Solar Powered Golf Cart

Andrew Bridges, Nick Paperno, Patrick Taylor, and David Yeung

School of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — This project outlines a design for a more efficient golf cart. The golf cart has 3 different modes of operation: efficient, high performance and power saving. In high performance mode, the golf cart is not as concerned with energy consumption. Power saving mode focuses on conserving energy to maximize the time until the golf cart runs out of energy. The golf cart will be self sustaining with replenish its power from solar panels and can be charged from wall outlet. There will be a display screen that will control what mode is on and will accurately display the current mode of operation, speed, charge remaining, and estimated time remaining.**

***Index Terms* — Electric Motors, Microcontrollers, Power MOSFETS, Pulse Width Modulation, and Solar Energy**

I. INTRODUCTION

In recent years, major industries throughout the world have been focused on saving nonrenewable resources. There are two main ways of accomplishing this. One way, is to use nonrenewable resources in a more efficient way. The other, is to simply stop using nonrenewable resources all together. This has sparked new life into the field of power engineering.

Our project focuses on making a more efficient, solar assisted, electric vehicle. Although we have implemented our design on a golf cart, our methods could be applied to almost any other electric vehicle. Our first design issue involved using the batteries in a more efficient manner. Optimizing the use of the batteries is possible because we do not need to draw the maximum energy at all times. The amount of energy that needs to be drawn depends on the driver's needs.

The goal of this project was to implement and design a more energy efficient golf cart that changes its energy consumption based on the driver's needs. The golf cart has the capability to switch between three modes of operation. In the high performance mode, the golf cart draws maximum energy from the batteries. Although this results in the shortest battery life, the golf cart accelerates much faster and has a higher top speed. In the efficient mode, the golf cart focuses on saving energy. This significantly increases battery life, but results in slower acceleration and lower top speed. In the last mode, standard mode, the golf cart has a balance between energy consumption and performance.

Although these modes could be implemented based on how much battery life was remaining, the driver is the one controlling which mode of operation he or she wants to use. There is a monitor to display what mode of operation the golf cart is currently in and buttons to allow the driver to change between modes of operation. If the driver knows he or she is making a short distance drive and wants to get there as fast as possible, he or she will simply touch a button to switch into high performance mode. This way he or she can get there as fast as possible and still not have to worry about the battery running out of energy. If the driver is planning on a long trip and is worried about the battery possibly running low, he or she can hit the button to switch into efficient mode. Otherwise, the typical mode of operation is standard mode.

In order to help the driver make a decision on what mode of operation to use. The monitor in the golf cart displays information such as battery life remaining and speed. The driver is able to see the differences in speed in each of the modes of operation. Displaying the speed and the battery life remaining will allow the driver to act accordingly.

A main goal of this project was to design a new method of controlling the speed of the golf cart. Typically, electric golf carts are controlled by using a variable resistor that is adjusted based on the accelerator pedal input. Simply altering this variable resistor system to change modes will not save energy. A new system was implemented that has energy conservation as a top priority. A system was designed that draws energy from the batteries in small pulses. The smaller the pulse, the more energy will be saved. The larger the pulse, the faster the golf cart will go. In conclusion, the high performance mode does not need to use this pulsing system. It constantly draws energy from the batteries at a steady rate. Standard mode uses the pulsing system in a way that increases battery life. Efficient mode uses even smaller pulses to save the most battery power. The tradeoff between energy and speed was vital for designing an energy efficient pulsing system for the golf cart.

II. VOLTAGE REGULATOR DESIGN

Each of the sensors along with the microcontroller and display screen all require a supply voltage that is significantly less than that of the total voltage produced by the batteries. Since using one battery to power the devices would drain the battery at a faster rate than the rest and using a voltage divider would not add any protection from fluctuations in current and voltage, the best way to power the devices is to use voltage regulators. The LM2576 adjustable voltage regulator and the LM117HV adjustable linear regulator will be used to step down the voltage to appropriate levels.

