Portable Solar Power Supply

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***Abstract* — This paper will discuss an alternative energy device, the Portable Solar Power Supply. Solar power is considered one the most environmentally friendly and abundantly available alternative source of energy. The Portable Solar Power Supply is designed to optimize capturing solar energy, storing it into a battery, and providing both standard household alternating current (AC) and most common direct current (DC) power. While this device is designed to optimize capturing solar energy and storing it into a battery, this device was designed to have it's weight and size minimized.**

Index Terms — Energy resources, Solar energy, Batteries,

I.INTRODUCTION

Due to the more apparent limitations of fossil fuels, solar energy is becoming more popular as the renewable energy source that could change the future[1]. It is available in abundance and its usage does not harm the environment with greenhouse gas emissions [1].

Developing a portable device that could capture this solar energy and supply it when needed is an invaluable solution to keeping up with the demand of portable devices. Also, a portable device that could provide power for non-portable devices that could be handy when used outdoors is of great significance. Examples of non-portable devices that can be handy when used outdoors are an electric fan, a projector to watch movies, a computer printer, and a microwave oven for people who want to heat up their food quickly.

The applications of a portable solar power supply is very broad. It can be used to supplement a mobile home's fuel powered portable generator. It can be used to provide power to devices while camping outdoors. Examples of devices used while camping outdoors that will utilize a portable solar charger are: a flashlight light with a rechargeable battery, a radio, a television, and also the battery of the vehicle that is used for transportation.

II. MOTIVATION

We live in a modern society where a vast area of technology is driven by portability, performance, and efficiency. As technology becomes more portable, there is greater dependence on finding mobile power to sustain this technology. Carrying back up sources of mobile power such as extra batteries is very convenient to sustain devices running on portable power but, batteries cannot be replenished by themselves. It is more convenient to have a portable power source that is capable of providing power, recharging by itself, has a minimal or no negative impacts on the environment, and is convenient to carry around. Such a power source is purely a portable system, independent of power outlets.

III. GOALS AND OBJECTIVES

The primary goal of this project is portability and efficiency. Throughout the research and building process of this project the following goals were the main focus for the group members:

- To create a portable power generation system that is easy to carry
- To develop a portable system that can charge most portable appliances (AC and DC)
- The portable power supply must look user-friendly and be simple to use
- The charging capability of this device must be equivalent to the charging ability of any indoor power outlet and any USB power outlet

To accomplish the goals previously mentioned, the group members had to rely on their knowledge of previous course work and skills acquired from attending college, work experience and elsewhere. The following objectives briefly describe some of the technical requirements needed to achieve the goals for this project:

- Must be capable of converting 12 V DC to 120 V AC
- Must be capable of supplying 5 V and 500mA DC power for USB Type A outputs
- The device must have a 90% efficiency rating
- Horizontal rotation to make an angle of 360˚ for solar tracking

- Maximum Power Point Tracking (MPPT) that will match the solar panel's impedance with the battery's impedance to ensure that the maximum power that is received by the solar panel is transferred to the battery.

IV. PROJECT FUNCTIONALITY

As mentioned earlier in the abstract of this paper, the Portable Solar Power supply is supposed to capture solar energy, store it into a 12 volt lead-acid battery, and then provide useful power for a broad range of devices that operation on both AC and DC power. To gain a better understanding of how this project will function as single unit, a basic block diagram illustrating the functionality of this project is illustrated below in Figure 1.

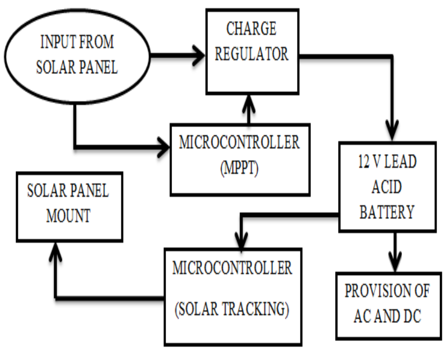

Fig. 1: Basic Block Diagram of the Functionality of the Portable Solar Power Supply

V. SOLAR PANEL

A 50 Watt 12V nominal output Monocrystalline solar panel was chosen for this project. The Monocrystalline panel was chosen because it has the higher efficiency, high power per area, high stability and high liability. This solar panel was bought on Amazon, which was manufactured by Ramsond with dimensions of 24.6' x 1.2' x 21'. It has a max power of 50W, a weight of only 8.8 pounds, max current of 2.92 Amps, and maximum operating voltage of 17.1 Volts (seen in Figure below). The solar panel we have chose for the project was a good choice in order to have solar tracking functionality. Solar tracking is one of the goals in our project, which will essentially keep the greatest amount of panel surface area perpendicular to the feeding light source at all times. Below in Figure 2 is an illustration of this solar panel.

