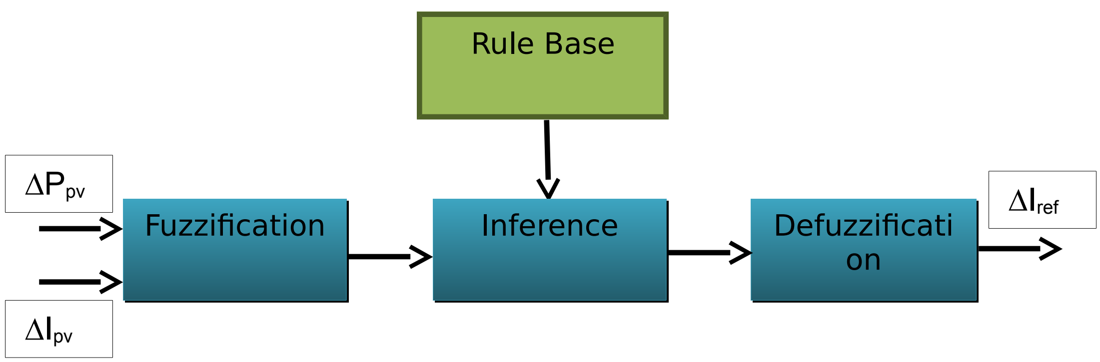


Figure 3.4-7 Fuzzy Logic Control Algorithm

3.4.3.5 Maximum Power Point Tracking Technology

There are two available MPPT controller products on the market that impact the design in different ways. Selection between these two products depends upon a complete understanding of the product characteristics and respective requirements for implementation.

One way that an MPPT charge controller can be implemented in a PV battery charging system is by using a programmable MPPT IC Chip. Due to the rapid advances in semiconductor devices, there are many manufacturers who offer MPPT IC chips. Some come pre-programmed with an MPPT algorithm that matches the impedance of the solar panel to the impedance of the battery before driving current to charge the battery. Also integrated into the chip is an Analog to Digital converter to sense voltages and currents.

Some of the main advantages of using an MPPT IC are the freedom to have more control with programmable features as well as the significant decrease in the size and weight of the system that it will provide. Research was conducted between a few MPPT IC chips from some of the largest semiconductor device manufacturers, like Texas Instrument and Linear Technologies. However, considering the power requirements for our project, there are not as many High Power MPPT IC Chips available without modifying the circuit which can become costly. Although there were some limited resources because it is still a fairly new technology, one was found that can meet the requirements of our design. The Linear Technology LT8490 High Voltage, High Current Buck-Boost battery Charge Controller with MPPT is a powerful MPPT charge controller that can handle input voltages from 6V to 80V and battery voltages from 1.3V to 80V. It uses a Perturb and Observe algorithm to find the maximum power point and has features which allow you to sense current, voltage, and temperature. In figure 3.4-7, a schematic of a typical application is shown for a PV battery charging system.

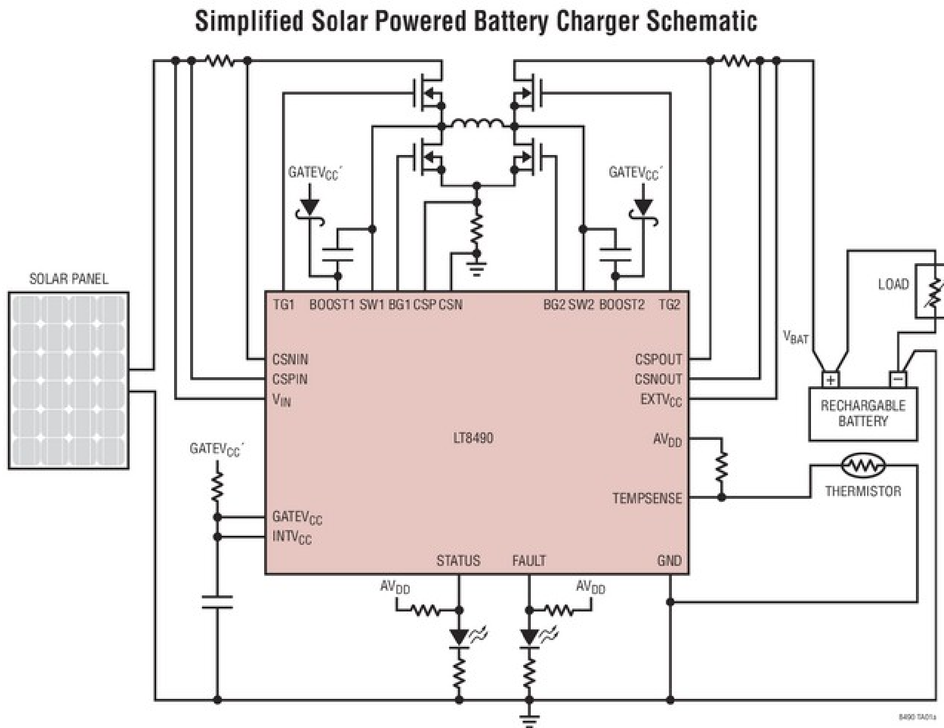


Figure 3.4-7 Schematic of a Simplified Solar Powered Battery Charger Using a LT8490

Permission from Linear Technology

3.5 DC – DC converter

To design a system that operates at optimal efficiency is the ultimate goal of any engineer. In order to do that, not just one, but all of the parts of a system must communicate and work in unison. Within an ideal world, most electronic projects would be designed to deliver an amount of power to the output that is equal to the power being supplied to the input. However, there is no evidence of an ideal world yet existing, therefore a voltage regulator is necessary to use in order to regulate the amount of voltage that is being delivered to the load. However, many devices also have subsections and sub-circuits that require a different amount of power in itself, therefore more than one voltage regulator must be considered to meet those power needs. For the purposes of our design, we will need a DC to DC converter to convert one DC voltage to another DC voltage, essentially regulating the amount of power being supplied to the load. It will work to keep the solar panel's input voltage constant and regulate the input voltage to optimally charge the battery under various load connections. The question of whether to use a linear or switching voltage regulator presented itself and was further analyzed in order to decide on which regulator would be appropriate for our design.

Linear voltage regulators are inexpensive, extremely user friendly, and well known to be fairly useful for powering really low powered devices. They work by using a resistive voltage drop to regulate the voltage. However, linear regulators are inefficient such that their method of operation causes a great amount of energy to be wasted as heat. The amount of heat wasted is proportional to the difference between the input and the output voltages. Therefore the larger the difference, then the greater the energy and the overall heat produced by the regulator. A typical way to resolve the heat issue is to use heatsinks to help dissipate the heat. Unfortunately, this may add to the cost and reduced battery life of the project.

Switching voltage regulators are circuits that are typically comprised of a switch, diode, and inductor and work off the basis of transferring power from the input to the output. The inductor in a switching regulator circuit also allows for versatility. Unlike linear regulators and due to the inductor limiting the current slew rate through the power switch, driving larger loads is possible through a switching regulator. Essentially, the inductor still plays the role of the energy storage device, in which its energy is calculated as a function of the current as shown in the following equation.

$$Energy = 0.5 * L * I^2 (Joules)$$

Although the inductor has a voltage drop associated with it, its current is 90 degrees out of phase with its voltage. This increases the efficiency of the system by allowing the energy stored in the inductor to be recovered during its discharge phase. With the use of the switch and controller, switching regulators are able to regulate the amount of energy being delivered to a particular load. By moving very small bits of energy from the input to the output, there is very little energy that is lost through heat. Therefore, the switching regulator is extremely more efficient than the linear regulator and more suitable for larger power output specifications. As seen in Figure 3.5-1, although linear regulators are less noisy and more environmentally friendly because of leaving behind a smaller carbon footprint, the result of wasting less energy and operating a system at a higher efficiency through a switching regulator was a tradeoff that was well worth it.

	Linear Voltage Regulator	**Switching Voltage Regulator**
Efficiency	Low	High

Noise	Low	High
Output Current	Low to Medium	Low to High
Step - Up Voltage	None	Yes
Step – Down Voltage	Yes	Yes
Carbon Footprint	Small	Large

Figure 3.5-1 Linear vs. Switching Regulator Table

The system's load power requirements used in this project will require a DC to DC converter to efficiently step down the voltage from the power supply. A schematic of the solar panel connected to a DC to DC converter which will regulate the voltage delivered to the load is shown in Figure 3.5-2. The load dictates the operating point of the solar panel when they are coupled together. Using Ohm's law, the impedance of the load (R_{load}) is given by the following equation where the (V_o) is the output voltage and (I_o) is the output current.

$$R(load) = \frac{Vo}{Io}$$

The optimal load for the solar panel is achieved when the maximum power point voltage (V_{mpp}) and current (I_{MPP}) are at their Maximum power points. Therefore the optimal resistance ($R_{optimal}$) of the panel is represented by equation (4).

$$R(optimal) = \frac{Vmpp}{Impp}$$

The maximum power point transfer from the solar panel to the load will occur when R_{load} is equal to $R_{optimal}$. Unfortunately, it is extremely difficult to build a PV system where the input impedance always matches the output impedance, therefore we will use a DC to DC converter to match the impedances for optimal performance.

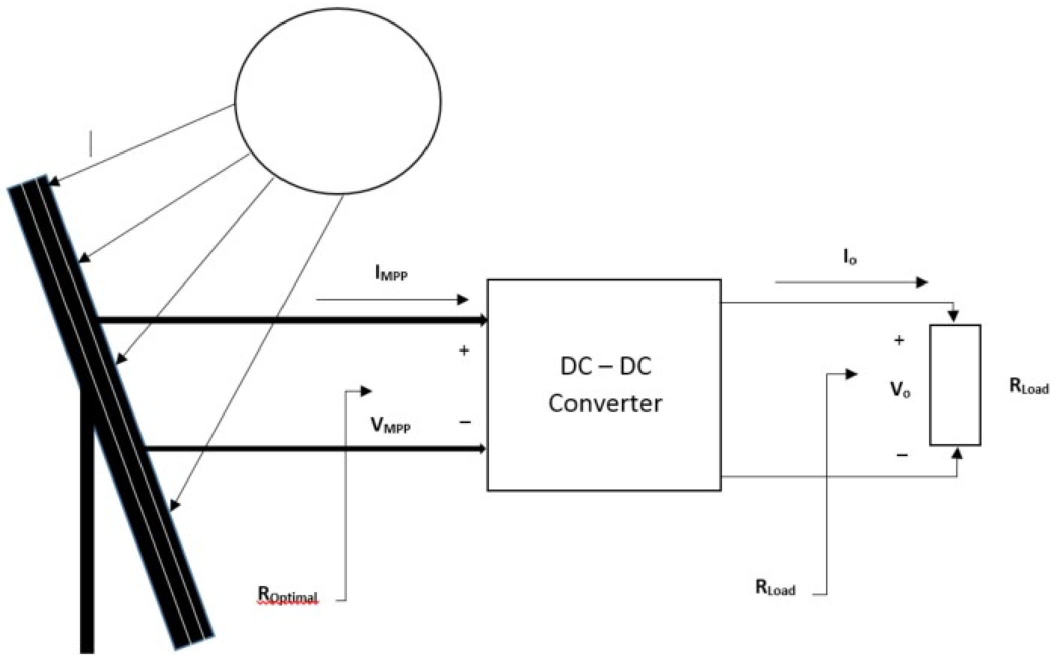


Figure 3.5-2 A PV panel connected to a DC to DC converter delivering a regulated voltage to the load

There are several topologies to consider when designing a switching voltage regulator circuit. Some of the main ones that will be considered for this project are the buck (step-down), boost (step-up), and the inverse regulator (buck-boost). All of these switching regulators use the Pulse Width Modulation (PWM) voltage regulation method, in which the feedback loop corrects the output voltage by changing the time that the switching element within the converter is on.

3.5.1 Buck Converter

The Buck regulator is most commonly used to convert a higher DC input voltage to a lower DC output voltage. By using a transistor as a switch, the PWM can activate the switch that connects and disconnects the inductor from the. When the switch is set to be on, the inductor is connected to the circuit and delivers current to the capacitor and load. When the switch is turned off, the inductor is disconnected from the circuit and adjusts to hold the current constant since the current through an inductor cannot change instantaneously. The diode then turns on from the decreasing current of the inductor and delivers current to the load and then back through the diode. The buck converter is efficient for stepping down the input voltage to the battery when the MPP of the solar panel is above the charging voltage of the battery. However, it is unable to operate when the MPP of the solar panel drops below the charging voltage of the battery usually during poor weather conditions causing there to be a low level of irradiance.

Therefore, a boost converter will also be considered for stepping up the voltage under these conditions.

3.5.2 Boost Converter

The Boost regulator does the opposite of the Buck regulator in which it converts a low DC input voltage into a higher DC output voltage. With a reconfiguration of the components from the Buck regulator, the Boost regulator delivers an output voltage of the same polarity as the input voltage. When the switch is on, current flows through the inductor as a result of the input voltage being forced across it. When the switch is off, the diode is forward biased from the decreasing inductor current and the capacitor then charges to a voltage higher than that of the input. Although the boost converter is an appropriate voltage regulator for stepping up the input voltage to the battery during times of intermittency, unfortunately, it won't be able to efficiently operate under all conditions. Therefore, the combination of the boost and buck converter will be considered for stepping the voltage and up and down when needed.

3.5.3 Inverting Buck to Boost Converter

Finally the Buck to Boost regulator is a cascaded combination of both voltage regulators. It converts a DC input voltage to an output voltage that is either higher or lower than the input with an opposite polarity. When the switch is on, an increase of current flows through the inductor which causes the capacitor to be the only current source to the load. When the switch is turned off, the inductor's current decreases and activates the diode which allows the inductor to supply current to the capacitor and load. Essentially, the current is supplied to the load from the capacitor when the switch is turned on and supplied from the inductor when the switch is turned off.

A buck converter is typically used for battery charging PV systems, however it doesn't perform well when the MPP goes below the charging voltage under horrible conditions. Since a stable PV system is required to take in an input supply that is either higher or lower than the output, Buck to Boost converters are excellent regulators to use. One of the important goals of our project is to draw the maximum amount of power from the solar panels all the time regardless of the load, therefore we decided to go with the Buck to Boost regulator to meet these critical needs.

One method of acquiring a DC to DC converter is by simply purchasing one that meets the voltage regulation needs of the system. However, purchasing the converter can limit us on future modifications and it can become costly for higher power PV systems. Another method that we may consider is to design the Buck-Boost converter ourselves. Fortunately, Texas Instrument has an online software tool called Webench that can be used for design simulations and can generate multiple designs of Buck-Boost controllers to compare according to your system's unique specifications. One of the best features of Webench is the freedom to modify your designed circuit based off of the amount of efficiency and cost your. Texas instruments also manufactures all of the electrical components to build the entire DC to DC converter, therefore it can also generate a BOM of all of the components needed to build the DC to DC converter circuit. To determine whether ths software would be helpful for us, design specifications were entered into the system and a list of potential Wide Range Buck-Boost controllers was generated as seen in Figure 3.5-3

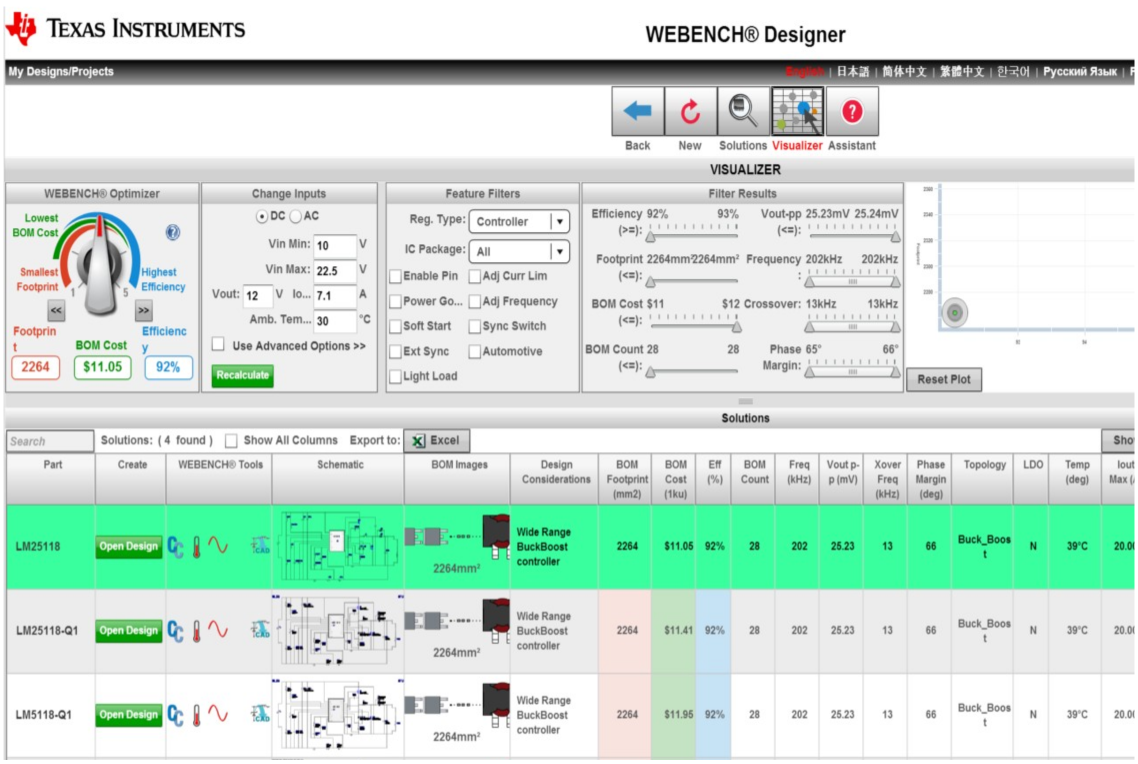


Figure 3.5-3 Texas Instruments Webench Design Tool for a Buck-Boost Controller-Courtesy Texas Instruments

While taking advantage of the customization settings, the cost and efficiency was tweaked so the system was able to generate a final result of the LM25118 Wide Range Buck-Boost Controller. This DC to DC converter topology meets our design’s voltage regulation requirements by having the ability to operate in both buck and boost mode when necessary with 92% efficiency. The schematic of the entire circuit was also available with a clear image of the pin_OUT layout as seen in Figure 3.5-4.

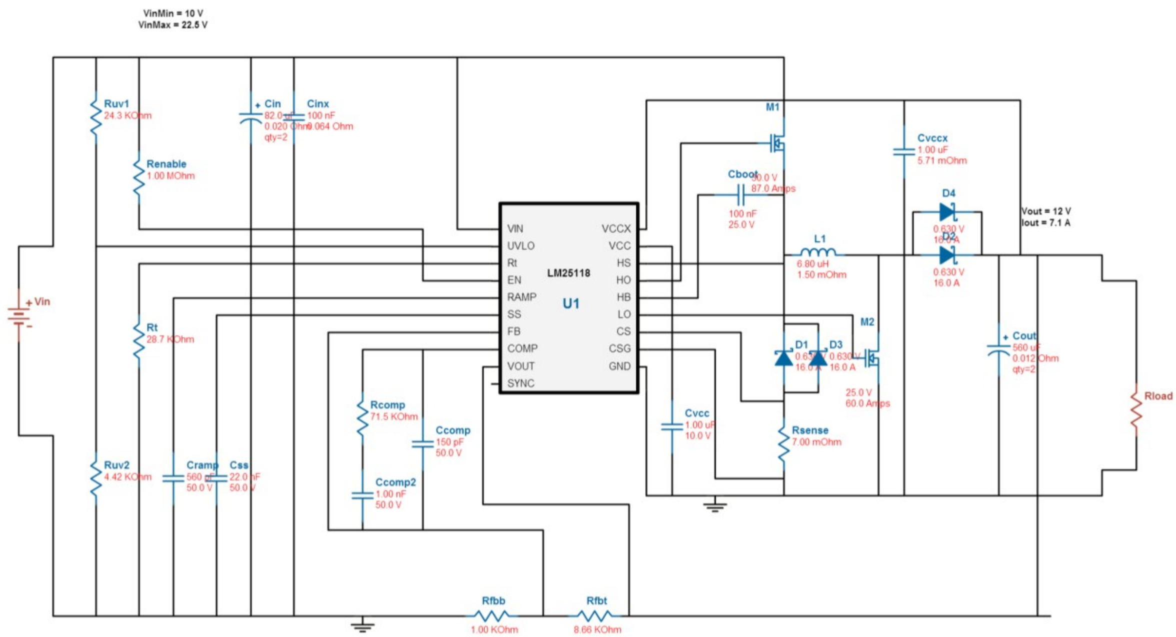
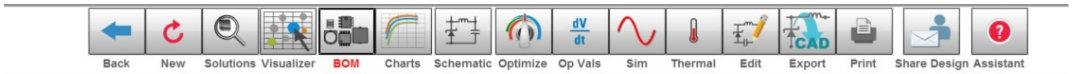


Figure 3.5-4 LM25118 Circuit Schematic to meet system power requirements

Courtesy Texas Instruments

A complete parts list of all the surface mounted component needed to build the circuit along with the entire BOM was also obtainable, as seen in Figure 3.5-5. Webench is a powerful tool that brings many perspectives to understanding the needs of your design when designing a circuit, while making it convenient to transfer it to a PCB board. Since Texas Instruments designs all of these components as well, the specifications are available with dimensions to help pre-determine how to maximize board space. The LM25118 is the best Wide Range Buck-Boost Controller for the UniverSOL Charging Station operating at impressive efficiency value of 92%.



BILL OF MATERIALS

Export to: Excel BOM Cost: $11.05 *Footprint is component footprint plus 1mm per side.

Part	Manufacturer	Part Number	Quantity	Price	Attributes	Footprint	Top View
Cboot	MuRata	GRM21BR71E104KA0	1	$0.01	Cap=100nF, ESR=0Ohm, VDC=25V	7	
Ccomp	Yageo America	CC0805JRNP09BN151	1	$0.01	Cap=150pF, ESR=0Ohm, VDC=50V	7	
Ccomp2	Yageo America	CC0805KRX7R9BB102	1	$0.01	Cap=1nF, ESR=0Ohm, VDC=50V	7	
Cin	Panasonic	35SVPF82M	2	$0.61	Cap=82uF, ESR=0.02Ohm, VDC=35V	106	
Cinx	Kemet	C0805C104K5RACTU	1	$0.01	Cap=100nF, ESR=0.064Ohm, VDC=50V	7	
Cout	Panasonic	20SVPF560M	2	$0.70	Cap=560uF, ESR=0.012Ohm, VDC=20V	151	
Cramp	Yageo America	CC0805KRX7R9BB561	1	$0.01	Cap=560pF, ESR=0Ohm, VDC=50V	7	
Css	Yageo America	CC0805KRX7R9BB22	1	$0.01	Cap=22nF, ESR=0Ohm, VDC=50V	7	
Cvcc	MuRata	GRM155R61A105KE1	1	$0.01	Cap=1uF, ESR=0Ohm, VDC=10V	3	
Cvccx	TDK	C1608X5R1C105K	1	$0.01	Cap=1uF, ESR=5.713mOhm, VDC=16V	5	
D1	Vishay-Semiconductor	MBRB1635PBF	1	$0.71	VFatIo=0.63V, Io=16A, VRRM=35V	210	
D2	Vishay-Semiconductor	MBRB1635PBF	1	$0.71	VFatIo=0.63V, Io=16A, VRRM=35V	210	
D3	Vishay-Semiconductor	MBRB1635PBF	1	$0.71	VFatIo=0.63V, Io=16A, VRRM=35V	210	
D4	Vishay-Semiconductor	MBRB1635PBF	1	$0.71	VFatIo=0.63V, Io=16A, VRRM=35V	210	

Figure 3.5-5 List of Surface Mounted Components for LM25118 Wide Range Buck-Boost Controller Circuit and Corresponding BOM

Courtesy Texas Instruments

3.6 Battery-Based Systems

One of the fundamental requirements of UniverSOL Charge Station is continuous operation without interruption of power. Because the core source of power generation is dependent upon solar power, that power is not always readily available due to durations of inclement weather and overnight periods. Consequently, the solar energy accumulated in periods of heightened energy consumption must be stored and then distributed utilizing a rechargeable battery. In accordance with these autonomous specifications for the stand-alone PV system, investigation into a battery-based system is necessary.

Battery-based systems are also a key component in maximizing solar efficiency. In order to achieve maximum power point control of the PV array, a battery based system is a required component for functionality.

3.6.1 Battery Bank Characteristics

Preliminary research suggests sizing of a battery to typically range between 12VDC and 24VDC for small to mid-size PV systems. Underestimating the size of a battery can be adjusted by connecting additional battery banks in series. However, knowledge of battery bank characteristics and simple calculations allow for a more accurate estimate and potential avoidance of underestimating total cost of the system. Considering the battery is one of the most vital components within the system and one of the most expensive, it is necessary to be as accurate as possible.

Specific Electrical System Load parameters must be determined in calculating the size of a battery. Establish all electrical load components of the system, power drawn from each component, and hours per day the component will be running. Use the following equations to calculate the total electrical system load per day:

$$\frac{Watt\ hours}{day} = \frac{Watts * Hours}{day} \sum \frac{Watt\ hours}{day} = Total\ Electrical\ Load / day$$

Based on the preliminary requirements and specifications of the project, the following components can be figured into a preliminary sizing of the battery attributed to the power requirements of the system:

Electrical Loads	Quantity	Watts	Hours/Day	Watt-Hours/day
Cell Phones	6	5	24	720
3.5" TFT Color Touch Screen	1	0.25	24	6
16F-series PIC MCU	1	0.2	24	4.8

Fig. 3.6-1 Electrical Loads UniverSOL Charge Station in Watt-Hours per day

Determining the battery energy storage capacity requires knowledge of both the Amp-Hour (Ah) rating and the rate of discharge. The amount of Amp-hours is how many amps are drawn from a battery in a number of hours. The rate of discharge is typically provided in C Ratings and determines how much time it takes for a battery to discharge. Most deep cycle batteries are rated at C/20 and C/100 which means that they discharge fully in 20 hours and 100 hours, respectively. For example, in order to calculate how many amps are discharged over the C period of time, given battery rating 1000 Ah C/20 and C/100:

$$\frac{Ah}{C / rating} = \frac{¿\ Amps\ discharged}{hr} : \frac{1000\ Ah}{20\,h} = 50 \frac{A \wedge 1000\ Ah}{100\,h} = 10\,A$$

Beyond having an adequate power supply to the system, a battery's Depth Of Discharge (DOD) rating is inherent to PV system design. The DOD is the maximum amount of energy the battery is capable of discharging in one cycle (one discharge and recharge period) and is rated in percentage of battery capacity. Because a PV system is expected to endure long durations of battery discharge, the DOD rating should be high enough to qualify as a deep cycle battery. This means that the battery must have the capability to be discharged at greater percentages withstanding more cycles without damaging the performance of the battery. Most manufacturers supply maximum ratings of 80% DOD in order to avoid complete depletion of the battery. However, design of a system that does not deplete more than 50% of the energy is common industry recommendation.

Battery lifetime plays an important role in the suggested 50% DOD specification. This is because the chemical reactions that take place during discharge can cause stress on the battery, and performance eventually diminishes until the battery dies. Moreover, the number of discharge/charge cycles the battery incurs decreases lifetime. When selecting a battery careful consideration must be taken on the number of cycles a battery should last to achieve optimal service life.

Figures 3.6-2 and 3.6-3 illustrate typical DOD rate versus Life Cycle rate of lithium ion and lead acid battery systems:

Depth of discharge	Discharge cycles
100% DoD	300 – 500
50% DoD	1,200 – 1,500
25% DoD	2,000 – 2,500
10% DoD	3,750 – 4,700

Table 2: Cycle life as a function of depth of discharge

A partial discharge reduces stress and prolongs battery life. Elevated temperature and high currents also affect cycle life.

Fig 3.6-2 DOD vs. Life Cycle (Lithium Ion)

Permission from Cadex

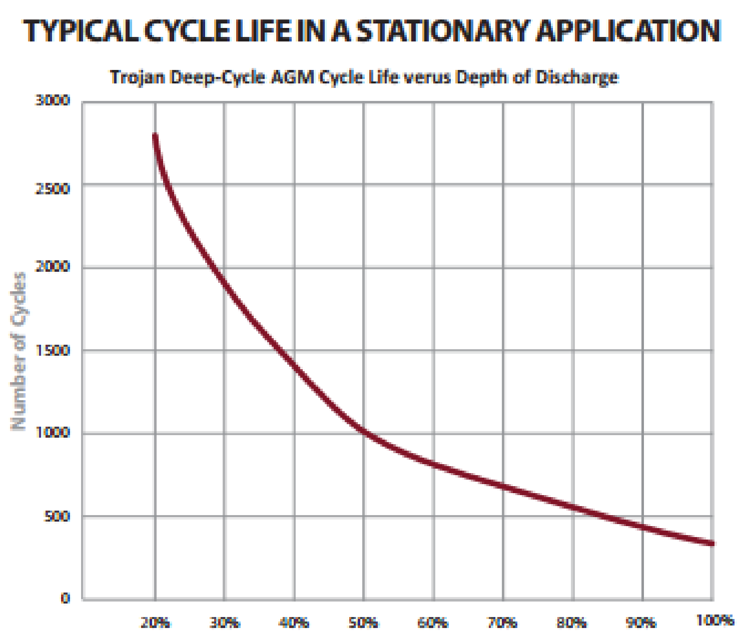


Fig 3.6-3 DOD vs. Life Cycle (Lead Acid)

Permission Pending from Trojan Battery

With Watt hours and DOD determined, the final parameter to establish is the maximum number of days the battery can operate without solar power. Recommendations suffice for 2-3 days for a stand-alone system on average, but can be as long as 5 days in harsh climates. A .85 battery percentage loss constant and the predetermined nominal battery size should be included.

$$\text{Battery Bank} ¿(¿) = \frac{\overset{\text{Amp Hours}}{\text{Watt hours} * \text{Days of Autonomy}}}{.85 * \text{Max}.\text{DOD} * \text{Nominal Battery Voltage}}$$

Applying the fundamental power equation P(Watts) = V(Volts) * I (Amps):

$$\frac{\text{Watt hours}}{\text{Amp hours}} = \text{Voltage}$$

Finally, when selecting a battery, some manufacturers provide voltage regulation, temperature compensation, and low voltage disconnect specifications. Since the project requires a charge controller (refer to Section 3.4.1), it is recommended to select a battery from a manufacturer that furnishes these specifications.