The LM2576 can handle input voltages up to 40V and the high voltage version can handle an input voltage up to 60V. The circuit used to implement the LM2576 is shown if Figure 1 with different values and will be used to drop the 36V from the batteries down to 12V to power the speed sensor. V_{in} for the equations will be 36V and V_{out} will be 12V. To find the equation of R2, equations 1 is modified into equation 2. The values for R1 and R2 will be calculated using the equations with $V_{ref} = 1.23V$ and R1 picked to be between 1 and 5kΩ. To simplify matters, R1 will be chosen to be 1kΩ. The value of R2 came out to be 8.75kΩ. The value of E x T will be calculated using the equation found in equation 3, where F = 52000, and will be used to find the value of L1 using the tables in the data sheet. The value of L1 will then be used to find the minimum output capacitance using the formula. The equation for V_{out} is give by:

$$V_{out} = V_{ref}\,(1 + R2/R1) \qquad (1)$$

$$R2 = R1\,(V_{out}/V_{ref} - 1) \qquad (2)$$

$$E \text{ x } T = (V_{in} - V_{out})\, V_{out}/V_{in} * 10\text{^}6/F \qquad (3)$$

$$C_{out}(min) \geq 13300\, V_{in}/(V_{out} * L) \qquad (4)$$

The minimum value for C_{out}, which is found in equation 4, came out to be 120.91µF. The values of the parts that are needed to implement the circuit can be found in Table 1. For simplicity and ease of buying parts, the input and output capacitance will be set at the same value. The resistors will be surface mount, thin film resistors that have a one percent tolerance and ceramic capacitors will be used due to price and tolerance.

Part	Value
R1	1kΩ
R2	7.15kΩ
C_{in}	470µF
C_{out}	470µF
L	330µH

Table 1 – Values of circuit components found from calculations

The LM7805 will be implemented using the circuit in Fig.-2 with the calculated values. The capacitors will be used if it is determined in testing that they are needed. This regulator will be used to step down the voltage from 12V to 5V so the remaining devices can be powered.

