



**EENG 4381**  
**Electrical Engineering Senior Design**

**Photovoltaic Battery Charger**

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## **Abstract**

The optimization of renewable energy has become increasingly important with the modern push to transition away from nonrenewable energy sources. Solar energy is one of the more prominent renewable energy options primarily due to the ability to quickly and easily implement these systems in many different places and for many different uses. The concern with designing a solar battery charger is constructing and implementing the system within budget and efficiency constraints. Preliminary research and analysis needed to be conducted for converter, switch, and control scheme decisions to accomplish the constraints placed upon the system. For the final implementation of the solar battery charger a boost converter, mosfet switch, and an output voltage controller were chosen. Multiple experiments were conducted on the converter as well as the controller, both individually and as a part of the entire system, to ensure that the system operated above the 95% efficiency constraint. The results show that the converter and the output voltage controller operate successfully within the system as designed to yield the desired output to charge a battery. As a result, the system achieved an efficiency rating of 97.3% while being below the budget constraint. Overall, the system functions as intended and meets all requirements needed to effectively charge a battery using solar energy.

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## Nomenclature

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
V	Voltage	V
I	Current	A
P	Power	W
R	Resistance	$\Omega$
D	Duty Cycle	-
L	Inductance	H
C	Capacitance	F
T	Time period	s
f	Frequency	Hz
K	Damping constant	-
x	Solar Insulation Constant	-

## **Introduction**

### **Problem Statement**

This report details the design of a solar battery charger that can be used in high-density residential areas as well as areas with a shortage of power generation. This design would use photovoltaic panels to generate renewable energy and send that energy to a power converter that would adjust the input voltage of the panel so that it is optimal for charging a battery. This project's primary objectives were to design a solar battery charger that achieved an efficiency of at least 95% and is as inexpensive as possible so that the breakeven point of our system would be less than comparable systems available on the market.

### **Background Research**

The study and optimization of renewable energy has become increasingly important with the modern push to transition away from fossil fuels and other nonrenewable energy. Solar energy is one of the more prominent renewable energy options primarily due to the ability to quickly and easily implement these systems in many different places and for many different uses. There are many aspects that go into the design of a solar battery charger but that does not mean that it has to be expensive or even complex. Solar battery chargers are rare but they are very useful as they are more efficient than basic solar energy connections. This is due to the fact that the output can be controlled so that battery charging is not only more efficient but also results in a better charge to the battery itself. This can be done by a number of different control algorithms and each alternative has its unique advantages and disadvantages. Throughout this report, the



details of how each component of this system was selected will be discussed as well as its functionality in this design of a solar battery charger.

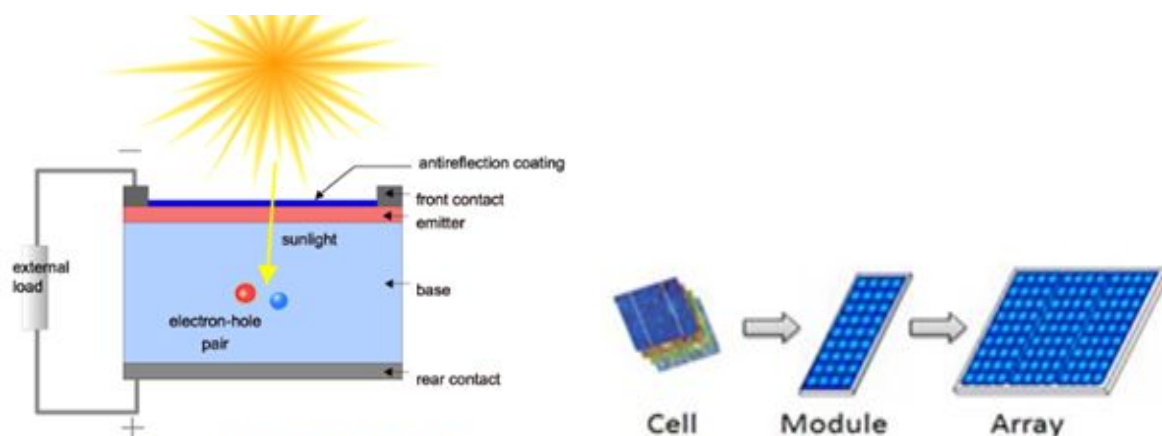
In places like Brazil, power generation is not enough to consistently supply all of the people in the area with power so they have scheduled power outages [10]. The lack of power generation is so inconsistent and underdeveloped that in many places in Brazil, power is only supplied on certain days of the week just to ensure that everyone gets power at least most of the week [10]. Places like these are primary examples of why solar energy generation systems are important to develop and improve but also increase the amount of these solar power systems that are implemented throughout the world. With the implementation of solar battery chargers like the one detailed in this report, the people living in these areas can have much more consistent power supplied to their residences and businesses.

Similarly to places with a lack of consistent power, the more fortunate places with consistent and sufficient power generation are being charged more than usual during peak load hours of the day. Peak load hours are the times during a typical day when the amount of energy used by people, or the load used, is significantly higher than other times of the day. These peak load hours happen twice a day and are typically in the morning when the working class go to work, typically around 6-8 AM, as well as around 5-8 PM when the working class returns from work [19]. During these peak load hours, electric utilities tend to charge more money per kilowatt-hour of power used in these high-density residential areas. So similarly to less fortunate places such as the previous example of Brazil, solar battery chargers can be used in bigger cities as well to lighten the load drawn from the utility companies so that people living in these area can save money on electricity.

This report strives to present an easy to implement solar battery charger that while being less expensive than comparable systems, also works in both of the examples presented above. This system is also designed to be scalable so no matter if someone needs to charge a single battery or an entire household, this solar battery charger can be easily upgraded or changed with only minor adjustments while staying affordable and simple in design. Whether this design is helping bring power and comfort to those who have none or helping people with power pay less so that they can focus on more important matters, this adaptable solar battery charger design is intended to present an affordable renewable energy option that is more efficient and simple than any competitors.

## Solar Insulation Analysis

Nowadays, electricity has costed significantly more than any other utility bill. This generation has been fortunate to exploit and develop the natural source of energy such as sunlight, wind, or water. For such high wind density place like the Texas Panhandle, wind energy would be the best option amongst other renewable energies, but there is an inconvenience on the location and accessibility. Recently, solar panels have made a huge impact, its size and reasonable price allow it to become a household use. Solar panels can be seen everywhere now, from big companies, to the street lights on the construction intersection. One of the states that use the most solar energy is California, as the state provides a great average in solar insulation. In Texas, San Antonio uses the most energy from solar panels [23]. With solar energy, the electricity cost is predictable for years to come. It will also prevent the pollution, reduce carbon dioxide, as well as being very reliable.



*Fig. 1 - Solar Panel Cell Structure and Configuration*

In order for the solar panel to convert solar energy into electricity is by using the photovoltaic effect. The process first requires a material which absorbs photons, solar energy, raising the electrons to a higher energy state and creating flow so that the high-energy electron

can separate to an external circuit. One of the surface materials of the solar panel is silicone. The next layer, the photovoltaic cell, can be made with crystalline, be wafer-based, or thin-film type. While crystalline has more efficiency in respect to price, the thin-film has its own advantages such as moderate price, but in return having a low efficiency [18].

	Bulk type / Wafer-based (Crystalline)			
	Mono-crystalline Si	Poly-crystalline Si	Poly-crystalline band	
Pros	• High efficiency	• High efficiency with respect to price	-	
Cons	• Increased manufacturing cost caused by the supply shortage silicon		-	
	Thin-film type			
	Amorphous Si	CIGS	CdTe	Polymer organic
Pros	• Low price	• Low price	• Able to automate all manufacturing process	• Low manufacturing
Cons		• Low efficiency		• Low efficiency

Fig. 2 - PV Cells chart

In the photovoltaic cell, a semiconductor material has two layers of doped silicon that are tightly bonded together. This makes up the n-layer, a high concentration of electrons, and a p-layer, high concentration of hole or deficiency of electron. When sunlight strikes the layered cell with enough wavelength and energy, it absorbs and allows electrons to travel freely.

Installation plays an important role in order to consume the maximum amount of solar power. The solar panel should be positioned in a north or south direction where there is no coverage causing shade above the solar panel. If consumers live in the northern hemisphere, the solar panel should be facing the south. Contrary of that, if consumers live in the southern hemisphere, the panel should be pointed to the north. So that is when the sun rises from the east and sets in the west, the panel will retain the maximum amount of power from the Sun. The

position of angle can be tilted as needed to adjust, depending on the season, to get the maximum amount of energy during peak time. In general, for a quick and easy way to place the panel is to take your latitude and add 15 degrees for winter, and subtract 15 degrees for the summer. There is also another method that requires more calculation, but is more effective to generate the most energy. In fact, consumers need to adjust the angle a little bit to compensate the conditions due to shade, leaves, dust, or debris.