3.6.2 Lead Acid vs. Lithium Ion

Research finds lead acid battery systems are currently the most commonly used in PV systems due to cost-efficiency, abundance of suppliers/products on the market, and low environmental impact. There are three major types of lead acid batteries: Flooded, Gel sealed, and Sealed Absorbed Glass Mat (AGM). Maintenance-free batteries are ideal for the project so flooded batteries will not be considered. Gel sealed batteries are less expensive than AGM, but must be charged slower at a lower voltage. However, AGM is phasing out the Gel battery due to reduction in charge and discharge time and improvements in the weight of the battery.

While lead acid is the proven option, advancements have been made in lithium ion batteries that could revolutionize PV systems. According to an article in PV magazine, “the need for storage solution is growing and lithium ion (Li-ion) batteries have emerged over the last few years as one of the preferred methods.” Some of the advantages include low self-discharging rate, high cycle life, very lightweight and compact, and better overall efficiency as compared to lead acid. However, increased cost and environmental hazard continue to influence PV system designers to lean towards lead acid.

In Figure 3.6-4, comparisons were made among three specifications of a 12V 100 Amp Hour battery system and the following conclusions were made:

Parameters	Lead Acid Gel Sealed	Lead Acid AGM	Lithium Ion
Average battery life	Replace every 3-5 years	Replace every 10 years	Replace every 10 years
Deep cycle DOD efficiency	50%	50%	80%
Weight	66 lbs.	64 lbs.	4 lbs.
Space requirements	8.1 x 8.1 x 5.9 inches	12.05 x 6.84 x 9.32 inches	7.17 x 6.61 x 3.03 inches
Cost	$200.00	$250.00	$560.00
Charge Efficiency	75%	75%	97%
Energy Efficiency	Moderate	Moderate	High
Environmental hazards	80% recyclable	97% recyclable	60% recyclable

Fig 3.6-4

3.7 Embedded System

Our project will make use of an embedded system which is a computer system that has a dedicated function within our larger electrical system. The embedded system we will implemented with the other hardware and mechanical parts of the whole system of the charging station. Primarily we are using the embedded system to send signals to multiple electronic and mechanical devices in order to power them to do a specific function at a specific time. Embedded systems are usually based around microcontrollers which are small central processing units(CPUs) that have different interfaces as well as integrated memory. The importance of using a microcontroller in our system as opposed to just a microprocessor is that we want the memory to be integrated in the processor as well as having peripheral interfaces embedded within it instead of using external chips. Embedded systems are used to control many devices everyone uses today such as traffic lights, factory controllers as well as MP3 players.

The importance of an embedded system in relation to the rest of the system is that its purpose is dedicated to controlling a particular task of the system. This makes it easy for us to optimize the system as a whole. As we expect this project to be able to be factory produced on a large scale once a proven prototype is built, we as engineers rely on the embedded system within to increase the performance of the system as well as maintain the system as reliable. Embedded systems allows us to use and design the system in this exact way while reducing the overall cost. Another important feature of embedded systems is that the react to real-time events. In our system we need something to be responsive to the user and deliver in real-time without delay in order to maximize customer satisfaction.

Common metrics involved with embedded systems are power, size, performance, and flexibility. The ability for the system to be small, powerful fast, energy efficient, and have the ability to change the functionality without incurring heavy costs are the main factors we are looking at in designing the embedded system within our product. We understand metrics and how important they are when selling your product and pitching the idea to investors. Embedded systems combine hardware and software together in order to optimize the different metrics being recorded by the project engineers. As Electrical and Computer Engineers, we are fit to design the system with all of the various technologies in order to solve the problem we have identified a need for.

Our embedded system will make use of a User Interface and will be one of the key front-end customer facing aspects and will connect the microcontroller with an LCD display screen. We will need to use software design for the front-end user interface with efficient hardware design supplying the correct power and using the least amount of available energy. The User Interface of the embedded system will use the LCD display as well as touch sensitive graphical screen. Connecting the user interface to the microcontroller will be a design challenges that we as engineers feel capable of creating with maximized efficiency and low cost. Processors of embedded systems can vary greatly between manufacturers through which central processing unit architectures are used. There are processors that are RISC based (Reduced Instruction Set Computing) as well as processors that have a more complex instruction set. Controlling the system is of high importance with embedded systems and there are several ways to implement software in an embedded system. Programming languages are used to program microcontrollers and different languages and be ported on different microcontrollers, depending on which microcontroller you use. One of the ways to control the system would be having a simple control loop that runs indefinitely and reacts to inputs and calls subroutines to manage a specific part of the system. Cooperative multitasking is a similar to the control loop scheme, but the main loop would be hidden inside an API. Each task is divided in its own environment to run in. An advantage with cooperative multitasking is that adding new software is easier than in the control loop programming. It is common with embedded system designers of large complex systems to create a real-time operating system which allows the programmers to focus on the specific device functionality instead of the operating system services. We believe that our system is too small for a real-time operating system and implementing one in our project would reduce the memory size of our microcontroller available and thus create higher cost on memory which we believe is not worth the cost. The main factor in designing the embedded software is the memory constraints of the system. This has to be accounted for as you need enough memory to run your system, and you also need to know the memory size for your database. Although most of the embedded system software will go unnoticed by the customer, as when controlling the power split and opening of the mechanical drawers and locks, the software will also be visible in the user interface.

Embedded systems connect with other objects and technologies through many different peripherals some of which include Serial Communication Interfaces and Universal Serial Bus and Multi Media Cards. It is possible for embedded systems to be connected to networks through Ethernet, but we don't currently see a need for network design in the embedded system of this product. Without the use of networks, we can select parts with networkless connections which should reduce the cost of the overall system. However adding this as a feature would require a large reconstruction of the entire system.

3.7.1 Microcontrollers

3.7.1.1 TI MSP 430

The TI MSP430 is one of the microcontrollers we wanted to research more as it seemed like a possible front runner of our main controller of our embedded system. The TI MSP430 is a mixed-signal microcontroller that has a 16 bit central processing unit created by Texas Instruments. The MSP430 was designed specifically for low cost and low power consumption, which we felt were some of the main concerns of our project. Low cost controllers are important when mass-producing products which is what led us the to MSP430 in the first place. The top speed of the CPU is 25MHz and the electric current of the processor can be less than 1 microAmpere in idle mode. A key factor of the MSP430 is the design in the low power consumption. It was created with fast wake-up ability from sleep mode which allows the microcontroller to minimize the power consumption by staying in sleep mode longer. Power consumption is very important because this product is using alternative energy to power the system, as we wanted to create something helpful for the environment. The MSP430 has a USB drive which makes programming the board easy and has one of the most common connections that our system will use to connect different devices.

One major concern for the MSP430 is that it does not have an external memory bus which requires all of the memory to be used from the on-chip memory which only consists of 512 KB of flash memory. Though our system is not largely complex or a memory hog, we are still concerned with the small amount of memory especially when it comes to displaying the graphics of the system on the LCD display. Though there are many generations of MSP 430s they all are powered by 1.8-3.6 V which is good, comparing to our systems expected energy input from solar power and battery consumption. The MSP430 uses 8 bit registers and contains 11 I/O ports which correspond to P0-P10. Every I/O pin can be configured as an input or output pin specifically and can be read from or written to individually. The whole line of MSP430 families all contain two types of Analog to Digital conversion for 10 and 12 bit converters and a 16 bit Sigma-Delta converter. An important piece of the MSP430 is that it contains an LCD controller that directly drives LCD screens for up to 196 segments.

The MSP430 CPU uses a Von Neumann architecture which is an electronic digital computer with a processing unit which contains processor registers and an arithmetic logic unit, a control unit which contains the instruction register and program counter, memory bank to store data and instructions, and an input mechanism as well as a separate output mechanism. The instruction fetch and data operation share a common bus in Von Neumann architecture, so they can not occur at the same time which could be a problem. The memory of the MSP430 is byte addressed and little-endian and made up of 16-bit words. Little-endian is key for our system because of the relation to the least significant byte being translated to the smallest memory address. This will help avoid confusion when dealing with the CPU. The instruction set is simple consisting of only 27 different instructions, and it supports both byte and word options for almost all instructions.

Developing for the MSP430 must be done in either C or C++ which works for our system since our engineers are familiar with the C programming language. Most of the engineers have worked previously with MSP430s as well so there will be no overhead in learning the microcontroller if we were to use the MSP430. The Integrated Development Environment is Eclipse based which is the preferred IDE for all of the engineers working on the product, which is a plus because of low learning curve.

3.7.1.2 Atmel Microcontroller

The Atmel Arduino microcontroller is a single-board microcontroller that consists of an open-source hardware board based on the ATmega328, which is an 8-bit RISC based microcontroller. It has 14 digital pins which can be used for input/output, a USB connection, and 6 analog inputs. The Amtel Arduino Uno has 32KB of flash memory and the recommended input voltage is 7-12 Volts which is higher than the MSP430 and a little bit of a concern due to the focus in energy constraints for this product. The product website also states that although it can run with a voltage of less than 7V, the board will become unstable under those conditions. The speed of the CPU is 16 MHz which is slower than the MSP430 but contains more pins to use for input and output.

The Atmel Arduino comes with its own integrated development environment that runs on most PCs and allows the user to write programs in C or C++ programming languages which is just the same as the MSP430. A difference from the MSP430 is that you can put your Arduino board together yourself instead of buying the already assembled board so you have some variation in the things that you put on the board which would be a plus. The IDE included with the Atmel Arduino is designed specifically for people who are new to programming, and although all engineers working on this product have programmed before, the electrical engineers have less exposure than the computer engineers so this could help get everyone involved in the software side easier. Arduino IDE has a simple button to upload the code to the Arduino environment which causes the bootloader to have a shorter timeout which is good, but we don't see the system being connected to a computer after the system is completed. The IDE is easier to get for Arduino as it is designed for people to use as hobbies, opposed to Code Composer Studio from Texas Instruments which is a little bit more of a hassle to download, and some of the engineers designing the product have had trouble previously using the software on a linux based system, which deters the engineers from Texas Instruments. Compiling code with the Arduino software is easier as the IDE copies the code and automatically creates simple main functions to compile the code and upload that code to the board. Because of the design intending to be used by newcomers the ease of using the Atmel Arduino is a big plus in picking the right microcontroller for the product.

When the Atmel Arduino is connected to a Mac OS X or Linux computer it will automatically reset instead of requiring a button press to reset the device. The added support for Linux is a huge plus as some other software is harder to use and unstable on those operating systems. The Atmel Arduino is pre-programmed to ignore malformed data which makes debugging easier and would be easy to find problems. It is also equipped with overcurrent protection that will automatically break the connection until the short or overload is removed which is actually a really key idea in this product as you don't want to short out the currents going to the customer devices. However you cannot apply more than 500 mA to the USB port which seems to be a bit of a concern since most mobile devices run off of 1 mA.

However, though the ease of use and customizability of the Arduino are enticing, the cost of the board, the power consumption, the small processing power and large amount of energy used are not exactly what the engineers are looking for in a microprocessor. The extra pins are useful, but as the system is not incredibly complex the extra pins cannot make up for the power consumption by the microcontroller which makes it a poor choice for mass marketing in an energy efficient product.

3.7.1.3 PIC Microcontroller

PIC(Programmable Interface Controllers) microcontrollers are very popular in both industry and for hobbyists due to their low cost, large user base, and large collection of application notes. PIC microcontrollers are highly customizable, as they have a large variety of 8, 16 and even 32-bit microcontrollers. Within each different size microcontroller there are as much as 800 different options with different amount amounts of pins with as much as 100 on a single board. An important feature of the PIC microcontroller is that it is designed with eXtreme Low Power technology maximizing sleep time and decreasing overall energy use. The active current for 8-bit boards can be as low as 30 microAmps, while the minimal sleep current can be as low as 10 microAmps.

PIC microcontrollers feature a version of modified Harvard Architecture which has separate storage and signal pathways for instruction and data. Modified Harvard allows contents of instruction memory to be accessed as if it were data. Since the data and instructions come from separate sources, the microcircuit design is simpler and benefits clock speed without a price increase. The design of the PIC is focused in optimizing speed-to-cost ratio, which is important when thinking about creating a large mass-produced product. With the reduced cost of the microcontroller, it also features a Reduced Instruction Set Computing(RISC) design strategy making it easy for someone, like the engineers of the group, to learn in a small amount of time. However with the high performance and the low cost, there are also some disadvantages of the microcontroller. Register bank switching is required to use the entire RAM of the microcontroller. Register bank switching means that it can only access a small amount of the total address space at one time, meaning it needs to switch blocks in the RAM to access different areas of the data and instruction set which takes a small amount of time. Also, not all registers can directly reference the RAM or constant variables that have been declared, and some registers can only use the accumulator. This causes a waste of some register space if you need to access the RAM directly, which causes a higher register count to actually not make a difference at all.

Main features of the PIC are the sleep mode, and the watchdog timer. Many of the microcontrollers on the market have a sleep mode in order to use the least amount of energy possible. This is very important for the product as its main purpose is to save energy and be as energy efficient as possible. A watchdog timer is a computer timer thats main purpose is to recover from computer malfunctions. If running correctly, the computer would regularly reset the watchdog timer so it wouldn’t time out and consider that a malfunction, but when the software or hardware gets damaged, then the computer can not reset the timer so it does time out and the watchdog notices this and throws an error to correct. This is really important in our embedded system design because the CPU will not be easily accessible by physical human contact, so it is important for the computer and system to be self-reliant and self-correcting.

The company that makes PIC microcontrollers, Microchip, provides a free integrated development environment with the purchase of the microcontroller called MPLAB which comes standard with assembler, linker, and debugger. However, they sell C compilers for the microcontrollers that integrate directly with MPLAB. Students can receive free versions of C compilers with their student accounts. Although the student version will have all of the features of the normal program, after 60 days all of the optimizations will be disabled. Third parties make compilers that can integrate to MPLAB and with those you can get C, Basic, and Pascal programming languages. Because of the variety of the microcontrollers and what you can get with them, we feel that this is a good choice as the main microcontroller design. The PIC can be connected to a computer using USB 2.0 and the code can be directly downloaded from versions of Microchip's compilers and programmable IDEs.

3.7.2 Printed Circuit Board

A printed circuit board electrically connects all of the electronic components of our system using conductive tracks. Printed circuit boards can be either single sided which would have one copper layer, or double sided which would have multiple copper layers. Manufacturing of printed circuit boards can be broken down into many steps and the figure below shows a flowchart of creating a double sided printed circuit board.

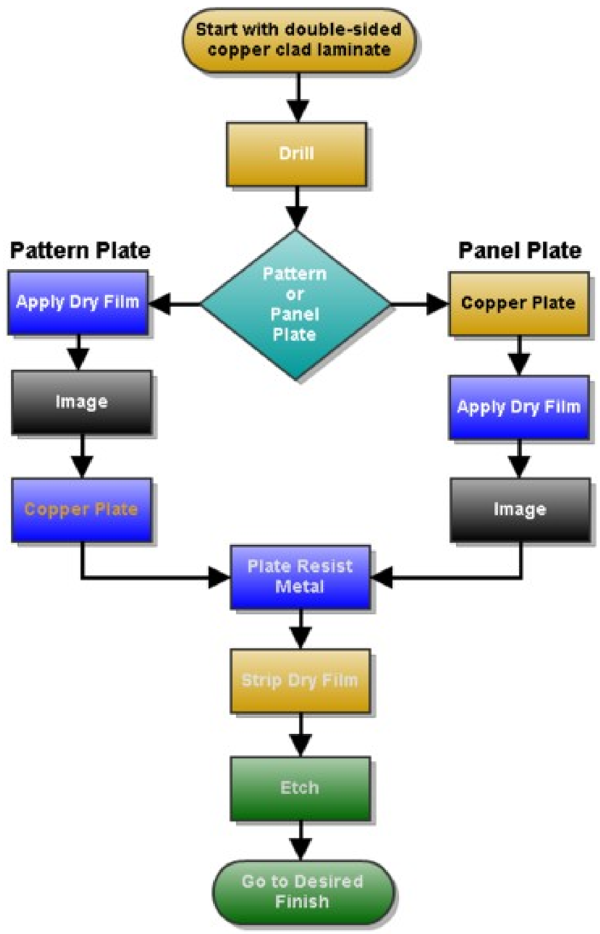


Figure 3.7.2.a

After the board has been completed, then all of the electronic components must be attached to it through the use of soldering. Then, after the board is populated with all of the electronic components you must run a variety of test with power running to it and without any power running to the board. The IPC (Association Connecting Electronics Industries) publishes standards for a printed circuit board's design, assembly, and quality control, which results in limits on the way a printed circuit board can be made.

It is important to specifically design a printed circuit board specifically for what your system needs and then create the board from those specifications. The flowchart we will be using for our deciding what to do with the printed circuit board can be found in the figure below.

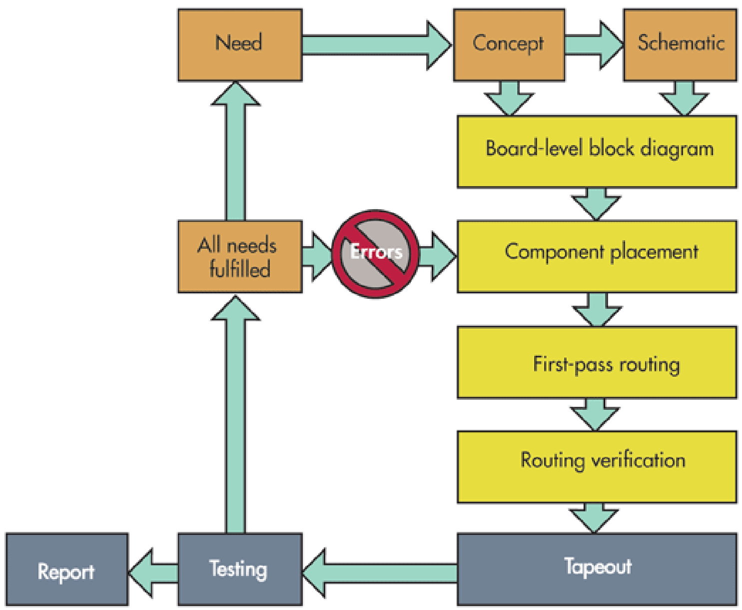


Figure 3.7.2.b

We need to follow all of these steps including the testing to ensure we have created the perfect printed circuit board for our system. Before we even build the board we will need to run software of PCB design controller to build our board on the computer and place all of the components and test the schematics on the computer before it gets built. Due to the lack of funding we are unable to test the board after construction and purchase a new one, so the design process must be very thorough to ensure that our design will work correctly and be the most efficient for our system.

Creating the board first digitally on the computer allows for easy access of moving components around finding the most efficient placement for the wires. Testing the board before we actually construct it will prevent the need for a redesign later on in the building process of the project. An important thing to note about having to design a printed circuit board is the thermal index of the board and which components have high temperatures or are prone to damage when next to a very high thermal component. Following these steps we have discovered in our research will ensure that we will have the perfect printed circuit board for our system and everything will work correctly while constructed. This will provide us with low cost in purchasing the board, as well as a high sense of familiarity when the board is manufactured.

3.8 Analog to Digital Converter (ADC)

An analog-to-digital converter is a device that converts a continuous quantity like voltage into a digital number that represents the quantity's amplitude. This is a main feature of our entire embedded system and project because we are receiving voltage from our battery and other sources and need to turn it into amperes to be able to charge the phones. Since analog to digital conversion requires a quantization of the input source there is usually a degree of error that comes with the conversion. To prevent further errors, analog to digital converters usually perform the conversions periodically throughout the length of the signal. The result from the analog to digital converter is a sequence of digital values which represent a discrete-amplitude digital signal. Analog to digital converters are often characterized by its signal to noise ratio and how accurately it can measure a value from an input signal relative to the amount of noise it introduces in the system. When measuring noise, the analog to digital converter is often summarized with the number of bits it returns that are on average not noise, or effective number of bits which is sometimes abbreviated ENOB. When you have an analog to digital converter, the main goal is to achieve perfect reconstruction within the device, which happens when the analog to digital converter operates at a sampling rate that is greater than twice the bandwidth of the signal. The output of an analog to digital converter is usually represented by a two's complement binary number that would be proportional to the input signal voltage.

Converters usually work in terms of resolution, which refers to the number of discrete values it can produce over the range of analog values. As stated above the result is usually stored as a two's complement binary number, so the resolution is most usually represented as bits. The quantization error is determined by the resolution of the converter and the those two are used to get the signal to noise ratio. If an analog to digital converter has a resolution of 8 bits then the converter can encode 256 different analog input levels since 2 raise to the 8 (bit) power is equal to 256. With the range of 256, the actual values can vary on whether or not the device is signed or unsigned. If it were signed then it could go from -128 to 127 and unsigned would be from 0 to 255. The resolution is usually expressed as the variable Q and resolution can be expressed electrically as well, in which you would find the minimum amount of voltage change that would be required to change one of the output bits or levels. The voltage resolution can be expressed using the equation below,

$$Q = \frac{E_{\mathrm{FSR}}}{2^M},$$

where Q is the resolution and M is the number of bits in the resolution (8 in the aforementioned example) and the E_{FSR} is given in this equation:

$$E_{\mathrm{FSR}} = V_{\mathrm{RefHi}} - V_{\mathrm{RefLow}},$$

where the two V values are the extreme lower and upper bounds of the set of voltages that can be coded.

The quantization error that has been mention is the amount of noise that is introduced into the system by quantization in the ideal converter. The error comes from rounding the values from the input voltage and the output digitized value. The goal is to get the error to be as small as possible, and in an ideal analog to digital converter the error is distributed between -½ of the least significant bit and ½ of the least significant bit. If the signal error is distributed uniformly between these values, then you can calculate the signal-to-quantization-noise ratio which is abbreviated as SQNR. The equation to calculate the SQNR can be found below:

$$\mathrm{SQNR} = 20\log_{10}(2^Q) \approx 6.02 \cdot Q\ \mathrm{dB}$$

where Q in this equation is simply the number of quantization bits. To increase this signal to noise ratio, you can oversample the system and using noise shaping can force more quantization error out of the band and thes increasing efficiency. The other big factor of error in ADC are non-linear errors. These are caused by physical imperfections in the device, but can mitigated through vigorous testing as well as calibration. Integral Non-Linearity and Differential Non-Linearity reduce the effective resolution by the converter by reducing the dynamic range of signals that can be digitalized.

When getting an analog to digital converter commercially, you usually must purchase ons as an integrated circuit and most converters use a sample between 6 and 24 bits of resolution. Commercially the converters have somewhere between -½ to ½ of the least significant bit error to -1 ½ to 1 ½ of the least significant bit, so there is a big range of errors in the commercial purchasing of a converter. The amount of pins is the most correlated value of price when it comes to purchasing a converter, as each added pin increases the size of the converter. In order to save space, pins, and cost, it is common for an analog to digital converter to sent their data 1 bit at a time over a serial interface to the computer. Most converters also have many inputs that feed together through the use of a multiplexer, and they are commonly used for musical recording and digital signal processing. We would be using the converter for digital signal processing to store and virtually transport the signal in a digital form to the LCD display.

A basic visualization of how the analog to digital converter changes the signals can be shown in the picture below.

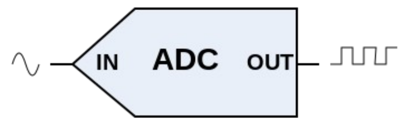


Figure 3.8.a

3.9 Sensors

3.9.1 Voltage Sensors

The important thing in a voltage sensor is that it can accurately and reliably detect the presence of voltage in a wire or in a piece of electrical equipment without making direct contact to that wire or equipment's capacitor. Most voltage sensors are very small and inexpensive. It is important to use a small device when sensing the voltage so that not much space is taken up in the main circuit board, where more space means more expensive. We need to use the voltage sensors to make sure we are sending the right amount of electricity to all of the parts of the system. As described below, LEDs current grows exponentially with increased voltage so it is important not to give too much voltage so you don't damage the LED.

When connecting certain sensors or resistors to a microcontroller you can program the microcontroller to output the amount of voltage through it by connecting to the right pins on the board. Many microcontrollers can read the amount of current or voltage through certain pin ports in the main board and thus can print those values out when the programmer wants them.

It is important to decide whether we want a device that can continually give us values for the voltage throughout the life of the system, or if there are distinctly different times when we would like to know the voltage before we transfer it somewhere else. This will decide which type of voltage sensing we would like to use in our embedded system.

3.9.2 Current Sensors

As with voltage sensors, the current sensor is used to show how much ac or dc current is in the system at any given time. This is important so we don't waste any current by sending a cell phone more than one milliAmpere when it can only handle one. It is important in making our overall system as efficient as possible by monitoring the amount of current going everywhere in the embedded system noting all of the required currents and actual currents and making the change if necessary. Current sensors will also help debugging problems of certain parts of the system not doing their job correctly, we can make sure it is getting the right amount of current.

Current sensors are relatively inexpensive and if we can find a current and voltage sensor together for very cheap we would go with the combined model. The sensor detects the amount of current in the wire or electrical piece and creates an electrical current signal of either AC or DC proportional to the current reading in the wire. Current sensors can even display things in a digital output which would then not require another analysis of the signal through an analog to digital converter which would save efficiency. The current sensors are designed using many different technologies such as a single resistor with voltage directly related to current, or the measuring of the electrical field around the wire. The design we are most interested in is one that can give us a high degree of certainty with low cost.

3.10 LCD Displays

An LCD display is a liquid crystal display that uses light crystals' light modulation properties to display images, however light crystals do not actually emit light directly. LCD displays use the same basic technology as 7-segment displays, except LCD displays images are made up of a large amount of incredibly small pixels, while a 7-segment display would use much larger display nodes. LCDs are used in a large number of electronic products through the world now including televisions, smart phones airplane cockpits, watches and calculators. In the television market, LCDs have basically replaced all of the cathode ray tube (CRT) displays due to the flat panel display and light weight. LCDs have the widest range of sizes of all of the screen displays out there, and LCDs are not susceptible to image burn-in like plasma displays are since they do not use phosphors. LCD screens are more energy efficient that CRTs and can also be disposed of more safely, and the low energy cost of LCD screens makes it optimal for small battery powered electronic devices. The low energy cost is very important in a product whose main focus is to provide a cheap alternative energy source to a variety of devices. Since the LCD display screens will be constantly displaying a small amount of images in the product, it is important that there is no image burn-in, as our product would need constant replacing of the screen.

Although LCD displays do not have image burn-in they are susceptible to image persistence which is a temporary version of screen burn-in. This is caused by the fact that liquid crystals have a naturally relaxed state, and when you apply a voltage to those crystal they rearrange themselves to block certain waves of light. This causes the liquid crystals to develop a tendency to stay in the same position, especially if they are being used over and over again in the same place and same color. This causes the color of the crystals and pixels to be off by a small amount, which looks similar to an image being burned in. The difference however is that this isn't permanent and to get rid of it all you have to due is get the liquid crystals back to their relaxed state. Another way of preventing this all together is to use a screensaver whenever you have an LCD display on for a long period of time.

The pixels in an LCD display usually are made up by a layer of molecules that are lined up between two polarizing filters and two transparent electrodes. If the liquid crystals were not in between the polarizing filters, than the light would be blocked by another polarizer. Since the actual LCD panels do not physically display, emit, or produce any light of their own, they require external light to produce the image on the screen. When LCD displays were first introduced they primarily used a Cold Cathode Fluorescent Lamp to spread light across the display, but currently most LCD screens are designed with LED(light emitting diode) backlight. There are two versions of LED lighting for LCD displays called WLED and RGB-LED. WLED is made up of a full array of white LED placed behind the LCD panel and the panel has the ability to dim the brightness of the LEDs if they need to. RGB-LEDs are very similar to WLED but instead of a matrix of white LEDs they have a matrix of RBG-LEDs behind it. RBG-LEDs have the widest color scope of all of the LCD displays and are primarily used for professional graphics editing and can be very very expensive. Due to the cost of RBG-LEDs and the absence of need for intense color spectrum, we will not be going with WLED lit LCD display.

Advantages of LCD displays are that they are very small and light and use minimal power and electricity. This is very important as our system is designed to be light and small, and maximize the energy efficiency. Since the LCD has a very low power consumption and uses little energy, the amount of heat that is dissipated from the screen is also minimal. LCDs also emit less electromagnetic radiation compared to CRT monitors which is important for public safety and the people who will be using the product. One downside of the LCD is that sometimes images can be hard to see if someone is wearing polarized sunglasses. The fact that this product is intended for some outdoor use might cause some visualization problems to people wearing a particular type of sunglasses while trying to use the product. The LCD displays also lose a bit of contrast when they are in high temperature areas for an extended period of time. Although image quality and color spectrum are not of utmost importance for the product, it is still important to note that this could cause a concern.

3.11 LEDs

Our project requires multiple LEDs to indicate whether the phone in the station is done charging or not. The light-emitting diodes that we will be using will be of the colors red and green. LEDs have very low energy usage which is important to our overall system because we are trying to minimize the energy used to have the cheapest most reliable and most efficient system. LEDs are very cheap until you are using them to light up an entire room with only LEDs. We will be using small LEDs which will be very cheap to have 6 as part of the overall system. Although many LEDs are now used for displaying text and numbers, such as in 7-segment displays, due to their fast switching, we will not being using them for this purpose.

LEDs can come in a variety of different designs ranging from just one color, to bi-colored and even tri-colored LEDs. Our system will only be using two very basic common colors for our LEDs so it is important to note that there will be LEDs that we can buy that will display both of these colors in one LED and remove the need to purchase two different ones in order to display the two different colors. Bi-colored LEDs that we can use can come in two different families. We can have a bi-colored LED that where the two dies are connected to the same two leads, which uses the direction of current to decide which color to display, or bi-colored LEDs that have separate leads for each die which would let them be controlled independently.

The current of bi-colored LEDs is around 20-40 milliAmperes and takes up approximately 5 millimeters. LEDs also typically have a lifespan of around 50,000 hours of use which would relate to 14 years of using the LEDs for 10 hours a day. This length of life is good for the sustainability of the system and would require replacement much less frequently than other types of lighting sources. LEDs current are dependent exponentially on the voltage of the LED which can cause problems when a small amount of change in the forward voltage would translate to a large amount of change in the forward current which, if over the forward current limit, could damage or even destroy the LED. To avoid this we would likely need to use a constant current supply instead of having some variable amount of voltage going to the LED.