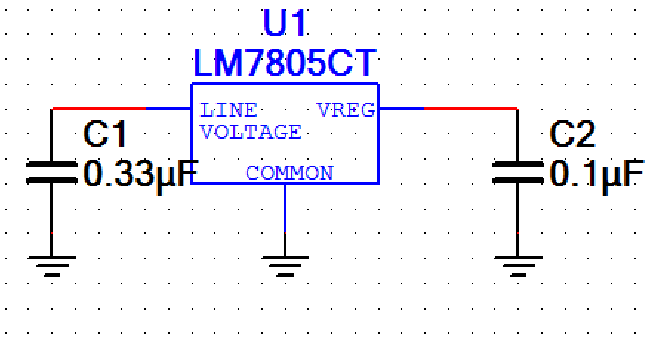


Figure 2 – Circuit for LM7805 linear regulator

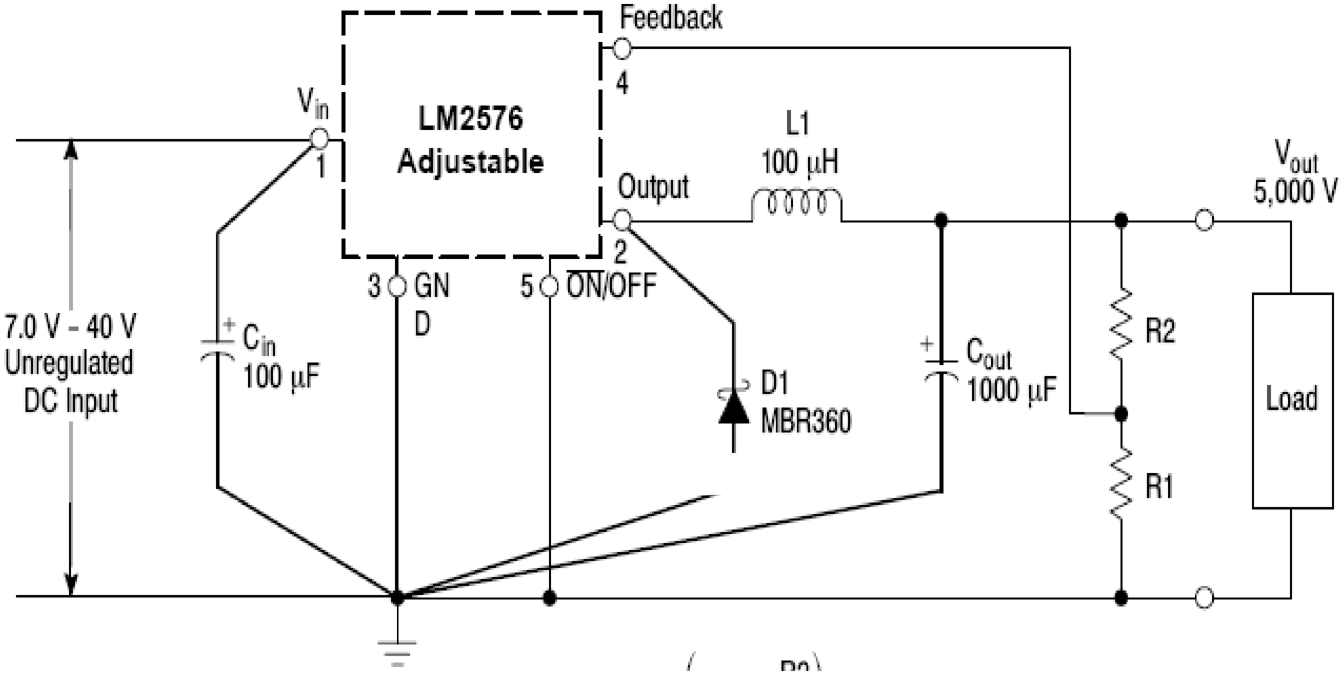


Figure 1 – Circuit for LM2576 adjustable regulator from ON Semiconductor data sheet

III. PRINTED CIRCUIT BOARD DESIGN

The printed circuit board, shown in Figure 3, for this project will be designed using PCB123 V4 Design Suite from Sunstone. This software allows the user to create a schematic while at the same time creating a printed circuit board layout. There are a few drawbacks in using the software that can be easily overcome by creating a footprint from scratch using the ‘create footprint’ or ‘edit footprint’ command. The printed circuit board will contain the two voltage regulators that will step the voltage down from 36V to 10V and then from 10V to 5V. The board will also be used to route the sensor outputs to the correct destinations. The line width of the input traces was determined using a trace width calculator found online at *ANSI PCB Trace Width Calculator*. The switching regulator was assumed to have a twenty percent efficiency to find out the approximate input current that the regulator would be seeing. This was found to be about 4.02A and the trace width was designed to handle 5A just to be on the safe side. The large blue rectangle in the middle of the board is a ground plane that will make it easier to connect all the components to ground. The three holes in the top right are there just in case the MOSFET that will be used with the speed controller cannot fit onto the board that the speed controller is located on.

IV. SENSOR DESIGN

There are three sensors that need to be taken into account when designing the system. The current sensor that will be used is the CSLT6B100 open-loop Hall Effect sensor made by Honeywell. This sensor will be set to measure the output current of the batteries will be placed directly after the ignition switch. If the cable that will be used to connect the batteries to the system have a diameter of 5.2 mm, then the sensor will be placed around the cable with wires attaching it back to the rest of the circuit. If the diameter of the cable is larger or small enough that it can easily go though the sensor, the current sensor will be mounted on the circuit board with an appropriate sized wire fed through it.