Solar Panel Angle Calculation		
Method:	Seasons:	Calculations:
Method 1: Easy Way (most commonly)	Summer	Latitude – 15 degrees
	Winter	Latitude + 15 degrees
Method 2: Effectively Way	Summer	(Latitude x 0.9) – 23.5 degrees
	Spring & Fall	Latitude – 2.5 degrees
	Winter	(Latitude x 0.9) + 29 degrees

[18]

*Fig. 3 - Solar Panel Angle Calculation Table*

## **Photovoltaic Panel Selection**

In order to select a solar panel for a photovoltaic battery charger, recognize the amount of power desired and the amount of space that is available to place the solar panel or panels. Then a cost analysis is completed based on the solar insulation values in the desired area of implementation. After becoming aware of these variables, there is two different approaches for picking a solar panel. The first path would be to go ahead and buy a solar panel that is within budget and capable of dispensing the power necessary. Taking this route makes the rest of the photovoltaic battery charger system become dependent on the selected solar panel. Selecting the solar panel first makes all of the input values immediately known, allowing consistency for designing the rest of the system. The advantage of choosing this method is that the budget for the project will become more desirable and well known, as the solar panels are the most expensive and most meaningful part of a photovoltaic battery charger [7].

The other option of selecting a solar panel would be to wait and buy the perfect solar panel for the system, after the system is already designed. This allows more flexibility in the overall design of the solar battery charger. Instead of being limited to fixed inputs, this allows the rest of the system to be designed with great efficiency and no restrictions. The flaw in this method however is designing the perfect system that is needed but in return, being forced to buy a solar panel that is extremely expensive, surpassing the desired budget [28].

## **Operating Solar Panel for this Design**

The solar panel that is being used for this project is from the ES-A Series Photovoltaic Panels manufactured by Evergreen Solar. In this series of solar panels there is five different solar

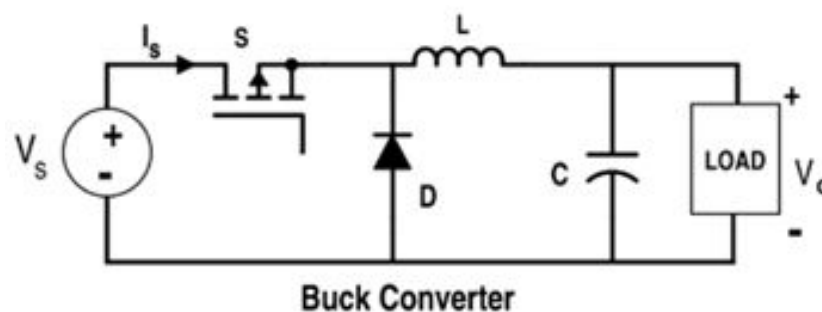
panels that have different ranges of potential power output. The five different solar panels range from 190 Watts to 210 Watts. With voltages varying from 17.4 Volts to 18.7 Volts respectively with the Watts. The maximum Amperes of each solar panel varies from 10.92 Amperes to 11.23 Amperes. The solar panel that was used in the making and testing of the photovoltaic battery charger is the ES-A-205-fa2. These solar panels were previously purchased by the West Texas A&M Electrical Engineering Program. There are two individual solar panels and they are both identical. The maximum values that the solar panels can each provide is, 205W, 18.4V, and 11.15A. Each solar panel weighs 41 pounds. The dimension of each solar panel is 65 inches tall, 35.9 inches wide, and 1.8 inches thick. With solar panel in hand and the values of the solar panel known, the process of designing a functioning photovoltaic battery charger begins. The ES-A Series Photovoltaic Panels data sheet can be found in Appendix A.

## Converter Selection

There is multiple converters that would work for this particular project. Each of the DC-DC converters are arranged slightly differently to complete different task. This project requires an increase and steady voltage in order to efficiently charge a battery source. The following section will show a couple of converters considered in this project and schematics of each one corresponding.

### DC-DC Buck Converter

The main objective of the buck converter is to convert input voltage to a lower voltage. The consequence of this is raising the amperage corresponding to the voltage linearly [26]. The reason the buck converter is a popular choice of a converter is its ability to increase battery life. Which is why it is seen in so many different electronics. The difficulty with building the buck converter is that there is a floating ground that is extremely difficult in implementing in a small circuit like this[2]. It also raises current making the converter not as safe as other options. The following picture is a schematic with all of the components necessary in a buck converter[1].

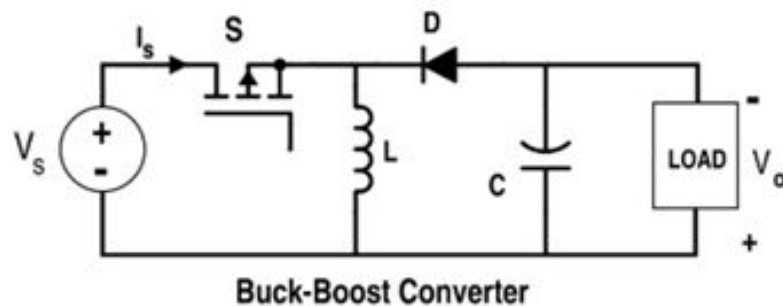


*Fig. 4 - Schematic for DC-DC Buck Converter (From All About Circuits)*



## **DC-DC Buck Boost Converter**

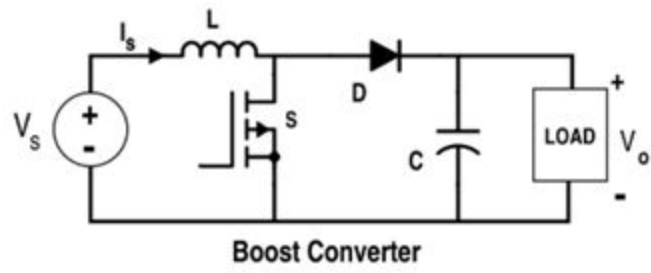
The buck boost converter is a DC-DC converter that can vary your output voltage to any desired voltage, higher or lower than the original input voltage. This converter is extremely versatile and would be great for the project. The only flaw with the buck boost converter, similarly to the buck converter, is that you would need to implement a floating ground. This makes this versatile converter difficult to implement by hand. The following image is a schematic of a simple DC-DC buck boost converter[1].



*Fig. 5 - Schematic for the DC-DC Buck-Boost Converter (From All About Circuits)*

## **DC-DC Boost Converter**

The boost converter is an electronic device that takes an input of DC voltage and raises it while at the same time lowering the amperage. The boost converter has a consistent output which is needed in order to consistently charge a battery. The boost converter is also one of the easier converter circuits to implement and troubleshoot compared to the other DC-DC converters. Which makes the boost converter the selected converter in the photovoltaic battery charger, because it raises voltage, lowers current, and is simple to implement. The following image is a basic boost converter schematic.



*Fig. 6 - Schematic of the DC-DC Boost Converter (From All About Circuits)*

## **Boost Converter**

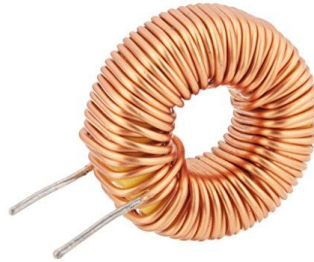
After analysing the different types of converters and making a selection of what converter should be the best fit for the project. The boost converter was the obvious choice for the need and time for our project. The boost converter is made up of an inductor, switch, diode, and capacitor. As explained previously, the boost converters main objective is raise output voltage while lowering output current. The boost converter is a necessity for charging the battery when the the output of the solar panel isn't ideal. This DC-DC converter makes up the bulk of the photovoltaic battery charger.

Designing and implementing such a converter is especially tedious and timely. The positive of the converter is that it is inexpensive to build. Most of the time there is already an integrated circuit that has already been created and on the market that is easily implemented and easy to use. With our needs of such great power, voltages, and currents, the components have to be specially ordered individually. In order to know what the ratings of each component must be you have understand what the converter does and be able to design the converter with special equations.

### **Boost Converter Components**

The major component to any converter is the inductor. The inductor is a loop of coiled wire that relies on current to operate. In the boost converter the inductor is connected in series with the output of the solar panel. Being the first component in the boost converter. The inductor takes in current and releases current based on the flow of direction. The flow of direction is

created by the rest of the circuit. The following image is a simple inductor that is exposed and has no casing opposed to the one used later.



*Fig. 7 - Simple Inductor*

The next component is the switch. The switch is what allows the inductor to charge and discharge. The switch is given a pulse at which the circuit allows the different direction of power. The rate at which the switch switches is called the duty cycle. The duty cycle is the number adjusted in order to get the correct output voltage. The switch is an extremely fragile component in the boost converter. So making sure it is functioning properly and at the right pace is absolutely required for the circuit to operate correctly. The following image is of a simple MOSFET.



*Fig. 8 - MOSFET Switch-IRF540N*

The next component to talk about is the diode. The diode in the boost converter restricts current going through the circuit to only go one direction. This protects the switch so that current does not burn it up. It also allows the flow of direction to be towards the output. The diode must be rated for extremely high current so that nothing will be allowed to flow back towards the switch, but only towards the output. The following image is of a individual diode.