Fig. 2: 50 Watt Monocrystalline Solar Panel.

VI. MAXIMUM POWER POINT TRACKING

Maximum power point tracking (MPPT) was one of the critical features of the battery charging process of this project. It increases the efficiency of charging the battery from the solar panel. The maximum power point occurs where the current and voltage at which a solar module can generate the maximum power. The maximum power point location is not known in advance.

To gain a better understanding of how MPPT increases the efficiency of the charging process for the Portable Solar Power Supply, a close examination of the electrical characteristics of a solar panel will be discussed [2]. Solar panels convert photons from the sun striking their surfaces into electricity of a characteristic voltage and current [2]. The electrical output of a solar panel can be plotted on a graph of voltage (V) versus current (I) (an IV curve) [2]. Looking at the performance of a solar panel in Figure 3 below, the resulting line on the graph shows the current output of the panel for each voltage at a specified light level and temperature [2]. The current is constant until arriving at the higher voltages, when it falls off rapidly [2]. This IV curve applicable to the electrical output of all solar panels [2].

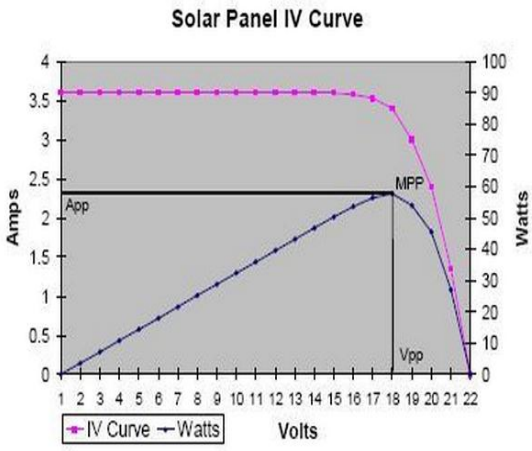

Fig. 3: Current, voltage, and Power Curves for Solar Panels. Reprinted with Permission Granted from Tim Nolan, www.timnolan.com

However, in a solar power system there is more concern about the power that can be extracted out of the system, power that can be used to do useful work [2]. In an electrical system, power is measured in watts, which is the product of the voltage and current (W = I x V) generated by the panel [2]. Looking at the graph of the watts generated by the solar panel in Figure shows an interesting characteristic: the maximum watts are produced at a panel voltage of about 18 V [2]. This value is called the maximum power point (MPP) [2]. The purpose of the charge controller is to generate the maximum power from the solar panels so, for a solar panel with the performance characteristics in Figure 2, operating the solar panel very close to this value is optimal [2]. For the Portable Solar Power Supply, if the solar panel was used to charge a 12 V battery directly, the battery would pull the operating voltage of the solar panel down from its MMP voltage (18.4 V) to its own voltage [3]. There is a DC/DC converter built into the charge controller to convert the solar panel's higher voltage, and lower current into a lower voltage and higher current output for the battery [2]. This conversion process ensures that the input power is the same at the output [2].

For any solar panel, the MPPT is not fixed [2]. The IV curves change with the amount of light, the temperature of the panel, and also for each individual solar panel [2]. As the curves change, the MPPT also changes [2].

The charge controller for the Portable Solar Power Supply uses an iterative approach to finding this constantly changing MPP [2]. This iterative approach is called the Hill Climbing Algorithm [2]. This Hill Climbing Algorithm is implemented on an Arduino Microcontroller. The software that implements the Hill Climbing Algorithm is described below [2]:

- Increase the conversion ration of the DC/DC/converter.
- Measure the solar panel Watt.
- If the solar panel watts are greater than the last measurement ,
- Then it is climbing the front of the hill, loop back and do it again.
- Else if Watts are less than the last time measurement,
- Then it is on the back side of the hill, decrease the conversion ratio and loop back to try again

This Hill Climbing Algorithm occurs about once a second in the charge controller and performs a good job of keeping the solar panel operating at its maximum power point [2].

Below in Figure 4 is a schematic illustration of the charge controller that was built by our group.