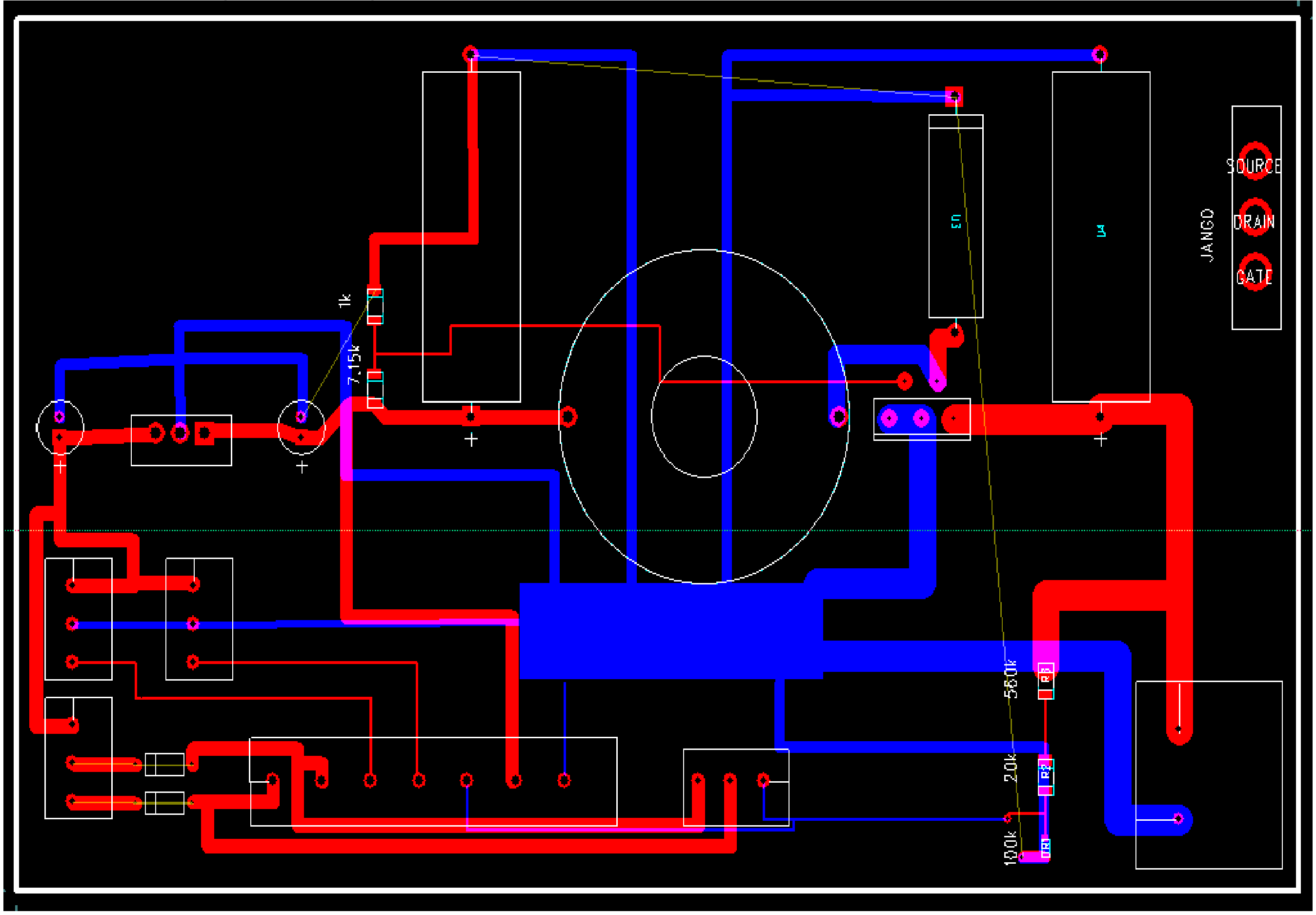


Figure 3 – PCB layout

The speed sensor that will be used will be the 55100 Mini Flange Mount Hall effect sensor made by Hamlin. This sensor will be mounted above the front wheel axel to make it as close to the rest of the circuit as possible. A three wire cable that will come with the sensor will be used to attach the sensor to the rest of the circuit. A magnet will be placed around the axel just below the speed sensor to give it something to detect.

The voltage sensor will be represented by a voltage divider circuit in parallel with the batteries. It is the only sensor that requires some thoughtful design to it since it shouldn't draw a lot of power from the batteries. A simple two resistor circuit will be used to do the calculations and yielded that the first resistor in the series R1 = 5.8R2 where R2 is the second resistor in the series. R2 will be set at 100kΩ making R1 equal to 580kΩ. The maximum power consumption of this circuit is only 1.91mW of power making it less of a drain on the batteries than if 10kΩ and 58kΩ resistor were used. The problem is that there are no 580kΩ resistors to speak of. R1 will be divided up into two resistors, like in Figure 4, consisting of a 560kΩ and a 20kΩ resistor. The voltage just before the 100kΩ will be the one being used as the input voltage to the HUD and microcontroller.

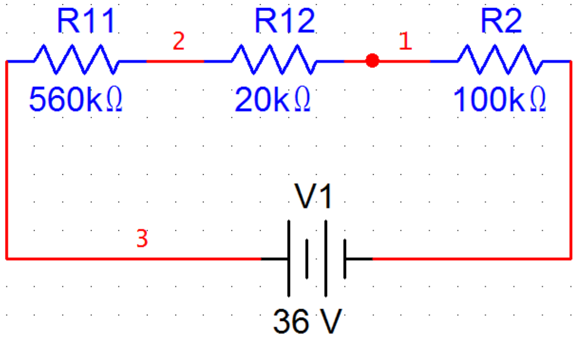


Figure 4 – Voltage divider circuit for voltage sensor

V. OVERVIEW OF HUMAN INTERACTIVE DISPLAY

A human interactive display was mounted in the golf cart so the driver can change modes of operation and view information related to the golf cart. The human interactive display, at its homepage, displays the current mode of operation, allows the driver to change his current mode of operation, as well as displays speed, and estimated charge remaining. For example, if the golf cart is currently in its standard mode of operation, and the driver desires an increase in speed and acceleration at the cost of battery life, he or she has the ability to hit the "high performance mode" button, which in turn changes the mode of the golf cart from standard mode to high performance mode. The programmable logic controller for the human interactive display needs inputs from the speed sensor and the voltage sensor associated with the estimated charge remaining. With these inputs, the logic controller was programmed to display the speed with correct formatting in miles per hour and the estimated charge remaining as a time and percentage.