*Fig. 9 - Simple Diode*

The last component in the boost converter is the capacitor. The capacitor is strictly a voltage device that does not rely on current. The capacitor is connected in parallel at the very end of the circuit and is used to smooth out the output voltage. After the boost converter is constantly changing and switching the output voltage is varying extremely. The capacitor continuously charges and discharges in order to smooth out the voltage and make it as consistent as possible. The size of the capacitor and inductor are the major effects of output voltage, along with the duty cycle. The following image is of a capacitor that would be used in a similar boost converter.



*Fig. 10 - Simple Capacitor*

## **Designing the Boost Converter**

The first thing that must be established in order to build a boost converter is the inputs that will be received from the solar panel. In this case the solar panel is going to give out a maximum of 18.4 Volts and 11.15A. Making the peak power 205W. With your solar panel outputs known, select a desired converter output voltage. There is no equation that is used to determine the output voltage. It is solely based on the desired voltage wanted to charge the battery at. For this instance, a voltage of 24V was selected to charge the battery. It is not a giant leap from the 18.4V input. As well as a simple value for which a battery can be selected.

With the output values of the solar panel known along with the desired output voltage selected the duty cycle can be calculated. The duty cycle is unitless and is just a percentage. It makes up the time the inductor is charging or discharging to get the correct output voltage. The duty cycle is calculated by the equation [26].

$$D = 1 - (V_{in}/V_{out})$$

### ***Equation 1. Duty Cycle***

The outcome of this equation makes the duty cycle at .25 or 25% which means the inductor is charging 25% of the time and discharging 75% of the time.

Now that the duty cycle is known we can calculate the size of the inductor. The equation used for sizing the inductor is [26]

$$L = (D * (1 - D)^2) * R / (2 * f)$$

### ***Equation 2. Inductor Size***

With  $f$  being the frequency in hertz and the  $R$  being resistance in ohms. The resistance is calculated from the battery being 2.44 Ohms. The value calculated for the inductor is  $67.5\mu\text{H}$ . With the value known you must then account for the current that will be going through the inductor. The max current through the inductor is 11.15A. Now when purchasing an inductor you need a value of at least  $67.5\mu\text{H}$  and can withstand at least 11.15A.

The next calculation is the capacitor. The equation for calculating the capacitor is [26]

$$C = (V_{out} * D) / (2 * dV * R * f)$$

***Equation 3. Value for Capacitor***

The value for the capacitor comes out to be  $27.5\mu\text{F}$ . With the capacitor being strictly voltage oriented the only other necessary information needed for selecting a capacitor is the voltage running across it. The voltage the capacitor will equal the output voltage of 24V. Therefore the capacitor in the boost converter must have at least a value of  $27.5\mu\text{F}$  and be rated for at least 24V.

The switch and diode have no equations to be able to calculate their values, but ratings at which the voltage and currents they must withstand. The diode must be rated for 11.15A and 24V. While the switch must be rated for at least 11.15A and 24V. These values are found from the inputs of the solar panel and the desired output voltage of the boost converter.[26]

The final step to achieving an acceptable boost converter is to find out what mode the boost converter will be in. In order to do this confirm the values of the designed boost converter by comparing  $K$  to  $K_{crit}$ . This is a damping ratios determined by the duty cycle, the inductor size, and the resistance of the load. If  $K$  is greater than  $K_{crit}$ , then the converter is in Continuous Conduction Mode. If  $K_{crit}$  is greater than  $K$ , the converter is in discontinuous mode. Proving that

the converter designed is in continuous conduction mode is extremely important. It proves that the converters increase in voltage is not dependent of the resistance of the battery. That the current will be stable and reliable to charge the battery, and the efficiency of the circuit is high. K can be calculated by using the equation [26]

$$K = \frac{2 \times L \times F_s}{R}$$

***Equation 4. Damping Ratio***

equalling 9.4 (unitless). Kcrit can be found by [Electronics]

$$K_{crit} = D(1 - D)^2$$

***Equation 5. Critical Damping Ratio***

equalling 0.14 (unitless). In result K is greater than Kcrit. In conclusion, this means that the designed boost converter is in continuous conduction mode and properly designed.



## **IRF540N Switch**

The switch, which is one of the primary components to the boost converter, has to be carefully and precisely selected. Small electronic switches like the one that is used in the boost converter are extremely delicate and easy to blow if not taken care of properly. Short circuits, unexpected jults of current, heat, and delicacy of the connection points are all things to consider in implementing a switch in a high powered system [32].

### **Switch Model**

The switch that is needed for the photovoltaic battery charger must be able to handle at least 18V, 11.15A, and handle 100 kHz switching frequency. After doing shopping, the IRF540N MosFET switch was selected. It shows to easily handle all of the previous values. The IRF540N is rated for 100V and 33A. With a small amount of resistance, 44m $\Omega$ , which leads to minimal power loss through the circuit. In order to power the switch you must have a controller pulsing 5 volts through the gate pin continuously turning on and off the switch and the rated duty cycle. In this case the switch needs to be switched on for 25% of the time and off 75% at a frequency of 100 kHz {Maurice] With this switch, or any switch, being aware of the temperature it can handle is crucial. Unfortunately, as the switch is heated the Ids current goes down. Making the circuits malfunctioning point lower as shown in the figure below.

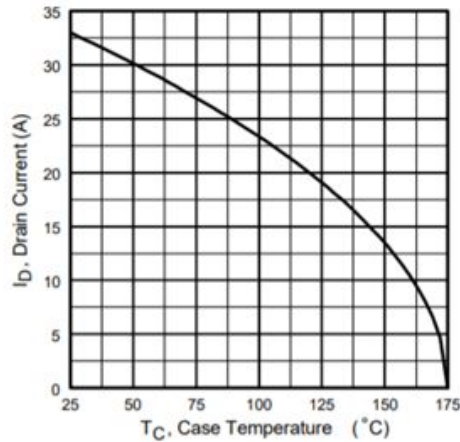


Fig. 11 - Drain Current Vs. Temperature (From IRF540N Data Sheet)

With the potential amount of power running through the switch, the heat will rise begin to rise. With the photovoltaic battery charger designed to run for hours at a time, and day after day, this is a potential problem.

**Switch Protection**

In order to protect the switch and give it the longest life possible, a protection system must be implemented [32]. The first step to this is dissipating the heat given off by the circuit. The decision was made to include a heat sink that wraps around the MosFET switch like a jacket and relieves some of the heat from the MosFET. The image below shows a heatsink that would encase the IRF540N.



Fig. 12 - Ordinary heatsink (From Amazon.com)

With the heatsink properly embedded around the IRF540N, the switch will be able to give off the heat given by the circuit and have it displaced into the switch. This allows for a longer more dependable lifespan of the MosFET to switch the boost converter.

## **Microcontroller Selection**

### **Introduction**

Microcontrollers are single chip computer processing units that allow for a program to be stored and carried out that are implemented in systems to primarily function as a processing unit [3]. There are multiple microcontrollers on the market ranging in various sizes and processing power to control systems such as a key fob for a car or small kitchen appliances. These examples range from allowing a button to be pushed and sending a signal to an automobile to unlock the doors to reading the input given and varying the speed of a blender through external sensors that are implemented into the microcontroller.

For the photovoltaic battery charger system, there was a call for a controller to send a pulse wave to turn on and off to the MosFET switch which in combination with the other components in the boost convert will adjust the voltage as needed.

### **Selection**

On the market today, there are various types of controllers along with multiple variations of each type. This makes for selecting appropriate controller for this type of magnitude a bit of a struggle. A few considerations to accept when selecting a controller are: functions, processing power, inputs/outputs, price, and coding language. With this particular type of converter selected, the current and voltage sensors, and the need to handle independently within the system, and the need to adjust to the pulse wave frequencies with ease allows one to consider either a Raspberry Pi or an Arduino microcontroller.

The Raspberry pi considered for the photovoltaic battery charger was the Raspberry PI 3 Model B as shown in fig.13. This model contains the processing power to function as intended, along with the ability to have Bluetooth and WiFi capabilities in case of further implementation for a wireless receiver that was considered but due to time constraints the idea was left. This particular model also has a dedicated HDMI output which would allow for the ease of connection a display but considering that this system could be placed in the outside elements, this could present in damaged equipment. Also, this particular model, based on the current and voltage sensors implemented in the converter to read real time data from the panels, have libraries for each sensor that can easily be implemented into the Raspberry PI. One of the main functions in considering the Raspberry Pi was the Linux operating system that it operates on along with the python coding language. This system is easy to use for most beginners, but one downfall is that while it could be used for the scare of convert designed, the operation system (OS) was not intended for real-time processing which is what the charger uses to make sure that the input solar rays are being boosted into real time [15].