Since the LEDs use less energy and power than normal incandescent lights, they also emit less carbon dioxide and thus the footprint of an LED is less than that of a normal incandescent light. While an average 40-watt light bulb will emit 196 pounds of carbon dioxide in a year, an LED in that same time frame will only average 30 pounds of carbon dioxide emissions. This is very important for us when designing our system because we are environmentally friendly and try to make all of our decisions be the least damaging to the environment.

3.12 LCD Touch Screen Display

Touch screen displays are visual electronic displays that the user can control through the use of multi-touch gestures of one or more fingers, as well as special stylus' created for the touch screen. The touch screen display takes out the need for some type of device for control of the system and allows the user to just use the screen directly with their hands. This will limit the power consumption since there will be no need for a mouse or touchpad, and thus no waste of power to such devices. Touch screens are currently used in a variety of uses such as smart phones and tablets, as well as ATM machines, so many of our customers will be already familiar with the technology and have a small learning curve.

Resistive touch screens are made up of several layers, and most importantly have two thin, transparent electrically-resistive layers. The two layers face each other with a small gap in-between and when pressed upon by a finger, then the two layers become connected and reactive to each other. Resistive touch screen display panels are most commonly used in restaurants and factories due to the high resistance of liquid. A resistive touch screen would be a good idea for the product since it could be displayed outside and people would be carrying drinks with them so water contact would be high probability. However a disadvantage is the need to press down on the screen to connect the two layers.

Another popular version of touch screen displays are capacitive touch screens which consist of the glass coated with an invisible conductor like indium tin oxide. The conductor uses the human body like an electric source and that causes a distortion in the electrostatic field of the screen which is then recorded and measured as a change in capacitance of different areas of the screen. A key difference between capacitive and resistant touch screens are that capacitive touchscreens cannot be used with gloves on, as it relies on an electrical conductor of the human body to notice the touch input. Recently, companies have been creating even smaller capacitive touch screen displays by building the capacitors inside the actual display itself, thus removing a layer. Below is a picture of a capacitive touch screen reacting to a touch gesture. You can see the capacitors detecting the change in the electric current where the finger is on the screen.

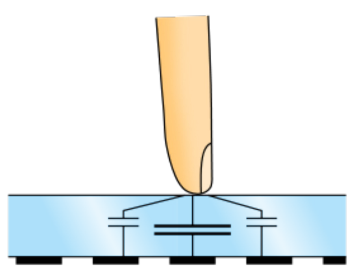


Figure 3.12.a

Multipoint touch screens have been built recently to allow for reacting to multiple touch gestures simultaneously, but these are more expensive for the same size screen. The product will not have a need for multiple users on one touch screen at a time, so in order to save cost the engineers will probably not use a multipoint touch screen display. The touch screen display will be for the user interface of the system allowing a customer to click buttons to initiate tasks on the screen.

3.13 Cell Phone Power Requirements

The team needs to replicate the power requirements needed to quickly charge a cell phone battery. There are four types of cell phone rechargeable batteries. Beginning with the newest technology, they are Lithium Polymer (Li-Poly), Lithium Ion (Li-Ion), Nickel Metal Hydride (NiMH), and Nickel Cadmium (Ni-Cd).

Official Name	Common Name	Fast Charge	Advantages	Disadvantages
Lithium Polymer	Li-Poly	• 2 - 4 Hours	• Newest, most advanced technology • Lightweight, • Does not suffer from "Memory Effect" • Provides more power • Can be used in thinner cell phones	• Battery sealed in a pouch, not standard case; cell phone using Li-Poly will be sealed to prevent punctures • Needs to be recharged more often • More expensive to make
Lithium Ion	Li-Ion	• 2 – 4 Hours	• Lighter • Longer discharge time • Most currently used battery • No "Memory Effect"	• More expensive • Can overheat if charged over 24 hours • Heavier than a Li-Poly • Fragile; protection circuit is required to assure safety
Nickel Metal Hydride	NiMH	• 2 – 4 Hours	• Slower discharge • Safer for the environment • Less prone to "Memory Effect"	• Older technology • Must be fully discharged before recharging to prevent crystallization • High discharge rates • More expensive
Nickel Cadmium	Ni-Cd	• 1 Hour	• Rugged • Economical • Fast charging • Holds charge	• Faster discharge technology • Unsafe for the environment • Primarily in cylindrical shape

				• Suffers from "Memory Effect"

Table 3.13-1 Current Cell Phone Battery Types

Though the power necessary to charge any of these batteries could be almost any source from 1 Watt to 5 Watts, it is the voltage that is crucial. Understand that using fewer watts would result in lower current and less charge coming into the cell phone, causing a longer charging time. Wattage should be between 3.5 and 7.5 W, and a steady DC output voltage of around 5 V would provide a sound charge to any cell phone using the UniverSOL.

We need to create a power system that takes generated solar power, stores it into a battery system, uses a transformer or a converter to generate a steady and regulated DC output power supply, and have that power the charging system of the UniverSOL and supply charge energy to the users' cell phones.

Cell phone rechargeable batteries have a reputation of being difficult. Some are slow, over-heat or burning out if charged for too long, or do not fully charge. This depends upon the battery being used in the phone, and a challenge we need to address. One major problem with most cell phone rechargeable batteries is the "Memory Effect." "Memory Effect" is the phrase used to describe when a certain type of rechargeable battery is recharged without being fully discharged. This causes the battery to configure to a shortened charging cycle, and leads to reduced charging capacity. Complaints then arise of cell phones never completely charging, or the cell battery quickly expires.

3.14 Cell Phone Charge Cables

3.14.1 Central Universal Serial Bus Hub

UniverSOL is designed to charge multiple cell devices fast and securely, by utilizing solar power energy harnessed from a solar panel. To be able to provide high-speed and robust charge, the team decided to pursue a central hub design with multiple ports, each with a universal serial bus (USB) cable to each charging locker. Our determinants: speed, reliability, and cost, factored into this decision. We also needed high-powered multiple port USB hubs, that has the ability to receive AC current from the battery. These factors lead us to two possible candidates for consideration.

Photive PH-50W. The first is by Photive PH-50W. The 6 port USB rapid charger is compact, has overcharge protection to charge safely without over heating or damaging devices. It provides 50 watts and 10 amps of power among the six ports. Photive developed Advanced Intelliport Technology that identifies the cell

phone and provides maximum power it needs for a speedy charge; it is compatible with Apple, Android, Blackberry, and other technologies.
The cost is $29.99 plus shipping.

Bolse 7-Port Fast Charger. The second consideration is the Bolse 7-Port Fast Charging USB Charging Station. It has 60W with 5volts and 12 amps across the seven ports, and boasts to be Bolse uses its SmartIC Technology which regulates by distributing the correct charge to each cell device individually and simultaneously, automatically recognizing what you have plugged in with our micro smart chip. Once the battery is full, charging will automatically stop for that specific device. With various manufacture devices plugged in, each one will receive an OEM quality charge, which is the best possible in terms of speed and effectiveness. Each port is equipped with an over current, over voltage, and short circuit. The cost is $35.99 with free shipping.

Proceeding forward, the team choose to utilize the Bolse with the seven ports. Though we will use six for the six charging lockers, the seventh port will be available if our other components need to be charged, such as the touch screen.

1) 8-Pin Lightning for i5/5s, i6
2) 30-pins for i3GS, i4, i4S
3) Micro USB GALAXY S3 S4, Note 2, HTC, SONY, Most Android phones.
4) A special charging plug for S5, Note 3

3.14.2 Universal Serial Bus Cables

In our research, we found out that not all universal serial bus (USB) cables, chargers, and connectors are created equal. This supports our observations that certain PC USB outlets were faster chargers, or one USB cord charged faster than another, or a replacement wall charger was painfully slow compared to another generic wall charger. In our research, we considered costs, reliability, and rate charge our USB cables would provide.

There are three USB specifications: USB1.0, USB 2.0, and USB 3.0. USB 2.0 is what is sold and used in most house-holds. Evaluating a USB 2.0 cable for our needs of speed, durability, and cost, we considered using USB 2.0 28/24 awg cable for the UniverSOL. AWG, or awg, means American Wire Gauge and it designates the size of the copper wire being used.

Most aftermarket USB 2.0 cords had 28/28 awg, and are slower in charging cell devices. The reason is what the numbers mean. The first number is the gauge of wire for data transfer, and the second number is gauge of wire for charging. A 28 gauge wire is narrower and thus does not provide a fast rate for charging. On the other hand, the 28/24 awg is has a 24awg wire, which is 60% thicker than

28awg, and able to handle 2amps of charge. The USB 2.0 28/24 awg is a serious consideration.

However, for our high-powered charging station, the team examined the research on the SuperSpeed USB 3.0. USB 3.0 offers increased transfer rates of up to 4.8Gbp; that is ten times faster than the USB 2.0 28/28 awg can offer. USB 3.0 also offers increased maximum bus power, improved power management, and new connectors and cables that facilitate the higher transfer speeds and additional power. USB 3.0 is able to moves up to 900mA (0.9A), and charging downstream and dedicated charging ports provide up to 1500mA (1.5A). Its connectors also offer backward compatibility for USB 2.0 connectors, which are important in the design and decisions of the Charger Cable Outlets.

Some of the research came from the USB Implementation Forum, Inc., (USB-IF) which is, "…a non-profit corporation founded by the group of companies that developed the Universal Serial Bus specification. The USB-IF was formed to provide a support organization and forum for the advancement and adoption of Universal Serial Bus technology. The Forum facilitates the development of high-quality compatible USB peripherals (devices), and promotes the benefits of USB and the quality of products that have passed compliance testing."

USB-IF issued a white paper on February 1, 2013, on, "Managing Connector and Cable Assembly Performance for USB SuperSpeed." SuperSpeed is another name for the USB 3.0 cable. The white reviews various reasons and possibilities why the current USB 3.0 cables are not performing to expectations, and experience significant data and transmission loss.

Since the white paper was produce, reliability in the USB 3.0 has increased and more people choosing this technology. The cost is minimally more than a USB 2.0, and there is within budget. The durability and reliability of current USB 3.0 is dependent upon a reputable supplier with a history of quality products. The team is choosing to go forward with the USB 3.0 SuperSpeed cables because of the increase in quality, the increase of reaching the 5 GB speeds, but will pursue the cable purchase through a reputable on-line supplier in the event there is a failure.

One aspec of the USB 3.0 to consider is whether to pursue the standard or the gold platted outlets. The condsiderations again are speed, durability, and cost. Seems according to the internet research that gold connections help retard corrosion and assists in data transfer. Since we are not concerned with either in the build of the UniverSOL, we will use the standard outlet ends. [2]
Within USB Cables, there are numerous outlets available: A/A for hub-to-port connects, A/B for data transfer, and A/Micro-A for charging of peripheral cell devices, as well as male-to-male, male-to-female, and female-to-female.   In our instance, we will be using the A/A, male-to-female outlets from our central USB Hub.

Once the team decided upon the USB 3.0 SuperSpeed cable with the Male-to-Female A/A outlets would be used in the construction of the UniverSOL prototype, we pursued various suppliers. The USB-IF advises to purchase USB 3.0 cables from a reputable supplier for best reliability. Local suppliers Best Buy and Office Depot did not have the needed cables in-stock, and directed us to their websites. However, costs of their cables exceed our budget and we chose to continue to look elsewhere.

Amazon.com provided the most suppliers and the most reviews. The team felt comfortable ordering products from them, and chose to proceed with the six Amazon Basic 3.0 cable in 1 meter lengths. This length will provide enough surplus cable to effortlessly connect the multi-connector plug in the cell to the USB 3.0 hub.

3.14.3 Voltage Management

The UniverSOL will allow the users to know when their cell phones are still charging and when the charging is complete. In order to do this, we need to confirm current is coming into the connected cell phone, monitor the current coming into each phone, make sure that the phone is not receiving too much current as to burn out the battery, stop the current flowing into completely charged phones. A voltage monitor is critical at this step, and the team chose the original Charger Doctor for this task.

The original Charger Doctor is a USB device that allows you to view voltage and amperage that a USB device uses when plugged into a computer or a wall outlet. The Charger Doctor unit allows 3.5 to 7.0 volts, and measures 0.0 to 3.0amps, with a deviation of plus or minus of 1-2%, so it is fairly accurate. It has a male-input power that plugs into the female USB power source, and a female output port to plug in the USB cable multi-plug connector.

Internally, the Charger Doctor is components are comprised a screen with four seven-segment display, USB power in plug, USB power out port on the one side of the board. On the back, is a programmed PIC microcontroller chip, a decoupling capacitor for the microchip, a transistor, two resistors, and a really big resistor labeled R050 which is a 50 micro-ohm current sensing resistor that allows the microchip to calculate the amount of amperage the unit is using. This ability to calculate the amount of amperage and thus determine when the cell phone is completely charged, will be used not only to confirm the cell phones are charging, but as a switch for the LED Notifier.

3.14.4 Universal Charging Connectors

The team is planning on using a 4-in-1 USB charging cable sold by COTTEE on Amazon. It supports: Apple Lightning 8 pin for iPhone 6 plus, 6, 5S, 5, Lightning 30 Pins, Micro USB, Compatible for Samsung Galaxy S5 and Samsung Galaxy Note 3,, Multiple Charging Cable for iPhone 5S 5C 5, iPhone 4s 4, iPad 4 3 2, iPad mini, iPad air, Samsung Galaxy S5 S4 S3, Note 2, Note 3, Most Android Cell Phones, Tablets and Devices. Each cord is $8.99 and the rating is high for reliability and durability.

The USB end is five inches in length, would remain behind the charging compartment connected to the other USB end leading to the hub. The remaining four chargers would go through the cable access grommet and into the charging compartment. The 4-in-1 would allow most charging choices for each compartment, thus making each of the compartments universal charging stations.

Image 3.14.4-1 4-in1 USB Charging Cable sold by COTTEE, permission pending

3.14.5 Diagram of the Cell Phone Charging System

Within this section, the team is providing a system diagram of the charging cables, listing the possible parts and components that will be used in the UniverSOL. The columns are organized by Systems: Solar Power System, Cell Phone Charge Cable System, and the Cabinet Case System. The Cabinet Case System breaks out into three parts of the Cell Phone Charge Cables that will be within each locker: Charger Doctor, COTTEE 4-in-1 Charging Cable, and the LED Notifier. This flow Phone Locker and Unit Housing system. The tables consist of generic parts lists based upon our preliminary research. As the Project progresses, the parts list may receive revisions, with the final parts listed in Section 6.1 Parts Acquisition. Also, the costs provide are inflated estimates so we remain within budget.

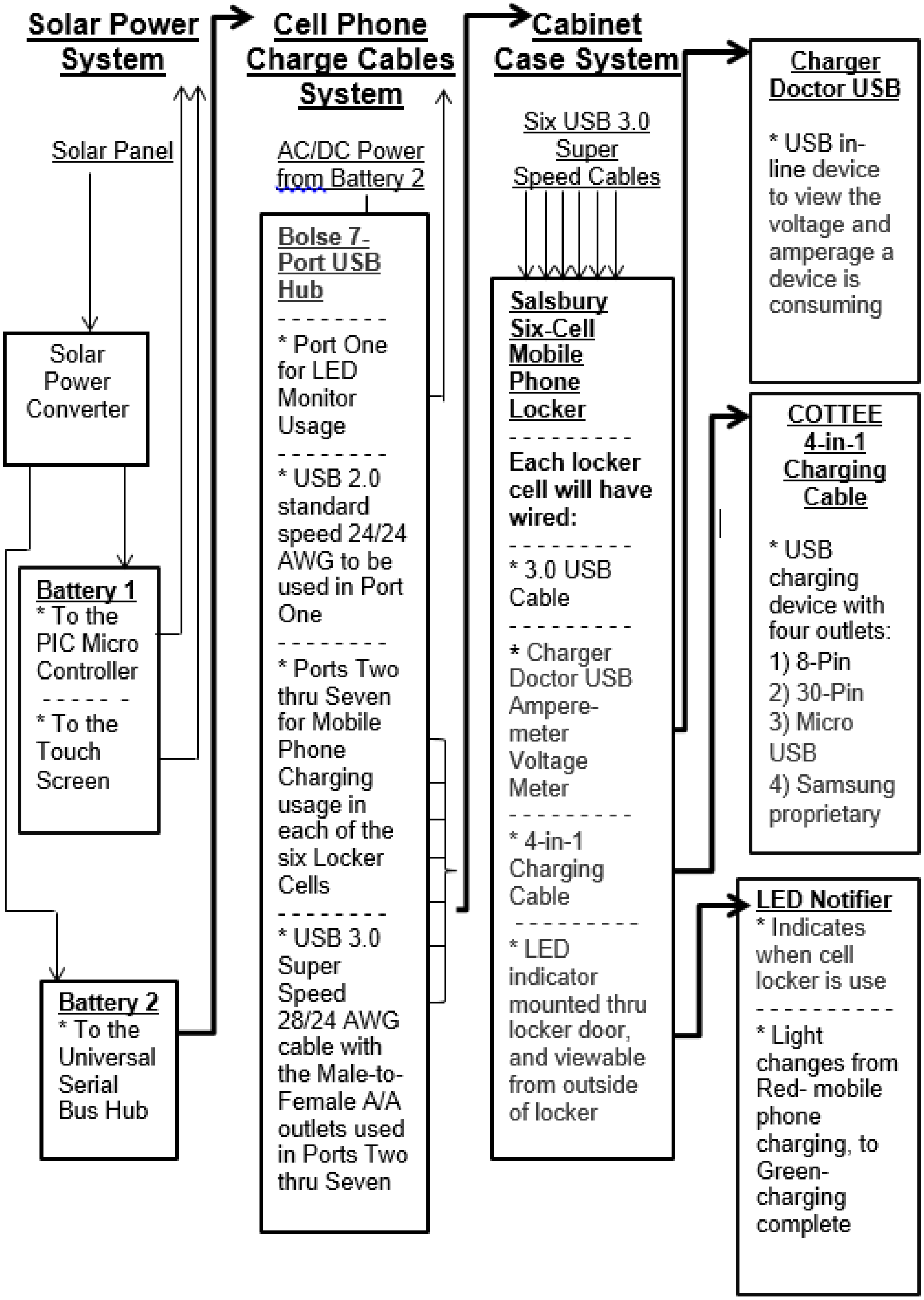


Figure 3.15.5-1

3.15 Cabinet Case Structure

The case surrounding the UniverSOL depends upon the components used to physically build the UniverSOL. The largest physical component is the cell phone locker. Much thought and discussion has been put into this, as this will determine the shape and scope of our project. The locker units other attributes were discussed and researched, as they are important to the final production of the UniverSOL: the number of cells, the dimensions of each cell, mounted or recessed unit, made of aluminum or another metal, weight considerations, locking capabilities, color, and cost.

After this key component is determined, the rest of the systems (Solar Power, Battery Power Supply, Touch Screen, etc.) will be able to be built around the lockers. The team then will be able to design a cabinet case to enclose the physical components and make the UniverSOL very presentable.

3.15.1 Current Cell Charging Locker Technology

Our first research was on other products out there; we wanted to see where is the current technology and how is it being used. The team studied their designs, looking for components, elements, and workings that may work with our design, We also discussed areas that we could possibly improve upon, as well as factors that were either not reasonable for the UniverSOL.

Our research revealed that there are not very many solar powered cell phone charges. The ones that are solar powered either 1) do not offer security, or 2) are huge, offering 48 cell phone lockers. We were surprised that the ability to see if your cell phone has been charged is limited, since that is the purpose of using the cell phone charging locker.

Therefore, we agreed the requirements and options of the UniverSOL cell phone locker are: have 5 to 6 locker cells; each cell is secure with a keyed lock; each door has a window; each cell has ability to be wired for an LED and charging plugs; each locker will be able to charge most cell phone technologies within the past ten years. The team also agreed that each cell should be larger enough to accommodate the more modern and larger cell phones, and the LED should not only illuminate the cell, but turn on when the cell phone is connected, remain red while charging, and turn green when the charge is complete.

Existing Technology Company	Pros	Cons	Takeaways

GoCharge www.gocharge.com	- Various styles, but we looked specifically at "Hawker" - Locker door window - 6 universally compatible compartments - 17"touch screen for ads - Easy to use - Portable - Located in USA	- Not solar - Universal card reader charges users - No keyed locks - Charge card locks and unlocks - No LED in each locker, - Unable to tell if phone is completely charged	*** Lockers are vertical** *** 6 Universally compatible compartments** *** Locker, window door** **NOT Solar** **NO LED** **NO Card Reader**
ChargeBox www.chargebox.com	- Large screen for advertising - Keyed lock - Free to the user - Easy to use - Permanent locations - Location app to find nearest box	- Not solar. - Each cell supports a single brand of cell phone - Only 30 mins of charge - No window - 5 doors on each unit	*** Lockers are vertical** *** Free to user** *** Locations app** **NOT Solar** **NO Locker Door Window** **LIMITED to 30 minutes** **NOT Universal in each locker**
ChargeCube www.chargecube.us	- Free to use - 6 lockers able to charge 98% of current technology - 17inch for ads - How-to video shows cabinet organization - Locked door window - Keyed lock - Located in USA	- Not solar - No explanation on the purpose of the small touch screen - No LED light in each cell - Unable to tell if cell phone is charged	*** Lockers are vertical** ***Free to use** *** Almost universal compatibility** *** Window locker doors** ***NO idea of what the small screen is for** ***NO LED**

Table 3.15.1-1 Current Cell Phone Charging Technology Companies

3.15.2 Cell Phone Lockers

Now that we know the details of what we need from a cell phone locker, we began the search for a locker unit that will suit our needs. There are cell phone lockers available in various sizes, mounted or recessed, various cell compartment dimensions, and with various locking mechanisms. We are determining which configuration would work best for the UniverSOL: 1

compartment wide by 5 compartments tall, or 2 compartments wide by 3 compartments tall. The determination of the locker configuration will influence the design of the UniverSOL.

Three manufactures for each configuration will be reviewed. The team is pursuing the cell compartments with a longer depth, along with a window for viewing and may need to cut it out ourselves if this is not an option in both configurations. Each compartment will need an access point for the charging cables to come thru and be accessible to charge the cell phone. Both cost and availability are considered as well.

One additional five-vertical locker manufacturer may be considered. American Locker custom builds cell phone lockers with charging adapters and possibly a window. A request for a quote was submitted to them and we are waiting for their response. Once we receive their data, we may consider their design.

3.15.2.1 Manufactures of the Vertical Configuration

The vertical configuration is one compartment wide and five compartments tall, and will be mountable so as to attach the UniverSOLs frame. The team calls this the five-locker configuration.

First is Hallowell. Their five-locker vertical configuration is constructed of 20-gauge steel. The door is a single sheet of 20-gauge steel, non-ventilated, no window, and will be keyed with a cylinder cam lock. They will provide two keys for each lock.. The hinges are continuous piano hinge securely welded to the door and riveted to the frame. The entire unit is painted light gray and heat treated to prevent rusting. The overall dimensions are 9.0”W by 31.5”H by 12.0”D, and weighs 24 pounds. The unit comes with a two year warranty against defects in materials and workmanship, sans the finish and deliberate vandalism. However, there is no opening in the rear of the each locker to allow charging cables into the compartment; so we would have to modify the locker, and that would nullify the warranty. The cost is $255.75 including shipping; item is shipped by five days of ordering, shipped by ground with a time of about 5-7 business days, and is distributed by Grainger.

Florence Manufacturing produces and sells under the name Mailbox Works. Their five-vertical locker is constructed from heavy gauge anodized aluminum and comes in a choice of the original aluminum or ten other powdered-coated finishes. Each compartment is 8.0”W by 5.0”H by 6.4”D, and the entire unit is 9.56”W by 28.0”H by 7.5”D. The unit weighs 30 pounds. Each door does not have a window, nor is there access in the rear of each compartment to allow for cables. Mailbox Works website states they can help customize your order; we will ask if windows or cutoff to allow for a window can be designed into each door, as well rear wall access opening to allow for cables into the compartment. There is no mention of the costs for customization. However, item will be shipped six weeks after receiving order. The cost is $285.80 and includes shipping.

The third is www.SchoollLockers.com, a division of Jorgenson Industrial. Their five compartment vertical cell phone locker unit is overall 9.0”W by 30”H by 9.0”D, with the compartments being 9.0”W by 6.0”H by 9.0”D. The locker is made with 16-gauge steel; the doors have piano hinges, and come with a powder-coated beige color. Keyed locks come standard, and altogether weighs 24 pounds. The item ships approximately six to eight days after payment is processed, and shipping is about 4-7 days by ground. The cost is $139.11 plus shipping by ground from Nevada to Florida, and estimated $35.00, so we estimate $175.11.

	Hallowell	**Mailbox Works**	**School Lockers**
Cost with Shipping	$255.75	$285.84	$175.11
WxHxD Unit	9”Wx31.5”Hx12”D	9.56”Wx28’Hx7.5”D	9”Wx 30”Hx 9”D
WxHxD Compartment	7.5:Wx6”Hx11”D	8”Wx5”Hx6.4D	9’Wx6”Hx9”D
Weight in Pounds	24	30	24
Keyed Locks	Yes	Yes	Yes
Front Window	No	No, Optional Costs	No
Cable Access	No	No, Optional Costs	No
Delivery Time	10 -12 days	48 days	10 -18 days

Table –3.15.2.1-1 Five-Locker Vertical Configuration

3.15.2.2 Manufactures of the 2x3 Compartments Configuration

The other configuration we are considering is 2 compartments wide by 3 compartments tall, totaling six compartments. This unit will be mountable so as to attach the UniverSOLs frame. The team refers to this configuration as the 2x3 configuration.

The first is from Salsbury Industries, and their website is lockers.com. This model is made from aluminum, with aluminum non-vented doors and keyed locks. The compartment is 5.25”H by 6.5”W by 8.0”D; the entire unit is 17.5”W by 20”H by 9.25”D. This is a surface mounted unit, and would be secured into the frame of the UniverSOL. Though Salsbury offers three other colors, we will stick with gray. The unit weighs 20 pounds. The cost including shipping is $237.44, and would ship 10 – 14 days after payment clears, with a ground shipping method, the unit would arrive in about 17 - 20 days.

Salsbury has options on their website that other manufactures did not. An optional door with a window slot 5.5" W by .75"H is available for the model we were investigating. The cost is an additional $3.00 per door. This option is very good and convenient: it meets all of our needs as it allows limited, if not private, viewing of the cell phone inside the compartment, yet is wide enough to see if the LED Notifier has changed from charging red for ready-to-go green. We consider the user's privacy important, as the casual pedestrian cannot immediately see the cell phone in the compartment, and may deter possible theft, thus another level of security for the user.

Image 3.15.2.2-1 Optional windowed door from Salsbury. Permission pending.

The second option offered on the www.Lockers.com website is installed grommets for the rear of each compartment. This is specifically for cell phone charging lockers, and made for charging cables to enter from behind the unit. The 1 inch grommets would be installed at the factory for $5.00 each.

Image 3.15.2.2-2 Optional installed 1" grommet from Salsbury. Permission pending.

The total cost of the Salsbury unit with all options installed is $285.44.

Note that Salsbury has many distributors offering various pricing. One of them is Home Depot, and we investigated this option because instead of having the unit delivered and adding delivery costs, the unit can be picked up from the store through Home Depot's "Ship-to-Store" option, saving us some money.

Home Depot has the same unit for a cost of $210.00, with tax it is $222.60. This unit does not have the windowed doors nor the rear-installed 1" grommets. The Salsbury doors are $3.00 each ordered directly from Salsbury. The cost is $18.00, with shipping it is $29.35. Other suppliers charge the same amount per door, however shipping seems to be at a lower rate. If this unit is chosen, the team will pursue that option.

Salsbury doors are exclusive to Salsbury and will not fit other manufacturers. So if we decided on the Salsbury 2x3 configuration, we would utilize the doors. This is a very serious consideration, since any unit chosen would need to have a window in the door. To do this, we would most likely create it ourselves, or see if it is possible for the manufacturer to do it and if their labor is within our budget.

We are not pursuing the grommet installation option. At $5.00 for each grommet installation, the team believes this is too expensive and will pursue the installation ourselves. If another unit is chosen, we would need to install the grommet cable access opening ourselves.

Another vendor for Salsbury is www.budgetlockers.com. The locker unit we are researching and the windowed-doors for each compartment can be purchased through them. The same unit costs $225.83 with tax and shipping; this is more than Home Depot but less than buying direct from Salsbury. However, if we include the six doors, the total price is $244.89, which is less than both Home Depot and Salsbury.

The other manufacturer we are considering is Florence Manufacturing doing business as Mailbox Works. Their unit is made of heavy gauge anodized aluminum and comes in a choice of the original aluminum or ten other powdered-coated finishes. Each compartment is 8.0"W by 5.0"H by 6.4"D, and the entire unit is 17.56"W by 17.5"H by 7.5"D. The unit weighs 30 pounds. Each door does not have a window, nor is there access in the rear of each compartment to allow for cables. Mailbox Works website states they can help customize your order; we will ask if windows or cutoff to allow for a window can be designed into each door, as well rear wall access opening to allow for cables into the compartment. There is no mention of the costs for customization. However, item will be shipped six weeks after receiving order. Delivery will be 5 – 8 days. The cost is $377.49 and includes shipping. The four door model is $271.77 with shipping, and is closer to our budget, but we wanted five or six doors. This model is priced out of our budget.