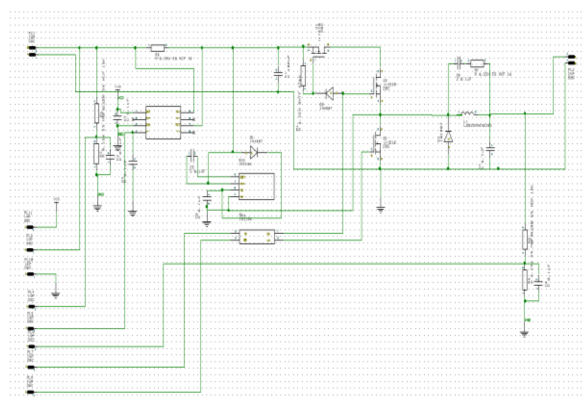

Fig. 4: Charge Controller

VII. MICROCONTROLLER

For the charge controller and solar tracking, the group decided to build two Arduino microcontrollers to perform these tasks. To build each Arduino, the components that the group used were: 1 protoboard, 22AWG wire, an LT1676 switching voltage regulator, 2 LEDs, 2 220 ohm resistors, 1 10k Ohm resistor 2 10uF capacitors, a 16 MHz clock crystal, 2

22 pF capacitors, a small momentary normally open (“off”) button, i.e. Omron type B3F. The group decided to build the Arduino with a switching voltage regulator as opposed to a linear voltage regulator due to the fact that switching voltage regulators are more efficient than linear voltage regulators. The voltage regulator was designed by using a LT1676 chip manufactured by Linear Technology. This buck converter will take the output of the charge controller and step it down to 5V and a current of 500mA. The LT1676 buck converter was also used for the DC to DC converter, which will be explained in full detail in the DC to DC converter section . One of the Arduinos that was built by the group is illustrated in Figure 5 below.

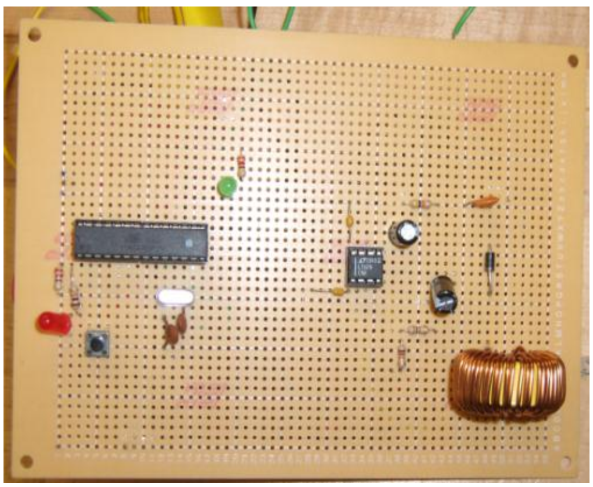

Fig. 5: Arduino Microcontroller with Switching Voltage Regulator

VIII. BATTERY

The battery chosen for this project is a 12 V Sealed Lead Acid battery with 6 cells and 35Ah, which is manufactured by Battery Mart. The battery has an approximate battery life of over 100,000 operating hours and 450A max discharge surge current and minimum charge current of 1 Amp. The battery’s dimension is 7.65’ x 5.25’ x 7.18’ and weighing 29 pounds, which was a good size in comparison to other batteries found while doing research. The battery is the heaviest part of the project, therefore, finding a battery at a good size and weight was a key factor for our project . The advantages of this battery are it has no memory effect, recyclable, and has long service life. The battery can also operate in wide temperatures ranging from -40 degrees to 60 degrees Celsius. The battery used in the project is shown in Figure 6 below.

Fig. 6: 12 Volt Lead- Acid Battery

IX. LCD DISPLAY

To monitor the status of the charge controller an SSCF20 20 line X 2 character LCD display was implemented into this project. This LCD display has a built-in HD44780 equivalent controller that makes it compatible with the Arduino microcontroller that the group used for the Portable Solar Power Supply. This LCD display has can display white text on a blue background. The interfacing is simplified with 4-bit and 8-bit communications. The dimension of this LCD display is 116.0 * 36.0 * 13.0 mm. It is wired to the Arduino microcontroller that the group built. Below in Figure 7 is an illustration of the LCD display.