*Fig. 13 - Raspberry Pi 3 Model B*

The Arduino microcontroller that was considered for this battery charger was the Arduino UNO Rev3 as shown in fig. 14. This particular microcontroller allows for the current and voltage sensors selected to be implemented with ease, which just like the Raspberry pi, the libraries are easily accessible for the coding language on the Arduino. Unlike the Raspberry Pi, the Arduino is intended more for a standalone device that can process in real time and can be monitored if needed through an external computer. This was taken into consideration as once implemented, one could be able to go monitor the converter at a remote location with easy and also be able to adjust any conde parameters such as the duty cycle. With this in mind, the coding language is based on C/C++ which is easy to grasp for anyone. The processing power of the Arduino UNO was sufficient enough to be able to be on constantly and still manage to process all of the input/output values to make sure that the adjustments that are being made and to be monitored as explained above.



*Fig. 14 - Arduino UNO R3*

## **Conclusion**

While both controllers can handle the need for the photovoltaic battery charger such as, implementing the duty cycle to the MosFET, and the price of both averaging around \$20 for the Arduino and \$35 for the Raspberry Pi of which are inexpensive, the main factors that allowed to

make a selection was the ability to program with hardly any background and the standalone features, which in turn being the Arduino UNO R3. This was the most feasible in this type of project and based on the groups understanding of programming languages made in selecting the Arduino.

## **Driver Circuit Analysis**

### **Introduction to Driver Circuits**

Driver circuits are one of the most crucial aspects of designing a converter. Without a functional and efficient driver circuit, the switch of your converter will not operate as intended and be more vulnerable to malfunctioning. A driver circuit is a combination of circuit elements or electronics that are used to activate and continue to operate another component of the circuit. MosFET switches, like the one used in this design, are sensitive and need to be carefully protected and simultaneously given specific pulses in order to turn the switch on and off [14]. MosFETs are voltage driven switches which means that the switch operates only based on the voltage given to the switch [14]. This characteristic changes the types of driver circuits that can be implemented for this switch. Multiple driver circuit strategies were discussed early in the design phase of this project. All of these alternatives were based around the voltage-sensitive characteristics of a MosFET. The two primary driver circuits compared were the implementation of a voltage divider or a photocoupler connected at the gate pin of the MosFET.

### **Voltage Divider**

A voltage divider is a driver circuit that utilizes multiple resistors arranged in a specific manner to control the current and voltage being supplied to the switch it is driving. These resistors can be designed with a certain resistance value to take any input voltage and adjust it to an output that can drive a MosFET without damaging the switch. The voltage divider circuit is based on the circuit analysis formula that enables the voltage across a specific resistor to be



calculated based on the other resistances in the system. The voltage divider formula seen in Fig ## is the basis for how this circuit can be designed to operate a switch.

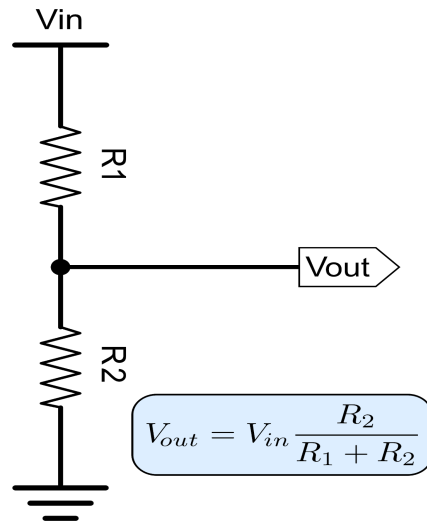


Fig. 15 - Voltage divider schematic

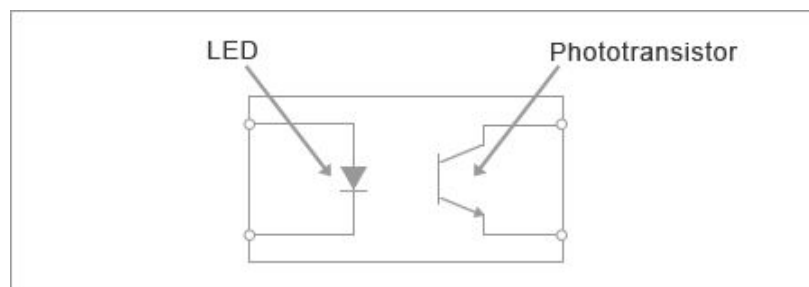
Using this formula, a voltage divider arranges resistors so that a source voltage (Vin) is reduced in a similar manner to how the mathematical formula works. In practice, a third resistor is placed on the output of the two parallel resistors primarily to protect the switch. Displayed in Fig. 15 is the circuit schematic of a voltage divider circuit. The primary purpose of a voltage divider is to be able to use the source voltage of the system to drive the MosFET.

Disadvantages of this method of driver circuit are that if one of the resistors malfunctions, the rest of the system becomes ineffective. This can be seen by referencing the equation in Fig. 15. If one of the resistors becomes zero or even changes value slightly, the output voltage will be different and the switch will then be vulnerable. Another setback of voltage dividers is that while they can handle high voltages, high currents render these driver circuits ineffective as the resistors of the voltage divider will fail if high currents run through them. Due to the high currents of the design discussed in this report (approximately 11 A), a voltage divider

was not the driver circuit that was selected for the MosFET of this design. The easily controllable output voltage would have been very beneficial to this design but with the high currents delivered to the MosFET switch this circuit would have had a high failure rate.

## **Photocouplers**

A photocoupler, also called optocouplers and opto-isolators, are a switching circuit that uses an LED to generate a current through a phototransistor [How]. When a voltage is given to the photocoupler, it activates the LED [How]. The LED on the input side is not directly connected to the phototransistor but instead sends signals to the output transistor when the LED is activated [9]. The voltage given to the LED is converted to light signals (hence the prefix “photo” meaning light) and absorbed by the phototransistor connected to the output [9].



*Fig. 16 - Photocoupler schematic*

Photocouplers are not typically implemented the same way as voltage dividers as they typically are bought in pre-fabricated integrated circuits (IC). These 4-pin ICs have the advantage of being permanently connected so that implementing them in a design can be fast and simple, but on the contrary because they are pre-fabricated, they can only be set to the output they are designed for and not adjustable to any design. These photocouplers have to be purchased

with the correct ratings and tolerances in order to work successfully in a system design. This is not always a problem but does limit the usage of them slightly.

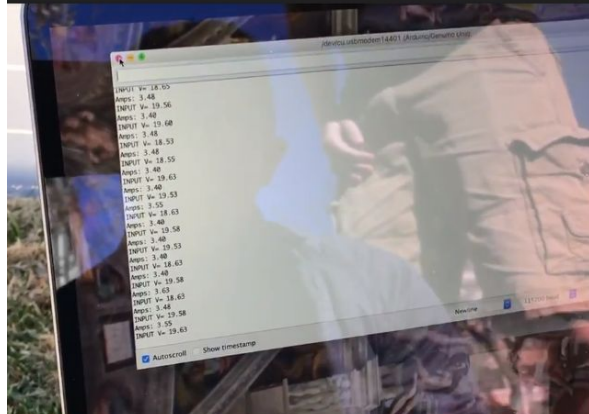
Similarly to voltage dividers, these circuits can be used to drive a MosFET but in a different way. Photocouplers are more commonly used as protection devices due to the fact that instead of controlling the voltage given to the switch; the current is regulated instead. This difference has its own advantages and disadvantages. The advantages of a photocoupler are that it is a great component to help protect the MosFET from overcurrent conditions. Photocouplers also make the design of the circuit easier due to it being prefabricated and pre-designed. There are, however, disadvantages to photocouplers. These components need to be used in combination with voltage regulators to ensure that the LED does not malfunction based on a high amount of voltage being applied. Typically 5V regulators are used with MosFET switches so that the switch will operate but will not be met with too much power.

For this design, a photocoupler was chosen as the driver circuit. This decision was mostly influenced by the large power that the system would be experiencing due to the solar power. One of the most problematic aspects of a solar powered system is that the current in the system can be higher, so to combat this a photocoupler was implemented to further protect the switch. Protection of the switch one a top priority throughout this design and that is what ultimately led to the decision of using a photocoupler as the driver circuit.

## **Output Voltage Controller**

Many control schemes were considered throughout the design phase of the project. After much consideration and multiple tests on the boost converter, it was decided that the most effective strategy to maximize the charging of the battery was to implement an output voltage controller. This type of control scheme would use a sensor to measure an output voltage ( $V_o$ ) and compare that to a preset reference voltage ( $V_{ref}$ ) in the microcontroller. The microcontroller would compare  $V_o$  to  $V_{ref}$  and proceed to a decision-making process. If  $V_o$  is equal to  $V_{ref}$  then the system will not change. In the case of  $V_o$  being less than  $V_{ref}$ , the microcontroller will increase the duty cycle of the MosFET switch of the boost converter by 0.5% so that the output will become closer to  $V_{ref}$ . On the contrary, if  $V_o$  is greater than  $V_{ref}$ , the microcontroller will decrease the duty cycle of the MosFET by 0.5% therefore decreasing the output voltage so it is closer to  $V_{ref}$ . The system will adjust the duty cycle once every 10 seconds in practice but for the sake of the project testing, we ran the controller at a delay of 0.3 seconds.