	Salsbury Industries	**Salsbury Industries via Home Depot**	**Salsbury Industries via Budget Lockers**	**Mailbox Works**

Cost with Shipping	$237.44 $285.44 w/ all options	$222.60 $251.95 w/doors	$225.83 $244.89 w/doors**	$377.49
WxHxD Unit	17.5”Wx20”Hx9.25”D	17.5”Wx20”Hx9.25”D	17.56”Wx17.5’Hx7.5”D	17.56”Wx17.5’Hx7.5”D
WxHxD Compartment	5.25”Wx6.5”Hx8”D	5.25”Wx6.5”Hx8”D	8”Wx5”Hx6.4D	8”Wx5”Hx6.4D
Weight in Pounds	20	20	20	30
Keyed Locks	Yes	Yes	Yes	Yes
Front Window	No; $3 per door option	No; $3 ea. Self-installed	No, $3 ea. Self-installed	No, Optional Costs
Cable Access	No; $5 per opening option	No	No	No, Optional Costs
Delivery Time	20 Days	10-20 days	10-20 days	48 days

Table 3.15.2.2-3 2Wx3H Compartment Configuration

3.15.3 Case Cover

UniverSOL will have a metal case cover provided by Protocase. The case will house the main components of the unit, with the front allowing placement of our recessed touch screen and the recessed cell phone lockers, as well as the support beams coming out from the top rear of the case to support the solar panel.

The lower part of the case will be secured to our base, hiding the unsightly base and barely showing the caster wheels. The case will be secured to our frame with metal screws that will be countersunk and flush with the case. The case will also go through a wrap procedure, whereas a plastic film is applied to the entire case, providing protection and a more appealing, marketable product.

The rear of the case has two access doors. The first access door is for the top shelf. It will provide access to the components. The second access door is to allow access to the second and lower shelves. The door will have vents on the bottom to allow air flow to cool the batteries and the warmer components. The two shelve access will also allow for the ease of addressing the wiring of the UniverSOL.

Protocase has worked with other University of Central Florida Senior Design students in helping them accomplish their projects. The team contacted Kim Fudge, Account Manager of Protocase, and communicated our gratitude for their $400.00 sponsorship for our project, the UniverSOL. In the near future, once we have a solid design in place for the UniverSOL, we will connect with Ms. Fudge again and seek Protocase’s assistance.

3.15.4 Interior Structure

3.15.4.1 The Base

The base of the Cell Phone UniverSOL Charger (Cell Phone SOL) will be a custom built dolly. Made of four 2” by 4” boards, four swivel castors with locks, the frame of the base will be able to withstand the weight of the SOL, which is approximately 110 to 120 pounds.

The frame of the base will consist of two boards cut to a length of 18 inches, and the other two boards cut to a length of 12 inches. The shorter length boards will be secured on top of the longer boards, creating a flush corner, and secured together with two dry-screw nails in each corner. When completed, the boards will create an 18” by 12” rectangle.

For mobility, four casters will be attached to the bottom of the base rectangle, one in each corner. We decided on 2 inch swivel casters with non-marking rubber wheels with locking mechanisms. The depth of each is 3 inches, width of 2 ½ inches, and a height of 2 inches. The load capacity of each caster is 90 pounds, allowing our base a maximum weight load of 360 pounds.

The wooden frame of our base will be covered by our metal casing cabinet that will enclose the Cell Phone SOL. However, the casters will remain visible and accessible for transporting the project.

3.15.4.2 The Frame

The Cell Phone UniverSOL Charger (the Cell Phone SOL) will have a metal skeletal frame within the aluminum external case housing. The metal frame will support the weight of the SOL and provide organization for the components that make up the SOL. There may be metal shelving to add to stability and to place the components upon within the UniverSOL.

Estimated weight of all components will be approximately 120 pound. The following table 3.15.4.2-1 shows the components and their weights, given in pounds.

Major Components	Estimated Weight
Cell Phone Locker	20#
Solar Panel	20#
Two Batteries	20# (10# each)
USB Hub	3#
Touch Screen	6#

Metal Case	20#
Various Components	10#
Total Estimated Weight in Pounds	**120#**

Table 3.15.4.2-1 Breakdown of Component Weights

The frame will be of steel composition, with three shelves to support the SOL. Its dimensions will be 12 inches deep by 18 inches wide by 57 inches high. The supporting base is 6 inches, making the overall unit 5 feet, 3 inches tall, not including the solar panel. The rear two posts, however, will be 8 feet, 3 inches in height, and will be the support for the solar panel.

The shelves will be aluminum wire shelving and brackets, bolting directly into the frame. The first, or lower shelf, will be where the frame attaches to the castor base, ensuring stability and transportability. This shelf will house the batteries servicing the charging for the cell phones, power for the cooling fans, power for the USB hub, as well the power supply for the touch screen computer. The two batteries will store all power needed to operate the SOL. The first cooling fan will be mounted on the lower shelf along with both batteries.

The middle shelf will support the cell phone locker. The locker weighs twenty pounds empty. With additional weight of a maximum six cell phones, the charging wires and components, we believe the shelf will need to safely support a load of at least 30 pounds. Therefore, the shelf will be constructed by steel heavy gauge wire or a pre-formed steel shelf plate, and attached to the frame by brackets, bolts, and locking washers. As an added precaution, trestle supports will be added under the shelf, to provide added strength and stability, as well as security to prevent the fall of the locker with high-priced cell phones.

The third shelf at the top of the frame will house the touch screen components, the USB hub, and additional components for the solar panel. This area will contain the fragile hardware that drives the UniverSOL and the computer for the touch screen. Once again, the flooring will need to be secure and flat, so as the electrical components will not fall or become dislodged.

Note that though each shelf will be attached to the frame, the shelves themselves will not come all the way to the rear of the case. This is to allow clearance for the wiring to be pulled from one shelf to another without causing a blockage in service or confusion.

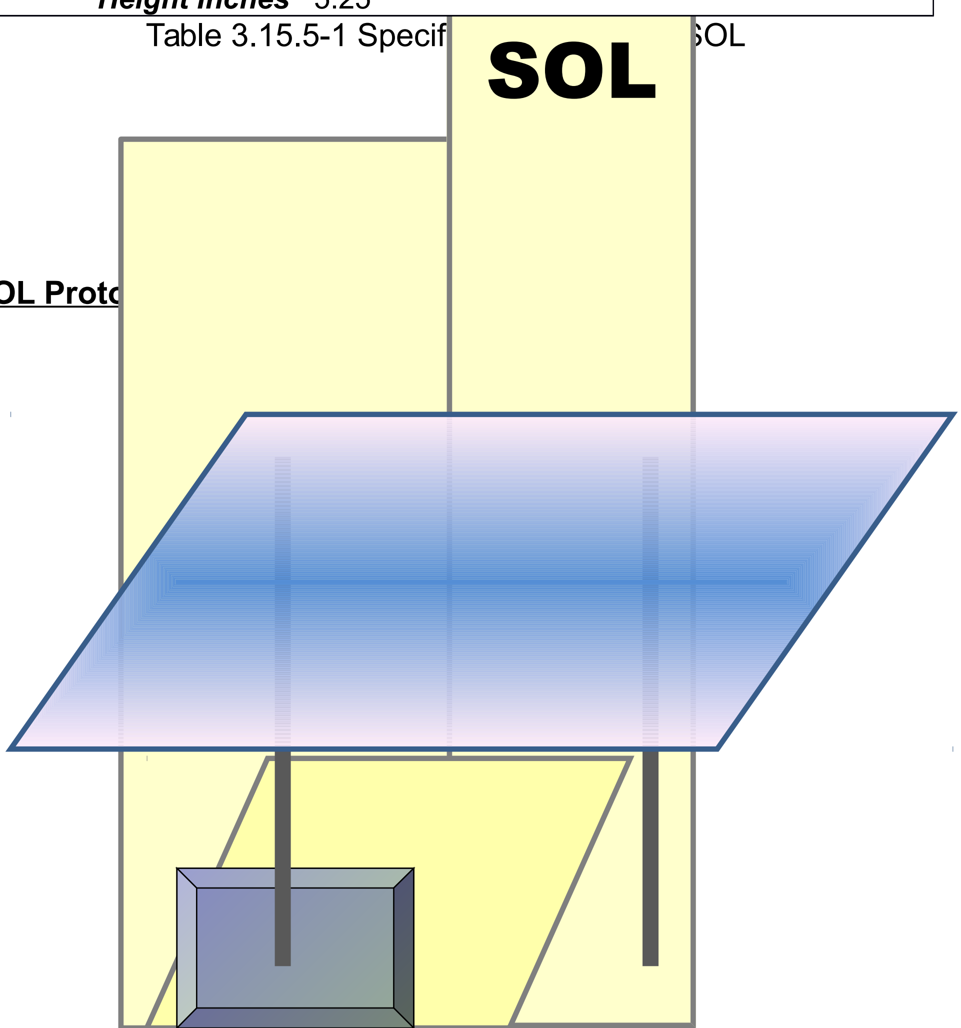
3.15.5 UniverSOL Prototype Specifications

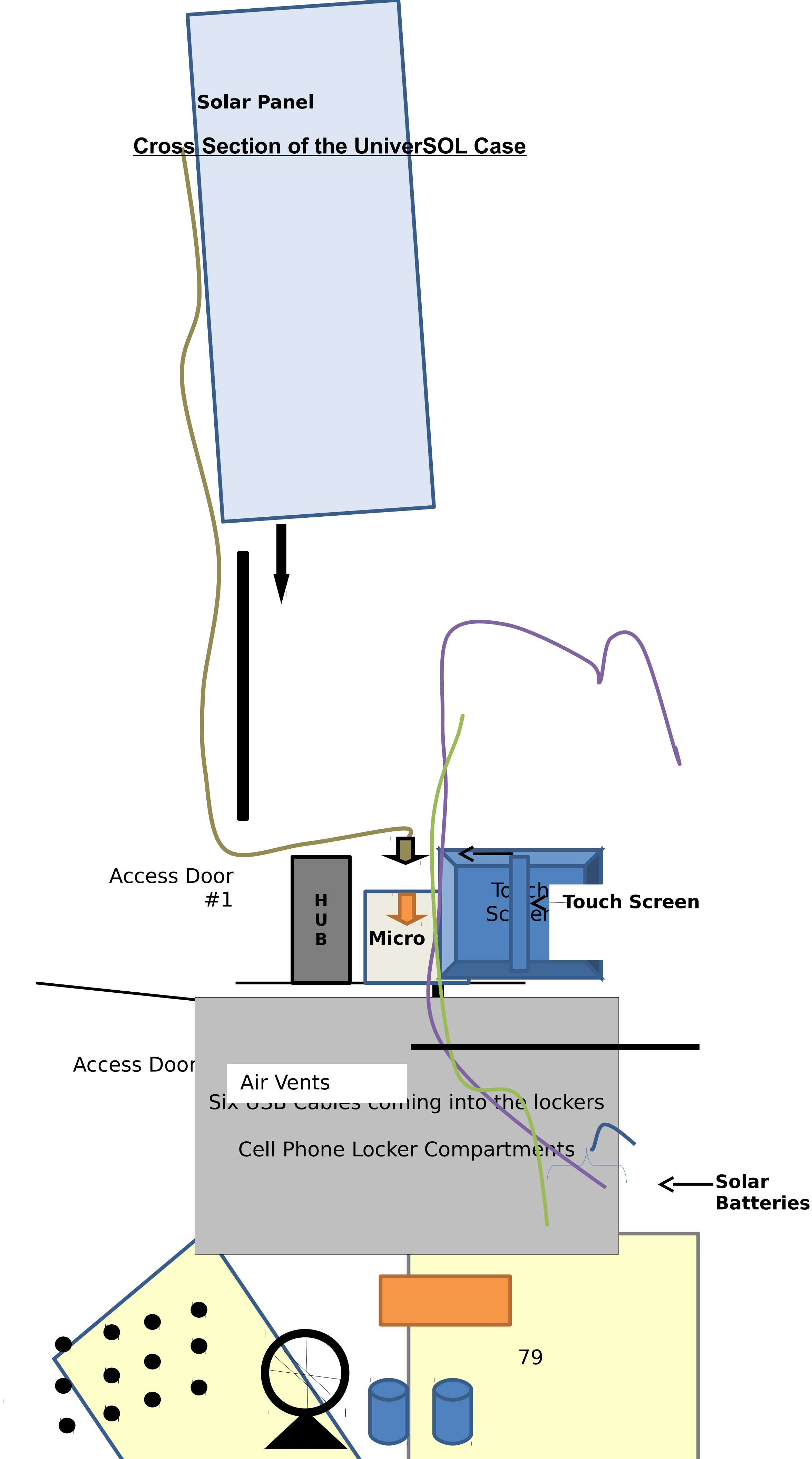
The specifications of the UniverSOL are show in the below chart. A prototype design of the UniverSOL as well as a cross-section diagram follows the chart.

• **Height Inches** 83.0
• **Width Inches** 42.0
• **Depth Inches** 22.0
• **Base Specifications** * ***Height Inches*** 53.0 * ***Width Inches*** 18.0 * ***Depth Inches*** 22.0
• **Touch Screen** * ***Width Inches*** 10.5 * ***Height Inches*** 8.5
• **Recessed Cell Phone Locker Unit** * ***Width Inches*** 17.5 * ***Depth Inches*** 8.75 * ***Height Inches*** 20.0
• **Cell Phone Compartment** * ***Openings*** 6 * ***Width Inches*** 6.5 * ***Depth Inches*** 8.0 * ***Height Inches*** 5.25

Table 3.15.5-1 Specif SOL

<u>**UniverSOL Proto**</u>




Solar Panel
Cross Section of the UniverSOL Case
Access Door #1
H U B
Micro
Touch Screen
Access Door
Air Vents
Six USB Cables coming into the lockers
Cell Phone Locker Compartments
Solar Batteries

4.0 Project Hardware/Software Integration

Vent Ho

Solar Power Converter

Based on the requirements established for the project, integration of electrical and computer systems is absolute. The enclosure with locking mechanisms technically accounts as a mechanical system, built in essence to support and house the electrical and computer components, but for these particular project requirements can be classified with the hardware components. In Figure 4.0-1, a System Outline of the components representing the hardware and software systems illustrates the top level structure of the PV System Electrical and Computer design. A detailed description, analysis, and design realization of the unification of these components is provided in the Design Summary Sections for both the Hardware and Software.

A

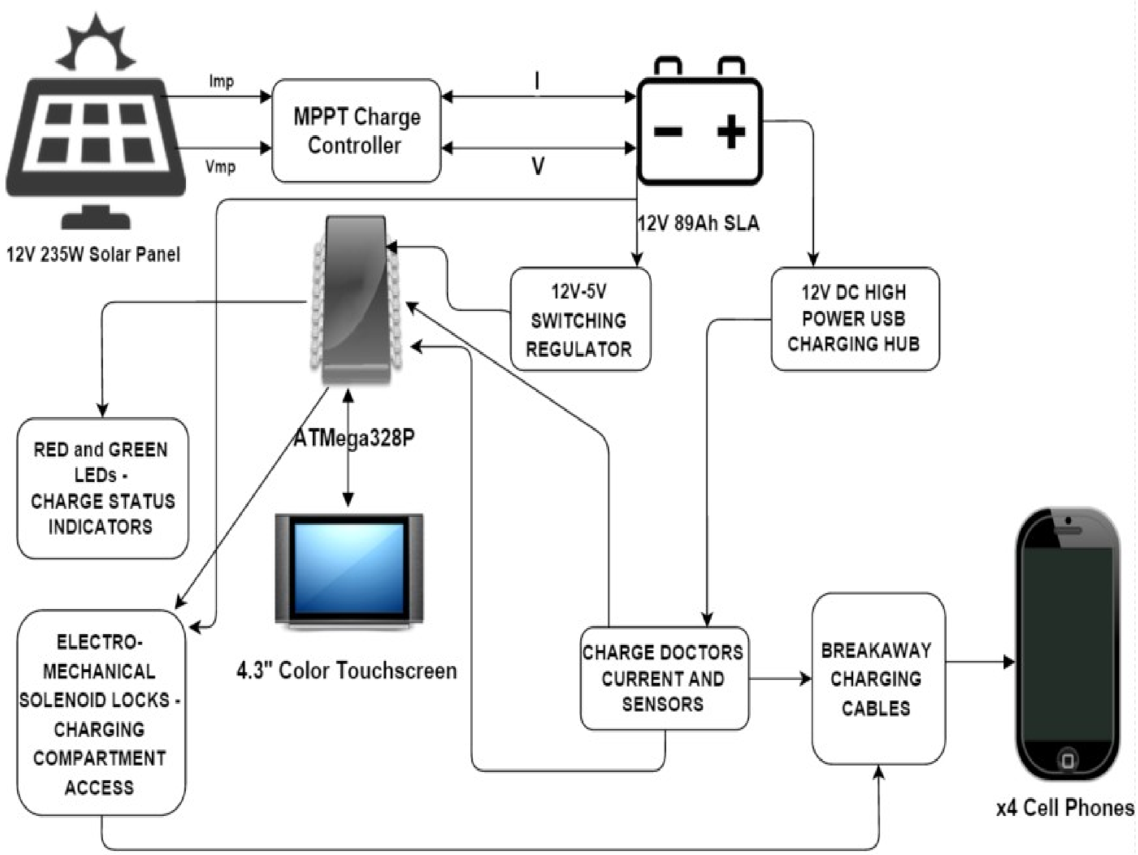


Figure 4.0-1 System Outline of Hardware/Software Integration

5.0 Design Summary of Hardware

Following extensive research among all aspects applicable to the design of UniverSOL Charge Station, hardware parts were designed for and selected. All of these components are interconnected through a network of modules that can be divided up into nested levels of power supplying, power receiving, power managing, and computing equipment. Individual hardware devices and relative subsystem models are highlighted in this section.

5.1 Power Supply System Management

The Power System network is comprised of a main hub that distributes power to the subsystems. The main system relies upon a 235 W solar panel to furnish all power for the off-grid project. The battery receives power from the panel, stores the energy, and relays it to all relying components by discharging into the subsystems. The MPPT charge controller is cable connected by 12 AWG wire in series between the solar panel and battery, and converts voltage and current of the received panel power to an acceptable 12 V battery supply. Exceeding 12 V results in overcharge of the battery and eventually will cause the battery to bubble up, emit gasses, and possible explode. An additional feature supplied within the MPPT charge controller selected is the built-in heat sink to dissipate the excess heat to cool the device.

Because the station's battery has 12 V DC while the cell phone batteries charge at 5 V, the team overcame the stepping down voltage problem as well as distribution of voltage among the four lockers.

The solution was the implementation of the WAGAN Quad Power USB hub. The WAGAN hub has a single 12 V DC input and four 5 V USB output ports. The device is rated at 6.8 A, with two ports rated at 2.4 A, and the other two rated at 1 A. The maximum current a cell phone can draw while charging is 1A. The WAGAN is equipped with internal overvoltage protection, short circuit protection, and overheating protection for each port, shutting down the port to prevent accidental overload.

The four output lines from this device are fed through a 6-inch Male to Female USB cable, into an in-line current/volt meter. Each port has its own current/volt meter for visual inspection and demonstration purposes, to verify the SOC of each phone. Out of each current/volt meter, a modified USB cable carries the power to the circuit board. The USB male end connects to the in-line current/volt meter port and the other end's flying leads are soldered into the circuit board.

Traces on the circuit board are connected to four linear current sensors. Output traces from the sensors are connected the power cables leading to each locker. When a user plugs in a cell phone to be charged, the circuit is complete from the UniverSOL station's battery to the cell phone battery.

The 12 V battery power is also being fed into the circuit board. This 12 V is being used to control the power to the solenoid locks on each of the four lockers. The 12 V is also being fed to the LM7805 voltage regulator. The output of the voltage regulator is 5 V, and is being distributed to various devices on the circuit board, including the ATmega328p processor and the current sensors.

The final detail considered in power management was selecting devices powered by either DC or AC. In the case that AC driven devices were used, the system would have been required to be designed to include an inverter. This would have increased the cost of the system greatly. Because the cell phones require DC and the battery supplies DC and both are the major powering receiving and supplying components of the system, respectively, the other components were selected accordingly for DC power.

5.1.1 PV System Analysis/Design

System Load Calculations were the first step in selecting components for a Solar PV System. The electrical load, all appliances being powered by the main system hub, was the foremost determining factor on sizing the heart of the system (i.e. solar panel, battery, and charge controller). It was important to size these parts correctly because they were the bulk of the system cost. .

A spreadsheet was compiled applying equations and information from Sections 3.4.3 (Charge controller), 3.6.1(Battery), and 5.1.2 (Solar panel). Each time, a newly sized component was researched and priced. Initially, the design called for powering 6 cell phones allowing 2 days of autonomy. Figure 5.1-6 illustrates these original design calculations.

Electrical Loads	Quantity	Watts	Hours/Day	Watt-Hours/day
Cell Phones	6	5	24	720
3.5" TFT Color Touch Screen	1	0.25	24	6
ATmega 328 P	1	0.2	24	4.8
				730.8
Design Parameters	Nominal Values	Units		
Autonomy	2	Days		
Nominal Battery Voltage	12	Volts		
DOD	0.6	Percent		
Average Sun Hours Central Florida	5.76	Hours/Day		
Design Results	Nominal Values	Units	Cost	
Battery Bank Size	238.82	Amp-hours	$700.00	
Solar Panel Amperage	10.57	Amps	$300.00	
Charge Controller Amperage Capacity	23.44	Amps	$265.00	
			$1,265.00	Total Main System Cost

Figure 5.1-1 6 Cell Phones/2 Days Autonomy

While this system exhausted over half of the budget, there were ample funds left over for the remaining design components. However, funding that was initially accounted for was on hold, so a reevaluation of the system was necessary to accommodate for the budget. The first idea was to reduce the days of autonomy in order to size for a smaller system. Considering the project requirements, ideally the system will only have to operate solely off of the battery during showcase periods which could be at most approximately 8 – 10 hours in a day. Furthermore, the cost of the battery was almost double the price of the other two components and depended on days of autonomy as a factor for size. The PV System reduction analysis is illustrated in Figure 5.1-2.

Electrical Loads	Quantity	Watts	Hours/Day	Watt-Hours/day
Cell Phones	6	5	24	720
3.5" TFT Color Touch Screen	1	0.25	24	6
ATmega 328 P	1	0.2	24	4.8
				730.8
Design Parameters	Nominal Values	Units		
Autonomy	1	Days		
Nominal Battery Voltage	12	Volts		
DOD	0.6	Percent		
Average Sun Hours Central Florida	5.76	Hours/Day		
Design Results	Nominal Values	Units	Cost	
Battery Bank Size	119.41	Amp-hours	$400.00	
Solar Panel Amperage	10.57	Amps	$300.00	
Charge Controller Amperage Capacity	23.44	Amps	$265.00	
			$965.00	Total Main System Cost

Figure 5.1-2 6 Cell Phones/1 Day Autonomy

While the design received some reduction in Battery Bank Size Capacity, thus reducing cost slightly, it did not affect the Charge Controller Capacity or the Solar Panel Amperage. Because Solar Panel Amperage does not fluctuate based on autonomy this can be expected. Furthermore, Solar Panel products are designed linearly for Amperage Capacity verses Wattage. So no reduction in Amperage Capacity equates to no reduction in Watt Capacity.

For this reason, the electrical load was reduced from 6 cell phones to 4 cell phones. Reducing the electrical load reduced both Battery Bank Size and Solar Panel Amperage, which was expected because both calculations depend on the electrical load. By reducing the electrical load and designing the days of autonomy for the specific project requirements, the system was designed to operate compatibly and efficiently at a more reasonable price.

A further design amendment to the system was made because we were fortunate enough to obtain a solar panel through the University of Central Florida Senior Design Lab. The solar panel wattage was increased from a minimum design requirement of 150 W to a 235 W solar panel. The only effect this had was an increase in the charge controller amperage capacity from 15.63 Amps to 24.48 Amps. However this had no effect on the cost of the design. So the final design cost was reduced by $230.00. Figure 5.1-3 illustrates both the reduction in number of phones and the increase in charge controller amperage capacity for a one day autonomous off-grid PV system.

Electrical Loads	Quantity	Watts	Hours/Day	Watt-Hours/day
Cell Phones	4	5	24	480
4.3" Touch Screen	1	0.25	24	6
ATmega 328 P	1	0.2	24	4.8
				490.8

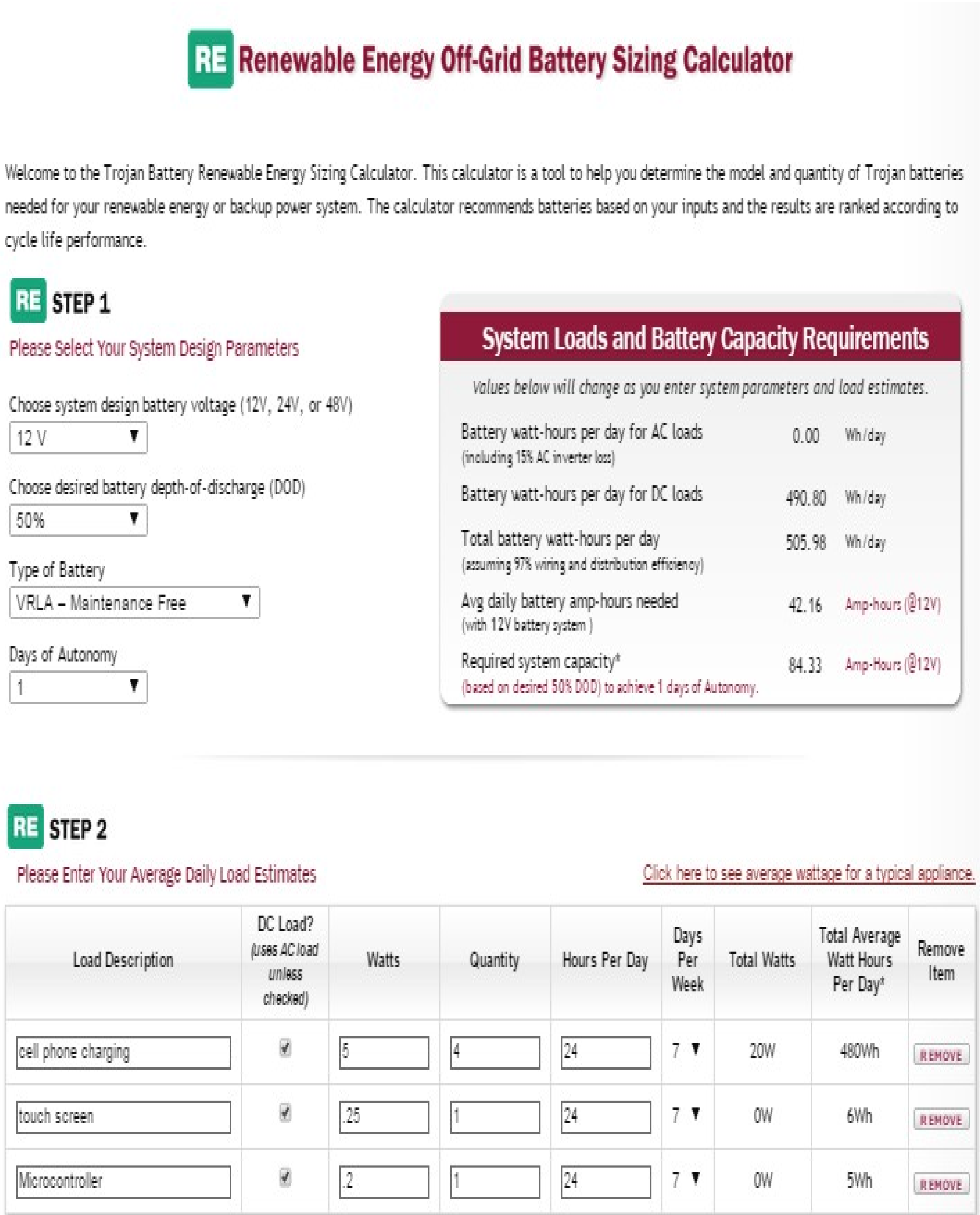
Design Parameters	Nominal Values	Units
Autonomy	1	Days
Nominal Battery Voltage	12	Volts
DOD	0.6	Percent
Average Sun Hours Central Florida	5.76	Hours/Day

Design Results	Nominal Values	Units	Cost	
Battery Bank Size	80.20	Amp-hours	$250.00	
Solar Panel Amperage	7.10	Amps	$0.00	
Charge Controller Amperage Capacity	24.48	Amps	$265.00	
			$515.00	Total Main System Cost

Figure 5.1-3 4 Cell Phones/1 Day Autonomy/235 W Panel

The final minimum PV System design included a 235 W solar panel (size of panel provided that accommodates 7.1 Amperage Capacity), 12 Volt 80 Ah (minimal) Capacity Battery, and a Charge Controller that should have been able to handle 24.5 Amps. Additional design considerations and specifications for these components are addressed in corresponding Hardware Design Sections.

All design efforts were verified by software from both Trojan Battery (battery) and AltEstore (charge controller) off-grid calculators in Figures 5.1-4 and 5.1-5. The numbers generated from the calculators remained relatively close to the calculated nominal values for the systems. The UniverSOL design calculations came within 5% of the Trojan off-grid calculator for the battery. Comparatively, the minimum design requirements for the UniveSOL Charge Controller came within 2% of the Alt-E off-grid calculator.



Renewable Energy Off-Grid Battery Sizing Calculator

Welcome to the Trojan Battery Renewable Energy Sizing Calculator. This calculator is a tool to help you determine the model and quantity of Trojan batteries needed for your renewable energy or backup power system. The calculator recommends batteries based on your inputs and the results are ranked according to cycle life performance.

STEP 1

Please Select Your System Design Parameters

Choose system design battery voltage (12V, 24V, or 48V)
12 V

Choose desired battery depth-of-discharge (DOD)
50%

Type of Battery
VRLA – Maintenance Free

Days of Autonomy
1

System Loads and Battery Capacity Requirements

Values below will change as you enter system parameters and load estimates.