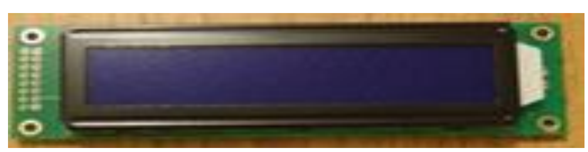

Fig. 7: 20 Character by 2 Line LCD Display

X. SOLAR TRACKING

During the research process, the group learnt that if solar tracking was implemented into the project, it can increase the amount of energy delivered into the battery of the Portable Solar Power Supply. The group decided to implement a single axis tracking system that follows the azimuth of the sun. Based on research, the group decided to only incorporate a horizontal axis tracking system because it is expected to increase the efficiency of the portable Solar Power Supply by 26 percent, while a two-axis tracking system that can track the elevation of the sun along with the azimuth, is expected to increase the efficiency of a solar system up to 32 percent [3]. A two-axis tracking system will only yield a 5 percent increase in efficiency when compared to a single axis tracking system that will follow the azimuth of the sun.

XI. SERVO MOTOR

For this project to be capable of single axis tracking that tracks the azimuth of the sun, a servo motor was used. The group chose to use a large ROB-09064 servo with a standard 3 pin power and control cable. The dimension of this servo motor is 41 by 20 by 38 mm. Some of the features that made this servo a suitable choice for this project is listed below:

- 3 pole ferrite, all nylon gear
- Top ball bearing
- Operating Voltage: 4.8 V ~6.0 V
- Operating Speed:
  - 0.20 sec/60 degree (4.8 V)
  - 0.16 sec/60 degree (6.0 V)
- Stall torque:
  - 5.2 kg*cm (4.8 V)
  - 6.5kg*cm (6.0 V)
- Temperature Range: -20 ℃~60 ℃
- Dead band width: 4μs
- Connector wire length: 32cm

XII. PHOTORESISTORS

Photoresistors play a critical role to perform solar tracking. For this project, the group chose to use a pair of VT935G photoresistors. The absolute maximum temperature range for operating and storage of these photoresistors are -40 to +75 degrees Celsius. The continuous power dissipation is 80mW and derate above 25 ˚C is 1.6mW/ ˚C. The active surface of these photoresistors are plastic coated for protection. These photoresistors have a maximum peak voltage of 100 volts. The sensitivity of these photoresistors are 0.90γ typ. The photoresistors will be placed on the solar mount with a shadowbox between the two, which will cast a shadow in the direction of where the sun is facing causing a circuit response. Below in Figure 8 is an illustration of the pair of photoresistors that were used for solar tracking.

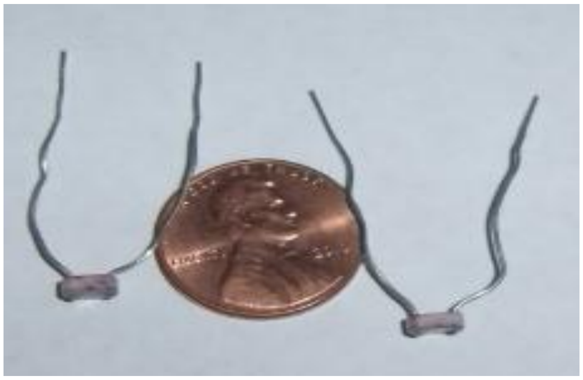

Fig. 8 Photoresistors

XIII. DC-TO-DC CONVERTER

One of the main goals of the project was having a DC output having a 5V and 500mA output. The DC to DC converter will be connected to a DC output, which is a USB type A. This buck converter can take in a range of 8 to 40V and step it down to 5V with a current of 50 mA. The buck converter we are using is a LT1676 manufactured by linear technology. The LT1676 will take 12V in from the battery and step it down to the desired output. It has an efficiency of 85% when the current load is at 500 mA.

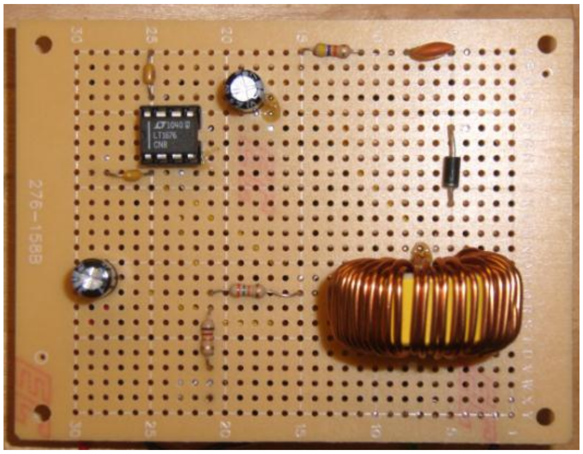

Fig. 9: DC-to-DC Converter

Figure 9 above shows the LT1667 soldered on the protoboard. It was not a complicated circuit and was able to output 5V and a current of an average of 450mA current when testing with a 10 ohm resistor.