This design uses an Arduino Uno R3 controller to implement this control scheme into our system. Using the Arduino, we are able to run separate programs simultaneously to the output voltage controller program. This allowed us to observe the behavior of the controller using sensors to ensure that the output voltage controller was operating as intended. This program can be seen in Figure 17 displaying values as they are given by the sensor. These values were crucial to determine the sensor error. Most electrical components have at least a small degree of error, so in order to ensure our design is as accurate as possible. The final design compensated for an error of about 0.3 V.



*Fig. 17 - Computer program displaying Voltage Sensor values*

Ultimately, we decided on an output voltage controller because we wanted our system to be scalable to any system size. When we were trying to decide on a size of battery to test our system on, we realized that the size of battery will be completely dependant on our customer and the magnitude of the system in general. Therefore setting a reference voltage depending on the size of battery will be a easy change depending on who uses this system and can be easily changed if somebody wants to upgrade their system as well.

The results of this control scheme can be seen in Figure 18 below. Using an oscilloscope, we can see the duty cycle of the switch and how it changes as the output voltage controller operates.



*Fig. 18 - Duty Cycle displayed using oscilloscope*

Figure 18 shows where the duty cycle starts when the system first turns on. The duty cycle starts at 10% and remains there until the sensors detect a change in voltage. The output voltage controller will then adjust the duty cycle so that the output voltage is equal to the reference voltage that is defined in the coding of the controller. The duty cycle can be seen to end up around 24.5% in Figure 18 at an output voltage set to be 24 V.

## **Battery Selection**

### **Introduction**

During the design of the Photovoltaic battery charger and looking at various implementations of how and where to place such system there are a couple key factors that come to a final selection of a battery. Three factors considered in selecting a battery were: Price, footprint, and material type. All of these factors tie into each other which is why we stayed with the main types of batteries; sealed lead acid and lithium-ion

### **Sealed Lead Acid**

These particular types of batteries are most commonly used in a wide range of systems. These are maintenance free as there is really nothing else need to keep these batteries going. An advantage that a sealed battery, as shown in fig. 19, has is there is no need to keep it ventilated, so this could be placed in a small enclosed frame or a location where there might be small to no ventilation. Sealed lead acid batteries are most commonly found in car batteries and have a lifespan of about 3-5 years [18].

Advantages of having a sealed lead acid battery include:

- Easy of manufacturing, therefore inexpensive
- Have been improved, therefore reliable
- Little maintenance needed
- Discharge rate is low compared to other battery types

Disadvantages of having a sealed lead acid battery include:

- Heavy and bulky
- Acid build up which is harmful to the environment
- Due to mass production the battery could result defective or improper charging



*Fig. 19 - Sealed Lead Acid Battery*

## **Lithium-Ion**

These batteries are what cellular devices have along with other electronic devices use to allow for a more improved discharge rate and since they are the newest of all the batteries explained, they are constantly improving as the years go by. The maintenance factor for this particular type is minimum, there is still a disadvantage of aging faster than a lead acid for example, even when not in use, this could happen with the first two years [18].

Advantages of having lithium-ion battery include:

- Higher capacities due to high energy density (More packed in a smaller form factor)
- Low discharge, efficient to use
- Minimal maintenance

Disadvantages of having a lithium-ion battery include:

- Expensive to manufacture



- Aging of battery within first couple years
- Not as well developed than other types
- Needed to be in a cool location to reduce aging



*Fig. 20 - Lithium-ion Battery*

## **Conclusion**

While there are other types of batteries such as a nickel cadmium battery which does present advantages such as a high number of discharge/charge rate, it also presented the most environmentally unfriendly conditions which with our system being implemented in the outdoors in some cases, we didn't want a potential customer to be affected [18].

While only considering the sealed acid and lithium-ion on the all factors, we came to a conclusion that the a sealed battery would be the most practical due to the low maintenance and the commodity of being able to replace the battery, if needed, in a fast timed manner without having to special order one, in which could be the case of going with a lithium-ion battery. Price did come in to play greatly as the design of the converter is scalable, we did not want to overlook the detail of once implemented, if the converter or size of the battery storage needed to be greater, it could easily be done with minimal time and pain.

## Budget Analysis

As of 2017, the cost of solar panel has fallen rapidly from previous years, the average of national price is \$3.14 per watt of 6kW system. Indeed, the average price per watt in United States are in range from \$2.71 to \$3.60. For the average size, installation cost in U.S is approximately around \$11,000 to \$15,000 after tax credits, depending on the location of state the resident lives in. The price is reflected on how much electricity the consumer wants to generate. In general, the bigger the system, the higher the cost due to more equipment and labor. In some states, government and utility companies encourage residents to have solar energy for their home. They would even offer rebates and other tax incentives that can further reduce the solar energy system expenses. The total cost may vary depending on the state that consumers live in.

[6]

STATE	SOLAR PRICE RANGE (6 KW)	SOLAR PRICE RANGE (10 KW)
Washington	\$9,954 – \$13,650	\$16,590 – \$22,750
Florida	\$9,198 – \$11,970	\$15,330 – \$19,950
Rhode Island	\$13,104 – \$15,792	\$21,840 – \$26,320
New York	\$12,264 – \$16,044	\$20,440 – \$26,740
Massachusetts	\$12,264 – \$15,372	\$20,440 – \$25,620
Connecticut	\$12,222 – \$15,078	\$20,370 – \$25,130
New Hampshire	\$12,096 – \$14,868	\$20,160 – \$24,780
California	\$11,928 – \$15,204	\$19,880 – \$25,340
South Carolina	\$11,886 – \$14,574	\$19,810 – \$24,290
Oregon	\$11,802 – \$15,162	\$19,670 – \$25,270
New Jersey	\$11,802 – \$14,574	\$19,670 – \$24,290
Colorado	\$11,676 – \$14,952	\$19,460 – \$24,920
Pennsylvania	\$11,634 – \$14,490	\$19,390 – \$24,150
Illinois	\$11,424 – \$13,944	\$19,040 – \$23,240
Texas	\$10,962 – \$13,818	\$18,270 – \$23,030

Fig. 21 - Average of Solar Panel pricing in United States [energysage.com]

The Average cost of solar panels for homes in Texas, as of December 2018, is \$3.12 per watt. This means that for a 5-kW residential solar system, the cost is \$15,600 before solar incentives and \$10,920 after claiming back the solar tax credit. The average monthly payment is \$94 making even zero down solar systems cash flow positive from the first day [26].

\$3.12 per watt  Av. Cost per watt of residential solar panels installation	\$2.18 per watt  Av. cost of solar panels for home  After 30% solar tax credit	\$94  Av. Monthly payment on solar panels	\$2.41 per watt  Financed solar system  After 30% solar tax credit	\$28,900 savings  Av. Lifetime Savings
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*Fig. 22 - Per Watt Costs [24]*

Our solar cost calculator will calculate how many solar panels you need for your house to cover your energy bill and get the correct size solar system from the best local solar providers near you. In some cases, solar payback can be as short as 5-8 years, leaving you with 20 years or more of free power. [26] Comparing between San-Antonio, Texas versus Amarillo/Canyon, Texas the prices are different by approximately \$2,000. One of the reasons is that San Antonio is amongst the top 10 cities of the nation in using solar energy. With high demand, the cost of solar energy is becoming cheaper than the Amarillo area. In Amarillo and Canyon are, solar energy is new to most residents, as the geography here is likely to produce more wind and less sun than San Antonio. As for the state, Texas is still one of the states with a reasonable price to install, compared to California and Arizona where they use more solar panels for energy.

Solar panel cost for CPS customers in San Antonio for different system sizes

SYSTEM SIZE	COST OF SOLAR FOR ALL SAN ANTONIO HOMEOWNERS (POST ITC)	COST OF SOLAR FOR CPS ENERGY CUSTOMERS
3 kW	\$6,951	\$5,691
5 kW	\$11,585	\$9,485
7 kW	\$16,219	\$13,279
10 kW	\$23,170	\$18,970
12 kW	\$27,804	\$22,764

Fig. 23 - Solar Panel Costs in San Antonio, Texas [6]

The average life of solar panel can be used 20 to 30 years. In return it takes solar panels three to seven years to compensate homeowners and begin saving them money. There are many benefits to build your own solar panels such as cost savings and faster solar installation provided by a company. There are many kits available that provides everything for a consumer to build a household power solar panel from scratch. As for single solar panel for a project that homeowner can use will be calculated on the amount of leverage a buyer has, different types of panels are chosen, and the size of system that they want to use. In general, installers alone cost around 85 cents per watt, while retail consumers pay around 1 dollar/watt. Solar panel range from 150-350 watts depending on the price and quality of the panel. But if homeowners go through do it yourself solar panel systems from retailers, the cost will be higher based on the calculation of one dollar per watt.