Battery watt-hours per day for AC loads (including 15% AC inverter loss)	0.00	Wh/day
Battery watt-hours per day for DC loads	490.80	Wh/day
Total battery watt-hours per day (assuming 97% wiring and distribution efficiency)	505.98	Wh/day
Avg daily battery amp-hours needed (with 12V battery system)	42.16	Amp-hours (@12V)
Required system capacity* (based on desired 50% DOD) to achieve 1 days of Autonomy.	84.33	Amp-Hours (@12V)

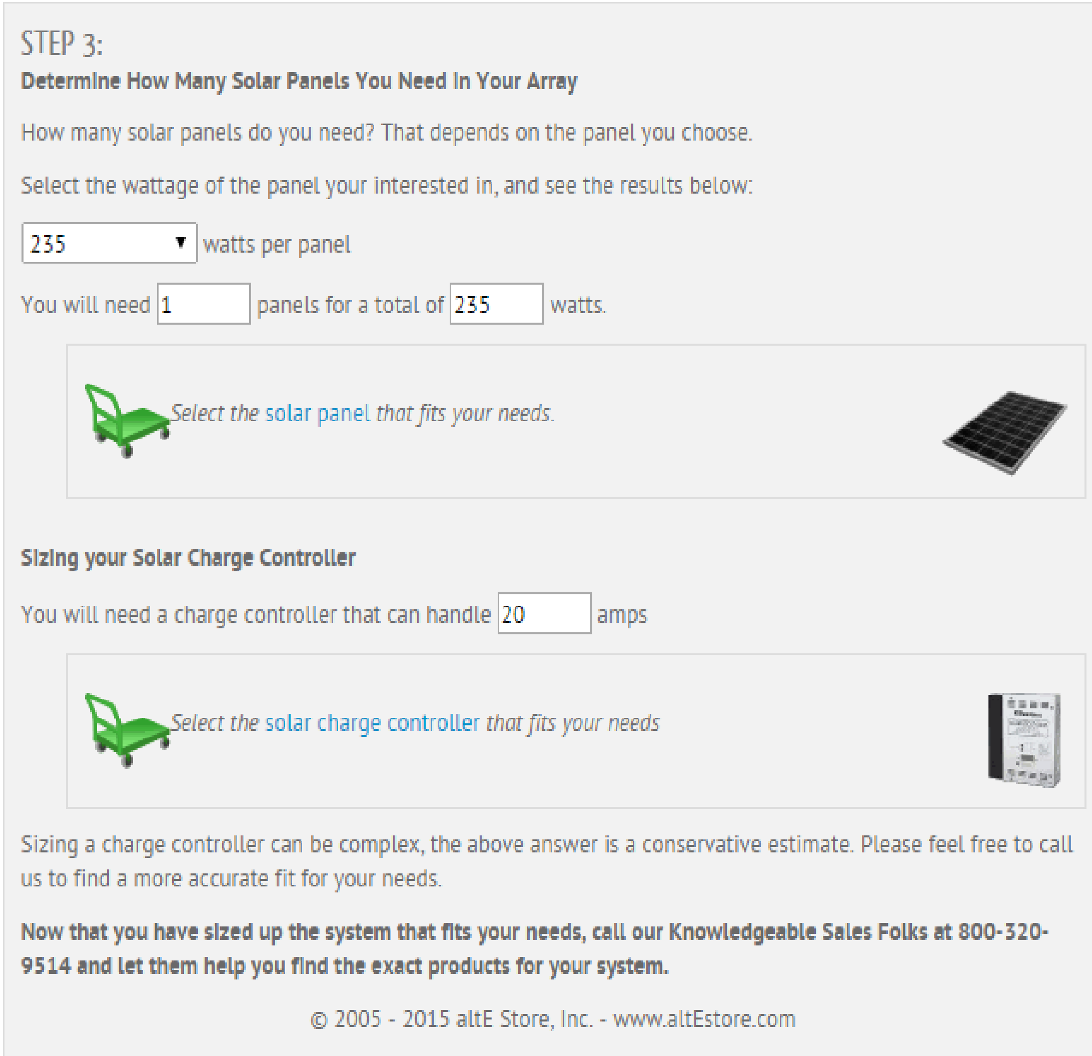
STEP 2

Please Enter Your Average Daily Load Estimates

Click here to see average wattage for a typical appliance.

Load Description	DC Load? (uses AC load unless checked)	Watts	Quantity	Hours Per Day	Days Per Week	Total Watts	Total Average Watt Hours Per Day*	Remove Item
cell phone charging	✓	5	4	24	7	20W	480Wh	REMOVE
touch screen	✓	.25	1	24	7	0W	6Wh	REMOVE
Microcontroller	✓	.2	1	24	7	0W	5Wh	REMOVE

Figure 5.1-4 Trojan Battery Off-Grid Calculations 4 Cell Phones/1 Day Autonomy


STEP 3:

Determine How Many Solar Panels You Need In Your Array

How many solar panels do you need? That depends on the panel you choose.

Select the wattage of the panel your interested in, and see the results below:

235 ▾ watts per panel

You will need 1 panels for a total of 235 watts.

Select the solar panel that fits your needs.

Sizing your Solar Charge Controller

You will need a charge controller that can handle 20 amps

Select the solar charge controller that fits your needs

Sizing a charge controller can be complex, the above answer is a conservative estimate. Please feel free to call us to find a more accurate fit for your needs.

Now that you have sized up the system that fits your needs, call our Knowledgeable Sales Folks at 800-320-9514 and let them help you find the exact products for your system.

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Figure 5.1-5 AltE Store Off-Grid Calculations 4 Cell Phones/1Day Autonomy

5.1.2 Solar Panel

One major factor considered in determining which polycrystalline panel to go with is sizing it properly for our particular system. With a 12V lead acid battery that meets the requirements of supplying power to the load and operating autonomously for 24 hours under periods of low irradiation, the total Wh/day being supplied from the battery could be calculated and used to size the proper PV panel for our system.

$$Total\,\frac{Wh}{day}(24\,hours\,of\,autonomy)=\frac{Wh}{day}$$

$$Total\frac{Ah}{day}=\frac{\frac{Wh}{day}}{batttery\,nominal\,voltage}$$

$$Average\ Amount\ Of\ Sun\,hours \in Central\,Florida = 5.76\,annually$$

$$Solar\ Panel\ Amperage=\frac{Total\frac{Ah}{day}}{5.76\left(\frac{h}{day}\right)}$$

From the design calculations in Section 5.1.1, a polycrystalline solar panel with a current rating above 7.1 Amps is required to supply the power to charge the battery. There are many manufacturers of solar panels in the US and although two similar panels may have the same power rating, there may be other specifications between them which do not match. Therefore, unless designed by the same manufacturer, it is not safe to assume that two similar solar panels are equivalent.

There are a great number of factors to consider when deciding on the right solar panel for a particular PV system. It is clear that efficiency is the greatest factor when dealing with PV Systems, however for the purposes of our design, a solar panel that simply meets the design's power requirement of delivering an output current of 7.1A. The UniverSol Charge Station's power input supply is the Suntech 235W Polycrystalline Solar Panel which just minimally exceeds the system's current rating at 7.79A. The major deciding factor in using this particular solar panel in our system is that it was given to us at no cost to utilize by the University of Central Florida's CECS Senior Design Department. Therefore, the solar panel meets our requirements and is extremely cost effective for our budget.

5.1.3 Lead Acid Battery

Lead Acid batteries became the leading choice once it was determined that these batteries were the most in practice with PV Systems and performance delivery dependable. Furthermore, vast amounts of information regarding lead acid batteries exist on safety precautions, trouble shooting issues, design integration into PV systems, and performance enhancements.

However, for a thorough analysis, a close table comparison of 12 V 100 Ah Lead Acid Gel, Lead Acid AGM, and Lithium Ion, was compiled in Figure 3.6-4. Other than a moderate cost difference, Lead Acid AGM compares well to Lead Acid Gel Batteries, but exceeds expectations in lifetime and recyclability. Lithium Ion Batteries appealed because they were 16 times more lightweight and more compact. Furthermore, Lithium Ion improves DOD by 30%, and improves energy and charge efficiency. Yet, they were over twice as expensive and much more detrimental to the environment.

Because this was a renewable energy project, environmental hazards were avoided as much as possible. In this project, weight was handled because it was designed to be stationary and space was easily accommodated for in the enclosure. Moreover, the MPPT Charge Controller was implemented to improve charge and energy efficiency by 30% or more, so the gain offered by Lithium Ion is supplemented by this factor. For these reasons, the investment did not qualify the extra expense for Lithium Ion batteries in this system.

As noted in Section 5.1.1, the battery was minimally sized to fit the PV system at 12 V and 80 Ah. The Trojan Battery 27-AGM Deep Cycle 12 V 89 Ah was selected to power the system. This battery came with manufacturer specifications on Voltage Set Points and a built-in Temperature Compensation. Designing for the Voltage Set Points of the Charge Controller based on battery specifications was ideal for utmost efficiency. The SB3000i MPPT Charge Controller Temperature Compensator must be ordered at an additional cost, so the 27-AGM offset some of the additional cost that may have been saved by using Lead Acid Gel.

5.1.4 MPPT Charge Controller

Certain requirements had to be met for the use of any charge controller within our system based on specifications from the solar panel, battery, and design calculations. For our system the qualifying factors included:

- Solar Panel Maximum Power at STC (Pmax): 235 W 60 Cell Module
- Battery Voltage: 12V for small off-grid PV systems
- Solar Panel Open-Circuit Voltage (Voc): 37.0 V
- Amperage Capacity Output Charge Current: 24.5 A

The amperage Capacity for the charge controller was determined to be higher than the minimum design requirement of 15.6 A due to an increase in the size of the solar panel wattage. There was a built- in 1.25 NEC power factor buffer in the design calculations that increased the requirement from 19.6 A to 24.5 A. This power factor buffer is provided for days in which the solar panel actually produces excess power than what it is rated for. This will occur on the highest of irradiation days, under the most perfect of conditions. However, it was determined that the PV system could afford this small loss under these rare conditions because the system supplies a more than ample power supply.

Three products were selected meeting the specifications. A table was compiled comparing the additional features desired for system operation and design functionality to select the best charge controller for the system:

Characteristics	MorningStar ProStar-30 PWM Controller System	Blue Sky SB3000i MPPT Controller System	Linear Technology LT8490 I.C. System
Efficiency	75-78%	95%	97%
Power Loss	30%	5%	2-3%
Cost	$128.00	$265.00	$195.00
Digital Display	Yes	Yes	No
Temperature Compensation	Yes	Optional	No
Communications Control	No	Remote Access	No

Figure 5.1-7 Comparison of Leading Charge Control Technology

The team selected the Blue Sky SB 3000i MPPT Charge Controller because one of the main focuses for design requirements was system sustainability and efficiency. Optimizing power using MPPT assisted in meeting this precedent. Maximizing power was especially important since the days of autonomy were reduced to one (refer to Section 5.1.1) to ensure that the battery minimally discharges during regular operation. When the system first reaches an autonomous state, the battery is expected to be close to, if not, full.

Lastly, selection relied upon the characteristics, some of which are featured in Figure 5.1-7. Referencing Figure 5.1-7, the digital display [1] and charge status indications [2] on the front of the controller allowed for easy reading of the voltage output from the charge controller to the battery and the three stage charge status of the battery, respectively. In addition, Blue Sky provided a key [3] that indicated what standard condition the battery was in, ranging from low to charging, based on battery status discharge level verses the voltage input needed to charge the battery. These features were advantageous for simplified testing for the accuracy of the controller and performance. Adjustable Voltage Set Points provided optimal synchronicity to the battery bank SOC. Finally, simplicity of design played an important factor. Integration of the SB3000i into the system requires little additional design and minimal cost, while Integration of the MPPT I.C. required more extensive supplementary design and assumes more space on the PCB (refer to Section 3.4.3.5). The SB3000i was connected in series with the solar panel and battery using cable connections and did not require placement on the PCB, requiring less real estate. Given the time constraints and potential cost increase to implement another design, the upfront investment was practical.

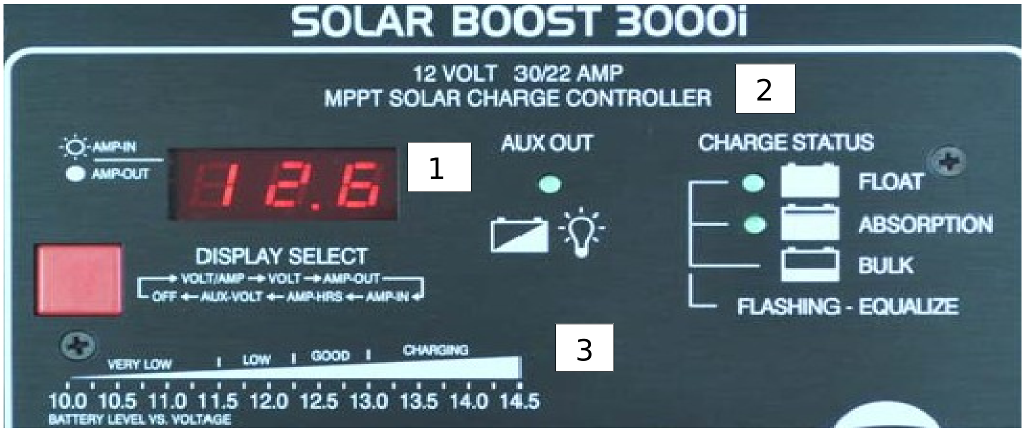

Figure 5.1-8 Solar Boost 3000i MPPT Solar Charge Controller

For a 60 Cell PV module, both the Battery and PV compression terminals require # 12 AWG wire tightened to a nominal 15.9 in-lb (1.80 nm).

5.1.5 DC to DC Converter

5.1.5.1 12V to 5V BUCK Switching Voltage Regulator

With a rechargeable SLA 12V battery delivering power to the system's loads, a voltage regulator is used to step down the voltage from 12V to 5V in order to meet the power requirements of the other system electrical components. Many of the system's electrical components require a 5V DC input to operate. For instance, the Atmega328 MCU, ACS712's Current Sensors, and Shift Register all require a 5V input voltage supply in order to operate. At any given time the UniverSol Charge Station can pull a total of 0.795A from the Voltage regulator, therefore we have assured that it can efficiently meet this condition without overheating and damaging. The system uses the Murata 580-OKI78SR5/1.5W36C BUCK Switching Voltage Regulator because it meets our design requirements by using the Buck technology to efficiently step down the voltage from 12V to 5V and can deliver an output current of 1.5A. This regulator has a three pin configuration and an extremely small footprint as seen in Figure 5.1-10.

Input Voltage Range (V)	7 to 36
Design Origin	Murata Power Solutions
Dimensions (inch)	0.41 x 0.65 x 0.30
Dimensions (mm)	10.4 x 16.5 x 7.62
Efficiency (%)	90.5

Figure 5.1-10

Murata 580-OKI78SR5/1.5W36C BUCK Switching Voltage Regulator- Printed with Permission from Murata Power Solutions

5.1.5.2 Touch screen Voltage Regulator

Although the 4.3” touchscreen can take a range of input voltage supply, we are also using the 12V to 5V BUCK Switching Voltage Regulator as its input power supply. With 5V delivered to the touchscreen, it can handle all of our system’s design requirements.

5.1.6 Voltage Management

The UniverSOL must maintain consistent voltage so if surges and fluctuations occur, all components within the circuit are protected. Voltage management allows our charging system to work efficiently as possible. Because of the important of voltage management, many modern electronic component have regulators built into their circuitry.

5.1.6.1 High Power USB Charging Hub

Most fast and powerful charging hubs are powered by AC. While the team investigated some and really like a couple, we saw a problem with the design. The UniverSOL power is DC, and DC to AC inverter would need to be used in order to use the discussed hubs. Though this can be done physically by adding a DC to AC inverter, the cost would be out of the budget for the UniverSOL.

The alternative is to use DC power outlet, such as the kind that plugs into the power port, or old cigarette lighter, of a vehicle. The team investigated a few designs and determined the Wagan Quad Power 9.6v 4-Port hub meets the needs required of the UniverSOL. Each 2.4A port is programmed with overload and overheating protection

The Quad Power Hub allows 10-15VDC from the lithium-ion battery, with 5VDC over the 9.6A. This is reassuring, as there may be a time a user attempts to charge another rechargeable device, such as a tablet or e-cigarette, on the UniverSOL. A tablet is easily able to pull 2.1-2.4A while charging. With 2.4A at each port, the Wagan Quad Power is able to accommodate that port without sacrificing charging amps to the other three ports. Because the Wagan has four ports, the UniverSOL will have four charging lockers.

5.1.6.2 USB Charging Cables

This section specifically addresses the UniverSOL cell phone charging concerns. The UniverSOL is using USB 3.0 cables for power transfer from high-power USB hub to the PCB and then to the charging lockers. Both USB 2.0 and 3.0 can take the same voltage, but USB 3.0 can conduct more amps, thus providing a faster charge.

To maintain the voltage stream as determined by the individual cell phone while providing the fastest and safest charge to the user's cell phone battery, the team is using the SuperSpeed USB 3.0 cables in three-foot lengths. This will allow the maximum 900 milliamps (mA) current. Though many cell phones restrict the incoming current to 500mA source, new cell phone technology is moving towards the charging current speeds of 900mA.

The team felt comfortable ordering the cables from Amazon and is currently using the Amazon Basic 3.0 cable in 1 meter lengths. This length will provide enough surplus cable to effortlessly connect the multi-connector plug in the cell to the USB 3.0 hub.

5.1.7 Current Sensors

The UniverSOL has a current sensor on each USB cable entering into the PCB. The current sensor we are using is the Charger Doctor, and modifications have been made to help monitor the data for each charging cell phone battery. The ability to calculate the amount of amperage and thus determine when the cell phone is completely charged, will be used not only to confirm the cell phones are charging, but as a switch for the LED Notifier. The Charger Doctor has both an amperage current sensor and a volt sensor, and both of these sensors will be used in providing the data to the team via the rear control panel.

A voltage monitor is critical at this step, and the team chose the original Charger Doctor for this task. The Charger Doctor is a current and voltage sensing device. Each is mounted on the rear control panel, allowing the team to view the voltage and current flowing into a charging locker that is in use. Once the user connects the cell phone to a charging plug, a current draw of near 0.9A and a voltage of 5V should be observed on the Charger Doctor. When the cell phone is fully charged and still connected, a current of 0.29A is observed. When the cell phone is disconnected, the Charge Doctor will read 0.0A. These three current levels of 0.9A, 0.29A, and 0.0A are important so the team can know the status of the charging cell phones at any time. These levels are also read by the Hall-Effect Based Linear Current Sensor, so as to illuminate the proper charging status LEDs

The original Charger Doctor is a USB device that allows you to view voltage and amperage that a USB device uses when plugged into a computer or a wall outlet. The Charger Doctor unit allows 3.5 to 7.0 volts, and measures 0.0 to 3.0amps, with a deviation of plus or minus of 1-2%, so it is fairly accurate. It has a male-input power that plugs into the female USB power source, and a female output port to plug in the USB cable multi-plug connector.

Internally, the Charger Doctor is components are comprised a screen with four seven-segment display, USB power in plug, USB power out port on the one side of the board. On the back, is a programmed PIC microcontroller chip, a decoupling capacitor for the microchip, a transistor, two resistors, and a really big resistor labeled R050 which is a 50 micro-ohm current sensing resistor that allows the microchip to calculate the amount of amperage the unit is using.

5.2 ATMega328P Microcontroller

The team chose to use a ATMega328P microcontroller to control the various input and output data of the UniverSOL's operation. ATMega328P microcontrollers are inexpensive, reliable, and widely available. The microcontroller is mounted on the PCB with all connections wired into the board. Other external components, such as resistors and capacitors, are also mounted on the same board so as to interface with the ATMega328P microcontroller as needed. The diagram below displays the microcontroller with the planned input and output connections.

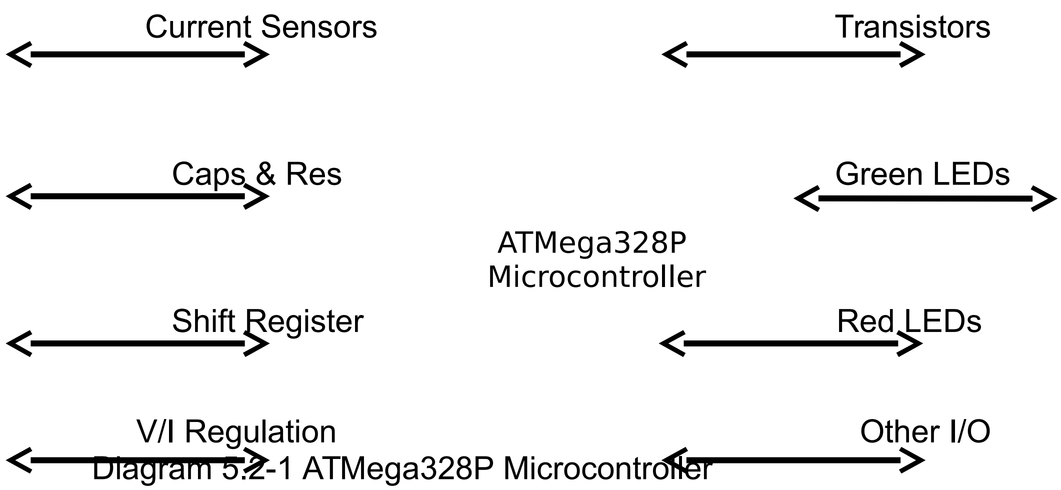

Diagram 5.2-1 ATMega328P Microcontroller

5.3 Input/Output Devices

The UniverSOL is interactive with the user. The follow section expounds on the devices and the user experience.

5.3.1 Monitor Display Communication

The main point of communication between the user and the UniverSOL is the LCD touch screen monitor. The touch screen monitor is internally mounted to the unit with the monitor's display viewable through a cut-out of the metal case. The touch screen will be interactive, providing information about the user's cell phone, and relaying back information on the status of cell phone charge. When a user approaches the UniverSOL and touches the screen, the user will be offered four choices on the Welcome page: Set Up a New Charge, Currently Charging, Learn More about the UniverSOL, and Information about Our Sponsors.

5.3.1.1 Input/Output Expansion

One of the system design obstacles that we overcame was to expand the input/output pins of the Atmega328. There are several ways to accomplish this however we decided to utilize a shift register because of the group's familiarity with the device and the simplicity of its implementation. The UniverSol Charge Station uses the 74HC_HCT9595 Shift Register to increase the input/output pins of the Atmega328. It uses only three digital pins from the Atmega328 and it increases to 8 pins that are utilized to activate the LED Charge Status

5.3.1.2 User ID and PIN Page

The team decided that the UniverSOL needed users to have a User ID and PIN so that it can establish power usage to a specific locker, thus conserving energy; provide the user with specific data regarding the user's cell phone battery, the amount of charge needed; provide an estimated time needed to achieve 100% battery charged; to provide security so other users and onlookers are not aware of the user's personal cell phone data.

The first selection is the Set Up a New Charge page, and it will direct the user to a screen showing available lockers. Once the user touches the locker to use, the UniverSOL will display the User ID and PIN screen. The touch screen has a statement displayed asking the user to enter in a 4-character User ID and then press Enter touch screen button. Below this statement, the touch screen will display the upper-case alphabet and numbers 0-9 set up in five columns and seven rows, with the letters going across alphabetically from left to right for the first five rows (note, the letter X will not be used), and the last two rows will have numbers going from left to right, beginning with 0 – 4 on the first row, and 5 – 9 on the following row. The display will have 25 letters plus 10 digits to make 35 characters available for entry. Characters can be used more than once. A Backspace touch button and an Enter touch button will be on an eighth row below the alpha and numeric choices.

Above the columns has a User ID field with four empty blanks. When the user touches a character, the UniverSOL saves the character and displays the character in the corresponding field. When all four fields are completed and the user touches the Enter button, the screen changes to the PIN screen.

The PIN screen looks similar. The user is asked to enter in a four-digit PIN and press the Enter touch screen button. Below these directions are displayed five columns and two rows of numbers, 0 – 4 on the first row and 5 – 9 on the second row. Again, a Backspace touch button and an Enter touch button are shown. When the user enters in the PIN, a four-space display on the same page will display an asterisk for each choice the user makes. After the four choices are chosen, the user touches the Enter touch screen button, and the UniverSOL asks the user to re-enter the PIN to confirm user accuracy.

When both the User ID and the PIN are entered and saved into the memory of the UniverSOL, the user will be shown a third screen, the Data Screen. The screen will ask the user to plug in the cell phone into the port of the chosen charging locker if it has been done already. The screen will display the User ID, the locker number, and the data the UniverSOL has collected from the cell phone: the current power available from the cell phone battery in terms of a percentage, the remaining battery amount needed to be charged in terms of a percentage, and the estimated time needed to completely charge the cell phone battery, and the “Green Chart” information. Finally, the touch screen will state below this data that the user can return at any time, enter in the User ID and PIN on the Login In page to find out the current data status of the charging cell phone battery.

5.3.1.3 Currently Charging Page

The next touch screen page choice is the Currently Charging page. A current user touches the screen to initiate the Welcome page, and chooses the Currently Charging touch button. That leads to a Login page.

The Login page instructs the user to enter in the User ID and the PIN. The user sees a User ID field and the corresponding PIN field under it. The user also sees the familiar alpha and numeric columns and rows with the Backspace and Enter touch buttons. The Login page has a statement asking the user to enter in the User ID and then press the Enter touch button. The user input response shows in the corresponding User ID fields. After the Enter button is touched, a new statement stating for the user to enter in the PIN and to press the Enter touch button when finished displays. The user input response shows in the PIN fields.

When the correct information is entered, the UniverSOL will display the current data of the cell phone battery. Two screens are possible at this point, depending upon the data. If the cell phone battery is not completely charged, the current battery charge data will display in terms of percentages, and the updated estimate of time needed to complete a full charge displays. If the cell phone is completely charged, the touch screen will display the message for the user to safely disconnect the cell phone, and the “Green Chart” information. An Exit touch screen button shows on the screen for the user to touch. Also, a 14 second timer is activated once this is shown, that at the end of the 14 seconds the default Welcome screen is shown. The 14 second timer helps to ensure privacy for the UniverSOL users.

When incorrect information is inputted by the user, an error message stating the User ID and PIN do not match displays and asks the user to re-enter in the User ID and PIN. After three attempts, an error message stating that the User ID and PIN are locked, and not able to retrieve current charging data. The message also states that this has no effect on charging the cell phone battery, only the user either must wait until the LED lights turn green to ensure a fully charged battery or physically check the cell phone display. Last message on the screen will be a warning to remind to inform the user that once the charging cell phone is disconnected from the plug, a new User ID and PIN will need to be generated in order for power to flow to the plugs within the charging locker.

5.3.1.4 Learn More about the UniverSOL Page

The Learn More about the UniverSOL screen, known as the Learn More page, has four information buttons for the user to choose: Solar Power Used, At-home Solar Power Applications, Building Highlights of the UniverSOL, and Biographies of the UniverSOL Team Members. At the bottom of each page is a Back button to return to the previous Learn More screen. At the bottom of the Learn More screen is a Back touch button to allow the user to return to the Welcome screen.

The Biography page has a photo and the team member’s name listed under the photo, and a Back touch button to return to the previous Learn More page. The user can touch on the team member photo or name, and read the biography. At the bottom of the page is a Back button for the user to return to the previous Biography page.

5.3.1.5 Our Sponsors Page

The Our Sponsors page shows our Thank You message to all of our sponsors, and displays the logo of each sponsor, with a touch Back button at the bottom of the page. When a user touches the sponsor logo, a Sponsor page will show and a photo show occurs, rotating between the gift letter from the sponsor, a photo of the team with the sponsored item in usage with the UniverSOL, and an advertisement display page for the sponsor. A Back touch button is at the bottom of the page to allow the user to return to the previous page.

5.3.1.6 Thank You Page

Anytime during the charging process, the user can unlock the charging locker and disconnect the cell phone from the charging process. Once the disconnection is registered, the touch screen monitor immediately displays the Thank You page. The page informs the user disconnection has occurred and the cell phone battery is no longer charging, and the “Green Chart” information. Under this statement, is another statement that thanks the user for using the UniverSOL, and welcomes the user back again.

5.3.1.7 Built-in Default Programming

Most every page that is displayed for on the touch screen has a default of eight seconds before the screen returns the Welcome page. The exception is when the current data is being displayed, and that page has a 14 second timer. When the Welcome page eight second timer has expired, the touch screen displays a screen saver program featuring photos of the UniverSOL, the UniverSOL name, and a message to touch the screen anywhere to charge the cell phone battery using the UniverSOL.

5.3.2 Resistive Touch Screen

The team chose the Adafruit 3.5” 320x480 Color TFT Touch Screen for use in the UniverSOL. The Raspberry resistive touch screen is made from two flexible sheets of resistive materials separated by an air gap. When the user touches the screen the pressure of the top layer point connects with the bottom layer, creating the connection of communication. Thus, the input can be created by a user with a finger, a gloved finger, a pen, a stylus. Also, resistive touch screens are more tolerant of the elements, and are used in high-traffic areas. ATM machine screens, restaurant ordering screens, hand-held video games, and kiosk screens are examples of resistive touch screen monitors.

The point the user touches on the screen is the point of input, shown as a circle on the diagram. When a contact occurs between planes X and Y, a point of resistance is created and the voltage drops. The following chart supplies the Raspberry specifications.

Display Screen	3.5” Diagonal

Resolution	480 x 320
Color System	16bit
Brightness	250cd/m^2
Viewing Angle	140 degrees
Input Signal	AV1, AV2, VGA, HDMI, DVI
Input Voltage	6-12 VDC
Power Consumption	≤6W
Dimensions	4.5”H x 5.5”W x 1.0” D
Weight	29.6 ounces

Table 5.3.2-1 Specifications for the Adafruit 480x320

6.0 Design Summary of Software

This section is the most important, along with the hardware design section, as it describes the entire project's software design and system control. This section breaks down all of the individual aspects of the software run in the background of the system to make it work. The software is broken down into two main portions, the User Interface and touch screen display, and the overall system control.

6.1 Initial Design Architecture and Diagrams

The UniverSOL charging station is designed to be very easy to use for the customer. We anticipate a large variable demographic to be using our system so it is important the that User Interface on the LCD touch screen is easy to use, even for people who are not used to touch screen technology. The figure 6.1-1 below shows the initial design of the user interface and the flowchart between the different screens someone would see if they were to use our system.