Before the display was installed, code was written for the display controller. The code is able to take voltages as inputs, convert those using equations that are specific for each sensor, and display various information on the display. The display and its associated controllers are mounted to the golf cart. Holes were drilled into the frame of the golf cart so wires can run from the display to the controllers. Additional materials were used to mount the display in a location that allow it to be easily viewed by the driver. Sensors are connected to the memory in the display controller so that the charge remaining, time remaining, speed, and distance can be displayed. The current mode of operation is also displayed. Three buttons were connected to the memory in the display controller. Each button is used for one of the modes of operation. The driver can press one of these buttons if he or she wants to switch modes of operation. These buttons were installed in a location that the driver can easily reach.

VI. PROGRAMMING OVERVIEW

The Arduino Uno microcontroller was programmed to perform the tasks specified in the requirements. The LCD monitor displays 4 elements at all times: battery life remaining, time remaining, speed, and mode of operation. For these outputs to be displayed, there are several associated inputs. Voltage sensors are used to measure the battery life remaining and calculate the estimated time remaining. A speed sensor is used to measure the speed and calculate distance traveled. Both of these sensors are connected to pins in the Arduino Uno. Three buttons are used so the driver can input which mode of operation he or she would like to use. These buttons are also connected to pins in the Arduino Uno.

All inputs are technically voltages. For example, the speed sensor outputs voltages that are translated to certain speeds. These voltage inputs are read by the pins in the Arduino Uno and are stored in variables that are programmed in Java. To display speed on the LCD monitor, this voltage must be converted to miles per hour. This conversion is done by using a formula that automatically alters the voltages associated with the speed sensor into miles per hour. The voltage that is output from the voltage sensor is altered using two formulas and then stored in two different variables. The two formulas convert the voltage into the estimated time remaining and into the battery life remaining. Time remaining is displayed in the format HH:MM. Battery life remaining is a percentage.

VII. SOLAR PANEL ROOF SYSTEM

SOLAR PANEL

The lab efficiency, as shown in Figure 2.5 1, is about 24% for monocrystalline silicon, about 18% for polycrystalline silicon, and about 13% for amorphous silicon. The production efficiency, as shown in Figure 2.5 1, is 14%–17% for monocrystalline silicon, 13%–15% for polycrystalline silicon, and 5%–7% for amorphous silicon. Now the lab efficiency will always be a higher value than those of the production value. Now factoring in cost along with the efficiency, it was determined that polycrystalline silicon solar panels were the most effective solar panels to use.

Material	Efficiency in the Lab (%)	Efficiency of production Cells (%)
Mono-crystalline silicon	about 24%	14 % to 17 %
Polycrystalline silicon	about 18%	13 % to 15 %
Thin Film	about 13%	5 % to 7 %

Table 2 – Solar Panel materials and efficiency

To determine the amount of voltage needed to charge the batteries, equation 5 was used. The V_{charge} needed to charge the batteries correctly will be 2.25 Volts and the number of cells in the battery bank is 18 cells. From the equation, the amount of voltage to charge the batteries from the solar panels would roughly 40.5 Volts.

$$V_{charge} = \#\ of\ cells * \ V_{charge} \qquad (5)$$

The polycrystalline silicon solar panels used in solar powered golf cart will be Canadian Solar CS6P-215-B, due to the relative cheap price and high voltage associated with it. Now From Table 3, it is determined that only 29.00 Volts and 7.4 Amps can be taken from a single 215 Watt solar panel. To reach the needed 40.5 Volts that is required to charge the batteries, a second panels is need to be connected in series to the first panel. This will increase the maximum voltage to 58 Volts and the current will remain the same.

Power Rating	215 W
Open Circuit Voltage	36.50 V
Short Circuit Current	8.01 A
Maximum Power Voltage	29.00 V
Maximum Power Current	7.40 A

Table 3 – CS6P-215-B specifications

Now solar panels do not have the ability to charge at maximum voltage throughout the day due to temperature. To determine the amount of voltage the panels, equation 6 shows how much of the total voltage from the solar panels is received during a certain temperature.

$$V_T = Temperature\ Coefficient * 2 * V_{Solar} \qquad (6)$$

Now the temperature Coefficient is equal to roughly -0.5 % per degree Celsius. For example in 80°F or ~27°C, the voltage coming from the solar panels used would be

ROOF MOUNT

Since most polycrystalline silicon solar panels are extremely large, a new roof is designed. Using the actual solar panels as the roof itself, only a new frame is need to be applied to the top of the golf cart to securely fasten the solar panels into place. In Figure 5, the new roof frame was designed. The new roof frame was designed to use the original support beams on a pre-existing golf cart. In this design, wood was being used due to budget constraints. Because of large amounts of heat that will be emitted from the solar panels, there will be an open area that will allow the heat to disperse.