Equipment plays an important role in solar panel installation, not all solar panels (or inverters) are created equal. Some of the more efficient equipment comes with a higher price tag. More efficiency, higher-quality equipment comes with benefits that may be worth the added

cost, however, better hardware can produce more electricity with the same amount of sunlight, and often comes with a more comprehensive warranty. [6]

For this particular system and using solar insolation averages of the San Antonio, Texas region; we can accurately predict that the 410 Watt solar panel system with an efficiency above 97% can produce an average of 540 kWh per year. Using the electricity price during peak demand times in San Antonio, the system can save an average of \$113.17 per year. This is assuming the unpredictable peak capacity charge added by the electric utility. This lowers the cost by an average of \$18.00 per month during summer months. This adds on to the total yearly earnings to be approximately \$131.17. With the project costing \$577.30, the project will pay for itself in approximately four to six years with the lifespan being twelve to fifteen years. This can lead to a potential net savings of nearly \$2,000 over the lifetime of the system. This gives the system a pay off of three and a half times the original investment.

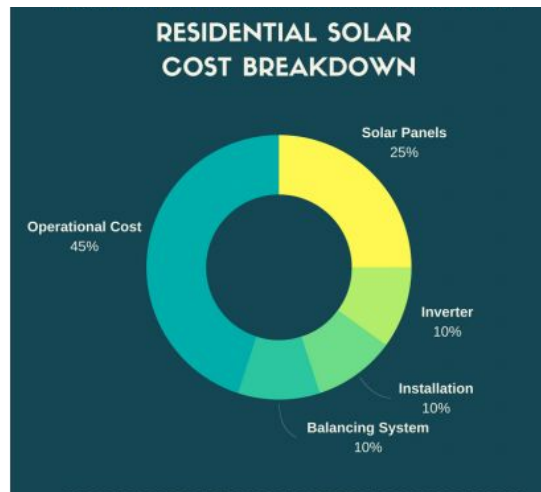


Fig. 24 - Cost Breakdown of Solar Power Systems [25]

## Project Cost Analysis

Items/Components	Items Purchase (\$)	Items Used (\$)
205 Watts Solar panel	180	FREE
12V 15AH	31.50	31.50
Rectifier Diodes (20SQ045)	7.62	7.62
Rectifier Diodes (15SQ045)	6.95	--
4 Pins DIP Mounting coupler	5.27	--
T0-220 clip-on Heat Sink	5.99	5.99
Voltage Sensor	6.99	6.99
ACS712 Current Sensor	9.29	9.29
L7805 Linear Voltage regulator	7.99	7.99
Arduino UNO-R3	19.60	19.60
RFP3ONO6LE MosFET	16.88	16.88
Electrolytic Capacitor range	14.99	14.99
9V 1A Arduino Power adapter 110-V AC	6.49	6.49
Rubber mat	20.56	20.56
68 micro-Henries inductor (2 x 17.65/each)	35.30	35.30
Wire	21.95	21.95
<b>TOTAL Cost:</b>	<b>397.37</b>	<b>205.15</b>

## **Project Implementation**

The Photovoltaic battery charger is was designed with the purpose of integrating it into residential home this particular phase of the charger was implemented in the lab for testing purposes along with replacing an actual battery with a high capacity resistor to allow for high peak currents and voltage that in the beginning stages were varying in sporadic conditions. In doing so this allows for a safer environment since there are chances that the current could spike along with the high voltages that were being run through the system.

One of the safety measures to prevent any damage to both us and the system was to apply a rubber mat that was purchased at a local hardware store. The mat created an insulator on the bottom of the circuit, where all the soldering and any possible exposed wires could prevent a shock or short of the entire circuit. While the mat provided an insulator while increasing the amperage and voltage through the converter, as a group we still used typical lab safety measures such as closed toes rubber shoes, long sleeves and pants to prevent any type of stray electric shock to ourselves. This was all done as a precautionary measure but the variation of the currents and voltages going into the system and having the resistor take the high output currents and voltages.

The photovoltaic battery charger stayed in a controlled lab environment with the exception of taking the equipment, such as the converter (with rubber mat), solar panel, laptop, voltmeters and oscilloscope outside to make sure that the results given in the lab setting with the power source stay consistent with the solar panel. Same safety precautions were established to prevent any stray current or sparks that could harm anyone or equipment. The variations of

having the system outside and still in the open made the group cautious and also to act at an instant if the need to disconnect the solar panel or microcontroller presented itself.

The following sections show the implementations of each main section of the whole system such as the circuit or microcontroller.

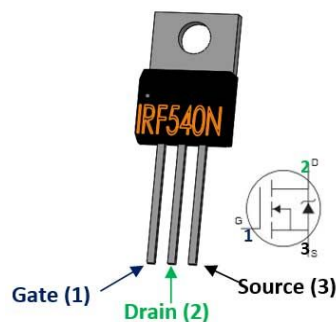
### **Circuit Implementation**

Implementing a circuit is not hard, but to make it work properly is something that needs time to finish. The circuit is drawing based on the project expected to have; but when implementing it, there's a few thing that can be changed, and keep in mind that the circuit can be added or removed the component to help the circuit flows easily. First thing to do is ordering the right components so they will not breakdown or explode due to high voltage or current go through it.

Starting out with the breadboard first and implementing as shown on the circuit graph. Connect one wire to positive and one wire to negative side for the voltage input. From there, each wire connects component to component in order as the circuit shown. Never skip ahead or have to go back later, because if the wire was not connected properly on one place would ruin the whole circuit. With this project, in order, start with the positive side of voltage input (name A), connect to the inductor, to the diode, and then connected to the reload resistor ( a replacement for the battery position that is tested in the lab, to see if the voltage works or not before connecting to the battery). What been mentioned above is just a connection of the positive side only, which is the top part of the circuit. Now start with the connection of the ground which is the negative side (usually located on the bottom of the graph); connect the other end of voltage input (name B) to the ground, and same for the reload resistor. Looking on the

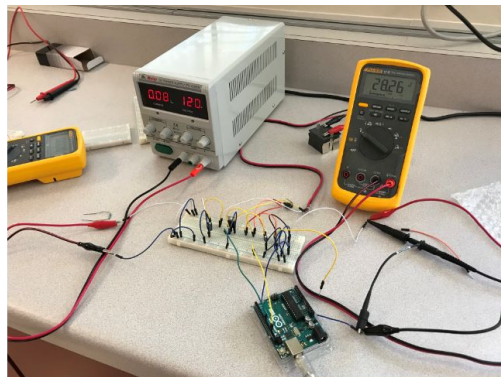


breadboard, there should be a connection of top and bottom to classify as positive and negative. From there, we can connect the middle part of the circuit where they connect positive-to-positive side, and the negative part to the ground. Connect the first voltage sensor, where the positive side of it will be connected between the voltage input and the inductor, and the negative end to the ground. Next is the current sensor, place it next to the first voltage sensor (the right side) and connect positive side to the positive, as negative to the ground. Same idea, connection for the MosFET, but this time connect it between the inductor and the diode. The MosFET has three terminals, in order from the front of MosFET: the left side is gate (G), the middle is drain (D), and the right is source (S). Make sure to connect the D terminal to the positive side, between the inductor and the diode, then connect the S terminal to the ground, and the G terminal will be connected to the arduino last. Next, connect the capacitor output and then the second voltage sensor between the diode to the reload resistor; where positive goes through positive side and the negative to the ground. Afterward, test with power supply by connecting to the voltage input ends (A and B) and slowly turn the voltage to the range that needed. On the other side where reload resistor are at, put the multimeter on positive and negative ends to see if voltage from input run through or not (also known at the output voltage). In what, if the output voltage is boosted or higher than the input voltage in range that is required, then the circuit is successfully connected.



*Fig. 25 - IRF540N MosFET terminals locations*

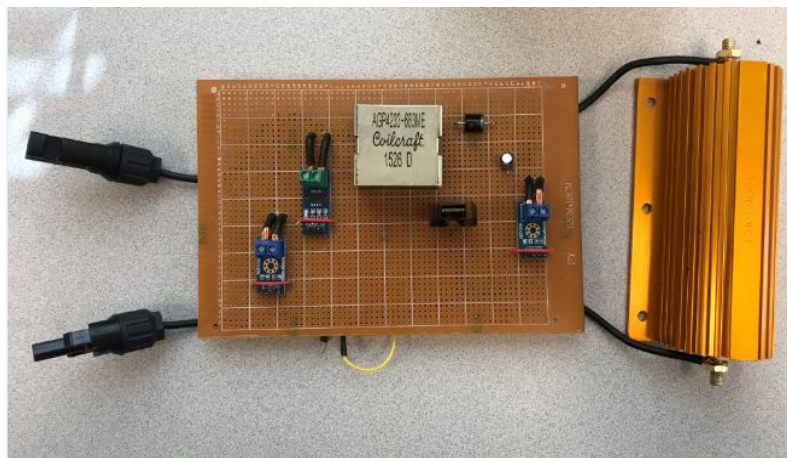
Once the circuit in breadboard works, it is time to work on the stripboard where requires soldering and connecting properly with correct wire to prevent overheating. Wire is required and important when soldering the circuit, so the current or the voltage that can go through it. If the wire duration is less than the required voltage and current, the wire and the components can be overheated and exploded. On the other hand, if the wire is too big for the voltage and current to go through, the circuit and the output voltage cannot get much power and get boosted as needed. To get as much of power and voltage, only pick the wire that in range of what the circuit needed.