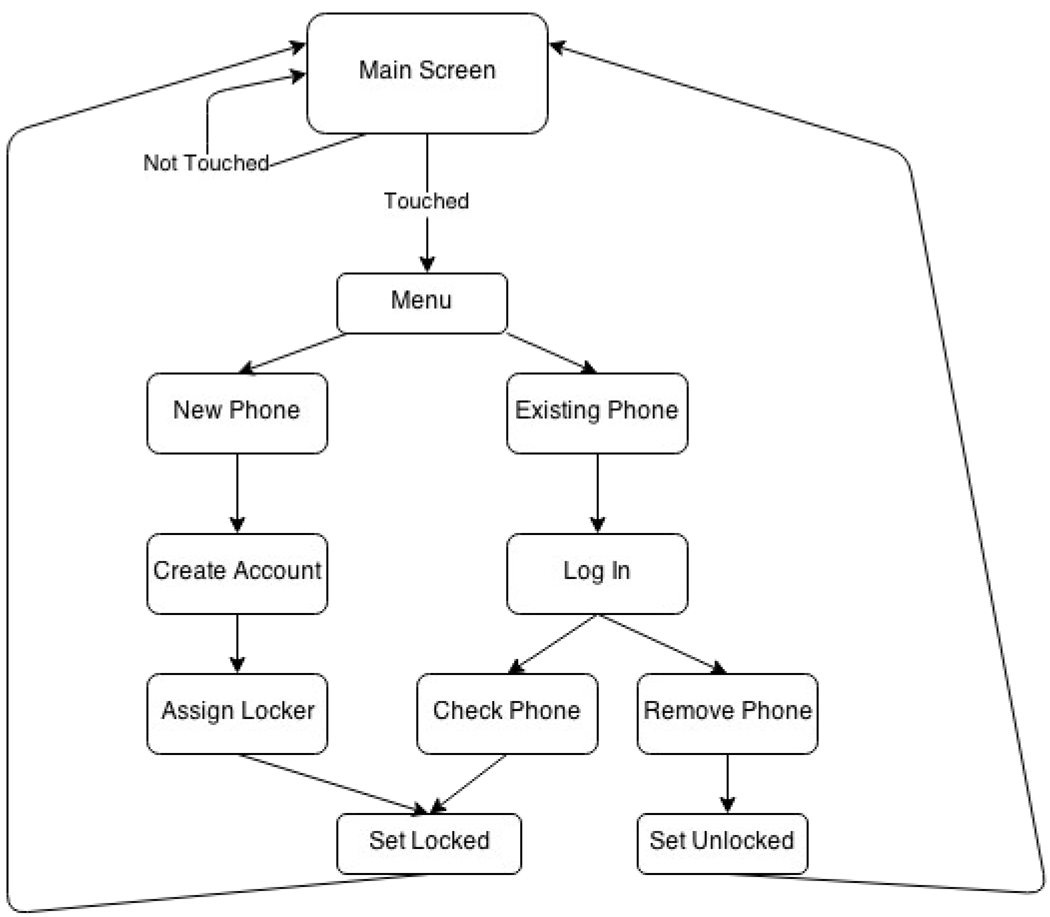

Figure 6.1-1 User Interface Flowchart

The flowchart in figure 6.1-1 above shows the flowchart of actions in the user interface portion of the software design. The code starts at the main screen which is where a screensaver or advertisements would be cycling through with pictures to display the advertisements. The flowchart then shows the different routes that the user can go through while trying to use the system. As Figure 6.1-1 shows, the design of the user interface is very basic with a small amount of different screens shown to the user.

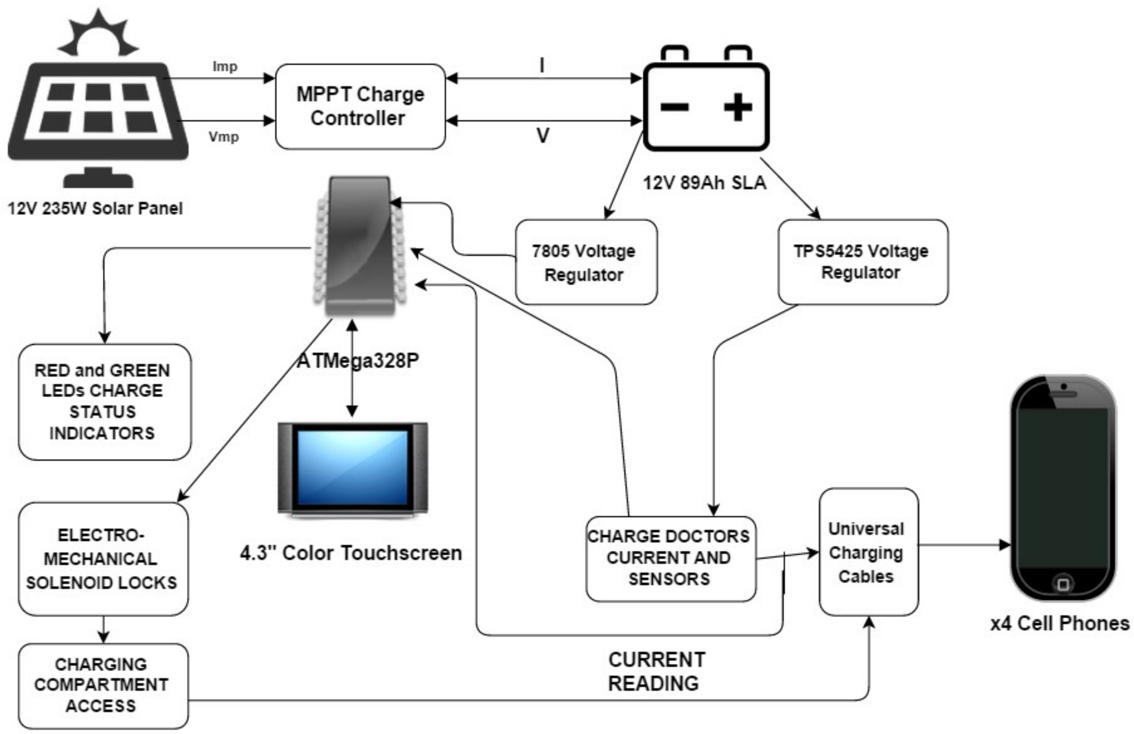

Figure 6.1-2 Microcontroller Diagram

The Figure 6.1-2 above shows all of the connections to the microcontroller. The microcontroller is in charge of giving access to the charging compartments as talked about in section 6.3.3 titled Secure Sign on. Inside the charging compartments the PIC microcontroller is also in charge of the LED indicators which will display the amount of charge of the phone for each compartment. The microcontroller is also connected to the voltage regulator for the battery of the entire system. It is important that the microcontroller regulates the voltage of the battery so the system is the most efficient and no electricity gets wasted. The microcontroller can regulate the amount of voltage going to each system and when something is not in use it won’t waste any of the energy on it.

6.2 Programming the Microcontroller

The AtMega328p microcontroller will be programmed in the Arduino programming language but to create the user interface touch screen display, we wanted to use Java since object oriented programming languages thrive with user interface and graphics display, but unfortunately this couldn't be done. The problem with this is that we cannot directly port Java code to the AtMega328p microcontroller so we had to import a specific library called the Gameduino library in order to create the user interface.

After we create our user interface we have to integrate the code into the more functional portion of the code regarding the specific voltages on the pins. The LCD will be connected to the microcontroller on certain pins which will be used in the code to display the correct graphics for the user interface.

The other section of code that will need to be written for the product is the code that controls the entire main system. Many of the components of the embedded system will be connected to the AtMega328p microcontroller to different pins located on the board.

6.2.1 Arduino Programming Language

The Arduino programming language will be used for the entire system design and it will control everything besides the user interface on the touch screen display which will be written with an imported library called the Gameduino Library. One of the main components connected to the microcontroller and programmed in regular Arduino syntax is the charging compartments and the various LEDs in each of the charging compartments that are programmed to turn on and off for given values of input. In order to increase the number of pins of the microcontroller we connected the LEDs to a shift register in order to control all of them from using only 3 pins. Here is the code that uses 3 pins connected to the shift register, a data, clock and latch pin, in order to light up a series of 8 different LEDs of different values.

```
//Updates the Shift Register
//Turns on the LEDs given by the Boolean array.
void updateShiftRegister(){
 digitalWrite(latchPin, LOW);

 for(int i=7; i>=0; i--){
   digitalWrite(clockPin, LOW);
   digitalWrite(dataPin, leds[i]);
   digitalWrite(clockPin, HIGH);
 }
 digitalWrite(latchPin, HIGH);
}
```

This function would be called after the microcontroller receives the values of the voltage and current coming from the phones which would indicate whether or not the phone still needed voltage and current to be charged. This would then be connected to the voltage regulator to determine whether or not to turn off the power to that specific locking compartment.

6.3 LCD Touch Screen Display

The touch screen display will be coded in Java, as the information it will hold will be the user interface interaction medium. The user will be required to use the system through the LCD touch screen and the touch screen will only consist of 2 different systems, the cycling advertisements that will run when the system is idle, and the user interface display when the system is in use. The LCD touch screen will contain buttons that are written in with the Gameduino library will listen for the button presses to update the view. The views will then be displayed on the LCD touch screen and the user will be given the option to select another button from the LCD touch screen.

The LCD touch screen will be continuously available for any user to touch and touching of the screen in sleep mode will update the screen to the main home screen to start the process of using the product. The touch screen doesn’t require any prior knowledge from the user and its purpose is for ease of use and quick input and reaction.

The code is run on a continuous loop that is constantly looking for a user input value, so any time the user presses a button on the touch screen, something will happen when the screen gets updated.

6.3.1 User Interface Design

The user interface starts with the main home screen which will consist of just one button that will read start, as shown below in figure 6.3.1-1. This button will prompt the user to start the system, this will be the Main Screen as shown in Figure 6.1-1.

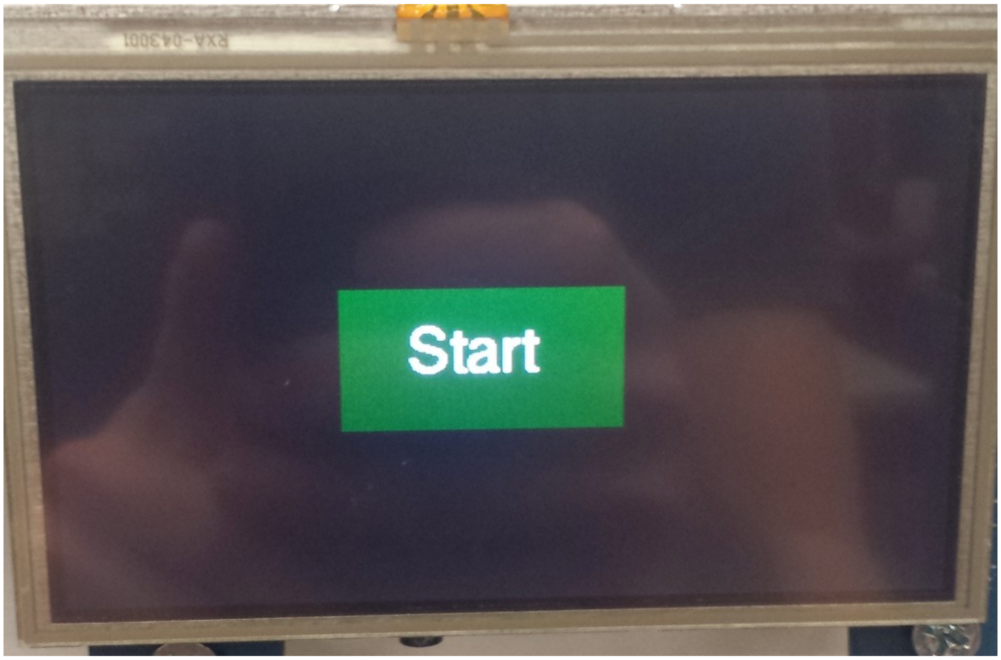

Figure 6.3.1-1

This figure shows the location(260, 290) of the start button as well as the size(310, 150) of the starting button in our main home screen of the LCD touch screen display. Clicking the start button here would change the view of the system to Figure 6.3.1-2 which is shown below.

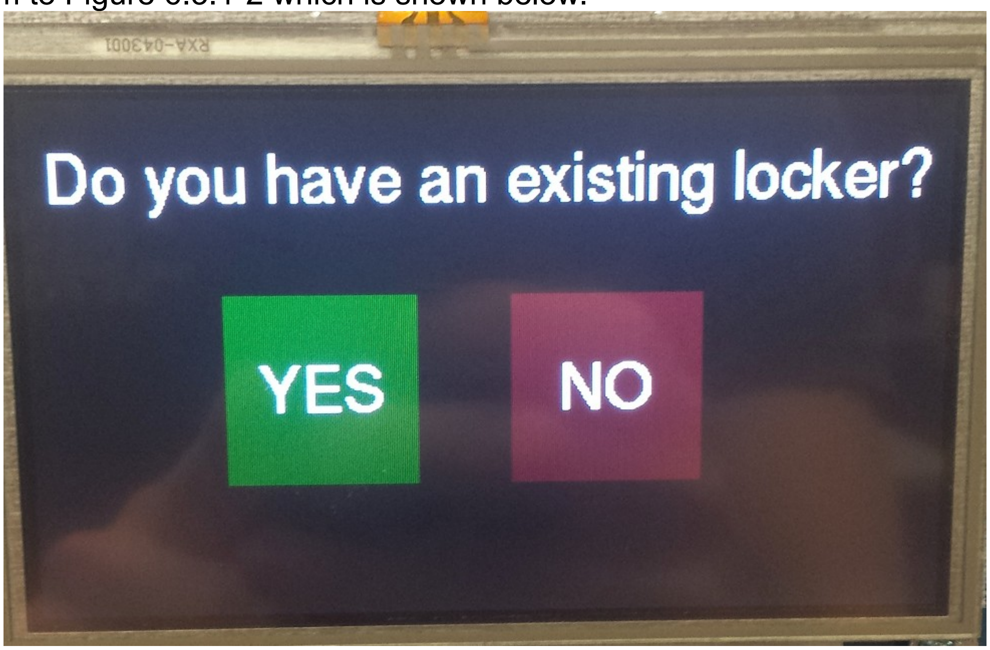

Figure 6.3.1-2

Figure 6.3.1-2 shows the screen that will be displayed after the user has clicked the start button in the main screen of the system. The figure shows the positions of the button in relation to the LCD touch screen display. The button size is displayed in the bottom right corner of the button and the top left location is displayed in the top left of the button. We believe that the buttons and text need to be big and colored in a way that is easy for the user to read.

The next step in using the system would be the user interface asking for a PIN number or asking to type in your previous PIN number if you already had a locker. In order to type in a PIN we had to design a touch screen number pad with * (asterisks) as the numbers instead of the actual digits. The number pad design can be seen in Figure 6.3.1-3 below and the rest of the screen will resemble the first two figures of this section, simplicity is key in the design of our user interface.

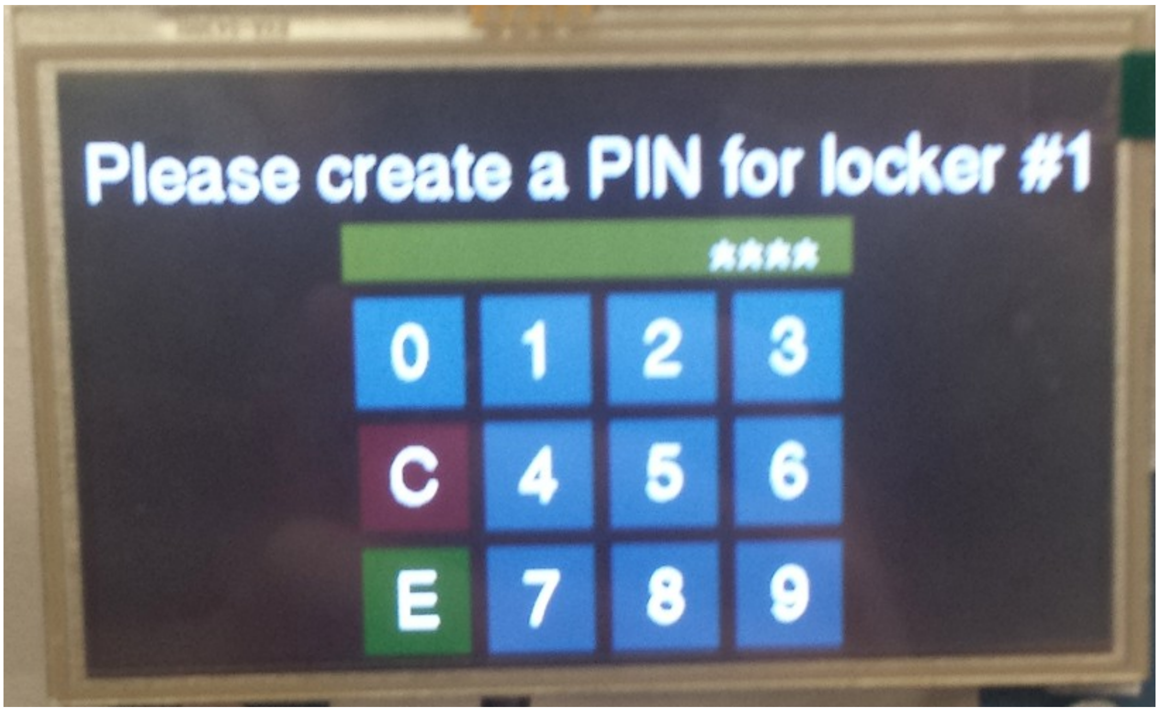

Figure 6.3.1.-3

The number pad designed for our login and account creation consists of the basic 0-9 base ten numbers as well as a clear and enter button. When inputting a PIN for the first time it will ask the user to input the PIN again to ensure that the user remembers the PIN they created and it is the correct PIN they want. The clear button will delete all of the digits of the currently typed PIN, we designed the clear button instead of a usual delete button because since all of the digits in the PIN are displayed as asterisks instead of the actual digits, it is easy for the user to not know the last digit they typed and thus the need for a single character delete would be useless.

An important feature of the user interface is the ability to quickly return to the main screen. We designed a button to constantly be in the upper right corner of the touch screen display that will be labeled “C” or “Back” and this button will quickly return control back to the main screen so that the user can begin the whole sequence of events again.

6.3.2 Touch Screen Interface

The touch screen interface will make use of events and record the location of the touch screen touches. The code below gets the values from where the LCD touch screen display is touched. This function would store the locations of the touch of the user and then call a function that would get if those locations are within the boundaries of a button on the screen.

```
// Function that gets called to check what button got pressed.
static int get_note()
{
  byte pressed = 0;
  while (pressed == 0) {
    drawscreen(screen, 0);
    if(screen == 0){
      if ((1 <= GD.inputs.tag) && (GD.inputs.tag <= 4))
        pressed = GD.inputs.tag;
    }
    else if(screen == 1){
      if ((5 <= GD.inputs.tag) && (GD.inputs.tag <= 12))
        pressed = GD.inputs.tag;
    }
    else if(screen == 2){
      if ((13 <= GD.inputs.tag) && (GD.inputs.tag <= 36))
        pressed = GD.inputs.tag;
    }
    else if(screen == 10){
      if(100 <= GD.inputs.tag && GD.inputs.tag <= 101)
        pressed = GD.inputs.tag;
    }
    updateLEDS();
  }
  play(pressed);
  return pressed;
}
```

The function getNote() is used to check if the user input is within the boundaries of one of the buttons on a screen and returns the value of the button that the user has pressed in the variable pressed. When this function is called and returns a value, then the actual function of the button and what that would do would be called. In our system when the button is pressed then the controller would modify the model and that in turn would update the view to another screen.

After getNote() is called we call a function called play, which is shown below. What this method does is that it highlights the button that the user pressed for a small amount of time and then returns the button to its original color. This is to show the user which button got picked up by the users touch. It is important to show the user which values are being recording so that no errant data gets stored into the microcontrollers memory.

When a value for pressed gets returned by the function, then the drawscreen function gets called which would actually draw the images and buttons on the LCD screen. This drawscreen method updates the screen view every time a button is pressed on the touch screen user interface. This is because every time that a button is pressed, it requires a different action by the touch screen, and will prompt the user for something different. Because it is constantly changing we are running everything on a loop and using a MVC architecture to update the view on the screen.

6.3.3 Secure Sign On

Since our product requires the user to leave a phone with the product, it is important that we create a system that is secure in order to prevent the possibility of one of the user's object being stolen. To do this, we designed a secure sign on system that would prevent the possibility of anyone getting into a locker that did not belong to them. Figure 6.3.3-1 below shows the class diagram of the locker which will hold all of the information stored for each locker in the system, and will also contain all of the methods for editing and modifying those lockers.

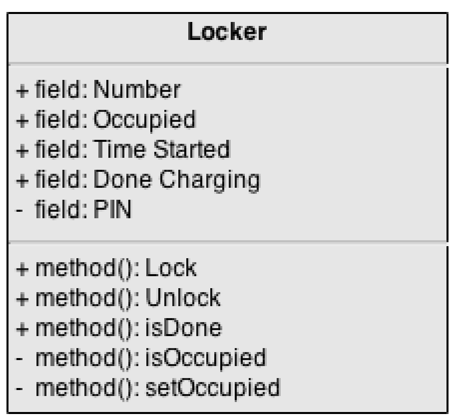

Figure 6.3.3-1

As Figure 6.3.3-1 shows, the locker class will contain the PIN associated with that locker as well as other important information about the locker such as the number and whether it is occupied. In order for someone to use a locker the system would first check the occupied field of the locker to make sure that that locker isn't already taken. It is important to note that the PIN field of the locker is private so no one can read the PIN besides the actual locker class that was created when the user chose one on the touch screen display.

Although the unlock method is public, it will require the PIN of the locker to be passed into it through user input so it would be impossible for someone who did not rent the locker to open up someone else's locked box. The user inputted PIN would then be compared to the PIN stored into field of the class and then allow or disallow the locking of the locker. With a 4 digit PIN there can be 10000 different PIN numbers, and after 3 incorrect inputted codes, the system would then prevent the locker from being opened for 5 minutes to avoid a trial and error system of typing every possible PIN into the digital touch key pad.

6.4 LED Charging Indicators

Installed within each charging locker will be two groups of light-emitting diodes (LED) within each locker a green group, and a red group, to provide charging information to the users of the UniverSOL. Red light indicates the cell phone battery is actively charging. Green light indicates the cell phone battery is fully charged and ready to go. When there is no light on it indicated that the locker is available for use, as there are no phones currently inside of it.

In order to illuminate an LED group and begin the cell phone battery-charging process, the user must identify on the touch screen which locker will be used and enter in a User ID and PIN to the UniverSOL. The User ID and PIN will alert the power management program to allow a charging flow into the specified locker. The User ID and PIN act as an energy conservation key mechanism, where only the needed lockers will supply power. This will help reduce any solar energy wastes and conserve energy within the battery. Thus, a person plugging in a cell phone without going through the User ID process will not receive charge for the cell phone battery, and no LED group will illuminate.

When the cell phone is connected to the proper charging plug, and thus the flow of energy occurs according to the current sensor the red LED group will illuminate. The red LED group will remain illuminated until the current sensor indicates the cell phone battery is completely charged. The red LED group will cease illumination and the green LED group will illuminate, indicating to the user the cell phone battery is fully charged. Once the phone has been taken out of the locker, both of the LEDs will turn off to indicate that the locker is available for use.

The window on each locker will allow the user on the door of the locker, so any user can quickly identify if that cell phone locker is occupied, as well as if the cell phone battery is received charge or charged. The user is also able to sign into the system and receive specific data about the status of the cell phone process.

6.5 Charging Lockers

The Universol is built on a metal locker frame of six box style lockers in a column configuration. The dimension of the entire metal locker frame is 12 inches wide by 72 inches high by 15 inches deep, after the removal of the metal legs. The dimension of each individual locker is 12 inches wide by 12 inches high by 15 inches deep. The door of each locker comes with a 5 inch wide by 6 inch high polycarbonate see-through window, and has room allow for the installation of a solenoid lock.

The lockers are labeled from top to bottom as Lockers 1 through 6, and each locker is dedicated to a certain function. Lockers 1, 3, 4, and 5 are dedicated cell phone charging lockers. Locker 2 will house the control panel and the touch screen. Locker 6 is housing the Universol's battery and the MPPT controller.

Each locker comes with pre-drilled holes to allow for wiring, and modifications are added to each locker. Lockers 1 through 5 have a white back panel installed 7.5 inches from the front of each locker, creating a false rear wall, with a drilled ½ inch opening to allow cable entry from behind the wall into the front. In Lockers, 1, 3, 4, and 5, the white back panel is used to mount the indicator light panel. Locker 2 the white back panel is used to mount the touch screen. The rear metal wall of Locker 2 was removed to allow for control panel access.

Wiring for the cabinet is divided into right and left sides. The left side is the wiring to Lockers 1, 3, 4, and 5. The right side is the power to the control panel from Locker 6 to Locker 2.

- Assembled Measurements: 72"H x 12"W x15"D
- Compartment Measurements: 12"H x 12"W x 15"D
- Compartments are constructed of 16 gauge steel
- Compartment 2 has an open back
- Doors on Charge Compartments modified with solenoid locks
- Doors feature a blue powder coated aluminum finish
- Each door includes polycarbonate see-through door panel
- Each door is hinged vertically on right side
- Each compartment includes modified back

Figure 6.5-4 Specifications of the Salsbury Data Transfer Locker

Front View Rear View

Figure 6.5-5 UniverSOL cabinet, front and rear views

7.0 Project Prototype Construction and Coding

7.1 Current Parts Acquisitions and Bill of Materials

The team is keeping close attention to parts and costs as we proceed with purchasing and acquiring them from various suppliers and vendors. Below is the current BOM for the UniverSOL. As the build of the UniverSOL progresses, the BOM will fill out with the parts used in the design. The final BOM will have the parts that were used in the final design. The BOM is color-coded where the item is the color of the budget section from which it is attributed. Below the table is a budget color key for reference.

1	UniverSOL Enclosure	custom	$100/$100	
1	**Solar Panel**	RNG-150D	$300/$239	**$61 under budget**
1	Blue Sky MPPT Charge Controller-Solar Controller	SB3000i	$400/$263.08	$136.92 under budget
1	Linear Voltage Regulator	custom	$136.92/.39	$136.53 under budge
1	4-Chamber Charging Lockers	200	$250/	Researching
1	Adafruit 480x320 Touch Screen LED Monitor	FT10	$150/$249	**$99 over budget**
1	**Trojan Deep Cycle 12V 89 Ah Battery**	27-AGM	$300/$226.97	**$61 under budget**
2	**PCB**			Researching
6	**Charge Doctor USB Voltage Regulators**	KW-201	$250/$21.13	$228.87 remains
1	**16F-Series PIC MCU**		228.87/	Researching
1	**PIC Kit 3 Programmer**			Researching
1	**WAGAN Quad 4-Port 9.6V USB Hub**	WA2892	$100/$30	$70 under budget - -
1	**Line Voltage Regulator**	see Wagan		Within the USB Hub
6	**USB Cables**	1.5M 5FT MtoF	$70/21	$49 under budget- -
3	**LED Lights**	62-879C	$49/$24	**$25 under budgert**

Table 7.1-1 Bill of Materials

- Enclosure $100
- Solar Panel $300
- Components to the Solar Panel $400
- Charging Locker $250
- Touch Screen $150
- Solar Panel Battery $300
- Programming PIC, Circuit Boards, Components $250
- USB Port, Cables $100

Reference 7.1-2 Budget Color Key

7.2 PCB Design and Assembly

The PCB Board for the Univerol Charge Station was designed using CadSoft Eagle PCB Design software. The downloadable free version gave a limited amount of board space, therefore acquired the full version in order to meet the requirements of our systems PCB board. Beginning with the system's electronic circuit topology, a schematic was developed in CadSoft Eagle as shown in Figure 7.2-1.

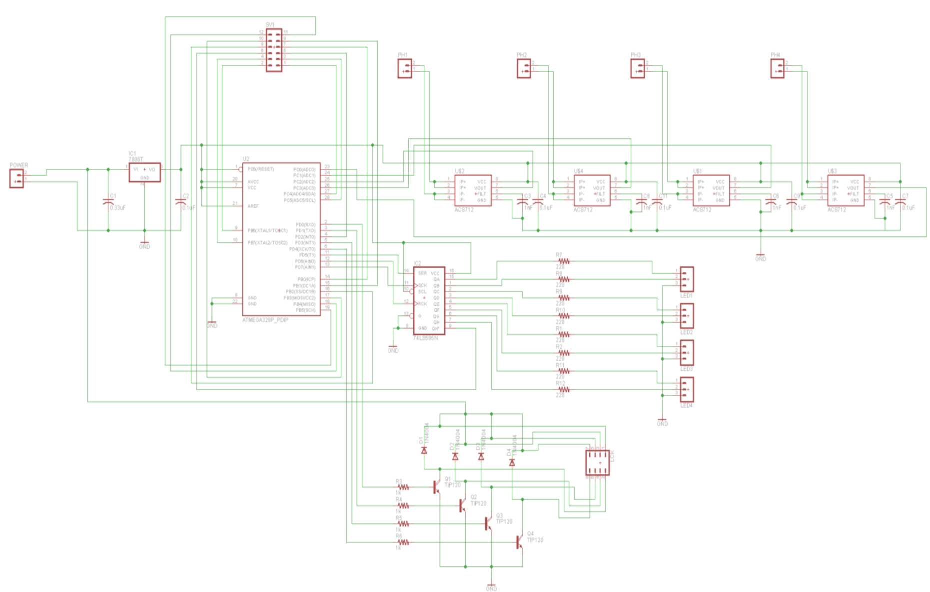

Figure 7.2-1 PCB Design Schematic

Many of the system's components were not found in CadSoft Eagle, therefore many of them were uploaded from external resources. Once the schematic was completed, the corresponding PCB board is generated from it. Using the software Auto Trace feature will instruct the program to place the traces on the board in the best possible configuration. However, the Auto Trace feature only generated a 70% completion rate with too many obstacles to overcome. Furthermore, the components and traces were meticulously laid out by hand on the PCB board as shown in Figure 7.2-2.