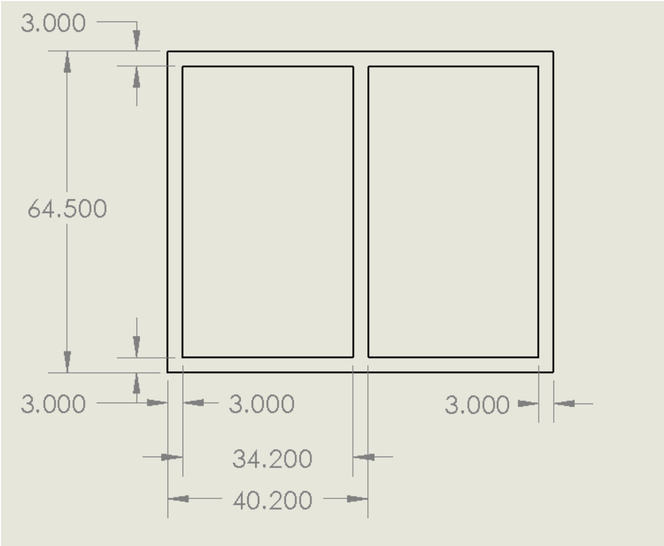


Figure 5 – Solar panel roof frame design

SOLAR CHARGE CONTROLLER

Most solar power systems use a solar charge controller to stop the excessive charge to the batteries. A charge control regulates the power going to the batteries from the panels. The basic principle behind a charge control is that it monitors the batteries' voltage. When the voltage hits the designated maximum voltage of the batteries, it will open another circuit and cuts off the flow of electricity to the batteries. Controllers also prevent reverse-current flow. When the solar panels aren't generating any power, it will still draw power from batteries. Controllers detect that no voltage is being produced from the solar panels and opens another circuit to cuts off the solar panel from the batteries. The basic controller uses relays or shunt transistors to disconnect the solar panels at the maximum voltage allowed. These however are not normally used anymore, though they are extremely reliable and don't use many parts. Many controllers use simple LED lights or digital meters to indicate what the status is; however, some, which normally are the newer models, have built in computer interfaces to monitor and control the solar panel controller. Modern controllers use a pulse width modulation, or PWM, to have the amount of power decrease slowly as the batteries reach the maximum charge by using the float charging method or by switching the solar system controller's power devices. These charge controllers are also relatively cheaper than other types of solar charge controllers. This method allows the batteries to reach the maximum charge with the less amount of stress than the basic controller by making sure the batteries do not overheat. This will help extend the batteries' life expectations and keep the batteries in a state of float, or fully charged state, indefinitely. Instead of having a steady charge coming from the panels, a pulse width modulation charge controller sends out a series of short pulses of voltage to the batteries. The controller constantly checks the voltage in between the pulses. When the batteries are fully charged, it will just send a very short pulse to the batteries every so often. When the battery is being discharged, the pulses will be longer. The Pulse width modulation system works using algorithms, which reduce the current to avoid overheating of the batteries and gas releasing from the batteries. This will still have the a continuous charging be in effect, so the amount of power going to the battery will not raise the amount of time to fully charge the battery. [1]

The pulse width modulation solar charge controller used in the golf cart is the Morningstar TS-45. Very few pulse width modulation solar charge controllers can charge a 36 Volt battery system. The TS-45 is also relatively cheap compared to other PWM charge controllers. In Table 4, the TS-45 datasheet is shown. The TS-45 has a small self-consumption of less than 20 mA. It also has an operating ambient temperature range of -40°C to +60°C. To charge to 36 Volts, the charge controller needs to be turned to the 48 Volts charge system and then have a custom setting of 40.5 Volts being the charge voltage.

Rated Current	45 A
System Voltage	12-48V
Minimum voltage to operate	9 V
Self-consumption	<20mA
Operating ambient temperature	-40°C to +60°C

Table 4 – Morningstar TS-45 specifications

The solar charge controller will be attached to batteries with 10 gauge copper wires. Since the solar panels use special wires, with unique MC4 connecters, an additional extension wire is needed and cut in half to allow the solar panels to be connected to the solar charge controller. The solar charge controller itself will be attached to one of the back support beams out of the reach of the sun. This will allow the solar charge controller to be in the open air, to help disperse heat.