*Fig. 26 - Breadboard testing*

When soldering the circuit to the stripboard, follow same steps as the breadboard circuit. But this time, take time to strip the wire and solder neatly and carefully so it will not ruin the board. Remember, if soldering so much of filler metal into the joint of component-to-component or component-to-wire will prevent power to go through. But if it is too less of filler metal, they will not connect properly and cause electric strike and burn easily. (As explain and not to confuse, soldering differs from welding in that soldering does not involve melting the work

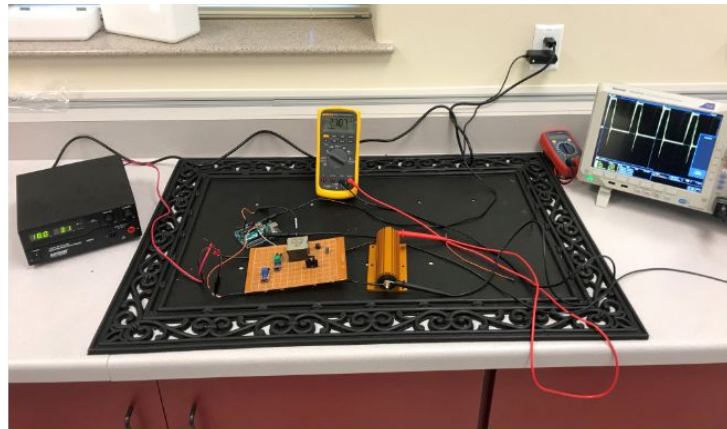
pieces.) Once the stripboard is finish soldering, turn on the power supply and test to see if the voltage and current are running through or not, and if the output voltage (reload resistor) is boosted or not. If there is no voltage running through the reload resistor, use the multimeter and check each component to see if there is any pick-up of input voltage. From there, the circuit will show where it goes wrong and solves the problems. After pointing out the problem, unsolder that part and fix it; then resolder again. The other reason why solder enough but not too much of filler metal is to help unsoldering easily. Be really careful with soldering and keep in mind that solder and unsolder many times on same spot, can prevent accuracy and precise of the voltage and current. The filler metal will get into the wire so much that can cause the lost of voltage, and the percentage error will be higher. Coding can be the hardest part of the project, but not getting correct connecting on the circuit will never get any result at all.



*Fig. 27 - PCB implementation of the converter*

Overall, get the right circuit with the correct components is the first step. Second, test the breadboard to see if the circuit successfully works. Once all part work properly on the breadboard with boosted output voltage, implement on the stripboard and test to see if things work out or not. It is important to take time and focus on the circuit, especially working with

power supply, higher current (amps) can be dangerous. When test with power supply, make sure to turn the power supply voltage to zero and then connect the wire to the circuit. From there, slowly turn the voltage to the desire amount of input voltage that will be tested; and never touch any component with bare hand once it is connected. If the current go way above the desire current by more than 3 or 4 amperes, turn off the power supply, because when the current is too high, any of the component can be overheated and exploded, most likely will be the resistor or MosFet switch will be burnt or exploded.



*Fig. 28 -Final lab experiment with completed circuit design*

### **Controller Implementation**

For the needed circuit to be a functional boost converter, there was a need to implement the microcontroller, which as explained in the above sections, was the Arduino Uno Rev3. The Arduino played a crucial role, that of allowing a pulse wave to flow through the MosFET switch which on the programing side allowed for the switch to be on 25% of the time and off 75% of the time in ideal conditions. The easy of the C language in an Arduino allowed for the group, even with minimal coding background, easy to understand and allow for any sort of adjustments.

The microcontroller once connected directly into the MosFET switch was powered through an outside source such as an external wall-plug or in most cases, during testing and troubleshooting, through USB plugged directly into a laptop. By plugging the Arduino directly into the computer and through the Arduino IDE (Program that allows for a user to write a program for the Arduino and compile/send to the Arduino) it allows for a visual on the code itself but also since there are voltage and current sensors plugged into the board, allowed for real time values of the input/output voltages and currents. The process became essential as when running the first tests of the charger with the solar panels, instead of going back and forth, the laptop allowed for onsite troubleshooting of the various adjustments on the code and also get a generalized idea if the program was functioning as intended.

### **Troubleshooting**

When building circuits by soldering there is more than likely going to be troubleshooting involved during the process. The first time building the boost converter there was not as many connection points to the voltage source wire and the drain wire. In result there was a lack of connection leading to a short circuit[Van Gog]. When testing the circuit for the first time the current shot through the roof, not even being able to get any values due to safety factors and having to immediately turn off the power supply. This was the biggest setback due to having to rebuild the circuit entirely. After rebuilding the circuit with individual connection points to the voltage wire and the ground wire. After securing these connections the circuit still did not work. The voltage and currents looked odd, but not as if there was a short circuit. Using a multimeter to view voltages going through each component, the switch seemed to be conducting lower than the

rest. After detaching the IRF540N, switch, and making a sample circuit with a simple LED light, the switch had blown due to the previous short circuit.

After replacing the switch, the boost converter started working exactly how it was designed. When testing the output voltage controller and pulse codes, there was five other IRF540N switches blown along the way. Two of the six switches that had to be replaced were due to broken pins. This was immediately noticed once detached from the boost converter. Besides the poor connections on the first boost converter, everything went accordingly, except for the occasional switch failure.

## **ABET (Student Learning Outcomes)**

### **Application of Mathematics, Science and Engineering (a)**

Many engineering skills were used over the course of this design. The design of the power converter along with all of the electronics utilized may of the skills taught in multiple of our electrical engineering classes. Computer science skills were also used in the design and coding of the microcontroller. Mathematics were predominantly used in out hand calculations during the design phase of the converter, but were also very important to take our results and calculate efficiency numbers.

### **Analysis and Experimentation (b)**

Extensive analysis was performed on the boost converter as well as the solar panels used in the experiments. Analysis was also performed on every component of the converter individually to ensure that no faulty components were used in the design. Experimentally, tests were conducted on every stage of the boost converter design. Multiple experiments were performed under high load conditions to ensure that the system would operate as intended under maximum conditions. Experiments were also conducted on the final design in sunny as well as cloudy weather.

### **System Design (c)**

The solar battery charger design detailed in this report was implemented with several constraints. The most important constraints of this project were a budget of \$ 2,000 and a system

efficiency requirement of a minimum of 95%. The final design totaled well under \$2,000 and boosted an efficiency of 97.3%.

### **Multidisciplinary Teamwork (d)**

While every member of the design team was an electrical engineer, many people of different disciplines assisted in multiple aspects of the design. During the fabrication process, an industrial engineer assisted in the fabrication process as well as suggesting methods of implementing a microcontroller. While coding the microcontroller, computer scientists were consulted to ensure the code functioned as intended.

### **Solving Engineering Problems (e)**

Designing the parameters of the boost converter presented many engineering problems. The most challenging engineering problems we faced were calculating the duty cycle of the switch and designing the converter to match the solar panel parameters. Throughout the project timeline, the design presented many small issues that as a group were addressed and solved as the design project.

### **Professional and Ethical Responsibilities (f)**

The ethical responsibilities of an engineering group are very important. Safety and overall project quality were priorities that we promised our solar battery charger would possess. We ensured that these aspects were prioritized throughout the entire project timeline. This design was ethically responsible as we never claimed the project could do anything that it cannot.



Throughout the entire design process, we made decisions that would not bring harm or inconvenience to our customers or anybody that comes in contact with our system. We also made sure to uphold our professional and ethical responsibilities to not sell a faulty system or a system that is not safe.

### **Effective Communication (g)**

Communication was a strong suit of this group throughout the semester. We were very effective at communicating what we all needed from one another and when deadlines for certain project sections. Whether we were meeting on a weekend or setting up a meeting after school hours, every member of this group participated in every design meeting and communicated when they were not available and vice versa. Our communication skills were very useful for the troubleshooting process of the project. We all worked together to discover the problems with our system and collaborated with one another to formulate solutions to every complication we faced. This made the later end of the project much more manageable as every member was contributing to what needed to be completed and asking questions to clear up any confusion. This group is very proud of its ability to communicate effectively and solve any engineering problems concerning this project.

### **Engineering Impact (h)**

Solar battery chargers are an increasingly desired system that could have major global impact. As the planet continues to get more populated, more energy is needed to supply this continually growing need for power. Renewable energy will be necessary in order to keep

society powered so humanity can continue to innovate and grow. Systems like the one detailed in this design, would be very helpful to rich, populated areas and poverty-ridden areas alike. This system can change lives no matter if it is reducing the costs of electricity bills or supplying power to places that have none to inconsistent supplies.