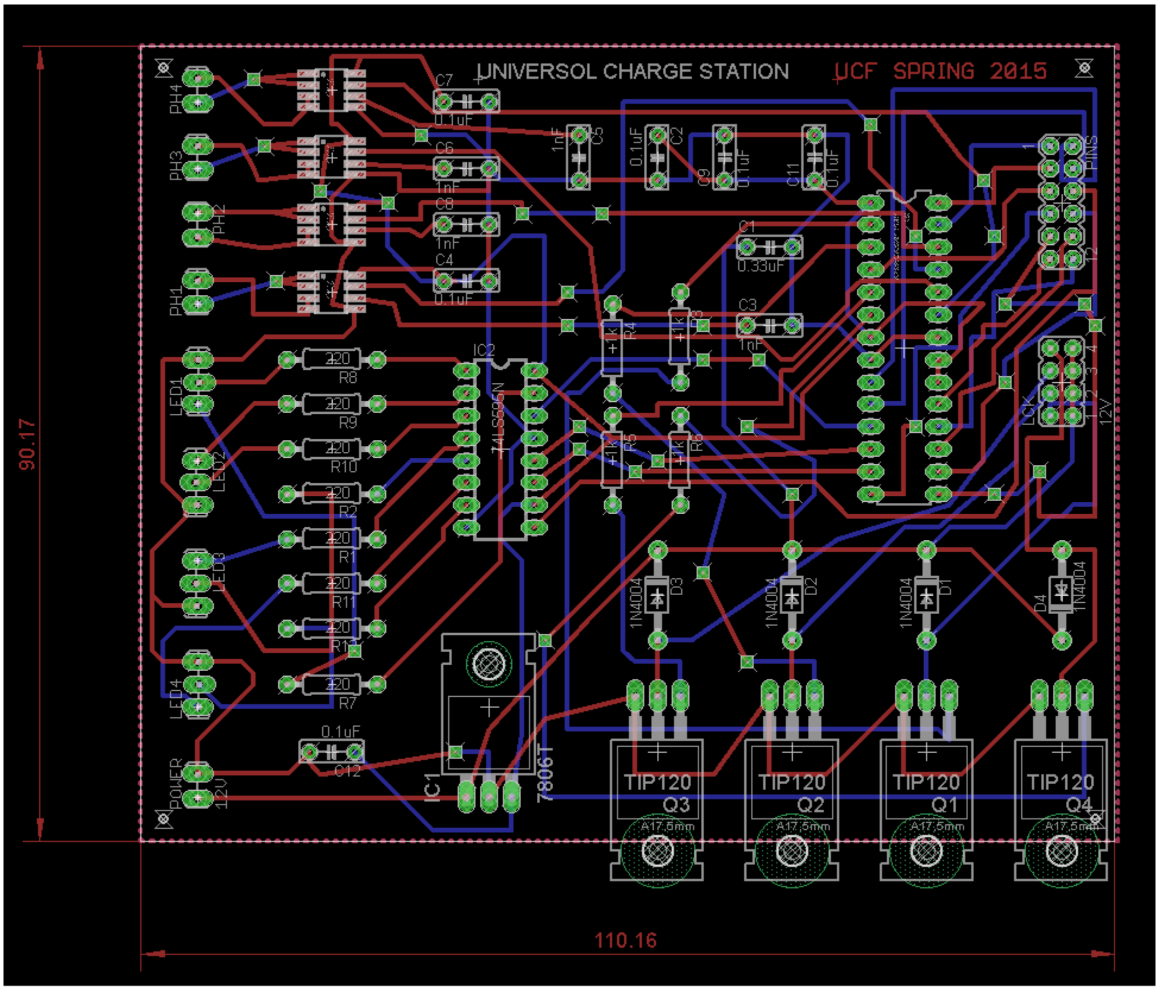

Figure 7.2-2 PCB Layout

The board is made up of a combination of surface mounted and dip and sip packaged components. There are traces along the top, bottom, and a combination of both to meet to meet their destination node. Once the PCB design was completed and the results of testing generated no errors, Gerber files were then created to be sent to Osh Park for manufacturing. Osh Park was able to manufacture three boards for us with only a ten day turnaround time.

Once the board was received, the electrical components were soldered on by the team as seen in Figure 7.2-3. A combination of surface mounted and hole through components were mounted onto the board and then it was tested. The team was fortunate enough to have the board working on the first try with no errors.

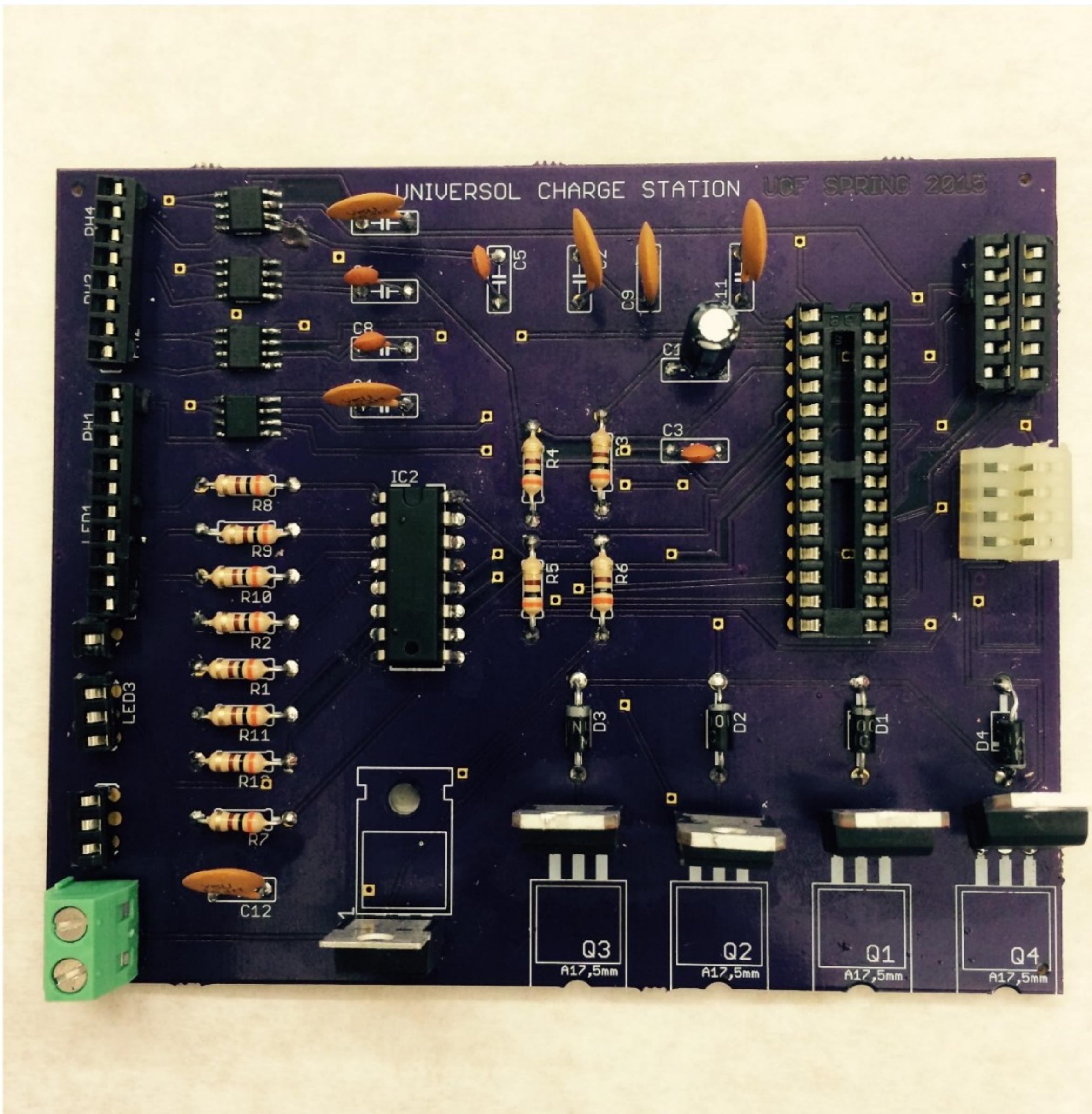

Figure 7.2-3 Assembled PCB

7.3 Final Coding Plan

The code will be posted on Google Drive for all of the members to look at and edit upon their own free will, and the code will also be posted on GitHub for version control. GitHub makes editing the code easier as you can see the difference in the code each time someone makes a change. It is important to put the code online in some type of shared environment so everyone can work on the code together and does not require the group to be meeting in person to work on the project, all members can work from their own respective offices.

The code will be writted in the Arduino programming language using Ardiunio's native IDE. The Arduino IDE is the program specifically made for the AtMega328p microcontroller and it is important to use this to ensure the least amount of bugs possible. Arduino IDE can be used on all Windows, Mac, and Linux operating system computers, which was important for code integration and having multiple engineers be able to edit the code.

The final coding plan is split up into two portions. The code that will be written directly related to the physical pins and then the code that is written with the Gameduino library for the user interface. All of the code was written in the Arduino programming language but the imported library allowed us to create different graphics to be displayed on the touchscreen. This would have not been able to have been accomplished using just the standard library of Arduino. In order for any of the code related to the physical pins, such as the lock signals, LED signals, and voltage readings, the code on the Gameduino library has to be paused in order for the functional code to know what to do. After the functional part of the program has finished, you can resume the SPI touch screen interface.

The user interface will use the model-view-controller architecture and update the screens based on button clicks and mouse events that come from the LCD touch screen display. Whenever a button is pressed, then the backend code updates the values for that screen state and that updates the model and view on the actual LCD screen. The user interface is meant to be very basic and have a small amount of things going on in the screens. The user interface is designed to be easy and quick to use, as the user will most likely be trying to get things done quickly to return to their leisure.

The main portion of the code will act as the overall controller of the system, and it runs on a continuous loop. The loop runs and calls separate functions when some values from the current sensors change in value, allowing real time updating of both the locking mechanism and the LEDs. This will allow the microcontroller to act autonomously forever after the product has been completed. There will be no need to make repairs on the code or have to debug anything any further. The code will be written with sensors to pick up changes in the environment and call functions on those changes to have the system change dynamically. The system is designed to run continuously for a long period of time and the coding design reflects that aspect of the product.

8.0 Development Testing

Test methods and procedures encompassed a significant portion of Spring 2015. The team implemented three phases of testing throughout the build and redesign periods. Stage 1 Test Phase consisted of testing individual component true function against factory specifications and performance expectations based on the design model. Stage 2 Test Phase was initiated during and following prototype builds in order to realize the functioning and compatibility of each subsystem and how a particular system reacted to another system. The majority of trouble shooting had to be performed during this stage in order to detect any problems early on, and to avoid any possible individual and conjunctive system malfunctions during final build. Stage 3 Test Phase commenced after final build when the Hardware and Software Systems were tested as a fully integrated system into the complete product.

Extensive documentation was critical during all test phases. Precise, accurate recording of results assisted in trouble shooting of problem areas and the redesign process.

8.1 Hardware Test Environment

The hardware test environments included the indoor UCF Campus Senior Design Lab Site, the indoor Off-Campus Lab Site, locations outside the UCF Campus grounds, and an outdoor location in the proximity of the Off-Campus Lab Site. The UCF and Off-Campus Lab Sites were generally room temperature, expected ranging from between 20°C - 23°C (68°F - 73°F). Obviously the outdoor lab environment temperature conditions fluctuated, which was a necessary situation to test temperature sensitive devices and the complete system.

8.2 Hardware Specific Tests

Specific testing relative to hardware components and subsystems were performed to realize and achieve the best performance results possible. Sections 8.1 and 8.2 provide a detailed outline of the how and why these hardware testing procedures occur.

8.2.1 PV System Testing

System testing was conducted in both indoor and outdoor environments at the designated site location. Outdoor site locations were necessary because batteries are sensitive to fluctuating temperature conditions and the system is an outdoor product. Testing locations were dependent on the relativity of the required data collected in the process. Testing also had to be conducted in different states of connectivity to other devices, with exceptional consideration paid to the functioning of the solar panel/charge controller/battery operation.

Testing of the MPPT charge controller relied upon connection to the solar panel and battery as an integrated system. Lab simulation of the power sources were used in place for preliminary Product Specification testing. However, true testing for system performance was always conducted while connected.

Product Specification, Integrated System, and Efficiency Testing were implemented in order to test and record divergences in performance and determine possible failure in the battery or systems. Key steps in the testing process follow:

1. Addressed Testing Preparation. Secured vent caps and cleaned battery terminals when necessary. Secured wires and tightened connections to manufacturer specifications for all devices.
2. Applied key test case scenarios in outdoor conditions. Operated the battery for lengthy periods of time in low/high temperature conditions.
3. Used either volt/current meters unless otherwise specified.
4. Measured the output voltage and current of the battery stand-alone at full charge in both outdoor and indoor testing using volt meters.
5. Measured the output voltage and current of the battery stand-alone at varying states of DOD in both outdoor and indoor testing.
6. Connected the Battery to the MPPT Charge Controller and Solar Panel System. Measured the output voltage and current of the battery in the Integrated System at full charge in both outdoor and indoor testing.
7. Measured the input current and voltage to the Charge Controller delivered from the Solar Panel.
8. Connected Integrated System electrical loads to battery and tested voltage during various states of discharge. Verified that the battery delivered the specified power it was intended to.
9. Recorded and analyzed results to manufacturer specifications and expected performance ratios to test for system gains.

The fully integrated system was tested in the lab and on a cool, intermittent low/high irradiation day (partly cloudy) with the battery discharged below 70%. Because the battery determined the amount of current that flowed into it, the PV system had to be in this state, known as Bulk charge mode, in order to achieve the MPP gains.

The battery was discharged using the electrical load supply in the Senior Design Lab set at 25 A of load to quickly draw the battery down to the required SOC status. The 25 A load was the highest this battery was capable of being discharged at, and the procedure took approximately 20 – 25 minutes to achieve below 70% capacity. To monitor the SOC status of the battery, open circuit voltage readings were taken across the terminals after removing the load. The readings were applied to the battery specifications provided by the manufacturer illustrated in Fig. 8.2-1. For this particular system, the VOC measurement range was determined between 12.35 and 12.45 to be between 60 and 70 % capacity.

SOC	VOC
100	12.84
75	12.54
50	12.24
25	11.94
0	11.64

Figure 8.2-1 VOC related to SOC status for Trojan 12V 89 Ah AGM

If the system had been designed using a basic charge controller that regulated through Pulse Width Modulation (PWM), the current output would not exceed the panel Imp rating of 7.79 A. However, with MPPT, that current output value from the charge controller was increased as the voltage dropped, resulting in a significant increase in power gain delivered to the system. The expected PWM output calculated using the following equation:

$$PWM = Vout * Imp$$

In the lab setting, using a simulated PV power supply, the system achieved a 48% gain. Under low irradiation conditions outside, the charge controller acted as a PWM controller because the current output did not exceed the Imp. Under high irradiation conditions, the system performed exceedingly well with a 54% gain. Normally, gains in excess of 40% can be expected in cooler temperatures with highly discharged batteries. In addition, actual charge current increases can be amplified based on the greater difference between PV Vmp and battery voltage [2]. In this system's case, the Vmp is 37 V, while the battery voltage is 12 V, justifying these high gains. Fig. 8.2-2 illustrates the data collected during testing and the calculated results.

SETTING	Pin W	Vout	Iout	PV Pout W	PWM Pout W	System Gains
Lab	150	13.3	10.3	137	67	47%
Low	46	12.9	3.4	43.8	43.8	0%
High	228	13.6	14.4	195.8	105.9	54%

Figure 8.2-2 Summary of PV System Activity

8.2.2 Solar Panel Testing

Testing of the Suntech 235W Polycrystalline Solar Panel was done outside specifically to record a few conditions. Those conditions were Isc, Voc when the panel wasn't connected to anything and the voltage and current when the panel was connected to the MPPT controller and battery. The panel was tested with a multimeter without anything connected under sunny weather conditions and it gave us readings of Voc = 35.0V and Isc = 8.1A, which were very close to the manufacturer's ratings. Next, the panel was tested with the MPPT controller and battery connected inline. The group was happy to see the panel delivering 7.5A which meets the system's requirements of a minimum of 7.1A.

8.2.3 Voltage Regulator Testing

Testing of the 12V to 5V switching voltage regulator was done in the laboratory using a multimeter. Once the switching regulator was received, it was tested in a simple schematic to check for an output voltage of 5V when feeding it 12V. The first part was a success as the multimeter read 5V exactly when supplying 12V into its input terminal. Next, the switching regulator was assembled onto the PCB board for final testing. With all of the electrical components of the system working in conjunction on the PCB, 12V was supplied to the board and the input terminal of the switching regulator. Gratefully, the multimeter read a constant 5V from the output terminal. All of the components which receive 5V from the switching regulator were also tested from their Vcc pins and were all successfully receiving 5V.

8.2.4 High Power USB Hub Testing

Upon receiving the Wagan Travel Charge Quad Power 4-port hub, the team will test the functionality of the hub. The hub has a 12V/10A barrel plug designed to be inserted into a vehicle's 12VDC socket, and provide the DC power directly from the vehicle's battery. The OEM specifications are based this charging structure.

The hub will be connected into a vehicle's outlet, and the team will begin testing with electronic devices. In addition to cell phones, the team decided to include other devices that require charging, as those users may want to utilize the charging capabilities of the UniverSOL too. Electronics the team agreed upon were tablets, e-cigarettes, a laptop, newer cell phones, and older cell phone technologies.

To help ensure accuracy of the data collected, the Charge Doctor current sensor will be employed. The data collected are amps, voltages, and times per each device; the OEM charging data for the device; and the Wagan Quad Power hub spec sheet data.

If the hub passes the testing process, the team will proceed forward with its incorporation into the UniverSOL design. If the hub fails or performs poorly during the testing intervals, the team will document the specific failure, explain why it was a failure, and then discuss if this failure will prevent the current hub from being used in the UniverSOL's construction. Finally, the team may need to revisit the hub hardware research, and chose another hub for testing.

8.2.5 Microcontroller Unit Functionality

The main purpose of these tests are to make sure the microcontroller is getting power from the battery and all of the wires are correctly plugged into the microcontroller. The main tests for the microcontroller unit functionality are looking at the voltage regulator randomly while the system is running and making sure the microcontroller is providing power to the correct components at the correct time. Apart from the voltage regulator it is important to test that the microcontroller is reading the code correctly and it can be compiled without and errors. To test this microcontroller will be plugged into the computer with the written software on it and then that code will be downloaded to the board. We need to makes sure that there are no debugging errors and that the code downloads in its completion, because if only a portion of the code was downloaded than the overall system would not work correctly. We need to make sure after the microcontroller has downloaded the code that the microcontroller will turn on and the reset button restarts the microcontroller. It is easy to test the current and voltages from the microcontroller with an oscilloscope so we will do so to make sure we are not proving too much power to the microcontroller and causing it to overheat and damage itself.

8.3 Software Testing Environment

There will be three different environments in which we will run the different software tests we have created. The first environment will be just to test the functionality of the user interface with the integrated touch screen display. The only components that will be used for these tests are the microcontroller and the touch screen display. The tests for this environment can be found in section 8.4.1 below. The second environment that will be tested will be the user interface connected with the lockers which contain the locking mechanism as well as the connected cellular devices and the LED indicators. The tests that will be run for this environment can be found below in section 8.4.2. The third environment that we will specifically run tests on is the overall complete system. Once the entire prototype is built and everything is connected we want to make sure that all of the software inside the system is running correctly and that the system is working as planned.

8.4 Software Specific Testing

8.4.1 User Interface Testing

These tests will be run with only the microcontroller and the LCD touch screen connected. It is important that the User Interface works independently of the rest of the system before you connect that to the entire system to avoid errors and debugging issues. Testing smaller systems before integrating them into the larger systems makes finding and debugging error much easier, as there are less places for the code to go wrong. With these two components connected together the tests we want to run and the checklist tables are found below. The table will be filled out at testing time with the results of each test as well as any notes for each test inputted into the table.

1. Does the main screen load when the microcontroller is powered on?
2. Does the main screen go into screensaver/advertising mode when it is not touched for 3 minutes?
3. Does the screen saving mode cycle through multiple images/movements to ensure that no image burn happens on the screen?
4. Is the main menu button clickable?
5. Does the main screen button click take you to the proper screen of deciding whether or not you already have a locker initialized?
6. When you click new locker or existing locker does the LCD screen take you to the new screen with the respective options?
7. When user creates a new locker does the system display the number pad?
8. Are the number pad digits clickable?
9. Do the inputted numbers display as asterisks instead of the actual number?
10. Does the clear button delete all of the typed digits?
11. Does the enter button prompt the user to re-enter their PIN?

Test	Results (Pass/Fail)	Notes
1.	Pass	All good, wires a little tempormental, be careful
2.	Pass	N/A
3.	Pass	No image burn on screen, load pictures from SDcard
4.	Pass	N/A
5.	Pass	Takes to locker input screen

6.	Pass	New locker auto registers a locker for user, Pin screen is displayed
7.	Pass	Number pad displayed
8.	Pass	Digits are clickable
9.	Pass	Never displays actual number
10.	Pass	Clear Deletes all Asterisks
11.	Pass	Enter asks to re enter PIN

Table 8.4.1-1

8.4.2 LCD and Locker System Testing

These tests below will be run with the microcontroller the LCD touch screen and the entire locking mechanism and compartments connected together. The main goal of these tests is to make sure that there are no errors when accessing new lockers and the system does not allow for lockers to be assigned to multiple people. As with section 8.4.1 all of the test results will be stored in a table and completed at test time. It is important to test this system for security of the user's personal items.

1. Does the system allow you to reserve a locker?
2. Does the system require you to type your PIN in two times for verification of creating an account?
3. Will the system let you reserve a locker that is already reserved?
4. Will the system let you reserve a total of 4 lockers?
5. If you already have a locker will the system let you log in?
6. If you type the wrong PIN will the system allow you to open your locker?
7. When you remove your phone from the locker does the system mark the locker as unoccupied?
8. Can you re-reserve a locker after someone has checked out of that same locker?

Test	Results (Pass/Fail)	Notes
1.	Pass	Can reserve if none taken
2.	Pass	Entering PIN displays re-enter screen
3.	Pass	No Will not allow reservation of locker twice
4.	Pass	Yes can reserve all 4 lockers

5.	Pass	Existing locker screen displayed correctly.
6.	Pass	No, Displays wrong PIN screen
7.	Pass	Locker can be re-occupied by someone else
8.	Pass	Continuation of 7

Table 8.4.2-1

8.4.3 Complete System Testing

These tests are to ensure that with the completion of the entire system, with all of the components interacting together, works as intended and nothing got damaged with the addition of different components. These will be the final software tests before the prototype can be marked as ready for production. The tests in this section will re-test all of the tests of the system in the previous sections as well as add new tests to make sure the entire system works. The tests are listed below and the table will be filled out when the tests are done with the results of each test as well as any specific notes that the tester has about the specific test attempted.

1. Does the main screen load when the microcontroller is powered on?
2. Does the main screen go into screensaver/advertising mode when it is not touched for 3 minutes?
3. Does the screen saving mode cycle through multiple images/movements to ensure that no image burn happens on the screen?
4. Is the main menu button clickable?
5. Does the main screen button click take you to the proper screen of deciding whether or not you already have a locker initialized?
6. When you click new locker or existing locker does the LCD screen take you to the new screen with the respective options?
7. When user creates a new locker does the system display the number pad?
8. Are the number pad digits clickable?
9. Do the inputted numbers display as asterisks instead of the actual number?
10. Does the clear button delete all of the typed digits?
11. Does the enter button prompt the user to re-enter their PIN?
12. Does the system allow you to reserve a locker?
13. Does the system require you to type your PIN in two times for verification of creating an account?
14. Will the system let you reserve a locker that is already reserved?
15. Will the system let you reserve a total of 4 lockers?
16. If you already have a locker will the system let you log in?
17. If you type the wrong PIN will the system allow you to open your locker?

18. When you remove your phone from the locker does the system mark the locker as unoccupied?
19. Can you re-reserve a locker after someone has checked out of that same locker?
20. When a phone is plugged into a locker does the LED come on immediately?
21. When a phone is plugged into a locker does the LED stay on until the phone is removed?
22. Does the LED change from red to green when the phone is done charging?
23. Does the system remember your PIN correctly when checking your phone?
24. Does the system detect no phone plugged into a reserved locker and mark that locker as available?

Test	Results (Pass/Fail)	Notes
1.	Pass	See 8.4.1-1
2.	Pass	See 8.4.1-1
3.	Pass	See 8.4.1-1
4.	Pass	See 8.4.1-1
5.	Pass	See 8.4.1-1
6.	Pass	See 8.4.1-1
7.	Pass	See 8.4.1-1
8.	Pass	See 8.4.1-1
9.	Pass	See 8.4.1-1
10.	Pass	See 8.4.1-1
11.	Pass	See 8.4.1-1
12	Pass	See 8.4.1-2
13.	Pass	See 8.4.1-2
14.	Pass	See 8.4.1-2
15.	Pass	See 8.4.1-2
16.	Pass	See 8.4.1-2

17.	Pass	See 8.4.1-2
18.	Pass	See 8.4.1-2
19.	Pass	See 8.4.1-2
20.	Pass	Red Led lights immediately
21.	Pass	LED stays on
22.	Pass/Fail	Works for most phones, some phones draw too much current so red stays on. Might need to update for every possible phone current level
23.	Pass	N/A
24.	Pass	Yes displays no lighted LEDs

Table 8.4.3-1

9.0 Project Operation

The UniverSOL Charge Station was designed for public use. Therefore, it is necessary to provide a detailed description of how to operate the device. The user interface was developed to be user-friendly and the following steps are a guided walk- through of the process.

1. To begin the process, the user presses start on the touch screen interface located in the second locker.
2. The first-time user will be prompted "Do you have an existing locker?" As a first-time user, select NO.
3. The machine selects an available locker and the touch screen prompts the user to enter a PIN number for that specific locker. The user should then enter a four-digit pin.
4. Once the pin is entered, the user is prompted to enter the pin a second time.
5. If the user enters an incorrect pin number, the user will be prompted "Wrong. Try Again.".
6. Once the proper pin is entered, the user has gained access to the locker as the locking mechanism releases. The user can now open the door.
7. The user places the phone to charge in the machine, connecting the phone to the proper charging end for the user's particular phone. The user can then close the locker which will immediately lock the phone inside.

8. The user can view that the phone is charging after the door is locked through the window on the front of the machine. The red lights turn on indicating that the phone is charging.
9. The user can periodically check on the charge of the phone by viewing if the light is red or green. When the light turns green, the phone is fully charged.
10. To open the locker and retrieve the phone, the user presses “Start” on the touch screen.
11. Once again, the user will be prompted “Do you have an existing locker?” As a returning user, select YES.
12. The user will enter the PIN number initially selected by the user and the locker will open to retrieve the phone. The user will then close the lock

10.0 Administrative Content

Throughout the Research and Design process, detailed documentation of Milestones and Financing was conducive to the overall outcome of the project. Coupled with weekly Status Meetings and a Document Control system set up, the team collaborated on several issues relative to not only the development of the system, but to ensure that administrative duties, division of work assignments, and communications were addressed and managed accordingly, in a timely manner. In addition, these processes allowed for the team to follow-up with one another, make and/or communicate design and deadline decisions, and distribute work evenly.

Meeting minutes taken during the status meetings were an effective way to organize current and previous topics of discussion, guarantee follow-through of outstanding items, revisit decisions that were made, and recall previous week's discussions. A Status Meeting spreadsheet was placed on a shared drive for all members to have access to. In between the weekly meetings, any member that wanted to make certain that a concern, topic, or issue was addressed simply placed it into the board for follow-up at the upcoming meeting. Utilizing this tool assisted in moving forward in a timely manner throughout the project, making sure that every member of the team had a voice that was valued and shared, and communication lines stayed open and on topic. Figure 9.0-1 is a sample excerpt from the month of October of the meeting minutes taken during proceedings.

Timeline	**Topics to be Discussed**	**Final Determinations**
Week of 10/11/2014	*Division of Research Document*	Defined group Expectations (due dates, working together), defined what needs to be figured out first in order to design other parts of the systems
	Research information documentation and locations	We have to document all of our research in a Works Cited in the Appendix. I have been saving the links for my research and placing them in a file along with papers/journals on the subjects. I began a Research and Documentation Folder for it. Please add a folder of your own and if you haven't been documenting your research please begin to do so.
	Ordering Parts – Preparing for Winter Break	Discuss what can be ordered/acquired and/or set a date of determination so that we can start prototyping in December
	Funding Status	Dr. Richie informed group last week that it will be 4-6 weeks before we find out about funding approval due to ABET delays
	Setting up Final Paper	Issues with using Google Drive formatting for Microsoft Word, establish a new Shared drive and set up a document following quality control guidelines set forth in assignment

Day of 10/16/2014		
	Senior Design Project Summary Sheet for Marketing	Completed
	Establish Team Contact for Senior Design Day 2015	Group 17 Point of Contact CECS Senior Design Day Spring 2015 – John Curristan e-mail address: curristanj@gmail.com
Week of 10/17/2014		
	Research Paper	Individual research and writing the paper. Broke into groups of two and meeting at convenience to discuss design and research
Week of 10/24/2014		
	Electrical Load Preliminary design – Determine wattage from all the components everyone is researching; show electrical load list and verify if the list is current	Need to add the USB HUB and obtain wattage on the components
	Electrical Load Preliminary design – How long each component will be powered in a 24 hour period	All components so far need to be running 24 hours/ day
	Preliminary Battery Bank Design	Upon completion of Electrical Load determinations, Estimated Battery Bank can be determined
	Powering Phones	Extensive research has been done on breakout cables and USB Hub for powering phones; narrowed it down to a few options; Decisions to be made on design following final write-up on research section of final paper
	Enclosures and Locking Compartments	Decided to use mobile phone locker as sub enclosure for phones, and build the enclosure around it. Still may use protocase, may fabricate or outsource fabricating of outside enclosure to a third party. More investigation into cost and time constraints to decide best route
	Funding Status	Still awaiting approval on Duke Funding and Protocase

	Ordering parts	Awaiting funding and want to do some research before final decisions; Have a 30 day window to turn in receipts and do not want to miss that window
	Research Paper	Discussed copyright permission requests to ensure everyone is using proper documentation; Followed up on individual progress of the paper in anticipation for the Nov. 13th rough draft deadline; Determined the Appendix sections will include acronyms

Figure 9.0-1 Meeting Minutes from Weekly Status Meetings

Division of work was addressed using a similar spreadsheet on the same shared drive entitled Document Control. This spreadsheet maintained the research and writing sections of the final paper. The list was derived directly from the Table of Contents to ensure that every section anticipated for the final paper was addressed. Each section was assigned to a member, designating a Lead and Secondary. A Lead was assigned to each category to be the “expert” on the topic and research and write the corresponding section. A Secondary was assigned to some of the sections in cases where the design may need supplemental input, a second opinion, or as a back-up based on time constraints. This was generally assigned with respect to which sections and respective Leads were closely related in scope. Figure 9.0-2 is a sample excerpt from the Hardware and Software Design Sections.