VIII. BATTERY SELECTION

The golf cart requires a 36 volt power source to power the motor. Of the available battery technologies we reviewed lithium ion (Li-ion), Ni-CD, and lead acid. The cell voltage and discharge characteristic for each of the technologies is shown in the figure 6.

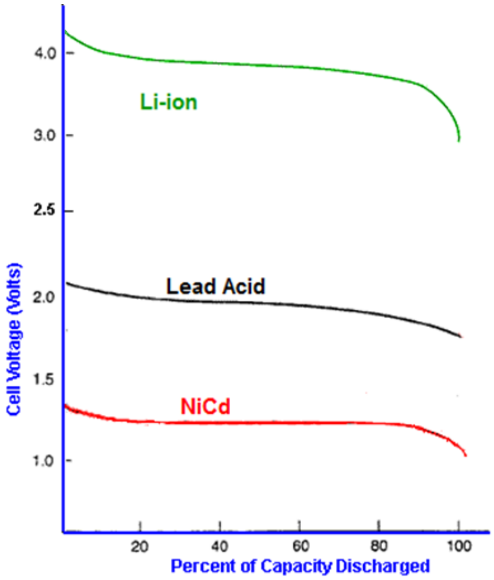


Figure 6 – battery cell voltage and discharge [2]

The Li-ion battery and the NiCd battery had advantages over the lead acid battery in energy density and consistent cell voltage discharge respectively. The choice to use lead acid batteries in the golf cart was made because of their low cost and the shape of the 6V deep cycle battery. The frame within the golf cart was designed to house the standard 6V deep cycle lead acid battery produced for golf carts. Using the lead acid batteries would not require any modification to frame, and so would save time in implementation. For this project absorbed glass matt (AGM), gel cell, and wet cell lead acid batteries were considered. To determine what type of lead acid battery to use the available capacity, Peukert number, and cost was considered

The available capacity of the batteries is determined by Peukert's Equation, shown in equation 7. This equation factors in the current drawn from the batteries, the time over which the batteries are discharged, and the Peukert number for the specific type of battery technology.

$$I^n * T = C \qquad (7)$$

Peukert's Equation

Where

- I is the current drawn of the battery
- n is the Peukert number for the battery
- T is the time over which the battery is discharged
- C is the available capacity of the battery

Figure 7 shows how the Peukert number affects the available capacity of a battery as the current drawn from it increases.

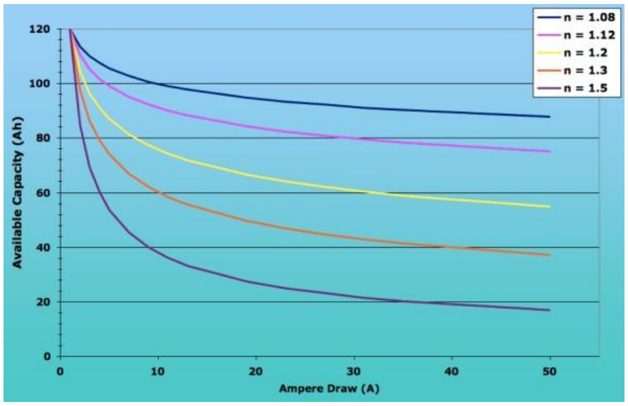


Figure 7 – Available Capacity vs. Amp Draw for 120Ah Battery [3]

As shown in figure 7 increasing the current drawn from the battery decreases the available capacity on a non-linear scale. Choosing a battery with a lower Peukert number would increase its available capacity as current draw is increased. Table 5 shows the comparison between the 3 lead acid battery technologies reviewed for the project.

Battery Type	Approximate Peukert Number	Cost per Battery	Cost to implement within the golf cart
6V AGM	1.08	$329	$1974
6V Gel Cell	1.12	$269	$1614
6V Wet Cell	1.2	$159	$0

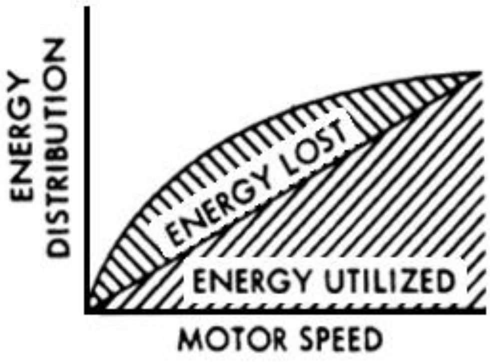
Table 5 – Comparison of Lead Acid batteries

The AGM and gel cell lead acid batteries have an increased capacity over the wet cell lead acid battery due to their lower Peukert number. The golf cart was donated to the project with 6 wet cell lead acid batteries. The choice to keep the wet cell batteries was made to reduce the overall cost of the project.