The converter was hooked up to the USB type A output and was able to charge a cell phone for testing purposes.

XIV. DC/AC INVERTER

Basically, power inverter or inverter is a very useful electrical device which converts DC voltage into AC voltage depending on the desired output need. If you want to boost the DC voltage read across a battery or a solar panel into AC voltage, the best way to do so is to use a Power Inverter. Such is the main purpose of this section, using a Power inverter we would elevate a particular 12 DC volts from a solar panel and converts it into 120 AC volts. The realization of this specific purpose could achieve using a variety of inverters, some with more efficiency than others and also more expensive. Our goal is to create and build such an efficient device with the least cost of money possible that also presents more features and better performance.

Modern inverters, however, configure in a way that they use a basic circuit diagram that converts the low DC voltage into a high DC voltage first, and then converts the high DC into a desired AC output voltage. This process is carrying out through some different components that constitute the inverter configuration system itself. Among these components we can illustrate:

1. A DC to DC converter or a simple microcontroller that takes the low input DC and converts it into a high DC out.
2. An H-bridge inverter which is nothing but a very efficient electronic circuit that converts the incoming high DC voltage from the DC to DC converter or Microcontroller into the desired AC output voltage using a couple of high power MOSFETs which act like electronic switches.
3. A Pulse Width Modulator (PWM) which is a special circuit that control and regulate the output AC voltage resulted from the H-bridge inverter. Usually, the PWM uses simple method by comparing a fixed frequency and magnitude triangular carrier with the AC waveform desired.
4. A digital filter which is most often used to correct and reconfigure the output at any desired frequency. Depending on the response we have, low pass, high pass, and band pass behavior with a specific frequency, an active filter can be used to reduce the attenuations of the signal and sharp the edge at cutoff frequency.

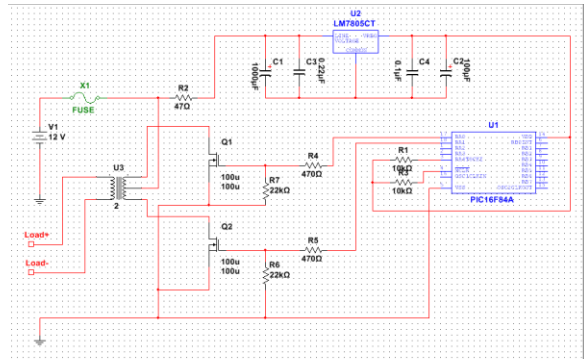

Fig. 10: Schematic of Inverter

The previous schematic is the one considered for the inverter design. Originally, we wanted to use a high voltage DC to DC converter, more specifically, a high DC voltage that would take 12V DC from the battery and convert it into 170V DC. After, a lot of research, we concluded that this high voltage DC to DC converter would not be so convenient for our project and we considered to use a transformer instead in order to boost the high AC voltage. Also, we have proposed to use a MSP430F449; however, after analysis of this particular microcontroller, we realized that the use of another microcontroller would be more convenient since all we need is generate the pulse width modulation to operate the MOSFETs on the bridge. The microcontroller we have considered this time is the PIC16F628A. As specifications, we only used six (6) of the eighteen (18) of this particular microcontroller.

Also, for the transformer we have considered a 12 – 0 – 12 on the primary side and a 200 V AC on the secondary side. In addition, considering that the output AC voltage derived from the inverter supposes to be at 60Hz which is considered to be low frequency signals, we have decided to build a low-pass filter in order to reduce and reject the high-frequencies that may be resulted, and as well as clean the system from external noises and attenuations.

The following picture is the final design of the Inverter. As stated, we expected to output 120V RMS and 2.5A at 60 Hz without any load connected to it.

After testing, the results were very close to realization. We were able to output 118V RMS and 2.3A at 60 Hz, which leads us to an efficiency of 90 percent.