Sections	Lead	Secondary
5.0 Design Summary of Hardware	Amy	
4.1 Initial Design Architectures and Related Diagrams 4	Amy	Jonathan
5.1 Power System Management 1	Amy	Jonathan
5.1.1 System Load Calculations 1	Amy	Jonathan
5.1.2 Solar Panel 1	Jonathan	
5.1.3 Lead Acid Battery 1	Amy	
4.2.5 Battery Charge and Discharge Control 1	Amy	
5.1.4 MPPT Charge Controller	Amy	Jonathan
4.2.6 Analog to Digital Converter (ADC) 1	John	Brock
5.1.5 Voltage Regulator	Jonathan	Amy
5.1.5.1 PIC MCU Voltage Regulator 1	Jonathan	
5.1.5.2 Touchscreen Voltage Regulator 2	Jonathan	
5.1.6 Cell phone High Power USB Charging Hub 1	John	
5.1.7 Voltage Sensors 1 Phone	John	
5.1.8 Current Sensors 1 phone	John	
5.2 Embedded Subsystem 1	John	Brock
5.2.1 Microcontroller 2	John	Brock
5.3 Input/Output Devices		
5.3.1 LCD Touch Screen Display 1	John	
5.3.2 LCD Display 1	John	
5.3.3 State of Charge Indication 1	John	
6.0 Design Summary Software		
6.1 Initial Design Architectures and Related Diagrams 2	Brock	
6.2 Programming the Microcontroller 1	Brock	
6.2.1 C Programming Language 1	Brock	
6.2.2 Java Programming Language 1	Brock	
6.2.4 PIC Microcontroller 1	Brock	
6.3 LCD Touch Screen Display 1	Brock	

Section Status	
In Progress	(light blue)
Completed	(purple)
Eliminated	(red)

Figure 9.0-2 Document Control Research and Design

10.1 Milestones Discussion

Managing a large-scale project can easily fall behind schedule without the implementation of a time management program to adhere to. In order to meet the final deadlines for the project, periodic subordinate internal deadlines were established. The timelines assist in keeping the entire team working in harmony and allowed for fluid research, design, prototype, build, redesign, and test processes.

In building the timelines, these fundamental stages were addressed. The primary components critical to the design of the project were singled out as they primarily affected the overall design. Setting dates of completion allowed for team members to work in conjunction with one another as individual tasks were assigned without cause for delay on other aspects of the project.

Illustrated in Figures 9.1-1 and 9.1-2 are the Fall 2014 and Spring 2015 Timelines, respectively, updated throughout the end of the project.

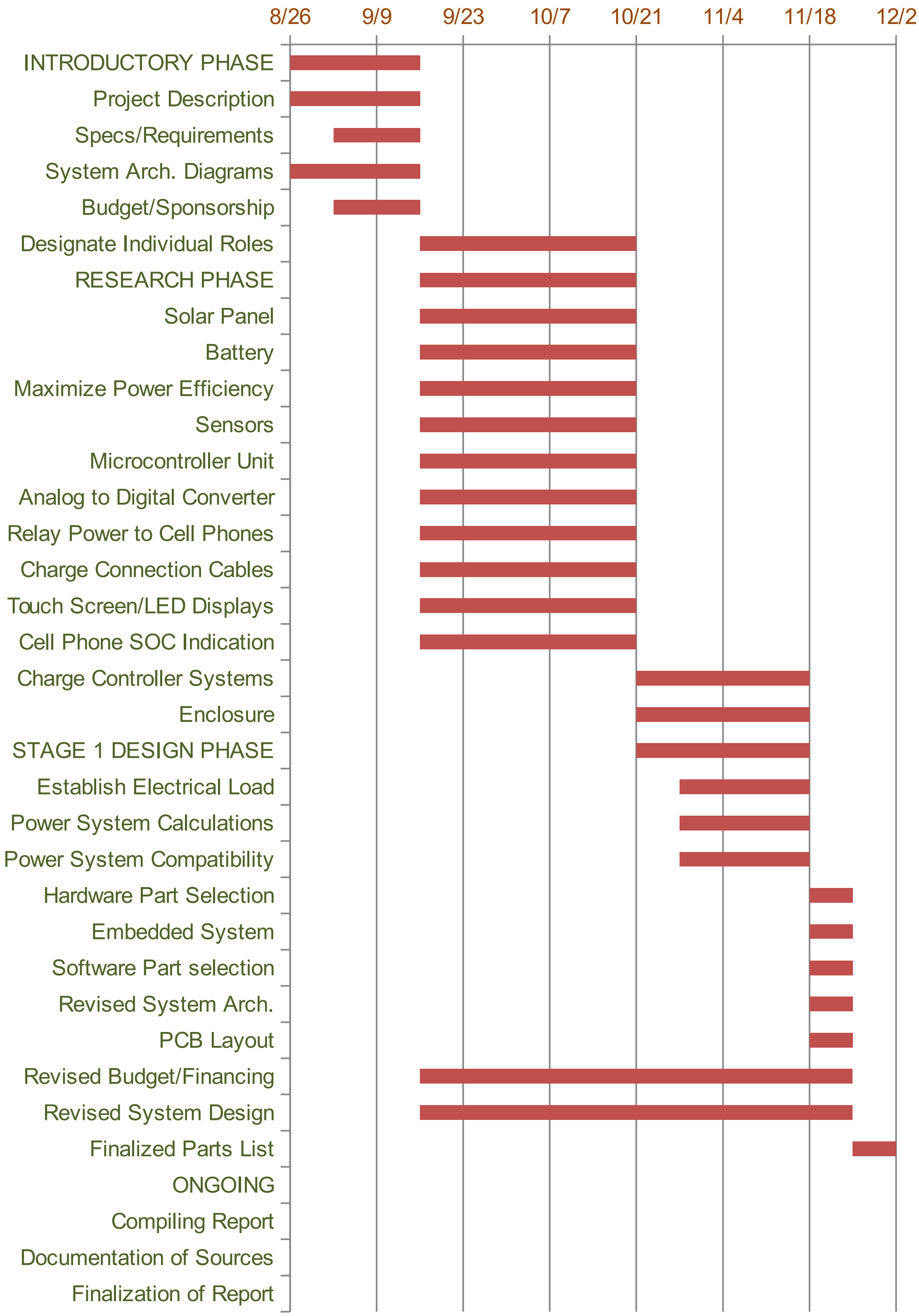
8/26
9/9
9/23
10/7
10/21
11/4
11/18
12/2
INTRODUCTORY PHASE
Project Description
Specs/Requirements
System Arch. Diagrams
Budget/Sponsorship
Designate Individual Roles
RESEARCH PHASE
Solar Panel
Battery
Maximize Power Efficiency
Sensors
Microcontroller Unit
Analog to Digital Converter
Relay Power to Cell Phones
Charge Connection Cables
Touch Screen/LED Displays
Cell Phone SOC Indication
Charge Controller Systems
Enclosure
STAGE 1 DESIGN PHASE
Establish Electrical Load
Power System Calculations
Power System Compatibility
Hardware Part Selection
Embedded System
Software Part selection
Revised System Arch.
PCB Layout
Revised Budget/Financing
Revised System Design
Finalized Parts List
ONGOING
Compiling Report
Documentation of Sources
Finalization of Report

Fig 9.1-1 Fall 2014 Senior Design I Timeline

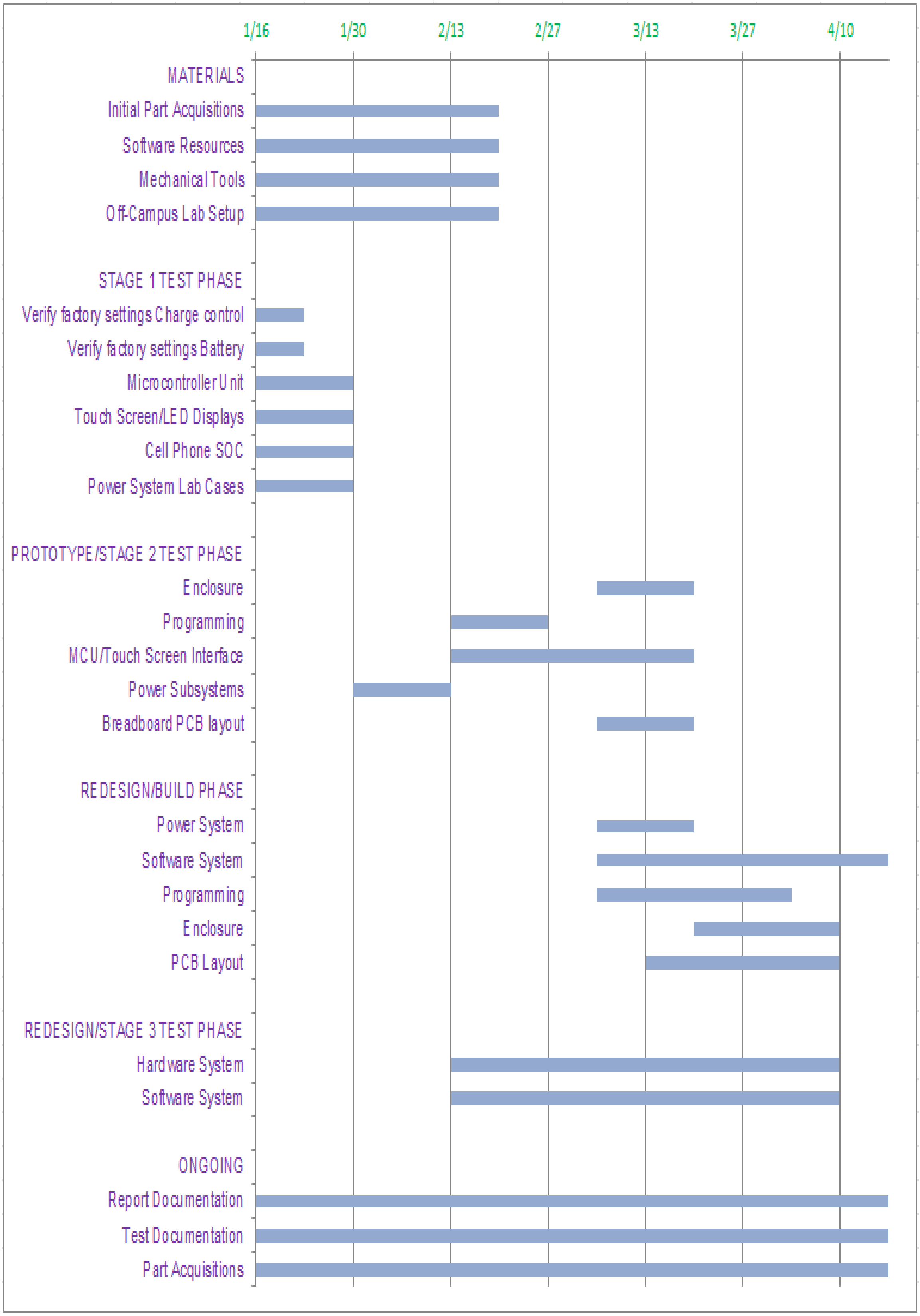

Fig 9.1-2 Spring 2015 Senior Design II Timeline

The timeline that was projected for Fall 2014 ran rather seamlessly throughout the semester. The only setback that occurred was the plan to start ordering parts the week of November 18th. Budget concerns due to funding approval/disapproval dictated the scope of the design because the integral components of the project were the most expensive. However, the team was able to use that time to redesign for changes to suit the budget. As expected in most engineering situations, timelines can be affected by a number of situations. As future engineers, the team collaborated, modified the lead time for parts, and reassessed the projected timeline going forward for the Spring 2015 semester.

The projected timeline for Spring 2015 was modified several times for various reasons including part ordering/delays, redesign and modifications to the system. This was expected due to the occurrences that come with the territory of designing and building a prototype in engineering. As schedule modifications were made and delays occurred, the team concentrated on other aspects of the design to ensure a workable project delivered on time.

10.2 Budget and Finance Discussion

The UniverSOL project received a sponsorship from Leidos Energy of $700.00. The team is very thankful for the generous grant, and is applying it towards the building of the UniverSOL. However, the current budget amounts were upon a previous sponsorship of $2000.00. The team overestimated some budget areas and that as the construction of the UniverSOL progresses; the budget may change again to accommodate changes in design.

Enclosure	$100.00
Solar Panel	$300.00
Components to the Solar Panel	$400.00
Charging Locker	$250.00
Touch Screen	$150.00
Solar Panel Battery	$300.00
Programming PIC, Circuit Boards, Components	$250.00
USB Port, Cables	$100.00
Miscellaneous Components	$150.00
Total	**$2,000.00**

Table 9.2-1 Proposed Budget

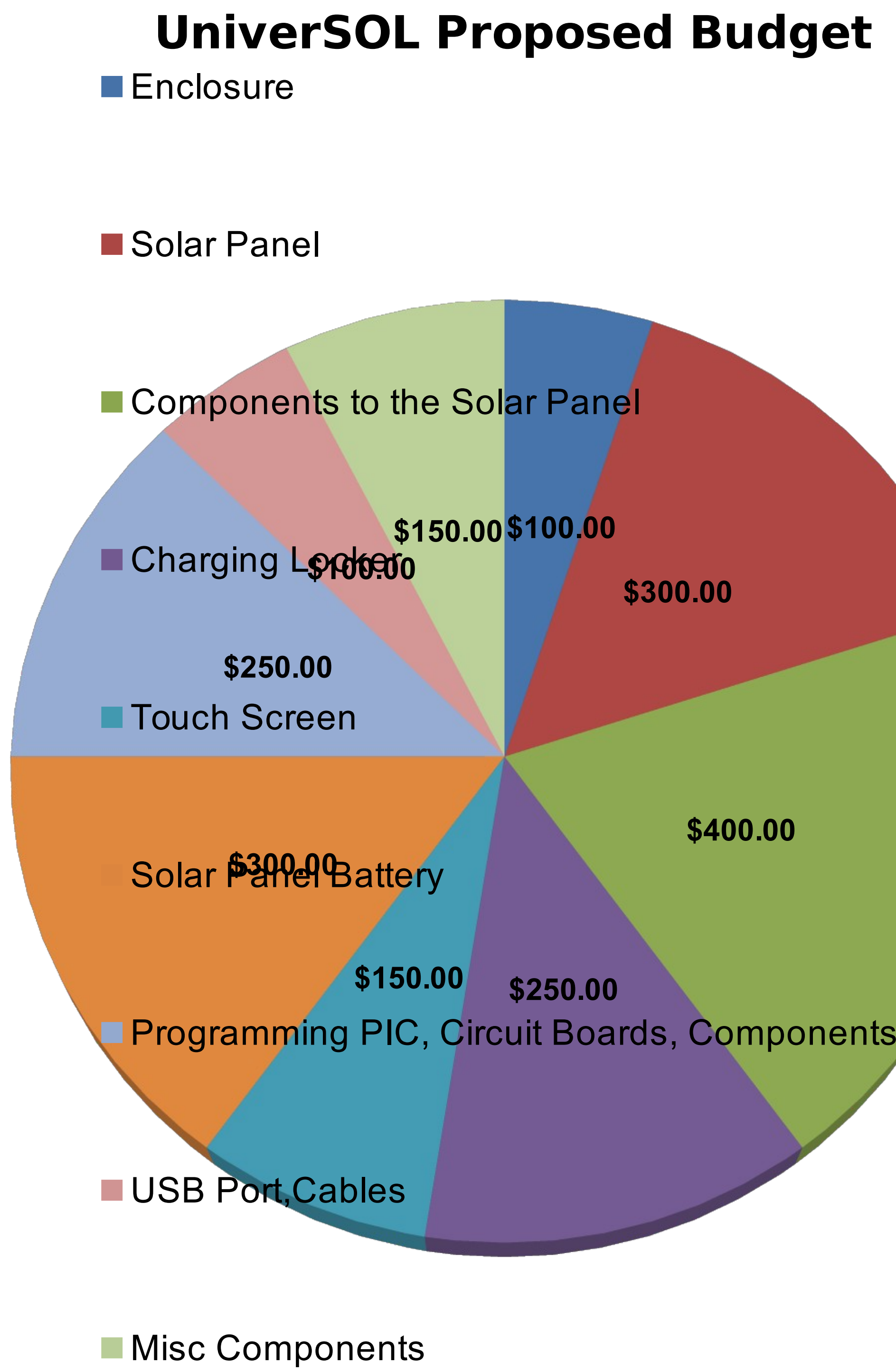
UniverSOL Proposed Budget
Enclosure
Solar Panel
Components to the Solar Panel
Charging Locker
Touch Screen
Solar Panel Battery
Programming PIC, Circuit Boards, Components
USB Port,Cables
Misc Components
$100.00
$300.00
$400.00
$250.00
$150.00
$300.00
$250.00
$100.00
$150.00

Figure 9.2-2

10.3 Division of Work

Each member of the team played a vital role in accomplishing the completion of this project. While the entire team was involved in the administration and project planning, individual attention relative to the design project were assigned. Fig. 10.3-1 illustrates the primary focus of the team members throughout the implementation and design of the UniverSOL Charge Station.

Amy	Jonathan	Brock	John
• Power System • Battery • MPPT • Microcontroller • Hardware • Testing	• DC to DC Converters • PCB Design • Hardware • Testing • Fabrication	• Software • Microcontroller • Touchscreen • Testing • Security System	• Hardware • Sensors • Safety • Programming • Testing • Fabrication

Figure 10.3-1 Work Distribution Table

11.0 Project Conclusion

The UniverSOL Charge Station was developed as an environmental-friendly and sustainable product that benefits society. While the initial cost of the system may appear to be expensive, the overall impact that this station delivers is well worth the initial investment. The system provides a much desired service to the public at no cost to the user, while promoting clean energy. With the user in mind, the touch screen interface application is easily understandable and simple to use. The viewing windows with indicator lights allow for the user to easily verify the status of the phone. The locking mechanism system provides the user with a secure environment allowing comfort in leaving such an expensive, important device unattended. The solar energy system provides an avenue to reducing the carbon footprint because all of the energy used by the station is harnessed from one of the greatest natural resources in the world: the sun. This product is ideal for businesses that have a lot of outside traffic such as amusement parks, outdoor malls, or concert and sporting venues. These businesses can provide the consumers with a no-cost, convenient way to charge phones. In return, the consumer will have the ability to take many photographs and use social media in those environments, thus promoting the businesses.

The UniverSOL Charge Station Project also provided the team with many valuable experiences in the field of engineering. Electrical and computer engineering design and system integration were coupled with aspects of mechanical engineering to develop the final product. Furthermore the engineers of this product gained many beneficial skills related to the interdisciplinary field of engineering including project planning and management, budget constraints, presentation, prototyping, testing, and reporting.

Appendices

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Appendix B- Copyright Permissions

Mon 12/1/2014 12:35 PM
Kevin Flynn <kflynn@linear.com>
RE: Submission Received: Feedback/Website Comments
To jonagman@knights.ucf.edu

Hello Jonathan,

Yes, you have permission to use information in our datasheet. Good luck with your design project!

Regards,
Kevin Flynn
Technical Communications Manager
Linear Technology Corporation

From: Linear Technology [mailto:mylinear@linear.com]
Sent: Saturday, November 29, 2014 12:15 PM
To: webcomments@linear.com
Subject: Submission Received: Feedback/Website Comments

First Name: Jonathan
Last Name: German
Company/Organization: University of Central Florida
Email Address: jonagman@knights.ucf.edu
Telephone:
City:
State:
Country: United States
Questions/Comments: Greetings, I am a student at the University of Central Florida who is currently working on a Senior Design Project of a Photovoltaic System. I am in the process of researching MPPT IC controllers with Buck-Boost Converters and I would like to request permission to use information from the datasheet of the LT8490. Specifically, I would like to use the image of the Simplified Solar Powered Battery Charger Schematic on page 1. Thank you, Jonathan German

Mon 12/1/2014 11:47 AM

Gray-Hann, Pamela <Pamela.Gray.Hann@nrel.gov>

NREL maps

To jonagman@knights.ucf.edu

You replied to this message on 12/1/2014 4:13 PM.

Action Items + Get more apps

Hi Jonathan, I received your request for permission to use a map and a graph for your project. Could you please send me the links to the map and graphic you want to use so I can review and send you the correct attribution language. Thanks

-----Original Message-----
From: jonagman@knights.ucf.edu [mailto:jonagman@knights.ucf.edu]
Sent: Friday, November 28, 2014 10:37 AM
To: NREL E-Mail Contact
Subject: NREL.gov website inquiry

You got a message from Jonathan German (jonagman@knights.ucf.edu).

The last page they viewed before the webmaster page was: http://www.nrel.gov/about/contacts.html

Their message:
Greetings,

I am a student at the University of Central Florida who is currently working on a Senior Design Project of a Photovoltaic System. I am in the process of researching solar energy and PV cells and would like to request permission to use information from your website. Specifically, I would like to use the map titled "Photovoltaic Solar Resource of the United States" and the line graph titled "Best Research-Cell Efficiencies."

Thank you,

Jonathan German

Tue 12/2/2014 10:05 AM

Gray-Hann, Pamela <Pamela.Gray.Hann@nrel.gov>

RE: NREL maps

To Jonathan German

Jonathan, thanks for the clarification.

Permission is granted to use the U.S. solar map and the efficiency graphic for your project, as long as the following attribution language is used:

"This solar map was created by the National Renewable Energy Laboratory for the U.S. Department of Energy."

"This efficiency graph was created by the National Renewable Energy Laboratory for the U.S. Department of Energy."

Also please note that the NREL developed maps and graphics are not to be used to imply an endorsement by NREL, the Alliance for Sustainable Energy, LLC, the operator o NREL, or the U.S. Department of Energy - Jonathan, note that this statement does not have to be cited, it is just for your information.

Let me know if you have any questions. Thank you for your interest in our work.

From: Jonathan German [mailto:JONAGMAN@knights.ucf.edu]
Sent: Monday, December 01, 2014 2:14 PM
To: Gray-Hann, Pamela
Subject: RE: NREL maps

Hello Pamela,

Here are the following links to the maps and graphs that I would like to use:

Photovoltaic Solar Resource of the United States

http://www.nrel.gov/gis/solar.html

Best Research-Cell Efficiencies

http://www.nrel.gov/ncpv/images/efficiency_chart.jpg

Thank you,

Jonathan German

From: Gray-Hann, Pamela [mailto:Pamela.Gray.Hann@nrel.gov]
Sent: Monday, December 1, 2014 11:47 AM
To: jonagman@knights.ucf.edu
Subject: NREL maps

Hi Jonathan, I received your request for permission to use a map and a graph for your project. Could you please send me the links to the map and graphic you want to use so I can review and send you the correct attribution language. Thanks

-----Original Message-----
From: jonagman@knights.ucf.edu [mailto:jonagman@knights.ucf.edu]
Sent: Friday, November 28, 2014 10:37 AM
To: NREL E-Mail Contact
Subject: NREL.gov website inquiry

Copyright Permission

REPLY REPLY ALL FORWARD

Mark as unread

parkinsona
Mon 11/3/2014 8:28 PM

To: info@openstaxcollege.org;

Good morning,

I am a student at the University of Central Florida currently working on a Senior Design Project Design of a Photovoltaic System. I am researching solar power efficiency and would like to request a copyright permission to use information from your website. Specifically, I would like to use the image Figure 1 for angle of incidence in your article entitled The Law of Reflection.

Regards,

Amy Parkinson

[OpenStax College] Re: Copyright Permission

REPLY REPLY ALL FORWARD

Mark as unre

OpenStax College <info@openstaxcollege.org>
Tue 11/4/2014 5:17 PM
Inbox

To: parkinsona <parkinsona@knights.ucf.edu>;

- To help protect your privacy, some content in this message has been blocked. To re-enable the blocked features, click here.
- To always show content from this sender, click here.

##- Please type your reply above this line -##

Your message (4898) has been solved. To reopen this conversation, just reply to this email.

Support Staff (OpenStax College)
Nov 04 03:16 PM

Hello,

The image is available under a CC BY license. This means that you are free to take this resource provided that you give attribution back to OpenStax College per the license. There is no charge for this re-use; however, we are a non profit so donations are always graciously accepted!

In order to cite a resource and to provide proper attribution you can find at the very bottom of the particular page a tab that says "Attribution" This will expand the tab and you will see "How to reuse & attribute this content". This box will provide you with all of the details you might need.

Best regards,
Denver Greene
Associate Director: Customer Service

Peer-Reviewed | Customizable | Free Textbooks
OpenStaxCollege.org
info@openstaxcollege.org
713-348-5012

copyright 1 of 1

Reprint Request (was Re: Amy Parkinson | Article Comment/Question)

DELETE REPLY REPLY ALL FORWARD ...

Michael Welch <michael.welch@homepower.com>
Mon 11/10/2014 5:47 PM
Inbox

Mark as unread

To: parkinsona; Ben Root <ben.root@homepower.com>;

Hi Amy. You have permission to use the information you have requested (the two illustrations, for your senior project), with the following requirement:

With every instance of usage, include this statement: "Reprinted with permission. © 2014 Home Power Inc., www.homepower.com . "

Thanks, and best of luck.

parkinsona wrote at 12:40 PM 11/10/2014:

> Good afternoon Ben,
>
> I also received a response from Michael Welch and would like to answer his questions prior to using your materials. These images will be used only in my document. The paper will eventually be posted as a document on a website following the completion of the project. I am aware that I must credit each image. I can also provide a link to your article below the image if you would like. I just wanted to clarify that since the final project document is required to be posted on a senior design website for UCF, that you would still approve.
>
> Thank you,
>
> Amy Parkinson
>
> On Nov 8, 2014, at 10:23 AM, web@homepower.com wrote:
>
> > Sent: Saturday, November 8, 2014 - 10:23
> > Website user:
> >
> > From: Amy Parkinson
> > Email: parkinsona@knights.ucf.edu
> > Topic: Article Comment/Question
> > Subject: Copyright Permission
> >
> > Good morning,
> >
> > I am a student at the University of Central Florida currently working on a Senior Design Project Design of a Photovoltaic System. I am researching PWM controllers and would like to request a copyright permission to use information from your website. Specifically, I would like to use images from your article entitled 2012 Charge Controller Buyer's (the PWM graph and Sample Three Stage Charging Regime.
> >
> > Regards,
> >
> > Amy Parkinson
> >
> > File Attached:

Michael Welch
Sr. Editor
Home Power magazine
www.homepower.com

Matthijs Vader <mvader@victronenergy.com>
Tue 11/11/2014 4:03 PM
Inbox

To: ☐ parkinsona@knights.ucf.edu;
Cc: ☐ Victronenergy service <service@victronenergy.com>;

Action Items

Dear Amy Parkinson,

Yes that is fine of course. Could you send me a copy of the paper once you are done? Could be interesting.

Best regards,

Matthijs

Sent from my iPhone

Begin forwarded message:

From: Victronenergy service <service@victronenergy.com>
Date: 11 Nov 2014 08:54:27 GMT+1
To: Matthijs Vader <mvader@victronenergy.com>
Subject: FW: Copyright Permission

Met vriendelijke groet,
Best regards,

Denise Streunding
Service and Repair
Victron Energy B.V.
De Paal 35
1351 JG Almere-Haven
Tel.: +31-365359703
Fax: +31-365311666
E-mail: service@victronenergy.com
Site: www.victronenergy.com

Van: parkinsona [mailto:parkinsona@knights.ucf.edu]
Verzonden: maandag 10 november 2014 21:24
Aan: Victronenergy service
Onderwerp: Copyright Permission

Good afternoon,

I am a student at the University of Central Florida (USA) currently working on a Senior Design Project Design of a Photovoltaic System. I am researching solar charge controllers and would like to request a copyright permission to use information from your website. Specifically, I would like to use one or two graph images from the white paper entitled "Which solar charge controller: PWM or MPPT?".

Regards,

Amy Parkinson

Copyright Permission

John Bradshaw <John.Bradshaw@cadex.com>
Mon 11/10/2014 3:30 PM
Inbox

To: ☐ parkinsona;

Hi Amy

Yes, you may use the requested content. Please cite source where appropriate.

Regards,

John Bradshaw - Marketing Communications Manager
Cadex Electronics Inc. | www.cadex.com
Vancouver | Minneapolis | Frankfurt
Tel: +1 604 231-7777 x319 | Toll Free: 1-800 565-5228

Follow us on Twitter: twitter.com/cadexelectronic
Join us on Facebook: facebook.com/cadexelectronics
Add us on Google+: plus.google.com/+Cadex

>>> parkinsona <parkinsona@knights.ucf.edu> 11/10/2014 12:28 PM >>>
Good morning,

I am a student at the University of Central Florida currently working on a Senior Design Project Design of a Photovoltaic System. I am researching batteries and would like to request a copyright permission to use information on your website batteryuniversity.com. Specifically, the article isBU-808: How to Prolong Lithium-based Batteries and the image is Table 2: Cycle life as a function of depth of discharge.

Regards,

Amy Parkinson

Tue 12/2/2014 11:35 AM

Bassuk, Larry <l-bassuk@ti.com>

RE: Copyright Permission

To Jonathan German

Action Items + Get more apps

Thank you for your interest in Texas Instruments. We grant the permission you request in your email below.

On each copy, please provide the following credit:

Courtesy Texas Instruments

Regards,

Larry Bassuk
Deputy General Patent Counsel &
Copyright Counsel
Texas Instruments Incorporated
214-479-1152

From: Jonathan German [mailto:jonagman@knights.ucf.edu]
Sent: Friday, November 28, 2014 6:32 PM
To: copyrightcounsel@list.ti.com - Copyright and trademark web requests (May contain non-TIers)
Subject: [Requests & questions from ti.com] Copyright Permission

Greetings,

I am a student at the University of Central Florida who is currently working on a Senior Design Project of a Photovoltaic System. I am in the process of researching DC to DC converters and I would like to request permission to use information from your Webench Design Tool. I used the online software to design a Buck-Boost controller for my PV design and I would like to include it in my report. Specifically, I would like to use images of the visualizer screen where I inputted my system's power specification values, the LM2511 BOM, and schematic.

Thank you,

Jonathan German