### **Life-Long Learning (h)**

This project increased our knowledge of how solar powered systems work and the need for renewable energy systems. Background research on this project led to many revelations on how efficient and inexpensive renewable energy systems can be. Even greater though, was our increased knowledge of how to fabricate a circuit. Nobody in this group had any knowledge of how to build a circuit from scratch, but by working together we found the knowledge and skills we needed to complete the design. The soldering skills, design of components, and troubleshooting skills were the most valuable lessons that we learned during this project.

### **Contemporary Issues (j)**

Renewable energy is a very relevant contemporary issue at the present time. With energy sources like coal and other fossil fuels diminishing faster than ever, engineers must find a way to generate energy to keep up with the growing demand of the modern world. With our system being as inexpensive as possible, we hope to persuade more people to make the investment in renewable energy to not only help the environment but to save money on electricity as well. Our entire project was based on a contemporary issue so this was not avoidable for us.

### **Modern Engineering Tools (k)**

For this design, we used modern engineering tools such as Matlab to do software simulations as well as modern engineering practices to make some hand calculations. Many pieces of modern engineering equipment were used in this design as well. We used multimeters and software to measure voltages and currents all through our system to ensure its safety as well as efficiency. Using modern techniques, we were able to code a microcontroller to operate in a high power solar energy system.

## **Conclusion**

The use of a photovoltaic battery charger present a supplementary system for residential homes. In implementing such system into these areas, the consumers will lower their electrical expenses just by allowing the photovoltaic system to charge the battery during the day and to have the stored power from the battery to discharge into the house when the peak times occur.

As explained in the report, the implementation of the boost converter and the way the Arduino recognizes the output voltages to adjust the duty cycle. The ideal set up for the duty cycle for switching the MosFET on and off is at 25% on and 75% off but the Arduino program is full adjustable to the type of battery that a consumer might select, in this projects case was a lead acid battery for which the duty cycle will adjust the output voltages to 24V to maintain optimum charge rates. Along with the simplicity of adjusting the program, this system is fully adjustable, meaning that the components can be selected to be greater or smaller for the appropriate level on power needed, such as more solar panels and a larger battery to have more charge as a backup.

With the expenses on purchasing the system and implementing it in a residential home the consumer will have the whole system paid for in a few years, allowing them to see the need. The ability to make adjustments as needed with minimal programing background, the consumer can apply these changes if they decided to add more solar panels and a larger battery. Overall this particular project presents benefits for the consumer in high peak areas that will not take the consumer off the electrical grid completely but just act as a supplement for the times where a they would like to save money have the battery charged for the home needs during those times.

Also taking the consideration of applying this to a small shed for example in a remote location could present a benefit for different type of work fields that might need a small amount

of power for a few lights to power the shed. This idea can show how a simple Photovoltaic battery charger can be sized and implemented in other ways other than just a supplemental power source to a residential area.

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# Appendix A

## Datasheet for ES-A Series Solar Panels

### ES-A Series Photovoltaic Panels Safety, Installation and Operation Manual

#### Electrical Specifications at STC\*

	ES-A-190 -fa2	ES-A-195 -fa2	ES-A-200 -fa2	ES-A-205 -fa2	ES-A-210 -fa2
$P_{mp}$ (W)	190	195	200	205	210
$P_{mcc}$ (W)	171.3	175.9	180.6	185.2	189.8
$V_{mp}$ (V)	17.4	17.8	18.1	18.4	18.7
$I_{mp}$ (A)	10.92	10.96	11.05	11.15	11.23
$V_{oc}$ (V)	22.0	22.3	22.5	22.8	23.1
$I_{sc}$ (A)	11.80	11.90	12.00	12.10	12.20

Number of Cells	114
Bypass Diodes	2x Type Schottky UCQ530A04, 45 V, 30 A
Max. Series Fuse/ Max. Reverse Current	20A
UL Rated System Voltage	600V DC Maximum

#### Electrical Specifications at NOCT\*\*\*

$P_{mp}$ (W)	139.1	142.7	146.4	150.1	153.7
$V_{mp}$ (V)	16.3	16.5	16.7	16.8	17.0
$I_{mp}$ (A)	8.54	8.65	8.76	8.93	9.04
$V_{oc}$ (V)	20.0	20.3	20.5	20.7	21.0
$I_{sc}$ (A)	9.44	9.52	9.60	9.68	9.76
$T_{mod}$ (°C)	44.8	44.8	44.8	44.8	44.8

#### Temperature Coefficients

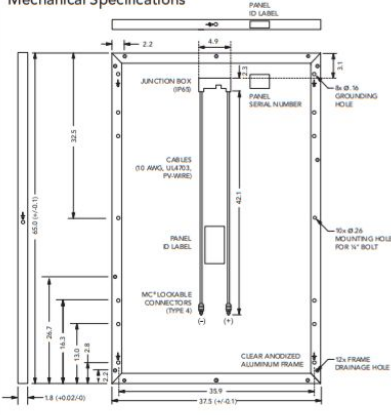
$\alpha P_{mp}$	-0.45 (%/°C)
$\alpha V_{oc}$	-0.43 (%/°C)
$\alpha I_{mp}$	-0.02 (%/°C)
$\alpha V_{oc}$	-0.32 (%/°C)
$\alpha I_{sc}$	-0.003 (%/°C)

\*At Standard Test Conditions: 1000 W/m<sup>2</sup>, 25°C cell temperature, AM 1.5 spectrum. Minimum specified power rating is 0% below  $P_{mp}$  for all products; other specifications are  $\pm 10\%$  of measured values per ASTM E 892. Specifications subject to change without notice. Warranty details available on request.

\*\*At PCT (PV-USA Test Conditions): 1000 W/m<sup>2</sup>, 20°C ambient temperature, 1 m/s wind speed

\*\*\* At Nominal Operating Cell Temperature Conditions: 800 W/m<sup>2</sup>, 20°C ambient temperature, wind velocity 1 m/s, AM 1.5 spectrum. The relative reduction of panel efficiency at 200W/m<sup>2</sup> irradiance in relation to 1000W/m<sup>2</sup> both at 25°C cell temperature and spectrum AM 1.5 is 0%.

#### Mechanical Specifications



ES-A-190, 195, 200, 205, 210  
All dimensions in inches; Weight 41 lbs. (18.6 kg)



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## Appendix B

### Microcontroller Code for Output Voltage Controller

```
1 #include <TimerOne.h>
2 float D = 105;
3 int x = 0;
4 //Voltage sensor 1 variables
5 int analogInput1 = A0;
6 float vout1 = 0.0;
7 float vin1 = 0.0;
8 float R11 = 30000.0; //
9 float R21 = 7500.0; // I
10 int value1 = 0;
11 //Voltage sensor 2 variables
12 int analogInput2 = A1;
13 float vout2 = 0.0;
14 float vin2 = 0.0;
15 float R12 = 30000.0; //
16 float R22 = 7500.0; //
17 int value2 = 0;
18 //MPPT variables
19 float vprev = 0;
20 float delv = 0;
21
22 void setup() {
23   //Pulse
24
25   //Voltage Sensor 1
26   pinMode(analogInput1, INPUT);
27   Serial.begin(115200);
28   Serial.print("INPUT VOLTS");
29
30   //Voltage Sensor 2
31   pinMode(analogInput2, INPUT);
32   Serial.begin(115200);
33   Serial.print("OUTPUT VOLTS");
34 }
35
36
37 void loop() {
38   Vsensor1();
39   Vsensor2();
40   MPPT();
41 }
42
43 void Vsensor1() {
44   // read the value at analog input
45   value1 = analogRead(analogInput1);
46   vout1 = (value1 * 5.0) / 1024.0; // see text
47   vin1 = vout1 / (R21/(R11+R21));
48
49   Serial.print("INPUT V= ");
50   Serial.println(vin1,2);
51   delay(50);
52 }
53
54 void Vsensor2()
55 {
56   value2 = analogRead(analogInput2);
57   vout2 = (value2 * 5.0) / 1024.0;
58   vin2 = vout2 / (R22/(R12+R22));
59
60   Serial.print("OUTPUT V= ");
61   Serial.println(vin2,2);
62   delay(50);
63 }
64
65 void MPPT() {
66   pinMode(9, OUTPUT);
67   Timer1.initialize(10);
68   Timer1.pwm(9, D);
69
70   // put your main code here, to run repeatedly:
71   float vi = analogRead(vin1);
72   float vo = analogRead(vin2);
73   float vim =(5/1024)*vi; //analog read will give value between 0 to 1023.
74   float vom = (vin2 * 5.0) / 1024.0;
75
76   float delv = (vin2+0.5);
77
78   if (delv < 24) {
79     D += 5;
80   }
81   if (delv > 24) {
82     x = (D-5);
83     D = x;
84   }
85   //analogWrite(9,D);
86   delay(300);
87 }
```