IX. MOTOR SPEED CONTROL

When the golf cart was donated to the project, it used a resistive speed control. Based on the throttle position a connection was made to different points on a resistor coil, which reduced the input voltage to the motor. Using this type of motor control, energy is wasted when current is passing though the resistor coil. To increase the efficiency of the motor control a pulse width modulated (PWM) motor control system was implemented. A comparison between the energy usage of a resistive and PWM motor control system is made in figure 8.

Resistive motor speed control



PWM motor speed control

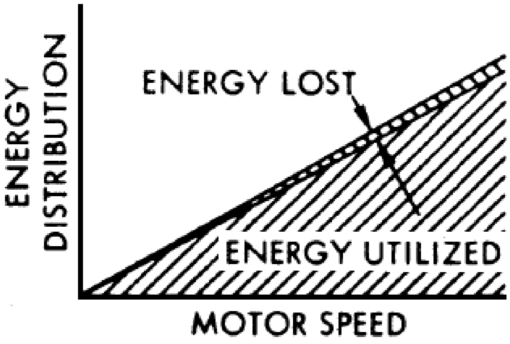


Figure 8 – comparison of resistive and PWM motor control [4]

To implement the PWM speed control the wiper assembly, previously used to measure the throttle position, was replaced with a 0-5kΩ potentiometer. The voltage drop across the potentiometer is measured by the Arduino Uno microcontroller to determine throttle position. Based on the throttle position the Arduino selects a PWM signal produced by the Stellaris EK-LM3S2965 microcontroller.

An example of a PWM signal can be found in figure 9. This PWM signal is then used to supply the gate voltage to an n-channel power MOSFET which supplies current and voltage to drive the motor. The system essentially turns the motor on when the PWM signal is high and off when the PWM signal is low. Using this method the current draw being supplied to the motor can be limited, which will increase the lifetime of the batteries and energy efficiency of the golf cart. Additionally the PWM motor control system makes it possible to implement different modes of operation by limiting the maximum duty cycle of the PWM signal. This will slightly decrease the speed of the golf cart, but will increase the amount of time the batteries will last before the golf cart needs to be recharged.

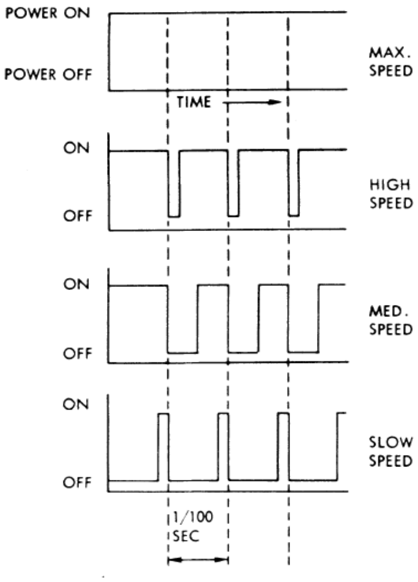


Figure 9 PWM signal [4]

X. CONCLUSION

This project was a very valuable one year long experience, which clean technology is used with renewable resources to decrease our carbon footprint in today's world. This system can also be detached and relocated to another golf cart with a small amount of effort to ensure longevity and maximize the potential of the system. It allows the batteries to last longer and have little need to be plugged into a wall outlet.

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BIOGRAPHIES

Nicholas Paperno is currently a student studying electrical engineering at the University of Central Florida. He has been attending the university for four years and will graduate with his bachelor's in May 2011. He then plans to attend graduate school at UCF to earn his masters and PH.D in electrical engineering.

Patrick Taylor is currently a senior at University of Central Florida. He plans to graduate with a Bachelor Degree in Computer Engineering in May 2011. He plans to continue his studies in a Masters and a PhD programs later in life.

David Yeung is currently a senior at University of Central Florida. He plans to graduate with A Bachelor degree in computer engineering in May 2011. He plans to pursue a career in the computer engineering profession.

Andrew Bridges is currently a senior at the University of Central Florida. He plans to graduate with a BS in Electrical Engineering in May 2011. Afterwards he plans to pursue a career in the electrical engineering field and further his education in a Masters Degree program.