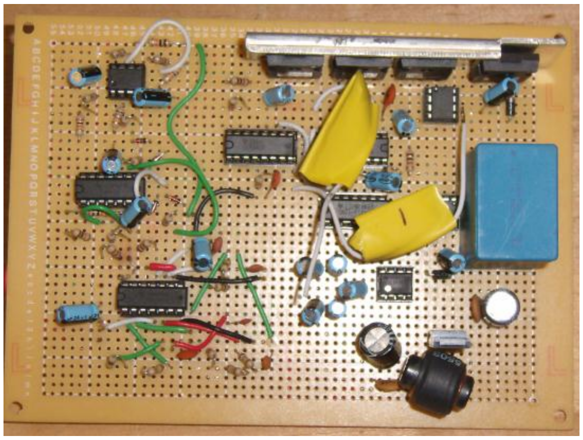

Fig. 11: Inverter

XV. FORMICA LAMINATED PLYWOOD BOX

In order for the project to be portable we designed a box to put all of the components inside. The box is made of 3/4" plywood and was laminated with Formica. The dimensions of the box are 20' x 8.5' x 13'. The box was designed with two handles on the side for convenience purposes to carry it around. The box has a door in the back in order to replace or change any of the components if needed so. The box has the solar panel mount and the servo motor screwed on the top of it. The front of the box will have the LCD screen, USB A type output, and a AC Output. Below in Figure 12 is an illustration of the box that was designed for this project

Fig. 12: Formica Laminated Plywood Box that was Designed by the Group

XVI. TESTING

After completion of the Portable Solar Power Supply, the group tested it as a single unit to make sure that everything works properly when connected together. The first type of testing was performed indoors. First we tested the solar tracking capabilities by shining a moving flashlight and checking to see if the solar panel will rotate to follow the direction of the moving flashlight. Then we measured the solar panel voltage and current and also the battery's voltage and current to see if the maximum power point features was functioning properly. After we testing these two features, based on the results obtained, we had evidence that these features were functioning properly. Based on the input and output current and voltage values obtained from the charge controller, it has an efficiency rating of 95 percent.

When the group was finished testing the battery charging portions of the project, the group progressed by testing the capability of this device to provide output AC nd DC power. The inverter was tested by plugging in a 5 Watt rating AC alarm clock radio into the output terminals of the inverter. The alarm clock radio functioned normally when connected to the inverter. The DC/DC converter was testing by connecting a cell phone that can be charged with a Type A USB cable than can fit into the output terminals of the DC/DC converter. The cell phone's display showed that it was charging properly.

The group then took the Portable Solar Power Supply outdoors to further test the solar tracking and maximum power point capabilities. These two features also worked as expected when the device was taken outdoors to be tested.

CONCLUSION

It was beneficial for the group to spend a semester doing research before building a real prototype of the Portable solar Power Supply. To create this project, some of the areas that the group had to do research on were power electronics, microcontrollers, and mechanical systems. Various components were modified during the prototyping stage for this project. The research assisted the group to be well familiar with the project to be implemented such that if a component needed to be substituted for another one during the prototyping stage, the group was ready to be able to adapt to this change and still meet the requirements of this project. Concerning efficiency, portability, and the capability to provide AC and DC power, the Portable Solar Power Supply met these requirements successfully. The most difficult challenge that the group encountered was designing a 360 degree horizontally rotating solar panel mount that would support the solar panel at an angle of 23 degrees for solar tracking.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of many professors and professionals in the engineering field. The group was able to take in the advice from multiple professors that made the project finish out in a smooth manner. We would like to thank Carbide Industries for donating the plywood and helping construct our Formica Laminated Plywood Box. We would also like to thank Linear Technology and Texas Instruments for helping us sample multiple components in order to get the best fit for our project. Finally, we would like to thank Dr. Richie for helping us through many obstacles we came across and giving us the right guidance to understanding a certain design process or technical issue.

REFERENCES

[1] "NI Developer Zone." *Maximum Power Point Tracking*. National Instruments, 07/007/2009. Web. 23 Jun 2012. <http://www.ni.com/whitepaper/8106/en>.

[2] Nolan, Tim. "Arduino PPT Solar Charger." *Arduino Peak Power Tracker Solar Charger*. CMS Made Simple, 10/005/2009. Web. 8 Jun 2012. <http://www.timnolan.com/index.php?page=arduino-ppt-solar-charger>.

[3]"NI Developer Zone." *Solar Tracking*. National Instruments, 31/008/2010. Web. 12 Jul 2012. <http://www.ni.com/whitepaper/8105/en.

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Amos Nortilien is a senior at the University of Central Florida. He will be graduating with a B.S in Electrical Engineering in December 2012. His interests include watching soccer, video games, church, and social services. He plans on pursuing on Digital Signal Processing as well as Analog Filters Design. He also plans to pursue a PhD on design and implementation within Power Generation.